APS COUNCIL OF REPRESENTATIVES 2017

President
Laura H. Greene,* Florida State University,
National High Magnetic Field Laboratory

President-Elect
Roger W. Falcone,* University of California,
Berkeley/LLBL

Vice President
David J. Gross,* Kavli Institute for Theoretical
Physics, University of California, Santa Barbara

Past President
Homer A. Neal,* University of Michigan

Chief Executive Officer
Kate P. Kirby, Harvard Smithsonian (retired)

Speaker of the Council
Daniel Kleppner,* Massachusetts Institute of
Technology (Emeritus)

Treasurer
James Hollenhorst,* Agilent Technologies

Corporate Secretary
Ken Cole, American Physical Society

General Councillors
Nadya Mason, Gail McLaughlin,*
Bonnie Fleming, Andrea Liu

International Councillors
Eliezer Rabinovici, Johanna Stachel,
Kiyoshi Ueda, Marta Losada

Chair, Nominating Committee
Paul Chaikin, New York University

Chair, Panel on Public Affairs
Frances A. Houle, Lawrence Berkeley National
Laboratory

Editor in Chief
Michael Thoennessen, Michigan State University
(on leave)

Division, Forum and Section Councillors
Miriam Forman (Astrophysics), Timothy Gay* (Atomic,
Molecular & Optical Physics), William Bialek (Biological
Physics), Robert Continetti (Chemical Physics),
Giulia Galli (Computational Physics), John Bradley
Marston* (Condensed Matter Physics), Ann Karagozian
(Fluid Dynamics), Beverly Berger (Gravitational Physics),
Nicholas Bigelow* (Laser Science), Samuel Bader
(Materials Physics), Akif Baha Balantekin (Nuclear
Physics), P. Michael Tuts (Particles & Fields), Thomas
Roser (Physics of Beams), Cary Forest (Plasma Physics),
Murugappan Muthukumar (Polymer Physics), Noah
Finkelstein (Forum on Education), Julia Goski, (Forum
on Graduate Student Affairs), Dan Kleppner* (Forum on
History of Physics), John Rumble* (Forum on Industrial
and Applied Physics), Young-Kee Kim* (Forum on
International Physics), Pushpa Bhat* (Forum on Physics
and Society), Philip Johnson (Mid-Atlantic Section), Carlos
Wexler (Prairie Section)

Senior Management Team
Mark Doyle, Chief Information Officer, Jane Hopkins
Gould, Chief Financial Officer, Kate P. Kirby, Chief
Executive Officer, Michael Thoennessen, Editor in Chief,
Matthew M. Salter, Publisher, James W. Taylor, Deputy
Executive Officer and Chief Operating Officer

* Voting Members of the APS Board of Directors

Please note: APS has made every effort to provide
accurate and complete information in this Bulletin.
However, changes or corrections may occasionally
be necessary and may be made without notice after
the date of publication. To ensure that you receive the
most up-to-date information, please check the meeting
Corrigenda distributed with this Bulletin, the Meeting
App, the Meeting Website, or the “Program Changes”
board located near Information.
## Table of Contents

- Code of Conduct for APS Meetings ............................................................ 2
- Acknowledgments........................................................................................ 3
- Program Overview ....................................................................................... 4
- Session Numbering Scheme ........................................................................ 4
- Review Presentations ................................................................................... 4
- Invited Presentations .................................................................................... 4
- Tutorial Presentations .................................................................................. 5
- Contributed Papers - Oral ............................................................................ 5
- Contributed Papers - Poster ......................................................................... 5
- Poster Sessions............................................................................................. 6
- Guidelines for Scientific Presentations ....................................................... 8
- Abstract Policy ............................................................................................. 8
- Mini-Conferences ........................................................................................ 8
- Prize and Awards .......................................................................................... 9
- Science Education and Outreach Activities .............................................. 10
- Other Activities of Interest .......................................................................... 10
- General Information ................................................................................... 12
- Housing Information .................................................................................... 13
- Maps ........................................................................................................... end of issue
CODE OF CONDUCT FOR APS MEETINGS

It is the policy of the American Physical Society (APS) that all participants, including attendees, vendors, APS staff, volunteers, and all other stakeholders at APS meetings will conduct themselves in a professional manner that is welcoming to all participants and free from any form of discrimination, harassment, or retaliation. Participants will treat each other with respect and consideration to create a collegial, inclusive, and professional environment at APS Meetings. Creating a supportive environment to enable scientific discourse at APS meetings is the responsibility of all participants.

Participants will avoid any inappropriate actions or statements based on individual characteristics such as age, race, ethnicity, sexual orientation, gender identity, gender expression, marital status, nationality, political affiliation, ability status, educational background, or any other characteristic protected by law. Disruptive or harassing behavior of any kind will not be tolerated. Harassment includes but is not limited to inappropriate or intimidating behavior and language, unwelcome jokes or comments, unwanted touching or attention, offensive images, photography without permission, and stalking.

Violations of this code of conduct policy should be reported to meeting organizers, APS staff, or the APS Director of Meetings. Sanctions may range from verbal warning, to ejection from the meeting without refund, to notifying appropriate authorities. Retaliation for complaints of inappropriate conduct will not be tolerated. If a participant observes inappropriate comments or actions and personal intervention seems appropriate and safe, they should be considerate of all parties before intervening.

(This number is only open during registration hours.)
Welcome to the 59th Annual Meeting of the Division of Plasma Physics (DPP) of The American Physical Society (APS). All technical sessions, including the Mini-Conferences, will be held in the Wisconsin Center. We hope you find the meeting informative, productive, exciting, and enjoyable.

APS and DPP are pleased to announce that we have a mobile meeting app available to attendees. After downloading the app to your mobile device, you will be able to read the abstracts, view the speaker index, create a personal schedule of presentations, and see maps of the Wisconsin Center. For instructions on how to download the app please see the flyers at the DPP Registration Desk or at the Meeting Information Booth.

Since printed Bulletins are no longer provided to attendees, a complete meeting Bulletin was sent to all pre-registrants by email before the start of the meeting.

ACKNOWLEDGMENTS

Program Organization
We thank the DPP Program Committee for the outstanding program they have assembled.

Program Committee Members
John Cary, Chair Elect and Program Chair
Carl Sovinec, Local Arrangements Coordinator
Earl Scime, Chair
David Newman, Vice Chair
Hui Chen, Secretary-Treasurer
Richard Dendy, EPS Representative
Mitsuru Kikuchi, AAPPS-DPP Representative

Basic Plasma Physics:
Troy Carter, Alain Brizard, James Danielson, Nuno Loureiro, Mark Cappelli, John Foster, Amy Keese

Beams, Plasma Accelerators, Coherent Radiation:
Carl Schroeder, Hong Qin, Howard Milchberg, Bernhard Hidding

Inertial Confinement:
Christine Coverdale, Jason Bates, Ryan McBride, Laura Berzak Hopkins, Brian Albright, Mingsheng Wei

High Energy Density Plasmas:
Scott Hsu, Dan Sinars, Bhuvana Srinivasan, Charles Seyler, Chuang Ren, Alla Safranov

Low Temperature Plasmas:
Tobin Munsat, Alex Likhanskii, Venkatt Ayyaswamy, Steve Shannon

Magnetic Confinement Experiments:
Bill Heidbrink, John Canik, Uri Shumlak, Jonathan Menard, David Anderson

Magnetic Confinement Theory:
Valerie Izzo, James Myra, Greg Hammett, Paul Terry

Science Education and Public Outreach:
Arturo Dominguez

Astrophysical and Space Plasma:
Ellen Zweibel, Kris Beckwith, Mark Golkowski, Vladimir Sotnikov

We thank Jason TenBarge for organizing a Mini-Conference on Bridging the Divide Between Space and Laboratory Plasma Physics; and Alexey Arefiev, Stepan Bulanov, and Mattias Marklund for organizing a Mini-Conference on Laser-Matter Interactions: the Next Generation.

Local Arrangements
Special thanks go to Carl Sovinec of University of Wisconsin for overseeing the local arrangements for the 2017 annual meeting and assisting with the coordination of Teachers’ Day activities.

Meeting Staff
The DPP expresses its appreciation to the APS Meetings Department staff members for their efforts in coordinating the scientific program and meeting logistics: Terri Olsen, Ebony Adams, Donna Greene, Vinaya Sathyasheelappa, and Donald Wise. We also
thank Lee Warren and the Freeman Team, and Matt Chaney and the Hargrove Team.

A special thank you goes to Saralyn Stewart, DPP Administrator, for her comprehensive assistance.

PROGRAM OVERVIEW

The program committee has organized a program consisting of four invited review papers, 93 invited papers, three invited postdeadline papers, and four tutorial invited papers (chosen from approximately 200 nominations). The total number of abstract submissions is approximately 1902. On Thursday morning Dmitri Ryutov, Lawrence Livermore National Laboratory, will give the Maxwell Prize Address.

Note: the APS DPP Program Committee has decided that all LCD projectors will have the high-resolution 16x9 format. Please plan accordingly.

SESSION NUMBERING SCHEME

Each session has a code consisting of two letters and a number. The first letter indicates the time slot for that session, the second letter indicates the type of session, and the number indicates the room location. The numbering scheme is driven by requirements of the APS meeting database system.

First Letter in Session Code = Time slot designation
A, F, M, S, X = 8:00 am Review/Prize Time Slot
B, G, N, T, Y = 9:30 am Invited Time Slot
C, J, P, U = 2:00 pm Invited Time Slot
D, K, Q, V = 3:00 pm Invited Time Slot
E, H, L, R, Z = Other Afternoon & Evening Time Slots

Number in Session Code = Room location at the Wisconsin Center.
For example: BO4 = Monday, 9:30 am, oral contributed, in Room 201 AB and CO7 = Monday, 2:00 pm, oral contributed in Room 203 AB.

REVIEW PRESENTATIONS

All review papers are 50 minutes long, followed by 10 minutes for Q&A. They will be presented each morning at 8:00 am, Monday through Wednesday, and Friday in Ballroom C of the Wisconsin Center. LCD projectors will be used in all oral sessions at the expense of DPP.

Monday
Dov Shvarts, NRCN, Israel/University of Michigan
Recent NIF Discovery Science Experiments to Verify the Late Time Evolution of Rayleigh-Taylor and Richtmeyer-Meshkov Hydrodynamic Instabilities

Tuesday
Philip Snyder, General Atomics
Physics of the Tokamak Pedestal, and Implication for Magnetic Fusion Energy

Wednesday
Gregory Howes, University of Iowa
Bringing Space Down to Earth

Friday
Dennis Whyte, Massachusetts Institute of Technology
The Science and Technology Case for High-Field Fusion

On Thursday morning, Dmitri Ryutov will give the James Clerk Maxwell Prize for Plasma Physics Address in Ballroom C. The address will be 50 minutes long followed by 10 minutes for Q&A. The title of the address is: Scaling Laws for the Dynamical Plasma Phenomena.

INVITED PRESENTATIONS

Each invited paper is 25 minutes plus 5 minutes for discussion. Invited presentations will be held morning and afternoon in 102 ABC and 103 ABC in the Wisconsin Center. This year, Review and Invited
speakers have been especially encouraged to include a slide or two in their talks regarding the open scientific questions in the area of their presentation.

Poster versions of review, invited, and tutorial talks are optional and are scheduled Monday through Friday, in the following half-day session, in a designated area of Exhibit Hall D. For example, the Monday morning review and invited talks may also be presented as posters in the Monday afternoon poster session. This option will be available on Monday morning for invited papers that are scheduled on Friday morning. LCD projectors will be used in all oral sessions at the expense of DPP.

**Invited and Review Technical Papers Publication in Physics of Plasmas**

Arrangements have been made to publish the invited and review technical papers in the 29th Annual Special Issue of *Physics of Plasmas*. This year’s guest editor is John Cary, chair of the 2017 Program Committee. All submissions of technical papers will be available via PXP, the journal’s online submission and peer review system. Invited speakers have received submission instructions, but should remember that submissions must be identified as a DPP technical paper by selecting one of the DPP options as the manuscript type.

**Tutorial Presentations**

Tutorial presentations have proven to be a valuable addition to the program and have helped foster the cross-fertilization of ideas. Four tutorials will be offered this year. The duration of each is 50 minutes plus 10 minutes for Q&A, and each tutorial is the first talk in an afternoon invited talk session, Monday through Thursday. Tutorial presentations will be held in 102 ABC. The goal of a tutorial is to explain basic principles to those not working in a specific area and to convey an appreciation of the accomplishments, issues, and objectives of that area. The tutorial presentations assume an audience with a graduate level understanding of basic plasma physics, but no familiarity with the research area that is the subject of the tutorial. In contrast, the traditional invited presentations are intended to expand upon the latest research within a subfield. LCD projectors will be used in all oral sessions at the expense of DPP.

**Contributed Papers - Oral**

Oral presentations are 10 minutes long plus 2 minutes of Q&A, and will be held Monday through Friday morning beginning at 9:30 am; afternoon oral presentations will begin at 2:00 pm. More than 35% of the scientific program is oral presentations. They will take place in Rooms 203 C, 203 AB, 202 AB, and 201 AB in the Wisconsin Center. Every effort will be made to adhere to the 12-minute schedule for contributed oral presentations. If speakers are not present at the appointed time, the presiding chair will call for a 12-minute break to maintain the schedule. Likewise, the chair should adhere to the 12-minute limit for each contributed talk. Presiding chairs are expected to enforce the Society’s rule that a presenter attempting to deliver a second oral paper in the same session will have that presentation placed at the end of the session, to be given if time permits at the discretion of the presiding chair. LCD projectors will be used in all oral sessions at the expense of DPP.

**Contributed Papers - Poster**

More than 59% of the scientific program is poster presentations. Poster sessions will be held in Exhibit Hall D, Monday through Friday morning 9:30 am to 12:30 pm, and Monday through Thursday afternoon 2:00 pm to 5:00 pm. Poster boards are 8 feet (wide) x 4 feet (high). Pushpins will be provided. It is recommended that each poster include a title and list of authors in large letters and a large-type copy of the abstract for casual observers, with the remaining poster board devoted to the details for those who are particularly interested in the work, and that attention is paid to the production of effective visuals. Poster presentations should be arranged so that a number of people may view them at one time. Handouts of printed material and a method for correspondence are often helpful. If you leave your assigned board, write a note indicating when you will return. Please clear the poster board promptly at the end of your session. DPP is not responsible for papers left on and around boards beyond the allotted poster session time.
POSTER SESSIONS

Hall D

Session BP11: Poster Session I
Monday, October 23, 9:30am-12:30pm
Space and Astrophysical Plasmas; FRC; PMI; Energetic Particles; Other Concepts; Measurement and Diagnostic Techniques; Laser-Plasma Instabilities
1–40.......... SPACE AND ASTROPHYSICAL PLASMAS
41–67......... FRC
68–86......... PMI
87–95......... ENERGETIC PARTICLES
96–110....... OTHER CONFINEMENT CONCEPTS AND NEXT STEPS
111–125...... ICF MEASUREMENT AND DIAGNOSTIC TECHNIQUES
126–139...... LASER-PLASMA INSTABILITIES

Session CP11: Poster Session II
Monday, October 23, 2:00-5:00pm
Dusty Plasmas and Sheaths; Z-Pinch, X-Pinch, Dense Plasma Focus, and HED; Stellarator, Disruptions, and MHD
1–28.......... DUSTY PLASMAS AND SHEATHS
29–48.......... Z-PINCH, DENSE PLASMA FOCUS AND HED
49–89.......... STELLARATOR
90–134......... DISRUPTIONS AND MHD

Session GP11: Poster Session III
Tuesday, October 24, 9:30am-12:30pm
Reconnection; Laser-plasma Interactions and Acceleration; Plasma Technology; DIII-D I; Hohlraum and X-Ray Cavity Physics; Computation
GP11.1 ...... RECONNECTION 2–25 = 24
GP11.26..... LASER-PLASMA INTERACTIONS AND ACCELERATION 27–57 = 31
GP11.58..... PLASMA TECHNOLOGY 59–118 = 60
GP11.119.. HOHLRAUM AND X-RAY CAVITY PHYSICS = 120–156 = 37

Session JP11: Poster Session IV
Tuesday, October 24, 2:00-5:00pm
Education and Outreach; High School or Undergraduate Research; C-Mod, MST, & MFE Theoretical Methods
JP11.01 ...... EDUCATION AND OUTREACH 2–6 = 5
JOP11.7..... HIGH SCHOOL OR UNDERGRADUATE RESEARCH 8–100 = 93
JP11.101.... MST (no abstract(s) available) = 0
JP11.102.... OVERVIEW OF MST RESEARCH 103–125 = 23
JP11.126.... THEORETICAL METHODS 127-152 = 26

Poster Sessions continued on next page
Session NP11: Poster Session V

*Wednesday, October 25, 9:30am-12:30pm*

Turbulence & Transport; DIII-D II; Compact Torus; HEDP I; Low Temperature Plasmas; Mini-Conference on Bridging the Divide Between Space and Astrophysical Plasmas

NP11.02...... TURBULENCE AND TRANSPORT 2–34 = 33
NP11.35...... HEDP I 36–64 = 29
NP11.65...... DIII-D 11 66–108 = 43
NP11.109..... COMPACT TORUS 110–125 = 16
NP11.126..... LOW TEMPERATURE PLASMAS 127–152 = 26

Session PP11: Poster Session VI

*Wednesday, October 25, 2:00pm-5:00pm*

HEDP II; Compression and Burn; NSTX-U & Boundary; Direct, Indirect, and Polar-drive; Hydrodynamic Instability; Basic Plasmas

PP11.1 ......... HEDP II 2–33 = 32
PP11.34 ...... COMPRESSION AND BURN 35–38 = 4
PP11.39 ...... NSTX-U 40–69 = 30
PP11.70 ...... BOUNDARY 71–95 = 25
PP11.96 ...... DIRECT, INDIRECT AND POLAR-DRIVE 97–99 = 3
PP11.100 ..... HEAVY ION FUSION–101–102 = 2
PP11.103 ..... HYDRODYNAMIC INSTABILITY 104–108 = 5
PP11.109 ..... BASIC PLASMAS–110–151 = 42

Session TP11: Poster Session VII

*Thursday, October 26, 9:30am-12:30pm*

Diagnostics & Sources; Heating & Current Drive, Transport, & Diagnostics; Intense Beams, Ion Acceleration, and Laser-solid Interactions

TP11.1 ......... DIAGNOSTICS AND SOURCES 2–28
TP11.29 ...... INTENSE BEAMS, ION ACCELERATION, AND LASER-SOLID INTERACTIONS 30–52
TP11.53 ...... HEATING AND CURRENT DRIVE 54–76
TP11.77 ...... TRANSPORT 78–110

Session UP11: Poster Session VIII

*Thursday, October 26, 2:00pm-5:00pm*

Non-Neutral, Antimatter and Strongly Coupled Plasmas; Waves; Conventional and Spherical Tokamaks; Magneto-Inertial Fusion

UP11.1 ......... NON-NEUTRAL,ANTIMATTER AND STRONGLY COUPLED PLASMAS 2–50=49
UP11.51 ...... TOKAMAKS 52–85 = 34
UP11.86 ...... SPHERICAL TORUS 87–109 = 23
UP11.110 ..... MAGNETO-INERTIAL FUSION 111–140 = 30

Session YP11: Poster Session IX

*Friday, October 27, 9:30am-12:30pm*

Supplemental; Post-Deadline Abstracts

YP11.1 ......... SUPPLEMENTAL 2–22
YP11.23 ...... POST-DEADLINE 24–68
GUIDELINES FOR SCIENTIFIC PRESENTATIONS

James Callen, University of Wisconsin, has developed some useful materials for preparing effective scientific presentations. The Program Committee urges all attendees to prepare clear and effective presentations. James Callen’s website, entitled “Materials for Preparing Effective Scientific Talks, Posters” is available online as pdf documents at http://homepages.cae.wisc.edu/~callen/talks.html

摘要政策

由APS规则，规定第一作者必须在会议期间进行口头报告。第一个人可以在同一抽象中列出。额外的摘要由同一第一作者在周五上午9:30至12:30在 Exhibit Hall D 补充海报会议。未在规定截止日期前九月十四日提交的摘要将被分派至午后海报会议。作者必须将摘要提交至展示区，或联系 Donna Greene 以获取详情。

Mini-Conferences

两场微型会议定于周三上午和下午以及周四上午和下午在 Wisconsin Center 举行。请查看 Epitome 获取演讲者开始时间。

所有微型会议均组织以口头演讲加问答形式，并可能包括海报。他们采取问答的形式以促进与会者讨论和互动。LCD 投影仪将用于所有口头会议，由 DPP 负担费用。

Laser-Matter Interactions: The Next Generation

Wednesday, October 25 at 9:30 am and 2:00 pm
Room 202 DE

Organizers: Alexey Arefiev, Stepan Bulanov, and Mattias Marklund

Description: The interaction of charged particles with ultraintense electromagnetic (EM) pulses is the cornerstone of a newly emerging area of research, high intensity particle physics, located at the intersection of quantum electrodynamics (QED) and the theory of strong EM background fields. The latter significantly alter the physics of typical QED processes, leading to effects not encountered in perturbative quantum field theory. Recently, there has been a surge of interest in these processes due to the planning and realization of new laser facilities, such as the Extreme Light Infrastructure (ELI) and the European Xray Free Electron Laser (XFEL), which will be able to deliver EM pulses of unprecedented intensities to test the predictions of high intensity particle physics. Moreover, the development of compact multi-GeV laser electron accelerators adds another component necessary to carry out these studies. The electron motion becomes so violent during the laser-matter interaction at these intensities that the emission of electromagnetic radiation by electrons starts to play a role in electron dynamics, i.e. the so-called radiation reaction. The photons emitted during the electron acceleration by the laser can then interact with each other and with the field of the laser pulse, generating copious numbers of electron-positron pairs. The new facilities will also offer unparalleled capabilities to diagnose these previously unexplored regimes of light-matter interactions. Understanding of the underlying multi-scale physics and the resulting collective effects requires an approach that combines expertise in both the plasma physics and the quantum electrodynamics. The approach would also need to involve advanced analytical techniques, high performance computing, and carefully designed experiments. To facilitate the development of such an approach and a development of a broad collaboration, we propose a mini-conference that will bring plasma theorists, modelers, and experimentalists together with experts from the strongfield physics community.
Bridging the Divide Between Space and Laboratory Plasma Physics

[Sponsored by the APS Topical Group in Plasma Astrophysics (GPAP)]

Thursday, October 26 at 9:30 am and 2:00 pm
Room 202 DE
Organizer: Jason TenBarge

Description: Many of the challenges facing the laboratory plasma physics and fusion confinement communities are rooted in fundamental kinetic plasma physics phenomena that are also crucial to understand the physics of the heliosphere and astrophysical systems. Yet, the separate research communities addressing these different scientific problems rarely interact with each other, even though the underlying physics has many commonalities. The APS Topical Group in Plasma Astrophysics is dedicated to fostering cross disciplinary interaction among plasma physicists, space physicists, and astrophysicists, and we believe this proposed mini-conference will serve to encourage communication between these distinct communities. The guiding principle to promote these cross-disciplinary interactions in the design of the mini-conference follows. We will have two, half-day oral sessions followed by one poster session the following day. Each oral session will consist of three 30-minute solicited talks, with one observational space physics speaker, one laboratory plasma physicist, and one theory speaker that bridges the divide between space and laboratory plasmas. We hope to orchestrate the three solicited talks for each oral session so that they cover similar physics topics but from different points of view, observational, laboratory, and theory. For example, in space physics, we would like to have two observers present some of the exciting new results from recent and forthcoming missions, two presentations from laboratory plasma physicists discussing space physics relevant results and experiments and opportunities available to the space community for collaboration, and two theoretical or computational talks from a plasma physics perspective covering the fundamental physics common to space and laboratory plasma physics. The aim is that the common themes will encourage significant interactions between plasma physicists and space physicists. Following the three solicited oral talks will be six 15-minute contributed talks covering a wide range of research problems relevant to the session.

PRIZE AND AWARDS

Awards will be presented at the banquet on Wednesday, October 25.

James Clerk Maxwell Prize for Plasma Physics

Thursday, October 26, 8:00 am
Ballroom C

Recipient: Dmitri Ryutov, Lawrence Livermore National Laboratory

Prize Citation: For many outstanding contributions to the theoretical plasma physics of low and high energy density plasmas, open and closed magnetic configurations, and laboratory and astrophysical systems.

The John Dawson Award for Excellence in Plasma Physics Research

Recipients: Andrew MacKinnon, Lawrence Livermore National Laboratory; Chikang Li, Fredrick Séguin, Richard Petrasso, Massachusetts Institute of Technology; Marco Borghesi, The Queen’s University, Belfast; Oswald Willi, Heinrich Heine University Düsseldorf. Citation: For pioneering use of proton radiography to reveal new aspects of flows, instabilities, and fields in high-energy-density plasmas.

The Marshall N. Rosenbluth Outstanding Doctoral Thesis Award

Wednesday, October 25, 2:00 pm
Room 103 ABC

Recipient: Jonathan Squire, California Institute of Technology. Citation: For fundamental contributions to dynamo theory, particularly the analytical and computational elucidation of the magnetic shear current effect.

The Thomas H. Stix Award for Outstanding Early Career Contributions to Plasma Physics Research

Wednesday, October 25, 2:00 pm
Room 103 ABC

Recipient: Ian Chapman, Culham Centre for Fusion Energy, UKAEA

Citation: For groundbreaking experimental and theoretical studies in tokamak stability.
Katherine E. Weimer Award for Women in Plasma Science

Wednesday, October 25, 2:00 pm
Room 103 ABC

Recipient: Félicie Albert, Lawrence Livermore National Laboratory

Citation: For pioneering development and characterization of x-ray sources from laser-wakefield accelerators and Compton scattering gamma-ray sources for applications in high energy density science and nuclear resonance fluorescence.

Science Education and Outreach Activities

For over the past two decades, the DPP annual meeting has featured Science Teachers’ Day and the Plasma Sciences Expo to increase awareness of plasma science in the classroom and help inspire and excite the next generation of plasma scientists.

Science Teachers’ Day

Tuesday, October 24, 7:30 am – 4:00 pm

Local teachers will have their first chance to experience APS DPP education when they arrive at the Hilton Milwaukee City Center Hotel. They will spend the morning learning about the fundamentals of fusion energy and plasma science. For the remainder of the day they will attend workshops about content of their choosing, focusing on such subjects as the nature of matter, the electromagnetic spectrum, Newton’s Laws, and how to bring hands-on plasma activities into the classroom.

A lunch with scientists and other teachers, sponsored by APS DPP, is a highlight, providing a kind of networking rarely available to them. The DPP invites participating teachers to attend any part of the annual meeting.

Plasma Sciences Expo

Thursday and Friday, October 26-27, 8:00 am – 2:30 pm
Thursday, October 26, 6:00 pm – 8:00 pm

The Plasma Sciences Expo will be held in the Wisconsin Center. The Expo features hands-on experiments from national and international institutions, as well as local education and industrial venues for middle school and high school students, teachers, and parents. Students will have an opportunity to talk with scientists while visiting a variety of exhibits and interactive displays. The University of Wisconsin Wonder of Physics booth, a popular anchor of the Expo for many years, will have a strong presence.

The general public is invited to the expo evening session on Thursday, October 26. All meeting participants are invited to attend any session that fits their schedule.

Other Activities of Interest

Companions’ Breakfast

Monday, October 23, 8:30 am to 11:00 am
Juneau Room, Hilton Milwaukee

Join other companions for a DPP-sponsored complimentary breakfast at Hilton Milwaukee. You will have an opportunity to meet other companions and reacquaint with friends from past DPP meetings. A representative from Visit Milwaukee will attend the breakfast to talk about tours offered and sites to see while visiting the city.

Women in Plasma Physics Luncheon

Monday, October 23, 12:30 pm to 2:00 pm
Regency Ballroom, Hilton Milwaukee

To attend the luncheon, mark the appropriate space on the Registration Form. The lunch tickets are $25 for regular attendees and $10 for graduate and undergraduate students. The lunch cost is partially subsidized by DPP. Discussion on issues of interest to women in plasma physics will be encouraged at each table. The luncheon is open to all conference attendees.

University Fusion Association (UFA) General Meeting

Monday, October 23, 7:00 pm to 9:00 pm
102 ABC, Wisconsin Center

The University Fusion Association (UFA, university-fusion.org) is a nonprofit organization focused on the development of plasma science and technology for the long-term development of a new, environmentally attractive energy source using controlled thermonuclear fusion. The UFA advocates for univer-
sity fusion energy and plasma science research and education by representing universities and university researchers to congressional policy makers and funding agencies, organizing planning workshops, and providing community leadership. The UFA General Meeting discusses issues of relevance to fusion energy and plasma science research in U.S. universities. The UFA meeting is open to all members of the community and all conference attendees.

**Town Meeting on Concerns of Junior Scientists**
*Tuesday, October 24, 12:45 pm to 2:00 pm*
*Room 201AB, Wisconsin Center*

The DPP Committee on Concerns of Junior Scientists (COJS) is pleased to announce an informal panel discussion. The chair of COJS, Eve Stenson, Max Planck Institute for Plasmas Physics, welcomes all conference attendees.

**Meet the Editors of the APS Journals**
*Tuesday, October 24, 5:00 pm to 6:30 pm*
*Ballroom Foyer, Wisconsin Center*

The Editors of the APS Journals cordially invite all DPP annual meeting attendees to join them for conversation and refreshments. Your questions, suggestions, compliments and complaints about the journals are welcome. We hope you will join the Editors.

**Fellowship Opportunities for Grad Students in Plasma Physics**
*Tuesday, October 24, 5:15 pm to 6:15 pm*
*Room 203C, Wisconsin Center*

Graduate students and undergraduates thinking about graduate school are especially welcome to attend this info session on fellowship opportunities. Representatives from DOE, NSF and NASA will be presenting on programs designed to support students at different stages of their academic careers. Recipients of these fellowships will also share their experiences.

**Student Appreciation Reception**
*Tuesday, October 24, 6:00 pm to 7:00 pm*
*Room 201 CD, Wisconsin Center*

Please plan to attend a complimentary reception in honor of high school and undergraduate students.

Earl Scime, DPP Chair, cordially welcomes all DPP meeting attendees, and encourages their open discussion on topics of interest to students. Student Poster Award recipients will be announced. Student advisors are particularly encouraged to attend. Refreshments will be served.

**LGBTQ Networking Dinner**
*Tuesday, October 24, 7:00 pm to 9:00 pm*

Join fellow LGBTQ plasma physicists and their families for an informal networking dinner on Tuesday evening. We’ll meet in front of the DPP Meeting Registration Desk at 7:00 pm and walk to a local restaurant. Please bring a method of payment for your dinner.

**Special Screening: Let There Be Light**
*Tuesday, October 24, 8:00 pm to 9:30 pm*
*Room 102ABC, Wisconsin Center*

**Plasma Science Christian Fellowship**
*Wednesday, October 25, 6:45 am to 7:45 am*
*Room 202AB, Wisconsin Center*

The Plasma Science Christian Fellowship (PSCF) is an informal affiliation of students and scientists working in plasma and fusion energy research. Formed in 2006, the PSCF seeks to provide a forum to discuss how faith connects to the workplace experience and life as scientists. Please join in for an hour on Wednesday morning before the opening session review talk. Bring your own coffee and breakfast, if desired. Contact Darren Craig (darren.craig@wheaton.edu) if you have questions or need additional information. Hope to see you there.

**Special Screening: Let There Be Light**
*Wednesday, October 25, 12:30 pm to 2:00 pm*
*Ballroom C, Wisconsin Center*

**Topical Group on Plasma Astrophysics (GPAP) Business Meeting**
*Wednesday, October 25, 12:30 pm to 2:00 pm*
*Room 203AB, Wisconsin Center*

GPAP will hold its annual business meeting during the DPP annual meeting in San Jose. The GPAP meeting is open to all conference attendees.
High Energy-Density Science Association (HEDSA) Business Meeting

*Wednesday, October 25, 12:30 pm - 2:00 pm*

**Room 203C, Wisconsin Center**

HEDSA will hold its business meeting Wednesday during the DPP annual meeting in San Jose. The HEDSA meeting consists of business, updates, and new information and is open to all conference attendees.

Division of Plasma Physics (DPP) Business Meeting

*Wednesday, October 25, 5:15 pm to 6:15 pm*

**Room 203C, Wisconsin Center**

The business meeting of the Division of Plasma Physics will include reports of actions undertaken by DPP on issues important to our membership. New items of business will be considered in the following order: (1) Written motions, together with any supporting arguments, received by the Secretary-Treasurer, Hui Chen, at the DPP Registration Desk, Wisconsin Center, before noon on Monday, October 23, or which were emailed to Hui Chen (chen33@llnl.gov) by noon on Friday, October 20, 2017. Copies of such material will be displayed on a bulletin board near the DPP registration area in order to give members reasonable notice in case they wish to participate in the discussion and vote on such motions. (2) Written motions submitted to the Secretary-Treasurer prior to the start of the business meeting. (3) Other new business not included in (1) or (2).

DPP Reception and Banquet

*Wednesday, October 25*

**Reception: Crystal Ballroom Foyer, Hilton Milwaukee, 6:30 pm**

**Banquet: Crystal Ballroom, Hilton Milwaukee, 7:30 pm**

The official banquet of the DPP will be held on Wednesday evening. A cash-bar reception preceding the evening banquet at 6:30 pm will be held in the San Jose Ballroom Foyer. A subsidized banquet ticket can be purchased for $40 at the registration desk Tuesday, October 24 up to 5:00 pm. Tickets will be sold on a space-available basis and are non-refundable. Tickets must be presented for admission at the door to the banquet hall. Tickets will not be sold at the door. The banquet program will include presentation of the James Clerk Maxwell Prize, the John Dawson Award for Excellence in Plasma Physics Research, the Thomas H. Stix Award for Outstanding Early Career Contributions to Plasma Physics Research, the Marshall N. Rosenbluth Outstanding Doctoral Thesis Award in Plasma Physics, and recognition of newly elected APS Fellows and Landau-Spitzer Award.

GENERAL INFORMATION

All technical sessions, the DPP Business Meeting, the Child Care Room, the APS DPP Job Fair, Exhibitors, the Speaker Ready Room, and the Plasma Sciences Expo will be in the Wisconsin Center. Teachers’ Day workshops will be held in the Hilton Milwaukee City Center Hotel.

Information Desk

**Wisconsin Center Concourse**

Check the daily hours of operation and any program changes at the APS DPP Information Desk.

Child Care Room

**Wisconsin Center Green Room**

A child care room is available located in the Center, for parents/caregivers to use at no cost to attendees.

APS DPP Membership Booth and Souvenir Store

*Monday-Wednesday, October 23-25, 8:00 am – 5:00 pm*

**Wisconsin Center Concourse**

The APS Membership Department staff will be on hand to answer questions about APS and DPP membership.

DPP Registration Desk

**Wisconsin Center**

**Hours:**

<table>
<thead>
<tr>
<th>Day</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday, October 22</td>
<td>2:00 pm – 7:00 pm</td>
</tr>
<tr>
<td>Monday, October 23</td>
<td>7:00 am – 5:00 pm</td>
</tr>
<tr>
<td>Tuesday, October 24</td>
<td>7:00 am – 4:00 pm</td>
</tr>
<tr>
<td>Wednesday, October 25</td>
<td>7:00 am – 3:00 pm</td>
</tr>
<tr>
<td>Thursday, October 26</td>
<td>7:00 am – 3:00 pm</td>
</tr>
<tr>
<td>Friday, October 27</td>
<td>7:00 am – 12:00 pm</td>
</tr>
</tbody>
</table>
Registration Fees

Pre-Registration fees before October 13:
  - APS Member $480
  - Nonmember $605
  - Retired/Unemployed APS Member $180
  - Student member $100
  - One-Day APS Member $250
  - One-Day Nonmember $310
  - Undergraduate/High School Student $0

On-Site registration fees after October 13:
  - APS Member $570
  - Nonmember $695
  - Retired/Unemployed APS Member $190
  - Student member $150
  - One-Day APS Member $290
  - One-Day Nonmember $353
  - Undergraduate/High School Student $0

WiFi Service

Network ID: APSDPP
WiFi will be available in the Wisconsin Center public space and Hall D.

Messages
Message boards will be located near the DPP Registration Desk in the Wisconsin Center Concourse.

Speaker Ready Room

Wisconsin Center Room 102E
All speakers are encouraged to first visit the Speaker Ready Room to test your presentation with a technician to ensure successful connectivity in your session for your presentation. This will ensure the sessions run smoothly. Presenters are not allowed to use personal projectors.

Monday, October 23 8:00 am – 5:00 pm
Tuesday, October 24 8:00 am – 5:00 pm
Wednesday, October 25 8:00 am – 5:00 pm
Thursday, October 26 8:00 am – 5:00 pm
Friday, October 27 8:00 am – 10:00 am

HOUSING INFORMATION

Hilton Milwaukee City Center Hotel
509 West Wisconsin Avenue, Milwaukee, Wisconsin 53203
($169 Single/Double; $119 Gov’t rate—subject to increases as described by the GSA)

Rates do not include any applicable taxes.

Failure to check-in on your scheduled arrival date will result in a no-show charge of one-night guest room rate, plus tax. If you know you will be late on your scheduled arrival date or if you check out earlier than your scheduled departure date, contact the hotel to discuss their policy.

Please Note: The APS DPP has made every effort to provide accurate and complete information in this publication. However, changes or corrections may occasionally be necessary and may be made without notice after the printing date. To ensure that you receive the most up-to-date information, please check the “Program Changes” board located near APS DPP Information Booth.
## Epitome of the 2017 59th Annual Meeting of the APS Division of Plasma Physics

### 08:00 Monday Morning  
23 October 2017

<table>
<thead>
<tr>
<th>Session</th>
<th>Title</th>
<th>Speaker(s)</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR1</td>
<td>Review: In Search of Late Time Evolution Self-similar Scaling Laws of Rayleigh-Taylor and Richtmyer-Meshkov Hydrodynamic Instabilities - Recent Theoretical Advance and NIF Discovery-Science Experiments</td>
<td>Dov Shvarts</td>
<td>Ballroom C</td>
</tr>
</tbody>
</table>

### 09:30 Monday Morning  
23 October 2017

<table>
<thead>
<tr>
<th>Session</th>
<th>Title</th>
<th>Speaker(s)</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>BI2</td>
<td>Ablators, Instabilities, and Asymmetries</td>
<td>Debra Callahan, Andrea Kritcher, S.X. Hu, Suzanne Ali, Andrew MacPhee, Steve MacLaren</td>
<td>102ABC</td>
</tr>
<tr>
<td>BI3</td>
<td>Gyrokinetics and Plasma Turbulence</td>
<td>Simon Freethy, Tobias Goerler, Jeronimo Garcia, Gary Staebler, Scott Parker, Choongki Sung</td>
<td>103ABC</td>
</tr>
</tbody>
</table>

### 12:45 Monday Noon  
23 October 2017

<table>
<thead>
<tr>
<th>Session</th>
<th>Title</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE1</td>
<td>Town Meeting on Plasma Physics at the National Science Foundation</td>
<td>201AB</td>
</tr>
</tbody>
</table>

### 14:00 Monday Afternoon  
23 October 2017

<table>
<thead>
<tr>
<th>Session</th>
<th>Title</th>
<th>Speaker(s)</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT2</td>
<td>Tutorial: Classical and Quantum Approaches to Extreme Laser-plasma Physics</td>
<td>Mattias Marklund</td>
<td>102ABC</td>
</tr>
<tr>
<td>C13</td>
<td>HED</td>
<td>Kirk Flippo, Mark May, Taisuke Nagayama, Yuan Shi, Robert Kirkwood, Joao Santos</td>
<td>103ABC</td>
</tr>
<tr>
<td>CO4</td>
<td>C-Mod</td>
<td></td>
<td>201AB</td>
</tr>
<tr>
<td>CO5</td>
<td>HEDP Laboratory Astrophysics</td>
<td></td>
<td>202AB</td>
</tr>
<tr>
<td>CO6</td>
<td>Turbulence and Transport</td>
<td></td>
<td>202C</td>
</tr>
<tr>
<td>CO7</td>
<td>Laser-Plasma Instabilities</td>
<td></td>
<td>203AB</td>
</tr>
</tbody>
</table>
CO8  Neutron Diagnostics and Measurement Techniques/Direct Drive ICF  Room: 203C

CP11  Poster Session II: Dusty Plasmas and Sheaths; Z-Pinch, X-Pinch, Dense Plasma Focus, and HED; Stellarator, Disruptions, and MHD  Room: Exhibit Hall D

15:00 MONDAY AFTERNOON  23 OCTOBER 2017

DI2  L/H, Zonal  Jeffrey Parker, Xiang Fan, Ahmed Diallo, Seung-Hoe Ku  Room: 102ABC

19:00 MONDAY EVENING  23 OCTOBER 2017

EE2  University Fusion Association General Meeting  Room: 102ABC

08:00 TUESDAY MORNING  24 OCTOBER 2017

FR1  Review: Physics of the Tokamak Pedestal, and Implications for Magnetic Fusion Energy  Philip Snyder  Room: Ballroom C

09:30 TUESDAY MORNING  24 OCTOBER 2017

GI2  Pedestal and Low-Temperature Physics  Jerry Hughes, Robert Wilcox, Yongkyoon In, Michael Keidar, Erik Wagenaars, Yan Feng  Room: 102ABC

12:45 TUESDAY NOON  24 OCTOBER 2017

HE1  Town Meeting on the Concerns of Junior Scientists  Room: 201AB
<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
<th>Event</th>
</tr>
</thead>
</table>
| 14:00 TUESDAY AFTERNOON 24 OCTOBER 2017 | JT2       | Tutorial: Contemporary Machine Learning: Techniques for Practitioners in the Physical Sciences  
Brian Spears  
Room: 102ABC |
|                    | JI3       | Rotation and Flows  
Arash Ashourvan, Alexander Lebschy, Richard Fridstrom, T. Stoltzfus-Dueck, Rongjie Hong, Sean Mattingly  
Room: 103ABC |
|                    | JO4       | Spherical Tokamaks, Other  
Room: 201AB |
|                    | JO5       | Particle Generation and Acceleration  
Room: 202AB |
|                    | JO6       | Waves and Space Plasmas  
Room: 202C |
|                    | JO7       | Hydrodynamic Instability I  
Room: 203AB |
|                    | JO8       | EOS and High-Z Multiply Ionized Atomic Physics  
Room: 203C |
|                    | JP11      | Poster Session IV: Education and Outreach; High School or Undergraduate Research; C-Mod, MST, & MFE Theoretical Methods  
Room: Exhibit Hall D |
| 15:00 TUESDAY AFTERNOON 24 OCTOBER 2017 | KI2       | Warm/Dense  
Stephanie Hansen, Bastian B. L. Witte, D.N. Polsin, Mianzhen Mo  
Room: 102ABC |
| 17:00 TUESDAY EVENING 24 OCTOBER 2017 | LE1       | Meet the APS Editors  
Room: Ballroom Foyer |
|                    | LE2       | Fellowship Opportunities for Graduate Students in Plasma Physics  
Room: 202AB |
|                    | LE3       | Women in Plasma Physics  
Room: Regency Ballroom |
| 17:15 TUESDAY EVENING 24 OCTOBER 2017 | LE4       | Student Appreciation Reception  
Room: 201CD |
| 17:30 TUESDAY EVENING 24 OCTOBER 2017 | LE5       | Special Screening: Let There Be Light  
Room: 102ABC |
| 08:00 WEDNESDAY MORNING 25 OCTOBER 2017 | MR1       | Review: Bringing Space Down to Earth: Exploring the Physics of Space Plasmas in the Laboratory  
Gregory G. Howes  
Room: Ballroom C |
<table>
<thead>
<tr>
<th>Time</th>
<th>Event Description</th>
<th>Room</th>
</tr>
</thead>
</table>
| 09:30 WEDNESDAY MORNING | Reconnection: Experiments and Observations  
Jack Hare, Joseph Olson, Joel Dahlin, Ami DuBois, W. Fox, Li-Jen Chen | 102ABC     |
|              | Disruptions and Energetic Particles  
David Pfefferle, Carlos Paz-Soldan, Cedric Reux,  
Diego del-Castillo-Negrete,  
Eric Fredrickson, David C. Pace | 103ABC     |
| 12:30 WEDNESDAY NOON | GPAP Business Meeting  
Room: 203AB | 203AB      |
| 14:00 WEDNESDAY AFTERNOON | Tutorial: Experiments and Models of MHD Jets and Their Relevance to Astrophysics and Solar Physics  
Paul Bellan  
Room: 102ABC | 102ABC     |
|              | DPP Award Session and Legacy of Kaw  
Ian Chapman, Felicie Albert, Jonathan Squire, Robert Goldston, Ping Zhu, Wojciech Rozmus | 103ABC     |
|              | Research in Support of ITER  
Room: 201AB | 201AB      |
|              | Warm Dense Matter  
Room: 202AB | 202AB      |
|              | Computation  
Room: 202C | 202C       |
|              | Hohlraum and X-Ray Cavity Physics II  
Room: 203AB | 203AB      |
|              | Magneto-Inertial Fusion I  
Room: 203C | 203C       |
|              | Mini-Conference on Laser-Matter Interactions: The Next Generation II  
Room: 202DE | 202DE      |
|              | Mini-Conference on Laser-Matter Interactions: The Next Generation I  
Room: 202AB | 202AB      |
|              | Mini-Conference on Laser-Matter Interactions: The Next Generation I  
Room: 203AB | 203AB      |
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:00 WEDNESDAY AFTERNOON 25 OCTOBER 2017</td>
<td>PP11 Poster Session VI: HEDP II; Compression and Burn; NSTX-U &amp; Boundary; Direct, Indirect, and Polar-drive; Hydrodynamic Instability; Basic Plasmas</td>
<td>Exhibit Hall D</td>
</tr>
<tr>
<td>17:15 WEDNESDAY EVENING 25 OCTOBER 2017</td>
<td>QI2 Turbulence/Waves, Matthew Kunz, Alfred Mallet, Daniel Told, Seth Dorfman</td>
<td>102ABC</td>
</tr>
<tr>
<td>08:00 THURSDAY MORNING 26 OCTOBER 2017</td>
<td>SR1 James Clerk Maxwell Prize Address: Scaling Laws for the Dynamical Plasma Phenomena, D. D. Ryutov</td>
<td>Ballroom C</td>
</tr>
<tr>
<td>09:30 THURSDAY MORNING 26 OCTOBER 2017</td>
<td>TI2 Direct Drive, Fast Ignition, and Kinetic Modeling, R. Betti, J.A. Marozas, Tomoyuki Johzaki, H. Sio, William Taitano, Hans Rinderknecht</td>
<td>102ABC</td>
</tr>
<tr>
<td>14:00 THURSDAY AFTERNOON 26 OCTOBER 2017</td>
<td>UT2 Tutorial: Integrated Tokamak Modeling: When Physics Informs Engineering and Research Planning, Francesca Poli</td>
<td>102ABC</td>
</tr>
<tr>
<td>15:00 WEDNESDAY AFTERNOON 25 OCTOBER 2017</td>
<td>TI3 Stability, Scenarios, and MHD, Brendan C. Lyons, Francesca Turco, Alexander Bock, Joshua Reusch, M. Gatu Johnson, Yue Zhang</td>
<td>103ABC</td>
</tr>
<tr>
<td>17:15 WEDNESDAY EVENING 25 OCTOBER 2017</td>
<td>TO4 EAST</td>
<td>201AB</td>
</tr>
<tr>
<td>17:15 WEDNESDAY EVENING 25 OCTOBER 2017</td>
<td>TO5 Strongly-coupled/Dusty Plasmas</td>
<td>202AB</td>
</tr>
<tr>
<td>18:30 WEDNESDAY EVENING 25 OCTOBER 2017</td>
<td>TO6 Low Temperature and Technology</td>
<td>202C</td>
</tr>
<tr>
<td>08:00 THURSDAY MORNING 26 OCTOBER 2017</td>
<td>TO7 Magneto-Inertial Fusion II</td>
<td>203AB</td>
</tr>
<tr>
<td>09:30 THURSDAY MORNING 26 OCTOBER 2017</td>
<td>TO8 High-Energy Density Physics, High-Field Physics, and Intense Beams</td>
<td>203C</td>
</tr>
<tr>
<td>14:00 THURSDAY AFTERNOON 26 OCTOBER 2017</td>
<td>TM9 Mini-Conference on Bridging the Divide Between Space and Laboratory Plasma Physics I</td>
<td>202DE</td>
</tr>
<tr>
<td>UT2 Tutorial: Integrated Tokamak Modeling: When Physics Informs Engineering and Research Planning, Francesca Poli</td>
<td>102ABC</td>
<td></td>
</tr>
<tr>
<td>Code</td>
<td>Title</td>
<td>Time</td>
</tr>
<tr>
<td>-------</td>
<td>-------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>UI3</td>
<td>Complex Plasmas and Reconnection&lt;br&gt;<em>Eric Hunter, Matthew Stoneking, Matthew Affolter, Dominik Kraus, Young Dae T., Luca Comisso</em>&lt;br&gt;Room: 103ABC</td>
<td>08:00 FRIDAY MORNING&lt;br&gt;27 OCTOBER 2017</td>
</tr>
<tr>
<td>UO4</td>
<td>PMI &amp; Boundary</td>
<td></td>
</tr>
<tr>
<td>UO5</td>
<td>Radiation Generation</td>
<td></td>
</tr>
<tr>
<td>UO6</td>
<td>Sources and Diagnostics</td>
<td></td>
</tr>
<tr>
<td>UO7</td>
<td>Compression and Burn II</td>
<td></td>
</tr>
<tr>
<td>UO8</td>
<td>HED Hydrodynamics</td>
<td></td>
</tr>
<tr>
<td>UM9</td>
<td>Mini-Conference on Bridging the Divide Between Space and Laboratory Plasma Physics II</td>
<td></td>
</tr>
<tr>
<td>UP11</td>
<td>Poster Session VIII:&lt;br&gt;Non-Neutral, Antimatter and Strongly Coupled Plasmas;&lt;br&gt;Waves;&lt;br&gt;Conventional and Spherical Tokamaks;&lt;br&gt;Magneto-Inertial Fusion&lt;br&gt;Room: 202DE</td>
<td></td>
</tr>
<tr>
<td>WE1</td>
<td>Town Meeting on ITER Status and Plans&lt;br&gt;<em>T.C. Luce, Derek Thuecks, Syun’ichi Shiraiwa, E.H. Martin</em>&lt;br&gt;Room: 102ABC</td>
<td>19:30 THURSDAY EVENING&lt;br&gt;26 OCTOBER 2017</td>
</tr>
<tr>
<td>VI2</td>
<td>Transport&lt;br&gt;<em>T.C. Luce, Derek Thuecks, Syun’ichi Shiraiwa, E.H. Martin</em>&lt;br&gt;Room: 102ABC</td>
<td>15:00 THURSDAY AFTERNOON&lt;br&gt;26 OCTOBER 2017</td>
</tr>
<tr>
<td>XR1</td>
<td>Review: The Science and Technology Case for High-Field Fusion&lt;br&gt;<em>D. Whyte</em>&lt;br&gt;Room: Ballroom C</td>
<td>09:30 FRIDAY MORNING&lt;br&gt;27 OCTOBER 2017</td>
</tr>
<tr>
<td>YI2</td>
<td>SOL and Divertor&lt;br&gt;<em>Youwen Sun, Cameron Samuell, Ralph Kabe, Fulvio Militello, Bin Chen, Houyang Guo</em>&lt;br&gt;Room: 102ABC</td>
<td></td>
</tr>
<tr>
<td>YI3</td>
<td>Plasma Acceleration&lt;br&gt;<em>Jorge Vieira, Jeroen van Tilborg, Alessandro Cianchi, Timon Mehring, Paul Scherkl, Donald A. Spong</em>&lt;br&gt;Room: 103ABC</td>
<td></td>
</tr>
<tr>
<td>YI4</td>
<td>SOL and Divertor&lt;br&gt;<em>Youwen Sun, Cameron Samuell, Ralph Kabe, Fulvio Militello, Bin Chen, Houyang Guo</em>&lt;br&gt;Room: 102ABC</td>
<td></td>
</tr>
<tr>
<td>YI5</td>
<td>Plasma Acceleration&lt;br&gt;<em>Jorge Vieira, Jeroen van Tilborg, Alessandro Cianchi, Timon Mehring, Paul Scherkl, Donald A. Spong</em>&lt;br&gt;Room: 103ABC</td>
<td></td>
</tr>
<tr>
<td>YO4</td>
<td>Energetic Particles and Transport&lt;br&gt;Room: 201AB</td>
<td></td>
</tr>
<tr>
<td>YO6</td>
<td>Magnetized HEDP and HED Measurement/Diagnostic Techniques&lt;br&gt;Room: 202C</td>
<td></td>
</tr>
<tr>
<td>YO7</td>
<td>Hydrodynamic Instability II/Compression and Burn III&lt;br&gt;Room: 203AB</td>
<td></td>
</tr>
<tr>
<td>YP11</td>
<td>Poster Session IX: Supplemental; Post-Deadline Abstracts&lt;br&gt;Room: Exhibit Hall D</td>
<td></td>
</tr>
<tr>
<td>ZE1</td>
<td>Prize Drawing&lt;br&gt;Room: 102ABC</td>
<td></td>
</tr>
</tbody>
</table>
Invited Papers

8:00
AR1 1 In search of late time evolution self-similar scaling laws of Rayleigh-Taylor and Richtmyer-Meshkov hydrodynamic instabilities - recent theoretical advance and NIF Discovery-Science experiments
DOV SHVARTS, Nuclear Research Center-Negev, Israel

Hydrodynamic instabilities, and the mixing that they cause, are of crucial importance in describing many phenomena, from very large scales such as stellar explosions (supernovae) to very small scales, such as inertial confinement fusion (ICF) implosions. Such mixing causes the ejection of stellar core material in supernovae, and impedes attempts at ICF ignition. The Rayleigh-Taylor instability (RTI) occurs at an accelerated interface between two fluids with the lower density accelerating the higher density fluid. The Richtmyer-Meshkov (RM) instability occurs when a shock wave passes an interface between the two fluids of different density. In the RTI, buoyancy causes “bubbles” of the light fluid to rise through (penetrate) the denser fluid, while “spikes” of the heavy fluid sink through (penetrate) the lighter fluid. With realistic multi-mode initial conditions, in the deep nonlinear regime, the mixing zone width, H, and its internal structure, progress through an inverse cascade of spatial scales, reaching an asymptotic self-similar evolution: \( h_{\text{RT}} = \alpha_{\text{RT}} A t^2 \) for RT and \( h_{\text{RM}} = \alpha_{\text{RM}} t^\theta_{\text{RM}} \) for RM. While this characteristic behavior has been known for years, the self-similar parameters \( \alpha_{\text{RT}} \) and \( \theta_{\text{RM}} \) and their dependence on dimensionality and density ratio have continued to be intensively studied and a relatively wide distribution of those values have emerged. This talk will describe recent theoretical advances in the description of this turbulent mixing evolution that sheds light on the spread in \( \alpha_{\text{RT}} \) and \( \theta_{\text{RM}} \). Results of new and specially designed experiments, done by scientists from several laboratories, were performed recently using NIF, the only facility that is powerful enough to reach the self-similar regime, for quantitative testing of this theoretical advance, will be presented.

SESSION B12: ABLATORS, INSTABILITIES, AND ASYMMETRIES
Monday Morning, 23 October 2017; Room: 102ABC at 9:30; Russell Follett, University of Rochester, presiding

Invited Papers

9:30
B12 1 Exploring the limits of case-to-capsule ratio, pulse length, and picket energy for symmetric hohlraum drive on NIF
DEBRA CALLAHAN, LLNL

Over the past two years, we have been exploring low gasfill hohlraums (He fill at 0.3-0.6 mg/cc) as an alternate to the high gasfill hohlraums used in NIC and the High Foot campaigns (He fill at 1-1.6 mg/cc). These low fill hohlraums have significantly reduced laser-plasma instabilities and increased coupling to the target as compared to the high fill hohlraums and take us to a new region of parameter space where the hohlraum is limited by hydrodynamic motion of the hohlraum wall rather than by laser plasma interactions. The outer cone laser beams interacting with the hohlraum wall produce a “bubble” of low density, high Z material that moves toward the center of the hohlraum. This gold or depleted uranium bubble eventually intercepts the inner cone beams and prevents the inner cone beams from reaching the waist of the hohlraum—where they are needed to get a symmetric implosion. Thus, the speed of the bubble expansion sets the allowable pulse duration in a given size hohlraum. Data and simulations suggest that the bubble is launched by the early part of the laser pulse (“picket”) and the gold/gas interfaces moves nearly linearly in time toward the axis of the hohlraum. The velocity of the bubble is related to the square root of the energy in the picket of the pulse – thus the picket energy and pulse duration set the allowable hohlraum size and case-to-capsule ratio. In this talk, will discuss a data based model to describe the bubble motion and apply this model to a broad set of data from a variety of ablators (CH, HDC, Be), pulse durations (6-14 ns), case-to-capsule ratios (rhohl/rcap of 3-4.2), hohlraum sizes (5.4-6.7 mm diameter), and hohlraum gasfill densities (0.3-0.6 mg/cc). We will discuss how this model can help guide future designs and how improvements in the hohlraum (foam liners, hohlraum shape) can open up new parts of parameter space.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA273.
10:00

BI2 2 Comparison of plastic, high-density carbon, and beryllium as NIF ablators*
ANDREA KRITCHER, Lawrence Livermore National Laboratory

An effort is underway to compare the three principal ablators for National Ignition Facility (NIF) implosions: plastic (CH), High Density Carbon (HDC), and beryllium (Be). This presentation will summarize the comparison and discuss in more detail the issues pertaining to hohlraum performance and symmetry. Several aspects of the hohlraum design are affected by the ablator properties, as the ablator constrains the first shock and determines the overall pulse length. HDC targets can utilize shorter pulse lengths due to the thinner, higher density shell, and should be less susceptible to late time wall motion. However, HDC requires a larger pcket energy to ensure adequate melt, leading to increased late time wall movement. Be is intermediate to CH and HDC in both these regards, and has more ablated material in the hohlraum. These tradeoffs as well as other design choices for currently fielded campaigns are assessed in this work. To assess consistently the radiation drive and symmetry, integrated postshot simulations of the hohlraum and capsule were done for each design using the same methodology. The simulation results are compared to experimental data. Using this post-shot model, we make a projection of the relative plausible performance that can be achieved, while maintaining adequate symmetry, using the full NIF laser, i.e. 1.8 MJ/500 TW Full NIF Equivalent (FNE). The hydrodynamic stability of the different ablators is also an important consideration and will be presented for the current platforms and projection to FNE.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

10:30

BI2 3 High-Energy-Density–Physics Studies for Inertial Confinement Fusion Applications*
S.X. HIU, Laboratory for Laser Energetics, U. of Rochester

Accurate knowledge of the static, transport, and optical properties of high-energy-density (HED) plasmas is essential for reliably designing and understanding inertial confinement fusion (ICF) implosions. In the warm-dense-matter regime routinely accessed by low-adiabat ICF implosions, [1] many-body strong-coupling and quantum electron degeneracy effects play an important role in determining plasma properties. The past several years have witnessed intense efforts to assess the importance of the microphysics of ICF targets, both theoretically and experimentally. On the theory side, first-principles methods based on quantum mechanics have been applied to investigate the properties of warm, dense plasmas. Specifically, self-consistent investigations have recently been performed on the equation of state, thermal conductivity, and opacity of a variety of ICF ablators such as polystyrene (CH), beryllium, carbon, and silicon over a wide range of densities and temperatures [2-5]. In this talk, we will focus on the most-recent progress on these ab initio HED physics studies, which generally result in favorable comparisons with experiments. Upon incorporation into hydrocodes for ICF simulations, these first-principles ablator-plasma properties have produced significant differences over traditional models in predicting 1-D target performance of ICF implosions on OMEGA and direct-drive–ignition designs for the National Ignition Facility.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944. *In collaboration with L. A. Collins, T. R. Boehly, G. W. Collins, J. D. Kress, and V. N. Goncharov.


11:00

BI2 4 Probing the seeding of hydrodynamic instabilities from non-uniformities in ablator materials using 2D velocimetry*
SUZANNE ALI, Lawrence Livermore National Laboratory

Despite the extensive work done to characterize and improve the smoothness of ablator materials used in inertial confinement fusion, features indicative of seeded instabilities from these materials are still observed. A two-dimensional imaging velocimetry technique has been used on Omega (OHRV 2D-VISAR system) to measure the velocity roughness of shock fronts launched by indirect drive in the three ablator materials of current interest. We have used this diagnostic, coupled with extensive pre-shot target metrology, to study the presence of shock-front perturbations in GDP, beryllium, and high density carbon ablators. Observed features are small variations from one-dimensional evolution, but are important for fully understanding the effects of surface topography, dynamic material response, and internal heterogeneities on the stability of ICF capsules. For all three ablators we have quantified perturbations that can dominate conventional surface roughness seeds to hydrodynamic instability.

*This work performed was under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
11:30
BI2 5 Measurement and mitigation of X-ray shadow imprint of hydrodynamic instabilities on the surface of Inertial Confinement Fusion capsules due to the fill tube∗
ANDREW MACPHEE, Lawrence Livermore Natl Lab

Indirectly-driven Inertial Confinement Fusion (ICF) implosions on the National Ignition Facility (NIF) employ a small diameter (10 μm) fill tube to supply the cryogenic deuterium-tritium (DT) fuel to the capsule. Recent experimental observations characterizing the perturbation produced by this fill tube have revealed an unexpected shadow imprinted instability mechanism [1], whereby several of the x-ray spots formed on the inside wall of the hohlraum cast directional shadows of the fill tube onto the surface of the capsule. Reduced ablation in the corresponding umbrae of these shadows leads to a pattern of radial ridges of excess ablator material measuring ~100 nm above the surrounding capsule surface.

By the time the capsule has converged ~2x from its original radius, the areal density (ρR) perturbation of these spoke-like features becomes comparable to that of central hole due to the fill tube itself. We report both quantitative radiographic measurements of this newly observed perturbation (for several ablator materials) as well as the results of two strategies for mitigating against such shadow imprinted instabilities: 1.) reducing the fill tube diameter and wall thickness to produce a smaller perturbation that blows down to low density more quickly, and 2.) modifying the driving laser pulse for the lower-intensity inner beams to allow more time for the fill tube to blow down to low density prior to the onset of shadow imprint, which is produced by the more-intense outer beams during the later part of the drive. Results and analysis from both focused radiographic experiments as well as the impact on the performance of layered DT ignition implosions will be discussed.

∗Work performed under the auspices of the U.S. D.O.E. by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.


12:00
BI2 6 A near one-dimensional 2-shock indirectly driven implosion at convergence ratio ∼30∗
STEVE MACLAREN, Lawrence Livermore National Laboratory

Inertial confinement fusion implosions at the National Ignition Facility, while successfully demonstrating self-heating due to alpha-particle deposition, have fallen short of the performance predicted by one-dimensional multi-physics implosion simulations. The current understanding, based on simulations as well as experimental evidence, suggests that the principle reason for the disagreement is a breeching of the cold fuel assembly at stagnation which would otherwise completely confine the hot spot. 3-D simulations indicate a combination of low-mode symmetry swings and ablation-front hydrodynamic instability seeded by engineering features such as the capsule tent and fill tube lead to localized thinning and perforation of the stagnated fuel, resulting in a loss of hot spot pressure and energy. We describe a short series of experiments on the NIF designed specifically to avoid these issues in order to understand if, once they are removed, a suspended-fuel-layer deuterium-tritium implosion can achieve 1-D simulated performance. The particular implosion system combines a thick capsule shell with an elevated initial ablation temperature to minimize the ablation front perturbations from the engineering features, and incorporates a large ratio of hohlraum-to-capsule radius as a means to permit a higher degree of control over implosion symmetry. The resulting implosion at a convergence ratio of ~30 was not perfectly spherically symmetric as observed by both neutron and time-resolved x-ray imaging diagnostics. However, the stagnation observables match closely the performance predicted by 1D simulations, including, when some hot spot motion is accounted for, the apparent ion temperature. We present this result along with the design for an upcoming 2-shock experiment to test whether this level of agreement with the 1D model can be achieved in the self-heating regime.

∗This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344.
a 30-channel correlation ECE (CECE) radiometer, measures radial profiles (0.5 <r/a <0.8) of low-k (ktheta rhos <0.3) temperature fluctuations as well as frequency spectra and radial correlation lengths in unprecedented detail in both L- and H-mode. Typical L-mode levels are in the range 0.3 – 0.8%. The second is formed by the addition of a reflectometer on the same line of sight to enable measurements of the phase angle between turbulent density and temperature fluctuations. Design predictions are followed by a more traditional “post-diction” validation study with GENE. Using a cutting edge synthetic diagnostic GENE shows a factor 1.6 - 2 over-prediction of the fluctuation amplitude, while matching both ion and electron heat fluxes within experimental error. Detailed sensitivity scans are underway to understand the robustness of this disagreement and a detailed assessment of the experimental errors has been carried out. The discrepancy opens questions about the role of multi-scale turbulence physics, but also indicates the need for the comparison of more experimental turbulence properties to have a more complete validation hierarchy. In an effort to understand the discrepancy, predictions of the nT-phase and the radial correlation length have been made along with an assessment of their sensitivity to experimental errors. Comparison to experimental measurements will be discussed.

∗This work is supported in part by the US DOE under Grants DE-SC0006419 and DE-SC0017381. This work has also received funding from the European Union’s Horizon 2020 research and innovation programme under Grant agreement number 633053.

10:00
BI3 2 Recent gyrokinetic turbulence insights with GENE and direct comparison with experimental measurements
TOBIAS GOERLER, Max Planck Institute for Plasma Physics

Throughout the last years direct comparisons between gyrokinetic turbulence simulations and experimental measurements have been intensified substantially. Such studies are largely motivated by the urgent need for reliable transport predictions for future burning plasma devices and the associated necessity for validating the numerical tools. On the other hand, they can be helpful to assess the way a particular diagnostic experiences turbulence and provide ideas for further optimization and the physics that may not yet be accessible. Here, synthetic diagnostics, i.e. models that mimic the spatial and sometimes temporal response of the experimental diagnostic, play an important role. In the contribution at hand, we focus on recent gyrokinetic GENE simulations dedicated to ASDEX Upgrade L-mode plasmas and comparison with various turbulence measurements. Particular emphasis will be given to density fluctuation spectra which are experimentally accessible via Doppler reflectometry. A sophisticated synthetic diagnostic involving a fullwave code has recently been established and solves the long-lasting question on different spectral roll-overs in gyrokinetic and measured spectra as well as the potentially different power laws in the O- and X-mode signals. The demonstrated agreement furthermore extends the validation data base deep into spectral space and confirms a proper coverage of the turbulence cascade physics. The flux-matched GENE simulations are then used to study the sensitivity of the latter to the main microinstability drive and investigate the energetics at the various scales. Additionally, electron scale turbulence based modifications of the high-k power law spectra in such plasmas will be presented and their visibility in measurable signals be discussed.

10:30
BI3 3 Non-linear isotope and fast ions effects: routes for low turbulence in DT plasmas
JERONIMO GARCIA, CEA

The isotope effect, i.e. the fact that heat and particle fluxes do not follow the expected Gyro-Bohm estimate for turbulent transport when the plasma mass is changed, is one of the main challenges in plasma theory. Of particular interest is the isotope exchange between the fusion of deuterium (DD) and deuterium-tritium (DT) nuclei as there are no clear indications of what kind of transport difference can be expected in burning plasmas. The GENE code [1] is therefore used for computing DD vs DT linear and nonlinear microturbulence characteristics in the core plasma region of a previously ITER hybrid scenario at high beta obtained in the framework of simplified integrated modelling. Scans on common turbulence related quantities as external ExB flow shear, Parallel Velocity Gradient (PVG), plasma beta, collosionality or the number of ion species have been performed. Additionally, the role of energetic particles, known to reduce Ion Temperature Gradient (ITG) turbulence has been also addressed [2,3]. It is obtained that the ITER operational point will be close to threshold and in these conditions turbulence is dominated by ITG modes. A purely weak non-linear isotope effect, absent in linear scans, can be found when separately adding moderate ExB flow shear or electromagnetic effects, whereas collisionality just modulates the intensity. The isotope effect, on the other hand, becomes very strong in conditions with simultaneously moderate ExB flow shear, beta and low q profile with significant reductions of ion heat transport from DD to DT [3]. By analyzing the radial structure of the two point electrostatic potential correlation function it has been found that the inherent Gyro-Bohm scaling for plasma microturbulence, which increases the radial correlation length at short scales form DD to DT, is counteracted by the concomitant appearance of a complex nonlinear multiscale space interaction involving external ExB flow shear, zonal flow activity, magnetic geometry and electromagnetic effects. The number of ion species and the fast ion population is also found to play a role in this non-linear process whereas a symmetry breaking between D and T, with systematic reduced heat and particle transport for T, is always obtained.

3J. Garcia et al., Nucl. Fusion 57, 014007 (2017).
B13 4 Transport Barriers in Bootstrap Driven Tokamaks*
GARY STAEBLER, General Atomics

Maximizing the bootstrap current in a tokamak, so that it drives a high fraction of the total current, reduces the external power required to drive current by other means. Improved energy confinement, relative to empirical scaling laws, enables a reactor to more fully take advantage of the bootstrap driven tokamak. Experiments have demonstrated improved energy confinement due to the spontaneous formation of an internal transport barrier in high bootstrap fraction discharges. Gyrokinetic analysis, and quasilinear predictive modeling, demonstrates that the observed transport barrier is due to the suppression of turbulence primarily due to the large Shafranov shift. ExB velocity shear does not play a significant role in the transport barrier due to the high safety factor. It will be shown, that the Shafranov shift can produce a bifurcation to improved confinement in regions of positive magnetic shear or a continuous reduction in transport for weak or negative magnetic shear. Operation at high safety factor lowers the pressure gradient threshold for the Shafranov shift driven barrier formation. The ion energy transport is reduced to neoclassical and electron energy and particle transport is reduced, but still turbulent, within the barrier. Deeper into the plasma, very large levels of electron transport are observed. The observed electron temperature profile is shown to be close to the threshold for the electron temperature gradient (ETG) mode. A large ETG driven energy transport is qualitatively consistent with recent multi-scale gyrokinetic simulations showing that reducing the ion scale turbulence can lead to large increase in the electron scale transport. A new saturation model for the quasilinear TGLF transport code, that fits these multi-scale gyrokinetic simulations, can match the data if the impact of zonal flow mixing on the ETG modes is reduced at high safety factor.

*This work was supported by the U.S. Department of Energy under DE-FG02-95ER54309 and DE-FC02-04ER54698.

B13 5 Multiscale Full Kinetics as an Alternative to Gyrokinetics*
SCOTT PARKER, Dept. of Physics, Univ. of Colorado, Boulder

Gyrokinetics has been extremely successful for modeling low frequency well-magnetized plasmas. However, for many plasmas, the expansion parameters in gyrokinetic theory are not so small. Until now, gyrokinetics was the only useful kinetic simulation model available for low frequency and weakly unstable plasmas even when its validity was questionable. Here, we report a new simulation model with full kinetic ions (Lorentz force dynamics) using implicit multi-scale techniques. This is the first six-dimensional model to accurately capture low-frequency physics, including finite Larmor radius (FLR) effects and weak gradient drive drift wave-type instabilities, operating comfortably within domain of gyrokinetics. Such a model allows for verification of gyrokinetics and can help identify the relative importance of higher order terms in gyrokinetic theory. Here we present full kinetic simulations of the toroidal ion-temperature-gradient (ITG) instability in tokamak plasma geometry. We will discuss the orbit averaging and sub-cycling techniques as well as the implicit variational integrator for the particle trajectories necessary to preserve adiabatic invariants. Results comparing the full kinetic model with gyrokinetics are reported. In slab geometry, excellent agreement is obtained linearly and nonlinearly including full FLR effects. High-frequency Ion Bernstein waves, which are present in the full kinetic model can easily be suppressed with the implicit time advance while maintaining FLR effects. The fully kinetic toroidal model uses field-line-following coordinates for the field quantities providing well-resolved field-aligned mode structure. Benchmarks with gyrokinetics within the domain of validity of gyrokinetics show excellent agreement. Nonlinear ITG simulations in slab geometry with both gyrokinetics and full kinetics will be compared in more marginal steep gradient regimes [1].

*Collaborators: B. Sturdevant, M. Miecnikowski, Y. Chen, Y. Hu. Work supported by the U.S. Dept. of Energy.


B13 6 Physics of thermal transport and increased electron temperature turbulence in the edge pedestal of ELM-free, H-mode regimes on DIII-D*
CHOONGKI SUNG, University of California, Los Angeles

It has been observed, for the first time, that suppression of Edge Localized Modes (ELMs) in tokamak plasmas is accompanied by an increase in electron temperature turbulence. A correlation electron cyclotron emission technique has been utilized to quantify the observed increase: 40% increase in Quiescent H-mode (QH-mode) and 70% increase in 3D field ELM suppressed H-mode. Since reliable ELM-free H-mode operation is essential for future burning plasma experiments, it is crucial to develop a validated predictive capability for these plasmas. Linear stability analysis using TGLF has provided an explanation for the observations and has indicated that the underlying physical mechanisms are different in the two regimes. In QH-mode, profile gradients and the associated linear growth rate are decreased compared to ELMing H-mode. However, the ExB shearing rate is reduced by an even greater factor such that turbulent transport is no longer suppressed by flow shear. In contrast, during 3D field ELM suppressed H-mode, gradients are increased and TGLF predicts that a large increase in linear growth rate is primarily responsible for the increased turbulence. Power balance analysis using ONETWO is also consistent with the changes in electron thermal transport being due to the increased turbulence. These new findings are significant since they i) provide a physics explanation of these changes via TGLF analysis and enable validation of the model in the key pedestal region, and ii) support the hypothesis that turbulent
transport partially replaces ELM-dominated transport during ELM-free operation. These results form a basis to develop a predictive understanding of pedestal regulation in ELM suppressed regimes.

*Supported by the US DOE under DE-FG02-08ER54984, DE-FC02-04ER54698.

SESSION BO4: DIII-D TOKAMAK
Monday Morning, 23 October 2017
Room: 201AB at 9:30
Ahmed Diallo, Princeton Plasma Physics Laboratory, presiding

Contributed Papers

9:30
BO4 1 Overview of Recent DIII-D Experimental Results* MAX FENSTERMACHER, LLNL DIII-D TEAM Recent DIII-D experiments contributed to the ITER physics basis and to physics understanding for extrapolation to future devices. A predict-first analysis showed how shape can enhance access to RMP ELM suppression. 3D equilibrium changes from ELM control MPs, were linked to density pumpout. Ion velocity imaging in the SOL showed 3D C linked to density pumpout. Analysis showed how shape can enhance access to RMP ELM suppression.

*Supported by the US DOE under DE-FG02-97ER54415 and DE-FC02-04ER54698.

9:42
BO4 2 High confinement in negative triangularity discharges in DIII-D* M.E. AUSTIN, U. Texas A. MARINONI, MIT M.L. WALKER, Gen. Atomics M.W. BROOKMAN, U. Texas J.S. DE-GRASSIE, A.W. HYATT, C.C. PETTY, K.E. THOME, Gen. Atomics T.L. RHODES, C. SUNG, UCLA O. SAUTER, SPC Discharges with negative triangularity (δ) shape have been created in DIII-D with H-mode-like confinement (H\text{95y} = 1.2) and high normalized beta (β_r = 2.6) with L-mode-like edge pressure profiles and no ELMs. These inner-wall-limited plasmas with δ = −0.4 had the same global performance as a positive triangularity (δ = 0.4) ELMing H-mode discharge with the same I_p, elongation and area. Preliminary fluctuation data shows negative δ plasmas have lower turbulence levels, typically reduced by 20%, in the outer region of the plasma. 0.7 <r/a<1.0, compared to equivalent positive δ discharges. Correspondingly, transport analysis indicates reduced ion and electron diffusivities for negative δ compared to the positive δ cases. Also, the positive triangularity discharges had 30-50% lower neutron rates as the identically heated negative triangularity ones, due primarily to impurity retention and deuterium dilution. These results show that negative triangularity is a viable candidate for reactor scenarios with its high confinement, ELM-mitigated characteristics plus a more economical and effective option for divertor placement.

10:06
BO4 4 Plasma Response to n=3 Magnetic Perturbations in Noninductive Hybrid Plasmas in the DIII-D Tokamak* R. NAZIKIAN, A. BORTOLON, N. FERRARO, N. LOGAN, PPPL C.C. PETTY, C. PAZ-SOLDAN, General Atomics T.L. RHODES, UCLA R. MOYER, D. ORLOV, UCSF F. TURCO, Columbia University 3D magnetic perturbations (MPs) are effective in suppressing Type-I and Grassly ELMs in DIII-D noninductive Hybrid plasmas over a wide range of q95 (5.2-7.5) and beam torque (6-4.2 Nm) with minimal confinement degradation (β_r ≈ 3.2, H\text{95y} ≈ 1.2). Recent experiments elucidate the role of the plasma response to n=3 MPs that is responsible for the effectiveness of ELM suppression in this regime. Scans of the n=3 applied spectrum were performed using the new ASIPP Super Supplies and by comparing the plasma response to even/odd parity and single row I-coil configurations. Even parity is poor at driving plasma response and for ELM suppression, consistent with model predictions. All other coil configurations showed strong amplification by the plasma, ≈ 4x larger than for the β_r ≈ 1.8 ITER inductive scenario, consistent with predictions from linear MHD modeling. These results reveal the beneficial role of high beta and elevated q95 for the suppression of ELMs by MPs in Advanced Tokamak scenarios.

*Supported under USDOE Agreement DE-AC02-09CH11466, DE-FC02-04ER54698, DE-FG02-08ER54984.
MONDAY MORNING • B04

10:18

B04 5 Stability of helical cores in high performance tokamak discharges* ANDREAS WINGEN, ROBERT WILCOX, SUDIP SEAL, STEVEN HIRSHMAN, Oak Ridge National Laboratory FRANCESCULA TURCO, Columbia University The threshold for spontaneous growth of n=m=1/1 helical cores in tokamaks is determined using VMEC. This stability model is based on a DIII-D hybrid discharge with helical core, and it predicts ITER (15MA scenario) to operate far in the helical core unstable regime. Helical cores can only exist in tokamak discharges with monotonic but low, or reversed q-shear and q_{min} \approx 1 in the core. The helical core is a saturated internal kink mode; its stability limit is proportional to (dp/d\rho)B_0^2 around q = 1. Below the stability limit, applied 3D fields can drive a helical core to finite size, as in DIII-D. Above it, a random 3D kick excites a large helical core. In the DIII-D hybrid discharge the helical core contributes to flux pumping, but it is unclear, if helical cores are experimentally detrimental, once they grow in size. Helical cores occur frequently in C-Mod due to impurities; modeling shows, they become unstable in these discharges due to a reversed shear profile, which lowers the stability boundary.

*Supported by US DOE under DE-AC05-00OR22725, DE-FG02-04ER54698.

10:30

B04 6 Test of the Eich model for ELM energy densities in DIII-D* MATTHIAS KNOLKER, LMU Munich A. BORTOLON, G. CANAL, PPLP T. ABRAMS, T. EVANS, A.W. LEONARD, GAR NAZIKIAN, PPLP H. ZOHM, IPP A collisionality scan on DIII-D reveals that peak parallel ELM energy densities during Type-I ELMs are within 0.5 – 2 times of a new model (T. Eich, NME 2017, in publication). In contrast to the model our analysis shows pedestal pressure dependence of ELM energy density. We find proximity to the L-H threshold as important scaling factor beyond the Eich model. ELMs with large energy densities were observed when barely above the LH-threshold. Linear stability analysis with ELITE shows that lower n peeling-balooning modes with deeper eigenfunctions result in higher divertor heat loads. Measurements with fast soft X-ray and infrared thermography facilitate tracking the distribution of conducted and radiated ELM energy. As ITER will operate close to the LH-threshold our studies emphasize the importance of considering the full pre-ELM phase and not only static profiles for determining the heat load.

*Supported by US DOE under DE-AC05-00OR22725, DE-FG02-04ER54698.

10:42

B04 7 Advances in Understanding and Control of Plasma Rotation on DIII-D* B A GRIERSON, N LOGAN, S HASKEY, A ASHOURVAN, PPLP D ERNST, MIT C CRYSTAL, J DEGRASSIE, GA J BOEDO, UCD T TALA, A SALMI, VTT Momentum transport experiments on DIII-D have advanced our understanding of the core and edge rotation by showing that (1) core rotation in low-torque electron-heated ITER-like plasmas displays hollowing driven by turbulence in the absence of MHD, (2) intrinsic rotation in torque-free electron-heated plasmas follows the favorable rho and nu scalings as previously found in intrinsic torque experiments using NBI, (3) the edge plasma rotation can be controlled through shaping of triangularity and X-point radius, and (4) rotation and density profiles have separate dependencies on the applied 3D field spectra. These advances inform strategies to avoid low torque disruptions by tailoring turbulent modes that minimize rotation hollowing, and provide confidence in dimensionless scaling of intrinsic torque and rotation to ITER. The triangularity and X-point position provide important new actuators on the rotation beyond neutral beam injection that are available for any diverted tokamak including ITER. The separation of spectral dependencies of the momentum and density explain how quiescent braking as well as edge isolated ELM control are possible even in machines with limited toroidal harmonic EPC coils.

*Work supported by US DOE under DE-AC02-09CH11466, DE-FC02-04ER54698.

10:54

B04 8 Role of turbulence in determining particle transport in DIII-D* SASKIA MORDJICK, College of William and Mary LEI ZENO, TERRY ROHDES, UCLA ANTTI SALMI, TUOMAS TALA, VTT Recent advances in DIII-D identify how changes in turbulence and ExB shear affect particle transport in H-mode plasmas. Using a combination of co- and counter- injected neutral beams to vary applied torque, the ExB shear is systematically scanned at fixed power and fueling. When the ExB shear is reduced below the linear gyro-kinetic growth rates inside the pedestal top (\rho=0.6-0.8), the particle confinement is strongly reduced by an increase in outward diffusion. Furthermore, a slow modulation in ECH power from 1 to 3 MW shows that the density reduction (“pump-out”) originates in the same region. Time-dependent analysis finds that the pump-out begins with a strong increase in density fluctuations measured by DBS at \rho=0.78, where the initial density reduction is largest, along with an increase in the linear growth rate of the Ion Temperature Gradient (ITG) mode. Turbulence modeling by TGLF shows that the plasma eventually transitions from an ITG mode to a Trapped Electron Mode (TEM) regime during high power ECH, but the TEM is not the initial cause of density pump out. For stationary density profiles, the frequency of the dominant unstable mode (i.e., ITG or TEM) correlates with the local density gradient, as predicted by theoretical simulations.

*Supported by US DOE DE-SC0007880, DE-FC02-04ER54698.

11:06

B04 9 Local Access Conditions for ELM-free Pedestals in DIII-D Quiescent H-mode Plasmas* THERESA WILKS, MIT-PSFC A GAROFALO, General Atomics J.W. HUGHES, MIT-PSFC K.H. BURRELL, XI CHEN, General Atomics X. XU, LLNL MIT TEAM, GENERAL ATOMICS COLLABORATION, LLNL COLLABORATION Quiescent H-mode (QH-mode) has been identified as an attractive stationary operational regime in tokamaks due to its lack of edge localized modes (ELMs), along with good particle and impurity control due to the presence of MHD or edge turbulence. Local edge access conditions such as a critical edge rotational shear for the transition from a QH-mode to a typical ELMy H-mode in DIII-D are explored. The experimentally determined critical shearing rates are compared to a theoretical model, which demonstrates a linear relationship with \sqrt{(T_e + T_i)/(\rho L_p \Delta x)} where T is temperature, k_{pol} the poloidal wave number, L_p the pressure gradient scale length, and \Delta x the radial width of the mode. Linear BOUT++ stability calculations are performed to calculate edge turbulence characteristics included in the model, such as mode structure, dominant toroidal mode number, and growth rates, and are shown to compare well with experimental observations from pedestal profiles, BES, and magnetics.

*Work supported by the U.S. DOE under DE-FC02-04ER54698 and DE-SC0014264.
11:18

**BO4 10 A unique predator-prey system of coupled turbulence, drive, and sheared ExB flow in the pedestal of high performance DIII-D plasmas**

K. BARADA, T.L. RHODES, W.A. PEEBLES, L. ZENG, UCLA K.H. BURRELL, L. BARDOCZI, X. CHEN, GA A unique, long-lived predator-prey oscillation regime (3-12 energy confinement times) is observed to replace coherent edge harmonic oscillations in recent low-torque quiescent high confinement (QH) mode plasmas. The physics of this system has been revealed through simultaneous measurements of local density turbulence, ExB velocity, and ExB shear. The phase space of V and n exhibits the characteristics of a predator-prey cycle with a rotation of n (prey) and V (predator). The time-lag in the evolution of V at different pedestal locations which has been found to dictate V evolution. The phase space of V and n is observed to be toroidally symmetric and shows no degradation in beta or energy confinement compared to an all-carbon divertor. In contrast, a high beta (q < 1) divertor with off-axis electron cyclotron current drive (ECCD) and q<sub>min</sub> > 1.5 with off-axis ECCD experiences an on-axis W accumulation throughout the discharge. The application of on-axis ECCD in the hybrid scenario, the velocity to diffusion ratio (V/D) calculated with STRAHL reverses sign in the core, producing a more aligned density and temperature pedestal. In this scenario, the pedestal is significantly wider during the detachment state. In contrast, the open divertor, i.e. with the strike point on a flat target plate, the pedestal width is reduced during the detachment state. In contrast, the detached divertor with a baffle-dome divertor or small-angle-slot divertor, the pedestal is significantly wider during the detachment state.

Supported by US DOE under DE-FG02-07ER54917, DE-FG02-04ER54758, DE-FG02-04ER54698, DE-FG03-95ER54309, and DE-FG02-04ER54762.

11:30

**BO4 11 Understanding the influence of current profile and RF heating on impurity transport in advanced tokamak scenarios**

B.S. VICTOR, S.L. ALLEN, M.T. OLSON, L.L. L. MAn, D.M. THOMAS, T.W. PETRIE, General Atomics E.A. UNTERBERG, ORNL B.A. GRIEpson, P.P. E.M. HOLLAMMAN, UCSD K.E. THOMAN, ORAU Recent DIII-D experiments show that the advanced tokamak hybrid scenario is compatible with a tungsten (W) divertor. The hybrid scenario, with on-axis electron cyclotron current drive (ECCD) and q<sub>min</sub> > 1.5, experiences an off-axis ECCD and shows no degradation in beta or energy confinement compared to an all-carbon divertor. In contrast, a high q<sub>min</sub> scenario (q<sub>min</sub> > 1.5) with off-axis ECCD experiences an on-axis W accumulation throughout the discharge. The application of on-axis ECCD in the hybrid scenario, the velocity to diffusion ratio (V/D) calculated with STRAHL reverses sign in the core, producing an off-axis peak in the W density profile. These results indicate that plasmas with broader current density profiles and off-axis ECCD are more susceptible to high-Z impurity accumulation. Results from the hybrid plasmas show the feasibility of a steady-state scenario with a W divertor, thus improving the physics basis of Q=5 steady-state operation on ITER.

Supported by US DOE under DE-AC52-07NA27344 and DE-FG02-04ER54698.

11:42

**BO4 12 Characterizing Tungsten Sourcing and SOL Transport during the Metal Rings Campaign**

D.M. THOMAS, T. ABRAMS, General Atomics E.A. UNTERBERG, Oak Ridge National Laboratory D. DONOVAN, University of Tennessee Knoxville J.D. ELDER, University of Toronto W.R. WAMPLER, Sandia National Laboratory DIII-D TEAM The Metal Rings Campaign on DIII-D utilized two isotopically and poloidally distinct toroidal arrays of tungsten coated inserts in the lower divertor to study W divertor erosion near the outer strike point (OSP) and divertor entrance and subsequent migration in a mixed-material (C-W) environment. In AT hybrid discharges (P<sub>aux</sub> = 14 MW, H<sub>95</sub> = 1.6, β<sub>n</sub> = 3.7) with rapid ELMs (δ<sub>ELM</sub> ~ 0.7%) W impurities are seen to reach the midplane predominantly from the OSP region rather than the divertor entrance (far-SOL). Conversely, in scenarios with less frequent larger ELMs (δ<sub>ELM</sub> ~ 60 Hz, δW/W ~ 3.6%), the W impurities are found to transport equally from the OSP and entrance region. ELM-resolved spectroscopic measurements of W sourcing indicate that large ELMs can source W at many times the inter ELM rate. The peak W erosion rate can shift radially outwards consistent with the ELM energy flux, thereby shifting the balance between strikepoint and far-SOL sources. Changes in the peak erosion locations between forward and reversed Bt discharges are consistent with ExB ion drift effects. Evidence for a near-SOL impurity buildup between the divertors driven by the parallel grad-Ti force is also seen.

*Work supported under USDOE Cooperative Agreement DE-FC02-04ER54698.

11:54

**BO4 13 Impact of target material on D and D<sub>2</sub> recycling in DIII-D ELM My H-mode discharges**

Igor BYKOV, Eric HOLLämMANN, Dmitriy RUDAKOV, Richard MOYER, Joe BOEDO, Univ of California - San Diego Rui DIN Huiqian WANG, ORAU EZEKIAI UNTERBERG, ALEXIS PRIESEMIEISTER, ORNL CHRISTOPHER CHROBAK, TYLER ABRAMS, GA Jon WATKINS, SNL Charles LASNIER, Adam MCLEAN, LLNL DIII-D operation with W divertor inserts shows molecular recycling flux (measured by Fulcher-a spectroscopy) is reduced between ELMs in comparison with a C divertor where the flux is dominated by D<sub>2</sub> molecules (>90%). This effect is partly explained by the higher reflection probability of atomic D on W. During ELMs, the molecular fraction drops by factor >2 on both C and W targets. To study the effect of higher ion impact energy (E<sub>imp</sub>) on transient D re-emission during ELMs we have applied fast electrostatic bias to a DiMES probe equipped with a W and C sample set. A 50% increase of E<sub>imp</sub> from (~150 eV due to biasing led to transient increase of atomic D re-emission flux on both targets. Similar increase of the D<sub>2</sub> flux was only seen on C. Thus, the ratios of atomic and molecular fluxes on C varied in a similar way to those measured during ELMs. This variation in molecular recycling fraction with material has implications for the dynamics of density pedestal recovery between ELMs, the overall global particle balance of the system, and possibly the overall detachment onset conditions transiently due to the ELM particle influx.

*Supported by the US DOE under DE-FG02-07ER54917, DE-FG02-04ER54758, DE-FG02-04ER54698, DE-FG03-95ER54309, and DE-FG02-04ER54762.

12:06

**BO4 14 Effects of divertor geometry on H-mode pedestal structure near divertor detachment**

Huiqian WANG, Oak Ridge Associated University Houyang Guo, Anthony LEONARD, Auna MOSER, Thomas OSBORNE, Philip SNYDER, Emily BELLi, Richard GROEBNER, Dan THOMAS, General Atomics - San Diego Jonathan WATKINS, Sandia National Lab Zheng YANG, University of Wisconsin Madison Divertor geometry is found to significantly affect the shape of H-mode pedestal profiles as a function of density up to divertor detachment. In the open divertor, i.e. with the strike point on a flat target plate, the pedestal width is reduced during the detachment state. In contrast, for the closed divertor, i.e. with a baffle-dome divertor or small-angle-slot divertor, the pedestal is significantly wider during the detachment state. In addition, near divertor detachment, the open diverted plasma exhibits a more aligned density and temperature pedestal, while in the closed divertor the detachment results in a greater relative shift between the density and temperature pedestal. Moreover, enhanced fluctuations are excited with divertor detachment in both divertor geometries. The fluctuations appear to be...
stronger in the open divertor than that in the closed divertor, opposite to previous results with additional transport broadening the pedestal.

*Work supported by US DOE under DE-FC02-04ER54698, DE-NA-0003525.

12:18
BO4 15 Modelling the detachment dependence on strike point location in the small angle slot divertor (SAS) with SOLPS* LIVIA CASALI, Oak Ridge Associated Universities BRENT COVELLE, HOUYANG GUO, General Atomics The new Small Angle Slot (SAS) divertor in DIII-D is characterized by a shallow-angle target enclosed by a slot structure about the strike point (SP). SOLPS modelling results of SAS have demonstrated divertor closure’s utility in widening the range of acceptable densities for adequate heat handling. An extensive database of runs has been used to study the detachment dependence on SP location in SAS. Density scans show that lower Te at lower upstream density occur when the SP is at the critical location in the slot. The cooling front spreads across the entire target at higher densities, in agreement with experimental Langmuir probe measurements. A localized increase of the atomic and molecular density takes place near the SP, which reduces the target incident power density and facilitates detachment at lower upstream density. Systematic scans of variables such as power, transport, and viscosity have been carried out to assess the detachment sensitivity. Therein, a positive role of the viscosity is found.

*This work supported by DOE Contract Number DE-FC02-04ER54698.

Contributed Papers

9:30
BO5 1 Direct Laser Acceleration in Laser Wakefield Accelerators* J.L. SHAW, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester K.A. MARSH, C. JOSHI, UCLA N. LEMOS, LLNL and UCLA The direct laser acceleration (DLA) of electrons in a laser wakefield accelerator (LWFA) has been investigated. We show that when there is a significant overlap between the drive laser and the trapped electrons in a LWFA cavity, the accelerating electrons can gain energy from the DLA mechanism in addition to LWFA. The properties of the electron beams produced in a LWFA, where the electrons are injected by ionization injection, have been investigated using particle-in-cell (PIC) code simulations. Particle tracking was used to demonstrate the presence of DLA in LWFA. Further PIC simulations comparing LWFA with and without DLA show that the presence of DLA can lead to electron beams that have maximum energies that exceed the estimates given by the theory for the ideal blowout regime. The magnitude of the contribution of DLA to the energy gained by the electron was found to be on the order of the LWFA contribution. The presence of DLA in a LWFA can also lead to enhanced betatron oscillation amplitudes and increased divergence in the direction of the laser polarization.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

9:42
BO5 2 Influence of plasma density on the generation of 100’s MeV electrons via Direct Laser Acceleration* AMINA HUSSAIN, T. BATSON, Univ of Michigan - Ann Arbor A.V. AREFIEV, UCSD H. CHEN, R.S. CRAKXTON, A. DAVIES, D.H. FROULA, D. HABERBERGER, LLE O. JANSEN, UCSD K. KRUSHELNICK, Univ of Michigan - Ann Arbor P.M. NILSON, W. THEOBALD, LLE T. WANG, UCSD G.J. WILLIAMS, LLNL W. WILLINGALE, Univ of Michigan - Ann Arbor The role of plasma density and quasi-static fields in the acceleration of electrons to many times the ponderomotive energies (exceeding 400 MeV) by high-energy, picosecond duration laser pulses via Direct Laser Acceleration (DLA) from underdense CH plasma was investigated. Experiments using the OMEGA EP laser facility and two-dimensional particle-in-cell simulations using the EPOCH code were performed. The existence of an optimal plasma density for the generation of high-energy, low-divergence electron beams is demonstrated. The role of quasi-static channel fields on electron energy enhancement, beam pointing and divergence elucidate the mechanisms and action of DLA at different plasma densities.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-FOA-0001109.

9:54
BO5 3 A detailed examination of the LWFA in the Self-Guided Nonlinear Blowout Regime for 15-100 Joule Lasers* ASHER DAVIDSON, ADAM TABLEMAN, PEICHENG YU, WEIMING AN, FRANK TSUNG, WARREN MORI, University of California, Los Angeles, CA 90095, USA WEI LU, Tsinghua University, Beijing, China RICARDO FONSECA, GOLPI Instituto de Plasmas e Fusio Nuclear, Instituto Superior Tecnico, Universidade de Lisboa, Lisbon, Portugal We examine scaling laws for LWFA in the regime nonlinear, self-guided regime [1] in detail using the quasi-3D version of the particle-in-cell code OSIRIS. We find that the scaling laws continue to work well when we fix the normalized laser amplitude while reducing plasma density. It is further found that the energy gain for fixed laser energy can be improved by shortening the pulse length until self-guiding almost no longer occurs and that the energy gain can be optimized by using lasers with asymmetric longitudinal profiles. We find that when optimized, a 15 J laser may yield particle energies as high as 5.3 GeV without the need of any external guiding. Detailed studies for optimizing energy gains from 30 J and 100 J lasers will also presented which indicate that energies in excess of 10 GeV can be possible in the near term without the need for external guiding.

*This work is supported by the NSF and DOE.


10:06
BO5 4 Optimization of electron beam properties from intense laser pulses interacting with structured gas jets KELLY SWANSON, HAI-EN TSAI, SAM BARBER, REMI LEHE, HANN-SHIN MAO, SVEN STEINKE, JEROEN VAN TILBORG, KEI NAKAMURA, CAMERON GEDDES, CARL SCHROEDER, ERIC ESAREY, WIM LEEMANS, Lawrence Berkeley Natl Lab Through precision tailoring of the plasma density profile, control of laser-plasma-accelerated electron beams injected along a shock-driven downramp was demonstrated. The relationships between the electron beam spatial profile and steering, and the downramp slope, shock angle and the plasma density profile were investigated using a 1.8 J, 45 fs laser interacting with a mm-scale gas jet. We demonstrate that injection is highly sensitive to these
parameters, and by adjusting the density profile high-quality electron beams over a tunable range of energies were produced. Simple models were developed to explain these relationships and are in good agreement with the experimental results, advancing the understanding of downramp injection.

10:18
**BOS 5 Control of quasi-monoenergetic electron beams from laser-plasma accelerators by adjusting shock density profile**

HAI-EN TSAI, KELLY K. SWANSON, REMI LEHE, SAM K. BARBER, FUMIKA ISONO, JÖRGE G. OTERO, XINYAO LIU, HANN-SHIN MAO, SVEN STEINKE, JEROEN VAN TILBORG, CAMERON G. R. GEDDES, WIM LEE MANS, Lawrence Berkeley Natl Lab

High-level control of a laser-plasma accelerator (LPA) using a shock injector was demonstrated by systematically varying the shock injector profile, including the shock angle, up-ramp width and shock position. Particle-in-cell (PIC) simulation explored how variations in the shock profile impacted the injection process and confirmed results obtained through acceleration experiments. These results establish that, by adjusting shock position, up-ramp, and angle, beam energy, energy spread, and pointing can be controlled. As a result, e-beam were highly tunable from 25 to 300 MeV with <8% energy spread, 1.5 mrad divergence and <1 mrad pointing fluctuation. This highly controllable LPA represents an ideal and compact beam source for the ongoing MeV Thomson photon experiments. Set-up and initial experimental design on a newly constructed one hundred TW laser system will be presented.

*This work is supported by the US DOE under Contract No. DE-AC02-05CH11231, and by the US DOE National Nuclear Security Administration, Defense Nuclear Nonproliferation R&D (NA22).*

10:30
**BOS 6 Measured emittance dependence on injection method in laser plasma accelerators**

SAMUEL BARBER, JEROEN VAN TILBORG, CARL SCHROEDER, REMI LEHE, HAI-EN TSAI, KELLY SWANSON, SVEN STEINKE, KI NAKAMURA, CARL G. R. GEDDES, CARLO BENEDETTI, ERIC ESAREY, WIM LEE MANS, Lawrence Berkeley Natl Lab

The success of many laser plasma accelerator (LPA) based applications relies on the ability to produce electron beams with excellent 6D brightness, where brightness is defined as the ratio of charge to the product of the three normalized emittances. As such, parametric studies of the emittance of LPA generated electron beams are essential. Profiting from a stable and tunable LPA setup, combined with a carefully designed single-shot transverse emittance diagnostic, we present a direct comparison of charge dependent emittance measurements of electron beams generated by two different injection mechanisms: ionization injection and shock induced density down-ramp injection. Notably, the measurements reveal that ionization injection results in significantly higher emittance. With the down-ramp injection configuration, emittances less than 1 micron at spectral charge densities up to ~2 pc/MeV were measured.

*This work was supported by the U.S. DOE under Contract No. DE-AC02-05CH11231, by the NSF under Grant No. PHY-1415596, by the U.S. DOE NNSA, DNN R&D (NA22), and by the Gordon and Betty Moore Foundation under Grant ID GBMF4898.*

10:42
**BOS 7 Generating high brightness electron beams using density down ramp injection in nonlinear plasma wakefields**

THAMINE DALICHAOUCH, XI NLU XU, ASHER DAVIDSON, PEICHE NG YU, WEIMING AN, CHAN JOSHI, CHAO JIE ZHANG, WARREN MORI, Univ of California - Los Angeles FEI

LI, WEI LU, Tsinghua University RICARDO FONSECA, IST Portugal

In the past few decades, there has been much progress in theory, simulation, and experiment towards using Plasma wakefield acceleration (PWFA) and Laser wakefield acceleration (LWFA) as the basis for designing and building compact x-ray free-electron-lasers (XFEL) as well as a next generation linear collider. Recently, ionization injection and density downramp injection have been proposed and demonstrated as controllable injection schemes for generating high quality relativistic electron beams. We present the concepts and full 3D simulation results using OSIRIS which show that downramp injection can generate electron beams with unprecedented brightnesses. However, full-3D simulations of plasma-based acceleration can be computationally intensive, sometimes taking millions of cpu-hours. Due to the near azimuthal symmetry in PWFA and LWFA, quasi-3D simulations using a cylindrical geometry are computationally more efficient than 3D Cartesian simulations since only the first few harmonics are needed in \( \phi \) to capture the 3D physics of most problems. We also present results from the quasi-3D approach on downramp injection and compare the results against full 3D simulations.

*Work supported by NSF and DOE.*

10:54
**BOS 8 Pulse Front Tilt and Laser Plasma Acceleration**

DANIEL MITTELBERGER, University of California-Berkeley and Lawrence Berkeley National Laboratory

KEI NAKAMURA, REMI LEHE, ANTHONY GONSALVES, CARLO BENEDETTI, WIM LEE MANS, Lawrence Berkeley National Laboratory

The Pulse front tilt (PFT) is potentially present in any CPA laser system, but its effects may be overlooked because spatiotemporal pulse characterization is considerably more involved than measuring only spatial or temporal profile. PFT is particularly important for laser plasma accelerators (LPA) because it influences electron beam injection and steering. In this work, experimental results from the BELLA Center will be presented that demonstrate the effect of optical grating misalignment and optical compression, resulting in PFT, on accelerator performance. Theoretical models of laser and electron beam steering will be introduced based on particle-in-cell simulations showing distortion of the plasma wake. Theoretical predictions will be compared with experiments and complimentary simulations, and tolerances on PFT and optical compressor alignment will be developed as a function of LPA performance requirements.

*This work was supported by the Office of High Energy Physics, Office of Science, US Department of Energy under Contract DE-AC02-05CH11231 and the National Science Foundation under Grant PHY-1415596.*

11:06
**BOS 9 Relativistic Electron Acceleration with Ultrashort MidIR Laser Pulses**

LINUS FEDER, DANIEL WOODBURY, Institute for Research in Electronics and Applied Physics, University of Maryland

VALENTINA SHUMAKOVA, CLAUDIA GOLLNER, Photonics Institute, Vienna University of Technology

ROBERT SCHWARTZ, Institute for Research in Electronics and Applied Physics, University of Maryland

AUDRIUS PUGŽLYS, ANDRIUS BALTUŠKA, Photonics Institute, Vienna University
of Technology HOWARD MILCHBERG, Institute for Research in Electronics and Applied Physics, University of Maryland We report the first results of laser plasma wakefield acceleration driven by ultrashort mid-infrared laser pulses (λ = 3.9 μm, pulsewidth 100 fs, energy <20 mJ, peak power <1 TW), which enables near- and above-critical density interactions with moderate-density gas jets. We present thresholds for electron acceleration based on critical parameters for relativistic self-focusing and target width, as well as trends in the accelerated beam profiles, charge and energy spectra which are supported by 3D particle-in-cell simulations. These results extend earlier work with sub-TW self-modulated laser wakefield acceleration using near IR drivers [1] to the Mid-IR, and enable us to capture time-resolved images of relativistic self-focusing of the laser pulse.

*This work supported by DOE (DESC0010706TDD, DESC0015516); AFOSR (FA95501310044, FA95501610121); NSF (PHY1535519); DHS.


11:18
BO5 10 Enhancement of Laser Wakefields via a Backward Raman Amplifier* JOSHUA LUDWIG, University of Alberta ALAIN MASSON-LABORDE, Commissariat à l'énergie Atomique WOJciech ROZMUS, University of Alberta STEFAN HULLER, Ecole Polytechnique SCOTT WILKES, Lawrence Livermore National Laboratory The Backward Raman Amplifier (BRA) is proposed as a possible scheme for improving laser driven plasma wakefields. One- and two-dimensional particle-in-cell code simulations with SCIPIC [1] and a 3-Wave coupling model are presented and compared to demonstrate how the BRA can be applied to the laser wakefield accelerator (LWFA) in the non-relativistic regime to counteract limitations such as pump depletion, diffraction, and dephasing [2]. Simulation results show that amplification of the driving pulse is strongest in the central high amplitude portion, causing the pulse to shorten both transversely and longitudinally. This results in a reduction or alleviation of the effects of diffraction, an increase in wake amplitude and sustainability, and provides direct insight into new methods of controlling plasma wakes in LWFA and other applications.

*JL is grateful for support from LLNL through the summer scholar program. JL and WR would like to acknowledge partial support from NSERC.


11:30
BO5 11 Strong Optical Shock excitation in the mismatched regime of bubble plasma-wave based LWFA* AAKASH SAHAI, Dept of Physics and John Adams Institute for Accelerator Sciences, Imperial College London, London We present investigations into the excitation of a strong optical shock [1] through slicing of a high intensity laser pulse driving a bubble plasma wave in a regime of mis-match between the incident laser waist-size and the bubble size (≥ 2√(πc/ωp0)) [2]. In the matched regime, it is well-known that over long timescales, the laser continuously undergoes differential frequency-shifts in different bubble phases, forming an optical shock [2,3]. In the mis-matched regime, rapid laser waist and resulting bubble oscillations change the location of the peak laser ponderomotive force. This changes the location and the magnitude of the peak electron density interacting with the laser pulse. A sudden increase in the electron density during a laser radial squeeze event, slices the laser envelope longitudinally near its peak amplitude, exciting a strong optical shock state. This is shown to occur much earlier in laser evolution only over a narrow range of plasma densities where the imbalance between the longitudinal & radial ponderomotive forces excites elongated bubbles, injects ultra-low emittance electron beams and sustains ultra-high peak plasma fields [4].

We acknowledge STFC Grants ST/J002062/1 and ST/P000835/1 for the John Adams Institute of Accelerator Science.

2PRSTAB 10, 061301 (2007).
3NJP 12, 0450 (2010).

11:42
BO5 12 Application of a laser-heater for advanced guiding of PetaWatt laser pulses in capillary plasmas* ANTHONY GONSALVES, JOOST DANIELS, CARLO BENEDETTI, HANNSHIN MAO, KEI NAKAMURA, CHRISTOPHER PIERONEK, CARL SCHROEDER, SVEN STEINKE, WIM LEEMANS, BELLA Center, Lawrence Berkeley National Laboratory Laser-plasma accelerators (LPAs) form an attractive scheme for developing compact accelerators, due to their high acceleration gradients. In the push to higher electron beam energies, one of the main challenges is to increase the dephasing length Ld over which energy can be transferred to the electrons, while keeping the laser confined to provide the required accelerating fields. Currently, the highest energy electron beams from an LPA have been achieved by using pre-formed density channels from capillary discharge plasmas [1]. Confinement of laser pulses with higher order mode content required higher density than optimum for reaching higher energies. Improved laser confinement at lower density, extending Ld, has been proposed through use of a ns-scale heater pulse before the ultrashort, high-powered pulse arrives [2]. Here, we present experimental results of applying this technique to channels of up to 20 cm in length to enhance guiding of PetaWatt pulses from the BELLA laser, including electron and laser properties from the accelerator.

*This work was supported by the Director, Office of Science, Office of High Energy Physics, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.


11:54
BO5 13 Group Velocity Measurements in Laser-Heated Capillary Discharge Waveguides for Laser-Plasma Accelerators* C.V. PIERONEK, Lawrence Berkeley National Laboratory; University of California-Berkeley J. DANIELS, Lawrence Berkeley National Laboratory; Eindhoven University of Technology A.J. GONSALVES, C. BENEDETTI, W.P. LEEMANS, Lawrence Berkeley National Laboratory To date, the most energetic electron beams from laser-plasma accelerators have been produced using gas-filled capillary discharge waveguides, which increase the acceleration length by mitigating diffraction of the driving laser pulse [1]. To reach higher electron beam energies, lower plasma density is required to reduce bunch dephasing. However, confinement of the driver is reduced for lower plasma density, reducing the acceleration length. A laser-heated capillary discharge waveguide, where the discharge is heated by a coaxial laser pulse, was proposed to create a steeper density gradient at lower density [2]. Here the first measurements of group velocity in laser-heated capillary discharges, obtained via spectral
interferometry, are presented. Increase of the driver group velocity and reduction in on-axis plasma density by laser-heating are shown.

*Work supported by the U.S. Dept. of Energy, Office of Science, Office of High Energy Physics, under Contract No. DE-AC02-05CH11231. Additional support by the National Science Foundation under Grant PHY-1415596.


12:06

BO6 14 On the Asymmetric Focusing of Low-Emittance Electron Bunches via Active Lensing by Using Capillary Discharges STEPHAN BULANOV, Lawrence Berkeley National Laboratory Gennadiy Bagdasarov, NaDezhda Bobrova, Alexey Boldarev, Olga Olkhovskaya, Pavel Sasorov, Vladimir Gasilov, Keldysh Institute of Applied Mathematics RAS Samuel Barber, Anthony Gon-salves, Carl Schroeder, Jeroen Van Tilborg, Eric Esarey, Wim Leemans, Lawrence Berkeley National Laboratory Tadzio Levato, Daniele Margaronne, Georg Korn, Institute of Physics ASCR Masaki Kando, Sergey Bulanov, National Institutes for Quantum and Radiological Science and Technology A novel method for asymmetric focusing of electron beams is proposed. The scheme is based on the active lensing technique, which takes advantage of the strong inhomogeneous magnetic field generated inside the capillary discharge plasma to focus the ultrarelativistic electrons. The plasma and magnetic field parameters inside a capillary discharge are described theoretically and modeled with dissipative MHD simulations to enable analysis of capillaryes of oblong rectangle cross-sections implying that large aspect ratio rectangular capillaries can be used to form flat electron bunches. The effect of the capillary cross-section on the electron beam focusing properties were studied using the analytical methods and simulation-derived magnetic field map showing the range of the capillary discharge parameters required for producing the high quality flat electron beams.

12:18

BO6 15 >1 Hz Renewable Films for Plasma Mirrors for High Repetition Rate Petawatt Class Laser Systems* Anthony Zingale, Jordan Purcell, Ohio State University Patrick Poole, Lawrence Livermore National Laboratory Ginevra Cochrán, Christopher Willis, Douglass Schumacher, Ohio State University Improving the intensity contrast of >1 Hz, high power lasers presents a unique challenge. Recently, we demonstrated a device capable of creating renewable plasma mirrors for intensity contrast enhancement based on variable thickness liquid crystal films. Tuning the thickness of these freely suspended films between 10 and 300 nm allows minimization of the weak-field reflectivity, where the films act as a conventional anti-reflection coating. The maximum possible intensity contrast enhancement from a single film exceeds a factor of 350 [1]. Films were formed on demand and-in situ, eliminating the need to raster or replace optics between shots. Here we describe a prototype device that can accommodate petawatt laser systems operating above 1 Hz. The prototype has shown sustained film production at 3 Hz for 20,000 plasma mirrors using <10 μL of the liquid crystal 8CB. We also discuss measurements of film surface quality to diagnose prolonged plasma mirror reflect performance.

*This material is based upon work supported by the NNSA under DE-NA0003107.


9:30

BO6 1 Laser-driven magnetic reconnection in the multi-plasmoid regime Samuel Totorica, Tom Abel, Stanford, KIPAC, SLAC Frederico Fiuz, SLAC Magnetic reconnection is a promising candidate mechanism for accelerating the nonthermal particles associated with explosive astrophysical phenomena. Laboratory experiments are starting to probe multi-plasmoid regimes of relevance for particle acceleration. We have performed two- and three-dimensional particle-in-cell (PIC) simulations to explore particle acceleration for parameters relevant to laser-driven reconnection experiments. We have extended our previous work [1,2] to explore particle acceleration in larger system sizes. Our results show the transition to plasmoid-dominated acceleration associated with the merging and contraction of plasmoids that further extend the maximum energy of the power-law tail of the particle distribution. Furthermore, we have modeled Coulomb collisions and will discuss the influence of collisionality on the plasmoid formation, dynamics, and particle acceleration.


9:42

BO6 2 3-D magnetic reconnection in colliding laser-produced plasmas* Jackson Matteucci, Princeton University will fox, Ppl Clement Moiassard, Ecole normale superieure de Cachan, France Amitava Bhattacharjee, Princeton University Recent experiments have demonstrated magnetic reconnection between colliding plasma plumes, where the reconnecting magnetic fields were self-generated in the expanding laser-produced plasmas by the Biermann battery effect. Using fully kinetic 3-D particle in cell simulations, we conduct the first end-to-end simulations of these experiments, including self-consistent magnetic field generation via the Biermann effect through driven magnetic field reconnection. The simulations show rich, temporally and spatially dependent magnetic field reconnection. First, we find fast, vertically-localized “Biermann-mediated reconnection,” an inherently 3-D reconnection mechanism where the sign of the Biermann term reverses in the reconnection layer, destroying incoming flux and reconnecting flux downstream. Reconnection then transitions to fast, collisionless reconnection sustained by the non-gyrotropic pressure tensor. To separate out the role 3-D mechanisms, 2-D simulations are initialized based on reconnection-plane cuts of the 3-D simulations. These simulations demonstrate: (1) suppression of Biermann-mediated reconnection in 2-D; (2) similar efficacy of pressure tensor mechanisms in 2-D and 3-D; and (3) plasmoids develop in the reconnection layer in 2-D, where as they are suppressed in 3-D.

*Supported by NDSEG Fellowship. This research used resources of the OLCF at ORNL, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC05-000R22725.
9:54
BO6 3 The role of current sheet formation in driven plasmoid reconnection in laser-produced plasma bubbles KIRILL LEZHNIN, Princeton University WILLIAM FOX, AMITAVA BHAT TACHARJEE, Princeton Plasma Physics Laboratory We conduct a multiparametric study of driven magnetic reconnection relevant to recent experiments on colliding magnetized laser produced plasmas using the PIC code PSC. Varying the background plasma density, plasma resistivity, and plasma bubble geometry, the results demonstrate a variety of reconnection behavior and show the coupling between magnetic reconnection and global fluid evolution of the system. We consider both collision of two radially expanding bubbles where reconnection is driven through an X-point, and collision of two parallel fields where reconnection must be initiated by the tearing instability. Under various conditions, we observe transitions between fast, collisionless reconnection to a Sweet-Parker-like slow reconnection to complete stalling of the reconnection. By varying plasma resistivity, we observe the transition between fast and slow reconnection at Lundquist number $S \approx 10^3$. The transition from plasmoid reconnection to a single X-point reconnection also happens around $S \approx 10^5$. We find that the criterion $\delta/d_J < 1$ is necessary for fast reconnection onset. Finally, at sufficiently high background density, magnetic reconnection can be suppressed, leading to bouncing motion of the magnetized plasma bubbles.

10:06
BO6 4 Electron acceleration in pulsed-power driven magnetic reconnection experiments JONATHAN HALLIDAY, JACK HARE, SERGEO LEBEDEV, LEE SUTTLE, SIMON BLAND, THOMAS CLAYSON, ELEANOR TUBMAN, Imperial College London SERGEI PIKUZ, TANYA SHELKOVENKO, Cornell University We present recent results from pulsed-power driven magnetic reconnection experiments, fielded on the MAGPIE generator (1.2 MA, 250 ns). The setup used in these experiments produces plasma inflows which are intrinsically magnetised; persist for many hydrodynamic time-scales; and are supersonic. Previous work has focussed on characterising the dynamics of bulk plasma flows [1,2], using a suite of diagnostics including laser interferometry, imaging) Faraday rotation, and Thompson scattering. Measurements show the formation of a well defined, long lasting reconnection layer and demonstrate a power balance between the power into and out of the reconnection region. The work presented here focuses on diagnosing non-thermal electron acceleration by the reconnecting electric field. To achieve this, metal foils were placed in the path of accelerated electrons. Atomic transitions in the foil were collisionally exited by the electron beam, producing a characteristic X-Ray spectrum. This X-Ray emission was diagnosed using spherically bent crystal X-Ray spectrometry, filtered X-Ray pinhole imaging, and X-Ray sensitive PIN diodes.


10:18
BO6 5 Fast magnetic reconnection supported by sporadic small-scale Petschek-type shocks TAKUYA SHIBAYAMA, KANYA KUSANO, ISEE, Nagoya University TAKAHIRO MIYOSHI, HIROSHIMA University GRIGORY VEKSTEIN, University of Manchester Magnetic reconnection is thought to play a core role in explosive energy conversion. According to the Sweet-Parker theory, it is difficult to conduct magnetic reconnection efficiently in highly conductive plasma. Petschek proposed another reconnection theory. However, numerical simulations suggest that Petschek reconnection is not stable in a system with spatially uniform resistivity. Some mechanism is needed to sustain the localized diffusion region. We perform resistive 2D MHD simulation in a large system with a high spatial resolution, and find that small-scale slow mode MHD shocks predicted by Petschek spontaneously form even under a uniform resistivity. In this process, growth of plasmoids in the current sheet play a role of localizing the diffusion region, and slow mode shocks form next to plasmoids. These plasmoids enhance magnetic reconnection intermittently and repeatedly. As a result, the reconnection rate increases up to 0.02. Furthermore, our simulation suggests that the obtained reconnection rate doesn’t depend on the Lundquist number. This is due to a similarity in the evolution of plasmoid in different scale. A part of this study is published in Physics of Plasmas [1].


10:30
BO6 6 Tearing Instability of a Current Sheet Forming by Sheared Incompressible Flow ELIZABETH TOLMAN, NUNO LOUREIRO, Plasma Science and Fusion Center, Massachusetts Institute of Technology DMITRI UZDENSKY, Center for Integrated Plasma Studies, University of Colorado, Boulder Sweet-Parker current sheets are unstable to the tearing mode, suggesting they will not form in physical systems. Understanding magnetic reconnection thus requires study of the stability of a current sheet as it forms. Such formation can occur as a result of sheared, sub-Alfvénic incompressible flows into and along the sheet. This work presents an analysis of how tearing perturbations behave in a current sheet forming under the influence of such flows, beginning with a phase when the growth rate of the tearing mode is small and the behavior of perturbations is primarily governed by ideal MHD. Later, after the tearing growth rate becomes significant relative to the time scale of the driving flows, the flows cause a slight reduction in the tearing growth rate and wave vector of the dominant mode. Once the tearing mode enters the nonlinear regime, the flows accelerate the tearing growth slightly; during X-point collapse, the flows have negligible effect on the system behavior. This analysis allows greater understanding of reconnection in evolving systems and increases confidence in the application of tools developed in time-independent current sheets to changing current sheets.

*This material is based upon work supported by the National Science Foundation Graduate Research Fellowship.

10:42
BO6 7 A Nonlinear evolution of tearing mode with resistivity and hyper-resistivity DING LI, WEN YANG, Institute of Physics, Chinese Academy of Sciences XUEQIAO XU, Lawrence Livermore National Laboratory A quasilinear model has been developed for nonlinear tearing mode with resistivity and hyper-resistivity in which only the quasilinear current effect has been taken into account. The nonlinear evolution equation has been derived analytically by using the perturbation method. It is shown that the nonlinear evolution of flux perturbation depends on both resistivity term and hyper-resistivity term. It is found that the hyper-resistivity plays a destabilizing effect.

*Supported by Strategic Priority Research Program of Chinese Academy of Sciences and National Natural Science Foundation of China.
10:54

BO6 8 Scaling Study of Reconnection Heating in Torus Plasma Merging Experiments YASUSHI ONO, MOE AKIMITSU, ASUKA SAWADA, QINGHONG CAO, HIDEYA KOIKE, HIRONORI HATANO, TAISHI KANEDA, HIROSHI TANABE, Univ of Tokyo We have been investigating toroidal plasma merging and reconnection for high-power heating of spherical tokamak (ST) and field-reversed configuration (FRC), using TS-3 (ST, FRC: R=0.2m, 1985-), TS-4 (ST, FRC: R=0.5m, 2000-), UTS (ST: R=0.45m, 2008-) and MAST (ST: R=0.9m, 2000-) devices. The series of merging experiments made clear the promising scaling and characteristics of reconnection heating: (i) its ion heating energy that scales with square of the reconnecting magnetic field $B_{rec}$, (ii) its energy loss lower than 10%, (iii) its ion heating energy (in the downstream) 10 time larger than its electron heating energy (at around X-point) and (iv) low dependence of ion heating on the guide (toroidal) field $B_g$. The $B_{rec}^2$-scaling was obtained when the current sheet was compressed to the order of ion gyroradius. When the sheet was insufficiently compressed, the measured ion temperature was lower than the scaling prediction. Based on this scaling, we realized significant ion heating up to 1.2keV in MAST [1,2] after 2D elucidation of ion heating up to 250eV in TS-3 [3,4]. This promising scaling leads us to new high $B_{rec}$ reconnection heating experiments for future direct access to burning plasma: TS-U (2017-) in Univ. Tokyo and ST-40 in Tokamak Energy Inc. (2017-). This presentation reviews major progresses in those toroidal plasma merging experiments for physics and fusion applications of magnetic reconnection.


11:06

BO6 9 Development of a sub-cm high resolution ion Doppler tomography diagnostics for fine structure measurement of guide field reconnection in TS-U HIROSHI TANABE, HIDEYA KOIKE, HIRONORI HATANO, TAKUMI HAYASHI, QINGHONG CAO, SHUNICHI HIMENO, TAISHI KANEDA, MOE AKIMITSU, ASUKA SAWADA, YASUSHI ONO, Graduate School of Frontier Sciences, University of Tokyo A new type of high-throughput/high-resolution 96CH ion Doppler tomography diagnostics has been developed using “multi-slit” spectroscopy technique for detailed investigation of fine structure formation during high guide field magnetic reconnection. In the last three years, high field merging experiment in MAST pioneered new frontiers of reconnection heating [1]: formation of highly peaked structure around X-point in high guide field condition ($B_g > 0.3T$), outflow dissipation under the influence of better plasma confinement to form high temperature ring structure which aligns with closed flux surface of toroidal plasma, and interaction between ion and electron temperature profile during transport/confine phase to form triple peak structure ($\tau_{ Fee} \sim 4ms$). To investigate more detailed mechanism with in-situ magnetic measurement, the university of Tokyo starts the upgrade of plasma parameters and spatial resolution of optical diagnostics as in MAST. Now, a new type of high-throughput/high-resolution 96CH ion Doppler tomography diagnostics system construction has been completed and it successfully resolved fine structure of ion heating downstream, aligned with closed flux surface formed by reconnected field.

*This work was supported by JSPS KAKENHI Grant Numbers 15H05750, 15K14279 and 17H04863.

11:18

BO6 10 Nonthermal particle acceleration in 3D relativistic pair reconnection* GREGORY WERNER, DMITRI UZDENSKY, University of Colorado VLADIMIR ZHANKIN, MITCHELL BEGELMAN, JILA, University of Colorado, and NIST Magnetic reconnection in relativistic pair plasma may power nonthermal high-energy flares in astrophysical sources (e.g., the Crab Nebula). Recently, 2D particle-in-cell (PIC) simulations have demonstrated nonthermal particle acceleration (NTPA) that could explain the observed nonthermal (i.e., power-law) photon spectra. However, 3D effects, such as the relativistic drift kink instability (RDKI), have the potential to disrupt NTPA. We present a systematic PIC investigation of 3D relativistic reconnection in collisionless pair plasma, showing that key observationally-relevant aspects of reconnection, such as energy dissipation rate and NTPA, are only weakly affected by increasing “3D-ness” – e.g., by increasing the simulation length in the third dimension or decreasing the guide magnetic field. NTPA remains a robust product of 3D reconnection, despite clear manifestation of the RDKI in the absence of strong guide field. While a strong guide field suppresses RDKI as expected, it also suppresses NTPA (in 2D and 3D), yielding power-law particle spectra with steeper slopes and lower cutoff energies; we conjecture that the effect of the guide field may be captured by including its enthalpy in the magnetization $\sigma$, which has previously been shown to affect the NTPA power-law.

*This work was supported by NSF, NASA, and DOE.

11:30

BO6 11 Non-thermal particle acceleration in 3D magnetic reconnection XIAOCAN LI, FAN GUO, HUI LI, Los Alamos Natl Lab Non-thermal particle acceleration is one major unresolved problem in space physics and astrophysics. Recent studies have shown that magnetic reconnection is one primary mechanism for particle energization in space and astrophysical plasmas. Using fully kinetic simulations, these studies have shown the formation of power-law particle energy distributions during reconnection. Mostly of those simulations are two-dimensional (2D), causing energetic particles being artificially confined in magnetic islands with closed field lines. By carrying out similar 2D kinetic simulations, we show that the distribution of accelerated particles integrated over the whole simulation box appears highly non-thermal, it is actually the superposition of a series of distributions in different sectors of 2D magnetic islands. To resolve the issue of artificially particle confinement, we carry out 3D kinetic simulations and show that the mixing of particles are enhanced by the development of turbulence and mixing of magnetic field lines. We investigate the local energy distribution as a result of including the 3D physics.

11:42

BO6 12 Relativistic reconnection in near critical Schwinger field KEVIN SCHOEFFLER, THOMAS GRISMAIER, GKP/Instituto de Plasmas e Fusao Nuclear, Universidade de Lisboa RICARDO FONSECA, DCTI/ISCTE Instituto Universitario de Lisboa LUIS SILVA, GKP/Instituto de Plasmas e Fusao Nuclear, Universidade de Lisboa DMITRI UZDENSKY, Center for Integrated Plasma Studies, Physics Department, University of Colorado Magnetic reconnection in relativistic pair plasma with QED radiation and pair-creation effects in the presence of strong magnetic fields is investigated using 2D particle-in-cell simulations. The simulations are performed with the QED module [1] of the OSIRIS framework that includes photon emission by electrons and positrons and single photon decay into pairs (non-linear Breit-Wheeler). We
investigate the effectiveness of reconnection as a pair- and gamma-ray production mechanism across a broad range of reconnecting magnetic fields, including those approaching the critical quantum (Schwinger) field, and we also explore how the radiative cooling and pair-production processes affect reconnection. We find that in the extreme field regime, the magnetic energy is mostly converted into radiation rather than into particle kinetic energy. This study is a first concrete step towards better understanding of magnetic reconnection as a possible mechanism powering gamma-ray flares in magnetar magnetospheres [2].


11:54
BO6 13 Apex Dips of Experimental Flux Ropes: Helix or Cusp?∗
MAGNUS HAW, PAKORN WONGWAITAYAKORKUL, Caltech
HUI LI, SHENGTAI LI, LANL, PAUL M. BELLAN, Caltech
We present a new theory for the presence of apex dips in certain experimental flux ropes. Previously such dips were thought to be projections of a helical loop axis generated by the kink instability. However, new evidence from experiments and simulations suggest that the feature is a 2D cusp rather than a 3D helix. The proposed mechanism for cusp formation is a density pileup region generated by nonlinear interaction of neutral gas cones emitted from fast-gas nozzles. The results indicate that small density perturbations can result in large distortions of an erupting flux rope, even in the absence of significant pressure or gravity forces. The density pileup at the apex also suppresses the m=1 kink mode by acting as a stationary node. Consequently, more accurate density profiles should be considered when attempting to precisely model the stability and eruption of solar flux ropes such as CME’s.
∗This work was supported by NSF under award 1348393, AFOSR under award FA9550-11-1-0184, and DOE under awards DE-FG02-04ER54755 and DE-SC0010471.

12:06
BO6 14 Relativistic magnetic reconnection driven by a moderately intense laser interacting with a micro-plasma-slab∗
LONGQING YL, Department of Physics, Chalmers University of Technology BAIFEI SHEN, Department of Physics, Shanghai Normal University ALEXANDER PUKHOV, Institut fuer Theoretische Physik I, Heinrich-Heine-Universitaet Duesseldorf TUNDE FULOP, Department of Physics, Chalmers University of Technology
Magnetic reconnection (MR) in the relativistic regime is generally thought to be responsible for powering rapid bursts of non-thermal radiation in astrophysical events. It is therefore of significant importance to study how the field energy is transferred to the plasma to power the observed emission. However, due to the difficulty in making direct measurements in astrophysical systems or achieving relativistic MR in laboratory environments, the particle acceleration is usually studied using fully kinetic PIC simulations. Here we present a numerical study of a readily available (TW-mJ-class) laser interacting with a micro-scale plasma slab. The simulations show when the electron beams excited on both sides of the slab approach the end of the plasma structure, ultrafast relativistic MR occurs. As the field topology changes, the explosive release of magnetic energy results in emission of relativistic electron jets with cut-off energy ~12 MeV. The proposed novel scenario can be straightforwardly implemented in experiments, and might significantly improve the understanding of fundamental questions such as field dissipation and particle acceleration in relativistic MR.

∗This work is supported by the Knut and Alice Wallenberg Foundation and the European Research Council (ERC-2014-CoG Grant 64712).

9:30
BO7 1 The advanced hohlraum research project∗
We present results from supporting experiments on laser-heated foams. Proposed new hohlraum concepts utilize different hohlraum shapes, multiple laser entrance holes, and alternate materials such as metal foam walls. For each design we assess the radiation drive efficiency, the time-dependent drive symmetry, and laser-plasma interaction issues such as backscatter and crossed beam energy transfer. Results from supporting experiments on laser-heated foams are also summarized.

∗Prepared by LLNL under LDRD 15-ERD-058.

9:42
BO7 2 Progress in Octahedral Spherical Hohlraum Study KE
LAN, Institute of Applied Physics and Computational Mathematics In this talk, we report on our progress in octahedral spherical hohlraum study, including theoretical study, experimental study, and 3D simulation development. For theoretical study, we will address the concept, configuration, design and robust (sensitivity) of the novel octahedral spherical hohlraums with cylindrical Laser Entrance Holes (LEH), the proposal of using 4ω-2ω laser as ignition driven, and a point design of ignition target with a spherical hohlraum. For experimental study, we will address all experiments implemented on the ShenGuang(SG) laser facilities since 2014, including improvement of laser transport by using the cylindrical LEHs in the spherical hohlraums, first spherical hohlraum energetics, first experimental demonstration of low laser-plasma instabilities in gas-filled spherical hohlraums at laser injection angle designed for ignition target, how to realize the laser injections into 6LEH spherical hohlraum on SGIII laser facility which was designed for the cylindrical hohlraums, and first energetics of 6LEH spherical hohlraum on SGIII laser facility, etc. For 3D simulation, we will address the physics included in our 3D code and the 3D simulation results on the 6LEH octahedral spherical hohlraums with cylindrical LEHs.

9:54
BO7 3 View Factor and Radiation-Hydrodynamic Simulations of Gas-Filled Outer-Quad-Only Hohlraums at the National Ignition Facility∗
CHRISTOPHER YOUNG, NATHAN MEEZAN, OTTO LANDEN, Lawrence Livermore National Laboratory A cylindrical National Ignition Facility hohlraum irradiated exclusively by NOVA-like [1] outer quads (44.5° and 50° beams) is proposed to minimize laser plasma interaction (LPI) losses and avoid problems with propagating the inner (23.5° and 30°) beams.
Symmetry and drive are controlled by shortening the hohlraum, using a smaller laser entrance hole (LEH), beam phasing the 44.5° and 50° beams [2-3], and correcting the remaining P₄ asymmetry with a capsule shim [4]. Ensembles of time-resolved view factor simulations [5] help narrow the design space of the new configuration, with fine tuning provided by the radiation-hydrodynamic code HYDRA.

*Prepared by LLNL under Contract DE-AC52-07NA27344.


10:06 BO7 4 Simulations of super-ellipse hohlraum targets as a path to high neutron yields* JOSE MILOVICH, PETER AMENDT, ERIK STORM, HARRY ROBEY, STEVE HAAN, OTTO LANDE, NATHAN MEEZAN, JOHN LINDL, LLNL. Recently neutron yields in excess of 10¹⁰ have been achieved at the National Ignition Facility (NIF) using a low-density gas fill hohlraum and a subscale high-density-carbon capsule [1]. The laser power used was near the current maximum level allowed on the inner cones of the NIF laser. While more energy can be extracted from the laser to provide additional improvement on the neutron yield, a more efficient design is desired. A new effort has begun to investigate alternatives to the current cylinder-shaped hohlraum for driving larger capsules (1.1 mm outer radius). If these new hohlraums can preserve the implosion symmetry, the additional absorbed energy is expected to provide a path to high neutron yield and potential ignition. Super-ellipse hohlraums, a generalization of an earlier rugby hohlraum design [2], have the advantage of a larger waist diameter and reduced parasitic energy losses from the corners of cylindrical hohlraums while still being able to produce the required capsule drive at the current energy and power limits available at the NIF. We will present plausible designs of these hohlraums based on the Lamé mathematical construction, and discuss their prospects to reach high neutron gains.

*Prepared by LLNL under Contract DE-AC52-07NA27344.

1NIF shot N170601.

10:18 BO7 5 Simulation of alternate hohlraum shapes for improved inner beam propagation in indirectly-driven ICF implosions* H. F. ROBEY, L. F. BERZAK HOPKINS, Lawrence Livermore National Security, LLC. Recent indirectly-driven ICF experiments performed on the National Ignition Facility have shown that the propagation of the inner beam cones is impeded late in the laser pulse by the growth of a gold bubble, which is initiated at the location where the outer beams hit the hohlraum wall and which expands radially inward into the hohlraum as the implosion progresses. Late in time, this gold bubble intercepts a significant portion of the inner beams reducing the available energy reaching the waist of the hohlraum and affecting the implosion symmetry. Integrated hohlraum simulations of alternate hohlraum shapes using HYDRA are performed to explore options for reducing the impact of the gold bubble on inner beam propagation. The simulations are based on recent NIF implosions using High-Density Carbon (HDC) ablators, which have shown good performance, but which could benefit from improved inner beam propagation.

10:54 BO7 8 Progress understanding how hohlraum foam-liners can be used to improve laser beam propagation through hohlraum plasmas* ALASTAIR MOORE, N MEEZAN, C THOMAS, K BAKER, T BAUMANN, M BIENER, S BHANDARKAR, C GUYON, W HSING, N IZUMI, O LANDEN, A NIKROO, M ROSEN, J MOODY, Lawrence Livermore National Laboratory. The expansion of a laser-heated hohlraum wall can quickly fill the cavity and reduce or prevent propagation of other laser beams into the hohlraum. To delay such plasma filling, ignition hohlraums have typically used a high-density gas-fill or have been irradiated with a short (< 10 ns) laser pulse; the former can cause laser plasma instabilities (LPI), while a short laser pulse limits the design space.
required to reach symmetric implosions. Foam-liners are predicted to mitigate wall motion in a low gas-fill hohlraum, and so would enable the hohlraum to usefully drive a capsule over a longer duration. On the National Ignition Facility we have been engaged in two types of experiments to study foam-lined hohlraums. The first aims to radiograph the expansion of a foam-lined Au wall in a cylindrical geometry and, using simulation, infer the location of the 1/4 \( r_{crit} \) surface. We observe that a 20 mg/cc \( \text{Ta}_2\text{O}_5 \) foam, 200 \( \mu \text{m} \) thick delays the expansion of Au hohlraum wall by 0.5 - 0.7 ns. The second type introduces a \( \text{Ta}_2\text{O}_5 \) foam-liner into a hohlraum and are designed to measure the effect of the foam-liner on capsule drive.

"This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

11:06
BO7 9 Investigation of First Three-Axis Cylindrical Hohlraum Experiment on Shenguang III* SHAOEN JIANG, LONGYU KUANG, HANG LI, LONGFEI JING, ZHIWEI LIN, LU ZHANG, LILING LI, JIANHUA ZHENG, YONGKUN DING, BAOHAN ZHANG, Research Center of Laser Fusion, China Academy of Engineering Physics YUNBAO HUANG TEAM A novel ignition hohlraum named three-axis cylindrical hohlraum (TACH) is designed for indirect-drive inertial confinement fusion. TACH is a kind of 6 laser entrance holes (LEHs) hohlraum, which has excellent radiation uniformity, low backscatter, acceptable energy efficiency and little predictable risk, and is a candidate of ignition hohlraum. The first experiment of TACH was performed on Shenguang III with the dimension \( 1.4 \text{ mm} \times 3.2 \text{ mm} \). 24 laser beams with 3 ns duration were injected into with the approximate incident angle \( 3.2 \text{ mm} \). Total laser energy was about 59 kJ, and the peak of radiation temperature reached about 192 eV. Results showed plasma filling is not obviously suppressed even with 0.5 atm pressure gas in the small hohlraum. All laser energy can be totally delivered into hohlraum in 3 ns duration even without filled gas. Backscatter was less than 2%.

*National Natural Science Foundation of China.

11:18
BO7 10 A United Modeling Approach for Three-Axis Hohlraum with 6 Laser Entrance Holes for Its Performance Optimization* YUNBAO HUANG, Guangdong University of Technology LONGFEI JING, SHAOEN JIANG, YUNKUN DING, Research Center of Laser Fusion, China Academy of Engineering Physics Recently, the hohlraum octahedral 6 laser entrance holes such as the spherical hohlraum with octahedral 6 LEHs or thee-axis hohlraum are proposed to be the candidate of ignition hohlraum, as their single laser rings and high performance, such as high radiation symmetry and no serious CBET effect. Then, a problem is to be solved on that if there an optimal hohlraum with 6 LEHs. Hence, we build a parametric free-form representation for the hohlraum with 6 LEHs on our developing software IRAD3D. With such representation, the spherical hohlraum with octahedral 6 LEHs and three-axis hohlraum can be easily obtained with different parameter values. In addition, such unified representation enables us to find a new structure hohlraum with high performance. Finally, we present several kinds of hohlraum with octahedral 6 LEHs and then their radiation asymmetry and temperature by setting different parameter values, and the optimal hohlraum with comparable radiation asymmetry and higher radiation temperature.

*National Natural Science Foundation of China.

11:30
BO7 11 Constraining heat-transport models by comparison to experimental data in a NIF hohlraum* W. A. FARMER, O. S. JONES, M. A. BARRIOS GARCIA, J. M. KONING, G. D. KERBEL, D. J. STROZZI, D. E. HINKEL, J. D. MOODY, L. J. SUTER, D. A. LIEDAHL, A. S. MOORE, O. L. LANDEN, Lawrence Livermore Natl Lab The accurate simulation of hohlraum plasma conditions is important for predicting the partition of energy and the symmetry of the x-ray field within a hohlraum. Electron heat transport within the hohlraum plasma is difficult to model due to the complex interaction of kinetic plasma effects, magnetic fields, laser-plasma interactions, and microturbulence. Here, we report simulation results using the radiation-hydrodynamic code, HYDRA, utilizing various physics packages (e.g., nonlocal Schurtz model [1], MHD, flux limiters) and compare to data from hohlraum plasma experiments which contain a Mn-Co tracer dot [2]. In these experiments, the dot is placed in various positions in the hohlraum in order to assess the spatial variation of plasma conditions. Simulated data is compared to a variety of experimental diagnostics. Conclusions are given concerning how the experimental data does and does not constrain the physics models examined.

*This work was supported by the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

11:42
BO7 12 Study Plasma Stagnation in Laser-Driven Hohlraums* C.K. LI, J.A. FREJNE, F.H. SEGUIN, R.D. PETRASSO, MIT S.C. WILKS, P.A. AMENDT, LLNL P.E. MASSON-LABORDE, S. LAFFITTE, V. TASSIN, CEA R. BETTI, E.M. CAMPBELL, T.C. SANGSTER, LLE G. GREGORI, A. BOTT, U. Oxford Understanding plasma stagnation in laser-driven hohlraums is important for inertial confinement fusion. It has been realized that the use of conventional single-species-averaged hydrodynamic codes for modelling stagnation is largely responsible for some disagreements between the experimental results and numerical simulations. A number of mechanisms which play important roles in this process have been missed in hydrodynamic simulations, including ion interpretation and diffusion. Self-generated fields and plasma instabilities observed in connection with plasma blow-off seen at hohlraum laser entrance holes provides additional compelling experimental evidence of non-hydrodynamic processes. To explore such phenomena, a series of experiments was performed at the Omega laser facility. Data obtained from several diagnostics, including monoenergetic-proton radiography and x-ray imaging, are compared with modified three-dimensional hydrodynamic simulations, providing new insight into hohlraum stagnation and a more complete physical picture of hohlraum dynamics.

*This work was supported in part by US DOE, LLNL and LLE.

11:54
BO7 13 NLTE atomic kinetics modeling in ICF target simulations† MEHUL V. PATEL, CHRISTOPHER W. MAUCHE, HOWARD A. SCOTT, OGDEN S. JONES, BENJAMIN T. SHIELDS, Lawrence Livermore Natl Lab Radiation hydrodynamics (HYDRA) simulations using recently developed 1D spherical and 2D cylindrical hohlraum models have enabled a reassessment of the accuracy of energetics modeling across a range of NIF target configurations. Higher-resolution hohlraum calculations generally find that the X-ray drive discrepancies are greater than previously reported. We identify important physics sensitivities in the
modeling of the NLTE wall plasma and highlight sensitivity variations between different hohlraum configurations (e.g. hohlraum gas fill). Additionally, 1D capsule only simulations show the importance of applying a similar level of rigor to NLTE capsule ablator modeling. Taken together, these results show how improved target performance predictions can be achieved by performing inline atomic kinetics using more complete models for the underlying atomic structure and transitions.

*Prepared by LLNL under Contract DE-AC52-07NA27344.

1Current affiliation: University of Illinois at Urbana-Champaign.

12:06

B07 14 Design of Thin-Au-Coating Sphere experiments on the OMEGA Laser to examine Hohlraum model DOV SHVARTS, University of Michigan, Nuclear Ressearch Center-Negev, Israel EREZ RAICHER, MATAN BEN DOV, Soreq Research Center, Israel KEVIN H. MA, University of Michigan ELAD MALKA, Nuclear Research Center-Negev, Israel Experiments performed by LLNL on OMEGA studying X-ray conversion efficiencies for Au (Dewald et al. PoP 2008), resulted in a “liberal” flux limiter value of 0.15 (the High Flux Model (Rosen et al. HEDP 2011)) needed to match simulations with these measurements. However, simulations using this HFM do not fit NIF Hohlraum experiments (Jones et al. PoP 2017) and a much more restrictive f = 0.03, related by the authors to Ion Acoustic Turbulence (IAT), was found to better fit the experimental data. This f = 0.03 does not fit the Au-Sphere data (Rosen et al. APS/DPP conference 2015). We re-examine the Au-Sphere simulations accounting for Ion Acoustic Turbulence effect on the thermal electron flux inhibition and enhanced laser absorption near critical density (K. Ma et al. APS/DPP conference 2016). New experiments, using thin Au-coatings (0.1-0.5mic) instead of thick (7mic) Au layers, are proposed to explore time dependent Thermal (0-2KeV) and M-band (2-4KeV) emissions as a function of Au-Coating thickness, using various values and models for flux limiter, and laser absorption. These new experiments are expected to add more restrictions to the development of new models.

This work was funded by the LLNL under subcontract B614207.

12:18

B07 15 Heat-Flux Measurements in Laser-Produced Plasmas Using Thomson Scattering from Electron Plasma Waves R.J. HENCHEN, V.N. GONCHAROV, D. CAO, J. KATZ, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester W. ROZMUS, University of Alberta, Edmonton, Canada An experiment was designed to measure heat flux in coronal plasmas using Thomson scattering. Adjustments to the electron distribution function resulting from heat flux affect the shape of the collective Thomson scattering features through wave-particle resonance. The amplitude of the Spitzer–Harm electron distribution function correction term (fj) was varied to match the data and determines the value of the heat flux. Independent measurements of temperature and density obtained from Thomson scattering were used to infer the classical heat flux (q = –xVT). Time-resolved Thomson-scattering data were obtained at five locations in the corona along the target normal in a blowoff plasma formed from a planar Al target with 1.5 kJ of 351-nm laser light in a 2-ns square pulse. The flux measured through the Thomson-scattering spectra is a factor of ~5 less than the xVT measurements. The lack of collisions of heat-carrying electrons suggests a nonlocal model is needed to accurately describe the heat flux.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

BP11 1 SPACE AND ASTROPHYSICAL PLASMAS

BP11 2 Gravity Acceleration and Gravity Paradox HAN HANYONGQUAN, 15611860790 TANG YUTENG, 15810953809 The magnitude of the gravitational acceleration of the earth is derived from low of universal gravitation. If the size and mass of the gravitational force are proportional to any situation, then the celestial surface gravity is greater than the celestial center near the gravity, and objective facts do not match. Specific derivation method, F = GMm / R2 = mg, g = GM/R2. G is the gravitational constant, M is the mass of the earth, and finally the g = 9.8 m/s 2 is obtained. We assume that the earth is a standard positive sphere, the earth’s volume V = 4πR3/3, assuming that the earth’s density is ρ, then M = ρ4πR3/3, ρU, the ρU into ρU get: g = Gρ4πR3/3 = ρU, the density of the earth is constant. Careful analysis of the formula ρU The result of this calculation, we can reach conclusion the gravity acceleration g and the radius of the earth is proportional. In addition to the radius of the Earth ρU the right is constant, That is, the Earth’s Gravity acceleration of the outer layer of the earth is greater than the Earth’s Gravity acceleration of Inner layer. We are in High School, Huaireou District, Beijing, China Author: hanyongquan tangyuteng TEL: 15611860790, 15810953809.

BP11 3 Reverse Current Shock Induced by Plasma-Neutral Collision PAKORN WONGWAITAYA KORNKUL, MAGNUS HAW, Caltech HUI LI, SHENGTAI LI, Los Alamos National Laboratory PAUL BELLAN, Caltech The Caltech solar experiment creates an archped plasma-fooled flux rope expanding into low density background plasma. A layer of electrical current flowing in the opposite direction with respect to the flux rope current is induced in the background plasma just ahead of the flux rope. Two dimensional spatial and temporal measurements by a 3-dimensional magnetic vector probe demonstrate the existence of this induced current layer forming ahead of the flux rope. The induced current magnitude is 20% of the magnitude of the current in the flux rope. The reverse current in the low density background plasma is thought to be a diamagnetic response that shields out the magnetic field ahead of the propagation. The spatial and magnetic characteristics of the reverse current layer are consistent with similar shock structures seen in 3-dimensional ideal MHD numerical simulations performed on the Turquoise supercomputer cluster using the Los Alamos COMPutation Astrophysics Simulation Suite. This discovery of the induced diamagnetic current provides useful insights for space and solar plasma.

BP11 4 From Scatter-Free to Diffusive Propagation of Energetic Particles: Exact Solution of Fokker-Planck equation MIKHAIL MALKOV, UCSD Propagation of energetic particles through magnetized turbulent media is reconsidered using the exact solution
of Fokker-Planck equation [PRD, 2017]. It shows that the cosmic ray (CR) transport in weakly scattering media is nondiffusive. Poor understanding of the CR transport obscures its sources and acceleration mechanisms. We present a simplified approximate version of the exact solution of Fokker-Planck equation that accurately describes a ballistic, diffusive and transdiffusive (intermediate between the first two) propagation regimes. The transdiffusive phase lasts up to 5-7 collision times and starts at about one-half of collision time. Since the scattering rate is energy-dependent, a large part of the energy spectrum propagates neither diffusively nor ballistically. Its treatment should rely on the exact solution. Significant parts of the spectra affected by the heliospheric modulation, for example, falls into this category. We present a new approximation of an exact Fokker-Planck propagator. It conveniently unifies the ballistic and Gaussian propagators, currently used (separately) in major Solar modulation and other CR transport models. The maximum deviation of the new propagator from the exact solution is less than a few percents.

*Supported by the NASA Astrophysics Theory Program, Grant No. NNX14AH36G.

**BP11 5 Cygnus Code Simulation of Magnetoshell Aerocapture and Entry System AKIHISA SHIMAIZU, University of Washington DAVID KIRTLER, MSNW LLC DAN BARNES, Coronado Consulting JOHN SLOUGH, MSNW LLC A Magnetoshell Aerocapture and Entry System (MAC) [1] is a novel concept for planetary atmospheric entry, which enables both manned and planetary deep space orbiter space missions that are difficult with present day technologies. The MAC uses a low-beta dipole plasma magnetoshell to produce a drag effect on the spacecraft through the collisional interactions between the entry atmospheric neutrals and the confined plasma in the magnetoshell, creating a dynamic and controllable plasma parachute for entry. To understand the performance and the behavior of the MAC, the Cygnus 2D Hall MHD code is used for this study. The Cygnus code is a 2D Hall MHD code with coupled external circuits, which has been originally developed for studying FRC formation, translation, merging, and compression. In this study, the Cygnus code is modified to support the MAC geometry with a simplified plasma-neutral model that accounts for electron-impact ionization, radiative recombination, and resonant charge exchange to simulate the collisional interaction processes for the MAC. [1] D. Kirtley et al. “A Plasma Aerocapture and Entry System for Manned Missions and Planetary Deep Space Orbiters”, NASA Niac Phase I Final Report, NNX12AR12G.

**BP11 6 3D3V hybrid-kinetic simulations with electron inertia effects of kinetic-range solar-wind turbulence SILVIO SERGIO CERRI, Dipartimento di Fisica, Università di Pisa, 56127 Pisa, Italy & Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, USA SERGIO SERVIDIO, Dipartimento di Fisica, Università della Calabria, 87036 Rende (CS), Italy FRANCESCO CALIFANO, Dipartimento di Fisica, Università di Pisa, 56127 Pisa, Italy Characterizing the nature of the turbulent fluctuations below the ion gyroradius in solar-wind turbulence and its dependence on the plasma parameters is a great challenge. Here we present a study of the sub-proton-scale cascade based on high-resolution hybrid-Vlasov (Eulerian) simulations of freely-decaying turbulence in 3D3V phase space, including finite electron inertia effects. Two proton plasma beta regimes are explored: $\beta_p = 1$ and $\beta_p = 0.2$ ($\beta$ is the ratio between thermal and magnetic pressures). At $\beta_p = 1$, the magnetic energy spectrum exhibit $k_z^{-5/3}$ and $k_z^{-7/2}$ power laws, while they are slightly steeper for $\beta_p = 0.2$. Nevertheless, both regimes develop a spectral anisotropy consistent with $k_z \sim k_z^{5/3}$ at $k_z \rho_p > 1$, and small-scale intermittency (the $\beta_p = 0.2$ case being slightly more intermittent than the $\beta_p = 1$ counterpart). In this context, we find that kinetic-range turbulence is consistent with a cascade of kinetic Alfvén waves type of fluctuations at $\beta_p = 1$, whereas the low-$\beta$ case presents a more complex scenario suggesting the simultaneous presence of several type of fluctuations.

**BP11 7 Energy Dissipation and Phase-Space Dynamics in Eul- rian Vlasov-Maxwell Turbulence** JASON TENBARGE, Princeton University JAMES JUNO, University of Maryland AMMAR HAKIM, Princeton Plasma Physics Laboratory Turbulence in a magnetized plasma is a primary mechanism responsible for transforming energy at large injection scales into small-scale motions, which are ultimately dissipated as heat in systems such as the solar corona, wind, and other astrophysical objects. At large scales, the turbulence is well described by fluid models of the plasma; however, understanding the processes responsible for heating a weakly collisional plasma such as the solar wind requires a kinetic description. We present a fully kinetic Eulerian Vlasov-Maxwell study of turbulence using the Gkeyll simulation framework, including studies of the cascade of energy in phase space and formation and dissipation of coherent structures. We also leverage the recently developed field-particle correlations to diagnose the dominant sources of dissipation and compare the results of the field-particle correlation to other dissipation measures.

*NSF SHINE AGS-1622306 and DOE DE-AC02-09CH11466.

**BP11 8 A Grad-Shafranov Model of Solar Equilibrium LEE GUNDERSON, AMITAVA BHATTACHARJEE, Princeton Plasma Physics Laboratory Helioseismology has revealed the internal density and rotation profile of the sun. However, knowledge of its magnetic fields and meridional circulation is confined much closer to the surface, and latitudinal variations in entropy are below detectable limits. Numerical simulations can offer insight into the interior dynamics, and help identify which ingredients are necessary to produce particular features. However, several gross features of the Sun can be understood from an equilibrium perspective, for example the 1-D density profile arising from steady-state energy transport from the core to the surface, or the tilting of rotation contours in the convection zone due to baroclinic forcing. To help answer the question of which features can be qualitatively explained by equilibrium, we propose analyzing stationary axisymmetric ideal MHD flows (i.e. the Grad-Shafranov equation) in the solar regime. We compare our model to that of Balbus (2009), recovering a similar rotation profile in bulk of the convection zone. Furthermore, it includes the effects of poloidal flow, developing a feature reminiscent of the near surface shear layer.

**BP11 9 Development of a Rotating Magnetized Plasma Device** DAVID COOKE, JAMES PATTON, REMINGTON REID, Air Force Rsch Lab-Albuquerque ASHLEY STILES, Assurance Technology Corporation PATRIK MORRISON, McMurry University ANDREI KOCH, Worcester Polytechnic Institute Momentum coupling in plasma is a mechanism that is central to a wide range of interesting and important phenomena, magnetosphere-ionosphere coupling, solar eruptions, the interaction of an electro-dynamic tether system in the Earth’s ionosphere, and the Critical Ionization Velocity (CIV) mechanism are a few examples. One result of the Space Shuttle Tethered Satellite experiment, TSS-1R, was that...
the current-voltage response of the experiment in all orbit conditions fell into a narrow range of curves when parameterized as a plasma probe [Thompson, GRL, 1998]. Another striking result was the lack of dependence on the Alfvén velocity or other electro-magnetic parameters. This result has led us to re-visit the understanding of the speed with which an electric field propagates along the magnetic field using EM-PIC simulation and experiments in our new magnetized plasma chamber. Our initial experiment is a rotating plasma using a solenoidal magnetic field and a radial electric field, with pulsed differential rotation of the plasma column to study the strength of coupling and propagation speed. Characteristics of our ‘first light’ rotating plasma will be presented.

*Supported by Air Force Office Scientific Research 16RVCOR264.

BP11 10 Laser Induced Fluorescence for Singly Ionized Atomic Iodine Thomas Steinberger, Earl Scime, West Virginia University While xenon is the standard propellant for a wide range of plasma thrusters, xenon is expensive and xenon propellant systems require heavy compressed gas tanks, pressure regulators, and other bulky hardware. Iodine has similar mass and is much easier to acquire than xenon. Iodines natural state of matter at room temperature is solid and is easily sublimated to gas with a simple heating element. This advantage for iodine is also a significant challenge when developing gas handling systems for iodine. Another challenge for iodine thrusters is a lack of well-defined spectroscopic diagnostics for single ionized iodine, specifically, a lack of a demonstrated laser induced fluorescence (LIF) scheme. We present emission spectroscopy measurements of iodine ion emission from the $6p^5 P_1 - 5d^5 D_1^e$ transition at 695.878 nm and the $6p^5 P_3 - 6s^5 S_2^e$ transition at 516.12 nm as a function of pressure and microwave power for a microwave excited iodine plasma in a sealed quartz cell at a pressure of 1 mTorr. The $5d^5 D_1^e$ state is metastable and was identified by Hargus et al. [48th AIAA Joint Propulsion, 2012] as a strong candidate for an iodine ion LIF scheme. We will also present preliminary LIF measurements using a tunable dye laser operating at 695.878 nm.

*Special thanks to Dr. William Hargus Jr. and Air Force Research Laboratory at Edwards AFB.

BP11 11 X-ray observations from RT-1 magnetospheric plasmas Tetsuya Sugata, Univ. of Tokyo Masaki Nishihara Collaboration, Zensho Yoshida Collaboration, Naoki Kenmochi Collaboration, Shotoar Kataura Collaboration, Kaori Nakamura Collaboration Planetary magnetospheres like Earth and Jupiter realize stable confinement of high beta plasma. The RT-1 device produces a laboratory magnetosphere by using a levitated superconducting coil for dipole magnetic fields and 8.2 GHz electromagnetic wave for plasma production ($n_e \sim 10^{17} m^{-3}$) and electron heating. In the recent experiments, the RT-1 device has achieved the local beta that exceeds 1. It is considered that the high energy component of electrons contributes to the beta value. Therefore, Si(Li) detectors measured the X-ray spectra from the peripheral plasmas in the range from a few keV to a few ten keV. The density of a few keV component and a few ten keV component are comparable and a few ten keV component dominates the majority of the high beta value that is operated up to 0.8. We found that 150 keV component of electrons exists near the outer of the levitated dipole magnet by using a CdTe detector.

BP11 12 Magnetic Diagnosis Upgrade and Analysis for MHD Instabilities on the J-TEXT Daojing Guo, Qiming Hu, GE ZHUANG, Nengchao WANG, Yonghua DING, Yuejin TANG, Haizhong University of Science & Technology QINGQUAN YU, Max-Planck-Institut für Plasmaphysik HUAZHONG UNIVERSITY OF SCIENCE & TECHNOLOGY TEAM, MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK COLLABORATION The magnetic diagnostic system on the J-TEXT tokamak has been upgraded to measure the magnetohydrodynam (MHD) instabilities with diverse bands of frequencies. 12 saddle loop probes and 73 Mirnov probes are newly developed. The fabrication and installation of the new probes are elaborately designed, in consideration of higher spatial resolution and better amplitude-frequency characteristic. In this case, the probes utilize two kinds of novel fabrication craft, one of which is low temperature co-fired ceramics (LTCC), the other is flexible printed circuit (FPC). A great deal of experiments on the J-TEXT have validated the stability of the new system. Some typical discharges observed by the new diagnostic system are reviewed. In order to extract useful information from raw signals, several efficient signal processing methods are reviewed. An analytical model based on lumped eddy current circuits is used to compensate equilibrium flux and the corresponding eddy current fluxes, a visualization processing based on singular value decomposition (SVD) and cross-power spectrum are applied to detect the mode number.

*Fusion Science Program of China (Contract Nos. 2015GB111001 and 2014GB108000) and the National Natural Science Foundation of China (Contract Nos. 11505069 and 11405068).

BP11 13 Structure-preserving geometric algorithms for plasma physics and beam physics Hong Qin, Princeton University and University of Science and Technology of China Standard algorithms in the plasma physics and beam physics do not possess the long-term accuracy and fidelity required in the study of multi-scale dynamics, because they do not preserve the geometric structures of the physical systems, such as the local energy-momentum conservation, symplectic structure and gauge symmetry. As a result, numerical errors accumulate coherently with time and long-term simulation results are not reliable. To overcome this difficulty, since 2008 structure-preserving geometric algorithms have been developed [1-11]. This new generation of algorithms utilizes advanced techniques, such as interpolating differential forms [3,5], canonical [7] and non-canonical [5,6] symplectic integrators, and finite element exterior calculus [8] to guarantee gauge symmetry and charge conservation [3,5], and the conservation of energy-momentum [3,4,5-11] and symplectic structure [1,3,4,5-11]. It is our vision that future numerical capabilities in plasma physics and beam physics will be based on the structure-preserving geometric algorithms.

8. H. Qin et al., NF 56, 014001 (2016).

BP11 14 Comparisons and applications of four independent numerical approaches for linear gyrokinetic drift modes OU WEIKE, HUASHENG XIE, Peking Univ YUEYAN LI, Zhejiang Univ ZHIXIN LU, BO LI, Peking Univ To help reveal the complete
picture of linear kinetic drift modes, four independent numerical approaches, based on the integral equation, Euler initial value simulation, Euler matrix eigenvalue solution, and Lagrangian particle simulation, respectively, are used to solve the linear gyrokineetic electrostatic drift mode equation in Z-pinch with slab simplification and in tokamak with a ballooning space coordinate. We identify that these approaches can yield the same solution with the difference smaller than 1%, and the discrepancies mainly come from the numerical convergence, which is the first detailed benchmark of four independent numerical approaches for gyrokineetic linear drift modes. Using these approaches, we find that the entropy mode and interchange mode are on the same branch in Z-pinch, and the entropy mode can have both electron and ion branches. And, at a strong gradient, more than one eigenstate of the ion temperature gradient mode (ITG) can be unstable and the most unstable one can be on non-ground eigenstates. The propagation of ITGs from ion to electron diamagnetic direction at strong gradient is also observed, which implies that the propagation direction is not a decisive criterion for the experimental diagnosis of turbulent mode at the edge plasmas [1].


BP11 15 Kinetic Simulations – Oshun (Vlasov-Fokker-Planck) and PIC (Osiris) – Physics and Open Source Software II The UCLA PICKSE Initiative ADAM TABLEMAN, MICHAEL TZOUFRAS, UCLA Department of Physics and Astronomy RICARDO FONSECA, IST - GoLP, Portugal W.B. MORI, UCLA Department of Physics and Astronomy We present physics results and general updates for two plasma kinetic simulation codes developed under the UCLA PICKSE initiative. We also discuss the issues around making these codes open source such that they can be used (and contributed to) by a large audience. The first code discussed is Oshun – a Vlasov-Fokker-Planck (VFP) code. Recent simulations with the VFP code OSHUN [1] will be presented for all of the aforementioned problems. The algorithmic improvements that have facilitated these studies will also be discussed. The second code discussed is the PIC code Osiris. Osiris is a widely respected code used in hundreds of papers. Osiris was first developed for laser-plasma interactions but has grown into a robust framework covering most areas of plasma research. One defining feature of Osiris is that it is highly optimized for a variety of hardware configurations and scales linearly over 1 million+ CPU nodes. We will discuss the recently released version 4.0 written in modern, fully-object oriented FORTRAN.


BP11 16 Validation of a Magnetized Liner Inertial Fusion (MagLIF) hotspot model to determine primary stagnation parameters MATTHEW EVANS, University of Rochester PATRICK KNAPP, MICHAEL GLINSKY, STEPHANIE HANSEN, MATT GOMEZ, CHRIS JENNINGS, TAISUKE NAGAYAMA, PIERRE GOURDAIN, BRENT JONES, Sandia National Laboratories A simplified 2D model of a MagLIF [1] hotspot at stagnation along with a Bayesian inference network is used to determine experimental stagnation parameters. The hotspot model is described by a series of 1-D isobaric cylindrical slices, each with six parameters: pressure, temperature, mix fraction, mix charge, radius, and linear areal density. The model is then fed into the Bayesian inference network which uses a Levenberg-Marquardt algorithm to perform non-linear least squares fit, then uses a Markov chain Monte Carlo (MCMC) to improve performance. Validation of the model is performed in two parts. First by performing the inversion using synthetic data generated by the model against itself. Next, simulation data generated by GORGON [2] is post processed to create synthetic diagnostics which are used in the inversion and compared to original states. Correlations among model parameters and diagnostics data and their implications for inferring model parameters are discussed.

BP11 17 Method for determining k-vector of a wave by a single spacecraft* PAUL BELLAN, Caltech A practical method [1] is described for determining the 3D wave-vector of quasi-neutral plasma waves using magnetic field and electric current density measurements made by a single spacecraft. This wave-vector knowledge can then be used to remove the space-time ambiguity produced by frequency Doppler shift associated with spacecraft motion so the actual plasma-frame wave dispersion relation is determined with no theoretical assumptions. The method involves applying the Wiener-Khinchin theorem to cross-correlations of the current and magnetic field oscillations and to auto-correlations of the magnetic field oscillations; the wave-vector is proportional to the ratio of the Fourier transforms of these cross- and auto-correlations. The method requires that each wave frequency component map to a unique wave-vector, a situation presumed true in many spacecraft measurement situations. Synthetic data examples that validate the method are presented. The method has recently been used successfully on data from the MMS spacecraft [2].

*Supported by DOE, NSF, and AFOSR.

1P. M. Bellan, JGR-Space Phys. 121, 8589 (2016).

BP11 18 New Magnetic Field Topologies and Amplification by Local Depletion of Electron Thermal Energy* A. FLETCHER, Boston University, MIT B. COPPLI, MIT The conventional theory of magnetic reconnection by the tearing mode in weakly collisional and collisionless plasmas involve characteristic length scales that are unrealistically small for space plasmas. This fact motivates the search for modes that produce magnetic reconnection over microscopic scale distances that remain significant when large macroscopic scale distances are considered. Modes that, depend on the existence of a significant electron temperature gradient can have this desired property [1]. A neutral sheet configuration is considered as in the case of Ref. [2] where auroral substorms have been proposed, for the first time, to result from magnetic reconnection processes occurring in the Earth’s magnetotail. Now a new kind of mode that is localized within the region where reconnection takes place is found with an exact analytical solution of the equation describing the reconnected field. The topology of this is different from that of the well known drift-tearing type of modes and consists of two parallel strings of magnetic islands.

*Supported in part by the U.S. DoE.


BP11 19 Particle transport characteristics of the RT-1 magnetospheric plasma using gas-puffing modulation technique NAOKI KENMOCHI, MASAKI NISHIURA, ZENSHO YOSHIDA, TETSUYA SUGATA, KAORI NAKAMURA, SHOTARO KATSURA, Graduate School of Frontier Sciences, The University of Tokyo The Ring Trap 1 (RT-1) device creates a laboratory magnetosphere that is realized by a levitated superconducting ring magnet in vacuum. The RT-1 experiment has demonstrated the self-organization of a plasma
clump with a steep density gradient; a peaked density distribution is spontaneously created through ‘inward diffusion’. In order to evaluate particle transport characteristics in the RT-1 magnetospheric plasmas which cause these inward diffusion, density modulation experiments were performed in the RT-1. Density modulation is a powerful method for estimating a diffusion coefficient D and a convection velocity V by puffing a periodic neutral gas. The gas puff modulation causes the change in the electron density measured by two chords of microwave interferometer (the radial positions r = 60 and 70 cm, vertical chord). In the case of 2 Hz gas puff modulation, the phase delay and the modulation-amplitude decay at the chord r = 60 cm are obtained with 15 degree and 0.8, respectively, with respect to the phase and the amplitude at r = 70 cm. The particle balance equations are solved on the assumption of profile shapes for D to evaluate D, V and particle source rate. The result suggests the inward convection in high beta magnetospheric plasmas.

BP11 20 Lunar mini-magnetospheres as electron scale plasma laboratories RA BAMFORD, B KELLETT, R BINGHAM, STFC RAL, Didcot, UK EP ALVES, F CRUZ, LO SILVA, IST Lisbon, Portugal Space offers few opportunities to make measurements under consistent conditions such as can be provided in the laboratory. Visible from Earth, the spectacular Reiner Gamma Formation, is the quintessential example of a lunar swirl - anomalous white wispy markings on the moons surface - that represents an integrated record of differential solar proton bombardment. The surface magnetic fields are 500 nT at most and the overall size of the magnetic anomalies (100s of km) is of the order or less than the ion gyroradius, and yet mini-magnetospheres, with miniature collisionless shocks, have been observed by spacecraft. The fixed location and footprint of magnetic fields provides almost laboratory like conditions. The data collected by a number of lunar survey missions since the 1960’s reflect this making them ideal objects to study at the fundamental electron scale. Theory and particle in cell simulations of these mini magnetosphere structures provide confirmation of the need to involve electron-scale dynamics.

BP11 21 Two-fluid studies including pressure tensor effects of current sheet instabilities and reconnection in the magnetotail* JONATHAN NG, Princeton University A HAKIM, PPPL A BHAT-TACHARJEE, Princeton University, PPPL The ballooning instability is a possible mechanism leading to the triggering of magnetic substorms and this is supported by observations of fluctuations in the ballooning frequency range in the Earth’s magnetotail [1,2]. Kinetic and MHD studies of generalised current sheets have shown how these instabilities can develop and affect dynamics of substorms by driving flows and causing the formation of plasmoids [3, 4]. Using a two-fluid model which includes pressure tensor effects, we first perform a study of current sheet instabilities and show that the ion pressure tensor is necessary for agreement with kinetic models. We then perform 3D simulations of magnetotail configurations to study the coupling between the ballooning instability and magnetic reconnection and the possible effects on substorm onset. Qualitative comparisons with THEMIS and MMS observations will be made.

*This work was supported by DOE Contract DE-AC02-09CH11466.

BP11 22 Magnetic Reconnection in Filaments and Solar Coronal Loops* M. ASGARI-TARGHI, CFA-Harvard, MIT B. COPPL, B. BASU, MIT A. FLETCHER, Boston University, MIT L. GOLUB, CFA-Harvard We propose that a magneto-thermal reconnection process is relevant to the physics of solar coronal loops. In this adopted model, magnetic reconnection is associated with electron temperature gradients, anisotropic electron temperature fluctuations and plasma current density gradients. Based on this model, we show that magnetic energy can be converted into electron thermal energy (and heating the corona [1]) and high energy particle populations. The input parameters for our model are based on the observations of the corona from the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO). We compare the results of our modeling with measurements of temperature, density and energy from relevant observations.

*Supported in part by the U.S. DoE.


BP11 23 Numerical modeling of the thin shallow solar dynamo J.B. O’BRYAN, T.R. JARBOE, Univ of Washington Nonlinear, numerical computation with the NIMROD code is used to explore and validate the thin shallow solar dynamo model [T.R. Jarboe et al. 2017], which explains the observed global temporal evolution (e.g. magnetic field reversal) and local surface structures (e.g. sunspots) of the sun. The key feature of this model is the presence and magnetic self-organization of global magnetic structures (GMS) lying just below the surface of the sun, which resemble 1D radial Taylor states of size comparable to the supergranule convection cells. First, we seek to validate the thin shallow solar dynamo model by reproducing the ~11 year timescale for reversal of the solar magnetic field. Then, we seek to model formation of GMS from convection zone turbulence. Our computations simulate a slab covering a radial depth ~3Mm and include differential rotation and gravity. Density, temperature, and resistivity profiles are taken from the Christensen-Dalsgaard model.

BP11 24 On self-organization of the solar magnetic fields* THOMAS JARBOE,1 THOMAS BENEDETT, KYLE MORGAN, University of Washington Recent advances in self-organization effects of magnetized plasma are shown to have a powerful effect in the Sun. The resulting model consists of a thin, magnetic equilibrium covering most of the solar surface below the photosphere, within the supergranules. The equilibrium is reshaped and reorganized on an 11-year half-cycle perhaps due to resistive diffusion. The thickness of the equilibrium makes the solar dynamo powerful enough to also fuel other solar phenomena, such as the chromosphere, the corona, the solar wind, and the current in the solar current sheet. It also explains the 180 degree flipping of the magnetic fields and the pattern of the radial magnetic field in the solar cycle, the flipping of the polar magnetic flux, the nature of sunspots and CMEs, the differences of the corona during solar minimum compared to solar maximum, the amplitude of torsional oscillations, the nature of supergranules and the plasma structure in solar prominences.

*US DOE.

1Place in section 2.5 next to John OBryan.

BP11 25 Anomalies in Cosmic Ray Composition: Explanation Based on Mass to Charge Ratio ADRIAN HANUSCH, TATIANA LISSEYKINA, Rostock University, Germany MIKHAIL MALKOV, UCSD Observations of galactic cosmic rays (CR) revealed the lack of our understanding of how CR elements are extracted from the supernova environments to be further accelerated in their shocks. Comparing the spectra of accelerated particles with different mass to charge ratios is a powerful tool for studying the physics of par-
BP11 26 Charge conserving current deposition scheme for PIC simulations in modified spherical coordinates* F. CRUZ, T. GRISMAYER, R.A. FONSECA, L.O. SILVA, GoLP/IPFN, Instituto Superior Tecnico, Lisbon, Portugal Global models of pulsar magnetospheres have been actively pursued in recent years. Both macro and microscopic (PIC) descriptions have been used, showing that collective processes of e-e plasma generation due to QED cascades, its self-consistent acceleration and radiative losses to the global dynamics of pulsar magnetospheres.

*Work supported by the European Research Council (InPairs ERC-2015-AdG 695088), FCT (Portugal) Grant PD/BD/114307/2016, and the Calouste Gulbenkian Foundation through the 2016 Scientific Research Stimulus Program.

BP11 27 Development of a hybrid gyrokinetic ion and isothermal electron fluid code and its application to turbulent heating in astrophysical plasma* YOHEI KAWAZURA, MICHAEL BARNES, University of Oxford PLASMA THEORY GROUP TEAM Understanding the ion-to-electron temperature ratio is crucial for advancing our knowledge in astrophysics. Among the possible thermalization mechanisms, we focus on the dissipation of Alfvén turbulence. Although several theoretical studies based on linear Alfvén wave damping have estimated the dependence of heating ratio on plasma parameters, there have been no direct nonlinear simulation that has investigated the heating ratio scanning plasma parameters. Schekochihin et al. (2009) proved that the turbulent heating ratio is determined at the ion Larmor radius scale. Therefore, we do not need to resolve all the scales up to the electron dissipation scale. To investigate the ion kinetic scale effectively, we developed a new code that solves a hybrid model composed of gyrokinetic ions and an isothermal electron fluid (ITEF). The code is developed by incorporating the ITEF approximation into the gyrokinetics code AstroGK (Numata et al., 2010). Since electron kinetic effects are eliminated, the new hybrid code runs approximately 2√mi/me times faster than full gyrokinetics codes. We will present linear and nonlinear benchmark tests of the new code and our first result of the heating ratio sweeping the plasma beta and ion-to-electron temperature ratio.

*This work is supported by STFC Grant ST/N000919/1. The authors also acknowledge the use of ARCHER through the Plasma HEC Consortium EPSRC Grant Number EP/L000237/1 under the projects e281-gs2.

BP11 28 Simulations of a Molecular Cloud experiment using CRASH* MATTHEW TRANTHAM, PAUL KETTER, ROBERT VANDERVORT, R. PAUL DRAKE, Univ of Michigan - Ann Arbor DOV SHVARTS, Univ of Michigan - Ann Arbor and Nuclear Research Center-Negev, Israel Recent laboratory experiments explore molecular cloud radiation hydrodynamics. The experiment irradiates a gold foil with a laser producing x-rays to drive the implosion or explosion of a foam ball. The CRASH code, an Eulerian code with block-adaptive mesh refinement, multigroup diffusive radiation transport, and electron heat conduction developed at the University of Michigan to design and analyze high-energy-density experiments, is used to perform a parameter search in order to identify optically thick, optically thin and transition regimes suitable for these experiments. Specific design issues addressed by the simulations are the x-ray drive temperature, foam density, distance from the x-ray source to the ball, as well as other complicating issues such as the positioning of the stalk holding the foam ball. We present the results of this study and show ways the simulations helped improve the quality of the experiment.

*This work is funded by the LLNL under subcontract B614207 and NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, Grant Number DE-NA0002956.

BP11 29 A low-dispersion, exactly energy-charge-conserving semi-implicit relativistic particle-in-cell algorithm GUANGYE CHEN, CHACON LUIS, ROBERT BIRD, DAVID STARK, LIN YIN, BRIAN ALBRIGHT, LANL. Leap-frog based explicit algorithms, either “energy-conserving” or “momentum-conserving”, do not conserve energy discretely. Time-centered fully implicit algorithms can conserve discrete energy exactly [1], but introduce large dispersion errors in the light-wave modes, regardless of timestep sizes. This can lead to intolerable simulation errors where highly accurate light propagation is needed (e.g. laser-plasma interactions, LPI). In this study, we selectively combine the leap-frog and Crank-Nicolson methods to produce a low-dispersion, exactly energy-and-charge-conserving PIC algorithm. Specifically, we employ the leapfrog method for Maxwell equations, and the Crank-Nicolson method for particle equations. Such an algorithm admits exact global energy conservation, exact local charge conservation, and preserves the dispersion properties of the leap-frog method for the light wave. The algorithm has been implemented in a code named iVPIC, based on the VPIC code [2] developed at LANL. We will present numerical results that demonstrate the properties of the scheme with sample test problems (e.g. Weibel instability run for 107 timesteps, and LPI applications.

2https://github.com/losalamos/vpic.

BP11 30 Compton scattering collision module for OSIRIS* FABRIZIO DEL GAUDIO, THOMAS GRISMAYER, Instituto Superior Técnico RICARDO FONSECA, Instituto Universidade de Lisboa

*Work supported by the European Research Council (InPairs ERC-2015-AdG 695088), FCT (Portugal) Grant PD/BD/114307/2016, and the Calouste Gulbenkian Foundation through the 2016 Scientific Research Stimulus Program.
Compton scattering plays a fundamental role in a variety of different astrophysical environments, such as at the gaps of pulsars and the stagnation surface of black holes. In these scenarios, Compton scattering is coupled with self-consistent mechanisms such as pair cascades. We present the implementation of a novel module, embedded in the self-consistent framework of the PIC code OSIRIS 4.0, capable of simulating Compton scattering from first principles and that is fully integrated with the self-consistent plasma dynamics. The algorithm accounts for the stochastic nature of Compton scattering reproducing without approximations the exchange of energy between photons and bound charged species. We present benchmarks of the code against the analytical results of Blumenthal et al. and the numerical solution of the linear Kompaneets equation and good agreement is found between the simulations and the theoretical models.

This work is supported by the European Research Council Grant (ERC-2015-AdG 695088) and the Fundaçao para a Cência e Tecnologia (Bolsa de Investigação PD/BD/114323/2016).

**BP11 31** Modification of the Magnetized Shercliff Layer Instability in the Princeton MRI Experiment by Conducting Endcaps

KYLE CASPARY, DAHAN CHOI, ERIK GILSON, Princeton Plasma Physics Laboratory JEREMY GOODMAN, Princeton University HANTAO JI, Princeton Plasma Physics Laboratory, Princeton University PETER SLOBODA, Princeton Plasma Physics Laboratory The Princeton MRI experiment is a modified Taylor-Couette device that uses a GaInSn eutectic working fluid to study rotating MHD flows. Results are presented from an experimental and numerical study investigating the effect of conducting axial boundary conditions, as opposed to insulating boundaries, on a free-Shercliff-layer instability. The free Shercliff layer is formed when a sufficiently strong magnetic field is imposed across a rotating, conducting fluid that is bounded axially by end caps with a pair of differentially rotating rings. With insulating end caps, the instability threshold corresponds to when the Elsasser number equals unity and the instability is characterized by a transition from flows with azimuthal structure with mode number \( m > 1 \) to flows with a dominant \( m = 1 \) mode. A reduced stability threshold is observed for a variety of sheared flows with the introduction of conducting end caps. In this case, the stability threshold is well-described by an Elsasser number of unity but using the conductivity and density of copper and the instability is characterized by fluctuations in multiple \( m > 1 \) modes. Measurements of the fluid velocity field are compared with results from the Spectral Finite Element Maxwell and Navier Stokes (SFEMaNS) code.

**BP11 32** The Role of Kinetic Instabilities in the Collisionless Turbulent Dynamo

D. A. ST-ONGE, M. W. KUNZ, Princeton University Conservation of the first adiabatic invariant \( \mu \) in a magnetized, collisionless plasma precludes turbulent amplification of the magnetic field. This is because any increase in magnetic-field strength would adiabatically increase the perpendicular pressure, whose growth is stringently limited by the finite free energy in the system. A mechanism is then needed to break \( \mu \) conservation in order to enable the amplification of a weak, primordial seed magnetic field to dynamically important strengths. Conveniently, amplification of the magnetic field in a high-beta plasma leads to pressure anisotropies large enough to trigger kinetic instabilities at ion-Larmor scales (e.g., firehose, mirror). These instabilities saturate by causing anomalous scattering of particles, breaking \( \mu \) conservation. This interplay between magnetic-field growth and kinetic instabilities adds a new layer of complexity to the more conventional (and much better understood) magnetohydrodynamic turbulent dynamo. Using self-consistent hybrid-kinetic, particle-in-cell simulations, we investigate the impact of these kinetic instabilities on the turbulent dynamo in a collisionless plasma, with a particular focus on how kinetic effects enable the amplification of magnetic fields and modify their structure.

*This work was supported by U.S. DOE contract DE-AC02-09CH11466.

**BP11 33** Precursor Events Involving Plasma Structures Around Collapsing Black Holes Binaries

M. MEDVEDEV, B. COPPI, MIT The plasma structures that can exist around black hole binaries can sustain intrinsic plasma collective modes [1] that have characteristic low frequencies related to the particle rotation frequencies around the binary system. As the collapse approaches, with the loss of angular momentum by emission of gravitational waves [2] from the binary system we have suggested [3] that the frequency of the fluctuating component of the gravitational potential can go through that of the intrinsic modes of the surrounding plasma structure and lead to a sharp amplification of them. Then the precursor to the event reported in Ref. [2], tentatively identified by the Agile X-\( \gamma \)-ray observatory [4] may be associated with the high energy radiation emission due to the fields produced by excitation of the proposed plasma modes. M. Tavani is thanked for bringing Ref. [4] to our attention while Ref. [3] was being completed.

*Supported in part by the U.S. DoE.


**BP11 34** Progress Towards High-Speed Operation of the Magnetorotational Instability Experiment and Diagnostic Development

E. P. GILSON, K. CASPARY, D. CHOI, F. EBRAHIMI, PPPL J. GOODMAN, Princeton U. H. JI, PPPL, Princeton U. M. LYSDANDROU, U. Chicago P. SLOBODA, PPPL M. TABBUTT, U. Wisconsin, Madison Estimates and simulations both suggest that the Princeton MRI experiment must operate with inner cylinder rotation rates \( > 1,500 \) rpm, corresponding to magnetic Reynolds numbers \( Rm > 3 \), in order for the flow to be unstable to the MRI. Results will be presented demonstrating progress towards high-speed operation while avoiding adverse effects from large dynamic pressure and heat. Recent studies show that conductive end caps increase the magnitude of the saturated MRI signal, enabling easier detection [1]. However, motor control feedback and pneumatically-driven brakes must be used to maintain control when forces arise from the interaction between induced currents in the rotating end caps and the 3,000 G applied magnetic field. The use of Hall probes and strain gauges to measure the azimuthal magnetic field and the torque at the inner cylinder will be discussed. Results from the Spectral Finite Element and Navier Stokes code have been used to better understand the expected shape of the MRI threshold curve with conducting end caps, the nature of the forces on the end caps, and to predict the magnetic fields and torques at the inner cylinder that result from the onset of the MRI.

BP11 35 Electron-Positron Cascade in Magnetospheres of Spinning Black Holes∗ ALEX L. FORD, KU BRETT D. KEENAN, LANE MIKHAIL V. MEDVEDEV, KU & MIT We quantitatively study the stationary, axisymmetric, force-free magnetospheres of spinning (Kerr) black holes (BHs) and the conditions needed for relativistic jets to be powered by the Blandford-Znajek mechanism. These jets could be from active galactic nuclei, blazars, quasars, micro-quasars, radio active galaxies, and other systems that host Kerr BHs. The structure of the magnetosphere determines how the BH energy is extracted, e.g., via Blandford-Znajek mechanism, which converts the BH rotational energy into Poynting flux. The key assumption is the force-free condition, which requires the presence of plasma with the density being above the Goldreich-Julian density. Unlike neutron stars, which in principle can supply electrons from the surface, BH cannot supply plasma at all. The plasma must be generated in situ via an electron-positron cascade, presumably in the gap region. Here we study varying conditions that provide a sufficient amount of plasma for the Blandford-Znajek mechanism to work effectively.

∗The authors acknowledge DOE partial support via Grant DE-SC0016368.

BP11 36 New Mexico Liquid Metal αω-dynamo experiment: Most Recent Progress JIAHE SI, RICHARD SONNENFELD, ART COLGATE, New Mexico Tech HUI LI, Los Alamos National Lab The goal of the New Mexico Liquid Metal αω-dynamo experiment is to demonstrate a galactic dynamo can be generated through two phases, the ω-phase and α-phase by two semi-coherent flows in laboratory. We have demonstrated an 8-fold poloidal-to-toroidal flux amplification from differential rotation (the ω-effect) by minimizing turbulence in our apparatus. To demonstrate the α-effect, major upgrades are needed. The upgrades include building a helicity injection facility, mounting new 100hp motors and new sensors, designing a new data acquisition system capable of transmitting data from about 80 sensors in a high speed rotating frame with an overall 200ks/sec sampling rate. We hope the upgrade can be utilized to answer the question of whether a self-sustaining αω-dynamo can be implemented with a realistic lab fluid flow field, as well as to obtain more details to understand dynamo action in highly turbulent Couette flow.

BP11 37 2D MRI-induced turbulence in high β PIC simulations GIANNANDREA INCHINGOLO, THOMAS GRISMAYER, GoLP/IPFN, Instituto Superior Tecnico, Universidade de Lisboa, Lisbon, Portugal NUNO F. LOUREIRO, Plasma Science and Fusion Center, MIT, Cambridge, USA RICARDO A. FONSECA, DCTI/ISCTE - Instituto Universitario de Lisboa, Lisboa, Portugal LUIS O. SILVA, GoLP/IPFN, Instituto Superior Tecnico, Universidade de Lisboa, Lisbon, Portugal The magnetorotational instability (MRI) is a crucial mechanism of angular momentum transport in a variety of astrophysical scenarios, as accretion disks nearness neutron stars and black holes. The MRI has been widely studied using MHD models and simulations, in order to understand the behaviour of astrophysical fluids in a state of differential rotation. When the timescale for electron and ion collisions is longer than the inflow time in the disk, the plasma is macroscopically collisionless and MHD breaks down. This is the case of the limit of weak magnetic field, i.e., as the ratio of the ion cyclotron frequency to orbital frequency becomes small. Leveraging on the recent addition of the shearing co-rotating frames equations of motion and Maxwell’s equations modules in our PIC code OSIRIS 3.0, we intend to present our recent results of the analysis of MRI in collisionless plasma. Increasing the scale of our simulations, we will show the first ab-initio PIC simulations of a 2D turbulence induced consistently during the saturation regime of the MRI. We will demonstrate the existence of a minimum scale $\lambda_{\text{crit}}$ that determine the comparison of a drift-kink instability in the plasma. This instability will activate the turbulence during the saturation regime of the MRI.

BP11 38 Electron holes observed in the Moon Plasma Wake* I H HUTCHINSON, MIT D MALASPINA, University of Colorado C ZHOU, MIT Electrostatic instabilities are predicted in the magnetized wake of plasma flowing past a non-magnetic absorbing object such as a probe or the moon. Analysis of the data from the Artemis satellites, now orbiting the moon at distances ten moon radii and less, shows very clear evidence of fast-moving isolated solitary potential structures causing bipolar electric field excursions as they pass the satellite’s probes. These structures have all the hallmarks of electron holes: BGK solitons typically a few Debye-lengths in size, self-sustaining by a deficit of phase-space density on trapped orbits. Electron holes are now observed to be widespread in space plasmas. They have been observed in PIC simulations of the moon wake to be the non-linear consequence of the predicted electron instabilities. Simulations document hole prevalence, speed, length, and depth; and theory can explain many of these features from kinetic analysis. The solar wind wake is certainly the cause of the overwhelming majority of the holes observed by Artemis, because we observe almost all holes to be in or very near to the wake. We compare theory and simulation of the hole generation, lifetime, and transport mechanisms with observations.

∗Work partially supported by NASA Grant NNX16AG82G.

BP11 39 Plasma Electron Hole Oscillatory Velocity Instability∗ CHUTENG ZHOU, IAN HUTCHINSON, Massachusetts Institute of Technology We report a new type of instability of electron holes (EHs) interacting with passing ions. The nonlinear interaction of EHs and ions is investigated using a new theory of hole kinematics. It is shown that the oscillation in the velocity of an EH parallel to the magnetic field direction becomes unstable when the hole velocity in the ion frame is slower than a few times the cold ion sound speed. This instability leads to the emission of ion-acoustic waves from the solitary hole and decay in its magnitude. The instability mechanism can drive significant perturbations in the ion density. The instability threshold, oscillation frequency and instability growth rate derived from our theory yield quantitative agreement with the observations from a novel high-fidelity hole-tracking Particle-In-Cell code. The instability can drive anomalous transport in space. Our result is important for studying slow electron holes that are strongly coupled to the ions.

∗This work is supported by NASA Grant NNX16AG82G Electron Hole Instabilities in the Plasma Wake of Moons, Asteroids, and Comets.

BP11 40 Relay transport of relativistic flows in extreme magnetic fields of stars WEIPENG YAO, BIN QIAO, ZHENG XU, Center for Applied Physics and Technology, HEDPS, SKLNPT, and School of Physics, Peking University, Beijing, 100871, China HUA ZHANG, Institute of Applied Physics and Computational Mathematics, Beijing 100094, China HENXIN CHANG, Center for Applied Physics and Technology, HEDPS, SKLNPT, and School of Physics, Peking University, Beijing, 100871, China CANGTAO ZHOU, SHAOPING ZHU, Institute of Applied Physics and Computational Mathematics, Beijing 100094, China XIANTU HE, Center for Applied Physics and Technology, HEDPS, SKLNPT, and School of Physics, Peking University, Beijing, 100871, China XIANTU HE,
We find that transport of relativistic flows in extreme magnetic fields can be achieved in a relay manner by considering the quantum electromagnetic (QED) cascade process, where photons play a key role as a medium. During the transport, the flow emits particle energy into photons via quantum synchrotron radiation and then gain particles back by magnetic pair creation, forming a “particle-photon-particle” relay. Particle-in-cell simulations demonstrate that forward transport of the flow density is realized by a self-replenishment process with photon-pair cascades, while that of the flow energy is accomplished due to a new coupling path through radiation of photons. This novel transport mechanism is closely associated with jet generation and disk accretion around the neutron star of X-Ray Binaries, offering a potential explanation for the powerful jets observed there.

**BP11 44 C-2W Magnetic Measurement Suite**

T. ROCHE, M.C. THOMPSON, M. GRISWOLD, K. KNAPP, B. KOOP, A. OTTAVIANO, M. TOBIN, TRI ALPHA ENERGY TAE, TRI ALPHA ENERGY, INC. TEAM Commissioning and early operations are underway on C-2W, Tri Alpha Energy’s new FRC experiment. The increased complexity level of this machine requires an equally enhanced diagnostic capability. A fundamental component of any magnetically confined fusion experiment is a firm understanding of the magnetic field itself. C-2W is outfitted with over 700 magnetic field probes, ~550 internal and ~150 external. Innovative in-vacuum annular flux loop / B-dot combination probes will provide information about plasma shape, size, pressure, energy, total temperature, and trapped flux when coupled with establish theoretical interpretations. The massive Mirnov array, consisting of eight rings of eight 3D probes, will provide detailed information about plasma motion, stability, and MHD modal content with the aid of singular value decomposition (SVD) analysis. Internal Rogowski probes will detect the presence of axial currents flowing in the plasma jet in multiple axial locations. Initial data from this array of diagnostics will be presented along with some interpretation and discussion of the analysis techniques used.

**BP11 45 Development of a Pulsed ~100MW Rotating Magnetic Field Ionization System for C-2W**

ERIK TRASK, ANDREY KOREPANOV, SHANNON KRAUSE, JOSH LEUENBERGER, ROGER SMITH, TRAVIS VALENTINE, WILL WAGGONER, TRI ALPHA ENERGY, INC. TAE TEAM TEAM The Rotating Magnetic Field (RMF) ionization system on the C-2W experiment at Tri Alpha Energy has been substantially upgraded from the previous system on the C-2U facility [1]. This system is used for ionizing gas prior to forming and accelerating Field-Reversed Configurations in the formation sections. Through the use of enhanced power units with increased stored energy, and an improved antenna design for better power coupling, a fully ionized plasma can now be produced in less than 100 us, in a background axial magnetic field in excess of 0.1 T, while at gas pressures in the ~1 mTorr range. The system design, characterization, and experimental ionization parameters will be discussed.

**BP11 46 High time resolution reconstruction of electron temperature profiles with a neural network in C-2U**

GABRIEL PLAYER, RICHARD MAGEE, ERIK TRASK, SERGEY KOREPANOV, RYAN CLARY, AND THE TRI ALPHA ENERGY TEAM, TRI ALPHA ENERGY, INC. One of the most important parameters governing fast ion dynamics in a plasma is the electron temperature, as the fast ion-electron collision rate goes as $\nu_{ei} \sim T_e^{1/2}$. Unfortunately, the electron temperature is difficult to directly measure—methods relying on high-powered laser pulses or fragile probes lead to limited time resolution or measurements restricted to the edge. In order to rectify the lack of time resolution on the Thomson scattering data in the core, a type of learning algorithm, specifically a neural network, was implemented. This network uses 3 hidden layers to correlate information from nearly 250 signals, including...
BP11 47 Fast imaging and modeling of the C-2U outflow jet and pre-ionization plasmas ERIK GRANSTEDT, E TRASK, R. J. SMITH, S. KRAUSE, D. SHEFTMAN, AND THE TAE TEAM, Tri Alpha Energy The C-2U device [1] used neutral beam injection and end-biasing to maintain an advanced beam-driven Field Reversed Configuration (FRC) plasma. A good electrical connection between the FRC and end-bias was critical for maintaining macroscopic stability. To model this electrical connection, characterization of the outflow jet plasma in this region is necessary. Limited access and the need for non-invasive instruments motivated optical diagnostics to be used for this purpose. High-speed cameras imaged visible light emission from neutral hydrogen and impurities. Tomographic reconstruction and neutral modeling was used to estimate the ionization rate and compare to the particle loss. The plasma macroscopic stability was also investigated. Imaging was also used to study the “pre-ionization” plasma in this region: the seed plasma which trapped the reversed magnetic flux during the initial FRC formation process.

BP11 48 Far infrared laser interferometry and polarimetry diagnostics for C-2W FRC experiment BIHE DENG, MARK ROUILLARD, PING FENG, MICHAEL BEALL, GREG SETTLES, GREG SNITCHLER, SHAWN ZIAEI, Tri Alpha Energy, Inc. TAE TEAM C-2W field-reversed configuration (FRC) experiments [1] are focused to resolve major physics issues facing the future of FRC devices. To achieve these goals, it is essential to measure the plasma equilibrium dynamics and monitor plasma fluctuations. One of the critical diagnostics under development is a 14-chord three-wave far infrared (FIR) laser interferometry and polarimetry system, which can provide simultaneous high temporal resolution measurements of density and Faraday rotation profiles with high accuracy. It is based on the previous successful experience of FIR polarimetry and interferometry measurements in C-2U FRC plasmas [2]. The physics considerations and the electro-optomechanical design and development of the system will be described, with discussions on challenges and solutions specific to diagnosing the high beta FRC plasmas. Initial experimental data will also be presented.

BP11 49 Measurement of magnetic null and field reversal in FRC plasmas using the Hanle effect DEEPAK GUPTA, Tri Alpha Energy KENNETH NORDIECK, University of Wisconsin, Madison RICHARD IGNACE, East Tennessee State University, Johnson City JOHN KINLEY, MARCEL NATIONS, Tri Alpha Energy TAE, TRI ALPHA ENERGY, INC. TEAM In FRC plasmas, knowledge of the magnetic null location is required for understanding and comparison with theory and modeling. More fundamentally, one would first like to affirm the presence of field reversal. Conventional methods like internal magnetic probes, Zeeman effect, MSE, etc. have limitations, either due to their perturbative nature or the relatively low internal magnetic fields of FRCs. Here, use of the Hanle effect to measure the magnetic null and field reversal in an FRC is presented. The measurements utilize polarization of resonance radiation from the ions in the plasma using either external illumination or self-illumination. The mechanism of the Hanle effect, conditions of its use as a plasma diagnostic, and various schemes for measurements in an FRC will be presented, along with results from initial tests using a DC plasma discharge with varying magnetic field. The diagnostic design for the C-2W FRC plasma experiment will be discussed.

BP11 50 Characterization of the C-2W Plasma Guns AMI DUBOIS, VLADIMIR SOKOLOV, SERGEY KOREPANOV, DIMA OSIIN, Tri Alpha Energy, Inc GABRIEL PLAYER, Northeastern University TAE TEAM Previous use of coaxial arc discharge plasma guns on the C-2U device exhibited great success in plasma stabilization and improved confinement. On the C-2W experiment, arc discharge plasma guns will again be used to facilitate the electrical connection between the plasma core and the divertor electrodes in order to maintain the electrode edge biasing and induce E x B shear to control plasma rotation. Each plasma gun contains an internal solenoid used to shape the plasma stream. Characterization of electron density (n_e), electron temperature (T_e), floating potential (V_f), and total plasma flux in an arc discharge lasting 6 ms without the internal solenoid are presented. A Langmuir probe located 27 cm axially outside of the plasma gun anode measures a bell-like radial n_e profile with peak n_e ∼10^{18} m^{-3} and T_e ∼ 2 - 10 eV. Observed spectral lines of impurity ions provide an estimate of T_e, and Balmer series line ratios of the main ion component are used to evaluate n_e at both the probe location and near the plasma gun anode. A calorimeter measures the plasma flux to be constant and equivalent to 1 kA.

BP11 51 Multi-Wavelength Interferometry and Axial Polarimetry on C-2W R J SMITH, S A DETTRICK, M ONOFRI, Tri Alpha Energy TAE TEAM Tri Alpha Energy’s C-2W device is operational and represents another major step in a progression of Field Reversed Configuration (FRC) confinement devices that have prolonged the lifetime, increased stability and added significant neutral-beam injection power to heat and sustain an FRC plasma. Crucial to plasma sustainment and increased lifetime is an understanding of the jet plasma and X-point dynamics. To address these issues, a two-color multi-chord tangentially viewing interferometer has been designed and installed at the high field (mirror) position of the machine. CO_2 and mmwave sources at 10.6 and 1000 um cover the density ranges of the translating FRC and the jet plasma. The small major radius at this location also provides the possibility for near on-axis axial interferometry/polarimetry using a standalone 150 μm quantum cascade laser giving a measurement directly related to the amount of reversed flux in the FRC. Recent results from the jet interferometer and on-axis axial polarimetry results for simulated plasmas with ray tracing will be presented.

BP11 52 Near-infrared Bremsstrahlung radiation measurements in an advanced beam-driven FRC plasma MARCEL NATIONS, DEEPAK GUPTA, NATHAN BOLTE, MATTHEW C. THOMPSON, TAE TEAM, Tri Alpha Energy, Foothill Ranch, CA In magnetically confined fusion plasmas, the effective ionic charge (Z_{eff}) is a measure of plasma impurity content. Knowledge of Z_{eff}...
profiles is critical since impurities can account for substantial radiative power losses. One method to determine $Z_{eff}$ is to measure the Bremsstrahlung continuum over a small spectral range free from line radiation. In TAE’s C-2 and C-2U machines, impurities in apparently line-free regions near 523 nm overwhelmed the expected line radiation. The near-infrared region is less affected by impurities and better suited for accurate Bremsstrahlung continuum measurements. For C-2W, an upgraded diagnostic system will be deployed to measure Bremsstrahlung signals near 1000 nm. The near-infrared system uses a suite of silicon avalanche photodetectors paired with a $D_n$ system to remove contributions from neutrals and attain improved $Z_{eff}$ estimates. A design scheme for measurements in an FRC at multiple lines-of-sight is presented and discussed.

BP11 53 Development of Spatial Heterodyne Spectroscopy Measurements for the C-2W Plasma Expansion Divertor DANIEL SHEFTMAN, TADAFUMI MATSUMOTO, MATTHEW THOMPSON, TRI ALPHA ENERGY TEAM. Accurate operation and high performance of the open field line plasma surrounding the Field Reversed Configuration (FRC) is crucial to achieving the goals of successful temperature ramp up and confinement improvement on C-2W. Attributes such as the outflow velocity and temperature of charge exchange or impurity ions can be measured through spectroscopic methods. However, light throughput is severely limited due to the low plasma density inside the divertors where the plasma expands rapidly before terminating on biasing plates. A field widened spatial heterodyne spectrometer was developed in order to address the challenge of making accurate spectroscopic measurements on the diffuse plasma. Design of a prototype of this spectrometer, including lab calibration and spectral line measurements performed on a compact toroid injector test stand, will be presented.

BP11 54 Studies on Plasmoid Merging using Compact Toroid Injectors IAN ALLFREY, TADAFUMI MATSUMOTO, THOMAS ROCHE, HIROSHI GOTA, TRI ALPHA ENERGY, INC. TAKAHIRO EDO, TOMOHIKO ASAI, NIKON UNIVERSITY DANIEL SHEFTMAN, DIMA OSIN, TRI ALPHA ENERGY, INC. NIHON UNIVERSITY TEAM. TAE TEAM, TRI ALPHA ENERGY, INC. TEAM C-2 and C-2U experiments [1] have used magnetized coaxial plasma guns (MCPG) to inject compact toroids (CTs) for refueling the long-lived mirror-confined plasma [2]. This refueling method will also be used for the C-2W experiment. To minimize momentum transfer from the CT to the FRC two CTs are injected radially, diametrically opposed and coincident in time. To improve understanding of the CT characteristics TAE has a dedicated test bed for the development of CT injectors (CTI), where plasmoid merging experiments are performed. The test bed has two CTIs on axis with both axial and transverse magnetic fields. The ~1 KG magnetic fields, intended to approximate the magnetic field strength and injection angle on C-2W, allow studies of cross-field transport and merging. Both CTIs are capable of injecting multiple CTs at up to 1 kHz. The resulting merged CT lives $>100\ \mu$s with a radius of $\sim25$ cm. More detailed results of CT parameters will be presented.


BP11 55 Performance Improvement of a Magnetized Coaxial Plasma Gun by adopting Iron-core Bias Coil and New Pre-Ionization System TAKAHIRO EDO, T. ASAI, F. TANAKA, S. YAMADA, A. HOSOZAWA, NIKON UNIVERSITY H. GOTA, T. ROCHE, I. ALLFREY, T. MATSUMOTO, TRI ALPHA ENERGY, INC. and THE TAE TEAM A magnetized coaxial plasma gun (MCPG) is a device used to generate a compact toroid (CT), which has a spheromak-like configuration. A typical MCPG consists of a set of axisymmetric cylindrical electrodes, bias coil, and gas-puff valves. In order to expand the CT operating range, the distributions of the bias magnetic field and neutral gas have been investigated. We have developed a new means of generating stuffing flux. By inserting an iron core into the bias coil, the magnetic field increases dramatically; even a small current of a few Amps produces a sufficient bias field. According to a simulation result, it was also suggested that the radial distribution of the bias field is easily controlled. The ejected CT and the target FRC are cooled by excess neutral gas that typical MCPGs require to initiate a breakdown [1,2]; therefore, we have adopted a miniature gun [3] as a new pre-ionization (PI) system. By introducing this PI system, the breakdown occurs at lower neutral gas density so that the amount of excess neutral gas can be reduced.


BP11 56 Bayesian Inference of FRC plasmas JESUS A. ROMERO, SEAN DETTRICK, MARCO ONOFRI, TRI ALPHA ENERGY, INC. TAE TEAM. Bayesian analysis techniques are currently being used at TAE to infer FRC magnetic topology and the radial profile of the electron density. The Bayesian method provides all the solutions compatible with both the prior assumptions and the measurements in the form of a probability distribution termed the posterior, from which the most likely solution and its uncertainty can readily be obtained. Bayesian analysis of field reversed configurations reveals strong field reversal on axis as well as non-monotonic radial density profiles. The later feature is only observed in global transport simulations in cases where significant fast ion pressure and current drive are present. Hence the inferred non-monotonic density profiles are indicative of current drive in the experiment.

BP11 57 Separatrix $E \times B$ Shear Flows and Turbulence Propagation in the C-2U FRC; Reflectometry Upgrades for C-2W LOTHAR SCHMITZ, TRI ALPHA ENERGY, INC., UCLA DANIEL FULTON, TRI ALPHA ENERGY, INC. CALVIN LAU, IHOH HOLOD, ZHIHONG LIN, UCI BIHE DENG, HIROSHI GOTA, TOSHIHIKO TAJIMA, MICHL BINDERBAUER, TRI ALPHA ENERGY, INC. THE TAE TEAM. Ion-scale modes were shown to be stable in the C-2/C-2U FRC core, in agreement with gyrokinetic simulation results, with a characteristic inverted toroidal wavenumber spectrum confirmed via Doppler Backscattering (DBS). Multi-scale turbulence ($2 < k_{\rho_s} \lesssim 4$0) has been observed via DBS in the mirror-confined scrape-off layer plasma, also in qualitative agreement with recent global gyrokinetic simulations. These simulations indicated radial inward propagation to the outer layer of the FRC core. Recent detailed analysis of turbulence interaction with large-scale $E \times B$ flow near the FRC separatrix, via DBS, also confirm radial inward turbulence propagation, but the radial turbulence correlation length exhibits a pronounced minimum just outside the separatrix at all wavenumbers, indicating effective radial transport barrier formation. An advanced Doppler Backscattering diagnostic design for C-2W, and prospects for simultaneous measurements of magnetic fluctuations via Cross-Polarization Scattering (CPS) will be discussed.
BP11 58 Fully-kinetic Ion Simulation of Global Electrostatic Turbulent Transport in C-2U

DANIEL FULTON, Tri Alpha Energy CALVIN LAU, JIAN BAO, ZHIHONG LIN, University of California, Irvine TOSHIKI TAJIMA, Tri Alpha Energy THE TAE TEAM TEAM

Understanding the nature of particle and energy transport in field-reversed configuration (FRC) plasmas is a crucial step towards an FRC-based fusion reactor. The C-2U device at Tri Alpha Energy (TAE) achieved macroscopically stable plasmas and electron energy confinement time which scaled favorably with electron temperature [1]. This success led to experimental and theoretical investigation of turbulence in C-2U [2,3,4,5], including gyrokinetic ion simulations with the Gyrokinetic Toroidal Code (GTC). A primary objective of TAE’s new C-2W device is to explore transport scaling in an extended parameter regime. In concert with the C-2W experimental campaign, numerical efforts have also been extended in A New Code (ANC) to use fully-kinetic (FK) ions and a Vlasov-Poisson field solver. Global FK ion simulations are presented. Future code development is also discussed.


BP11 59 Cross-separatrix Coupling in Nonlinear Global Electrostatic Turbulent Transport in C-2U

CALVIN LAU, Univ of California - Irvine DANIEL FULTON, Tri Alpha Energy, Inc. JIAN BAO, ZHIHONG LIN, Univ of California - Irvine MICHL BINDERBAUER, Tri Alpha Energy, Inc. TOSHIKI TAJIMA, Univ of California - Irvine: Tri Alpha Energy, Inc. LOTHAR SCHMITZ, Univ of California - Los Angeles THE TAE TEAM

In recent years, the progress of the C-2/C-2U advanced beam-driven field-reversed configuration (FRC) experiments at Tri Alpha Energy, Inc. has pushed FRCs to transport limited regimes. Understanding particle and energy transport is a vital step towards an FRC reactor, and two particle-in-cell microturbulence codes, the Gyrokinetic Toroidal Code (GTC) and A New Code (ANC), are being developed and applied toward this goal. Previous local electrostatic GTC simulations find the core to be robustly stable with drift-wave instability only in the scrape-off layer (SOL) region. However, experimental measurements showed fluctuations in both regions; one possibility is that fluctuations in the core originate from the SOL, suggesting the need for non-local simulations with cross-separatrix coupling. Current global ANC simulations with gyrokinetic ions and adiabatic electrons find that non-local effects (1) modify linear growth-rates and frequencies of instabilities and (2) allow instability to move from the unstable SOL to the linearly stable core. Nonlinear spreading is also seen prior to mode saturation. We also report on the progress of the first turbulence simulations in the SOL.

*This work is supported by the Norman Rostoker Fellowship.

BP11 60 Parallel Transport with Sheath and Collisional Effects in Global Electrostatic Turbulent Transport in FRCs

JIAN BAO, CALVIN LAU, ANIMESH KULEY, ZHIHONG LIN, Univ of California - Irvine DANIEL FULTON, Tri Alpha Energy, Inc. TOSHIKI TAJIMA, Univ of California - Irvine TRI ALPHA ENERGY, INC. TEAM

Collisional and turbulent transport in a field reversed configuration (FRC) is studied in global particle simulation by using GTC (gyrokinetic toroidal code). The global FRC geometry is incorporated in GTC by using a field-aligned mesh in cylindrical coordinates, which enables global simulation coupling core and scrape-off layer (SOL) across the separatrix. Furthermore, fully kinetic ions are implemented in GTC to treat magnetic-null point in FRC core. Both global simulation coupling core and SOL regions and independent SOL region simulation have been carried out to study turbulence [1-3]. In this work, the “logical sheath boundary condition” [4] is implemented to study parallel transport in the SOL. This method helps to relax time and spatial steps without resolving electron plasma frequency and Debye length, which enables turbulent transports simulation with sheath effects. We will study collisional and turbulent SOL parallel transport with mirror geometry and sheath boundary condition in C2-W divertor.


BP11 61 Whole Device Modeling of Compact Tori: Stability and Transport Modeling of C-2W

SEAN DETTRICK, DANIEL FULTON, Tri Alpha Energy CALVIN LAU, ZHIHONG LIN, University of California, Irvine FRANCESCO CECCHERINI, LAURA GALEOTTI, SANGEETA GUPTA, MARCO ONOFRI, TOSHIKI TAJIMA, Tri Alpha Energy THE TAE TEAM

Recent experimental evidence from the C-2U FRC experiment shows that the confinement of energy improves with inverse collisionality [1], similar to other high beta toroidal devices, NSTX [2,3] and MAST [4]. This motivated the construction of a new FRC experiment, C-2W, to study the energy confinement scaling at higher electron temperature. Tri Alpha Energy is working towards catalysing a community-wide collaboration to develop a Whole Device Model (WDM) of Compact Tori. One application of the WDM is the study of stability and transport properties of C-2W using two particle-in-cell codes, ANC and FPIC. These codes can be used to find new stable operating points, and to make predictions of the turbulent transport at those points. They will be used in collaboration with the C-2W experimental program to validate the codes against C-2W, mitigate experimental risk inherent in the exploration of new parameter regimes, accelerate the optimization of experimental operating scenarios, and to find operating points for future FRC reactor designs.


BP11 62 Vlasov Fokker Planck Study of Electron Dynamics in the Scrape Off Layer with Expander Divertor

S. GUPTA, P. YUSHMANOV, THE TAE TEAM, Tri Alpha Energy D. C. BARNES, Coronado Consulting

Control of electron heat losses in the open field region surrounding a Field Reversed Configuration (FRC) is important for sustaining higher temperatures in the FRC core, for favorable beam energy deposition, and for reducing loads on divertor plates. At TAE, a magnetic expander will be used to attain these objectives in the new C-2W machine and to comprehensively study expander divertor physics. The electron dynamics and electrostatic potential formation in the expanding magnetic field is analyzed using a 3-D (2 velocity and 1 spatial) Vlasov Fokker Planck code (Ksol). Numerical results showing the effect of collisionality, current, Z_{eff}, incoming distribution etc., on the formation of electrostatic potentials will be presented.

BP11 63 Characterization of magnetohydrodynamic transport in a Field Reversed Configuration

MARCO ONOFRI, PETER YUSHMANOV, SEAN DETTRICK, DANIEL FULTON, Tri Alpha Energy
and study, the background plasma is first taken to have uniform density in real space, such as a cyclotron theta mode on the beam ions. For this while macro-instabilities additionally create periodic structures in velocity space (chiefly with long wavelength, such as Bernstein or AIC modes), micro-instabilities manifest as periodic nodes in velocity space of deuterium and electrons, and a model of ionization creates fast temperature and energy is injected into a high-β background plasma. Inseparable ionization-induced effects, many unstable beam-driven modes were found. With the injection of a neutral beam into a 2D geometry perpendicular to B field is assumed. Cut-off for the electromagnetic O-wave and X-wave follows as well from the derivation of the relativistic frequency spectra. A discussion of the dispersion relations and the absorption processes which characterize such high-harmonic fast waves (HHFW). The latter ones have frequencies lying between the ion cyclotron and lower hybrid resonances and they may represent a viable path to develop an efficient method to deposit energy inside the FRC separatrix, as suggested by recent results obtained at NSTX. A significant upgrade of RF-Pisa to include HHFW has been undertaken. In particular, the so-called “quasi local approximation” [1] originally proposed for toroidal geometries has been re-derived for the cylindrical geometry and a new HHFW version of RF-Pisa concurrent to the FLR version has been developed. Here we present the first results of the application of the new code to FRC equilibria and we discuss the features of the dispersion relations and the absorption processes which characterize this novel regime.  

1 Brambilla, PPCF 44, 2423 (2002).

BP11 64 Synchrotron Radiation From Plasmas with Sub-Relativistic Temperatures ALES NECAS, SERGEI PUTVINSKI, DMITRI RYUTOV, PETER YUSHMANOV, Tri Alpha Energy TAE TEAM TEAM A simple expression for power radiated by synchrotron radiation from plasmas with electron temperatures between 50 – 200 keV is developed. We shall start by re-deriving [1] a general expression for power radiated in vacuum from an individual cyclotron harmonic. Adding up power radiated from individual harmonics shows an asymptotic approach to the power radiated from all harmonics. In a case of Te=50 keV, summing the first 10 harmonics well represents radiation from all harmonics. However, for Te=150 keV, we require to sum over 60 harmonics to adequately represent the total radiation. This is computationally demanding. What follows is a derivation of a simple expression for high harmonic power radiation in vacuum. It is of interested that this expression proofs to be reasonable even for low harmonic numbers. Next we shall present the derivation of the relativistic frequency spectra. A discussion of cut-off for the electromagnetic O-wave and X-wave follows as well as re-emission of synchrotron radiation. Wave propagation close to perpendicular to B field is assumed.


BP11 65 Stabilization of Beam-Driven Modes by Ionization-Induced Velocity Spread BRADLEY NICKS, ALES NECAS, TOSHIKI TAJIMA, Tri Alpha Energy TRI ALPHA ENERGY TEAM Using the implicit PIC code LSP, the stabilization of beam-driven modes by ionization-induced velocity-space broadening in 2D is analyzed. A neutral beam of hydrogen with variable temperature and energy is injected into a high-β background plasma of deuterium and electrons, and a model of ionization creates fast ions from the neutrals. The plasma is then examined for instabilities. Micro-instabilities manifest as periodic nodes in velocity space (chiefly with long wavelength, such as Bernstein or AIC modes), while macro-instabilities additionally create periodic structures in real space, such as a cyclotron theta mode on the beam ions. For this study, the background plasma is first taken to have uniform density and B⊥, and second, an FRC profile. In previous 1D studies without ionization-induced effects, many unstable beam-driven modes were found. With the injection of a neutral beam into a 2D geometry however, many of these modes are stabilized by the broadening of the beam velocity-space distribution. The broadening is strongest for ν⊥, spanning several multiples of the original neutral beam drift speed. Similarly, real-space spreading stabilizes macro-instabilities. Criteria for stability based on the degree of velocity-space and real-space spreading are found and are compared with the 1D case.

BP11 66 Numerical Study of HHFW Heating in FRC Plasmas FRANCESCO CECCHERINI, LAURA GALEOTTI, TRIALPHA ENERGY INC., USA MARCO BRAMBILLA, MAX PLANCK INSTITUTE FUER PLASMAPHYSIK, GERMANY SEAN DETTRICK, XIAOKANG YANG, TRIALPHA ENERGY INC., USA TAE TEAM The TriAlpha Energy (TAE) code RF-Pisa is a Finite Larmor Radius (FLR) full wave code developed over the years to study RF heating in the Field Reversed Configuration (FRC) in both the ion and electron cyclotron regimes. The FLR approximation is perfectly adequate to address RF propagation and absorption at the fundamental and second harmonic frequencies (as in the minority heating scheme), but it is not able to describe higher order processes such as high-harmonic fast waves (HHFW). The latter ones have frequencies lying between the ion cyclotron and lower hybrid resonances and they may represent a viable path to develop an efficient method to deposit energy inside the FRC separatrix, as suggested by recent results obtained at NSTX. A significant upgrade of RF-Pisa to include HHFW has been undertaken. In particular, the so-called “quasi local approximation” [1] originally proposed for toroidal geometries has been re-derived for the cylindrical geometry and a new HHFW version of RF-Pisa concurrent to the FLR version has been developed. Here we present the first results of the application of the new code to FRC equilibria and we discuss the features of the dispersion relations and the absorption processes which characterize this novel regime.

BP11 67 Energy spectrum and kinetics of the fusing particles D.D. RYUTOV, S.V. PUTVINSKI, P.N. YUSHMANOV, AND THE TAE TEAM, Tri Alpha Energy Incorporated The fusing particles (e.g., D and T, or p and 11B) contribution to the reaction rate can be found by the integration of the fusion reactivity over the particle distribution functions. The distribution function (e.g., Maxwellian) is depleted in the energy range determined by the highest reactivity and has to be replenished by particle collisions. The kinetics of the replenishment process may affect the rate of fusion energy release. We present a simple analysis of the corresponding kinetic problems for the conditions typical for the standard and advanced-fuel fusion reactions and assess the possible effect on the reaction yield.

BP11 68 PMI

BP11 69 Understanding the Effect of Gas Dynamics in Plasma Gun Performance for Simulating Fusion Wall Response to Disruption Events WILL RIEDEL, THOMAS UNDERWOOD, FABIO RIGHETTI, MARK CAPPELLI, Stanford University In this work, the suitability of a pulsed coaxial plasma accelerator to simulate the interaction of edge-localized modes with plasma first wall materials is investigated. Experimental measurements derived from a suite of diagnostics are presented that focus on both the properties of the plasma flow and the manner in which such jets couple with material interfaces. Specific emphasis is placed on quantifying the variation in these properties using tungsten tokens exposed to the plasma plume as the gun volume is progressively filled with more neutral gas. These results are mapped to the operational dynamics.
of the gun via a time-resolved Schlieren cinematic visualization of the density gradient within the flow. Resulting videos indicate the existence of two distinct modes with vastly different characteristic timescales, spatial evolution, and plasma properties. Time resolved quantification of the associated plasma heat flux for both modes, including a range spanning 150 MW m\(^{-2}\) - 10 GW m\(^{-2}\), is presented using both a fast thermocouple gauge and an IR camera. Both diagnostics in conjunction with a heat transfer model provide an accurate description of the energy transfer dynamics and operational characteristics of plasma guns.

*This work is supported by the U.S. Department of Energy Stewardship Science Academic Program.

\(\text{BP11 70 Erosion and Surface Morphology of Silicon Carbide Under Variable DIII-D Divertor Heat Fluxes* STEFAN BRINGUIER, TYLER ABRAMS, HESHAM KHALIFA, DAN THOMAS, LEO HOLLAND, General Atomics DMITRY RUDAKOV, University of California, San Diego ALEXIS BRIESEMIESTER, Oak Ridge National Laboratory A SiC coating of \(\sim250 \mu\text{m}\) deposited onto a graphite DiMES cap via chemical vapor deposition, was exposed to \(\sim80 \text{s}\) of H-mode plasma bombardment in the DIII-D outer divertor with steady-state heat fluxes up to 3 MW m\(^{-2}\) and transient loads due to ELMs typically peaking at \(\sim10\) MW m\(^{-2}\). In-situ monitoring of Si I and Si II atomic spectral lines revealed the presence of significant neutral Si and Si\(^{+}\) impurity influx, which are used to determine quantitative erosion rates via the S/XB method. No visual macroscopic flaking or delamination of the SiC coating was observed, supporting the notion that SiC is thermal-mechanically robust and compatible with graphite substrates at elevated temperatures. Post-mortem profilometric analysis also indicates no pronounced change in surface roughness after plasma exposure. Finally, we investigate aspects of preferential sputtering and changes to surface composition exposure using scanning electron microscopy and Auger electron spectroscopy.

*Work supported under USDOE Cooperative Agreement DE-FC02-04ER54698.

\(\text{BP11 71 Development and Testing of Dispersion-Strengthened Tungsten Alloys via Spark Plasma Sinterin}^*_{\text{g}}\) ERIC LANG, NATHAN MADDEN, CHARLES SMITH, JESSICA KROGSTAD, JEAN PAUL ALLAIN, Univ of Illinois - Urbana Tungsten (W) is a common plasma-facing component (PFC) material in the divertor region of tokamak fusion devices due to its high melting point and high sputter threshold [1]. However, W is intrinsically brittle and is further embrittled under neutron irradiation, and the low recrystallization temperature pose complications in fusion environments [1,2]. More ductile W alloys, such as dispersion-strengthened tungsten are being developed. In this work, W samples are processed via spark plasma sintering (SPS) with TiC, ZrC, and TaC dispersoids alloyed from 0.5 to 10 weight %. SPS is a powder compaction technique that provides high pressure and heating rates via electrical current, allowing for a lower final temperature and hold time for compaction [3]. Initial testing of material properties, microstructure, and composition of specimens will be presented. Deuterium and helium irradiations have been performed in IGNIS, a multi-functional, in-situ irradiation and characterization facility at the University of Illinois. High-flux, low-energy exposures at the Magnum-PSI facility at DIFFER exposed samples to a D fluence of \(1\times10^{20}\) cm\(^{-2}\) and He fluence of \(1\times10^{19}\) cm\(^{-2}\) at temperatures of 300-1000 C. In-situ chemistry changes via XPS and ex-situ morphology changes via SEM will be studied.

*Work supported by DOE contract DE-SC0010719.


\(\text{BP11 72 Investigation of the helium effects on deuterium retention in thin film lithium coatings on tungsten substrates* A.L. NEFF, J.P. ALLAIN, University of Illinois, Center for Plasma Material Interactions, Micro and Nanotechnology Center, Urbana, IL 61801 T.W. MORGAN, FOM Institute DIFFER-Dutch Institute for Fundamental Energy Research, Partner in the Trilateral Eurogeo Cluster, the Netherlands} \)

In a burning fusion plasma, the materials on the walls of the plasma vessel will have a significant effect on the performance of the plasma. Any amount of high Z wall material that is eroded will contaminate and cool the plasma and may lead to a disruption. Additionally, if the material retains or reflects fuel it can affect the stability of the plasma. A high recycling wall that retains minimal fuel will allow better control of the fuel inventory, especially tritium, in the walls [1]. In contrast, a low recycling wall leads to improved plasma performance by preventing instabilities in the plasma [2]. We have observed that when 5% He is added to D ions during low flux \((10^{17} \text{m}^{-2}\text{s}^{-1})\) dual ion beam irradiation the amount of D retained in the Li film diminishes [3]. This conclusion is based on the reduction of a XPS peak (at 533 eV) associated with D retention in Li films [4]. To further investigate this phenomenon, we have continued the dual beam studies in IGNIS (Ion-Gas-Nuclear Interactions with Surfaces) by varying the energy and concentration of He to D. Additionally, we exposed lithiumd W to sequential D and He plasmas \((10^{21} \text{m}^{-2}\text{s}^{-1})\) flux in Magnum PSI at DIFFER. With XPS, we analyzed the chemistry of the Li films and determined changes in retention. These results will be presented.

*Work supported by DOE contract DE-SC0014267.

4Work supported by US DOE Contract DE-FC02-04ER54698.
**BP11 74 Deuteron sputtering of Li and Li-O films**

ANDREW NELSON, LUXHERTA BUZI, ROBERT KAITA, BRUCE KOEL, 
Princeton Plasma Phys Lab. Lithium wall coatings have been shown to 
enhance the operational plasma performance of many fusion de-
vices, including NSTX and other tokamaks, by reducing the global 
wall recycling coefficient. However, pure lithium surfaces are ex-
tremely difficult to maintain in experimental fusion devices due to 
both inevitable oxidation and codeposition from sputtering of hot 
plasma facing components. Sputtering of thin lithium and lithium 
oxide films on a molybdenum target by energetic deuterium ion 
bombardment was studied in laboratory experiments conducted in 
a surface science apparatus. A Colutron ion source was used to 
produce a monoenergetic, mass-selected ion beam. Measurements 
were made under ultrahigh vacuum conditions as a function of sur-
facer temperature (90-520 K) using x-ray photoelectron spectroscopy 
(XPS), Auger electron spectroscopy (AES) and temperature pro-
gressed desorption (TPD). Results are compared with computer 
simulations conducted on a temperature-dependent data-calibrated 
(TRIM) model.

**BP11 75 Flux threshold determination for tungsten nano-fuzz 
formation using an 80 eV He-ion beam**

FRED W. MEYER, 
MARK E. BANNISTER, CHAD M. PARISH, Oak Ridge Na-
tional Laboratory. At the ORNL Multicharged Ion Research Fa-
cility (MIRF), we have extended our investigation of flux thresholds 
for He-ion induced nano-fuzz formation on hot tungsten surfaces 
down to plasma-edge-relevant energies of 80 eV. We measured the 
size of the incident ion beam by accurate flux-profile measurements, 
and the size of the region where tungsten nano-fuzz was formed by 
post-exposure SEM surface analysis and real-time monitoring of the 
hot W surface-emissivity change throughout the beam exposure. If 
tungsten nano-fuzz formation had a fluence threshold, the size of the 
observed nano-fuzz region would be expected to increase with 
fluence. We measured the size of the incident ion beam at 80 eV. 
We observed that the size of the observed nano-fuzz region would 
be expected to increase with exposure time, eventually filling the entire beam spot. Instead, 
we found that the region of nano-fuzz formation (1) was always 
smaller than the beam spot itself and (2) did not increase in size 
with time, i.e. with accumulated He ion fluence. By comparison of the flux profile and the spatial extent of the fuzz region we de-
termined a flux threshold of 9.5 + 3 x 10^13/m^2/s at 80 eV He ion 
impact energy. We show that the observed flux-threshold energy de-
pendence for nano-fuzz formation, which we have now mapped out 
from 80 eV to 8.5 keV, is well reproduced by the combined energy 
dependences of He-ion reflection, He-ion range and target-damage 
creation, determined using SRIM.

*Research sponsored by the LDRD program at ORNL, managed by 
UT-Battelle for the USDOE, and by the DOE OFES.

**BP11 76 Production of high-density highly-ionized helicon plas-
mas in the ProtoMPEX**

J.F. CANESES, ORNL N. KAFLE, M. SHOWERS, University of Tennessee, Knoxville R.H. GOULDING, T.M. BIEWER, J.B.O. CAUGHMAN, T. BIGELOW, J. RAPP, 
ORNL High-density (2-6e19 m-3) Deuteron helium plasmas in the 
ProtoMPEX have been produced that successfully use differen-
tial pumping to produce neutral gas pressures suitable for testing the 
RF electron and ion heating concepts. To minimize collisional 
losses when heating electrons and ions, plasmas with very low neu-
tral gas content (<0.1 Pa) in the heating sections are required. 
This requirement is typically not compatible with the neutral gas 
pressures (1-2 Pa) commonly used in high-density light-ion helicon 
sources. By using skimmers, a suitable gas injection scheme and 
long duration discharges (>0.3 s), high-density plasmas with very 
low neutral gas pressures (<0.1 Pa) in the RF heating sections have 
been produced. Measurements indicate the presence of a highly-
ionized plasma column and that discharges lasting at least 0.3 s are 
required to significantly reduce the neutral gas pressure in the RF 
heating sections to levels suitable for investigating electron/ion RF 
heating concepts in this linear configuration.

*This work was supported by the US. D.O.E. contract DE-AC05-
00OR22725.

**BP11 77 Measurements of ion energies during plasma heating of 
the Proto-MPEX High Intensity Plasma Source**

J.B.O. CAUGH-
Ridge National Laboratory P. PIOTROWICZ, University of Illi-
nois C.J. BEERS, N. KAFLE, M.A. SHOWERS, University of 
Tennessee The Prototype Materials Plasma Exposure eXperiment 
(Proto-MPEX) is a linear high-intensity RF plasma source that com-
bines a high-density helicon plasma generator with ion and electron 
heating sections. It is being used to study the physics of heating over-
dense plasmas in a linear configuration with the goal of deliver-
ing a plasma heat flux of ~10 MW/m^2 at a target. The helicon 
plasma is produced by coupling 13.56 MHz RF power at levels 
>100 kW. Additional heating is provided by ion cyclotron heating 
(IC) (~25 kW) and electron Bernstein wave (EBW) heating (~25 
kw) at 28 GHz. Measurements of the ion energy distribution with a 
retarding field energy analyzer (RFEA) show an increase in ion 
energies in the edge of the plasma when ICH is applied, which is 
consistent with COMSOL modeling of the power deposition from 
the antenna. Views of the target plate with an infrared camera show 
an increase in the surface temperature at large radii during ICH, and 
these areas map back to magnetic field lines near the antenna. 
The change in the power deposition at the target during ICH is compared 
with Thomson Scattering and RFEA measurements near the target.

*ORNL is managed by UT-Battelle, LLC, for the U.S. DOE under 
contract DE-AC-05-00OR22725.

**BP11 78 Modeling and Theory of RF Antenna Systems on 
Proto-MPEX**

P.A. PIOTROWICZ, University of Illinois at Urbana 
Champaign J.F. CANESES, R.H. GOULDING, D. GREEN, J.B.O. 
CAUGHMAN, ORNL N.R. RUZIC, University of Illinois at Urbana 
Champaign PROTO-MPEX TEAM The RF wave coupling of the 
helicon and ICH antennas installed on the Prototype Material Plasma 
Exposure eXperiment (Proto-MPEX) has been explored theoretically 
and via a full wave model implemented in COMSOL Multiphysics. 
The high-density mode in Proto-MPEX has been shown to occur when 
exciting radial eigenmodes of the plasma column which coincides 
with entering a Trivelpiece Gould (TG) anti-resonant regime, 
therefore suppressing edge heating in favor of core power deposition. The 
fast wave launched by the helicon antenna has a large wavelength 
and travels at a steep group velocity angle with the background 
magnetic field; for this reason the fast wave launched by the helicon 
 antenna efficiently couples power to the core plasma. However, the 
ICH heating scheme relies on a small wavelength slow wave to cou-
ple power to the core of the plasma column. Coupling slow wave 
power to the core of the plasma column is sensitive to the location 
of the Alfvén resonance. The wave-vector and group velocity vec-
tor of the slow wave in this parameter regime undergoes a drastic 
change in behavior when approaching the Alfvén resonance. Full
wave simulation results and dispersion analysis will be presented with suggestions to guide experimental progress.

*This work was supported by the U.S. D.O.E. contract DE-AC05-00OR22725.

BP11 79 High power plasma heating experiments on the Proto-MPEX facility* T.S. BIGELOW, C.J. BEERS, T.M. BIEWER, J.F. CANESES, J.B.O. CAUGHMAN, S.J. DIEM, R.H. GOULDING, D.L. GREEN, N. KAFLE, J. RAPP, M.A. SHOWERS, Oak Ridge National Laboratory Work is underway to maximize the power delivered to the plasma that is available from heating sources installed on the Prototype Materials Plasma Exposure eXperiment (Proto-MPEX) at ORNL. Proto-MPEX is a linear device that has a >100 kW, 13.56 MHz helicon plasma generator available and is intended for material sample exposure to plasmas. Additional plasma heating systems include a 10 kW 18 GHz electron cyclotron heating (ECH) system, a 25 kW ~8 MHz ion cyclotron heating ICH system, and a 200 kW 28 GHz electron Bernstein wave (EBW) and ECH system. Most of the heating systems have relatively good power transmission efficiency; however, the 28 GHz EBW system has a lower efficiency owing to stringent requirements on the microwave launch characteristics for EBW coupling combined with the lower output mode purity of the early-model gyrotron in use and its compact mode converter system. A goal for the Proto-MPEX is to have a combined heating power of 200 kW injected into the plasma. Infrared emission diagnostics of the target plate combined with Thomson Scattering,Langmuir probe, and energy analyzer measurements near the target are utilized to characterize the plasmas and coupling efficiency of the heating systems.

*ORNL is managed by UT-Battelle, LLC, for the U.S. DOE under contract DE-AC-05-00OR22725.

BP11 80 Observations of temperature rise during electron cyclotron heating application in Proto-MPEX* T.M. BIEWER, T. BIGELOW, J.F. CANESES, S.J. DIEM, J. RAPP, M. REINKE, ORNL, N. KAFLE, H.B. RAY, M. SHOWERS, Univ. Tennessee-Knoxville The Prototype Material Plasma Exposure eXperiment (Proto-MPEX) at ORNL utilizes a variety of power systems to generate and deliver a high heat flux plasma (1 MW/m2 for these discharges) onto the surface of material targets. In the experiments described here, up to 120 kW of 13.56 MHz “helicon” waves are combined with 20 kW of 28 GHz microwaves to produce Deuterium plasma discharges. The 28 GHz waves are launched in a region of the device where the magnetic field is axially varying near 0.8 T, resulting in the presence of a 2nd harmonic electron cyclotron heating (ECH) resonance layer that transacts the plasma column. The electron density and temperature profiles are measured using a Thomson scattering (TS) diagnostic, and indicate that the electron density is radially peaked. In the core of the plasma column the electron density is higher than the cut-off density (0.9x1019 m-3) for ECH waves to propagate and O-X-B mode conversion into electron Bernstein waves (EBW) is expected. TS measurements indicate electron temperature increases during 28 GHz wave application, rising (from 5 eV to 20 eV) as the neutral Deuterium pressure is reduced below 1 mTorr.

*This work was supported by the U.S. D.O.E. contract DE-AC05-00OR22725.

BP11 81 Power Balance Analysis of the Prototype-Material Plasma Exposure eXperiment* M.A. SHOWERS, ORNL/UT-Knoxville T.M. BIEWER, J.F. CANESES, J.B.O CAUGHMAN, A. LUMSDAINE, L. OWEN, J. RAPP, D. YOUCISON, ORNL C.J. BEERS, D.C. DONOVAN, N. KAFLE, H.B. RAY, UT-Knoxville The Prototype-Material Plasma Exposure eXperiment (Proto-MPEX) is a test bed for the plasma source concept for the planned Material Plasma Exposure eXperiment (MPEX), a steady-state linear device studying plasma material interactions for fusion reactors. A power balance of Proto-MPEX attempts to identify machine operating parameters that will improve Proto-MPEX’s performance, potentially impacting the MPEX design concept. A power balance has been performed utilizing an extensive diagnostic suite to identify mechanisms and locations of power loss from the main plasma. The diagnostic package includes infrared cameras, double Langmuir probes, fluoroptic probes, Mach probes, a Thomson scattering diagnostic, a McPherson spectrometer and in-vessel thermocouples. Radiation losses are estimated with absolute calibrated spectroscopic signals.

*This work was supported by the U.S. D.O.E. contract DE-AC05-00OR22725.

BP11 82 Experimental results from plasma transport on Prototype-Material Plasma Exposure eXperiment and comparison with B2-Eirene modeling* N. KAFLE, Univ of Tennessee, Knoxville J.F. CANESES, T.M. BIEWER, L. OWEN, Oak Ridge National Lab. M. SHOWERS, D. DONOVAN, Univ of Tennessee, Knoxville J.B. CAUGHMAN, R.H. GOULDING, JUERGEN RAPP, Oak Ridge National Lab. Proto-MPEX at ORNL is a linear plasma device that combines a helicon plasma source with additional microwave and RF heating to deliver high plasma heat and particle fluxes to a target. Double Langmuir probes and Thomson scattering are being used to measure local Te and ne at various radial and axial locations. A recently constructed Mach-double probe provides the added capability of simultaneously measuring Te, ne, and Mach number. With this diagnostic, it is possible to infer the plasma flow, particle flux, and convective heat flux at different locations along the plasma column in Proto-MPEX. Preliminary results show Mach numbers of 0.6 and 0.8 in either direction away from the helicon source, and no flow near the source for the case where the peak magnetic field was 1.0 T. In addition, the Thomson Scattering system has been upgraded to measure ne and Te profiles at two axial locations, upstream at the electron heating location and downstream close to the target. Measurements of particle flow and flux profiles, heat flux, and profiles of ne and Te will be discussed. The extensive coverage provided by these diagnostics permits data-constrained B2-Eirene modeling of the entire plasma column, and comparison with results of modeling of high density mode plasmas will be presented.

*Supported by the US. D.O.E. contract DE-AC05-00OR22725.

BP11 83 Development and Implementation of a New HELIOS Diagnostic using a Fast Piezoelectric Valve on the Prototype Material Plasma Exposure eXperiment* HOLLY RAY, Univ of Tennessee, Knoxville and Oak Ridge National Laboratory THEODORE BIEWER, JUAN CANESES, Oak Ridge National Laboratory JONATHAN GREEN, University of Wisconsin Madison ELIZABETH LINDQUIST, Hope College LEVON MCQUOWN, OLIVER SCHMITZ, University of Wisconsin Madison A new helium line-ratio spectral monitoring (HELIOS) diagnostic, using a piezoelectric valve with high duty cycles (on/off times ms), allowing for good background correction, and measured particle flowrates on the order of ~1020 particles/second is being implemented on Oak Ridge National Laboratory’s (ORNL) Prototype Material Plasma Exposure eXperiment (Proto-MPEX). Built in collaboration with the University of Wisconsin – Madison, the HELIOS diagnostic
communicates with a Labview program for controlled bursts of helium into the vessel. The open magnetic geometry of Proto-MPEX is ideal for testing and characterizing a HELIOS diagnostic. The circular cross-section with four ports allows for cross comparison between different diagnostics: 1) Helium injection with the piezo-electric puff valve, 2) HELIOS line-of-sight high-gain observation, 3) scan-able Double Langmuir probe, and 4) HELIOS 2D imaging observation. Electron density and temperature measurements from the various techniques will be compared.

“This work was supported by the US. D.O.E. contract DE-AC05-00OR22725 and DE-SC00013911.

**BP11 84 Development of a Dual-Laser Digital Holography Diagnostic for Surface Characterization at ORNL**

*J.C. Sawyer, The University of Tennessee, Knoxville T.M. Biewer, Oak Ridge National Laboratory C.E. Thomas, Third Dimension Technologies Z. Zhang, The University of Tennessee, Knoxville The Fusion and Materials for Nuclear Systems Division (FMNSD) at Oak Ridge National Laboratory (ORNL), in collaboration with The University of Tennessee, Knoxville and Third Dimension Technologies (TDT), presents continuing progress towards the development of a dual-laser digital holography (DH) technique for 3D imaging of plasma facing component (PFC) surfaces in real time. This update includes results from an “on the bench” single-laser DH demonstration. The dual-laser approach utilizes two CO2 lasers tuned to neighboring molecular CO2 lines to extend the 2π ambiguity of holographic interferograms to ~5 mm from the ~10 μm wavelength. Reconstruction of the interferogram allows for measurement of changes in surface topology at rates of ~2 mm/s. This status of a dual-laser DH system “on the bench,” demonstration and implementation on the Proto-MPEX device will be presented.

“This work was supported by The University of Tennessee JDRD program and the US. D.O.E. contract DE-AC05-00OR22725. Research sponsored by the Laboratory Directed Research and Development Program of ORNL, managed by UT Battelle, LLC, for the U.S. D.O.E.

**BP11 85 Numerical Assessment of Plasma Parameters and Surface Flux Scaling in the HDRA Stellarator**

*Steven Marcinko, Davide Currelli, Univ of Illinois - Urbana Pre-online scaling of expected HDRA operating conditions has been analyzed using EMC3-EIRENE, to which a self-consistent local Bohm-like diffusivity has been added. An inboard and outboard midplane limiter were tested with RF input to core-edge power deposition efficiencies of 10-50% for a 26 kW 2.45 GHz combined RF input discharge. Scaling laws for peak electron temperature, Bohm-like diffusivity, and heat and particle fluxes have been calculated for both low- and high-field discharges; peak electron temperatures, particle diffusivity, and heat fluxes at the outboard limiter were seen to follow approximately a power-law of type $f(P_{RF}) \propto a^b P_{RF}^c$, with typical exponents in the range $b \sim 0.55 - 0.60$. Higher magnetic fields have the tendency to linearize the heat flux dependence upon the RF power, with exponents in the range of $b \sim 0.75$. Particle fluxes at the outboard limiter are seen to saturate first, and then slightly decline for RF powers in excess of 120 kW in the low-field case and 180 kW in the high-field case.

**BP11 86 Investigation Of A Tin-Lithium Alloy As A Liquid Plasma-Facing Material**

*Heather Sandefur, David Ruzic, Center for Plasma-Material Interactions, University of Illinois Robert Kolasinski, Dean Buchenauer, Plasma-Surface Interactions Science Center, Sandia National Laboratories*

**BP11 87 ENERGETIC PARTICLES**

**BP11 88 Modelling ion cyclotron emission from KSTAR tokamak and LHD helical device plasmas**

*R. Dendy, Culham Centre for Fusion Energy Ben Chapman, Bernard Reaman, Sandra Chapman, Warwick University Tsuyoshi Akiyama, NIFS GunSuu YUN, POSTECH* New high quality measurements of ion cyclotron emission (ICE) from KSTAR and LHD greatly extend the scope and diversity of plasma conditions under which ICE is observed. Variables include the origin (fusion reactions or neutral beam injection) and energy (sub- or super-Alfvénic) of the minority energetic ions that drive ICE; the composition of the bulk plasma (hydrogen or deuterium) which supports the modes excited; plasma density in the emitting region, and the timescale on which it changes; and toroidal magnetic field geometry (tokamak or helical device). Future exploitation of ICE as a diagnostic for energetic ion populations in JET D-T plasmas and in ITER rests on quantitative understanding of the physics of the emission. This is tested and extended by current KSTAR and LHD measurements of ICE. We report progress on direct numerical simulation using full orbit ion kinetic codes that solve the Maxwell-Lorentz equations for hundreds of millions of particles. In the saturated regime, these simulations yield excited field spectra that correspond directly to the measured ICE spectra under diverse KSTAR and LHD regimes. At early times, comparison of simulation outputs with linear analytical theory confirms the magnetocoustic cyclotron instability as the basic driver of ICE.

*Supported by RCUK Energy Programme Grant EP/P012450/1, NRF Korea Grant 2014M1A7A1A03029881, NIFS budget ULHH029 and Euratom.

**BP11 89 Numerical Study on Wave-induced Beam Ion Prompt Losses in DIII-D Tokamak**

*Guoyong Fu, Zhicheng Feng, Jia Zhu, Zhejiang University William Heidbrink, UCI Michael Van Zeeland, General Atomics* A numerical study is performed on the coherent beam ion prompt losses driven by Alfvén eigenmodes (AE) in DIII-D plasmas using realistic parameters and beam ion deposition profile. The synthetic signal of fast-ion loss detector (FILD) is calculated for a single AE mode. The first harmonic of the calculated FILD signal is linearly proportional to...
the AE amplitude with the same AE frequency in agreement with the experimental measurement. The calculated second harmonic is proportional to the square of the first harmonic for typical AE amplitudes. The coefficient of the quadratic scaling is found to be sensitive to the AE mode width. The second part of this work considers the AE drive due to coherent prompt loss. It is shown that the loss-induced mode drive is much smaller than the previous estimate and can be ignored for mode stability.

**BP11 90** Electron kinetic effects on the nonlinear evolution of Reverse Shear Alfvén Eigenmodes YANG CHEN, University of Colorado at Boulder GUO-YONG FU, Zhejiang University, China SCOTT PARKER, University of Colorado at Boulder For near marginal EP driven Alfvén modes the main nonlinear saturation mechanism is the trapping of resonant particles in the wave field. As the drive increases, other nonlinear effects become important. We use gyrokinetic ion/drift-kinetic electron GEM PIC simulation to examine nonlinear effects due to zonal structures and excitation of higher harmonics of the driving mode (here an n=4 RSAE). We find that, with the n=0 and n=8 perturbations included, the n=4 saturation amplitude follows the trapping scaling at low growth rates. As the growth rate increases (by increasing the beam density), the initial n=4 saturation level is modified. Both the n=0 and the n=8 perturbations are force generated by the n=4 mode via the thermal species nonlinear effects. Unlike ITG, spontaneous excitation of the zonal flows is not seen. The effect of n=0 comes from the zonal electron and ion densities, which cause fine scales in the n=4 mode structure. The Er shearing effect appears to be small. Another nonlinear damping mechanism comes from kinetic electrons. The force generated n=8 electron current gives rise to a perpendicular n=4 current due to field line bending, and this perpendicular current leads to a significant Joule heating on the electrons and damping of the driving n=4 RSAE.

**BP11 91** 1D Resonance line Broadened Quasilinear (RBQ1D) code for fast ion Alfvénic relaxations and its validations* NIKOLA GORELENKOV, Princeton Plasma Phys Lab VINICIUS DUARTE, San Paulo University MARIO PODESTA, Princeton Plasma Phys Lab The performance of the burning plasma can be limited by the requirements to confine the superalfvenic fusion products which are capable of resonating with the Alfvénic eigenmodes (AEs). The effect of AEs on fast ions is evaluated using the quasi-linear approach [Berk et al., Ph.Plasmas’96] generalized for this problem recently [Duarte et al., Ph.D.’17]. The generalization involves the resonance line broadened interaction regions with the diffusion coefficient prescribed to find the evolution of the velocity distribution function. The baseline eigenmode structures are found using the NOVA-K code perturbatively [Gorelenkov et al., Ph.Plasmas’99]. A RBQ1D code allowing the diffusion in radial direction is presented here. The wave particle interaction can be reduced to one-dimensional dynamics where for the Alfvénic modes typically the particle kinetic energy is nearly constant. Hence to a good approximation the Quasi-Linear (QL) diffusion equation only contains derivatives in the angular momentum. The diffusion equation is then one dimensional that is efficiently solved simultaneously for all particles with the equation for the evolution of the wave angular momentum. The RBQ1D is validated against recent DIII-D results [Collins et al., PRL’16].

*Supported by the US Department of Energy under DE-AC02-09CH11466.

**BP11 92** Resonance frequency broadening of wave-particle interaction in tokamaks due to collision and microturbulence G. MENG, PPPL, PKU N. N. GORELENKOV, V. N. DUARTE, R. B. WHITE, A. BHATTACHARJEE, PPPL The resonance width of energetic particles (EPs) and waves is crucial for the understanding and modelling for EP transport. In this work, we use ORBIT to study the broadening of resonance for DIII-D shot 159243 and the parametric dependencies of the broadening width on bounce frequency, growth rate and scattering rate. With only perturbation applied, the broadening is inferred from kinetic Poincare plot. With additional scattering, the broadening width is obtained by studying particle redistribution. It is found that scattering leads to particle diffusion in phase space and increases resonance broadening significantly. With perturbation, scattering broadens resonance not only by kicking particles in and out the primary resonance island but also kicking particle across the adjacent secondary resonance island region. The redistribution process by mode trapping is much faster than scattering. The diffusion coefficient is larger at resonance island center than at the edge when perturbation is small. For DIII-D, anomalous stochasticity has more important effect on the broadening compared to the collisional scattering. Comparison with RBQ and NOVA-K is in progress. This work will improve the modelling of the nonlinear process and EP transport by providing analyses for synergistic effects due to different mechanisms.

**BP11 93** Frequency chirpings in Alfvén continuum GE WANG, HERB BERK, BORIS BREIZMAN, LINJIN ZHENG, Institute for fusion studies, University of Texas at Austin We have used a self-consistent mapping technique to describe both the nonlinear wave-energetic particle resonant interaction and its spatial mode structure that depends upon the resonant energetic particle pressure. At the threshold for the onset of the energetic particle mode (EPM), strong chirping emerges in the lower continuum close to the TAE gap and then, driven by strong continuum damping, chips rapidly to lower frequencies in the Alfvén continuum. An adiabatic theory was developed that accurately replicated the results from the simulation where the nonlinearity was only due to the EPM resonant particles. The results show that the EPM-trapped particles have their action conserved during the time of rapid chirping. This adiabaticity enabled wave trapped particles to be confined within their separatrix, and produce even larger resonant structures, that can produce a large amplitude mode far from linearly predicted frequencies. In the present work we describe the effect of additional MHD nonlinearity to this calculation. We studied how the zonal flow component and its nonlinear feedback to the fundamental frequency and found that the MHD nonlinearity doesn’t significantly alter the frequency chirping response that is predicted by the calculation that neglects the MHD nonlinearity.

**BP11 94** Tridimensional Thermonuclear Instability in Subignited Plasmas and on the Surface of the Pulsars* A. CARDINALI, ENEA B. COPPI, MIT Tridimensional modes involving an increase of the electron temperature can be excited as a result of alpha-particle heating in subignited D-T fusion burning plasmas when a nearly time-independent external source of heating is applied. The analyzed modes [1] are shown to emerge from an axisymmetric toroidal configurations and are radially localized around rational magnetic surfaces corresponding to \( q(r = r_0) = m_0/n_0 \) where \( m_0 \) and \( n_0 \) are the relevant poloidal and toroidal mode numbers. The radial width of the mode is of the order of the thermal scale distance. The mode has a rather severe damping rate, that has to be overcome by the relevant heating rate. Thus the temperature range to be considered is that where the D-T plasma reactivity undergoes a relatively large increase as a function of temperature. This kind of theory has been applied to the plasmas that are envisioned
to be associated with surface of pulsar and be subjects to (spatially) inhomogenous thermonuclear burning.

*Sponsored in part by the U.S. DoE.


BP11 95 Magnetic Reconnection Driven by Thermonuclear Burning∗ R. GATTO, Università Roma 1. B. COPPL, MIT. Considering that fusion reaction products (e.g. α-particles) deposit their energy on the electrons, the relevant thermal energy balance equation is characterized by a fusion source term, a relatively large longitudinal thermal conductivity and an appropriate transverse thermal conductivity. Then, looking for modes that are radially localized around rational surfaces [1], reconnected field configurations are found that can be sustained by the electron thermal energy source due to fusion reactions. Then this process can be included in the category of endogenous reconnection processes and may be viewed as a form of the thermonuclear instability that can develop in an ignited inhomogeneous plasma. A complete analysis of the equations supporting the relevant theory is reported.

*Sponsored in part by the U.S. DoE.


BP11 96 OTHER CONFINEMENT CONCEPTS AND NEXT STEPS

BP11 97 Initial operation of the Lockheed Martin T4B experiment M.L. GARRETT, A. BLINZER, F. EBERSOHN, S. GUCKER, J. HEINRICH, C. LOHFF, T. MCGUIRE, N. MONTECALVO, A. RAYMOND, J. RHOADS, P. ROSS, B. SOMMERS, E. STRANDBERG, R. SULLIVAN, J. WALKER, Lockheed Martin - Palmdale The T4B experiment is a linear, encapsulated ring cusp confinement device, designed to develop a physics and technology basis for a follow-on high beta (β ∼ 1) machine. The experiment consists of 13 magnetic field coils (11 external, 2 internal), to produce a series of on-axis field nulls surrounded by modest magnetic fields of up to 0.3 T. The primary plasma source used on T4B is a lanthanum hexaboride (LaB₆) cathode, capable of coupling over 100 kW into the plasma. Initial testing focused on commissioning of components and integration of diagnostics. Diagnostics include both long and short wavelength interferometry, bolometry, visible and X-ray spectroscopy, Langmuir and B-dot probes, Thomson scattering, flux loops, and fast camera imagery. Low energy discharges were used to begin validation of physics models and simulation efforts. Following the initial machine check-out, neutral beam injection (NBI) was integrated onto the device. Detailed results will be presented. © 2017 Lockheed Martin Corporation. All Rights Reserved.

BP11 99 Neutral Beam Development for the Lockheed Martin Compact Fusion Reactor FRANS EBERSOHN, REGINA SULLIVAN, Lockheed Martin - Palmdale The Compact Fusion Reactor project at Lockheed Martin Skunk Works is developing a neutral beam injection system for plasma heating. The neutral beam plasma source consists of a high current lanthanum hexaboride (LaB₆) hollow cathode which drives an azimuthal cusp discharge similar to gridded ion thrusters. The beam is extracted with a set of focusing grids and is then neutralized in a chamber pumped with Titanium gettering. The design, testing, and analyses of individual components are presented along with the most current full system results. The goal of this project is to advance in-house neutral beam expertise at Lockheed Martin to aid in operation, procurement, and development of neutral beam technology. © 2017 Lockheed Martin Corporation. All Rights Reserved.

BP11 100 Simulations in support of the T4B experiment ARTAN QERUSHI, PATRICK ROSS, CHRISS LOHFF, ANTHONY RAYMOND, NICCOLO MONTECALVO, Lockheed Martin - Palmdale Simulations in support of the T4B experiment are presented. These include a Grad-Shafranov equilibrium solver and equilibrium reconstruction from flux-loop measurements, collision radiative models for plasma spectroscopy (determination of electron density and temperature from line ratios) and fast ion test particle codes for neutral beam - plasma coupling. © 2017 Lockheed Martin Corporation. All Rights Reserved.

BP11 101 Magnetic Guarding: Experimental and Numerical Results JONATHON HEINRICH, GABRIEL FONT, MICHAEL GARRETT, Lockheed Martin Aeronautics D. ROSE, T. GENONI, D. WELCH, Lockheed Martin - Palmdale The magnetic field topology of Lockheed Martin’s Compact Fusion Reactor (CFR) concept requires internal magnetic field coils. Internal coils for similar devices have leveraged levitating coils or coils with magnetically guarded supports. Magnetic guarding of supports has been investigated for multipole devices (theoretically and experimentally) without conclusive results [1–4]. One outstanding question regarding magnetic guarding of supports is the magnitude and behavior of secondary plasma drifts resulting from magnetic guard fields (grad-B drifts, etc.). We present magnetic-implicit PIC modeling results and preliminary proof of concept experimental results on magnetic guarding of internal-supports and the subsequent reduction in total plasma losses. © 2017 Lockheed Martin Corporation. All Rights Reserved.


Simulation of High-Beta Plasma Confinement

GABRIEL FONT, Lockheed Martin DALE WELCH, ROBERT MITCHELL, Voss Scientific THOMAS MCGUIRE, Lockheed Martin

The Lockheed Martin Compact Fusion Reactor concept utilizes magnetic cusps to confine the plasma. In order to minimize losses through the axial and ring cusps, the plasma is pushed to a high-beta state. Simulations were made of the plasma and magnetic field system in an effort to quantify particle confinement times and plasma behavior characteristics. Computations are carried out with LSF using implicit PIC methods. Simulations of different sub-scale geometries at high-Beta fusion conditions are used to determine particle loss scaling with reactor size, plasma conditions, and gyro radii.

Advanced particle-in-cell simulation techniques for modeling the Lockheed Martin Compact Fusion Reactor

DALE WELCH, Voss Scientific GABRIEL FONT, Lockheed Martin ROBERT MITCHELL, DAVID ROSE, Voss Scientific

We report on particle-in-cell developments of the study of the Compact Fusion Reactor. Millisecond, two and three-dimensional simulations (cubic meter volume) of confinement and neutral beam heating of the magnetic confinement device requires accurate representation of the complex orbits, near perfect energy conservation, and significant computational power. In order to determine initial plasma fill and neutral beam heating, these simulations include ionization, elastic and charge exchange hydrogen reactions. To this end, we are pursuing fast electromagnetic kinetic modeling algorithms including a two implicit techniques and a hybrid quasi-neutral algorithm with kinetic ions. The kinetic modeling includes use of the Poisson-corrected direct implicit [1], magnetic implicit [2], as well as second-order cloud-in-cell techniques. The hybrid algorithm, ignoring electron inertial effects, is two orders of magnitude faster than kinetic but not as accurate with respect to confinement. The advantages and disadvantages of these techniques will be presented.

A design of the MHD stable axisymmetric mirror

ISAO KATANUMA, Univ of Tsukuba The PRC (Plasma Research Center GAMMA10) group is planning the construction of next linear device to perform the divertor experiment by using its endless flux since last year. One candidate device is considered to be a single axisymmetric mirror. The reasons are that the axisymmetric mirror has attractive features on a collaboration with the mirror community and a future mirror fusion device as well as the construction costs of pancake coils are lower than the base-ball coils. The axisymmetric mirror stabilizes the interchange modes with the help of large E x B azimuthal velocity shear flow surrounding the core plasma confining region. This flow shear is realized by making the radial electric field, which is similar to the vortex confinement of recent GDT [1]. Although this flow shear induces the Kelvin-Helmholtz instability, it is found to cause not so large radial transport when the magnitude of the flow shear is strong. The axisymmetric mirror also stabilizes the interchange modes with the help of large ion endless flux just like gas dynamic trap (GDT). Here the large endless flux is needed to perform the divertor experiment.

A high fusion power gain tandem mirror

T.K. FOWLER, University of California, Berkeley R.W. MOIR, Vallecitos Molten Salt Research T.C. SIMONEN, LLNL (retired) Utilizing advances in high field superconducting magnet technology and microwave gyrotrons we illustrate the possibility of a high power gain (Q = 10-20) tandem mirror fusion reactor [1]. Inspired by recent Gas Dynamic Trap (GDT) achievements [2] we employ a simple axisymmetric mirror magnet configuration. We consider both DT and cat. DD fuel options that utilize existing as well as future technology development. We identify subjects requiring further study such as hot electron physics, trapped particle modes and plasma startup.


A study of Tungsten effect on CFETR performance

SHENGYU SHI, University of Science and Tech of China XIANG GAO COLLABORATION, GUOQIANG LI COLLABORATION, NAN SHI COLLABORATION, VINCENT CHAN COLLABORATION, XIANG JIAN COLLABORATION An integrated modeling workflow using OMFIT/TGYRO is constructed to evaluate W impurity effects on China Fusion Engineering Test Reactor (CFETR) performance. Self-consistent modeling of tungsten(W) core density profile, accounting for turbulence and neoclassical transport, is performed based on the CFETR steady-state scenario developed by D.Zhao (ZhaoDeng, APS, 2016). It’s found that the fusion performance degraded in a limited level with increasing W concentration. The main challenge arises in sustainment of H-mode with significant W radiation. Assuming the power threshold of H-L back transition is approximately the same as that of L-H transition, using the scaling law of Takizuka (Takizuka et al., Plasma Phys. Control. Fusion, 2004), it is found that the fractional W concentration should not exceed 3e-5 to stay in H-mode for CFETR phase I. A future step is to connect this requirement to W wall erosion modeling.

*We are grateful to Dr. Emiliano Fable and Dr. Thomas Pütterich and Ms. Emily Belli for very helpful discussions and comments. We also would like to express our thanks to all the members of the CFETR Physics Group, and we appreciate the General Atomic Theory Group for permission to use the OMFIT framework and GAC code suite, and for their valuable technical support. Numerical computations were performed on the ShenMa High Performance Computing Cluster in the Institute of Plasma Physics, Chinese Academy of Sciences. This work was mainly supported by the National Mag-
BP11 108 A GDT-based fusion neutron source for academic and industrial applications∗ J. K. ANDERSON, C. B. FOREST, V. V. MIRNOV, E. E. PETERSON, R. WALEFFE, J. WALLACE, UW-Madison R. W. HARVEY, CompX The design of a fusion neutron source based on the gas dynamic trap (GDT) configuration is under way. The motivation is both the ends and the means. There are immediate applications for neutrons including medical isotope production and actinide burners. Taking the next step in the magnetic mirror path will leverage advances in high-temperature superconducting magnets and additive manufacturing in confining a fusion plasma, and both the technological and physics bases exist. Recent breakthrough results at the GDT facility in Russia demonstrate stable confinement of a beta ~60% mirror plasma at high Te (~1 keV). These scale readily to a fusion neutron source with an increase in magnetic field, mirror ratio, and ion energy. Studies of a next-step compact device focus on calculations of MHD equilibrium and stability, and Fokker-Planck modeling to optimize the heating scenario. The conceptualized device uses off-the-shelf MRI magnets for a 1 T central field, REBCO superconducting mirror coils (which can currently produce fields in excess of 30T), and existing 75 keV NBI and 140 GHz ECRH. High harmonic fast wave injection is damped on beam ions, dramatically increasing the fusion reactivity for an incremental bump in input power. MHD stability is achieved with the vortex confinement scheme, where a biasing profile imposes optimal ExB rotation of the plasma. Liquid metal divertors are being considered in the end cells.

∗Work supported by the Wisconsin Alumni Research Foundation.

BP11 109 How much does a tokamak reactor cost? J. FREIDBERG, MIT-PSFC A. CERFON, CIMS-NYU S. BALLINGER, J. BARBER, MIT-PSFC A. DOGRA, CIMS-NYU W. MCCARTHY, L. MILANESE, T. MOURATIDIS, MIT-PSFC W. REDMAN, CIMS-NYU A. SANDBERG, D. SEGAL, R. SIMPSON, C. SORENSEN, M. ZHOU, MIT-PSFC The cost of a fusion reactor is of critical importance to its ultimate acceptability as a commercial source of electricity. While there are general rules of thumb for scaling both overnight cost and levelized cost of electricity the corresponding relations are not very accurate or universally agreed upon. We have carried out a series of scaling studies of tokamak reactor costs based on reasonably sophisticated plasma and engineering models. The analysis is largely analytic, requiring only a simple numerical code, thus allowing a very large number of designs. Importantly, the studies are aimed at plasma physicists rather than fusion engineers. The goals are to assess the pros and cons of steady state burning plasma experiments and reactors. One specific set of results discusses the benefits of higher magnetic fields, now possible because of the recent development of high T rare earth superconductors (REBCO); with this goal in mind, we calculate quantitative expressions, including both scaling and multiplicative constants, for cost and major radius as a function of central magnetic field.

BP11 110 From Lawson to Burning Plasmas: a Multi-Fluid Approach∗ LUCA GUZZOTTO, Auburn University RICCARDO BETTI, University of Rochester The Lawson criterion [1], easily compared to experimental parameters, gives the value for the triple product of plasma density, temperature and energy confinement time needed for the plasma to ignite. Lawson’s inaccurate assumptions of 0D geometry and single-fluid plasma model were improved in recent work, where 1D geometry and multi-fluid (ions, electrons and alphas) physics were included in the model, accounting for physical equilibration times and different energy confinement times between species [2]. A much more meaningful analysis than Lawson’s for current and future experiment would be expressed in terms of burning plasma state (Q=5, where Q is the ratio between fusion power and heating power). Minimum parameters for reaching Q=5 are calculated based on experimental profiles for density and temperatures and can immediately be compared with experimental performance by defining a no-alpha pressure. This is done in terms of the pressure that the plasma needs to reach for breakeven once the alpha heating has been subtracted from the energy balance. These calculations can be applied to current experiments and future burning-plasma devices.

∗DE-FG02-93ER54215.


BP11 111 ICF MEASUREMENT AND DIAGNOSTIC TECHNIQUES

BP11 112 Feasibility of transition radiation diagnostic for hot electrons generated in indirect-drive experiment YAOYUAN LIU, JIAN ZHENG, GUANGYUE HU, University of Science and Tech of China DONG YANG, YONGGANLIU, SANWEILI, XIANHUAXIANG, ZHEBINGWANG, HUANZHANG, XIANSHI PENG, FENGWANG, SHAOJENJING, YONGKUN DING, Research Center of Laser Fusion, China Academy of Engineering Physics In the experiment of indirect-drive laser fusion, parameter instabilities like stimulated Raman scattering (SRS) can generate abundant hot electrons, which can preheat fuel and degrade target gain. Hot electrons are usually investigated through their bremsstrahlung measured with filter-fluoresce (FF) X-ray spectrometer. In this presentation, we propose the feasibility of studying hot electrons by detecting the transition radiation (TR) emitted when energetic electrons pass through the outer surface of a hohlraum. With aid of Monte Carlo simulations, we find that the intensity of optical TR is equivalent to that of 0.2 eV black-body radiation (BR) in the typical experiments of the SG-III prototype facility with the energy of ~10 kJ during 1 ns. Therefore, optical transition could be a candidate for the measurement of hot electrons without preheating. However, our simulations shows that the outer surface can be heated to 0.55 eV due to the hot electrons, leading to much brighter BR than the TR. In fact, our streaked optical pyrometer indicates that the preheating temperature reaches 0.7-1.0 eV. Hence it would be impossible to diagnose the hot electrons through optical TR. Our calculations show that it is plausibly feasible to detect the TR in the region of far infrared or THz.

BP11 113 First experiment on LMJ facility: pointing and synchronisation qualification OLIVIER HENRY, DIDIER RAFFESTIN, DOMINIQUE BRETHEAU, MICHEL LUTTMANN, HERVE GRAILLOT, MICHEL FERRI, FREDERIC SEGUINEAU, EMMANUEL BAR, LOIC PATIS...
SOU, PHILIPPE CANAL, FRANÇOISE SAUTAREL, YVES TRANQUILLE-MARQUES, CEA The LMJ (Laser mega Joule) facility at the CESTA site (Aquitaine, France) is a tool designed to deliver up to 1.2 MJ at 351 nm for plasma experiments. The experiment system will include 11 diagnostics: UV and X energy balances, imagers (Streak and stripe camera, CCD), spectrometers, and a Visar/pyrometer. The facility must be able to deliver, within the hour following the shot, all the results of the plasma diagnostics, alignment images and laser diagnostic measurements. These results have to be guaranteed in terms of conformity to the request and quality of measurement. The end of 2016 was devoted to the qualification of system pointing on target and synchronization within and between beams. The shots made with two chains (divided in 4 quads – 8 laser beams) have achieved 50 μm of misalignment accuracy (chain and quad channel) and a synchronization accuracy in the order of 50 ps. The performances achieved for plasma diagnostic (in the order of less 100 μm of alignment and timing accuracy less than 150 ps) comply with expectations. At the same time the first automatic sequences were tested. They allowed a shot on target every 6h:30 and in some case twice a day by reducing preparation actions, leading to a sequence of 4h:00.

BP11 114 Development of processing and analysis techniques for CR-39-based proton detectors for Inertial Confinement Fusion experiments at the NIF and OMEGA∗ M. MANZIN, B. LAHMANN, A. BIRKEL, E. DOEGL, R. FRANKEL, N. KABADI, C.E. PARKER, R.A. SIMPSON, H.W. SIO, G.D. SUTCLIFFE, J.A. FRENIE, M. GATU JOHNSON, C.K. LI, F.H. SEGUNI, R.D. PETRASSO, MIT CR-39 is a clear plastic polymer used for particle detection in several charged-particle spectrometers, including Step Range Filters (SRF) and the Magnetic Recoil Spectrometer (MRS), at the NIF and OMEGA Inertial Confinement Fusion (ICF) laser facilities. SRFs and MRSs have been recently used in basic science experiments on the ICF platform, for probing stellar-nucleosynthesis-relevant nuclear reactions and astrophysical phenomena such as collisionless shocks and turbulent dynamos. These new applications require extensions of established CR-39 analysis techniques. After exposure, the CR-39 is etched in sodium hydroxide to reveal tracks, and it is subsequently analyzed with a microscope. In this poster, two new developments in CR-39 analysis of proton tracks will be described: (1) the detailed mapping of track size and contrast versus proton energy and etch time for protons in the range 0.2–1 MeV, and (2) the extension of the coincidence counting technique for reduction of intrinsic background in CR-39 analysis to protons at energies >4 MeV. The results will be used to extend the range of information that can be obtained from CR-39 data from the NIF and OMEGA charged-particle spectrometers.

∗This work was supported in part by the U.S. DOE.

BP11 115 A Novel Peak Load Current Measurement for Magneto-Inertial-Fusion Targets∗ MARK HESS, KYLE PETERSON, DAVID AMPLEFORD, BRIAN HUTSEL, CHRISTOPHER JENNINGS, DANIEL DOLAN, WILLIAM STYGAR, MATTHEW GOMEZ, MATTHEW MARTIN, GRAFTON ROBERTSON, DANIEL SINARS, Sandia National Laboratories We have developed a novel method for measuring the peak load current (>15 MA) delivered to MagLIF targets on the Z pulsed power facility at Sandia National Laboratories using a Photonic Doppler Velocimetry (PDV) diagnostic in the final power feed section. Our diagnostic features a 600 micron thick aluminum PDV flyer, which is sufficiently thick to minimize the effects of magnetic diffusion in the flyer. In this regime, we can relate the peak velocity of the flyer to a peak magnetic pressure, and hence, peak load current, since the measured peak velocity is relatively insensitive to typical variability in MagLIF load current shapes. This allows for a quick analysis (<1 hour) in determining the peak MagLIF load current. We also demonstrate the agreement between measured peak load currents from this diagnostic and circuit models of Z machine, which have been developed at Sandia.

∗Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U. S. Department of Energy’s National Nuclear Security Administration under contract DE-NA0003525.

BP11 116 Utilization of Neutron Bang-time CVD diamond detectors at the Z Accelerator GORDON CHANDLER, KELLY HAHN, CARLOS RUIZ, BRENT JONES, PERRY ALBERTO, JOSE TORRES, MATTHEW GOMEZ, ERIC HARDING, ADAM HARVEY-THOMPSON, MARK HESS, PATRICK KNAPP, Sandia Natl Labs GARY COOPER, JEDEDIAH STYRON, University of New Mexico KEN MOY, IAN MCKENNA, Special Technologies Laboratory VLADIMIR GLEBOV, Laboratory for Laser Energetics DAVID FITTINGHOFF, MARK J. MAY, LUCAS SNYDER, Lawrence Livermore National Laboratories We are utilizing Chemical Vapor Deposited (CVD) Diamond detectors at ~2.3 meters on the Z accelerator to infer neutron bang-times from Magnetized Liner Inertial Fusion (MagLIF) sources yielding up to 3e12 DD neutrons and to bound the neutron time history of Deuterium Gas Pulf loads producing 5e13 DD neutrons. The current implementation of the diagnostic and initial results will be shown as well as our future plans for the diagnostic.

BP11 117 Obtaining the neutron time-of-flight instrument response function for a single D-T neutron utilizing n-alpha coincidence from the d(t, α)/n nuclear reaction∗ JEDEDIAH STYRON, Univ of New Mexico CARLOS RUIZ, KELLY HAHN, Sandia National Laboratories GARY COOPER, Univ of New Mexico GORDON CHANDLER, BRENT JONES, BRUCE MCFATTERS, JENNY SMITH, Sandia National Laboratories JEREMY VAUGHAN, Univ of New Mexico A measured neutron time-of-flight (nTOF) signal is a convolution of the neutron reaction history and the instrument response function (IRF). For this work, the IRF was obtained by measuring single, D-T neutron events by utilizing n-alpha coincidence. The d(t, α) in nuclear reaction was produced at Sandia National Laboratories’ Ion Beam Laboratory using a 300keV Cockcroft-Walton generator to accelerate a 2-μA beam, of 175keV D+ ions, into a stationary, 2.6-μm, ErT2 target. Comparison of these results to those obtained using cosmic-rays and photons will be discussed.

∗Sandia National Laboratories.

We are studying Magnetized Liner Inertial Fusion sources which utilize deuterium fuel and produce up to $4 \times 10^{12}$ primary DD and $5 \times 10^{10}$ secondary DT neutrons. For this concept, magnetizing the fuel can relax the stagnation pressures and densities required for ignition by insulating the hot fuel and confining the charged fusion products. The degree of magnetization of the fuel at stagnation is quantified using secondary DT neutron spectral measurements in the axial and radial directions and is also related to the ratio of the secondary DT yield to the primary DD yield. Measurements have confirmed that charged fusion products are strongly magnetized, as indicated by the product of the magnetic field and the fuel radius, to $\sim 0.4$ MG-cm. We present new results that compare the degree of fuel magnetization inferred from spectral and yield measurements.

BP11 119 The Magnetic Recoil Spectrometer for time-resolved neutron measurements (MRS) at the NIF* C.E. PARKER, J.A. FRENJE, C.W. WINK, M. GATU JOHNSON, B. LAHMANN, C.K. LI, F.H. SEGUIN, R.D. PETRASSO, MIT T.J. HILSABECK, J.D. KILKENNY, GA R. BIONTA, D.T. CASEY, H.Y. KHATER, LLNL C.J. FORREST, Y.YU. GLEBOV, C. SORCE, LLE J.D. HARES, Kentech Instruments O.H.W. SIEGMUND, Sensor Sciences. The next-generation Magnetic Recoil Spectrometer, called MRS, will provide time-resolved measurements of the DT-neutron spectrum. These measurements will provide critical information about the time evolution of the fuel assembly, hot-spot formation, and nuclear burn in Inertial Confinement Fusion (ICF) implosions at the National Ignition Facility (NIF). The neutron spectrum in the energy range 12-16 MeV will be measured with high accuracy ($\sim 5\%$), unprecedented energy resolution ($\sim 100$ keV) and, for the first time ever, time resolution ($\sim 20$ ps). An overview of the physics motivation, conceptual design for meeting these performance requirements, and the status of the offline tests for critical components will be presented.

BP11 120 Gamma-based Measurement of “Dark Mix” in ICF Capsules KEVIN MEANEY, H. HERRMANN, YH KIM, AB ZYLSTRA, H GEPPERT-KLEINRATH, NM HOFFMAN, AS YI, Los Alamos National Laboratory. Mix of capsule ablator into the fusion fuel is a source of yield degradation in inertial confinement fusion. Jetting or chunk mix, such as the elusive “meteors” that have been observed at NIF, can be difficult to diagnose because the chunks may not get hot enough to excite dopant x-rays, nor atomized enough for separated-reactants to fuse. Using the gamma reaction history (GRH-6m) diagnostic, (n,n’$\gamma$) gammas from strategically placed carbon layer within a beryllium capsule gives a measure of the time-resolved areal density of this carbon during the burn and hence an indication of the compression and spatial distribution of this layer. As the carbon moves further from the fuel, the areal density nominally decreases as $1/r^2$ for unablated material. However, mix of this carbon into the cold dense fuel layer or hot spot will have a significant effect on the carbon gamma signal. Different types of mix (e.g., jetting, Rayleigh-Taylor fingers, diffusive, . . . ) as well as features that can seed this mix (e.g., tents, fill, . . . ) will be discussed along with their expected effect on the carbon signal. The design for upcoming OMEGA shots, which will demonstrate this technique, and the potential for use on the NIF will be presented.

BP11 121 The Mini Orange Spectrometer (MOS) for Stellar and Big-Bang Nucleosynthesis studies at OMEGA and the National Ignition Facility* G.D. SUTCLIFFE, J.A. FRENJE, M. GATU JOHNSON, C.K. LI, C. PARKER, R. SIMPSON, H. SIO, F.H. SEGUIN, R.D. PETRASSO, MIT A. ZYLSTRA, LNL. A compact and highly efficient Mini Orange Spectrometer (MOS) is being designed for measurements of energy spectra of protons and alphas in the range of 1-12 MeV in experiments at the OMEGA laser facility and the National Ignition Facility (NIF). The MOS will extend charged-particle spectrometry at these laser facilities to lower energies ($<5$ MeV) and lower yields ($<5 \times 10^6$) than current instrumentation allows. This new spectrometer will enable studies of low-probability stellar nucleosynthesis reactions, including the $^3$He$^+\bar{\text{He}}$ reaction that is part of the solar proton-proton chain. Its unique capabilities will also be exploited in other basic science experiments, including studies of stopping power in ICF-relevant plasmas, astrophysical shocks and kinetic physics. The MOS design achieves high efficiency by maximizing the solid angle of particle acceptance. The optimization of the MOS design uses simulated magnetic fields and particle tracing. Performance requirements of the MOS system, including desired detection efficiencies and energy resolution, are discussed.

*This work was supported in part by the U.S. DoE, LLNL, and LLE.

BP11 122 High resolution spectrometer concepts for high temperature EXAFS measurements and 1D imaging of ignition capsules on NIF K. W. HILL, M. BITTER, L. GAO, B. KRAUS, P. C. EFTHIMION, Princeton Plasma Physics Lab M. B. SCHNEIDER, D. B. THORN, F. COPPI, Y. PING, K. L. KILLEBREW, A. G. MACPHEE, R. L. KAUFFMAN, P. BEIERSDORFER, Lawrence Livermore National Lab X-ray spectrometer concepts for two applications on NIF are being studied. An Extended X-ray Absorption Fine Structure (EXAFS) spectrometer will determine temperature at high pressure of dynamically compressed materials, by measuring K and L3 absorption edges at energies from 7112 to 18000 eV. A Johann geometry with spherically or toroidally bent crystals will avoid source-size broadening for spectral resolving power (E/ΔE) of $\sim 6000$. Energy-range selection is by crystal choice. The second is a 1D imaging spectrometer to measure the spatial distribution of plasma parameters to study stagnation of ignition capsules, based on either spherical or conical crystals with large spatial magnification. The desired spatial resolution is 5 μm. Predicted performance and prototype spectrometer measurements will be presented.

around $10^6$ s$^{-1}$ are routinely achieved. The DT and DD neutron sources generate up to $6 \times 10^6$ and $1 \times 10^7$ neutrons/s, respectively. One x-ray generator is a thick-target W source with a peak energy of 225 keV and a maximum dose rate of 12 Gy/min; the other uses Cu, Mo, or Ti elemental tubes to generate x-rays with a maximum energy of 40 keV. Diagnostics developed and calibrated at this facility include CR-39-based charged-particle spectrometers, neutron detectors, and the particle Time-Of-Flight (pTOF) and Magnetic PTOF CVD-diamond-based bang time detectors. The accelerator is also a valuable hands-on tool for graduate and undergraduate education at MIT.

*This work was supported in part by the U.S. DoE, SNL, LLE and LLNL.

BP11 124 Determining Light Decay Curves in a Plastic Scintillator using Cosmic Ray Muons* PRAVEEN WAKWELLA, SARAH MANDANAS, JOHN WILSON, HANNAH VISCA, STEPHEN PADALINO, SUNY Geneseo T. CRAIG SANGSTER, SEAN P. REGAN, Laboratory for Laser Energetics Plastic scintillators are used in ICF research to measure neutron energies via their time of flight (nToF). The energy resolution and sensitivity of an nToF system is directly correlated with the scintillation decay time of the plastic. To decrease the decay time, some scintillators are quenched with oxygen. Consequently, they become less efficient at producing light. As time passes, oxygen diffuses out of the scintillator this in turn increases light production and the decay time. Monoenergetic calibration neutrons produced at accelerator facilities can be used to monitor the decreased oxygen content, however this is a time consuming process and requires that the scintillators be removed from the ICF facilities on a regular basis. Here, a possible method for cross calibrating accelerator neutrons with cosmic ray muons is presented. This method characterizes the scintillator with accelerator-generated neutrons and then cross calibrates them with cosmic ray muons. Once the scintillators are redeployed at the ICF facility the oxygen level can be regularly monitored using muons in situ.

*Fundied in part by the United States Department of Energy through a Grant from the Laboratory for Laser Energetics.

BP11 125 Dual-Wavelength Interferometry and Light Emission Study for Experimental Support of Dual-Wire Ablation Experiments* ANDREW HAMILTON, JAMES CAPLINGER, VLADIMIR SOTNIKOV, Air Force Research Laboratory GENNADY SARKISOV, Raytheon JOHN LELAND, USRA In the Plasma Physics and Sensors Laboratory, located at Wright Patterson Air Force Base, we utilize a pulsed power source to create plasma through a wire ablation process of metallic wires. With a parallel arrangement of wires the azimuthal magnetic fields generated around each wire, along with the Ohmic current dissipation and heating occurring upon wire evaporation, launch strong radial outflows of magnetized plasmas towards the centralized stagnation region. It is in this region that we investigate two phases of the wire ablation process. Observations in the first phase are collisionless and mostly comprised of light ions ejected from the initial corona. The second phase is observed when the wire core is ablated and heavy ions dominate collisions in the stagnation region. In this presentation we will show how dual-wavelength interferometric techniques can provide information about electron and atomic densities from experiments. Additionally, we expect white-light emission to provide a qualitative confirmation of the instabilities observed from our experiments.

*This material is based upon work supported by the Air Force Office of Scientific Research under Award Number 16RYCOR289.

BP11 127 Magnetic field generation in finite beam plasma system ATUL KUMAR, CHANDRASEKHAR SHUKLA, BHAVESH PATEL, AMITA DAS, PREDHIMAN KAW,* Inst for Plasma Res The magnetic field generation is an important issue in a variety of contexts. In a beam plasma system, it is typically believed that the Weibel destabilization process causes the generation of magnetic fields at the electron skin depth scales. It has recently been shown, however, that a finite transverse size of the beam leads to the generation of the magnetic field at the long scale length of the beam (arXiv.org,1704.00970v1 [physics.plasm-ph], 2017). This has been attributed to a new instability associated with the Finite Boundary Size (FBS) operative in this context. In a realistic situation, the beam in addition to having a finite transverse extent would also have a finite temporal width. Keeping this in view in the present work a finite longitudinal extent of the beam has also been considered. Particle - In - Cell (PIC) simulations using OSIRIS were conducted which illustrates that in this case too the FBS instability is the first one to appear which is followed up by the KH at the edge and the Weibel in the bulk region. The magnetic field power spectrum has been observed to maximize at the longest scale of the beam size, as expected. In addition, we observe the relativistic shock formation, the beam focussing at the front and wake like structures in this case.

*This work is dedicated for Prof PK Kau who passed away on June 18, 2017.

BP11 128 A Concept for Measuring Electron Distribution Functions Using Collective Thomson Scattering* A.L. MILDER, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester A.B. Langdon [1] proposed that stable non-Maxwellian distribution functions are realized in coronal inertial confinement fusion plasmas via inverse bremsstrahlung heating. For $Z v_{th}^2 / v^2 > 1$, the inverse bremsstrahlung heating rate is sufficiently fast to compete with electron–electron collisions. This process preferentially heats the subthermal electrons leading to super-Gaussian distribution functions. A method to identify the super-Gaussian order of the distribution functions in these plasmas using collective Thomson scattering will be proposed. By measuring the collective Thomson spectra over a range of angles the density, temperature and super-Gaussian order can be determined. This is accomplished by fitting non-Maxwellian distribution data with a super-Gaussian model; in order to match the density and electron temperature to within 10%, the super-Gaussian order must be varied.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

BP11 129 Modelling of heat flux driven return current instability and ion acoustic turbulence WOJCEICH ROZMUS, Univ of Alberta M. SHERLOCK, Lawrence Livermore National Laboratory, Livermore, California 94551, USA A.V. BRANTOV, V. YU. BYCHENKO, P. N. Lebedev Physics Institute, RAS, Moscow

Hot plasmas with strong temperature gradients in inertial confinement fusion (ICF) experiments are examined for ion acoustic instabilities produced by electron heat flux. Return current instability (RCI) due to neutralizing current of cold electrons arising in response to large electron heat flux has been considered. First linear threshold and growth rates are derived in the nonlocal regime of the thermal transport. They are compared with results of Vlasov-Fokker-Planck (VFP) simulations in one spatial dimension. Very good agreement has been found between kinetic VFP simulations and linear theory of the RCI. Quasi stationary state of ion acoustic turbulence produced by the RCI is achieved in VFP simulations. A saturation of the RCI involves heating of ions in the tail of the ion distribution function, convection of the enhanced ion acoustic fluctuations from the unstable region of the plasma and anomalous electron resistivity. Further evolution of the ion acoustic turbulence and its effects on the absorption and transport are also discussed.

Detrimental Plasma Memory Effect Build Up Locally and Nonlinearly, as well as Globally and Fractally in RFP/SSD beams Subduced by Using STUD Pulses

The widely used laser-smoothing techniques introduce small-scale structures (speckles) with higher-than-average intensities. The stimulated Raman scattering (SRS) instability is more likely to grow in the intense speckles. On the other hand, if the temporal bandwidth of the laser is comparable to the growth rate of SRS, the SRS may be reduced. To study the interaction of SRS and time-varying laser speckles in kinetic regimes, a general laser antenna has been implemented in particle-in-cell (PIC) code OSIRIS. This antenna is capable of modeling smoothing by spectral dispersion (SSD), induced spatial incoherence (ISI), and spike train of uneven duration and delay (STUD) pulse. Preliminary results of SRS affected by different laser-smoothing techniques are discussed.

Particle-in-Cell Simulation of Laser Plasma Interactions in Multiple Speckles with Temporal Bandwidth

The widely used laser-smoothing techniques introduce small-scale structures (speckles) with higher-than-average intensities. The stimulated Raman scattering (SRS) instability is more likely to grow in the intense speckles. On the other hand, if the temporal bandwidth of the laser is comparable to the growth rate of SRS, the SRS may be reduced. To study the interaction of SRS and time-varying laser speckles in kinetic regimes, a general laser antenna has been implemented in particle-in-cell (PIC) code OSIRIS. This antenna is capable of modeling smoothing by spectral dispersion (SSD), induced spatial incoherence (ISI), and spike train of uneven duration and delay (STUD) pulse. Preliminary results of SRS affected by different laser-smoothing techniques are discussed.

This Work is supported by NSF and DOE.

Fluid modeling on three-dimensional two-plasmon decay instabilities and stimulated Raman scattering using FLAME-MD

We push our FLAME project forward with a newly developed code FLAME-MD (Multi-Dimensional) based on the fluid model presented in Ref. [1]. Simulations are performed to study two plasmon decay (TPD) instabilities and stimulated Raman scattering (SRS) in three dimensions (3D) with parameters relevant to ICF. 3D effects on the growth of TPD and SRS, including laser polarizations and multi beam configurations, are studied.

This material is based upon work supported by National Natural Science Foundation of China (NSFC) under Grant No. 11642020, 11621202; by Science Challenge Project (No. JCKY201612A505); and by DOE Office of Fusion Energy Sciences Grant DE-SC0014318.


Hot electron reduction in two-plasmon-decay by magnetic fields

We performed PIC simulations on two-plasmon-decay (TPD) and associated hot electron generation under perpendicular magnetic fields of 10 and 100 T. TPD linear growth and saturation levels are not significantly changed. Hot electron generation is significantly reduced when B=100 T but not when B=10 T. The reduction is due to disruption of the staged acceleration of hot electron through their gyro-motion. The reduction affects the low-energy hot electrons more than high-energy ones. Magnetic field generation mechanisms in target corona will also be discussed.

Work funded by DOE (DE-FC02-04ER54789, DE-SC0012316) and NSF (PHY-1314734).

The effect of magnetic fields on the kinetic evolution of nonlinear electron plasma waves and stimulated Raman scattering

Nonlinear wave-particle interactions can significantly affect the evolution of stimulated Raman scattering (SRS) for ICF-relevant parameters. An imposed magnetic field can alter the dynamics of these interactions and thereby the dynamics of SRS, altering the instability threshold and saturation. Particles resonant with an SRS-generated electron plasma wave can be rotated in velocity space, disrupting the nonlinear damping of electron plasma waves and changing the kinetically inflated SRS threshold. Resonant particles can also be rotated in physical space, changing the transverse kinetic dissipation of electron plasma waves and restricting trapped particle motion both within a single laser speckle as well as between neighboring laser speckles. We show PIC simulations of driven multi-dimensional electron plasma waves in the presence of an external field and illustrate how their nonlinear evolution is altered, particularly with regard to the dynamical behavior that can impact SRS.

Work was supported by the DOE under Grant Nos. DE-NA0001833 and DE-FC02-04ER54789.

Controlling Laser Plasma Instabilities Using Temporal Bandwidths Under Shock Ignition Relevant Conditions

We are performing particle-in-cell simulations using the code OSIRIS to study the effects of laser plasma interactions in the presence of temporal bandwidth under plasma conditions relevant to experiments on the Nike laser with induced spatial incoherence (ISI). With ISI, the instantaneous laser intensity can be 3-4 times larger than the average intensity, leading to the excitation of additional TPD modes and producing electrons with larger angular spread. In our simulations, we observe that although ISI can increase the interaction regions for short bursts of time, time-averaged (over many pico-seconds) laser plasma interactions can be reduced by a factor of 2 in systems with sufficiently...
large bandwidths (where the inverse bandwidth is comparable with the linear growth time). We will quantify these effects and investigate higher dimensional effects such as laser speckles and the effects of Coulomb collisions.

*Work supported by NRL, NNSA, and NSF.

BP11 136 PIC simulation and experiment comparison on hot electron generation and divergence* ELI BORWICK, SU-XING HU, CHUANG REN, University of Rochester JUN LI, UCSD We performed PIC simulations using laser and plasma conditions from hydro simulations of an OMEGA experiment [1] where hot electron divergence was measured. The simulations showed few hot electrons were generated under the given hydro conditions, which were just below the thresholds for SRS and TPD. Increasing the electron temperature by 20% increased hot electron generation but increasing the laser intensity did not. A newly developed diagnostic showed significant hot electron divergence when they were present, agreeing with the experiment. The results indicate that 1. the hydro conditions may be different in the experiment and the simulations and 2. hot electron generation may not scale with the TPD threshold parameter.

*Work funded by DOE (DE-FC02-04ER54789, DE-SC0012316, DE-NA0002730) and NSF (PHY-1314734).


BP11 137 Modeling Laser-Plasma Interactions in a Magnetized Plasma* EVA LOS, D. J. STROZZI, T CHAPMAN, W. A. FARMER, B. I. COHEN, LLNL We consider how laser-plasma interactions, namely stimulated Raman and Brillouin scattering, develop in the presence of a background magnetic field. Externally-launched waves in magnetized plasma have been studied in magnetic fusion devices for several decades, with relatively little work on their parametric decay. The topic has received scant attention in the laser-plasma and high-energy-density fields, but is becoming timely. The MagLIF pulsed-power scheme relies on an imposed axial field and laser-preheat [S. Slutz et al., Phys. Rev. Lett. 2012]. Imposing a field on a hohlraum to reduce hotspot losses has also been proposed [L. J. Perkins et al., Phys. Plasmas 2013]. We consider how the field affects the linear light waves in a plasma, e.g. by decoupling the left- and right- circular polarizations (Faraday rotation). Parametric instability growth rates are presented, as functions of plasma conditions, field strength, and geometry. The scattered-light spectrum, which is routinely measured, is also found.

*Work performed under auspices of US DoE by LLNL under Contract DE-AC52-07NA27344.

BP11 138 Characterization of long-scale-length plasmas produced from plastic foam targets for laser plasma instability (LPI) research* JAECHUL OH, J. L. WEAVER, V. SERLIN, S. P. OBENSCHAIN, Plasma Physics Division, Naval Research Laboratory, Washington, DC We report on an experimental effort to produce plasmas with long scale lengths for the study of parametric instabilities, such as two plasmon decay (TPD) and stimulated Raman scattering (SRS), under conditions relevant to fusion plasma. In the current experiment, plasmas are formed from low density (10-100 mg/cc) CH foam targets irradiated by Nike krypton fluoride laser pulses (λ = 248 nm, 1 nsec FWHM) with energies up to 1 kJ. This experiment is conducted with two primary diagnostics: the grid image refractometer (Nike-GIR) [1] to measure electron density and temperature profiles of the coronas, and time-resolved spectrometers with absolute intensity calibration to examine scattered light features of TPD or SRS. Nike-GIR was recently upgraded with a 5th harmonic probe laser (λ = 213 nm) to access plasma regions near quarter critical density of 248 nm light (4.5 x 10^13 cm^-3). The results will be discussed with data obtained from 120 μm scale-length [1] plasmas created on solid CH targets in previous LPI experiments at Nike.

*Work supported by DoE/NNSA.


BP11 139 Long Scalelength Plasmas for LPI Studies at the Nike Laser* J. L. WEAVER, J. OH, J. W. BATES, A. J. SCHMITT, D. M. KEHNE, M. F. WOLFORD, S. P. OBENSCHAIN, V. SERLIN, U. S. Naval Research Laboratory R. H. LEHMBERG, Research Support Instruments R. K. FOLLET, J. G. SHAW, J. F. MYATT, P. W. MCKENTY, LLE/Univ. of Rochester M. S. WEI, H. REYNOLDS, J. WILLIAMS, General Atomics F. TSUNG, UCLA Studies of laser plasma instabilities (LPI) at the Nike laser have mainly used short pulses, small focal spots, and solid plastic (CH) targets that have yielded maximum gradient scalelengths below 200 microns. The current experimental effort aims to produce larger volume plasmas with 5-10x reduction in the density and velocity gradients as a platform for SBS, SRS, and TPD studies. The next campaign will concentrate on the effects of wavelength shifting and bandwidth changes on CBET in low density (5-10 mg/cm^3) CH foam targets. This poster will discuss the development of this new LPI target platform based on modelling with the LPSE code developed at LLE. The presentation will also discuss alternative target schemes (e.g. exploding foils) and improvements to the LPI diagnostic suite and laser operations; for example, a new set of etalons will be available for the next campaign that should double the range of available wavelength shifting. Upgrades to the scattered light spectrometers in general use for LPI studies will also be presented.

*Work supported by DoE/NNSA.

Contributed Papers

12:45

BE1 1 Plasma Physics at the National Science Foundation VY-ACHESLAV LUKIN, National Science Foundation The Town Meeting on Plasma Physics at the National Science Foundation will provide an opportunity for Q&A about the variety of NSF programs and solicitations relevant to a broad cross-section of the academic plasma science community, from graduating college seniors to senior leaders in the field, and from plasma astrophysics to basic physics to plasma engineering communities. We will discuss recent NSF-hosted events, research awards, and multi-agency partnerships aimed at enabling the progress of science in plasma science and engineering. Future outlook for plasma physics and broader plasma science support at NSF, with an emphasis on how you can help NSF to help the community, will be speculated upon within the uncertainty of the federal budgeting process.
SESSION CT2: TUTORIAL: CLASSICAL AND QUANTUM APPROACHES TO EXTREME LASER-PLASMA PHYSICS
Monday Afternoon, 23 October 2017; Room: 102ABC at 14:00; Carl Schroeder, Lawrence Berkeley National Laboratory, presiding

Invited Papers

14:00

CT2 1 Classical and quantum approaches to extreme laser-plasma physics*
MATTIAS MARKLUND, Chalmers Univ of Tech

Current laser facilities explore a wide range of key parameters, such as intensity, energy, pulse length, and spectral and phase properties. The development of new laser systems will make it possible to further tailor such parameters. Surpassing the one petawatt level for laser systems takes us into a regime where previously suppressed processes become important, involving complex processes over a wide range of spatial and temporal scales. Microscopic and macroscopic processes, single-particle and collective effects, and classical and quantum physics come together in such scenarios, e.g., electron-positron pair creation. Our understanding of the interplay between optical fields, matter, and high-frequency radiation has largely depended on the use of classical methods. However, experimental and modeling activities for stepping outside the classical domain has increased tremendously over the last decade. We are now able to perform experiments on the quantum behavior of matter in strong lasers, and self-consistently model extreme plasmas, such as strong field pair plasmas or the plasma generation of multi-GeV photons. It is the aim of this talk to present where we are coming from, where we are at the moment, and what we can expect from future developments in this research field.

*This research is supported by the Swedish Research Council and the Knut & Alice Wallenberg Foundation.

SESSION CI3: HED
Monday Afternoon, 23 October 2017; Room: 103ABC at 14:00; Bhuvana Srinivasan, West Virginia University, presiding

Invited Papers

14:00

CI3 1 Late-time mixing and turbulent behavior in high-energy-density shear experiments at high Atwood numbers*
KIRK FLIPPO, Los Alamos National Laboratory

The LANL Shear experiments on the NIF are designed to study the Kelvin-Helmholtz instability (KHI), which is the predominate mechanism for generating vorticity, leading to turbulence and mixing at high Reynolds numbers. The KHI is pervasive, as velocity sheared and density-stratified flows abound, from accretion disks of a black holes to the fuel capsule in an ICF implosion. The NIF laser has opened up a new class of long-lived planar HED fluid instability experiments that can scale fluid experiments over impressive orders of magnitude in pressure (up to > Mbar), temperature (>10^5 K) and space (<10s of μm) and still recover classical fluid instability behavior, and elucidate mixing and plasma effects. The reproducibility allows for the unique capability in an HED experiment to directly measure values comparable to those in the mix model, the Besnard-Harlow-Rauenzahn (BHR[3]) model implemented in the LANL hydro-code RAGE, like the mixedness parameter, b, and the turbulent kinetic energy using the observed coherent features. We have acquired time histories of 4 tracer materials and 3 surface finishes spanning dynamic Atwood numbers from 0.63 to 0.88 and developed Reynolds numbers around 10^6. When the shocks cross, the layer is exposed to extreme shear forces and evolves into KHI rollers from an unseeded (but naturally broadband) surface. Two sets of data are acquired for each material type: an edge-view and a plan-view, through the plane of the material. The results hint at plasma physics effects in the layer. The edge-view is compared to BHR calculations, to understand mixing and layer growth. The BHR model matches the evolution and asymptotic behavior of the layer, and the initial scale-length used for the model correlates well to initial surface roughness, even when the surface is artificially roughened, forcing the layer’s evolution from coherent to disordered.

*This work performed under the auspices of the U.S. Department of Energy by LANL under contract DE-AC52-06NA25396.

14:30

CI3 2 Development of High Fluence, High Conversion Efficiency X-Ray Sources at the National Ignition Facility*
MARK MAY, Lawrence Livermore National Laboratory

Laser heated millimeter scale targets have provided recently some of the most powerful and energetic laboratory sources of x-ray photons (E = 6 - 24 keV) with high fluence and conversion efficiency (CE). These sources have included the K-shell of stainless steel (E = 5-9 keV) from cylindrical cavities having a CE of ~ 6.8% (Eout ~ 31 kJ), the K-shell of Kr (E = 8-20 keV) from gas pipes having a CE of ~ 1.6% (~ 20 kJ) and the L-shell of Ag (E = 3-5 keV) from novel nano-wire foam targets having a CE of ~ 16% (~ 81 kJ). The x-ray power and CE are dependent upon the peak electron
temperature in the radiating plasma created from these underdense \((n_e < 0.25 n_c)\) sources. The temperature can be limited by the available laser power and energy which can cause the fluence and the CE to be suboptimal especially for high Z K-shell sources. Cavity targets require several nanoseconds for the underdense plasma to fill the cavity but do have an increase in temperature and emission at late time from plasma stagnation on axis. In contrast the gas or foam targets heat volumetrically to an underdense source in less than a nanosecond which can be more efficient. Both the experimental and simulation details of these high fluence x-ray sources will be discussed.

This work was done under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

15:00

**CI3 3 Systematic measurements of opacity dependence on temperature, density, and atomic number at stellar interior conditions**

TAISUKE NAGAYAMA, Sandia National Laboratories

Model predictions for iron opacity are notably different from measurements performed at matter conditions similar to the boundary between the solar radiation and convection zones [1]. The calculated iron opacities have narrower spectral lines, weaker quasi-continuum at short wavelength, and deeper opacity windows than the measurements. If correct, these measurements help resolve a decade old problem in solar physics. A key question is therefore: What is responsible for the model-data discrepancy? The answer is complex because the experiments are challenging and opacity theories depend on multiple entangled physical processes such as the influence of completeness and accuracy of atomic states, line broadening, contributions from myriad transitions from excited states, and multi-photon absorption processes. To help determine the cause of this discrepancy, a systematic study of opacity variation with temperature, density, and atomic number is underway. Measurements of chromium, iron, and nickel opacities have been performed at two different temperatures and densities. The collection of measured opacities provides constraints on hypotheses to explain the discrepancy. We will discuss implications of measured opacities, experimental errors, and possible opacity model refinements.


15:30

**CI3 4 Laser-Plasma Interactions in Magnetized Environment**

YUAN SHI, Princeton Plasma Physics Laboratory

Propagation and scattering of lasers present new phenomena and applications when the plasma medium becomes magnetized. Starting from mega-Gauss magnetic fields, laser scattering becomes manifestly anisotropic [arXiv 1705.09758]. By arranging beams at special angles, one may be able to optimize laser-plasma coupling in magnetized environment. In stronger giga-Gauss magnetic field, laser propagation becomes modified by relativistic quantum effects [PRA 94.012124]. The modified wave dispersion relation enables correct interpretation of Faraday rotation measurements of strong magnetic fields, as well as correct extraction of plasma parameters from the X-ray spectra of pulsars. In addition, magnetized plasmas can be utilized to mediate laser pulse compression [PRE 95.023211]. Using magnetic resonances, it is not only possible to produce optic pulses of higher intensity, but also possible to amplify UV and soft X-ray pulses that cannot be compressed using existing technology.

This research is supported by NNSA Grant No. DE-NA0002948 and DOE Research Grant No. DEAC02- 09CH11466. 

1Department of Astrophysical Sciences, Princeton University. In collaboration with Qing Jia, Hong Qin, and Nathaniel J. Fisch.

16:00

**CI3 5 A Plasma Based Beam Combiner for Very High Fluence and Energy**

ROBERT KIRKWOOD, Lawrence Livermore National Laboratory

Recent work at NIF has demonstrated a plasma-based optic that combines the energy and fluence of many laser beams into a single bright beam, thus creating a new technique for designing future high energy density physics experiments. The technique uses the Cross Beam Energy Transfer (CBET) process [1] and shows for the first time that a plasma can combine beams to produce a single beam that emerges with energy and fluence beyond that of any of those input for delivery to a range of experimental targets. In an initial demonstration multiple beams of the National Ignition Facility (NIF) laser have been combined in a plasma to produce a directed pulse of light with \(4 + 1 \text{ kJ}\) of energy in its 1 ns duration which is 3.6 times the energy and 3.2 times the fluence of any of the incident beams during that period and is NIFs brightest 1ns duration beam of UV light [2]. These enhancements are due to the non-linear interaction of the beams with a self-generated plasma diffractive optic which is far more damage resistant than existing solid state optics, and is inherently capable of producing much higher single beam fluence and radiance than solid state refractive or reflective optics can. The initial results are
16:30

CI3 6 Laser-driven strong magnetostatic fields with applications to charged beam transport and magnetized high energy-density physics∗

JOAO SANTOS, CELIA - Universite de Bordeaux

Powerful laser-plasma processes are explored to generate discharge currents of a few 100 kA in coil targets, yielding magnetostatic fields (B-fields) in the ~kTesla range. The B-fields are measured by proton-deflectometry and high-frequency bandwidth B-dot probes [1]. According to our modeling [2], the quasi-static currents are provided from hot electron ejection from the laser-irradiated surface, accounting for the space charge neutralization and the plasma magnetization. The major control parameter is the laser irradiance $I_\lambda^2$. The B-fields ns-scale is long enough to magnetize secondary targets through resistive diffusion. We applied it in experiments of laser-generated relativistic electron transport into solid dielectric targets, yielding an unprecedented enhancement of a factor 5 on the energy-density flux at 60 μm depth, compared to unmagnetized transport conditions [3]. These studies pave the ground for magnetized high-energy density physics investigations, related to laser-generated secondary sources of radiation and/or high-energy particles and their transport, to high-gain fusion energy schemes and to laboratory astrophysics.

∗We acknowledge funding from French National Agency for Research (ANR), Grant TERRE ANR-2011-BS04-014, and from EUROfusion Consortium, European Union’s Horizon 2020 research and innovation programme, Grant 633053.

DAN BRUNNER, BRIAN LABOMBARD, ADAM KUANG, JIM TERRY, MIT PSFC ALCATOR C-MOD TEAM

The boundary heat flux width, along with the total power flowing into the boundary, sets the power exhaust challenge for tokamaks. A multi-machine boundary heat flux width database found that the heat flux width in H-modes scaled inversely with poloidal magnetic field ($B_p$) and was independent of machine size. The maximum $B_p$ in the database was ~0.8 T, whereas the ITER 15 MA, $Q_0=10$ scenario will be 1.2 T. New measurements of the boundary heat flux width in Alcator C-Mod extend the international database to plasmas with $B_p$ up to ~1.3 T. C-Mod was the only experiment able to operate at ITER-level $B_p$. These new measurements are from over 300 plasma shots in L-, I-, and EDA H-modes spanning essentially the whole operating space in C-Mod. We find that the inverse-$B_p$ dependence of the heat flux width in H-modes continues to ITER-level $B_p$, further reinforcing the empirical projection of ~500 μm heat flux width for ITER. We find ~50% scatter around the inverse-$B_p$ scaling and are searching for the ‘hidden variables’ causing this scatter.

∗Supported by USDoE award DE-FC02-99ER54512.

14:12

CO4 2 Boundary plasma heat flux width measurements for poloidal magnetic fields above 1 Tesla in the Alcator C-Mod tokamak∗ DAN BRUNNER, BRIAN LABOMBARD, ADAM KUANG, JIM TERRY, MIT PSFC ALCATOR C-MOD TEAM

14:24

CO4 3 The effect of feedback-controlled divertor nitrogen seeding on the boundary plasma and power exhaust channel width in Alcator C-Mod∗ B. LABOMBARD, D. BRUNNER, A.Q. KUANG, W. MCCARTHY, J.L. TERRY, MIT Plasma Science and Fusion Center

The scrape-off layer (SOL) power channel width, $\lambda_q$, is projected to be ~0.5 mm in power reactors, based on multi-machine measurements of divertor target heat fluxes in H-mode at low levels of divertor dissipation. An important question is: does presently being used to further validate models of CBET [3] which predict a larger number of non-resonant pump beams will scale up outputs still further.

∗This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.


λ_c change with the level of divertor dissipation? We report results in which feedback controlled nitrogen seeding in the divertor was used to systematically vary divertor dissipation in a series of otherwise identical L-mode plasmas at three plasma currents: 0.55, 0.8 and 1.1 MA. Outer midplane profiles were recorded with a scanning Mirror Langmuir Probe; divertor plasma conditions were monitored with ‘rail’ Langmuir probe and surface thermocouple arrays. Despite an order of magnitude reduction in divertor target heat fluxes (q'/~400 MW m\(^{-2}\) to ~40 MW m\(^{-2}\)) and corresponding change in divertor regime from sheath-limited through high-recycling to near-detached, the upstream electron temperature profile is found to remain unchanged or to become slightly steeper in the near SOL and to drop significantly in the far SOL. Thus heat in the SOL appears to take advantage of this impurity radiation ‘heat sink’ in the divertor by preferentially draining via the narrow (and perhaps an increasingly narrow) λ_c of the near SOL.

*Supported by USDoE award DE-FC02-99ER54512.

14:36
CO4 4 Measurements of Heat-flux Footprints at the Inner Divertor Target of Alcator C-Mod* J.L. TERRY, D. BRUNNER, B. LABOMBARD, MIT-PSFC IR thermography has been used to measure the footprints of heat-flux onto the inner high-field side divertor target in C-Mod in a variety of discharge conditions. These different magnetic-configurations (LSN, near-DN, and USN, with particular attention to near-DN configurations) and different confinement modes (I-mode, EDA H-mode, and ELM-free H-mode). Heat-fluxes and heat-flux widths during I-mode are especially of interest because of the enhanced power to the inner target that occurs in the “reversed” toroidal field condition that is favorable for I-mode. We find that under LSN conditions the footprints can be described by an “Eich-fit” function, with a characteristic length for heat-flux spreading into the SOL (λ_c) and a characteristic width for heat-flux spreading along the divertor leg. We find that the minimum values of λ_c in I-mode are consistent with the multi-machine observations that the H-mode λ_c on the outer target scales inversely with Bpol, with λ_c between 1 and 2 mm over the 0.6 < Bpol < 1.0T range. However, we also measure widths that are significantly larger, both within a single discharge and between discharges that are nominally similar. We will continue to search for “hidden” variables that might lead to the scatter of the widths above the observed minimum.

*Supported by USDoE award DE-FC02-99ER54512.

14:48
CO4 5 Investigation of parameter space for fully detached long-legged divertor operation* M. V. UMANSKY, LLNL B. LABOMBARD, MIT-PSFC M.E. RENSINK, T.D. ROGNLIEN, LLNL Recently it was found in numerical modeling that passively-stable fully detached divertor regimes exist in a broad range of input power from the core, for divertor configurations with radially or vertically extended, tightly baffled, outer divertor legs, with or without a secondary X-point in the leg volume [1]. This report presents a comparative computational study of detached divertor operation carried out for a variety of divertor configurations, expanding on the initial work reported in Ref. [1]. The parameters are based on those of the ADX tokamak design [2], and the simulations are carried out with the tokamak edge transport code UEDGE [3]. The simulations show that long-legged divertors have a large increase of the peak power handling capability, by up to an order of magnitude, compared to conventional divertors. For the detached divertor regime in these simulations, important physics combines interplay of strong convective plasma transport to the outer wall, confinement of neutral gas in the divertor volume, geometric effects including secondary X-point, and atomic radiation. As the power from the core is varied, the detachment front merely shifts up or down in the leg but remains stable. The present work addresses sensitivity of the detached divertor regime to various parameters used in the model, including the anomalous plasma transport, neutral transport, impurity radiation, and geometry of plasma-facing material surfaces.

*Supported by USDoE award DE-FC02-99ER54512.

15:00
CO4 6 Implementation of a long leg X-point target divertor in the ARC fusion pilot plant A.Q. KUANG, N.M. CAO, A.J. CREELY, C.A. DENNETT, J. HECLA, H. HOFFMAN, M. MAJOR, J. RUIZ RUIZ, R.A. TINGUELY, E.A. TOLMAN, D. BRUNNER, B. LABOMBARD, B.N. SORBOM, D.G. WHYTE, M. GROVER, C. LAUGHAM, MERL A long leg X-point target divertor geometry in a double null geometry has been implemented in the ARC pilot plant design [1], exploiting ARC’s demountable toroidal field (TF) coils and FLiBe immersion blanket, which allow superconducting poloidal field coils to be located inside the TF coils, adequately shielded from neutrons. This new design maintains the original TF coil size, core plasma shape, and attains a tritium breeding ratio ≈1.08. The long leg divertor geometry provides significant advantages. Neutron transport computations indicate a factor of 10 reduction in divertor material neutron damage rate compared to the first wall, easing requirements for high heat flux components. Simulations have shown that long legged divertors are able to maintain a passively stable detachment front that stays in the divertor leg over a wide power window [2], in principle, responding immediately to fast changes in power exhaust. The ARC design exploits this new paradigm for divertor heat flux control: fewer concerns about coping with fast transients and a focus on neutron-tolerant diagnostics to measure and adjust detachment front locations in the outer divertor legs over long timescales.

15:12
CO4 7 Studies of Lower Hybrid Range of Frequencies Actuators in the Arc Device* P. T. BONOLI, Y. LIN, S. SHIRAIWA, G. M. WALLACE, J. C. WRIGHT, S. J. WUKITCH, MIT - PSFC High field side (HFS) placement of lower hybrid range of frequencies (LHRF) actuators is attractive from both the standpoint of a more quiescent scrape off layer (SOL) and from the improved LH wave accessibility and penetration to higher electron temperature that results from the higher magnetic field on the HFS [1]. The resulting profiles of LH current drive (LHCD) are also more suitable for advanced tokamak (AT) operation where it is most desirable to provide a significant (~20-30%) contribution to the total current density with a broad profile extending from r/a ~0.5-0.85. Here we re-assess HFS LHCD in the ARC device [2] using a hierarchy of LHCD models that include a combined adjoint plus ray tracing calculation, a ray tracing plus 3D Fokker Planck calculation, and a full-wave plus Fokker Planck simulation.

*Supported by the U.S. DoE, Office of Science, Office of Fusion Energy Sciences, User Facility Alcator C-Mod under DE-FC02-99ER54512 and a PSFC Theory Grant under DE-FG02-91-ER54109.
15:24
CO48 Cross Machine Comparison of Turbulence and Transport Measurements on Alcator C-Mod and ASDEX Upgrade* A.J. Creely, MIT G.D. Conway, Simon Freethy, Tobias Gøler, Max Planck Institute for Plasma Physics N.T. Howard, A.E. White, MIT The ASDEX Upgrade Team Experimental turbulence and transport measurements aid in the effort to validate gyrokinetic codes such as GYRO and GENE. There seems to be some discrepancy between the ability of ion-scale simulations to match experimental heat fluxes on Alcator C-Mod [A.J. Creely, PoP 2017] and ASDEX Upgrade (AUG) [D. Told, PoP 2013], motivating additional experimental measurements, such as perturbative thermal diffusivity and electron temperature fluctuations. The perturbative thermal diffusivity is measured on both machines using partial sawtooth crashes [A.J. Creely, NF 2016] and cross machine parametric trends are investigated. Calculations based on partial sawtooth heat pulses are compared to modulated ECH heat pulses on AUG for the first time, and agree within uncertainty. Electron temperature fluctuations are measured with correlation ECE. Comparisons of total temperature fluctuation levels between gyrokinetic codes and experiment seem to show similar trends to electron heat flux, in that they are under-predicted on C-Mod, but matched or even over-predicted on AUG. This implies possible differences in the dominant plasma turbulence, but further study is needed.

*This work is also supported by the US DOE under Grants DE-SC0006419 and DE-FC02-99ER54512-CMOD, and by the US DoD and the Air Force Office of Scientific Research under the National Defense Science and Engineering Graduate (NDSEG) Fellowship, 32 CFR 168a.

15:36
CO4 9 On the ρs Scaling of Intrinsic Rotation in C-Mod Plasmas with Edge Transport Barriers* John Rice, Jerry Hughes, MIT PSFC Patrick Diamond, UCSD Norman CAO, Mark Chilenski, Amanda Hubbard, James Irby, MIT PSFC Yusuke Kosuga, Kyushu University Yujun Lin, Mit PSFC Matt Reinke, ORNL Elizabeth Tolman, Steve Wolfe, Steve Wukitch, Mit PSFC Changes in the core intrinsic toroidal rotation velocity following L- to H- and L- to I-mode transitions have been investigated in Alcator C-Mod tokamak plasmas. The magnitude of the co-current rotation increments is found to increase with the pedestal temperature gradient and ρs, and to decrease with toroidal magnetic field. These results are captured quantitatively by a model of fluctuation entropy balance which gives the Mach number M-co ∼ ρs/2 L/a-τ ∼ gradΤ ρs/Bτ in an ITG turbulence dominant regime. The agreement between experiment and theory gives confidence for extrapolation to future devices in similar operational regimes. Core thermal Mach numbers of ~0.07 and ~0.2 are expected for ITER and ARC, respectively.

*DoE Contract # DE-FC02-99ER54512.

15:48
CO4 10 Observations of Rotation Reversal and Fluctuation Hysteresis in Alcator C-Mod L-Mode Plasmas* N.M. CAO, J.E. RICE, A.E. WHITE, S.G. BAEK, A.J. CREELY, P.C. ENNEVER, A.E. HUBBARD, J.W. HUGHES, J. IRBY, P. RODRIGUEZ-FERNANDEZ, Massachusetts Institute of Technology M.A. CHILENSKI, Systems and Technology Research P.H. DI-AMOND, University of California, San Diego M.L. REINKE, Oak Ridge National Laboratory AND ALCATOR C-MOD TEAM, MIT Intrinsic core toroidal rotation in Alcator C-Mod L-mode plasmas has been observed to spontaneously reverse direction when the minimum value of the normalized collisionality ν∗, crosses around 0.4. In Ohmic plasmas, the rotation is co-current in the low density linear Ohmic confinement (LOC) regime and counter-current in the higher density saturated Ohmic confinement (SOC) regime. The reversal manifests a hysteresis loop in ν∗, where the critical collisionalities for the forward and reverse transitions differ by 10-15%. Temperature and density profiles of the two rotation states are observed to be indistinguishable within experimental error estimated with Gaussian process regression. However, qualitative differences between the two rotation states are observed in fluctuation spectra, including the broadening of reflectometry spectra and, under certain conditions, the appearance of high-k features in phase contrast imaging (PCI) spectra (kρs up to 1). These results suggest that the turbulent state can decouple from local profiles, and that turbulent self-regulation may play a role in the LOC/SOC transition.

*This work is supported by the US DOE under Grant DE-FC02-99ER54512 (C-Mod).

16:00
CO411 Investigating the Mode Structure of the Weakly Coherent Mode* T. GOLFINOPOULOS, B. LABOMBARD, A. HUBBARD, J.W. HUGHES, D. WHYTE, R. GRANETZ, E.M. DAVIS, E. EDLUrnd, P. ENNEVER, M. GREENWALD, E. MARMAR, M. PORKOLAB, S.M. WOLFE, S.J. WUKITCH, ALCATOR C-MOD TEAM, Massachusetts Institute of Technology The Weakly Coherent Mode (WCM), 200-500 kHz, kρs < 0.1 is an edge phenomenon associated with I-mode, a steady state, ELM-free confinement regime that has been observed on the Alcator C-Mod, ASDEX-Upgrade, and DIII-D tokamaks. I-mode is characterized by high particle flux, creating a separation of transport channels that leads to the development of a temperature pedestal, but not a density pedestal. The WCM is thought to contribute to this increased particle flux, though its precise role in regulating edge transport is not well-understood. Here, we investigate the structure of the WCM, particularly regarding poloidal asymmetry, using data from poloidally- and toroidally-arrayed Mirnov coils, as well as phase contrast imaging, with radial profiles of T, n, and Φ in the scrape-off layer provided by the Mirror Langmuir Probe. The WCM phenomenology is then compared to that of the Quasi-Coherent Mode, the edge fluctuation responsible for exhausting impurities in the Enhanced Dz H-mode.

*This work is supported by USDoE award DE-FC02-99ER54512.

16:12
CO4 12 Application of a deconvolution method for identifying burst amplitudes and arrival times in Alcator C-Mod far SOL plasma fluctuations Audun Theodorson, Odd Erik Garcia, Ralph Kube, UiT - The Arctic University of Norway Brian Labombard, Jim Terry, MIT Plasma Science and Fusion Center In the far scrape-off layer (SOL), radial motion of filamentary structures leads to excess transport of particles and heat. Amplitudes and arrival times of these filaments have previously been studied by conditional averaging in single-point measurements from Langmuir Probes and Gas Puff Imaging (GPI). Conditional averaging can be problematic: the cutoff for large amplitudes is mostly chosen by convention; the conditional windows used may influence the arrival time distribution; and the amplitudes cannot be separated from a background. Previous work has shown that SOL fluctuations are well described by a stochastic model consisting of a
super-position of pulses with fixed shape and randomly distributed amplitudes and arrival times. The model can be formulated as a pulse shape convolved with a train of delta pulses. By choosing a pulse shape consistent with the power spectrum of the fluctuation time series, Richardson-Lucy deconvolution can be used to recover the underlying amplitudes and arrival times of the delta pulses. We apply this technique to both L and H-mode GPI data from the Alcator C-Mod tokamak. The pulse arrival times are shown to be uncorrelated and uniformly distributed, consistent with a Poisson process, and the amplitude distribution has an exponential tail.

16:24

CO4 13 Comparison of measured and modeled gas-puff emissions on Alcator C-Mod*

SEUNG-GYOU BAEK, J. L. TERRY, MIT PSFC D. P. STOTLER, PPPL B. L. LABOMBARD, D. F. BRUNNER, MIT PSFC

Understanding neutral transport in tokamak boundary plasmas is important because of its possible effects on the pedestal and scrape-off layer (SOL). On Alcator C-Mod, measured neutral line emissions from externally-puffed deuterium and helium gases are compared with the synthetic results of a neutral transport code, DEGAS 2. The injected gas flow rate and the camera response are absolutely calibrated. Time-averaged SOL density and temperature profiles are input to a steady-state simulation. An updated helium atomic model is employed in DEGAS2. Good agreement is found for the Dø peak brightness and profile shape. However, the measured helium I line brightness is found to be lower than that in the simulation results by a roughly a factor of three over a wide range of density particularly in the far SOL region. Two possible causes for this discrepancy are reviewed. First, local cooling due to gas puff may suppress the line emission. Second, time-dependent turbulence effect may impact the helium neutral transport. Unlike deuterium atoms that gain energy from charge exchange and dissociation processes, helium neutrals remain cold and have a relatively short mean free path, known to make them prone to turbulence based on the Kubo number criterion.

*Supported by USDoE awards: DE-FC02-99ER54512, DE-SC0014251, and DE-AC02-09CH11466.

16:36

CO4 14 New investigation of reconnection time scale of the m/n=1/1 sawtooth instability in tokamak plasmas*

H. K. PARK, NFRI, UNIST Y. B. NAM, UNIST

The condition of magnetic shear and reconnection time scale of the m/n=1/1 flux rope (sawtooth instability) in the core of tokamak plasma have been disputed for more than four decades. Recent validation of the condition of the core magnetic shear (i.e., the core safety factor (q0)) is below ~ 1.0 before the crash and above ~ 1 after the crash) in KSTAR [1] encouraged to investigate the observed crash time scale which is known to be one or two order of magnitude faster than the critical reconnection time (τc ≡ √(τAτs)) proposed by the Kadomtsev model [2] where τA and τs are Alfvén and resistive time, respectively. It has been universal that the experimentally observed reconnection time scale is indeed faster than τc. It is rare but there are cases in which the reconnection time is comparable to τc. This paper investigates the role of the symmetry (poloidal and toroidal) of the 1/1 flux rope inside the q ~ 1 surface in determining the reconnection time.

*Supported by MSIP of Korea under NRF of Korea under Contract No. NRF-2014M1A7A1A03029865.


Contributed Papers

14:00

CO5 1 Collisionless magnetized shock formation and particle energization in scaled astrophysical conditions

EMMANUEL D‘HUMIERES, QUENTIN MORENO, XAVIER RIBEYRE, SOPHIE JÉQUIER, VLADIMIR TIKHONCHUK, Univ. Bordeaux, CNRS, CEA LAURENT GREMILLET, CEA, DAM, DIF MARK DIECKMANN, Linkoping Univ. PHILIPP KORNEEV, MPEI JULIEN FUCHS, LULI, Ecole Polytechnique

Collisionless shocks, which are held responsible for generating nonthermal particles and radiation in high-energy astrophysical objects, are widely believed to originate from micro-instabilities triggered in colliding flows. Recently, rapid theoretical developments have gone hand in hand with experimental efforts to generate collisionless shocks using powerful lasers. We have investigated both theoretically and numerically the possibility to use such lasers to study plasma collisions in strong large volume pulsed external magnetic fields. The presence of an external magnetic field can speed up the development of a collisionless shock that would otherwise be outside the reach of the largest laser systems available. The external magnetic field compression and the binary collisions between charged particles can also strongly affect the shock formation and the subsequent particle energization.

14:12

CO5 2 Experimental results of astrophysical collisionless shock experiments from NIF*


We discuss our laboratory experiments using the Omega and NIF lasers to investigate the dynamics of high Mach number collisionless shock formation in two interpenetrating plasma streams. It is believed that in astrophysical environments such shocks are the sites where seed magnetic fields are generated on a cosmologically fast timescale via the Weibel instability. Particle-in-cell (PIC) numerical simulations generate magnetic fields whose magnitude and scale are consistent with this concept. We will present recent experimental results [1,2] as well as simulations and theoretical interpretations of these observations. The NIF experiments were able to observe the counter-streaming flow interactions through the transition from collisional to collisionless regimes. The latest proton radiography results will be presented.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.


14:24

CO5 3 Opacity data for stellar models and its uncertainties*


This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
Radiative opacity of CH plasmas with doped Si and Ge at variable conditions are obtained. Calculations of a single configuration approximation are carried out. Radiative opacity of CH plasmas with doped Si and Ge is calculated in the framework of detailed-configuration accounting (DCA) model. A complete atomic database including energy level, oscillator strength and photoionization cross-section is established for H, C, Si and Ge. For ground and lowly excited states, large-scale multi-configuration Dirac Fock (MDCF) calculations are implemented with effects of configuration interaction included. For highly excited ones, calculations of a single configuration approximation are carried out. Radiative opacity of CH plasmas with doped Si and Ge at variable conditions are obtained and compared with the results of pure CH plasmas.

14:36

COS 4 Radiative opacity of CH plasmas with doped Si and Ge
JIAO LONG ZENG, CHENG GAO, JIAN MIN YUAN, National University of Defense Technology Radiative opacity of CH plasmas with doped Si and Ge is calculated in the framework of detailed-level-accounting (DLA) model. A complete atomic database including energy level, oscillator strength and photoionization cross-section is established for H, C, Si and Ge. For ground and slowly excited states, large-scale multi-configuration Dirac Fock (MDCF) calculations are implemented with effects of configuration interaction included. For highly excited ones, calculations of a single configuration approximation are carried out. Radiative opacity of CH plasmas with doped Si and Ge at variable conditions are obtained and compared with the results of pure CH plasmas.

14:48

COS 5 First Iron Opacity Experiments on the National Ignition Facility
THEODORE PERRY, EVAN DODD, TANA CARDENAS, BARBARA DEVOLDER, KIRK FLIPPO, HEATHER JOHNS, JOHN KLINE, MANOLO SHERRILL, TODD URBATSCHE, Los Alamos Natl Lab ROBERT HEETER, MARYUM AHMED, JAMES EMIG, CARLOS IGLESIAS, DUMA LIEDAHL, RICHARD LONDON, MADISON MARTIN, MARYLYN SCHNEIDER, NATHANIEL THOMPSON, BRIAN WILSON, Lawrence Livermore Natl Lab YE KATERINA OPACHIC, JAMES KING, ERIC HUFFMAN, RUSSEL KNIGHT, National Security Technologies JAMES BAILEY, GREGORY ROCHAU, Sandia Natl Lab Iron opacity experiments on the Sandia National Laboratories Z machine have shown up to factors of two discrepancies between theory and experiment. To help resolve these discrepancies an experimental platform for doing comparable opacity experiments is being developed on the National Ignition Facility (NIF). Initial iron data has been taken at a temperature of ~150 eV and an electron density of ~6x10^{21}/cm^3, but higher temperatures and densities will be required to address the discrepancies that have been observed in the Z experiments. The plans to go to higher temperatures and densities and how to deal with current issues with instrumental backgrounds will be discussed.

15:00

COS 6 Simulations of the National Ignition Facility Opacity Sample
M. E. MARTIN, R. A. LONDON, R. F. HEETER, Lawrence Livermore National Laboratory E. S. DODD, B. G. DEVOLDER, Los Alamos National Laboratory Y. P. OPACHICH, National Security Technologies D. A. LIEDAHL, Lawrence Livermore National Laboratory T. S. PERRY, Los Alamos National Laboratory A platform to study the opacity of high temperature materials at the National Ignition Facility has been developed [1]. Experiments to study the opacity of materials relevant to inertial confinement fusion and stellar astrophysics are being conducted. The initial NIF experiments are focused on reaching the same plasma conditions (T > 150 eV and Ne > 7 x 10^{23} cm^{-3}), for iron, as those achieved in previous experiments at Sandia National Laboratories’ (SNL) Z-facility which have shown discrepancies between opacity theory and experiment. We developed a methodology, using 1D HYDRA simulations, to study the effects of tamper thickness on the conditions of iron-magnesium samples. We heat the sample using an x-ray drive from 2D LASNEX hohlraum simulations. We also use this methodology to predict sample uniformity and expansion for comparison with experimental data.

15:12

COS 7 Initial experiments to understand the interaction of stellar radiation with molecular clouds
ROBERT VANDERVORT, JOSH DAVIS, MATT TRANTHAM, SALLEE KLEIN, University of Michigan DOV SHVARTS, University of Michigan, NRC/PAUL KEITER, PAUL DRAKE, University of Michigan Enhanced star formation triggered by local O and B type stars is an astrophysical problem of interest. O and B type stars are massive, hot stars that emit an enormous amount of radiation. This radiation acts to either compress or blow apart gas clumps in the interstellar media. For example, in the optically thick limit, when the radiation in the gas clump has a short mean free path, radiation is absorbed near the clump edge and compresses the clump. In the optically thin limit, when the mean free path is long, the radiation is absorbed throughout, acting to heat the clump. This heating explodes the gas clump. Careful selection of parameters, such as source density or source temperature, allow the experimental platform to access different hydrodynamic regimes. 2D CRASH simulations guide our parameter selection. A stellar radiation source is mimicked by a laser-irradiated, thin, gold foil, providing a source of thermal x-rays around 100 eV. The gas clump is mimicked by low-density CRF foam. We plan to show the preliminary experimental results of this platform in the optically thick limit, from experiments scheduled in August.

*This work was performed under the auspices of USDOE LANL Contract DE-AC52-07NA27344, Lawrence Livermore National Security, LLC.

**This work was performed under the auspices of USDOE LANL Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC.

*Performed under the auspices of USDOE LANL Contract DE-AC52-06NA25396.

This work is funded by the NNSA-DS and SC-OPES Joint Program in HEDP; Grant No. DE-NA0002956, and the NLUF Program, Grant No. DE-NA0002719, and through LLNL, University of Rochester by the NNSA/OICF under Cooperative Agreement No. DE-NA0001944. This work is funded by the Lawrence Livermore National Laboratory under subcontract B614207.
15:24 CO5 8 A Benchmark Experiment for Photoionized Plasma Emission from Accretion-Powered X-ray Sources* G. LOISEL, J. BAILEY, T. NAGAYAMA, S. HANSEN, G. ROCHAU, Sandia National Laboratories D. LIEDAHL, Lawrence Livermore National Laboratory C. FONTES, Los Alamos National Laboratory T. KALLMAN, Goddard Space Flight Center R. MANCINI, University of Nevada, Reno. Accretion-powered emission from X-ray binaries or black-hole accretion in Active Galactic Nuclei is a powerful diagnostic for their behavior and structure. Interpretation of x-ray emission from these objects requires a spectral synthesis model for photoionized plasma. Models must predict the photoionized charge state distribution, the emission photon processes, and the radiation transport influence on the observed emission. At the Z facility, we have measured simultaneously emission and absorption from a photoionized silicon plasma suitable to benchmark photoionization and spectrum formation models with ±5% reproducibility and E/dE > 2500 spectral resolution. Plasma density, temperature, and charge state distribution are determined with absorption spectroscopy. Self-emission measured at adjustable column densities tests radiation transport effects. Observation of 14 transitions in He-like silicon will help understand population mechanisms in a photoionized plasma. First observation of radiative recombination continuum in a photoionized plasma will be presented. *Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-NA-0003525.

15:36 CO5 9 Atomic kinetics of a neon photoionized plasma experiment at Z* D.C. MAYES, R.C. MANCINI, R.P. SCHOENFELD, University of Nevada, Reno J.E. BAILEY, G.P. LOISEL, G.A. ROCHAU, Sandia National Laboratories ZAPP COLLABORATION We discuss an experimental effort to study the atomic kinetics in neon photoionized plasmas via K-shell line absorption spectroscopy. The experiment employs the intense x-ray flux emitted at the collapse of a Z-pinch to heat and backlight a photoionized plasma contained within a cm-scale gas cell placed at various distances from the Z-pinch and filled with neon gas pressures in the range from 3.5 to 120 Torr. The experimental platform affords an order of magnitude range in the ionization parameter characterizing the photoionized plasma from about 5 to 80 erg*cm/s. Thus, the experiment allows for the study of trends in ionization distribution as a function of the ionization parameter. An x-ray crystal spectrometer capable of collecting both time-integrated and time-gated data is used to collect absorption spectra. The spectra show line absorption by several ionization stages of neon, including Be-, Li-, He-, and H-like ions. Analysis of these spectra yields ion areal-densities and charge state distributions, which can be compared with results from atomic kinetics codes. In addition, the electron temperature is extracted from level population ratios of nearby energy levels in Li- and Be-like ions, which can be used to test heating models of photoionized plasmas. *This work was performed by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy. DOE/NV/25946–2891.

15:48 CO5 10 X-ray heating of laboratory photoionized plasmas at Z* R MANCINI, T LOCKARD, D MAYES, University of Nevada, Reno G LOISEL, J BAILEY, G ROCHAU, Sandia National Lab-
CO5 13 Study of photoionization of supersonic gas jets at the pulsed power generator* KYLE SWANSON, VLADIMIR IVANOV, ROBERTO MANCINI, DANIEL MAYES, Physics Department, University of Nevada, Reno Supersonic, nitrogen, neon and argon, gas jets photoionized by a broadband x-ray flux were studied at the University of Nevada, Reno. The x-ray flux was produced by the collapse of a wire-array x-pinch implosion on the 1MA Zebra pulsed power accelerator, with photons mostly under 1keV and photon-energy integrated energy between 12kJ -16kJ. A Mach-Zehnder interferometer at 266 nm was set up to extract the atom number density profile of the jet before the Zebra shot. Air-wedge interferometers, at 266 and 532 nm, were used to determine the electron number density of the plasma during the Zebra shot. The ratio of electron to atom number densities provides the average ionization state of the plasma. A program has been developed to automate the extraction of phase shift maps from both types of interferometers. Preliminary results from the experiment are promising and show that a photoionized plasma has been created in the gas jet, thus demonstrating a new experimental platform to study photoionized plasmas in the laboratory.

*This work was sponsored by DOE Office of Science Grant DE-SC0014451.

CO5 14 Simulation and Modeling of Magnetized Jet Creation using a Hollow Ring of Laser Beams* YINGCHAO LU, EDISON LIANG, Department of Physics and Astronomy, Rice University LAN GAO, Princeton Plasma Physics Laboratory PETROS TZEFERACOS, University of Chicago ANDREW BIRKEL, Plasma Science and Fusion Center, Massachusetts Institute of Technology RUSS FOLLETT, DUSTIN FROULA, Laboratory for Laser Energetics, University of Rochester WEN FU, LILY HAN, Department of Physics and Astronomy, Rice University HANTAO JI, Princeton Plasma Physics Laboratory DON LAMB, Department of Astronomy and Astrophysics, University of Chicago CHI KANG LI, HONG SIO, RICHARD PETRASSO, Plasma Science and Fusion Center, Massachusetts Institute of Technology MINGSHENG WEI, General Atomics Using 20 OMEGA beams to form a ring pattern to irradiate a flat plastic target, we have created strongly magnetized, highly collimated jets. The density, temperature, flow velocity and magnetic field of the supersonic outflows were diagnosed using Thomson scattering, proton radiography, and x-ray imaging. We present 3D FLASH full-physics magnetohydrodynamics simulations of the experiments, which are in good agreement with the experimental data. These results demonstrate that our experimental configuration of a hollow ring of laser beams can become a versatile new platform to study magnetized jets in the context of laboratory astrophysics.

*DOE NNSA NLUF.

CO6 14 Magnetic Reconnection in MHD and Kinetic Turbulence* NUNO LOUREIRO, Massachusetts Inst of Tech-MIT STANISLAV BOLDYREV, University of Wisconsin-Madison Recent works have revisited the current understanding of Alfvénic turbulence to account for the role of magnetic reconnection [1, 2, 3]. Theoretical arguments suggest that reconnection inevitably becomes important in the inertial range, at the scale where it becomes faster than the eddy turnover time. This leads to a transition to a new sub-inertial interval, suggesting a route to energy dissipation that is fundamentally different from that envisioned in the usual Kolmogorov-like phenomenology. These concepts can be extended to collisionless plasmas, where reconnection is enabled by electron inertia rather than resistivity [4]. Although several different cases must then be considered, a common result is that the energy spectrum exhibits a scaling with the perpendicular wave number that scales between $k_{\perp}^{-8/3}$ and $k_{\perp}^{-3}$, in favourable agreement with many numerical results and observations.

*Work supported by NSF-DOE Partnership in Basic Plasma Science and Engineering, Award No. DE-SC0016215, and by NSF CAREER Award No. 1654168 (NFL); and by NSF Grant AGS-1261659 and by the Vilas Associates Award of UWM (SB).


14:12 CO6 2 Nature of Kinetic Scale Turbulence in the Earth’s Magnetosheath CHRISTOPHER CHEN, Queen Mary University of London STANISLAV BOLDYREV, University of Wisconsin-Madison We present measurements from the Magnetospheric Multi-Scale (MMS) mission, together with corresponding theoretical results, to investigate turbulence at kinetic scales in the Earth’s magnetosheath, the region downstream of the bow shock. In some respects, this turbulence is similar to that in the upstream solar wind, but one key aspect is the low-$\beta_{\perp}$ regime. The system consisted of a slow, low-density plasma flow impinging on the azimuthal magnetic field produced by a current-carrying wire. Data collected at multiple times captured dynamical features of shock formation for two levels of the current in the wire. The proton images show regions of magnetic compression, and sharp increases in density and temperature are observed by the Thomson scattering diagnostic, all evidence of shock formation. Combining measurements from both diagnostics, some shock characteristics can be determined.
difference is that whereas in the solar wind the ion and electron temperatures are typically comparable, \( T_i \sim T_e \), in the magnetosheath, the ions are typically much hotter \( T_i \gg T_e \) as a result of processing by the bow shock. Together with \( \beta_i \sim 1 \), this leads to a new type of turbulence close to electron scales. This turbulence is characterized by an increased magnetic compressibility, following a mode in which the inertial kinetic Alfvén wave, and a steeper spectrum of magnetic fluctuations, consistent with the scaling \( k_{\perp}^{-5/3} \) that we obtain from a set of nonlinear equations. This new regime of plasma turbulence may also be relevant for other astrophysical environments with \( T_i \gg T_e \), such as the solar corona, hot accretion flows, and regions downstream of collisionless shocks.

### 14:24 CO6 3 Reassessing Solar Wind Stability using Nyquist’s Method

**Kristopher Klein, Justin Kasper, Benjamin Alterman, Univ of Michigan - Ann Arbor Michael Stevens, Kelly Korreck, Smithsonian Astrophysical Observatory**

In nearly-collisionless plasmas, such as the solar wind, non-local thermodynamic equilibrium structures, including temperature anisotropies, beam populations with relative drifts, and anisotropic features, are frequently observed to persist. These features can act as sources of free energy which may drive instabilities that move the plasma closer to LTE. Analysis techniques applied to solar wind observations for the presence of such instabilities typically consider only a single source of free energy, such as the temperature anisotropy of the proton population. We have developed an efficient algorithm for general determination of linear stability considering all sources of free energy using Nyquist’s Method. By applying this method to the dispersion relation associated with a particular solar wind observation, we rapidly determine if the plasma is linearly unstable, and if so, how many normal modes are driven. Our technique is verified against well-characterized theoretical and observational cases from the literature, and applied to in situ observations from the Wind spacecraft to determine how additional sources of free energy affect the plasma’s stability and may govern the solar wind’s evolution.

### 14:36 CO6 4 Three-Dimensional Hybrid-Kinetic Simulations of Alfvénic Turbulence in the Solar Wind

**Lev Arzamasskiy, Princeton University Benjamin Chandran, University of New Hampshire Eliot Quataert, University of California, Berkeley**

The interplanetary medium hosts a solar wind, which contains a broadband turbulent spectrum of large-amplitude Alfvén waves. In this talk, we present results from hybrid-kinetic simulations of this turbulent and essentially collisionless system. We confirm power-law indices obtained in previous analytical and numerical (e.g., gyrokinetic) studies, and carefully explore the location of the spectral break and physics occurring at the ion-Larmor scale. In the low-beta regime, we find evidence of perpendicular ion heating, which we interpret as stochastic heating arising from interactions between ions and strong fluctuations at wavelengths comparable to the ion-Larmor scale. We explore the dependence of ion heating on plasma beta. Finally, we discuss the interpretation of spacecraft measurements of this turbulence by testing the Taylor hypothesis with synthetic spacecraft measurements of our simulation data.

*This work was supported by NASA Grant NNX16AK09G.

### 14:48 CO6 5 Relativistic MHD Turbulence with Synchrotron and Inverse-Compton Radiation Cooling

**Dmitri Uzdensky, University of Colorado Boulder and IAS**

This work investigates the energetic aspects and observational appearance of driven relativistic MHD turbulence in an optically thin, relativistically hot plasma subject to strong synchrotron and synchrotron-self-Compton (SSC) radiative cooling. Steady-state balance between turbulent heating and radiative cooling is shown to lead, essentially independent of turbulent driving’s strength, to a characteristic electron temperature of \( T_e/m_e c^2 \sim \tau_{e}^{-1/2} \), where \( \tau_{e} \ll 1 \) is the system’s Thomson optical depth. Furthermore, the SSC cooling power becomes automatically comparable to the synchrotron power. Under certain conditions, a few higher-order inverse-Compton components also become comparable to the synchrotron and SSC losses, and so the broad-band radiation spectrum of the system consists of several distinct peaks with gradually decreasing luminosity, separated by a factor of \( \tau_{e}^{-1} \gg 1 \) from each other. The number of these spectral components is governed by synchrotron self-absorption and Klein-Nishina effects. These findings have important implications for several classes of high-energy astrophysical systems including pulsar wind nebulae and black-hole-driven accretion flows, jets, and radio-lobes.

*Work supported by NSF, DOE, NASA, IAS, and the Ambrose Monell Foundation.

### 15:00 CO6 6 Kinetic simulations of turbulence in relativistic plasmas

**Vladimir Zhdankin, JILA Dmitri Uzdensky, Gregory Werner, University of Colorado at Boulder Mitchell Begelman, JILA, University of Colorado at Boulder**

We investigate driven turbulence in collisionless, magnetized, relativistic pair plasma by applying particle-in-cell simulations with up to 1024\(^3\) cells and 200 billion particles. The results agree with predictions from magnetohydrodynamic turbulence phenomenology at inertial-range scales, including a power-law magnetic energy spectrum with index near \(-5/3\), scale-dependent anisotropy of fluctuations described by critical balance, log-normal distributions for particle density and internal energy (related by a \(4/3\) adiabatic index), and the presence of intermittency. We also show that the magnetic energy spectrum steepens (to index near \(-4\)) at sub-Larmor scales, possibly indicating a kinetic cascade. We demonstrate efficient nonthermal particle acceleration that leads to a power-law particle energy distribution, which hardens with increasing magnetization (becoming shallower than \(-2\) for sufficiently high magnetization) and softens with increasing system size. We discuss the mechanisms of particle acceleration and propose an empirical formula for the distribution index. Our results imply that turbulence can be a viable source of energetic particles in high-energy astrophysical systems, such as pulsar wind nebulae, if scalings asymptotically become insensitive to the system size.

*This work was supported by NSF Grant AST-1411879.

### 15:12 CO6 7 Onset of magnetic turbulence in non-relativistic collisionless shocks

**Fredderico Fiuza, Charles Ruyer, Samuel Totorica, SLAC National Accelerator Laboratory**

Collisionless shocks are ubiquitous in astrophysical environments. In relativistic weakly magnetized environments, the Weibel or current filamentation instability is believed to be the dominant mechanism for magnetic field amplification and shock formation. Using 3D particle-in-cell simulations and analytic theory, we show that in the non-relativistic regime, the shock formation process is more complex. It first involves the B-field amplification by the Weibel instability (linear regime) and later the competition between filament merging and kink-like deformation of current filaments (longitudinal instability). The kink-instability dominates the slow down of the flows, shock
formation, and onset of magnetic turbulence. We will discuss the implication of these results for particle acceleration and the ability of laser-driven counter-streaming plasma experiments to probe this microphysics.

*This work is supported by DOE FES under FWP 100237 and FWP 100182.

15:24

CO6 8 Numerical design of a magnetized turbulence experiment at the National Ignition Facility* SCOTT FEISTER, Univ. of Chicago (UC) PETROS TZEFERACOS, UC JENA MEINECKE, Univ. of Oxford (O XF) ARCHIE BOTT, OXF DAMIANO CAPRILI, JT LAUNE, UCT TONY BELL, OXF ALEXIS CASNER, CEA France MICHEL KOENIG, Laboratoire d’Utilisation des Lasers Intenses (LULI) CHIKANG LI, Massachusetts Institute of Technology (MIT) FRANCESCO MINIATI, ETH Zurich RICHARD PETRASSO, MIT BRUCE REMINGTON, Lawrence Livermore National Laboratory (LLNL) BRIAN REVILLE, Queen’s University Belfast J. STEVEN ROSS, LLNL DONGSU RYU, Ulsan National Institute of Science Technology DMITRI RYUTOY, LLNL HONG SIO, MIT DAVID TURNBULL, LLNL ALEX ZYLSTRA, Los Alamos National Laboratory ALEXANDER SCHEKOCIHIN, OXF DUSTIN FROLKA, Laboratory for Laser Energetics HYE-SOOK PARK, LLNL DON LAMB, UC GIANLUCA GREGORI, OXF The origin and amplification of magnetic fields remains an active astrophysical research topic. We discuss design (using three-dimensional FLASH simulations) of a magnetized turbulence experiment at the National Ignition Facility (NIF). NIF lasers drive together two counter-propagating plasma flows to form a hot, turbulent plasma at the center. In the simulations, plasma temperatures are high enough to reach super-critical values of magnetic Reynolds number ($R_M$). Biermann battery seed magnetic fields (generated during laser-target interaction) are advected into the turbulent region and amplified by fluctuation dynamo in the above-unity Prandtl number regime. Plasma diagnostics are modeled with FLASH for planning and direct comparison with NIF experimental data.

*This work was supported in part at the University of Chicago by the DOE NNSA, the DOE Office of Science, and the NSF. The numerical simulations were conducted at ALCF’s Mira under the auspices of the DOE Office of Science ALCC program.

15:36

CO6 9 On the cascade reversal at the electron skin depth* GEORGE MILOSHEVICH, University of Texas at Austin MAN- ASVI LINGAM, Harvard University PHILIP MORRISON, The University of Texas at Austin There exist a wide class of systems that exhibit non-ideal effects such as Hall drift and electron inertia. The latter plays role on characteristic length scales smaller than the electron skin depth. To gain relevant understanding it is necessary to work with models such as extended MHD (XMHD) that capture these microscopic effects. XMHD is endowed with topological invariants –two helicities emerging from the Hamiltonian structure and useful for the Hamiltonian Energy-Casimir method [1]. In MHD turbulence the inverse cascade of magnetic helicity is often invoked to explain dynamo action. However, we predict [2] analytically that the phenomenon is suppressed at the electron skin depth, i.e. it appears that the cascade reverses direction. The ongoing investigations focus on a simplified 2D case, which is more amenable to numerical analysis. The analytical queries reveal similar behavior to 3D cascade reversal so we are confident that our 2D case study should be representative.

*DOE Grant No. DE-FG05-80ET-53088, NSF Grant No. AGS-1338944), DOE (Grant No. DE-AC02-09CH-11466).


15:48

CO6 10 Heat Transport in Interacting Magnetized Electron Temperature Filaments* RICHARD SYDORA, SCOTT KAR-BASHEWSKI, University of Alberta, Canada BART VAN COM- PERNOLLE, MATT POULOS, GEORGE MORALES, University of California, Los Angeles, USA Results are presented from basic heat transport experiments and numerical simulations of multiple magnetized electron temperature filaments in close proximity. This arrangement samples cross-field transport from nonlinear drift-Alfvén waves and large scale convective cells. Experiments are performed in the Large Plasma Device (LAPD) at UCLA. The setup consists of three biased Ce$^+$ crystal cathodes that inject low energy electrons (below ionization energy) along a strong magnetic field into a pre-existing large and cold plasma forming 3 electron temperature filaments embedded in a colder plasma, and far from the machine walls. A triangular spatial pattern is chosen for the thermal sources and multiple axial and transverse probe measurements allow for determination of the cross-field mode patterns and filament length. We have characterized the spontaneous thermal waves and drift-Alfvén waves that develop on an individual filament when a single source is activated. When the 3 sources are activated, and in close proximity, a complex wave pattern emerges due to interference of the various wave modes leading to enhanced cross-field transport and chaotic mixing. Steep thermal gradients develop in a periphery region of the filaments where higher azimuthal wavenumber drift-Alfvén modes are excited. Detailed spectral analysis and comparison with nonlinear fluid and gyrokinetic simulations will be reported.

*Work Supported by NSERC, Canada and NSF-DOE, USA.

16:00

CO6 11 On the universality of power laws for tokamak plasma predictions JERONIMO GARCIA, DAVID CAMBON, CEA Significant deviations from well-established power laws for the thermal energy confinement time, obtained from extensive databases analysis, have been recently reported in dedicated power scans. The validity and universality of power laws as tools for predicting plasma performance is analyzed in the framework of a simplified modeling for the heat transport which is however able to account for the interplay between turbulence and collinear effects with the input power which are known to reduce turbulence, such as fast ion pressure gradients or electromagnetic effects. Whereas at low power usual scaling laws are recovered with little influence of other plasma parameters, at high power it is shown how the exponents obtained are extremely sensitive to the heating deposition, the q profile or even the number and sampling of the points considered. In particular circumstances, even a minimum of the thermal energy confinement time with the input power can be obtained, which means that the approach of the energy confinement time as a power law is intrinsically invalid. Therefore, predictions of future plasma performance using such approach, mainly at high β, can lead to significant deviations from reality and provide misleading results.

16:12

CO6 12 Validation of Energetic Particle Transport in DIII-D Tokamak WENLUI ZHANG, WEI HU, HONGYING FENG, Institute of Physics, Chinese Academy of Science ZHIHONG LIN, University of California at Irvine DING LI, JINTAO CAO, CHAO DONG, Institute of Physics, Chinese Academy of Science First-
principle global Gyrokinetic Toroidal Code (GTC) is employed to simulate the turbulent transport in fusion plasmas with realistic equilibrium and profiles of DIII-D discharges. In the linear simulations, ion temperature gradient (ITG) mode and trapped electron mode (TEM) are found dominant exactly as experimentally observed in two shots with low plasma temperature and high temperature, respectively. In the nonlinear simulations, electrostatic fluctuation intensity, energetic particle (EP) diffusivity and the perturbations in its density and temperature are analyzed in detail for both the low-temperature ITG and high-temperature TEM cases. For these two cases, energetic particle’s diffusivity and density perturbation are almost on the same level in radial direction. This is in reasonable agreement with experimental results that no measured change of energetic particle transport is observed when dominant instability changes from low-temperature ITG to high-temperature TEM. The underlying mechanism responsible for these EP transport by background microturbulence is that the electrostatic fluctuation intensity spectrum in terms of perpendicular wavenumber are similar in nonlinearly steady stage for both low-temperature ITG and high-temperature TEM cases.

16:24
CO6 13 Role of poloidal flows on the particle confinement time in a simple toroidal device: an experimental study UMEESH KUMAR, R GANESH, Y. C. SAXENA, Inst for Plasma Res SHEKAR G. THATIPAMULA, Pohang University of science and Technology K. SATHYANARAYANA, DANIEL RAJU, Inst for Plasma Res In magnetized toroidal devices without rotational transform also known as Simple Magnetized Torus (SMT). The device BETA at the IPR is one such SMT with a major radius of 45 cm, minor radius of 15 cm and a maximum toroidal field of 0.1 Tesla. Understanding confinement in such helical configurations is an important problem both for fundamental plasma physics and for Tokamak edge physics. In a recent series of experiments it was demonstrated experimentally that the mean plasma profiles, fluctuation, flow and turbulence depend crucially on the parallel connection length, which was controlled by external vertical field. In the present work, we report our experimental findings, wherein we measure the particle confinement time for hot cathode discharge and ECRH discharge, with variation in parallel connection length. As ECRH plasma don’t have mean electric field and hence the poloidal rotation of plasma is absent. However, in hot cathode discharge, there exist strong poloidal flows due to mean electric field. An experimental comparison of these along with theoretical model with variation in connection length will be presented. We also present experimental measurements of variation of plasma confinement time with mass as well as the ratio of vertical field to toroidal magnetic field.

14:12
CO7 2 Measurements and modeling of Raman side-scatter in ICF experiments* PIERRE MICHEL, Lawrence Livermore National Laboratory M. J. ROSENBERG, Laboratory for Laser Energetics, University of Rochester T. CHAPMAN, Lawrence Livermore National Laboratory R. W. SHORT, W. SEKA, A. SOLODOV, Laboratory for Laser Energetics, University of Rochester C. GOYON, M. HOHENBERGER, J. D. MOODY, Lawrence Livermore National Laboratory S. P. REGAN, J. F. MYATT, Laboratory for Laser Energetics, University of Rochester Raman side-scatter, whereby the Raman scattered light is resonant at its turning point in a density gradient, was identified experimentally in planar-target experiments at the National Ignition Facility (NIF) in conditions relevant to the direct-drive scheme of inertial confinement fusion (ICF). This process was used to identify the principal sources of supra-thermal electrons in such conditions, which could preheat the target and reduce its compressibility. We have developed a new semi-analytical model of the instability, which describes both its convective and absolute aspects; we derived quantitative estimates of the amplification region in typical ICF regimes, which highlights the need for sufficient large laser spots to allow the instability to develop. Full-scale simulations of these experiments using the laser-plasma interaction code “pF3d” show SRS side-scatter largely dominating over back-scatter, and reproduce the essential features observed in the experiments and derived in the theory; we provide extrapolations to the case of spherical geometries relevant to direct-drive and discuss implications for indirect-drive ICF experiments.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.
occur throughout the sub-quarter-critical density plasma. In this talk a formalism is presented to investigate thresholds for absolute SRS in the context of direct-drive irradiation, comprising multiple beams having varying angles of incidence and polarization. Representative examples will be presented to illustrate the behavior of absolute SRS under these conditions, with emphasis on sidescatter at wavelengths below the half-harmonic of the laser.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


14:36
CO7 4 Modeling Stimulated Raman Scattering in Direct-Drive Inertial Confinement Fusion Plasmas for National Ignition Facility Conditions* A.V. MAXIMOV, J.G. SHAW, J.F. MYATT, R.W. SHORT, Laboratory for Laser Energetics, U. of Rochester. In the plasmas of direct-drive inertial confinement fusion (ICF), the coupling of laser power to the target plasma is strongly influenced by the laser–plasma interaction (LPI) processes driven by multiple crossing laser beams [1]. For the plasma parameters relevant to the conditions of the experiments at the National Ignition Facility (NIF), the threshold of the stimulated Raman scattering (SRS) is usually well exceeded because of the large scale length of the plasma density, making the study of SRS vital for the NIF ICF program. The SRS evolution starts as a convective or absolute instability [2], and the nonlinear saturation is determined by the ion-acoustic perturbations and kinetic effects. The LPI processes of cross-beam energy transfer and two-plasmon decay also drive the ion-acoustic modes and their interplay with SRS is analyzed.

*This work was supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


14:48
CO7 5 Nonlinear Fluid Simulation Study of Stimulated Raman and Brillouin Scatterings in Shock Ignition* CHUANG REN, Unite of Rochester LIANG HAO, IAPCM, Beijing, China RUI YAN, USTC, Hefei, China JUN LI, UCSD WENDA LIU, Univ of Rochester. We developed a new nonlinear fluid laser-plasma-instability code FLAME using a multi-fluid plasma model combined with full electromagnetic wave equations. The completed one-dimensional (1D) version of FLAME was used to study laser-plasma instabilities in shock ignition. The simulations results showed that absolute Stimulated Raman Scattering (SRS) modes growing near the quarter-critical surface were saturated by Langmuir-wave Decay Instabilities (LDI) and pump depletion. The ion-acoustic waves from LDI acted as seeds of Stimulated Brillouin Scattering (SBS), which displayed a bursting pattern and caused strong pump depletion. Re-scattering of SRS was also observed in a high temperature case. These results largely agreed with corresponding Particle-in-Cell simulations.

*Work funded by DOE (DE-SC0012316), NSF (PHY-1314734), NSFC (11642020, 11621202), and Science Challenge Project (No. JCKY201612A05).

15:00
CO7 6 Mitigation of cross-beam energy transfer in direct-drive inertial-confinement-fusion implosions with enhanced laser bandwidth* JASON BATES, U.S. Naval Research Laboratory JASON MYATT, JOHN SHAW, RUSSELL FOLLETT, University of Rochester JAMES WEAVER, U.S. Naval Research Laboratory ROBERT LEHMBERG, Research Support Instruments, Inc. STEPHEN OBENSCHAIN, U.S. Naval Research Laboratory. Cross-beam energy transfer (CBET) is a special category of stimulated Brillouin scattering in which two overlapping laser beams exchange energy by means of an ion acoustic wave in an under-dense expanding plasma [1]. CBET can cause the incident laser energy to be misdirected in direct-drive inertial-confinement-fusion (ICF) implosions, thereby reducing both the maximum ablation pressure achieved and the overall symmetry of the implosion [2]. One strategy for mitigating CBET may be to increase the bandwidth of the laser light, thereby disrupting the coherent wave-wave interactions underlying this resonant parametric process. In this presentation, we report on results of two-dimensional planar simulations performed with the code LPSE-CBET that demonstrate a significant reduction in CBET for bandwidths between 2 and 5 THz. Although large compared to OMEGA and NIF values (about 1 and 0.3 THz, respectively), it may be possible to reach such bandwidths with existing ICF lasers using a technique based on stimulated rotational Raman scattering [3], which is a subject that we also briefly discuss.

*Work supported by DOE/NNSA.


15:12
CO7 7 Polarization Rotation Caused by Cross-Beam Energy Transfer in Direct-Drive Implosions* D.H. EDGELL, R.K. FOLLETT, J. KATZ, J.F. MYATT, J.G. SHAW, D. TURNBULL, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester. The first evidence of polarization rotation caused by cross-beam energy transfer (CBET) during direct-drive implosions has been provided by a new beamlets diagnostic that was fielded on OMEGA. Beamlet images are, in essence, the end points of beamlets of light originating from different regions of each beam profile and following paths determined by refraction through the coronal plasma. The intensity of each beamlet varies because of absorption and many CBET interactions along that path. The new diagnostic records images in two time windows and includes a Wollaston prism to split each beamlet into two orthogonal polarization images recording the polarization of each beamlet. Only the common polarization components couple during CBET so when each beam is linearly polarized, CBET rotates the polarization of each beam. A 3-D CBET postprocessor for hydrodynamics codes was used to model the beamlet images. The predicted images are in good agreement with the images recorded by the new diagnostic.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

15:24
CO7 8 Using Wave-Based Cross-Beam Energy Transfer Simulations to Improve the Ray-Based Models Used in Inertial Confinement Fusion Applications* R.K. FOLLETT, D.H. EDGELL, D.H. FROULA, VN. GONCHAROV, I.V. IGUMENSHCHEV, J.G. SHAW, J.F. MYATT, Laboratory for Laser Energetics, U. of Rochester. Ray-based models of cross-beam energy transfer (CBET) are used in radiation–hydrodynamics codes to calculate laser-energy deposition for inertial confinement fusion (ICF) experiments. In direct-drive ICF, calculations suggest that CBET is responsible for a 10% to 20% reduction in laser energy absorption [1]. In indi-
rect drive, ray-based calculations predict full pump depletion of the outer cone beams [2]. Ray-based CBET models require artificial limiters to give quantitative agreement with experimental observables. The recent development of a 3-D wave-based solver (LPSE CBET) that does not rely on the paraxial or eikonal approximations allows the limitations of ray-based CBET models to be studied at conditions relevant to laser-driven ICF. The accuracy of ray-based CBET models is limited by uncertainties in the approximations used to account for the experimental realities of beam speckle, polarization smoothing, and interactions at caustics. A physics-based technique is proposed for including the effect of beam speckle in existing ray-based models that gives excellent agreement with the wave-based calculations.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


15:36  
CO7 9 Early Computed Hard X-Ray Emissions from Two-Plasmon–Decay Fast Electrons Not Observed in Experiments  
Point to Discrepancies in the Two-Plasmon–Decay Source Model*  
The temporal source of two-plasmon–decay (TPD) fast-electron transport in the 1-D hydrodynamic code LILAC, based on the measured, integrated hard x-ray (HXR) emission as a function of laser intensity, depends exponentially on the TPD threshold parameter up to about 0.9 and saturates above it. This model, along with LPSE simulations, produces HXR emissions much earlier than observed for certain shots. The amount of early emission depends on the rise time of the drive pulse and varies from a small shoulder to an early peak much larger than measured as the rise time decreases. The cause of this discrepancy could be that faster rise times limit the population of the thermal electron distribution near 10 keV, from which electrons are accelerated by the TPD plasma waves. Electron kinetic simulations will be performed with the Vlasov–Fokker–Planck code FPI to address the issue of the rise time of the 10-keV electron population as a function of the intensity rise time. Another cause could be an ~20% overestimate of the threshold parameter from the hydrodynamic conditions that would disappear over time.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

15:48  
CO7 10 First Experimental Comparisons of Laser-Plasma Interactions between Spherical and Cylindrical Hohlraums at SGIII Laser Facility  
YAOHUA CHEN, Institute of Applied Physics and Computational Mathematics ZHICHAO LI, Research Center of Laser Fusion, China Academy of Engineering Physics KE LAN, Institute of Applied Physics and Computational Mathematics  
In this report, we introduce our recent laser-plasmas instability (LPI) comparison experiment at the SGIII laser facility between the spherical hohlraums and the cylindrical hohlraums. Three kinds of filling are considered: vacuum, gas-filling with or without a capsule inside. The experiment has shown that the LPI level in the spherical hohlraum is close to that of the outer beam in the cylindrical hohlraum, while much lower than that of the inner beam. The experiment is further simulated by using our 2-dimensional radiation hydrodynamic code LARED-Integration, and the laser back-scattering fraction and the SRS spectrum are post-processed by the high efficiency code of laser interaction with plasmas HLIP. According to the simulation, the plasma waves are strongly damped and the SRS is mainly developed at the plasma conditions of electron density from 0.08 n_e to 0.1 n_e and electron temperature from 1.5 keV to 2.0 keV inside the hohlraums. However, obvious differences between the simulation and experiment are found, such as the SRS back-scattering is underestimated, and the numerical SRS spectrum peaks at a larger wavelength and at a later time than the data.

16:00  
CO7 11 Modeling Laser-Plasma Interaction over a Suite of NIF Experiments*  
We systematically study laser-plasma interaction (LPI) on NIF indirect-drive experiments, namely backlighting and high energy transfer. LLNL's best practice radiation-hydrodynamic simulation methodology [1] in the Lasnex simulation code [2] is employed without ad-hoc tuning to match experimental data. This entails converged numerical resolution, an improved DCA model for coronal (n_e < n_{crit}, T_e > 1 keV) gold opacity, electron heat flux strongly limited to 0.03 n_e T_e^{3/2} m_p^{-1/2}, and the line CBET model [3]. The rad-hydro plasma conditions are used for LPI analysis, namely linear instability gains, and the paraxial-envelope code pF3D [4]. Simulated scattered-light spectra are also compared to measurements. We initially focus on shots with low backscatter, so its self-consistent treatment should not be important. These shots have low hohlraum fill density and short laser pulses, and the only significant backscatter is outer-beams Brillouin. Our long-term goals are to understand reflectivity trends to guide target design and develop LPI mitigation strategies.

*Work performed under auspices of US DoE by LLNL under Contract DE-AC52-07NA27344.


16:12  
CO7 12 Vlasov-Fokker-Planck and PIC with Collisions Modeling of Stimulated Raman Scattering in the presence of Inverse-Bremsstrahlung heating in plasmas relevant to Inertial Confinement Fusion*  
ARCHIS JOGLEKAR, BENJAMIN WINJUM, WARREN MORI, Univ of California - Los Angeles  
Laser energy is absorbed in inertial fusion plasmas through the inverse-bremsstrahlung process. Theoretical work has predicted the evolution of non-Maxwellian electron distribution functions in the presence of inverse-bremsstrahlung heating [1], where the velocity gradient of the distribution function is relaxed at v ≥ 2v_{th} resulting in lower-than-Maxwellian Landau damping rates for electron plasma waves relevant to inertial fusion [2]. Here, we present the first self-consistent modeling of this process using OSHUN, a Vlasov-Fokker-Planck code, for conditions relevant to inertial fusion. We find enhanced SRS growth rates due to this effect in the collisional electron plasmas in the Trident experiments [3], as well as in the laser entrance hole of hohlraums during the picket pulse at the National Ignition Facility [4]. In hotter or lower Z, low density plasmas, this effect is muted due to the lower collisionality. Preliminary comparison of results from SRS simulations between OSHUN and OSIRIS with collisions will also be presented.

*Work supported by NSF and DOE.

16:24

**CO7 13** Anti-Stokes scattering and Stokes scattering of stimulated Brillouin scattering cascade in high-intensity laser-plasmas interaction* QINGSONG FENG, CHUNYANG ZHENG, ZHANJUN LIU, Peking University, CHENGZHOU XIAO, Hunan University QING WANG, LIHUA CAO, XIANTU HE, Peking University
The anti-Stokes scattering and Stokes scattering in stimulated Brillouin scattering (SBS) cascade have been researched by the Vlasov-Maxwell simulation. In the high-intensity laser-plasmas interaction, the stimulated anti-Stokes Brillouin scattering (SABS) will occur after the second stage SBS rescattering. The mechanism of SABS has been put forward to explain this phenomenon. In the early time of SBS evolution, only the first stage SBS appears, and the total SBS reflectivity comes from the first stage SBS. However, when the high-stage SBS and SABS occur, the SBS reflectivity will appear a burst behavior, and the total reflectivity comes from the SBS cascade and SABS superposition. The SABS will compete with the SBS rescattering to determine the total SBS reflectivity. Thus, the SBS rescattering including the SABS is an important saturation mechanism of SBS, and should be taken into account in the high-intensity laser-plasmas interaction.

*This research was supported by the National Natural Science Foundation of China (Grant Nos. 11375032, 11575035, 11475030 and 11435011), National Basic Research Program of China (Grant No. 2013CB834101) and Science Challenge Project, No. TZ2016005.

16:36

**CO7 14** Investigation of longitudinal relativistic effect on stimulated Raman backscattering by using one-dimensional Vlasov-Maxwell simulations QING WANG, ZHANJUN LIU, CHUNYANG ZHENG, Peking University, CHENGZHUO XIAO, Hunan University QINGSONG FENG, Peking Univ HAOCHU ZHANG, Institute of Applied Physics and Computational Mathematics, Beijing. 100094, China XIANTU XIANG, Peking University. The longitudinal relativistic effect on stimulated Raman backscattering (SRBS) is investigated by using one-dimensional (1D) Vlasov-Maxwell simulations. Using a short backscattered light seed pulse with a very small amplitude, the linear gain spectra of SRBS in strongly convective regime is presented by combining the relativistic and non-relativistic 1D Vlasov-Maxwell simulations, which is in excellent agreement with the steady-state linear theory. Meanwhile, we successfully predict the critical duration of the seed which can just trigger the kinetic inflation of the excited SRBS after the seed leaves the simulation box. In weakly convective regime, the transition from convective to absolute instability for SRBS can directly occur in linear regime due to the longitudinal relativistic modification. For the same pump, our simulations clearly demonstrate that the SRBS excited by a short and small seed pulse is a convective instability in the nonrelativistic case but becomes an absolute instability due to the decrease of the linear Landau damping from the longitudinal relativistic modification in the relativistic case.
of Imploding $D_2$ and $D_3$He Filled Capsules on the NIF$^*$ B. LAHMANN, J.A. FRENJE, M. GATU JOHNSON, F.H. SEGUNI, C.K. LI, R.D. PETRASSO, MIT E.P. HARTOUNI, C.B. YEAMANS, H.G. RINDERNKNECHT, D.B. SAYRE, G. GRIM, K. BAKER, D.T. CASEY, E. DE WALD, C. GOYON, L.C. JARROTT, S. KHAN, S. LEPAPE, T. MA, L. PICKWORTH, R. SHAH, LLNL J.L. KLINE, T. PERRY, A. ZYLSTRA, S.A. YI, LANL In deuterium-filled inertial confinement fusion implosions, 0.82 MeV $^3$He and 1.01 MeV T (generated by the primary DD reaction branches) can undergo fusion reactions with the thermal deuterium plasma to create secondary $D^3$He protons and DT neutrons, respectively. In regimes of moderate fuel areal density ($\rho R \sim 5 - 100 \text{ mg/cm}^2$) the ratio of both of these secondary yields to the primary yield can be used to infer the fuel $\rho R$, convergence ratio (CR), and an electron temperature ($T_e$). This technique has been used on a myriad of deuterium filled capsule implosion experiments on the NIF using the neutron time of flight (nTOF) diagnostics to measure the yield of secondary DT neutrons and CR-39 based wedge range filters (WRFs) to measure the yield of secondary $D^3$He protons.

$^*$This work is supported in part by the U.S. DoE and LLNL.

14:24 CO8 3 Indications of Bulk-Fluid Motion in Direct-Drive Implosions$^*$ O.M. MANNIN, K.S. ANDERSON, C.J. FORREST, V.Y.U. GLEBOV, V.N. GONCHAROV, J.P. KNAUER, P.B. RADHA, S.P. REGAN, T.C. SANGSTER, C. STOECKL, Laboratory for Laser Energetics, U. of Rochester The neutron spectrum produced by a burning plasma encodes essential information about the fusion products and serves as an important diagnostic for inertial confinement fusion experiments. At the Omega Laser Facility, neutron time-of-flight measurements are used to interpret the first and second moment of the neutron spectrum. These moments have been shown to be directly related to properties of the plasma, such as bulk fluid motion and apparent ion temperature. New measurement devices allow for unprecedented accuracy in the measurement of these moments and will provide a better understanding of the performance of direct-drive implosions. We present measurements of the first moment of the DT and $D_2$ peaks in DT implosions and show that variations in the first moment indicate bulk fluid motion of the plasma.

$^*$This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

14:36 CO8 4 A novel design for scintillator-based neutron and gamma imaging in inertial confinement fusion VERENA GEPPERT-KLEINRATH, THERESA CUTLER, CHRIS DANLY, AMANDA MADDEN, FRANK MERRILL, JOSH TYBO, PETR VOLEGOV, CARL WILDE, Los Alamos National Laboratory The LANL Advanced Imaging team has been providing reliable 2D neutron imaging of the burning fusion fuel at NIF for years, revealing possible multi-dimensional asymmetries in the fuel shape, and therefore calling for additional views. Adding a passive imaging system using image plate techniques along a new polar line of sight has recently demonstrated the merit of 3D neutron image reconstruction. Now, the team is in the process of designing a new active neutron imaging system for an additional equatorial view. The design will include a gamma imaging system as well, to allow for the imaging of carbon in the ablator of the NIF fuel capsules, constraining the burning fuel shape even further. The selection of ideal scintillator materials for a position-sensitive detector system is the key component for the new design. A comprehensive study of advanced scintillators has been carried out at the Los Alamos Neutron Science Center and the OMEGA Laser Facility in Rochester, NY. Neutron radiography using a fast-gated CCD camera system delivers measurements of resolution, light output and noise characteristics. The measured performance parameters inform the novel design, for which we conclude the feasibility of monolithic scintillators over pixelated counterparts.

14:48 CO8 5 Proton radiography experiments and 3D simulations of laser-driven hohlraums PAUL-EDOUARD MASSON-LABORDE, S. LAFFITE, CEA DAM DIF C.K. LI, MIT S.C. MILK, LLNL R. RQUIER, CEA DAM DIF Proton radiography experiments of laser-irradiated hohlraums (with 3 MeV DD) and 14.7 MeV D3He protons) performed at the Omega laser facility provide critical information on hohlraum environment: self-generated spontaneous electric and magnetic fields, plasma blow-off of the wall and hydrodynamic instabilities. Motion of the laser-driven plasma bubbles in gold and CH hohlraums under several different irradiation patterns have been analyzed by proton radiography. Comparisons with 3D hydrodynamic simulations in these different configurations coupled to a proton trajectory package will be presented. The 3D effect in plasma expansion, as well as the role and importance of electric field in the proton deflection will be discussed by comparisons to experimental results. All these comparisons provide insight into important issues in inertial confinement fusion and hohlraum physics.

15:00 CO8 6 Saturn Designs for Small Proton-Backlighter Targets at the National Ignition Facility$^*$ R.S. CRAXTON, E.M. GARCIA, L.T. BROWNING, Laboratory for Laser Energetics, U. of Rochester S. LE PAPE, H.-S. PARK, LLNL C.K. LI, PSFC, MIT A.B. ZYLSTRA, LANL Small exploding-pusher capsules with D3He fill are ideal sources for high-resolution proton radiography for many high-energy-density experiments at the National Ignition Facility (NIF). However, the laser energy that can be delivered to these capsules is currently limited by the need to minimize laser blowby—unabsorbed laser light passing by the target into opposing beam ports with the potential of damaging laser optics. This issue arises because it is logistically convenient to leave the indirect-drive phase plates in place. Saturn targets [1], in which the capsule is surrounded by a toroidal plastic ring, promise to remove the energy limitation by blocking blowby light, permitting a brighter proton source. A design has been developed using the 2-D hydrodynamics code SAGE [2] for a ring that can be used to block the laser blowby for target diameters from 440 to 866 μm and drive beams from any of the NIF quads. Full-power NIF beams can be safely used.

$^*$This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

GORY KEMP, JOHN MOODY, LLNL. Laser-foil interactions are well known to produce azimuthal magnetic fields around the laser spot due to the orthogonal density and temperature gradients that develop near the foil surface (the Biermann-Battery effect). Simulations show that these fields produced inside hohlraums used for indirect drive experiments at the National Ignition Facility (NIF); however, modeling these fields and their advection is very computationally expensive on the temporal and spatial scales relevant for typical NIF hohlraum experiments (∼10 ns, ∼few mm). The hohlraum geometry also makes directly probing the fields somewhat challenging, limiting the available experimental data on these fields under NIF conditions. In particular, the relative contributions of frozen-in and Nernst advection of the field away from the hohlraum wall is not currently well understood. We have developed a new target platform for direct measurements of the field topology in a NIF-relevant configuration. Using a single cone of NIF, a 2.5 mm long, 5.4 mm diameter Au ring is illuminated with a similar beam geometry to that of one ring of beams in a full-scale hohlraum experiment. The ring target has no end caps, providing a clear line of sight for probing through the ring. A D3He filled exploding pusher placed ∼5 cm below the ring is illuminated by an additional 60 beams of NIF to produce protons, some of which propagate through the ring.

*Work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344 and under LDRD support from LLNL.

15:24

CO8 8 Positron Radiography of Ignition-Relevant ICF Capsules* JACKSON WILLIAMS, HUI CHEN, JOHN FIELD, NINO LANDEN, DAVID STROZZI, Lawrence Livermore Natl Lab X-ray [1] and neutron [2] radiography are currently used to infer residual ICF shell and fuel asymmetries and areal density non-uniformities near and at peak compression that can impede ignition. Charged particles offer an alternative probe source that, in principle, are capable of radiographing the shell shape and areal density at arbitrary times, even in the presence of large x-ray self-emission. Laser-generated positrons are evaluated as a source to radiograph ICF capsules where current ultraintense laser facilities are capable of producing 2 × 10^22 relativistic positrons in a narrow energy bandwidth and short duration. Monte Carlo simulations suggest that both the areal density and shell radius can be reconstructed for ignition-relevant capsule conditions between 0.002–2 g/cm^2, and that this technique might be better suited to direct-drive.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and funded by the LDRD Program under project tracking code 17-ERD-010.


15:36

CO8 9 Advances in Modeling Direct-Drive Ignition at the National Ignition Facility* T.J.B. COLLINS, J.A. MAROZAS, Laboratory for Laser Energetics, U. of Rochester Polar direct drive (PDD) makes it possible to perform direct-drive–ignition experiments at the National Ignition Facility (NIF) while the facility is configured for indirect drive. We present for the first time PDD ignition-relevant target designs with decreased laser intensities. These designs include the physical effects of cross-beam energy transfer (CBET) and nonlocal heat transport, both of which substantially affect the target drive. In the PDD configuration, a multi-wavelength detuning strategy was found to be effective in mitigating the loss of coupling caused by CBET, allowing for implosion speeds comparable to those of previous designs. Target designs will be presented that span the region from alpha-particle heating to ignition. In addition, ignition-relevant designs will also be discussed for use in symmetric direct drive on the NIF.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

15:48

CO8 10 A Statistical Approach to Implosion Design on the OMEGA Laser* V. GOPALASWAMY, R. BETTI, Laboratory for Laser Energetics, U. of Rochester The 1-D campaign on OMEGA is backed by a novel approach aimed at producing an iterative and data-driven process to design optimized cryogenic implosions and improve the accuracy of 1-D physics models. The process does not preclude the possibility of significant systematic errors on OMEGA, nor does it assume that the hydrodynamic codes used in implosion design have all the necessary physical models. It only assumes that there exists some relationship between simulation and experimental results and uses statistical methods to model this relationship. Comparisons of hydrodynamic simulations of less-accurate physical models with more-accurate ones indicate that as long as equation of state is relatively well modeled, this assumption holds. By incorporating data from over 40 experiments on OMEGA, this approach has been used to design four targets with a two-shock pulse design for the 1-D campaign, and led to pre-shot predictions of yields within 5% and ion temperatures within 3% of the experimental values. One of these implosions has also produced the highest neutron yield (1.1 × 10^14) on an OMEGA cryogenic implosion with an areal density of ~105 mg/cm^2. The region of design space in which the predictive capability of this model is valid remains an open question.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

16:00

CO8 11 Three-Dimensional Hydrodynamic Simulations of the Effects of Laser Imprint in OMEGA Implosions* I.V. IGUMENSHCHEV, E.M. CAMPBELL, V.N. GONCHAROV, S.P. REGAN, A. SHVYDKY, Laboratory for Laser Energetics, U. of Rochester A.J. SCHMITT, NRL Illumination of direct-drive implosion targets by the OMEGA laser introduces large-amplitude broadband modulations in the absorbed energy from the largest (target size ~900-μm) to smallest (speckle size ~2-μm) spatial scales. These modulations “imprint” perturbations into a target that are amplified because of the secular and Rayleigh–Taylor growths during acceleration and deceleration of the target. The degradation of performance of room-temperature and cryogenic OMEGA implosions caused by these perturbations were simulated in three dimensions using the code ASTER. The highest-resolution simulations resolve perturbation modes as high as ℓ ~ 200. The high modes ℓ ~ 50 to 100 dominate in the perturbation spectrum during the linear growth, while the late-time nonlinear evolution results in domination of modes with ℓ ~ 30 to 50. Smoothing by spectral dispersion reduces the linear-phase mode amplitudes by a factor of ~ 4 and results in substantial improvements in implosion performance that is in good agreement with measurements. The effects of imprint on implosion performance are compared with the effects of other im-
plosion asymmetries, such as those induced because of laser beam imbalance, mistiming and mispointing, and target offset.

“This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

16:12 CO8 12 The Effect of Laser Imprint in OMEGA Cryogenic Implosions* P.B. RADHA, S.X. RU, B. BETTI, E.M. CAMPBELL, C.J. FORREST, V.N. GONCHAROV, J.P. KNAUER, R.L. MCCORORY, D.T. MICHEL, S.P. REGAN, T.C. SANGSTER, C. STOECKL, Laboratory for Laser Energetics, U. of Rochester J.A. FREJNIE, M. GATU JOHNSON, R.D. PETRASSO, PESC, MIT Single laser beam nonuniformity (laser imprint) can potentially compromise direct-drive implosion performance. Rayleigh–Taylor growth of short-wavelength nonuniformity imposed by laser speckle can grow during the acceleration phase of an implosion, resulting in a tenuous in-flight shell. Significant laser imprint can result in a thicker in-flight shell; reduced fusion yield, areal density, and ion temperature; wider burn; and a larger hot-spot radius than a stable shell. Simulations with the hydrodynamic code DRACO are presented for OMEGA cryogenic implosions spanning a range in adiabat and implosion velocity. These simulations include a three-dimensional ray trace. These simulations also include the effect of nonlocal heat conduction and cross-beam energy transfer. Signatures of laser imprint in cryogenic implosions are identified and comparisons to experimental observables are presented.

“This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

16:24 CO8 13 Dependence of Shock Timing on Coronal Parameters for OMEGA Direct-Drive Implosions* D. CAO, T.R. BOEHLKY, P.B. RADHA, D.N. POLSIN, S.P. REGAN, V.N. GONCHAROV, Laboratory for Laser Energetics, U. of Rochester Accurate shock timing is essential to produce the desired isentrope or adiabat α of an inertial confinement fusion implosion. However, plasma formation and its effects on shock timing are not fully understood, leaving an area of interest for improving shock-timing predictive capability. This study examines the shock-timing sensitivity of two key coronal feature parameters that can be potentially inferred experimentally: conduction-zone length $D_c$ and coronal temperature $T_c$. The former includes the plasma formation rate and influences the time between laser incidence and shock formation at the ablation surface, while the latter can influence shock strength. A two-picket implosion was simulated that had plasma profiles developing differing $D_c$ and $T_c$ after the end of the first picket (the profiles were otherwise identical). After launching the 2nd picket, correlations between the subsequent shock-merger time and main shock speeds (i.e., the observables with the VISAR diagnostic) to $D_c$ and $T_c$ are then calculated and in future experiments will be validated to improve code-predictive capability.

“This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

16:36 CO8 14 Asymmetrically driven implosion experiment on the Laser Mégajoule FRANCK PHILIPPE, PATRICIA SEYTOR, VERONIQUE TASSIN, RUDOLF ROSCH, BRUNO VILLETTE, CEA, DAM, DIF, Arpajon F-91297, France We report on the results of the first implosion experiments performed on the Laser Mégajoule (LMJ) facility. Their main purpose was to study implosion with large polar asymmetries of incident radiative flux on a capsule, while preserving azimuthal symmetry, in the context of ICF. In these experiments, one quad of LMJ is focused axially on a gold shield inside a hohlraum. The shield effectively divides the hohlraum in two compartments, and a capsule placed in the second compartment is indirectly driven by the x-ray flux generated in the first one. The subsequent asymmetric implosion is backlit by an x-ray source generated by another quad of LMJ and imaged with an x-ray microscope coupled to a framing camera. Time-gated x-ray radiographs of the implooding capsule and diode array measurements of the hohlraum x-ray emission are found to be in good agreement with FC12 radiative hydrodynamics simulations.

16:48 CO8 15 Experimental Results from the High-Adiabat Cryogenic Implosion Campaign on OMEGA* J.P. KNAUER, R. BETTI, V. GOPALASWAMY, M.J. BONINO, E.M. CAMPBELL, T.J.B. COLLINS, C.J. FORREST, V.YU. GLEBOV, V.N. GONCHAROV, D.R. HARDING, J.A. MAROZAS, F.J. MARSHALL, P.W. MCKENTY, P.B. RADHA, S.P. REGAN, T.C. SANGSTER, C. STOECKL, Laboratory for Laser Energetics, U. of Rochester The 1-D cryogenic experiments at the Omega Laser Facility are designed to systematically explore implosions where the multidimensional effects are small. These are typically high-adiabat ($\alpha \approx 7$) implosions where the implosion velocity is varied. The implosion velocity is increased by thinning the cryogenic DT layer and using larger diameter targets that increase the coupling of laser energy. Data are used to develop a predictive model for the 1-D implosion series. Experimental data are shown for implosion velocities from 350 to 500 km/s that give neutron yields $> 10^{14}$.

“This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

SESSION CP11: POSTER SESSION II: DUSTY PLASMAS AND SHEATHS; Z-PINCH, X-PINCH, DENSE PLASMA FOCUS, AND HED; STELLARATOR, DISRUPTIONS, AND MHD Monday Afternoon, 23 October 2017 Exhibit Exhibit Hall D at 14:00

CP11 1 DUSTY PLASMAS AND SHEATHS

CP11 2 Study of ND$_3$-enhanced MAR processes in D$_2$-N$_2$ plasmas to induce plasma detachment SHOTA ABE, SAIKAT CHAKRABORTY THAKUR, RUSS DOERNER, GEORGE TYNNAN, Univ of California - San Diego The Molecular Assisted Recombination (MAR) process is thought to be a main channel of volumetric recombination to induce the plasma detachment operation. Authors have focused on a new plasma recombination process supported by ammonia molecules, which will be formed by impurity seeding of N$_2$ for controlling divertor plasma temperature and heat loads in ITER. This ammonia-enhanced MAR process would occur throughout two steps. In this study, the first step of the new MAR process is investigated in low density plasmas ($N_e \approx 10^{16} m^{-3}$, $T_e \approx 4$ eV) fueled by D$_2$ and N$_2$. Ion and neutral densities are measured by a calibrated Electrostatic Quadrupole Plasma (EQP) analyzer, combination of an ion energy analyzer and mass spectrometer. The EQP shows formation of ND$_3$ during discharges. Ion densities calculated by a rate equation model are compared with
experimental results. We find that the model can reproduce the observed ion densities in the plasma. The model calculation shows that the dominant neutralization channel of $D^+_i (x=1-3)$ ions in the volume is the formation of $ND^+_y (y=3$ or $4$) throughout charge/D$^+$ exchange reactions with ND$_i$. Furthermore, high density plasmas ($N_e \approx 10^{16}$ m$^{-3}$) have been achieved to investigate electron-impact dissociative recombination processes of formed ND$_y^+$, which is the second step of the MAR process.

**CP11 3** Dressing effects on the occurrence scattering time retardation and advance in a dusty plasma MYOUNG-JAE LEE, YOUNG-DAE JUNG, Hanyang University HANYANG PLASMA TEAM The dressing effects on the occurrence scattering time for the dust-dust interaction are investigated in a complex plasma. The first-order eikonal analysis is applied to obtain the scattering amplitude and the occurrence scattering time for the dust-dust interaction. The result shows that dressing effect enhances the retardation phenomena of the occurrence scattering time in the forward scattering domain. It is shown that the oscillatory behavior of the scattered occurrence scattering time is getting more significant with an increase of the Debye length. It is also found that the retardation domain of the occurrence scattering time increases with a decrease of the Debye length. The variation of the occurrence scattering time retardation and advance due to the dressing effect is also discussed.

**CP11 4** Research progress and status of the Magnetized Dusty Plasma Experiment (MDPX)∗ EDWARD THOMAS, UWE KONOPKA, Auburn Univ ROBERT MERLINO, Univ. Iowa MARLENE ROSENBERG, UCSD MDPX TEAM The addition of a magnetic field has a profound influence on the properties of a complex/dusty plasma. The Magnetized Dusty Plasma Experiment (MDPX) device at Auburn University is a flexible, high magnetic field research instrument with a mission to serve as an open access, multi-user facility for the dusty plasma and basic plasma research communities. In the last year, the MDPX device has performed a broad range of experimental studies at magnetic fields $B \geq 3$ T; these are conditions where the electron gyro-radius is comparable to the diameter of the microparticles and the ion gyro-radius is comparable to the spacing between the microparticles. A variety of emergent phenomena are observed including a new type of imposed spatial ordering, significantly modified particle charging, coupling between ion and microparticle/nanoparticle transport, and new regimes of nanoparticle behavior.

∗This work is supported by the US Dept. of Energy (DE-SC0010485 and DE-SC00163630) and the NSF (PHY-1613087).

**CP11 5** Microparticle Deflection in a Plasmas as a Result of a Strong Magnetic Field∗ BRIAN LYNCH, UWE KONOPKA, DYLAN FUNK, EDWARD THOMAS, Auburn Univ In recent years the influence of a high magnetic field on the physics of complex plasma has been a topic of great interest. In particular, the dynamics may be significantly modified by the presence of large external magnetic fields. In a recent experiment using the Magnetized Dusty Plasma Experiment, the $g \times B$ deflection of charged dust grains falling through the bulk region of a magnetized plasma was observed. Using the deflection angle of the dust grains, it is possible to derive the particle charge. It is found that the charge on the grains is significantly lower than the estimates obtained from the OML model. This presentation will describe the experiments, the determination of the particle charge, and will discuss possible mechanisms that may be responsible for reducing the particle charge in a magnetized plasma.

∗This work is supported by NASA, the US Dept. of Energy, and the NSF.

**CP11 6** Effects of external magnetization on probe-induced voids in complex plasmas∗ SPENCER LEBLANC, EDWARD THOMAS, Auburn Univ Voids, or dust-free regions within a dust cloud in a complex plasma, have been observed and characterized for some time, both in microgravity settings [1] and in earth-based environments [2]. Created by a concentration of charge in the center of the void structure, the void boundary is formed at the point of equilibrium between the Coulomb force and ion-drag force on the dust grains. While there exists an extensive theoretical framework for understanding the dynamics of these voids [3,4], many mechanisms are still not completely understood. Of particular interest is the effect on void structure resulting from an externally implied magnetic field. Recently developed apparatus for studying complex plasmas within magnetic fields have allowed experimental observation of magnetized voids [5]. Recent results and analysis are presented from such experiments performed on the Magnetized Dusty Plasma Experiment (MDPX).

∗This work is supported by funding from the U. S. Department of Energy Grant Number DE-SC0010485 and DE-SC00163630.


**CP11 7** Methods for the characterization of imposed, ordered structures in MDPX∗ TAYLOR HALL, EDWARD THOMAS, Auburn University It is well understood that the microparticles in complex, or dusty, plasmas will form self-consistent crystalline patterns (plasma crystals) under the proper plasma parameters. In the Magnetized Dusty Plasma Experiment (MDPX), studies have been made of an imposed ordering of the dust particles to a two-dimensional grid where the dust particles are shown to become spatially oriented towards a wire mesh embedded in the upper electrode [1]. At high magnetic fields ($B \geq 1.5$ T), the particles become more confined to this structure with their motion limited to “hopping” through the grid pattern, or being confined to a single grid point [2]. A reliable and meaningful method of describing the degree to which the dust particles are restricted to this grid pattern is needed and a several potential methods for doing so are presented. The application of these techniques to characterize the background plasma parameters at which these imposed, ordered structures appear will be shown.

∗This work is supported by the U. S. Dept. of Energy and the NSF.

**CP11 8** DC response of dust to low frequency AC signals∗ MICHAEL MCKINLAY, UWE KONOPKA, EDWARD THOMAS, Auburn Univ Macroscopic changes in the shape and equilibrium position of clouds of charged microparticles suspended in a plasma have been observed in response to low frequency AC signals. In these experiments, dusty plasmas consisting of 2-micron diameter silica microspheres suspended between an anode and cath-
ode in an argon, DC glow discharge plasma are produced in a grounded, 6-way cross vacuum chamber. An AC signal, produced by a function generator and amplified by a bipolar op-amp, is superimposed onto the potential from the cathode. The frequencies of the applied AC signals, ranging from tens to hundreds of kHz, are comparable to the ion-neutral collision frequency; well below the ion/electron plasma frequencies, but also considerably higher than the dust plasma frequency. This presentation will detail the experimental setup, present documentation and categorization of observations of the dust response, and present an initial model of the response.

*This work is supported by funding from the US Dept. of Energy, Grant Number DE-SC0016330, and by the National Science Foundation, Grant Number PHY-1613087.

**CP11 9 Pattern formation and filamentation in low temperature, magnetized plasmas – a numerical approach** MOHAMAD MENATI, UWE KONOPKA, EDWARD THOMAS, Auburn Univ, Physics Dep., Auburn, AL In low-temperature discharges under the influence of high magnetic field, pattern and filament formation in the plasma has been reported by different groups. The phenomena present themselves as bright plasma columns (filaments) oriented parallel to the magnetic field lines at high magnetic field regime. The plasma structure can filament into different shapes from single columns to spiral and bright rings when viewed from the top. In spite of the extensive experimental observations, the observed effects lack a detailed theoretical and numerical description. In an attempt to numerically explain the plasma filamentation, we present a simplified model for the plasma discharge and power deposition into the plasma. Based on the model, 2-D and 3-D codes are being developed that solve Poisson’s equation along with the fluid equations to obtain a self-consistent description of the plasma. The model and preliminary results applied to the specific plasma conditions will be presented.

*This work was supported by the US Dept. of Energy and NSF, DE-SC0016330, PHY-1613087.

**CP11 10 Growth of nanoparticles in a strongly magnetized plasma** LENAIĆ COUDEIL, CNRS, Aix-Marseille Univ; SPENCER LEBLANC, TAYLOR HALL, UWE KONOPKA, EDWARD THOMAS, Auburn Univ. This presentation reports on the growth of nanoparticles in the Magnetized Dusty Plasma Experiment (MDPX) device. Two methods of production are investigated: (i) radio-frequency (rf) plasmas are produced in reactive gases (methane and acetylene) mixed with argon or hydrogen and (ii) nanoparticles are grown by sputtering the rf electrode (made of carbon, aluminium, copper, etc.). The growth of nanoparticles is followed by monitoring discharge parameters such as the powered electrode self bias and the rf current harmonic content. The dynamics of the growing dust particle cloud is investigated by recording the scattered light of a laser sheet with a high speed video camera. The size distribution and the internal structure of the produced nanoparticles are studied ex-situ using scanning and transmission electron microscopes. The influence of the strength of the magnetic field is explored and the changes in NP growth dynamics and transport are discussed.

*This work is supported by the US Dept. of Energy, DE-SC0016330.

**CP11 11 Effect of magnetic field on the phase transition in dusty plasma** SURABHI JAIswAL, Deutsches Zentrum für Luft- und Raumfahrt (DLR) EDWARD THOMAS, Auburn University RU-PAK MUKHERJEE, Institute for Plasma Research The formation of self-consistent crystalline structure is a well-known phenomenon in complex plasmas. In most experiments the pressure and rf power are the main controlling parameter in determining the phase of the system. We have studied the effect of externally applied magnetic field on the configuration of plasma crystals, suspended in the sheath of a radio-frequency discharge using the Magnetized Dusty Plasma Experiment (MDPX) device. Experiments are performed at a fixed pressure and rf power where a crystalline structure formed within the confining ring, but ramping the magnetic field up to 1.28 T. We report on the breakdown of the crystalline structure with increasing magnetic field. The magnetic field affects the dynamics of the plasma particles and first leads to a rotation of the crystal. At higher magnetic field, there is a radial variation (shear) in the angular velocity of the moving particles which we believe leads to the melting of the crystal. This melting is confirmed by evaluating the variation of the pair correlation function as a function of magnetic field.

*This work was supported by the US Dept. of Energy, DE-SC0010485.

1 Swati Baruah and Nilakshi Das, Phys. Plasmas 17, 073702 (2010).

**CP11 12 Molecular dynamic simulation of weakly magnetized complex plasmas** DYLAN FUNK, UWE KONOPKA, EDWARD THOMAS, Dept. Phys. Auburn University A complex plasma consists of the usual plasma components (electrons, ions and neutrals), as well as a heavier component made of solid, micrometer-sized particles. The particles are in general highly charged as a result of the interaction with the other plasma components. The static and dynamic properties of a complex plasma such as its crystal structure or wave properties are influenced by many forces acting on the individual particles such as the dust particle interaction (a screened Coulomb interaction), neutral (Epstein) drag, the particle inertia and various plasma drag or thermophoretic forces. To study the behavior of complex plasmas we setup an experiment accompanying molecular dynamic simulation. We will present the approach taken in our simulation and give an overview of experimental situations that we want to cover with our simulation such as the particle charge under microgravity condition as performed on the PK-4 space experiment, or to study the detailed influences of high magnetic fields.

*This work was supported by the US Dept. of Energy (DE-SC0016330), NSF (PHY-1613087) and JPL/NASA (JPL-RSA 1571699).

**CP11 13 RF attenuation as a dusty plasma diagnostic** BRANDON DOYLE, UWE KONOPKA, EDWARD THOMAS, Phys. Dept. Auburn Univ, Auburn, AL When a dusty plasma is formed by adding dust to a plasma environment, the electron density of the background plasma is depleted as the dust particles acquire their negative charge. The magnitude of the electron depletion depends on the dust particle charge, and thus its properties, as well as the dust number density. A direct measurement of the electron density in a dusty plasma therefore contains information about the charging state of the dust particles. This measurement is difficult to obtain without influencing the system. For example, Langmuir probes influence the system by creating voids, or they become unreliable due to their potential contamination with dust. A less invasive diagnostic tool might be realized using plasma chamber electrodes for a plasma impedance measurement as it depends on the excitation frequency: the spatially averaged electron density is derived from the electron plasma frequency, which is related to the radio frequency attenuation charac-
teristic. We present preliminary experiments using two impedance probe designs: probes immersed in a plasma and electrodes located at the edge of the plasma. We evaluate the potential application of this method for ground-based laboratory experiments and future microgravity experiment facilities aboard the ISS.

"This work was supported by JPL/NASA (JPL-RSA 1571699) the US Dept. of Energy (DE-SC0016330) and NSF (PHY-1613087).

CP11 14 Complex Plasmas under free fall conditions aboard the International Space Station* UWE KONOPKA, EDWARD THOMAS, JR., DYLAN FUNK, BRANDON DOYLE, *Phys. Dept. Auburn Univ., Auburn, AL, USA, JEREMIAH WILLIAMS, Wittenberg University, Springfield, OH, USA, CHRISTINA KNAPEK, HUBERTUS THOMAS, German Aerospace Center (DLR e.V.), Oberpfaffenhofen, Germany Complex Plasmas are dynamically dominated by massive, highly negatively charged, micron-sized particles. They are usually strongly coupled and as a result can show fluid-like behavior or undergo phase transitions to form crystalline structures. The dynamical time scale of these systems is easily accessible in experiments because of the relatively high mass/inertia of the particles. However, the high mass also leads to sedimentation effects and as a result prevents the conduction of large scale, fully three dimensional experiments that are necessary to utilize complex plasmas as model systems in the transition to continuous media. To reduce sedimentation influences it becomes necessary to perform experiments in a free-fall ("microgravity") environment, such as the ISS based experiment facility "Plasma-Kristall-4" ("PK-4"). In our paper we will present our recently started research activities to investigate the basic properties of complex plasmas by utilizing the PK-4 experiment facility aboard the ISS. We further give an overview of developments towards the next generation experiment facility "Ekoplasma" (formerly named "PlasmaLab") and discuss potential additional small-scale space-based experiment scenarios.

"This work was supported by the JPL/NASA (JPL-RSA 1571699), the US Dept. of Energy (DE-SC0016330) and the NSF (PHY-1613087).

CP11 15 Volumetric nature of synchronization of the dust acoustic wave with an external modulation* JEREMIAH WILLIAMS, Wittenberg University The dust acoustic wave (also known as the dust density wave) is low-frequency, longitudinal mode that propagates through the dust component of the dusty plasma system and is self-excited by the free energy from the ion streaming through the dust component. In the laboratory setting, the majority of the self excited dust acoustic waves that are observed are nonlinear, which allows for detailed studies of the nonlinear properties of this wave mode at the kinetic level. One such nonlinear process is synchronization, which is observed when the self-excited dust acoustic wave mode couples with and adjusts to an externally applied modulation. In this poster, we will present volumetric measurements of naturally occurring dust acoustic waves in an rf discharge as it becomes synchronous with an externally applied modulation in the spatial and temporal domains by applying a time-resolved Hilbert Transform to high-speed video imaging of the wave mode over a range of experimental conditions.

"This work is supported by US National Science Foundation through Grant No. PHY-1615420.

CP11 16 ALPHA (Adjustable Long Pulse High-Field Apparatus) W. J. BIRMINGHAM, E. M. BATES, C. A. ROMERO-TALAMAS, W. F. RIVERA, University of Maryland, Baltimore County The Dusty Plasma Laboratory (DPL) at the University of Maryland, Baltimore County (UMBC) is now finalizing the design and fabricating components for ALPHA, a high-field Bitter-type electromagnet to be used for magnetized dusty plasma experiments. When the system is complete, ALPHA will be programmable to dynamically increase or decrease fields of up to 10 T for nominally 10 seconds and up to several minutes. The magnet dimensions as well as power and cooling requirements were optimized according to a genetic algorithm developed in the DPL [1]. The cooling channel pattern design was obtained using an analytic methodology also developed in the DPL [2]. The final design parameters as well as the predicted performance characteristics of the magnetic core, the water cooling shell, and the DC power source are presented.


CP11 17 Excitation of an acoustic pulse by an impulsive shear flow in a dusty plasma* BIN LIU, JOHN GOREE, Department of Physics and Astronomy, The University of Iowa, Iowa City, IA 52242 DUSTY PLASMA TEAM A dusty plasma is a strongly-coupled plasma that contains micron-sized particles. These particles, also called dust particles, are highly charged by ambient plasma; they interact with each other, sustaining collective wave motion. Both longitudinal and transverse waves can in general be excited. Here we use an electrostatic three-dimensional (3D) simulation to reveal a wave excitation mechanism that is due to viscous heating. In the simulation, an impulsive force was applied to drive a shear flow motion with a sudden onset. After a delay, a longitudinal acoustic pulse wave was observed, propagating outwards from the edge of the flow. We found that the viscous heating due to shear motion can result in a brief localized rarefaction in the dust cloud, leading to the excitation of a longitudinal acoustic wave. The simulation parameters were motivated by the PK-4 instrument on the International Space Station (ISS).

*Work was supported by NASA.

CP11 18 BETA (Bitter Electromagnet Testing Apparatus) EVAN M. BATES, WILLIAM J. BIRMINGHAM, WILLIAM F. RIVERA, CARLOS A. ROMERO-TALAMAS, University of Maryland, Baltimore County The Bitter Electromagnet Testing Apparatus (BETA) is a 1-Tesla (T) prototype of the 10-T Adjustable Long Pulse High-Field Apparatus (ALPHA). These water-cooled resistive magnets use high DC currents to produce strong uniform magnetic fields. Presented here is the successful completion of the BETA project and experimental results validating analytical magnet design methods developed at the Dusty Plasma Laboratory (DPL). BETA’s final design specifications will be highlighted which include electromagnetic, thermal and stress analyses. The magnet core design will be explained which include: Bitter Arcs, helix starters, and clamping annuli. The final version of the magnet’s vessel and cooling system are also presented, as well as the electrical system of BETA, which is composed of a unique solid-state breaker circuit. Experimental results presented will show the operation of BETA at 1 T. The results are compared to both analytical design methods and finite element analysis calculations. We also explore the steady state maximums and theoretical limits of BETA’s design. The completion of BETA validates the design and manufacturing techniques that will be used in the succeeding magnet, ALPHA.
CP11 19 Potential profile near the virtual cathode in a dusty plasma device* DINESH RATHOD, SAROJ KUMAR DASH, ARUN SARMA, VIT UNIVERSITY, CHENNAI CAMPUS Existence of a virtual cathode in presence of dusty plasma has been studied by theoretical and numerical analysis. Using basic equations of charge dust, ions and electrons, the behavior of the potential in presence of dust has been calculated and plotted as a function of dust density. It was found that there is a change in potential difference between cathode and sheath potential which changes the threshold wall temperature compared to normal plasma condition. The threshold wall temperature has been increased due to the ability of micro-particles acquiring some electron charge and hence, reducing potential at the wall. Further with different values of (depends on dust density), threshold temperature remained same for an observed virtual cathode. Hence, behavior of potential was plotted for different with increasing wall temperatures. It has been observed that, at lower dust density, double layer like structure is formed near the virtual cathode. Occurrence of two virtual cathodes is observed, one before threshold temperature and one after it. However, irrespective of variation of potential difference near the wall and existence of two virtual cathodes, threshold temperature remained same.

*The authors would like to thank Science and Engineering Research Board(SERB) for their Grants and support.

CP11 20 Shock-like pulse experiment in a strongly coupled dusty plasma* ANTON KANANOVIČ, J. GOREE, Department of Physics and Astronomy, The University of Iowa, Iowa City, IA 52242 Compressional pulses are excited in a dusty plasma using a wire moved at a supersonic speed. The dusty plasma consists of a 2D monolayer of polymer microspheres electrified in a low-temperature argon RF plasma. The microspheres gained a large negative charge so that they interacted with each other as a strongly coupled component, partly shielded by the electrons and ions. The wire, which had a negative potential that repelled microspheres, was moved at a constant speed, causing a compressional pulse to propagate. This pulse had shock-like properties because the wire was moved faster than the longitudinal sound speed in the microspheres. The experiment was repeated for the dusty plasma both in liquid and solid states, all of the controlled parameters except for the dust kinetic temperature being equal. The laser rasters method was used to change the kinetic temperature. Several experimental runs were done with different wire speeds for the both cases. An increase in the wire propagation speed increased the propagation speed of the compressional pulse. High pulse propagation speeds were obtained with Mach numbers up to 5. For high pulse propagation speeds crystal buckling was observed. Video microscopy was the main diagnostic.

*Supported by U.S. Dept. of Energy.

CP11 21 Features of Gaussian Beam Traversing in Complex Plasma RUCHI SHARMA, SURESH C. SHARMA, Delhi Technological University A theoretical model describing the effect of dust on the self-focusing of the amplitude modulated laser beam propagating in a complex plasma has been proposed. For non-linear irradiance of the beam, electrons carry the non-uniform temperature results in more accretion of electrons on dust particles close to the axis. This leads to distorted electron density passage near the axis even after considering the ambipolar diffusion and direct the electromagnetic beam. In this analysis, while considering non-linear ohmic heating, dust charge balance, elastic and inelastic collision of constituent particles, momentum and energy balance equations have been solved simultaneously to govern the relation between the beam width parameter and distance of propagation. The dependence of beam width parameter with dimensionless propagation distance have been evaluated for different values of laser beam spot size, modulation index and different amplitude of the beam. Numerical calculations have been done to calculate the self-focusing length of the amplitude modulated beam propagating in the presence of dust particles. It is found that the self-focusing effect increases with the amplitude and modulation index of the beam but behave inversely with laser beam spot size.

CP11 22 Studies of magnetized plasma sheaths with secondary electron emissions using continuum kinetic simulations* PETR CAGAS, Virginia Tech AMMAR HAKIM, Princeton Plasma Physics Laboratory BHUvana SRINivasAN, Virginia Tech A continuum kinetic plasma model is used to study magnetized plasma sheaths by directly evolving the ion and electron distribution functions along with Maxwell’s equations. Appropriate boundary conditions are included to account for secondary electron emissions at the walls. Secondary electron emission (SEE) from a solid surface can drastically influence the plasma behavior – some recent works suggest that SEE can even reverse the gradient of the electrostatic potential in the plasma sheath. Therefore, a self-consistent SEE model based on real material parameters needs to be included in numerical models. Currently, SEE is commonly implemented using Monte-Carlo algorithms. However, this work presents a novel approach where the full velocity distribution function of SEE is directly constructed using the incident electron population and phenomenological material fits. This distribution function is then used as the boundary condition in the continuum kinetic simulation.

*This research was supported by the Air Force Office of Scientific Research under Grant Number FA9550-15-1-0193.

CP11 23 Direct experimental evidence of ion-ion co-stream instability excited in the sheath-presheath of Ar+He two-ion species plasma Vara Prasad Kella, Joydeep Ghosh, Prabal Chaittopadhyay, Devendra Sharma, Yogesh Saxena, Institute for Plasma Research Recent experimental measurements of ion flow speeds near the sheath edge of two-ion species plasma shows that, the ions reach the sheath edge with common sound speed other than their individual Bohm speeds at nearly equal ion concentrations. Baalrud et al., explain these results on the basis of ion-ion two-stream instability enhanced collisional friction between the ions. Some authors stipulate the existence of the instability indirectly, by measuring the ion flow speeds near the sheath edge. In these experiments, the instability is directly observed from the floating potential fluctuations from Langmuir probe placed near the sheath edge and from grid in Ar+He plasma. The frequency spectra shows broad band peaks with central frequency in the range 150-200 kHz. The intensity of the instability maximizes in the plasma produced with approximately equal ion concentrations of both the ion species. The frequency and amplitude of the peak decreases as the He$^+$ to Ar$^+$ concentration ratio decreases from unity. The phase velocity of the wave is measured as $\sim11\pm2$ km/s and identified to be twice the ion-sound speed in the bulk ($\sim6.3$ km/s), which is good agreement with earlier results of IAWs. The measured wave number and frequencies are compared with theoretical dispersion relations. These observations confirm the existence of ion-ion co-stream instability in sheath-presheath of two-ion species plasma.
CP 11 24 Measurement of sheath potential by three emissive-probe methods in DC filament plasmas near a biased grid∗ IN-JE KANG, IN-SUN PARK, Dept. Electrical Engineering, Hanyang University, Seoul, Republic of Korea EUGENE WACKERBARTH, Dept. Physics & Biophysics, University of San Diego MIN-KEUN BAE, Dept. Electrical Engineering, Hanyang University, Seoul, Republic of Korea NOAH HERSHKOWITZ, Dept. Engineering Physics, University of Wisconsin, Madison GREG SEVERN, Dept. Physics & Biophysics, University of San Diego KYU-SUN CHUNG, Dept. Electrical Engineering, Hanyang University, Seoul, Republic of Korea Plasma potential structures are measured with an emissive probe near a negatively biased grid (≈ −100 V, 80mm diam., 40 lines/cm) immersed in a hot filament DC discharge in Kr. Three different methods of analysis are compared: inflection point (IP), floating potential (FP) and separation point (SE) methods. The plasma device at the University of San Diego (length = 64 cm, diameter = 32 cm, source = filament DC discharge) was operated with $S \times n_e < 5 \times 10^{18} \text{cm}^{-3}$, $1 < T_e < 5 \text{eV}$, and 0.05 < $P_e < 0.1 \text{mTorr}$. Plasma potentials of between 5 & 10 volts were measured in the bulk and asymmetric potential drops in sheath and presheath regions between the front and the back side of mesh grid were observed. The differences between plasma potentials inferred by the 3 methods, and the question of validity of the techniques in the region of the sheath are treated in detail.

∗Membership Pending.

CP 11 25 Investigation of Ion Acoustic Wave Instabilities Near Positive Electrodes∗ RYAN HOOD, FENG CHU, SCOTT BAAL-RUD, ROBERT MERLINO, FRED SKIFF, University of Iowa Electron sheaths occur when an electrode is biased above the plasma potential, most often during the electron saturation portion of a Langmuir probe trace. Through the presheath, electrons are accelerated to velocities exceeding the electron thermal speed at the sheath edge, while ions do not develop any appreciable flow. PIC simulations have shown that ion acoustic instabilities are excited by the differential flow between ions and electrons in the presheath region of a low temperature plasma. We present the first experimental measurements investigating these instabilities using Laser-Induced Fluorescence diagnostics in a multidipole argon plasma. The plasma dispersion relation is measured from the power spectra of the imaged LIF signal and compared to the simulation results. In addition, optical pumping is measured using time-resolved LIF measurements and fit to a model in order to determine the diffusion rate, which may be enhanced due to the instability.

∗This research was supported by the Office of Fusion Energy Sciences at the U.S. Department of Energy under contract DE-AC04-94SL85000.

CP 11 26 Progress on the Development of the hPIC Particle-in-Cell Code CAMERON DART,∗ ALYSSA HAYES, RINAT KHAZIEV, STEPHEN MARCINKO, DAVIDE CURRENTO, University of Illinois at Urbana-Champaign LABORATORY OF COMPUTATIONAL PLASMA PHYSICS TEAM Advancements were made in the development of the kinetic-kinetic electrostatic Particle-in-Cell code, hPIC, designed for large-scale simulation of the Plasma-Material Interface. hPIC achieved a weak scaling efficiency of 87% using the Algebraic Multigrid Solver BoomerAMG from the PETSc library on more than 64,000 cores of the Blue Waters supercomputer at the University of Illinois at Urbana-Champaign. The code successfully simulates two-stream instability and a volume of plasma over several square centimeters of surface extending out to the presheath in kinetic-kinetic mode. Results from a parametric study of the plasma sheath in strongly magnetized conditions will be presented, as well as a detailed analysis of the plasma sheath structure at grazing magnetic angles. The distribution function and its moments will be reported for plasma species in the simulation domain and at the material surface for plasma sheath simulations.

CP 11 27 Three-dimensional and Sheath Boundary Effects on the Instabilities and transport in ExB Plasma Discharges∗ VINCENT MORIN, OLEKSANDR KOSHKAROV, ANDREI SMOLOYAKOV, Univ of Saskatchewan YEVGENY RAITSES, IGOR KAGANOVICH, Princeton Plasma Physics Laboratory Plasma devices based on the ExB drift are used for a variety of applications. However, transverse electron current due to ExB drift and diamagnetic flows are the sources of gradient-drift type instabilities which result in turbulence and anomalous transport. In the simplest case, the instabilities and resulting plasma dynamics are considered in neglect of the electron motion along the magnetic field. However, parallel electron dynamics may significantly affect the instability criteria for gradient-drift modes and result in new instabilities. In bounded systems, where the magnetic field lines are intercepted by material walls, the sheath becomes important. The sheath boundary conditions constrain the parallel electron dynamics and thus, via current closure (due to charge neutrality), modify instabilities. We consider sheath boundary conditions for dielectric walls and investigate their effect on the Simon-Hoh and lower-hybrid instabilities. The 3D eigenmode structure is investigated and the nonlinear evolution is studied with fluid simulations. The effects of boundary conditions open the way to control the instabilities via the “smart wall” boundaries which use segmented electrodes and active circuit elements to suppress the instabilities.

∗NSERC CANADA and AFOSR FA9550-15-1-0226.

CP 11 28 Effects of discrete stochastic charging of dust grains in protoplanetary disks∗ K. S. ASHRAFI, S. ESPARZA, C. XI-ANG, L. MATTHEWS, A. CARBALLIDO, T. HYDE, Center for Astrophysics, Space Physics and Engineering Research, Baylor University, One Bear Place 97310, Waco, Texas 76798-7310 B. SHOTORBAN, Department of Mechanical and Aerospace Engineering, University of Alabama-Huntsville, Huntsville, AL 35899 The stochastic nature of grain charging can play a significant role in the development of dust aggregate structure when the grains have a small charge. In this work, we use a model of discrete stochastic charging to calculate time-dependent electric charging of dust aggregates. We compare the electron and ion currents to micron and submicron aggregate grains, which consist of spherical monomers, to the currents to spherical grains of equivalent mass. The average charge and charge distribution are compared for aggregates composed of different monomer sizes. The aggregate morphology (whether the grain is compact or porous) affects the amount of charge collected and the available surface area for recombination on dust grains. Thus, the aggregate morphology as well as the dust fraction can affect the overall ionization balance in a plasma. The implications of our results for non-ideal magnetohydrodynamics in protoplanetary disks are briefly discussed in terms of the effect of disk ionization fraction and chemical networks.

∗Membership Pending.
CP11 29 Z-PINCH, X-PINCH, DENSE PLASMA FOCUS AND HED

CP11 30 An university-scale pulsed-power system using a bipolar Marx generator* PO-YU CHANG, SHENG-HUA YANG, MEI-FENG HUANG, ISAPS, National Cheng Kung University ISAPS, National Cheng Kung University A bipolar Marx generator is being built for x-ray sources or laboratory astrophysics and space research for university-scale laboratory. The system consists of ten stages. In each stage, two 1 μF capacitors connected in series are charged to ±30 kV storing 9 kJ of total energy. It delivers a current of ~200 kA to the load with a ~200 ns rise time during the discharge. It will be used for following three purposes: (1) gas-puff z pinches generating soft x-ray for bio-medical research in the future; (2) generating plasma jets to study interactions between plasma flows and unmagnetized/magnetized obstacles analogous to the interactions between solar winds and planetary magnetic fields or unmagnetized planets; and (3) studying the pinch in a dense plasma focus device. The results of current measurements and circuit characteristics are shown.

CP11 31 Development of a Self-Clearing MITL Topology MATTHEW MARTIN, ANDREW PORKWITSKY, DANIEL DOLAN, Sandia National Labs Recent experiments on the Z facility at Sandia National Labs have demonstrated significant plasma outflows onto the surface of our fusion targets when the load current exceeds 10 MA. These plasmas are believed to be sourced at the inner MITL from both hydrocarbon contamination and the metal of the MITL itself. We present simulations and the initial experimental results of a new MITL topology that attempts to minimize the production and transport of shotting plasma in the inner MITL, leading to improved current delivery and compression in magneto inertial fusion experiments at the Z facility.

CP11 32 Spectral Dependence of Stratified Electrothermal Instability in Tamped Aluminum 6061 with Current in a Skin Layer* BRUNO BAUER, TREvor HUTCHINSON, University of Nevada, Reno Thomas AWE, Sandia National Laboratories The stratified electrothermal instability (ETI) was recently observed on the surface of thick aluminum 6061 pulsed with rapidly rising lineal current density (3 × 10^15 A m^-2 s^-1) for 70 ns [1]. A transparent 70-μm-thick Parylene-N coating tamped the aluminum expansion and suppressed surface plasma. The evolution of the aluminum surface emission pattern was recorded with time-resolved microscopy (3-μm resolution). The images were converted into a series of black-body surface-temperature maps. Analysis of these temperature maps provides information on the evolution of temperature fluctuations, as a function of axial wavelength and azimuthal width. Perturbations with axial wavelength longer than 20 μm grow, while those with axial wavelength shorter than 10 μm decay. Comparing the spectral dependence of growth/decay rates with MHD simulations could test the modeling of ETI positive feedback and of damping by thermal conduction.

CP11 33 Experimental Investigation of Micrometer Scale Areal Density Variations in Metal Liners Driven by the 1 MA COBRA Pulsed Power Generator* LEVON ATOYAN, SERGEI PIKUZ, TANIA SHELKOVENKO, DAVID HAMMER, TOM BYVANK, Cornell University On the 20 MA Z machine, the seed for the MRT instability was mitigated in the Magnetized Liner Inertial Fusion experiment using a thick dielectric coating [1]. We have used high-resolution radiography to study the development of small-scale (∼10-30 μm) features in thin foils on the 1 MA, 100-200 ns COBRA pulsed power generator [2]. We examined those features quantitatively in a 16 μm thick cylindrical Al liner, where we show areal density variation of up to 40-50%. We then show how the features’ wavelength decreases when the material is changed from Al to Ni, Cu, and Ti, going from 21 ±4 μm for Al to 11 ±2 μm for Ti. Moreover, we show that expansion inhibition on both sides by dielectric material reduces small-scale feature size and density, and we show how pattern seeding can affect those parameters.

*This work was supported by the National Nuclear Security Administration Stewardship Sciences Academic Programs under Department of Energy Cooperative Agreement DE-NA0001836 as well as by the Department of Energy Grant Number DE-NA0002952.


CP11 34 Time-Resolved Thomson Scattering On Gas-Puff Z-Pinch Plasmas At Pinch Time* SOPHIA ROCCO, JACOB BANASEK, WILLIAM POTTER, BRUCE KUSSE, DAVID HAMMER, Cornell University The conditions and dynamics of neon gas puff z-pinch plasmas at pinch time are studied on COBRA, Cornell’s pulsed power generator (current rise time of ~240ns and approximately 0.9MA peak current). Radial tailoring of the gas puff mass-density profile using a triple-nozzle coaxial valve (two annular gas puffs and a central jet) enables production of both more stable and less stable (in regards to the magneto-Rayleigh Taylor instability) z-pinch implosions. A 526.5nm, 10J Thomson scattering diagnostic laser enables probing of the flow dynamics and plasma conditions of these implosions with both spatial and temporal resolution. The 3ns laser pulse is split in half, one of the beams delayed by up to 10ns relative to the other. This allows observation of streaked spectra for a total consecutive time of 6ns, providing sub-nanosecond resolution of the evolution of the pinch through stagnation. A gated spectrometer provides spatially-resolved spectra at the same time for comparison. Extreme ultraviolet imaging and laser schlieren imaging at multiple times enable monitoring of the implosion morphology as a function of time.

*Work supported by NNSA SSAP under DOE Cooperative Agreement No. DE-NA0001836 and Lawrence Livermore National Laboratory subcontract No. B619181.

CP11 35 Axial Magnetic Field Compression in Laboratory Plasma Jets* TOM BYVANK, WILLIAM POTTER, JOHN GREENLY, CHARLES SEYLER, BRUCE KUSSE, Cornell University Compression of an axial magnetic field correlates with density hollowing and azimuthal rotation of a plasma jet generated by the COBRA pulsed power machine (1 MA peak current in 100 ns rise time) in a radial foil (thin disk of 15 μm Al or Ti) configuration.
The plasma jet compresses an initially uniform \( \sim 1 \) T axial magnetic field (Bz) as it collimates along the central z-axis. Experimental measurements use a Bdot magnetic probe placed in the center of the hollow plasma jet. Experimental results show compression of an applied \( 1.0/\pm 0.1 \) T Bz to \( 2.4/\pm 0.3 \) T with aluminum jets and to \( 2.2/\pm 0.2 \) T with titanium jets. Predictions made by the extended magnetohydrodynamics (XMHD) code, PERSEUS, show compression to a \( 3.4 \) T Bz at the probe location for aluminum plasmas. For titanium plasmas, implementing radiation into the code is in progress. Additionally using the XMHD simulation, we explore the effects of changing current directions and how the magnetic field being tied to the electrons in Hall MHD (rather than being frozen to the ions in ideal MHD) influences the magnetic field advection. We overview physical reasons for the discrepancy between the experimental and simulation magnetic field compression measurements, including: surface plasma on Bdot probes, 2D and 3D simulation effects, and differences between ablation of a solid foil compared to a foil initialized as a plasma.

*Work supported by NNSA SSAP under DOE Cooperative Agreement DE-NA0001836 and NSF Grant PHY-1102471.

**CP11 36 Investigations of advected magnetic fields in experiments with supersonic plasma flows** ELEANOR TUBMAN, SERGEY LEBEDEV, GUY BURDIAK, LEE SUTTLE, MERIAM BERBOUCHA, DANIEL RUSSELL, THOMAS CLAYSON, JACK HARE, SIMON BLAND, JACK HALLIDAY, FRANCISCO SUZUKI-VIDAL, Imperial College, London Plasma flows created from the ablation of wires in wire array z-pinches can transport frozen-in magnetic fields. The presence of this advected magnetic field can significantly affect the structure of bow shocks that are formed when obstacles are placed in the plasma flow [1]. This is in contrast to the bow shocks that are present in many astrophysical scenarios where the fields do not dominate the conditions. We will present results of experiments performed using the MAGPIE (1 MA, 250 ns) pulsed power facility at Imperial College, London to better understand and control the magnetic fields transported within the plasma. Plasma flows used in these experiments were created using inverse wire arrays [1] and radial foil [2] configurations. Methods of putting obstacles or grids into the plasma flow to change the magnetic field structures are being tested and various diagnostics including Thomson scattering, interferometry, shadowgraphy and magnetic probes were used to characterise the resulting flow and magnetic field.


**CP11 37 Diagnostics for Magnetically Driven Implosions on the 1-MA MAIZE Facility** PAUL CAMPBELL, DAVID YAGER-ELORRIAGA, STEPHANIE MILLER, JEFF WOOLSTRUM, Univ of Michigan - Ann Arbor MICHAEL JONES, Sandia National Laboratories NICHOLAS JORDAN, Y.Y. LAU, RONALD GILGENBACH, RYAN MCBRIDE, Univ of Michigan - Ann Arbor The Michigan Accelerator for Inductive Z-pinch Experiments (MAIZE) is a 3-m-diameter Linear Transformer Driver (LTD) at the University of Michigan which supplies a fast electrical pulse (0–1 MA in 100 ns, for matched loads) to various experimental configurations. In order to better investigate these loads, new diagnostics are being developed. First, an EUV/XUV micro-channel plate pinhole camera and a UV laser imaging system are being implemented to better observe the instability structures that form during implosions. Second, an x-pinch radiography diagnostic is being developed to probe deeper into the plasma loads. Third, Rogowski coils are being developed for enhanced load current measurements. Finally, a bolometry system and photo-conducting diamond (PCD) detectors will be implemented to measure x-ray power and energy. These new systems, combined with the existing twelve-frame laser shadowgraphy, and b-dot current monitors, will be powerful tools for the investigation of imploding z-pinch experiments.

*This research was supported by the DOE through award DE-SC0012328, Sandia National Laboratories contract DE-NA0003525, the National Science Foundation, and a Nuclear Regulatory Commission new-faculty development Grant. D.Y.E. was supported by an NSF fello.

**CP11 38 Study of the effect of collisionality and cooling on the interactions of counter-streaming plasma flows as a function of wire material** GILBERT COLLINS, JULIO VALENZUELA, NICHOLAS AYBAR, FABIO CONTI, FARHAT BEG, University of California, San Diego We report on the effects wire material on collisionality and radiative cooling on the interactions of counter-streaming plasma jets produced by conical wire arrays on the \( \sim 200 \) kA GenASIS driver. In these interactions, mean free path \((\lambda_{\text{mfp}})\) scales with jet velocity \((v_{\text{j}})\), atomic mass \((A^2)\), and ionization \((Z^{+4})\), while cooling scales with atomic mass. By changing the material of the jets one can create slowly cooling, weakly collisional regimes using C, Al, or Cu, or strongly cooled, effectively collisionless plasmas using Mo or W. The former produced smooth shocks soon after the jets collide (near the peak current of 150 ns) that grew in size over time. Interactions of the latter produced multiple structures of a different shape, at a later time \((\sim 300 \) ns) that dissipated rapidly compared to the lower Z materials. We will report on the scaleability of these different materials to astrophysical phenomena.

*This work was partially supported by the Department of Energy Grant Number DE-SC0014493.

**CP11 39 Simulations Of Xenon and Krypton Doped Gas Puff Z-Pinch Implosions** VARUN TANGRI, Berkeley Research Associates J.L. GIULIANI, A. L. VELIKOVICH, N. D. QUART, A. DASGUPTA, Plasma Physics Division, Naval Research Laboratory J. P. APRUZSE, Consultant to the NRL through Icarus/Syntek Technologies A. J. HARVEY-THOMPSON, B. JONES, C.A. JENNINGS, Sandia National Laboratories The intriguing result that the presence of a small fraction of Xe (0.8% by number in the center jet) in an Ar gas puff shot can have a significant impact on the emitted K-shell radiation is examined. Experimental indications of this result were recently obtained from a pair of experiments [1] on Sandia National Laboratories’ Z machine. These shots were Z2603 (with Xe) and Z2605 (without Xe). The pair had similar initial density profile (outer shell, inner shell, and center jet) but one had the small aforementioned percentage of Xe dopant in the center jet. In addition, both shots had 1% Krypton in the middle shell. The resultant Ar K-shell yield considerably reduced from 373\pm9% to 129\pm9% kJ without an analogous change in the total radiation yield or emitted power. Simulations of this pair of shots will be presented using the Vash2-TCRE code. Detailed examination of the implosion dynamics and emitted radiation and its time- and space resolved K-shell synthetic spectra will be reported and compared with previous analysis [2]. The effect of varying the Xenon fraction as well as Krypton fraction on K-shell radiation and yield will also be examined.

*Work Supported by DOE/NNSA.

CP11 40 Simulations of an Argon Z-pinch Implosion with time-dependent non-LTE kinetics* N. OUART, A. DASGUPTA, J. GIULIANI, Naval Research Laboratory B. JONES, D. AMPLIFIED, A. HARVEY-THOMPSON, C. JENNINGS, Sandia National Laboratories V. TANGRI, R. CLARK, Berkeley Research Associates Three argon gas-puff implosions were performed on the Z-machine at SNL. These three loads had the same density profile from an 8cm dia. nozzle, a 1mg/cm mass, and a 2.5cm length. The experiments produced similar radiative powers and yields [1]. Simulations with the 2D MHD code Mach2-TCRE reproduced the experimental K-shell powers, yields, and emission region. It was also shown that the ratio of the Lyα to Heα-IC lines from the simulation had good agreement to measurements after peak K-power; however, the simulation’s line ratio was higher prior to the peak power. The authors attribute the difference to 3D effects or the implicit assumption of steady-state population kinetics [2]. This presentation will illustrate the effect of time-dependent level populations on the radiation from simulations using the NRL DZAPP code. DZAPP is a coupled 1D MHD, detailed non-LTE atomic physics with radiation transport, incorporating a transmission line circuit. The line ratios and K-powers from the steady-state and time-dependent populations will be presented and compared with experiment.

*This work supported by DOE/NNSA. SNL is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the US DOE/NNSA under contract DE-NA-0003525.


CP11 41 Optimizing Dense Plasma Focus Neutron Yields With Fast Gas Jets* MATTHEW MCMAHON, ELIZABETH STEIN, DREW HIGGINSON, CHRISTOPHER KUENY, ANTHONY LINK, ANDREA SCHMIDT, Lawrence Livermore Natl Lab We report a study using the particle-in-cell code LSP to perform fully kinetic simulations modeling dense plasma focus (DPF) devices with high density gas jets on axis. The high-density jets are modeled in the large-eddy Navier-Stokes code CharlesX, which is suitable for modeling both sub-sonic and supersonic gas flow. The gas pattern, which is essentially static on z-pinch time scales, is imported from CharlesX to LSP for neutron yield predictions. Fast gas puffs allow for more mass on axis while maintaining the optimal pressure for the DPF. As the density of a subsonic jet increases relative to the background fill, we find the neutron yield increases, as does the variability in the neutron yield. Introducing perturbations in the jet density via super-sonic flow (also known as Mach diamonds) allow for consistent seeding of the m=0 instability leading to more consistent ion acceleration and higher neutron yields with less variability. Jets with higher on axis density are found to have the greatest yield. The optimal jet configuration and the necessary jet conditions for increasing neutron yield and reducing yield variability are explored. Simulations of realistic jet profiles are performed and compared to the ideal scenario.

*This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and supported by the Laboratory Directed Research and Development Program (15-ERD-034) at LLNL.

CP11 42 Development of Diagnostics for the Livermore DPF Devices* JAMES MITRANI, RAHUL R PRASAD, YURI A PODPALY, CHRISTOPHER M COOPER, STEVEN F CHAPMAN, BRIAN H SHAW, ALEXANDER P POVIULUS, ANDREA SCHMIDT, LLNL LLNL is commissioning several new diagnostics to understand and optimize ion and neutron production in their dense plasma focus (DPF) systems. Gas fills used in DPF devices at LLNL are Deuterium (D2) and He accelerated onto a Be target, for production of neutrons. Neutron yields are currently measured with Helium-3 tubes, and development of yttrium-based activation detectors is currently underway. Neutron time-of-flight (ToF) signals from prompt neutrons will be measured with gadolinium-doped liquid scintillators. An ion energy analyzer will be used to diagnose energy distribution of D+ and He+ ions. Additionally, a fast frame ICCD camera has been applied to image the plasma sheath during the rundown and pinch phases. Sheath velocity will be measured with an array of discrete photodiodes with ns time responses. A discussion of our results will be presented.

*Supported by LLNL under Contract DE-AC52-07NA27344, and supported by the Laboratory Directed Research and Development Program (15-ERD-034) at LLNL and the Office of Defense Nuclear Nonproliferation Research and Development within U.S. Department of Energy.

CP11 43 Varying Radii of On-Axis Anode Hollo...Waves For kJ-Class Dense Plasma Focus* BRIAN SHAW, STEVEN CHAPMAN, STEVEN FALABELLA, ALEXEI PANKIN, JASON LIU, ANTHONY LINK, ANDREA SCHMIDT, Lawrence Livermore National Lab A dense plasma focus (DPF) is a compact plasma gun that produces high energy ion beams, up to several MeV, through strong potential gradients. Motivated by particle-in-cell simulations, we have tried a series of hollow anodes on our kJ-class DPF. Each anode has varying hollow sizes, and has been studied to optimize ion beam production in Helium, reduce anode sputter, and increase neutron yields in deuterium. We diagnose the rate at which electrode material is ablated and deposited onto nearby surfaces. This is of interest in the case of solid targets, which perform poorly in the presence of sputter. We have found that the larger the hollow radius produces more energetic ion beams, higher neutron yield, and sputter less than a flat top anode. A complete comparison is presented.

*This work was prepared by LLNL under Contract DE-AC52-07NA27344 and supported by Office of Defense Nuclear Nonproliferation Research and Development within U.S. Department of Energy’s National Nuclear Security Administration.

CP11 44 Deploying Solid Targets in Dense Plasma Focus Devices for Improved Neutron Yields* Y.A. PODPALY, S. CHAPMAN, A. POVIULUS, S. FALABELLA, A. LINK, B.H. SHAW, C.M. COOPER, D. HIGGINSON, I. HOLOD, Lawrence Livermore National Laboratory S. PEPE, B. GALL, National Security Technologies A.E. SCHMIDT, Lawrence Livermore National Laboratory We report on recent progress in using solid targets in dense plasma focus (DPF) devices. DPFs have been observed to generate energetic ion beams during the pinch phase; these beams interact with the dense plasma in the pinch region as well as the background gas and are believed to be the primary neutron generation mechanism for a D2 gas fill. Targets can be placed in the beam path to enhance neutron yield and to shorten the neutron pulse if desired. In this work, we measure yields from placing titanium deuteride foils, deuterated polyethylene, and non-deuterated control targets in deuterium filled DPFs at both megajoule and kilojoule scales. Furthermore, we have deployed beryllium targets in a helium gas-filled, kilojoule scale DPF for use as a potential AmBe radiological source replacement. Neutron yield, neutron time of flight, and optical im-
ages are used to diagnose the effectiveness of target deployments relative to particle-in-cell simulation predictions. A discussion of target holder engineering for material compatibility and damage control will be shown as well.


**CP11 45 Load Designs For MJ Dense Plasma Foci** A. LINK, A. POVLJUS, R. ANAYA, M. G. ANDERSON, J. R. ANGUS, C. M. COOPER, S. FALABELLA, LLNL D. GOERZ, Goerz Engineering Solutions LLC Goerz Engineering Solutions LLC D. HIGGINSON, I. HOLOD, M. MCMAHON, J. MITRANI, E. S. KOH, A. PEARSON, Y. A. PODPALLY, R. PRASAD, D. VAN LUE, J. WATSON, A. E. SCHMIDT, LLNL. Dense plasma focus (DPF) Z-pinch devices are compact pulse power driven devices with coaxial electrodes. The discharge of DPF consists of three distinct phases: first generation of a plasma sheath, plasma rail gun phase where the sheath is accelerated down the electrodes and finally an implosion phase where the plasma stagnates into a z-pinch geometry. During the z-pinch phase, DPFs can produce MeV ion beams, x-rays and neutrons. Megampere class DPFs with deuterium fills have demonstrated neutron yields in the 10^{12} neutrons/shot range with pulse durations of 10-100 ns. Kinetic simulations using the code Chicago are being used to evaluate various load configurations from initial sheath formation to the final z-pinch phase for DPFs with up to 5 MA and 1 MJ coupled to the load. Results will be presented from the preliminary design simulations. LLNL-ABS-734785

*This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory (LLNL) under Contract DE-AC52-07NA27344 and with support from the Computing Grand Challenge program at LLNL.

**CP11 46 The Effect of Interchanging the Polarity of the Dense Plasma Focus on Neutron Yield** SHENG JIANG, DREW HIGGINSON, ANTHONY LINK, ANDREA SCHMIDT, Lawrence Livermore National Lab. The dense plasma focus (DPF) Z-pinch devices can serve as portable neutron sources when deuterium is used as the filling gas. DPF devices are normally operated with the inner electrode as the anode. It has been found that interchanging the polarity of the electrodes causes orders of magnitude decrease in the neutron yield [1]. Here we use the particle-in-cell (PIC) code LSP [2,3] to model a DPF with both polarities. We have found the difference in the shape of the sheath, the voltage and current traces, and the electric and magnetic fields in the pinch region due to different polarities. A detailed comparison will be presented.

*Prepared by LLNL under Contract DE-AC52-07NA27344 and supported by the Laboratory Directed Research and Development Program (15-ERD-034) at LLNL. Computing support for this work came from the LLNL Institutional Computing Grand Challenge program.


**CP11 47 Ultra-Compact Electrostatic Confinement Fusion Device** GARRETT YOUNG, None. A unique, linear dual-beam configuration with an internal volume of 144 cc was simulated and operated. Deuterion ion paths were simulated using Mathematica and the electric field distribution was optimized relative to convergence density, potential well efficiency, and confinement time. The resulting cathode design is a departure from conventional systems, with gradual conical surfaces. The simulated trajectories correlated well to the observed operation, evidenced by two principle factors. First, the high transparency of the cathode due to the focused beams allowed for > 1 kW operation without duration-limiting temperature rise. Second, when compared to inertial electrostatic configurations, the constructed device achieved record steady-state D-D fusion rates per internal volume including 3.7E+4 fusions/sec/cc at 52 kV applied potential and 28 mTorr operating pressure.

**CP11 48 Progress towards experimental realization of extreme-velocity flow-dominated magnetized plasmas** T.E. WEBER, Los Alamos National Laboratory C.S. ADAMS, Virginia Polytechnic Institute and State University D.R. WELCH, Voss Scientific LLC G. KAGAN, Los Alamos National Laboratory I.A. BEAN, B.R. HENDERSON, Virginia Polytechnic Institute and State University A.J. KLIM, The Ohio State University Interactions of flow-dominated plasmas with other plasmas, neutral gases, magnetic fields, solids etc., take place with sufficient velocity that kinetic energy dominates the dynamics of the interaction (as opposed to magnetic or thermal energy, which dominates in most laboratory plasma experiments). Building upon progress made by the Magnetized Shock Experiment (MSX) at LANL, we are developing the experimental and modeling capability to increase our ultimate attainable plasma velocities well in excess of 1000 km/s. Ongoing work includes designing new pulsed power switches, triggering, and inductive adder topologies; development of novel high-speed optical diagnostics; and exploration of new numerical techniques to specifically model the unique physics of translating/stagnating flow-dominated plasmas. Furthering our understanding of the physical mechanisms of energy conversion from kinetic to other forms, such as thermal energy, non-thermal tails/accelerated populations, enhanced magnetic fields, and radiation (both continuum and line), has wide-ranging significance in basic plasma science, astrophysics, and plasma technology applications such as inertial confinement fusion and intense radiation sources.

*This work is supported by the U.S. Department of Energy, National Nuclear Security Administration. LA-UR-17-25786.

**CP11 49 STELLARATOR**

**CP11 50 Overview of physics goals for OP1.2a on Wendelstein 7-X** THOMAS SUNN PEDERSEN, Max Plank Institute for Plasma Physics W7-X TEAM Wendelstein 7-X achieved, and in many cases exceeded, the pre-defined goals for its first operation phase, OP1.1. Results include core values of \( T_e = 8 \text{ keV}, T_i = 2 \text{ keV} \) and \( n_e > 3 \times 10^{19} \text{ m}^{-3} \) and confinement times of 100-150 ms [1,2]. The next operation phase, OP1.2a, scheduled to start in fall 2017, features a much more elaborate set of plasma-facing components. 10 inertially cooled graphite test divertor units (TDU) have been installed, as have graphite tiles on all the heat shields and baffles. Upgrades have also been made to heating systems, diagnostics, and particle fueling systems. This will allow for significantly increased pulse lengths, heating power and plasma performance, in particular, higher plasma density, and higher ion temperatures, thereby
enabling a much more detailed investigation of the W7-X optimization and significantly higher triple products than achieved in OP1.1. The robustness of the TDU allows for an aggressive exploration of divertor operation scenarios in this phase. The main goals and plans, and, if available, first results of OP1.2a will be presented.

*This work has been carried out within the framework of the EURofusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under Grant agreement No 633053.


CP11 51 Initial observations on core transport in W7-X island divertor plasmas NOVIMIR PABLANT, Princeton Plasma Physics Laboratory FOR THE W7-X TEAM The current campaign of the Wendelstein 7-X (W7-X) stellarator, specified as OP1.2a, features the first operation with an island divertor and a completed carbon first wall. With the completion of the divertor, and recent upgrades to the ECRH heating system, higher temperatures and densities are expected than previously available during the first campaign (OP1.1), which featured a limiter plasma. After completion of wall conditioning, plasmas with \( T_e \sim T_i \) are expected to become accessible, allowing the investigation of plasma performance in the ion-root regime. Initial investigations of core transport in the W7-X island divertor are reported, along with measurements of the radial electric field. Measurements of temperature, density and radial electric field are compared at similar ECRH input powers between the island divertor plasmas from OP1.2a and the limiter plasmas from OP1.1.

CP11 52 Energetic Particle Loss Estimates in W7-X* SAMUEL LAZERSON, Princeton Plasma Physics Laboratory SIMPPA AKASLOMPOLO, MICHEAL DREVLAK, ROBERT WOLF, Max-Plank-Institut für Plasmaphysik DOUGLASS DARROW, DAVID GATES, Princeton Plasma Physics Laboratory W7-X TEAM The collisionless loss of high energy H\(^+\) and D\(^+\) ions in the W7-X device are examined using the BEAMS3D code [1]. Simulations of collisionless losses are performed for a large ensemble of particles distributed over various flux surfaces. A clear loss cone of particles is present in the distribution for all particles. These simulations are compared against slowing down simulations in which electron impact, ion impact, and pitch angle scattering are considered. Full device simulations allow tracing of particle trajectories to the first wall components. These simulations provide estimates for placement of a novel set of energetic particle detectors [2]. Recent performance upgrades to the code are allowing simulations with > 1000 processors providing high fidelity simulations. Speedup and future works are discussed.

*DE-AC02-09CH11466.


2G. Szalowski, Douglas Darrow, and F. Cecil, PPPL-4956 (2013).

CP11 53 3D Numerical Analysis of Radiative Edge Cooling in Wendelstein 7-X Island Divertor Scenarios* FLORIAN E Effenberg, OLIVER SCHMITZ, University of Wisconsin-Madison MICIEJ KRACHOWIAK, RALF KOENIG, Max-Planck-Institut für Plasmaphysik - Greifswald ALEXIS TERRA, Forschungszentrum Juelich GMBH BERND SCHWEER, Ecole Royale Militaire - Brussels JORG MUNOZ BURGOS, Astro Fusion Spectre STEUART LOCH, Auburn University W7-X TEAM A new high mirror island configuration is investigated featuring a more uniform distribution of heat and particle fluxes on horizontal and vertical divertor targets. For an upstream density of \( n_{up} = 2 \times 10^{19} \text{m}^{-3} \) at \( P_{ECRH} = 8 \text{MW} \) maximum heat loads up to \( q_{max} \approx 7.2 \text{MWm}^{-2} \) are calculated with the 3D fluid and kinetic edge transport Monte Carlo Code EMC3-EIRENE. Carbon eroded from the divertor targets is predicted to serve as effective intrinsic radiator enabling detached operational regimes at higher densities (\( n_{up} > 4 \times 10^{19} \text{m}^{-3} \)). The feasibility of active control of heat and particle flux levels by impurity seeding (C, H\(_2\), N\(_2\), Ne) will be discussed for the new island geometry. Impurity line radiation tends to concentrate in the islands for lower densities and causes a drop of flux levels correlated to the power loss fraction, \( \Delta q \propto \frac{\dot{q}_{\text{rad}}}{\dot{q}_{\text{loss}}} \). \( \beta \)-effects are taken into account based on the 3D MHD-equilibrium code HINT.

*This work was supported by the U.S. Department of Energy (DOE) under Grant DE-SC0014210.

CP11 54 The upgraded He/Ne beam diagnostic for active emission spectroscopy in the island divertor of Wendelstein 7-X* TULLIO BARBUI, FLORIAN E Effenberg, OLIVER SCHMITZ, University of Wisconsin-Madison MICIEJ KRACHOWIAK, RALF KOENIG, Max-Planck-Institut für Plasmaphysik - Greifswald ALEXIS TERRA, Forschungszentrum Juelich GMBH BERND SCHWEER, Ecole Royale Militaire - Brussels JORG MUNOZ BURGOS, Astro Fusion Spectre STEUART LOCH, Auburn University W7-X TEAM A significant enhancement of the line-ratio spectroscopy system on thermal helium and neon for the first divertor campaign of Wendelstein 7-X will enable measurement of electron density \( n_e \) and temperature \( T_e \) in front of the horizontal divertor target. The upgrade comprises 30 horizontal and 30 vertical lines of sight, which are channeled to a 19cm and a 32cm focal length spectrometers, allowing observation of the helium and neon lines as well as intrinsic impurities and Balmer series with high spectral resolution. Helium will be used as routine gas while neon will be tested in order to extend the applicability of the diagnostic to the detached divertor regime at very low \( T_e, T_i < \text{10eV} \). Gas injection is enabled by two boxes with 5 fast piezo valves each, mounted directly behind the divertor plates in one upper and one lower divertor module, which are magnetically connected in the 5/5 island configuration. Initial \( T_e/n_e \) measurements with helium beam will be shown together with results from neon injection and the status of the development of a dedicated collisional-radiative model for neon.

*This work has been funded by the Department of Energy under Grant DE-SC0014210 and by EURofusion under Grant No 633053.

CP11 55 First results from the Wendelstein 7-X Phase Contrast Imaging Diagnostic* ERIC EDLUND, MIKLOS PORKOLAB, MIT Plasma Science and Fusion Center OLAF GRULKE, ADRIAN VON STECHOW, LUKAS-GEORG BOTTGER, Max Planck Institut für Plasmaphysik Experiments in the first W7-X campaign achieved conditions of \( T_e > 8 \text{keV}, T_i > 2 \text{keV} \) and line-integrated densities of \( \approx 3 \times 10^{20} \text{m}^{-2} \), with energy confinement times close to the ISSeq scaling at about 100 ms [1]. The addition of an island divertor for the OP1.2 campaign is expected to lead to improved plasma performance. Experiments from this campaign will investigate the relative balance of neoclassical and turbulent transport
of energy and particles and further test the ISS04 scaling. Gyrokinetic modeling indicates that there may be measurable differences in turbulence amplitude and quality as the mirror ratio and rotational transform of the magnetic geometry are changed. Among the new W7-X diagnostics is a Phase Contrast Imaging (PCI) system, a joint effort between MIT and IPP. The PCI diagnostic measures electron density fluctuations that may arise from turbulence or coherent modes. The system is capable of detecting fluctuations spanning a frequency range of about 1 kHz to 2 MHz, and wavenumbers of about 0.5 cm\(^{-1}\) to 30 cm\(^{-1}\), depending on the optical configuration. We present initial PCI measurements of turbulent fluctuations in relation to global system parameters.

This work is supported by the US DOE under Grant Number DE-SC0014229.

\*This work is supported by US DOE under Grant Number DE-SC0013918.

CP11 56 Fast-camera imaging on the W7-X stellarator\* S.B. BALLINGER, J.L. TERRY, S.G. BAEK, MIT-PSFC K. TANG, MIT O. GRULKE, Max Planck Institute for Plasma Physics Fast cameras recording in the visible range have been used to study filamentary (“blob”) edge turbulence in tokamak plasmas, revealing that emissive filaments aligned with the magnetic field can propagate perpendicular to it at speeds on the order of 1 km/s in the SOL or private flux region. The motion of these filaments has been studied in several tokamaks, including MAST, NSTX, and Alcator C-Mod. Filaments were also observed in the W7-X Stellarator using fast cameras during its initial run campaign [1]. For W7-X’s upcoming 2017–18 run campaign, we have installed a Phantom V710 fast camera with a view of the machine cross section and part of a divertor module in order to continue studying edge and divertor filaments. The view is coupled to the camera via a coherent fiber bundle. The Phantom camera is able to record at up to 400,000 frames per second and has a spatial resolution of roughly 2 cm in the view. A beamsplitter is used to share the view with a slower machine-protection camera. Stepping-motor actuators tilt the beam-splitter about two orthogonal axes, making it possible to frame user-defined sub-regions anywhere within the view. The diagnostic has been prepared to be remotely controlled via MDSplus.

\*The MIT portion of this work is supported by US DOE award DE-SC0014251.

1G. Kocsis et al., 44th EPS Conf. (2017).

CP11 57 Feasibility of a Heavy Ion Beam Probe for W7-X\* T.P. CROWLEY, D.R. DEMERS, P.J. FIMOGNARI, Xanthe Technologies, LLC, Madison, WI O. GRULKE, R. LAUBE, Max-Planck-Institute for Plasma Physics, Greifswald, Germany A feasibility study of a Heavy Ion Beam Probe (HIBP) diagnostic for the Wendelstein 7-X (W7-X) superconducting stellarator, incorporating the accelerator and energy analyzer (currently in Greifswald) from the 2 MeV TEXT-U HIBP, is being carried out. The study’s results are positive: beam trajectory simulations in the W7-X standard magnetic configuration, with central densities up to 10\(^20\) m\(^{-3}\), predict that it will be possible to measure the equilibrium plasma potential and \(E_\parallel\) at all radii, and simultaneously measure temporally and spatially resolved fluctuations of \(n_e\) and potential for \(r/a>0.5\). This will provide a unique capability to advance understanding of neoclassical and turbulent particle and energy transport in W7-X. Within this feasibility study, the beam is injected and detected through the K11 and N11 ports respectively, and the toroidal magnetic field is in the \(\phi\) direction. Additional beam simulations reveal that most radii can be accessed in 7 other paradigm magnetic configurations. It’s anticipated that electrostatic beam steering suitable for studying all these configurations is plausible; it will have plate dimensions comparable to TEXT-U’s with smaller electric fields and higher voltages. Initial estimates of anticipated heat load from the W7-X plasma on the steering systems indicate it will be significant, but tractable. Our conclusion from these studies is that an HIBP diagnostic for W7-X is feasible.

\*This work is supported by US DoE Award DE-SC0013918.

CP11 58 3D Equilibrium Reconstruction with Islands\* M. CIANCIOSA, S.P. HIRSHMAN, S.K. SEAL, M.W. SHAFER, Oak Ridge National Laboratory Up until now, equilibrium reconstruction for studying 3D effects in fusion plasmas, has been limited to plasmas with nested magnetic topologies. To reconstruct plasmas with more general topologies, such as the island diverter of W7-X, it is necessary to use an equilibrium solver allowing for non-nested or stochastic magnetic fields. The SIESTA code tears the nested magnetic surfaces by applying resonant magnetic perturbations. These perturbations control the size of islands in the equilibrium solution and add another unknown parameter (the perturbation strength) to the equilibrium solution. Experiments show that measured temperature and density profiles flatten inside magnetic islands. Using this signal information, the size of the SIESTA island perturbation can be reconstructed by matching temperature and density profiles to flattened regions in experimental measurements. Recent work has coupled SIESTA into the V3FIT 3D equilibrium reconstruction code. From the SIESTA solution, V3FIT computes synthetic signals in the presence of magnetic islands. The unknown parameters of the model are then adjusted to minimize the mismatch between the observed and synthetic signal. Using this capability, initial results of reconstructed islands in a tokamak equilibrium will be presented.

\*Work supported by U.S. DOE under Contract DE-AC05-00OR22725.

CP11 59 High-rep-rate Thomson scattering for LHD\* D.J. DEN HARTOG, M. T. BORCHARDT, D. J. HOLLY, O. SCHMITZ, Univ of Wisconsin-Madison R. YASUHARA, I. YAMADA, H. FUNABA, M. OSAKABE, T. MORISAKI, National Institute for Fusion Science (Japan) A high-rep-rate pulse-burst laser system is being built for the LHD Thomson scattering (TS) diagnostic. This laser will have two operating scenarios, a fast-burst sequence of 15 kHz rep rate for at least 15 ms, and a slow-burst sequence of 1 kHz for at least 50 ms. There will be substantial flexibility in burst sequences for tailoring to experimental requirements. This new laser system will operate alongside the existing lasers in the LHD TS diagnostic, and will use the same beamline. This increase in temporal resolution capability complements the high spatial resolution (144 points) of the LHD TS diagnostic, providing unique measurement capability unmatched on any other fusion experiment. The new pulse-burst laser is a straightforward application of technology developed at UW-Madison, consisting of a Nd:YAG laser head with modular flashlamp drive units and a customized control system. Variable pulse-width drive of the flashlamps is accomplished by IGBT (insulated gate bipolar transistor) switching of electrolytic capacitor banks. Direct control of the laser Pockels cell drive enables optimal pulse energy extraction, producing >1.5 J \(q\)-switched pulses with \~20 ns FWHM. Burst operation of this laser system will be used to capture fast time evolution of the electron temperature and density profiles during events such as ELMs, RMP perturbations, and various MHD modes.
CP11 60 Simulation studies of neutron production and triton burn-up rates in the deuterium plasma of LHD S MURAKAMI, Y SAITO, M HOMMA, Dpt. Nuclear Eng., Kyoto Univ. H YAMAGUCHI, M ISOBE, K OGAWA, T NISHITANI, NIFS, NIFS LHD EXP GROUP TEAM The deuterium plasma experiment has been started from 2017 campaign in LH. The study of the energetic particle is one of the important issues in the deuterium plasma experiment of LHD. We investigate the D-D fusion reaction rates in the deuterium plasma to compare with the experimental results in LH. The NBI blip experiment was performed and the time behaviour of the neutron production rate was measured. We evaluate the neutron production rate by GNET-TD assuming the experimentally observed density and temperatures of the NBI blip experiment. We see a relatively good agreement in the time behavior of the neutron production rate. Also, we compare the simulation and experimental results in the stationary plasma. Next, we perform the triton burn-up simulation of the deuterium experiment of LH and evaluate the D-T fusion reaction rates to compare with the experimental results of the 14 MeV neutron diagnostic system.

CP11 61 Overview, Progress, and Plans for the Compact Toroidal Hybrid Experiment* G.J. HARTWELL, N.R. ALLEN, D.A ENNIS, J.D. HANSON, E.C. HOWELL, C.A JOHNSON, S.F. KNOWLTON, J.D. KRING, X. MA, D.A MAURER, K.G. ROSS, J.C. SCHMITT, P.J. TRAVERSO, E.N. WILLIAMSON, Auburn University The Compact Toroidal Hybrid (CTH) is an \( \ell = 2, m = 5 \) torsatron/tokamak hybrid (R_0 = 0.75 m, a_p \sim 0.2 m, and |B| \leq 0.7 T) which generates highly configurable confining magnetic fields solely with external coils but typically uses up to 80 kA of plasma current for heating and disruption studies. The main goals of the CTH experiment are to study disruptive behavior as a function of applied 3D magnetic shaping, and to test and advance the goals of the CTH experiment are achieved with a new optical coherence imaging diagnostic. The Coherence Imaging Spectroscopy (CIS) technique uses an imaging interferometer of fixed delay to provide 2D spectral images, making it ideal for investigating the non-axisymmetric geometry of CTH plasmas. Preliminary analysis of CIII interferograms indicate a net toroidal flow on the order of 10 km/s during the time of peak current. Bench tests using Zn and Cd light sources reveal that the temperature of the interferometer optics must be controlled to within 0.01°C to limit phase drift resulting in artificially measured flow. A new collaboration between Auburn University and the Max-Planck-Institute for Plasma Physics is underway to develop two new coherence imaging instruments for ion impurity flow measurements in orthogonal directions to investigate the 3D physics of the W7-X island divertor during OP1.2. A continuous wave laser tunable over most of the visible region will be incorporated to provide immediate and accurate calibrations of both CIS systems during plasma operations.

*Work supported by USDoE Grant DE-FG02-00ER54610.

CP11 62 Thomson scattering diagnostic on the Compact Toroidal Hybrid Experiment* P.J. TRAVERSO, D.A. ENNIS, G.J. HARTWELL, J.D. KRING, D.A. MAURER, Auburn Univ A Thomson scattering system is being commissioned for the non-axisymmetric plasmas of the Compact Toroidal Hybrid (CTH), a five-field period current-carrying torsatron. The system takes a single point measurement at the magnetic axis to both calibrate the two-color soft x-ray \( T_e \) system and serve as an additional diagnostic for the V3FIT 3D equilibrium reconstruction code. A single point measurement will reduce the uncertainty in the reconstructed peak pressure by an order of magnitude for both current-carrying plasmas and future gyrotron-heated stellarator plasmas. The beam, generated by a frequency doubled Continuum 2 J, Nd:YAG laser, is passed vertically through an entrance Brewster window and a two-aperture optical baffle system to minimize stray light. Thomson scattered light is collected by two adjacent f/2 plano-convex condenser lenses and routed via a fiber bundle through a Holospec f/1.8 spectrograph. The red-shifted scattered light from 533-563 nm will be collected by an array of Hamamatsu H11706-40 PMTs. The system has been designed to measure plasmas with core \( T_e \) of 100 to 200 eV and densities of \( 5 \times 10^{18} \) to \( 5 \times 10^{19} \text{ m}^{-3} \). Stray light and calibration data for a single wavelength channel will be presented.

*This work is supported by U.S. Department of Energy Grant No. DE-FG02-00ER54610.

CP11 63 Coherence Imaging Measurements of Impurity Flow in the CTH and W7-X Experiments* D.A. ENNIS, N.R. ALLEN, G.J. HARTWELL, C.A. JOHNSON, D.A. MAURER, Auburn Univ S.L. ALLEN, C.M. SAMUELL, LLNL D. GRADIC, R. KONIG, V. PERSEO, W7-X TEAM, IPP Greifswald Measurements of impurity ion emissivity and velocity in the Compact Toroidal Hybrid (CTH) experiment are achieved with a new optical coherence imaging diagnostic. The Coherence Imaging Spectroscopy (CIS) technique uses an imaging interferometer of fixed delay to provide 2D spectral images, making it ideal for investigating the non-axisymmetric geometry of CTH plasmas. Preliminary analysis of C III interferograms indicate a net toroidal flow on the order of 10 km/s during the time of peak current. Bench tests using Zn and Cd light sources reveal that the temperature of the interferometer optics must be controlled to within 0.01°C to limit phase drift resulting in artificially measured flow. A new collaboration between Auburn University and the Max-Planck-Institute for Plasma Physics is underway to develop two new coherence imaging instruments for ion impurity flow measurements in orthogonal directions to investigate the 3D physics of the W7-X island divertor during OP1.2. A continuous wave laser tunable over most of the visible region will be incorporated to provide immediate and accurate calibrations of both CIS systems during plasma operations.

*Work supported by USDoE Grant DE-FG02-00ER54610.

CP11 64 Non-axisymmetric equilibrium reconstruction and suppression of density limit disruptions in a current-carrying stellarator* XINXING MA, D. A. ENNIS, J. D. HANSON, G. J. HARTWELL, S. F. KNOWLTON, D. A. MAURER, Auburn University Non-axisymmetric equilibrium reconstructions have been routinely performed with the V3FIT code in the Compact Toroidal Hybrid (CTH), a stellarator/tokamak hybrid. In addition to 50 external magnetic measurements, 160 SXR emissivity measurements are incorporated into V3FIT to reconstruct the magnetic flux surface geometry and infer the current distribution within the plasma. Improved reconstructions of current and q profiles provide insight into understanding the physics of density limit disruptions observed in current-carrying discharges in CTH. It is confirmed that the final scenario of the density limit of CTH plasmas is consistent with classic observations in tokamaks: current profile shrinkage leads to growing MHD instabilities (tearing modes) followed by a loss of MHD equilibrium. It is also observed that the density limit at a given current linearly increases with increasing amounts of 3D shaping fields. Consequently, plasmas with densities up to two times the Greenwald limit are attained. Equilibrium reconstructions show that addition of 3D fields effectively moves resonance surfaces towards the edge of the plasma where the current profile gradient is less, providing a stabilizing effect.
CP11 65 Simulations of Low-q Disruptions in the Compact Toroidal Hybrid Experiment∗ E.C. HOWELL, J.D. HANSON, D.A. ENNIS, G.J. HARTWELL, D.A. MAURER, Auburn University Resistive MHD simulations of low-q disruptions in the Compact Toroidal Hybrid Device (CTH) are performed using the NIMROD code. CTH is a current-carrying stellarator used to study the effects of 3D shaping on MHD stability. Experimentally, it is observed that the application of 3D vacuum fields allows CTH to operate with edge safety factor less than 2.0. However, these low-q discharges often disrupt after peak current if the applied 3D fields are too weak. Nonlinear simulations are initialized using model VMEC equilibria representative of low-q discharges with weak vacuum transform. Initially a series of symmetry preserving island chains are excited at the q=6/5, 7/5, 8/5, and 9/5 rational surfaces. These island chains act as transport barriers preventing stochastic magnetic fields in the edge from penetrating into the core. As the simulation progresses, predominantly m/n=3/2 and 4/3 instabilities are destabilized. As these instabilities grow to large amplitude they destroy the symmetry preserving islands leading to large regions of stochastic fields. A current spike and loss of core thermal confinement occurs when the innermost island chain (6/5) is destroyed.

∗This work is supported by US Department of Energy Grant No. DE-FG02-00ER54610.

CP11 66 Benchmarking calculations of the magnetic field near the last closed flux surface with finite plasma pressure and current∗ J.C. SCHMITT, Auburn University A. BADER, University of Wisconsin-Madison M.R. CIANCIOSA, Oak Ridge National Laboratory M. DREVLAK, Max-Planck-Institut fur Plasmaphysik H. FRERICHS, University of Wisconsin-Madison S.A. LAZERSON, Princeton Plasma Physics Laboratory J.D. LORÉ, Oak Ridge National Laboratory D. MAURER, Auburn University The calculation of the magnetic field near the last closed flux surface in the presence of finite plasma pressure and current is important because of its impact on subsequent calculations. Subtle differences in the calculation of the magnetic field results in different magnetic field line trajectories, which are subsequently used to generate a ‘field-aligned’ grids for edge transport and divertor modeling with the EMC3-EIRENE code. Two methods of field calculations are discussed. One uses the virtual casing (VC) theorem and the other uses the magnetic vector potential. The VC theorem is implemented in the DIAGNO and EXTENDER codes, while the BWM code uses the magnetic vector potential. For both methods, a plasma equilibrium provided by VMEC is provided. Differences in the magnetic field and subsequent calculations for W7-X configurations will be presented and discussed. This work will help determine the strategy on how best to pass reconstructed equilibrium information from V3FIT to EMC3-EIRENE.

∗This work is supported by U.S. Department of Energy Grant DE-SC00014529.

CP11 67 Non-resonant divertors for stellarators∗ ALLEN BOOZER, Columbia University ALKESH PUNJABI, Hampton University The outermost confining magnetic surface in optimized stellarators has sharp edges, which resemble tokamak X-points. The plasma cross section has an even number of edges at the beginning but an odd number half way through the period. Magnetic field lines cannot cross sharp edges, but stellarator edges have a finite length and do not determine the rotational transform on the outermost confining surface. Just outside the last confining surface, surfaces formed by magnetic field lines have splits containing two adjacent magnetic flux tubes: one with entering and the other with an equal existing flux to the walls. The splits become wider with distance outside the outermost confining surface. These flux tubes form natural non-resonant stellarator divertors, which we are studying using maps.

∗This work is supported by US DOE Grants DE-FG02-95ER45333 to Columbia University and DE-FG02-01ER54624 and DE-FG02-04ER54793 to Hampton University and used resources of the NERSC, supported by the Office of Science, US DOE, under Contract No. DE-AC02-.

CP11 68 Effect of Magnetic Islands on Divertors in Tokamaks and Stellarators∗ ALKESH PUNJABI, Hampton University ALLEN BOOZER, Columbia University Divertors are required for handling the plasma particle and heat exhausts on the walls in fusion plasmas. Relatively simple methods, models, and maps from field line Hamiltonian are developed to better understand the interaction of strong plasma shaping and magnetic islands on the size and behavior of the magnetic flux tubes that go from the plasma edge to the wall in non-axisymmetric system. This approach is applicable not only in tokamaks but also in stellarators. Stellarator diverters in which magnetic islands are dominant are called resonant and when shaping is dominant are called non-resonant. Optimized stellarators generally have sharp edges on their surface, but unlike the case for tokamaks these edges do not encircle the entire plasma, so they do not define an edge value for the rotational transform. The approach is used in the DIII-D tokamak. Computation results are consistent with the predictions of the models. Further simulations are being done to understand why the transition from an effective cubic to a linear increase in loss time and area of footprint occurs and whether this increase is discontinuous or not.

∗This work is supported by the US DOE Grants DE-FG02-01ER54624 and DE-FG02-04ER54793 to Hampton University and DE-FG02-95ER45333 to Columbia University. This research used resources of the NERSC, supported by the Office of Science, US DOE, under Contract No. DE-AC02-05CH11231.

CP11 69 Nonsymmetric 3D MHD equilibrium and radial localization of trapped particles∗ WRICK SENGUPTA, HAROLD WEITZNER, Courant Institute of Mathematical Sciences, NYU Quasiisometry and omnigenity are key ideas proposed to ensure radial confinement of trapped particles in a stellarator. These constraints have stringent restrictions on magnetic geometry, some aspects of which are yet to be fully explored. In this work we obtain a local 3D MHD equilibrium expansion by analytically solving the MHD equilibrium equations. This expansion, although local, is sufficient to explore the deeply trapped particle physics, since it is carried out around a region of local minima of the magnitude of the magnetic field. Based on this analytical 3D equilibrium solution, we obtain the aforementioned constraints. We then extend this local analysis to a global one by expanding around the magnetic axis of the stellarator. Effects of curvature and torsion of the axis are treated self-consistently. We demonstrate that due to toroidal mode coupling, the expansion in flux coordinate near the axis is logarithmic and not purely algebraic. These non analytic terms can not be in general neglected. Our results show that it is far easier to satisfy the
omnigeneity condition than the quasisymmetry requirement. This implies, that there exists a large class of equilibrium close to quasisymmetry, which are still omnigeneous and allow inclusion of symmetry breaking error fields.

*This work was supported by the U.S. Department of Energy Grant No. DE-FG02-86ER53223.

**CP11 70** Relaxed MHD equilibria inside 3D shaped conducting surfaces A. HASSAM, J. TENBARGE, W. DORLAND, M. LANDREMAN, Univ. of Md. College Park W. SENGUPTA, NYU A 3D nonlinear dissipative MHD code is developed to allow relaxation to low-beta MHD equilibrium inside a shaped 3D conducting boundary with prescribed conserved axial magnetic flux and no external current. Formation of magnetic islands is allowed. Heat sources would be eventually introduced to allow possible non-stationary convection depending on the MHD stability properties. The initial development is done using UMHD (Guzdar et al., PF, 1993). A primary objective is to minimize numerical boundary noise. In particular, codes which specify the normal magnetic field \( B_n \) on bounding surfaces are prone to boundary noise generation. We shape the boundary to conform to the desired field shape so that \( B_n \) is zero on the boundary, employing curvilinear coordinates. Significant noise reduction has been achieved by this approach. Boundary noise is strongly suppressed if the boundary is modeled as a sharp ramp-down in resistivity, allowing relaxation to equilibrium but no penetration into the low resistivity region. Initial results have been verified w.r.t. analytic calculation in the weak shaping limit. A rotational transform is observed in helical shaping. Relaxed equilibria inside helically symmetric conducting boundaries will be presented.

**CP11 71** Influence of Thermal Anisotropy on Equilibrium Stellarator Beta Limits* T. A. BECHTEL, C. C. HEGNA, C. R. SOVINEC, University of Wisconsin - Madison The effect of anisotropic heat conduction on the upper beta limit of stellarator plasmas is studied using the nonlinear, extended MHD code NIMROD. The configuration under investigation is an \( l=2, M=10 \) torsatron with vacuum rotational transform near unity. Finite-beta plasmas are created using a volumetric heating source and temperature dependent resistivity; modeled with 22 stellarator symmetric (integer multiples of \( M \)) toroidal modes. Extended MHD simulations are then performed to generate steady state solutions that represent 3D equilibria. With increased heating, Shafranov shifts occur, and the associated break up of edge magnetic surfaces limits the achievable beta. Due to the presence of finite parallel heat conduction, pressure profiles can exist in regions of magnetic stochasticity. Here, we present results of independently varying the parallel and perpendicular thermal anisotropy. In particular, simulations show that the attained stored energy is a function of the magnitude of parallel and perpendicular thermal conduction for a given heat source, indicating that equilibrium beta limits are sensitive to anisotropic transport properties. Preliminary studies of MHD stability with non-stellarator symmetric modes, near the highest achievable beta, are also presented.

*Research supported by US DOE under Grant No. DE-FG02-99ER54546.

**CP11 72** Extension of the XGC code for global gyrokinetic simulations in stellarator geometry MICHAEL COLE, Princeton Plasma Physics Laboratory TOSEO MORITAKA, National Institute for Fusion Science ROSCOE WHITE, ROBERT HAGER, SEUNG-HOE KU, CHOONG-SEOCK CHANG, Princeton Plasma Physics Laboratory In this work, the full-f, gyrokinetic particle-in-cell code XGC is extended to treat stellarator geometries. Improvements to meshing tools and the code itself have enabled the first physics studies, including single particle tracing and flux surface mapping in the magnetic geometry of the heliotron LHD and quasi-isodynamic stellarator Wendelstein 7-X. These have provided the first successful test cases for our approach. XGC is uniquely placed to model the complex edge physics of stellarators. A roadmap to such a global confinement modeling capability will be presented. Single particle studies will include the physics of energetic particles’ global stochastic motions and their effect on confinement. Good confinement of energetic particles is vital for a successful stellarator reactor design. These results can be compared in the core region with those of other codes, such as ORBIT3d. In subsequent work, neoclassical transport and turbulence can then be considered and compared to results from codes such as EUTERPE and GENE. After sufficient verification in the core region, XGC will move into the stellarator edge region including the material wall and neutral particle recycling.

**CP11 73** GTC simulations of ion temperature gradient driven instabilities in W7-X and LHD stellarators HONGYU WANG, Fusion Simulation Center, Peking University, Beijing 100871, China; University of California, Irvine, CA 92697 We report GTC linear simulations of ion temperature gradient (ITG) instabilities in Wendelstein 7-X (W7-X) and Large Helical Device (LHD) stellarators. GTC has recently been updated to treat 3D equilibria by interfacing with MHD equilibrium code VMEC. GTC simulations of ITG have been carried out in both full torus and partial torus taking into account the toroidal periodicity of the stellarators. The effects of toroidal mode coupling on linear dispersions and mode structures in W7-X and LHD are studied. The mode structure in W7-X is more localized in the toroidal direction, and LHD is more extended in the toroidal direction and tokamak-like. Linear growth rates, real frequencies, and mode structures agree reasonably with results of EUTERPE simulations. In collaboration with I. Holod, J. Riemann, Z. Lin, J. Bao, L. Shi, S. Taimourzadeh, R. Kleiber, and M. Borchardt.

**CP11 74** Theory of turbulent saturation in stellarators: identifying mechanisms to reduce turbulent transport* C. C. HEGNA, P. W. TERRY, B. J. FABER, University of Wisconsin-Madison A theory for ion temperature gradient (ITG) turbulent saturation in stellarators is developed using a three field fluid model that allows for general 3D geometry. The model relies on the paradigm of nonlinear energy transfer from unstable to damped eigenmodes at comparable wavelength as the dominant saturation process. This mechanism is enabled by a three-wave interaction where the third mode primarily regulates the nonlinear energy transfer rate and depends upon the properties of the magnetic geometry. In particular, this work suggests that quasi-helically symmetric configurations may have an intrinsic advantage with regard to turbulent saturation physics relative to other configurations as multiple energy transfer channels can be exploited. Nonlinear energy transfer physics is quantified by the product of a turbulent correlation lifetime as computed from a three-wave frequency mismatch and a geometric coupling coefficient with larger turbulent correlation times denoting larger levels of nonlinear energy transfer and hence smaller turbulent transport. The theory provides an analytic prediction for how 3D shaping can be tuned to lower turbulent transport through saturation processes.

---

*University of Wisconsin-Madison

**CP11 75** GTC simulations of ion temperature gradient driven instabilities in W7-X and LHD stellarators HONGYU WANG, Fusion Simulation Center, Peking University, Beijing 100871, China; University of California, Irvine, CA 92697 We report GTC linear simulations of ion temperature gradient (ITG) instabilities in Wendelstein 7-X (W7-X) and Large Helical Device (LHD) stellarators. GTC has recently been updated to treat 3D equilibria by interfacing with MHD equilibrium code VMEC. GTC simulations of ITG have been carried out in both full torus and partial torus taking into account the toroidal periodicity of the stellarators. The effects of toroidal mode coupling on linear dispersions and mode structures in W7-X and LHD are studied. The mode structure in W7-X is more localized in the toroidal direction, and LHD is more extended in the toroidal direction and tokamak-like. Linear growth rates, real frequencies, and mode structures agree reasonably with results of EUTERPE simulations. In collaboration with I. Holod, J. Riemann, Z. Lin, J. Bao, L. Shi, S. Taimourzadeh, R. Kleiber, and M. Borchardt.

**CP11 76** Theory of turbulent saturation in stellarators: identifying mechanisms to reduce turbulent transport* C. C. HEGNA, P. W. TERRY, B. J. FABER, University of Wisconsin-Madison A theory for ion temperature gradient (ITG) turbulent saturation in stellarators is developed using a three field fluid model that allows for general 3D geometry. The model relies on the paradigm of nonlinear energy transfer from unstable to damped eigenmodes at comparable wavelength as the dominant saturation process. This mechanism is enabled by a three-wave interaction where the third mode primarily regulates the nonlinear energy transfer rate and depends upon the properties of the magnetic geometry. In particular, this work suggests that quasi-helically symmetric configurations may have an intrinsic advantage with regard to turbulent saturation physics relative to other configurations as multiple energy transfer channels can be exploited. Nonlinear energy transfer physics is quantified by the product of a turbulent correlation lifetime as computed from a three-wave frequency mismatch and a geometric coupling coefficient with larger turbulent correlation times denoting larger levels of nonlinear energy transfer and hence smaller turbulent transport. The theory provides an analytic prediction for how 3D shaping can be tuned to lower turbulent transport through saturation processes.
that can by used in optimization schemes for improved stellarator design.

*Research supported by U. S. DoE Grants DE-FG02-99ER54546, DE-FG02-93ER54222 and DE-FG02-89ER53291.

CP11 75 A multi-institutional Stellarator Configuration Study* DAVID GATES, Princeton Plasma Physics Laboratory A multi-institutional study aimed at mapping the space of quasi-axisymmetric stellarators has begun. The goal is to gain improved understanding of the dependence of important physics and engineering parameters (e.g. bootstrap current, stability, coil complexity, etc.) on plasma shape (average elongation, aspect ratio, number of periods). In addition, the stellarator optimization code STELLOPT will be upgraded with new capabilities such as improved coil design algorithms such as COILOPT++ and REGCOIL, divertor optimization options, equilibria with islands using the SPEC code, and improved bootstrap current calculations with the SFINCS code. An effort is underway to develop metrics for divertor optimization. STELLOPT has also had numerous improvements to numerical algorithms and parallelization capabilities. Simultaneously, we also are pursuing the optimization of turbulent transport according to the method of proxy functions. Progress made to date includes an elongation scan on quasi-axisymmetric equilibria and an initial comparison between the SFINCS code and the BOOTSJ calculation of bootstrap current currently available in STELLOPT. Further progress on shape scans and subsequent physics analysis will be reported. The status of the STELLOPT upgrades will be described. The eventual goal of this exercise is to identify attractive configurations for future US experimental facilities.

*This work is supported by US DoE Contract Number DE-AC02-09CH11466.

CP11 76 Recent Results from HSX and New Directions* DAVID ANDERSON, HSX TEAM, University of Wisconsin-Madison HSX has demonstrated many improvements resulting from quasi-helical symmetry in the magnetic field. Work has continued on measuring the plasma radial electric field and bootstrap current utilizing the Pfirsch-Schluter flows, with a new MSE diagnostic under development. With suppressed neoclassical transport, turbulent transport is dominant in HSX. Experimental measurements of turbulence have been undertaken with probes in the edge and interferometry in the core. GENE has shown TEM to be dominant mode with heat flux comparable to measurements. No profile stiffness is observed under present conditions. These studies are being extended to look at comparisons between heat flux and density fluctuations as a function of gradient scale length. A new microwave scattering diagnostic and CECE are being implemented. Laser blow-off impurity studies are underway. Energetic ion confinement, a key issue for stellarators, will be studied using NBI of energetic deuterons into a deuterium plasma as done in MST and CHS. Improved coil design is being examined using the REGCOIL and FOCUS codes, with a goal of reduced ripple and coil complexity for either an upgrade to HSX or a new device to extend quasi-symmetry studies into hot ion physics.

*Work supported by the US DOE under Grant DE-FG02-93ER54222.

CP11 77 Measurements and modeling of radial electric field and bootstrap flows in HSX* S. T. A. KUMAR, T. J. DOBBINS, W. GOODMAN, J. N. TALMADGE, F. S. B. ANDERSON, K. M. LIKIN, D. T. ANDERSON, UW-Madison M. LANDREMAN, University of Maryland Counter-streaming Pfirsch-Schluter (PS) parallel ion flows have been measured in HSX using charge exchange recombination spectroscopy. This method has provided an improved measurement of the radial electric field and ion bootstrap flows in the core of the plasma. The magnitudes of the experimentally measured radial electric field and ion bootstrap flows do not demonstrate the neoclassical features calculated with the PENTA code; the measured electric field values agrees with ion-root solution and the measured ion bootstrap flows agree with the electron-root solution. Several approaches have been undertaken recently to understand this discrepancy, for example, using a biased electrode to look for the helical ion resonance and improvements in the neoclassical calculation. Recent advances in measurements and modeling are presented.

*Work supported by the US DOE under Grant DE-FG02-93ER54222.

CP11 78 Evolution of intrinsic flows and radial electric field in HSX stellarator* T. J. DOBBINS, S. T. A. KUMAR, J. N. TALMADGE, K. M. LIKIN, F. S. B. ANDERSON, D. T. ANDERSON, Univ of Wisconsin, Madison The inboard/outboard asymmetry in impurity ion flow on the HSX stellarator is measured by the Charge Exchange Recombination Spectroscopy (CHERS) diagnostic. This allows the calculation of the bootstrap and Pfirsch-Schluter flows on a flux surface. The evolution of bootstrap flows has been measured in the HSX stellarator and compared with the evolution of bootstrap current. The flow evolution was found to be dependent on magnetic configuration and plasma parameters, while the electric field was found to be constant in time. With 50 kW ECHEL heating, the bootstrap flow decreased from 13 to 8 km/s from the beginning to the end of the discharge in the core of the plasma (r/a of .2) while the electric field remained constant at 2.5 kV/m. The Pfirsch-Schluter flow measurements are used to find the radial electric field. These measurements of radial electric field are compared the neoclassical values calculated by the PENTA code [1].

*Work supported by the US DOE under Grant DE-FG02-93ER54222.


CP11 79 Carbon impurity measurements in the HSX stellarator* J. M. MOHONEY, S. T. A. KUMAR, K. M. LIKIN, D. T. ANDERSON, Univ of Wisconsin, Madison Impurity behavior in stellarators is not fully understood despite important implications on device performance, in particular, an accumulation of impurities can lead to degradation of plasma energy due to radiative losses. Experiments are being conducted at HSX to measure the radial profiles and the time history of carbon impurity density using the charge exchange recombination spectroscopy (CXRS) diagnostic. Measurements of fully ionized carbon have been performed on various magnetic configurations, showing a peaked profile at the core in the standard configuration. An inversion technique was also developed to calculate localized C +5 profiles. Comparisons of impurity behavior between the standard and broken-symmetry configurations are presented.

*Work supported by the US DOE under Grant DE-FG02-93ER54222 and the Hilldale Research Fellowship.

CP11 80 Turbulence Measurements by Interferometry and Forward Scattering on the HSX Stellarator* C.B. DENG, D.L.
BROWSER, University of California, Los Angeles D.T. ANDERSON, F.S.B. ANDERSON, K.M. LIKIN, J.N. TALMADGE, University of Wisconsin-Madison After neo-classical transport was reduced by restoring symmetry along the helical axis, a primary physics goal for HSX is to study how 3-D shaping can reduce turbulence thereby requiring measurement of turbulence with k_{\rho r} up to 1. For characteristic HSX parameters (Te ~200 eV at t/a ~0.5 where the density gradient peaks), this condition corresponds to k_{\rho r} up to 7 cm^{-1}. To accommodate this goal, a new 9-chord HSX interferometer/far-forward scattering system has been designed to measure density turbulence at higher k. The new system employing high frequency sources and high sensitivity planar-diode mixers will allow us to reduce the aperture of the receiver optics to a few mm thereby increasing the maximum wavenumber to k~15 cm^{-1}. Reconfiguring the interferometer system into a finite-angle collective scattering arrangement is also planned as it will increase the measured k-spectrum up to 18 cm^{-1} with some spatial resolution (core or edge).

*Supported by USDOE Grants DE-FG03-01ER54615 and DE-FG02-93ER54222.

CP11 81 Experimental study of Nonlinear, Multi-Scale Turbulence in the HSX stellarator S. OHSHIMA, Kyoto University, Kyoto, Japan C.B. DENG, University of California, Los Angeles R.S. WILCOX, Oak Ridge National Laboratory, TN T. NISHIZAWA, A.F. ALMAGRI, K.M. LIKIN, J.N. TALMADGE, D.T. ANDERSON, F.S.B. ANDERSON, S.R. SAREF, University of Wisconsin-Madison Micro scale turbulence depends on parameters such as local magnetic shear and curvature, and also excitation and damping mechanisms of zonal flows relate to the topology of the configuration. In the HSX stellarator, the Langmuir probe measurements indicate that a nonlinear interaction exists among a zonal flow like mode in the frequency range up to 5 kHz, a coherent mode at 20 kHz, and broadband turbulence. These two coherent modes are interacting with broadband fluctuation, and moreover these modes couples with each other. Interestingly, the nonlinear interaction appears differently depending on the location on the flux surface, which demonstrates a toroidal asymmetry, attributed to three dimensional configurations, exists on the multi-scale interactions. The detail of the analysis results and a new dedicated experiment for zonal flow physics in HSX using a newly designed capacitive probe will be discussed in this poster.

CP11 82 TEM heat transport and fluctuations in the HSX stellarator: experiments and comparison with gyrokinetic simulation* J. SMONIEWSKI, B.J. FABER, University of Wisconsin-Madison E. SÁNCHEZ, I. CALVO, Laboratorio Nacional de Fusión, CIEMAT M.J. PUESCHEL, K.M. LIKIN, C.B. DENG, J.N. TALMADGE, University of Wisconsin-Madison The Helically Symmetric Experiment (HSX) has demonstrated reduced neoclassical transport in the plasma core with quasi-symmetry [Lore Thesis 2010], while outside this region the electron thermal diffusivity is well above the neoclassical level, likely due to the Trapped Electron Mode (TEM) [Weir PoP 2015, Faber PoP 2015]. We compare gyrokinetic simulations of the TEM to experimental heat flux and density fluctuation measurements for two configurations: Quasi-Helical Symmetry (QHS) and broken symmetry (Mirror). Both experiment and simulation show that the heat flux for Mirror is larger than for QHS by about a factor of two. Initial interferometer measurements provide evidence that density-gradient-driven TEMs are driving turbulence. Calculations of the collisionless damping of zonal flows provide another perspective into the difference between geometries. Similar to other stellarators [Monreal PPCF 2016], the zonal flow residual goes to zero at large wavelengths in both configurations. Additionally, the very short time decay of the zonal flow due to neoclassical polarization is constant between configurations. However, the collisionless damping time is longer and the zonal flow oscillation frequency is smaller in QHS than Mirror, consistent with reduced radial particle drifts.

*Supported by DOE Grant DE-FG02-93ER54222.

CP11 83 Comparing Turbulent Transport in Quasi-Helically Symmetric and Quasi-Axisymmetric Stellarators* I.J. MCKINNEY, M.J. PUESCHEL, J.N. TALMADGE, D.T. ANDERSON, B.J. FABER, University of Wisconsin-Madison, Madison, Wisconsin, USA H.E. MYNICK, Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA Stellarator optimization of turbulent transport requires designing a magnetic geometry unfavorable to excitation of microinstabilities and turbulence. This work focuses on a comprehensive comparison of two neoclassically optimized configurations, quasi-axisymmetry (NCSX) and quasi-helical symmetry (HSX), using a hierarchy of gyrokinetic models from adiabatic to kinetic electrons to fully electromagnetic physics. Linear simulations of the ion-temperature-gradient-driven mode with gyrokinetic code GENE reveal distinct differences between geometries. There are a significantly greater number of unstable eigenmodes in quasi-helical symmetry, with the long wavelength eigenmodes being more slab-like for quasi-helical symmetry as opposed to toroidal-like for quasi-axisymmetry. Additionally, each configuration has unique finite-\beta and kinetic ballooning characteristics. Nonlinear simulations show key differences in transport levels and scaling between flux tubes in each geometry. These findings inform the next step: changing magnetic geometry to affect microturbulence.

*Supported by DOE Grant DE-FG02-93ER54222.

CP11 84 Laser Blow-Off Impurity Injection Experiments at the HSX Stellarator* J.F. CASTILLO, A. BADER, K.M. LIKIN, D.T. ANDERSON, F.S.B. ANDERSON, S.T.A. KUMAR, J.N. TALMADGE, University of Wisconsin-Madison Results from the HSX laser blow-off experiment are presented and compared to a synthetic diagnostic implemented in the STRAHL impurity transport modeling code in order to measure the impurity transport diffusivity and convective velocity. A laser blow-off impurity injection system is used to rapidly deposit a small, controlled quantity of aluminum into the confinement volume. Five AXUV photodiode arrays are used to take time-resolved measurements of the impurity radiation. The spatially one-dimensional impurity transport code STRAHL is used to calculate a time-dependent plasma emissivity profile. Modeled intensity signals calculated from a synthetic diagnostic code provide direct comparison between plasma simulation and experimental results. An optimization algorithm with impurity transport coefficients acting as free parameters is used to fit the model to experimental data.

*This work is supported by US DOE Grant DE-FG02-93ER54222.

CP11 85 First steps in investigating fast ion confinement on the HSX stellarator* E.M. SCHILLING, K.M. LIKIN, F.S.B. ANDERSON, D.T. ANDERSON, Univ of Wisconsin, Madison The
Helically Symmetric eXperiment (HSX) is a Quasi-Helically Symmetric (QHS) stellarator that has been successfully optimized for improved neoclassical confinement, but fast ion confinement has not yet been investigated. Fast ion studies have been performed on similar experiments, such as the Madison Symmetric Torus (MST) [1] and the Compact Helical System (CHS) [2], but not yet for a QHS geometry. A 20 kV, 0.5 MW, 1.2 ms beam system has been adapted for use on HSX to perform such a study. By calculating the charge exchange and electron/proton impact cross sections for an approximated HSX plasma, a beam attenuation of at least 15% has been predicted. The density of beam ions has then been calculated together with a target ion density assuming some fast ion confinement, and a resulting D-D fusion rate has been predicted to produce no less than $1 \times 10^9$ neutrons/sec overall. Once the beam system is mounted onto HSX, this neutron flux will be measured by a neutron detector and a fast ion confinement time will be inferred. Currently, a test vacuum chamber with basic diagnostics is being constructed to verify the beam’s published performance characteristics.

*Work supported by the US DOE under Grant DE-FG02-93ER54222.


**CP11 86 Development of a limiter imaging system at the Helically Symmetric Experiment**


A visible camera diagnostic has been developed to study the HSX limiter plasma interaction. A straight line view from the camera location to the limiter was not possible due to the complex 3D limiter geometry of HSX, so a mirror/lens system was inserted into the plasma edge. A custom support structure for this optical system tailored to the HSX geometry was designed and installed which allows the system to be inserted and retracted as needed. The camera system has been absolutely calibrated and using H$_\alpha$ and C-III filters, can provide hydrogen and carbon photon fluxes, which through an S/XB coefficient, can be converted into particle fluxes. The resulting measurements have been used to obtain the characteristic penetration length of these species and will in the future be compared to magnetic field line following calculations and plasma edge simulations using EMC3-EIRENE to better understand the physics in the HSX edge.

*Work supported by the US DOE under Grant DE-FG02-93ER54222.

**CP11 87 Improving Coil Designs for the HSX Stellarator with FOCUS**

THOMAS KRUGER, Univ of Wisconsin, Madison
CAOXIANG ZHU, Princeton Plasma Physics Laboratory
AARON BADER, LUQUANT SINGH, DAVID ANDERSON, University of Wisconsin, Madison

We use the FOCUS code to generate improved coil sets for the HSX stellarator. FOCUS produces curves in 3D space to best reproduce a target plasma equilibrium. Unlike similar codes, the curves in FOCUS are not constrained to lie on a user-defined 2D surface. Therefore FOCUS can inherently solve problems such as determining the optimum coil-plasma distance for a given equilibrium. By adjusting the relative weights between a) the match to the plasma boundary, and b) the average coil length. We present the results from FOCUS where we attempt to improve the coil set by moving coils further away to reduce coil ripple, decreasing the number of coils to improve accessibility, and better matching the target plasma surface. We also present results of alternative coil designs with helical and saddle coils.

*Work supported by the US DOE under Grant DE-FG02-93ER54222 and UW Sorden account 233PRJ65ZM.

**CP11 88 Optimizing stellarator coil winding surfaces with Regcoil**

AARON BADER, Univ of Wisconsin, Madison
MATT LANDREMAN, University of Maryland
DAVID ANDERSON, University of Wisconsin, Madison
CHRIS HEGNA, University of Wisconsin, Madison

We show initial attempts at optimizing a coil winding surface using the Regcoil code [1] for selected quasi helically symmetric equilibria. We implement a generic optimization scheme which allows for variation of the winding surface to allow for improved diagnostic access and allow for flexible divertor solutions. Regcoil and similar coil-solving algorithms require a user-input winding surface, on which the coils lie. Simple winding surfaces created by uniformly expanding the plasma boundary may not be ideal. Engineering constraints on reactor design require a coil-plasma separation sufficient for the introduction of neutron shielding and a tritium generating blanket. This distance can be the limiting factor in determining reactor size. Furthermore, expanding coils in other regions, where possible, can be useful for diagnostic and maintenance access along with providing sufficient room for a divertor. We minimize a target function that includes as constraints, the minimum coil-plasma distance, the winding surface volume, and the normal magnetic field on the plasma boundary. Results are presented for two quasi-symmetric equilibria at different aspect ratios.

*Work supported by the US DOE under Grant DE-FG02-93ER54222.

**CP11 89 Application of adjoint methods for stellarator geometry sensitivity using REGCOIL**

ELIZABETH PAUL, MATT LANDREMAN, WILLIAM DORLAND, University of Maryland

A significant challenge to the feasibility of the stellarator is the design of simple coils which allow for diagnostic access and optimal physics properties. REGCOIL [1] employs a Tikhonov regularization approach to compute the current potential on a specified coil winding surface given a desired plasma surface. An objective function, which includes the normal magnetic field on the plasma surface and the squared current density, is minimized by solving a single linear system. This method achieves lower surface-integrated and maximum current potential and normal magnetic field and allows for greater control over the level of regularization than the NESCOIL method. We extend the REGCOIL approach by computing sensitivity of the objective function with respect to coil geometry parameters. We apply an adjoint method, a common technique for shape optimization problems in aerodynamics, allowing the gradients with respect to a large number of control parameters to be computed rapidly. We compute the sensitivity by analytically differentiating the objective function. This extended REGCOIL approach can be applied within an optimization iteration to obtain coil surfaces which better reproduce the desired plasma shape and maximize coil-coil separation.

*Work supported by the US DOE under Grant DE-FG02-93ER54222.

**CP11 90 DISRUPTIONS AND MHD**

**CP11 91 Comparison of Cryogenic Pellet Shatter Theory to Experiments using Disruption Mitigation Pellets**

T. E. GEBHART, S. K. COMBS, S. J. MEITNER, L. R. BAYLOR, Oak Ridge National Laboratory
P. B. PARKS, General Atomic

Mitigating disruptions is essential for high energy density tokamaks such as ITER. The technique of injecting
large shattered cryogenic pellets is presently the best option. To better understand the mitigation of a disruption using shattered pellet injection (SPI), we must better understand the process behind the shattering and subsequent flight of the shattered pellet material. The main questions that are being addressed are 1) what criteria must be met for a pellet to break upon impact with an angled surface? and 2) what is the resulting particle size distribution after shattering? These questions are addressed using theoretical shattering models and comparison with experimental measurements. Solid deuterium, neon, and argon are used in the various phases of disruption mitigation (DM) and thus, an overall model must accommodate the shattering of all mixtures of these gasses. Designs of SPI disruption mitigation systems are heavily influenced by the strategic shattering of pellets just before entering the plasma. Experimental apparatuses that include pellet shatter tubes for JET and DIII-D were tested along with a large pellet, small angle, impact test that has implications for the ITER DM system. Comparison of the shattering measurements with the theoretical models will be shown.

*This abstract has been authored by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the U.S. Department of Energy.

**CP11 92 Simulations of Neon Pellets for Plasma Disruption Mitigation in Tokamaks** NICOLAS BOSVIEL, ROMAN SAMULYAK, Stony Brook University PAUL PARKS, General Atomics Numerical studies of the ablation of neon pellets in tokamaks in the plasma disruption mitigation parameter space have been performed using a time-dependent pellet ablation model based on the front tracking code FronTier-MHD. The main features of the model include the explicit tracking of the solid pellet/ablated gas interface, a self-consistent evolving potential distribution in the ablation cloud, JxB forces, atomic processes, and an improved electrical conductivity model. The equation of state model accounts for atomic processes in the ablation cloud as well as deviations from the ideal gas law in the dense, cold layers of neon gas near the pellet surface. Simulations predict processes in the ablation cloud and pellet ablation rates and address the sensitivity of pellet ablation processes to details of physics models, in particular the equation of state.

**CP11 93 Interpreting Disruption Prediction Models to Improve Plasma Control** MATTHEW PARSONS, University of Illinois at Urbana-Champaign In order for the tokamak to be a feasible design for a fusion reactor, it is necessary to minimize damage to the machine caused by plasma disruptions. Accurately predicting disruptions is a critical capability for triggering any mitigative actions, and a modest amount of attention has been given to efforts that employ machine learning techniques to make these predictions. By monitoring diagnostic signals during a discharge, such predictive models look for signs that the plasma is about to disrupt. Typically these predictive models are interpreted simply to give a ‘yes’ or ‘no’ response as to whether a disruption is approaching. However, it is possible to extract further information from these models to indicate which input signals are more strongly correlated with the plasma approaching a disruption. If highly accurate predictive models can be developed, this information could be used in plasma control schemes to make better decisions about disruption avoidance.

*This work was supported by a Grant from the 2016-2017 Fulbright U.S. Student Program, administered by the Franco-American Fulbright Commission in France.

**CP11 94 Real-time plasma event monitoring on TCV** THOMAS CORNELIS BLANKEN, FEDERICO FELICI, Eindhoven University of Technology, Eindhoven, the Netherlands CRISTIAN GALPERTI, Ecole Polytechnique Federale de Lausanne, SPC-EPFL, Lausanne, Switzerland THE TCV TEAM, THE EURO-FUSION MST1 TEAM A tokamak reactor plasma control system (PCS) supervisor must take decisions about discharge segment scheduling, exception handling (e.g. emergency shutdown), and prioritized control tasks [1], based on chains of plasma events, such as stability limit violations, deviations from target values, and predicted/predicted behavior, and actuator failure [2]. We present first results of a real-time plasma event monitor for NTMs and locked modes on the TCV tokamak. The event monitor contains finite-state automata, with events based on user-defined thresholds on MHD amplitude signals [3]. This work supports the integration of high-level plasma supervision, control and actuator management for disruption avoidance experiments.

*See author list of S. Coda et al., 2017 Nuclear Fusion 57 102011* and author list of “H. Meyer et al., 2017 Nuclear Fusion 57 102014”.


**CP11 95 Disruption Event Characterization and Forecasting in Tokamaks** J. W. BERKERY, S. A. SABBAGH, Y. S. PARK, J. H. AHN, Y. J. JANG, J. D. RIQUEZES, Columbia U S. P. GERHARDT, C. E. MYERS, PPPL The Disruption Event Characterization and Forecasting (DECAF) code, being developed to meet the challenging goal of high reliability disruption prediction in tokamaks, automates data analysis to determine chains of events that lead to disruptions and to forecast their evolution. The relative timing of magnetohydrodynamic modes and other events including plasma vertical displacement, loss of boundary control, proximity to density limits, reduction of safety factor, and mismatch of the measured and desired plasma current are considered. NSTX-U databases are examined with analysis expanding to DIII-D, KSTAR, and TCV. Characterization of tearing modes has determined mode bifurcation frequency and locking points. In an NSTX database exhibiting unstable resistive wall modes (RWM), the RWM event and loss of boundary control event were found in 100%, and the vertical displacement event in over 90% of cases. A reduced kinetic RWM stability physics model [1] is evaluated to determine the proximity of discharges to marginal stability. The model shows high success as a disruption predictor (greater than 85%) with relatively low false positive rate.

*Supported by US DOE Contracts DE-FG02-99ER54524, DE-AC02-09CH11466, and DE-SC0016614.


**CP11 96 Studies of the DIII-D disruption database using Machine Learning algorithms** CRISTINA REA, ROBERT GRANETZ, Massachusetts Institute of Technology ORSO MENEGHINI, General Atomics A Random Forests Machine Learning algorithm, trained on a large database of both disruptive and non-disruptive DIII-D discharges, predicts disruptive behavior in DIII-D with about 90% of accuracy. Several algorithms have been tested and Random Forests was found superior in performances for this particular task. Over 40 plasma parameters are included in the database, with data for each of the parameters taken from ~500k time slices. We focused on a subset of non-dimensional plasma parameters, deemed to be good predictors based on physics considerations. Both binary (disruptive/non-disruptive) and multi-label (label based on the elapsed time before disruption) classification...
problems are investigated. The Random Forests algorithm provides insight on the available dataset by ranking the relative importance of the input features. It is found that $q_{95}$ and Greenwald density fraction ($n/n_c$) are the most relevant parameters for discriminating between DIII-D disruptive and non-disruptive discharges. A comparison with the Gradient Boosted Trees algorithm is shown and the first results coming from the application of regression algorithms are presented.

*Work supported by the US Department of Energy under DE-FC02-04ER54698, DE-SC0014264 and DE-FG02-95ER54309.

CP11 97 Disruption Warning Database Development and Exploratory Machine Learning Studies on Alcator C-Mod* KEVIN MONTES, CRISTINA REA, ROBERT GRANETZ, MIT Plasma Science and Fusion Center A database of about 1800 shots from the 2015 campaign on the Alcator C-Mod tokamak is assembled, including disruptive and non-disruptive discharges. The database consists of ~40 relevant plasma parameters with data taken from ~160k time slices. In order to investigate the possibility of developing a robust disruption prediction algorithm that is tokamak-independent, we focused machine learning studies on a subset of dimensionless parameters such as $\beta_p$, $n/n_c$, etc. The Random Forests machine learning algorithm provides insight on the available data set by ranking the relative importance of the input features. Its application on the C-Mod database, however, reveals that virtually no one parameter has more importance than any other, and that its classification algorithm has a low rate of successfully predicted samples, as well as poor false positive and false negative rates. Comparing the analysis of this algorithm on the C-Mod database with its application to a similar database on DIII-D, we conclude that disruption prediction may not be feasible on C-Mod. This conclusion is supported by empirical observations that most C-Mod disruptions are caused by radiative collapse due to molybdenum from the first wall, which happens on just a 1-2ms timescale.

*Supported by the US Dept. of Energy under DE-FC02-99ER54512 and DE-FC02-04ER54698.

CP11 98 Development of a 1.5D plasma transport code for coupling to full orbit runaway electron simulations* J.D. LORE, D. DEL CASTILLO-NEGRETET, L. BAYLOR, L. CARBAJAL, ORNL A 1.5D (1D radial transport + 2D equilibrium geometry) plasma transport code is being developed to simulate runaway electron generation, mitigation, and avoidance by coupling to the full-orbit kinetic electron transport code KORC [1]. The 1.5D code solves the time-dependent 1D flux surface averaged transport equations with sources for plasma density, pressure, and poloidal magnetic flux, along with the Grad-Shafranov equilibrium equation for the 2D flux surface geometry. Disruption mitigation is simulated by introducing an impurity neutral gas ‘pellet’, with impurity densities and electron cooling calculated from ionization, recombination, and line emission rate coefficients. Rapid cooling of the electrons increases the resistivity, inducing an electric field which can be used as an input to KORC. The runaway electron current is then included in the parallel Ohm’s law in the transport equations. The 1.5D solver will act as a driver for coupled simulations to model effects such as timescales for thermal quench, runaway electron generation, and pellet impurity mixtures for runaway avoidance. Current progress on the code and details of the numerical algorithms will be presented.

*Work supported by the US DOE under DE-AC05-00OR22725.


CP11 99 Lifetime and Universal Distribution of the Seed Runaway Electrons ADRIAN FONTANILLA, BORIS BREIZMAN, Institute of Fusion Studies, University of Texas at Austin The lifetime (LT) of pre-existing runaway electrons (RE) determines how likely the RE will undergo avalanche multiplication. We calculate the LT of RE via the kinetic equation (KE). We show that the rate of thermalization of RE depends on the value of the parameter $\alpha \equiv (Z + 1)/\sqrt{\tau_{rad}}$ (where $\tau_{rad}$ is the synchrotron time scale normalized to the collisional and $Z$ is the ion charge) compared to the electric field. We identify two cases where the rate is slow enough to enable a transformation of the KE into an eigenequation; the eigenfunction typifies the shape of the distribution function and the eigenvalue is the LT. In one case, $\alpha^2 \ll 1$: the field required to sustain the pre-existing runaways is barely larger than the Connor-Hastie field, $E_c$. In the second case, $\alpha^2 \gg 1$: the requisite field is much greater than $E_c$. The largeness of the field in this case enables us to universalize the KE via rescaling procedure.


CP11 100 Topological Dependence of Runaway Avalanche Threshold in Momentum Space* CHRISTOPHER MCDEVITT, ZEHUA GUO, XIAN-ZHU TANG, Los Alamos National Laboratory A detailed study of the physics responsible for the formation of an avalanche instability of runaway electrons is carried out. A set of large-angle collision operators of varying complexity, ranging from a simple source term to a novel energy-momentum conserving form, are developed and implemented. The use of a conservative form allows for the back reaction of the secondary electrons onto the primary electrons to be accounted for. The incorporation of this feedback process requires the modification of the Coulomb logarithm in order to avoid double counting collisions. A systematic procedure for delineating small and large angle collisions, and thus avoiding the double counting of collisions, is developed. It is found that the avalanche threshold is tightly linked to the merger of an O and X point in the momentum space of the primary electrons. Such a close correlation is shown to be largely independent of the details of the large-angle collision operator employed, and thus provides a robust indicator of an avalanche instability.

*This work was supported by DOE OFES and ASCR under SCREAM SciDAC project.

CP11 101 Suppression of high-energy electrons generated in both disrupting and sustained MST tokamak plasmas* M.D. PANDYA, B.E. CHAPMAN, University of Wisconsin-Madison S. MUNARETTO, General Atomics B.S. CORNILLE, K.J. MCCOL-LAM, C.R. SOVINEc, University of Wisconsin-Madison A.M. DUBOIS, Tri Alpha Energy A.F. ALMAGRI, J.A. GOETZ, University of Wisconsin-Madison High-energy electrons appearing during MST tokamak plasma disruptions are rapidly lost from the plasma due apparently to internal MHD activity. Work has just recently begun on generating and diagnosing disruptions in MST tokamak plasmas. Initial measurements show the characteristic drop in central temperature and density preceding a quench of the plasma current. This corresponds to a burst of dominantly $n=1$ MHD activity, which is accompanied by a short-lived burst of high-energy electrons. The short-lived nature of these electrons is suspected to be due...
to stochastic transport associated with the increased MHD. Earlier work shows that runaway electrons generated in low density, sustained plasmas are suppressed by a sufficiently large m=3 RMP in plasmas with q(a)<3. RMPs of various poloidal mode number can be generated with an array of saddle coils wound around the vertical insulated gap in MST’s thick conducting shell. With an m=3 RMP, the degree of runaway suppression increases with RMP amplitude, while an m=1 RMP has little effect on the runaways[1]. Nonlinear MHD modeling with NIMROD of these MST plasmas indicates increased stochasticity with an m=3 RMP, while no such increase in stochasticity is observed with an m=1 RMP.

*Work supported by US DOE.

1S. Munaretto et al., PoP in preparation.

**CP11 102 Nonlinear Fluid Model Of 3-D Field Effects In Tokamak Plasmas** J D CALLEN, C C HEGNA, M T BEIDLER, University of Wisconsin-Madison

Extended MHD codes (e.g., NIMROD, M3D-C1) are beginning to explore nonlinear effects of small 3-D magnetic fields on tokamak plasmas. To facilitate development of analogous physically understandable reduced models, a fluid-based dynamic nonlinear model of these added 3-D field effects in the base axisymmetric tokamak magnetic field geometry is being developed. The model incorporates kinetic-based closures within an extended MHD framework. Key 3-D field effects models that have been developed include: 1) a comprehensive modified Rutherford equation for the growth of a magnetic island that includes the classical tearing and NTM perturbed bootstrap current drives, externally applied magnetic field and current drives, and classical and neoclassical polarization current effects, and 2) dynamic nonlinear evolution of the plasma toroidal flow (radial electric field) in response to the 3-D fields. An application of this model to RMP ELM suppression precipitated by an ELM crash [1] will be discussed.

*Supported by Office of Fusion Energy Sciences, Office of Science, Dept. of Energy Grants DE-FG02-86ER53218 and DE-FG02-92ER54139.


**CP11 103 Nonlinear Modeling of Forced Magnetic Reconnection with Transient Perturbations** MATTHEW T BEIDLER, JAMES D CALLEN, CHRIS C HEGNA, CARL R SOVINEC, University of Wisconsin-Madison

Externally applied 3D magnetic fields in tokamaks can penetrate into the plasma and lead to forced magnetic reconnection, and hence magnetic islands, on resonant surfaces. Analytic theory has been reasonably successful in describing many aspects of this paradigm with regard to describing the time asymptotic-steady state [1]. However, understanding the nonlinear evolution into a low-slip, field-penetrated state, especially how MHD events such as sawteeth and ELMs precipitate this transition, is in its early development. We present nonlinear computations employing the extended-MHD code NIMROD, building on previous work [2] by incorporating a temporally varying external perturbation as a simple model for an MHD event that produces resonant magnetic signals. A parametric series of proof-of-principle computations and accompanying analytical theory characterize the transition into a mode-locked state with an emphasis on detailing the temporal evolution properties.

*Supported by DOE OFES Grants DE-FG02-92ER54139, DE-FG02-86ER53218, and the U.S. DOE FES Postdoctoral Research program administered by ORISE and managed by ORAU under DOE contract DE-SC0014664.


**CP11 104 Algebraic motion of vertically displacing plasmas** AMITAVA BHATTCHARJEE, DAVID PFEFFERLE, EERO HIRVIJOKI, PPPL

The vertical displacement of tokamak plasmas is modelled during the non-linear phase by a free-moving current-carrying rod coupled to a set of fixed conducting wires and a cylindrical conducting shell. The models capture the leading term in a Taylor expansion of the Green’s function for the interaction between the plasma column and the vacuum vessel. The plasma is assumed not to vary during the VDE such that it behaves as a rigid body.

In the limit of perfectly conducting structures, the plasma is prevented from coming in contact with the wall due to steep effective potential barriers by the eddy currents, and will hence oscillate at Alfvénic frequencies about a given force-free position. In addition to damping oscillations, resistivity allows for the column to drift towards the vessel on slow flux penetration timescales. The initial exponential motion of the plasma, i.e. the resistive vertical instability, is succeeded by a non-linear sinking behaviour, that is shown analytically to be algebraic and decelerative. The acceleration of the plasma column often observed in experiments is thus conjectured to originate from an early sharing of toroidal current between the core, the halo plasma and the wall or from the thermal quench dynamics precipitating loss of plasma current.

**CP11 105 Model of vertical plasma motion during the current quench** BORIS BREIZMAN, Institute for Fusion Studies, The University of Texas at Austin

DMITRII KIRAMOV, Kurchatov Institute, Moscow, Russia

Tokamak disruptions impair plasma position control, which allows the plasma column to move and hit the wall. These detrimental events enhance thermal and mechanical loads due to halo currents and runaway electron losses. Their fundamental understanding and prevention is one of the high-priority items for ITER. As commonly observed in experiments, the disruptive plasma tends to move vertically, and the timescale of this motion is rather resistive than Alfvénic. These observations suggest that the plasma column is nearly force-free during its vertical motion. In fact, the force-free constraint is already used in disruption simulators. In this work, we consider a geometrically simple system that mimics the tokamak plasma surrounded by the conducting structures. Using this model, we highlight the underlying mechanism of the vertical displacement events during the current quench phase of plasma disruption. We also address a question of ideal MHD stability of the plasma during its resistive motion.

*Work supported by the U.S. Department of Energy Contracts DEFG02-04ER54742 and DE-SC0016283.

**CP11 106 Model Development for VDE Computations in NIMROD** K. J. BUNKERS, C. R. SOVINEC, Univ of Wisconsin, Madison

Vertical displacement events (VDEs) and the disruptions associated with them have potential for causing considerable physical damage to ITER and other tokamak experiments. We report on simulations of generic axisymmetric VDEs and a vertically unstable case from Alcator C-MOD using the NIMROD code [1]. Previous calculations have been done with closures for heat flux and viscous stress. Initial calculations show that halo current width is dependent on temperature boundary conditions, and so transport together with plasma-surface interaction may play a role in determining halo.
currents in experiments. The behavior of VDEs with Braginskii thermal conductivity and viscosity closures and Spitzer-like resistivity are investigated for both the generic axisymmetric VDE case and the C-MOD case.

“This effort is supported by the U.S. Dept. of Energy, Award Numbers DE-FG02-06ER54850 and DE-FC02-08ER54975.


CP11 107 Computations of Vertical Displacement Events with Toroidal Asymmetry∗ C. R. SOVINEC, K. J. BUNKERS, University of Wisconsin-Madison Nonlinear numerical MHD modeling with the NIMROD code [https://nimrodteam.org] is being developed to investigate asymmetry during vertical displacement events. We start from idealized up/down symmetric tokamak equilibria with small levels of imposed toroidally asymmetric field errors. Vertical displacement results when removing current from one of the two divertor coils. The Eulerian reference-frame modeling uses temperature-dependent resistivity and anisotropic thermal conduction to distinguish the hot plasma region from surrounding cold, low-density conditions. Diffusion through a resistive wall is slow relative to Alfvénic scales but much faster than resistive plasma diffusion. Loss of the initial edge pressure and current distributions leads to a narrow layer of parallel current, which drives low-n modes that may be related to peeling-dominated ELMs. These modes induce toroidal asymmetry in the conduction current, which connects the simulated plasma to the wall.

“Work supported by the US DOE through Grant Numbers DE-FG02-06ER54850 and DE-FC02-08ER54975.

CP11 108 Mechanism for destabilization of ideal ballooning modes in a 3D tokamak.∗ T B COTE, C C HEGNA, Univ of Wisconsin-Madison M WILLENSDORFER, E STRUMBERGER, W SUTTROP, H ZOHM, Max Planck Institute for Plasma Physics ASDEX UPGRADE TEAM Recent observations on ASDEX-Upgrad have shown toroidally localized MHD activity in the presence of applied 3D fields [1]. In this study, we investigate the physical mechanisms that determine this result with an emphasis on 3D shaping. Experimentally relevant 3D VMEC equilibria are analyzed to determine stability in the edge pedestal region, and the ballooning mode is found to localized at specific field-lines corresponding to minima in the local magnetic shear. 3D distortion of the flux surfaces cause significant change in the normal torsion, a key component of the local shear, and act as the primary mechanism for ballooning destabilization on certain field-lines. The degree of localized ballooning instability is shown to scale with the amplitude of the 3D displacement through its effect on the local shear.

“Supported by US DOE under Grant Numbers DE-FG02-86ER53218 and DE-FG02-92ER54139.


CP11 109 Nonlinear Plasma Response to Resonant Magnetic Perturbation in Rutherford Regime∗ PING ZHU, University of Science and Technology of China, University of Wisconsin-Madison XINGTING YAN, WENLONG HUANG, University of Science and Technology of China Recently a common analytic relation for both the locked mode and the nonlinear plasma response in the Rutherford regime has been developed based on the steady-state solution to the coupled dynamic system of magnetic island evolution and torque balance equations. The analytic relation predicts the threshold and the island size for the full penetration of resonant magnetic perturbation (RMP). It also rigorously proves a screening effect of the equilibrium toroidal flow. In this work, we test the theory by solving for the nonlinear plasma response to a single-helicity RMP of a circular-shaped limited tokamak equilibrium with a constant toroidal flow, using the initial-value, full MHD simulation code NIMROD. Time evolution of the parallel flow or “slip frequency” profile and its asymptotic approach to steady state obtained from the NIMROD simulations qualitatively agree with the theory predictions. Further comparisons are carried out for the saturated island size, the threshold for full mode penetration, as well as the screening effects of equilibrium toroidal flow in order to understand the physics of nonlinear plasma response in the Rutherford regime.

∗Supported by National Magnetic Confinement Fusion Science Program of China Grants 2014GB124002 and 2015GB101004, the 100 Talent Program of the Chinese Academy of Sciences, and U.S. Department of Energy Grants DE-FG02-86ER53218 and DE-FC02-08ER54975.

CP11 110 Effects of Toroidal Rotation on Neoclassical Toroidal Viscosity Torque in Tokamak Edge Pedestal Induced by Resonant Magnetic Perturbation∗ XINGTING YAN, University of Science and Technology of China PING ZHU, University of Science and Technology of China, University of Wisconsin-Madison Previous analysis for static tokamak equilibria indicates that the neoclassical toroidal viscosity (NTV) torque in edge pedestal region induced by external resonant magnetic perturbation (RMP) can reach the same order of magnitude as other momentum sources such as neutral beam injections [1]. However, toroidal rotation often persists in tokamak experiments, especially in the edge pedestal region. How the edge rotations may affect the NTV torque remains an open question. In this work, we evaluate the influence of toroidal rotation on NTV torque in the edge pedestal region, using the method developed in previous work [1]. We find that toroidal rotation can modify not only the magnitude, but more importantly, also the profile of NTV torque significantly. Even for a rigid toroidal rotation, as its magnitude increases, the peak value of NTV torque decreases, whereas its peak location moves towards the core region. The detailed comparisons of NTV torque for different toroidal rotation magnitudes and profiles, in terms of its significance in the edge pedestal region, will be reported and discussed.

∗Supported by the National Magnetic Confinement Fusion Science Program of China under Grant Nos. 2014GB124002 and 2015GB101004, and the 100 Talent Program of the Chinese Academy of Sciences.


CP11 111 A Model of Energetic Ion Effects on Pressure Driven Tearing Modes in Tokamaks∗ M.R. HALFMOON, Univ of Tulsa D.P. BRENNAN, Princeton University A.J. COLE, Columbia University J.M. FINN, Tibbar Plasma Technologies An analytic, reduced cylindrical model of linear resistive tearing modes, taking into account the effect of a high-energy, non-Maxwellian ion population as a perturbation in pressure, is applied to study the stability of high aspect ratio tokamak equilibria. The model captures the essential physics driving or damping the modes through variations in the magnetic shear. We focus on the stability of the $m/n = 2/1$ tearing mode. The drift-kinetic motion of high-energy ions is modeled after a method discussed by Hu and Betti [1], and entered into an asymptotic matching formalism for the resistive MHD dispersion relation.
CP11 112 Identifying the interaction mechanisms between the tearing mode and drift-wave turbulence* S.D. JAMES, University of Tulsa D.P. BRENNAN, Princeton University C. HOLLAND, University of California, San Diego We present nonlinear simulations of a three-field model evolving density, vorticity, and magnetic flux in a slab geometry. Drift wave turbulence is driven by an equilibrium density gradient, extending throughout the domain while a magnetic island can be driven unstable at a rational surface in the center of the domain. We utilize an equilibrium with prescribed tearing stability properties and turbulent drives. The results show the stability of the tearing mode is affected by the presence of the turbulence and the energy transport between them is discussed in the context of a turbulent resistivity. Nonlinear island widths are presented as a function of the tearing mode stability parameter, $\Delta$, and the equilibrium density gradient. The threshold for significant nonlinear growth of the tearing mode is modified by the background flow and turbulence, and the nonlinear saturated states of the island become oscillatory in the turbulent fields.

*Supported by US DOE Grant DE-SC0010520.

CP11 113 A Novel Kinetic Electron Model for Tearing Mode in Magnetic Confined Plasmas DONGJIAN LIU, Sichuan University JIAN BAO, ZHIHONG LIN, University of California, Irvine, TAO HAN, Sichuan University GTC TEAM. GTC TEAM Compared with the fluid simulation, kinetic simulation of the collisionless tearing mode has been performed via a novel kinetic electron model. Based on the Gyrokinetic Toroidal Code simulation, the new electron model can not only recover the linear behavior of collisionless tearing mode, but also show great computational advantages in the kinetic simulation of long wavelength magnetohydrodynamic (MHD) and short wavelength drift-Alfvenic instabilities.

CP11 114 Magnetic flux pumping mechanism prevents sawtoothing in 3D nonlinear MHD simulations of tokamak plasmas ISABEL KREBS, Max-Planck/Princeton Research Center for Plasma Physics STEPHEN C. JARDIN, Princeton Plasma Physics Laboratory SIBYLLE GUENTER, KARL LACKNER, MATTHIAS HOELZL, ERIKA STRUMBERGER, Max Planck Institute for Plasma Physics, Garching, Germany NATE FERRARO, Princeton Plasma Physics Laboratory 3D nonlinear MHD simulations of tokamak plasmas have been performed in toroidal geometry by means of the high-order finite element code M3D-C1 [1]. The simulations are set up such that the safety factor on axis ($q_a$) is driven towards values below unity. As reported in [2] and [3] the resulting asymptotic states either exhibit sawtooth-like reconnection cycling or they are sawtooth-free. In the latter cases, a self-regulating magnetic flux pumping mechanism, mainly provided by a saturated quasi-interchange instability via a dynamo effect, redistributes the central current density so that the central safety factor profile is flat and $q_a \approx 1$. Sawtoothing is prevented if $\beta$ is sufficiently high to allow for the necessary amount of flux pumping to counterbalance the tendency of the current density profile to centrally peak. We present the results of 3D nonlinear simulations based on specific types of experimental discharges and analyze their asymptotic behavior. A set of cases is presented where aspects of the current ramp-up phase of Hybrid ASDEX Upgrade discharges are mimicked. Another set of simulations is based on low-$q_{edge}$, discharges in DIII-D.

$\beta$ Krebs et al., submitted to Phys. Plasmas.

CP11 115 3D nonlinear modeling of the coupling and phase locking of magnetic Islands in tokamaks* STEPHEN JARDIN, NATHANIEL FERRARO, JIN CHEN, DAVID PFEFFERLE, Princeton Plasma Phys Lab. Many tokamak discharges develop multiple tearing modes possessing different mode numbers. These modes are observed to phase lock to one another, resulting in a flattening of the core toroidal plasma rotation profile, which can have deleterious effects on transport and MHD stability. In order to study these phenomena with minimum assumptions, we use the M3D-C1 3D nonlinear MHD code to perform initial value simulations of the evolution of equilibria unstable to both the 2/1 and 3/2 modes, but having sheared toroidal rotation. Initial attempts to perform these simulations led to numerical instabilities developing once the islands got to a certain size. In order to study the cause of this instability, we developed a small model code that solves a pure convection equation in 1D. We find that an implicit Crank-Nicholson method in time and Hermite Cubic finite elements (as are used in the toroidal direction in the M3D-C1 code) is not a convergent algorithm. Adding a small second order diffusion term, proportional to the velocity, improves the numerical stability properties but is not convergent in the first-derivative of the solution. Instead, adding a much smaller forth-order spatial derivative term proportional to the velocity leads to an algorithm in which both the solution and the first derivative converge as $1/N^2$. Adding similar toroidal forth derivative terms to the M3D-C1 code eliminated the numerical instability.

*This work was supported by US DOE Contract DE-AC02-09-CH11466.

CP11 116 Modeling Error Fields and Disruptions in NSTX-U* N.M. FERRARO, C.E. MYERS, J.-K. PARK, D. PFEFFERLE, S.C. JARDIN, PPL M.T. BEIDLER, U. WISCONSIN, Madison M.L. REINKE, ORNL. Error field penetration and mode locking are among the most common sources of disruptions in tokamaks, and may also play an important role in the suppression of edge-localized modes (ELMs). Results from NSTX-U operations suggest that error fields may have had a considerable impact on plasma stability and transport, with locked modes commonly observed in L-mode discharges. We present models of error fields due to imperfections in the toroidal and poloidal field coils in NSTX-U, and consider the impact of these fields on the plasma equilibrium, including the impact on the magnetic pitch angle and heat flux at the divertor targets in high-performance NSTX-U model equilibria. Furthermore, we report on progress in modeling the nonlinear processes of error field penetration and disruptions with the extended-MHD code M3D-C1, with the goal developing predictive models of the processes by which error field penetration leads to disruptions or ELM suppression.

*This work was supported by US DOE Contract DE-AC02-09-CH11466 and the SciDAC Center for Extended MHD Modeling.
CP11 117 Poloidal structure of the plasma response to $n = 1$ Resonant Magnetic Perturbations in ASDEX Upgrade - L. MARRELLI, P. BETTINI, P. PIOVESAN, D. TERRANOVA, Consorzio RFX, Italy L. GIANNONE, V. IOGCHINE, M. MARASCHEK, W. SUTTROP, M. TESCHKE, Max-Planck-Institut fur Plasmas Physik, Garching, Germany Y.Q. LIU, CCFE, Culham Science Centre, UK D. RYAN, Department of Physics, University of York, UK EUROFUSION MISTI TEAM,* ASDEX UPGRADE TEAM The hybrid scenario, a candidate for high-beta steady-state tokamak operations, becomes highly sensitive to 3D magnetic field near the no-wall limit. A predictive understanding of the plasma response to 3D fields near ideal MHD limits in terms of validated MHD stability codes is therefore important in order to safely operate future devices. Slowly rotating ($5 - 10$ Hz) $n = 1$ external magnetic fields have been applied in hybrid discharges in ASDEX Upgrade for an experimental characterization: the global $n = 1$ kink response has been measured by means of SXR and complete poloidal arrays of $b_0$ probes located at different toroidal angles and compared to predictions of MHD codes such as MARS-F and V3FIT-VMEC. A Least-Squares Spectral Analysis approach has been developed together with a Monte Carlo technique to extract the small plasma response and its confidence interval from the noisy magnetic signals. MARS-F correctly reproduces the poloidal structure of the $n = 1$ measurements: for example, the dependence of the dominant poloidal mode number at the plasma edge from $q_{95}$ is the same as in the experiment. Similar comparisons with V3FIT-VMEC will be presented.

*See author list of “H. Meyer et al. 2017 Nucl. Fusion 57 102014”.

CP11 118 Plasma response model to resonant magnetic perturbations - MARISA ROBERTO, Instituto Tecnologico de Aeroautica, Sao Jose dos Campos, Brazil ANDRE CARLOS FRAILE JUNIOR, Instituto Tecnologico de Aeronautica, Instituto de Estudos Avancados, Divisao de Aerotermodinamica de Hipersonica IBERE LUIZ CALDAS, Universidade de Sao Paulo, Instituto de Fisica, Sao Paulo, Brazil Magnetically confined plasmas in tokamaks usually do not operate under equilibrium conditions and high temperature particles are transported to the reactor wall, causing its erosion. External resonant windings or coils can be used to generate a perturbative magnetic field that modifies particle transport near the plasma border. A pair of helical wires placed at the reactor external wall is used to create a resonant magnetic perturbation (RMP) capable of reducing the amount of particles colliding with the wall. However, the plasma is also affected by RMPs and it modifies the magnetic field lines. In this work, a semi-analytical model in polar toroidal coordinates was developed to study the plasma response, which has been modeled as a helical current sheet at the resonant surface with the condition that the total radial magnetic field vanishes at this surface. This condition is associated to the mitigation of magnetic islands around the resonant surface. Poincaré plots have shown that the plasma response regularizes the magnetic field lines around the resonant surface.

CP11 119 Tearing mode dynamics and sawtooth oscillation in Hall-MHD* ZHIWEI MA, WEI ZHANG, SHENG WANG, Zhejiang Univ Tearing mode instability is one of the most important dynamic processes in space and laboratory plasmas. Hall effects, resulted from the decoupling of electron and ion motions, could cause the fast development and perturbation structure rotation of the tearing mode and become non-negligible. We independently developed high accuracy nonlinear MHD code (CLT) to study Hall effects on the dynamic evolution of tearing modes with Tokamak geometries. It is found that the rotation frequency of the mode in the electron diamagnetic direction is in a good agreement with analytical prediction. The linear growth rate increases with increase of the ion inertial length, which is contradictory to analytical solution in the slab geometry. We further find that the self-consistently generated rotation largely alters the dynamic behavior of the double tearing mode and the sawtooth oscillation.

*National Magnetic Confinement Fusion Science Program of China under Grant No. 2013GB104004 and 2013GB111004.

CP11 120 Pfirsch-Schluter Current in and near a Magnetic Island: Singular Behavior and Symmetry Effects.* ALLAN REIMAN, Princeton Plasma Phys Lab DHANUSH RADHAKRISHNAN, NYU The current along magnetic field lines that enforces quasi-neutrality is called the “Pfirsch-Schluter current”. We show that the Pfirsch-Schluter current has, in general, a logarithmic singularity at the X-line of a magnetic island separatrix if $\nabla \cdot \mathbf{j}_n$ is nonzero there. The singular component of the Pfirsch-Schluter current vanishes if the configuration is stellarator symmetric about a point on the X-line. (Symmetric with respect to simultaneous reflection in the poloidal and toroidal angles.) We consider, in particular, the case where $\mathbf{j}_n$ is determined by the MHD equilibrium force-balance equation and the pressure gradient is determined by a diffusion equation. There is a critical scale length, $\chi_c$, determined by the ratio of the perpendicular and parallel diffusion coefficients, such that the pressure is not flattened on flux surfaces within a distance of order $\chi_c$ about the X-line. The variation of pressure on flux surfaces in that region leads to a nonzero $\nabla \cdot \mathbf{j}_n$ at the X-line, and a large Pfirsch-Schluter current near the X-line. This is a significant piece of physics that is absent in analytical calculations for perturbed cylindrical models having a single resonant Fourier component, and in 3D codes that have no variation in pressure within their flux surfaces.

*This work was supported by DOE Contracts Nos. DEAC02-76CH03073 and DE-AC02-09CH1146.

CP11 121 Influence of toroidal rotation on tearing modes? HUISHAN CAI, University of Science and Technology of China JINTAO CAO, DING LI, Institute of Physics Tearing modes stability analysis including toroidal rotation is studied. It is found that rotation affects the stability of tearing modes mainly through the interaction with resistive inner region of tearing mode. The coupling of magnetic curvature with centrifugal force and Coriolis force provides a perturbed perpendicular current, and a return parallel current is induced to affect the stability of tearing modes. Toroidal rotation plays a stable role, which depends on the magnitude of Mach number and adiabatic index $\Gamma$, and is independent on the direction of toroidal rotation. For $\Gamma > 1$, the scaling of growth rate is changed for typical Mach number in present tokamaks. For $\Gamma = 1$, the scaling keeps unchanged, and the effect of toroidal rotation is much less significant, compared with that for $\Gamma > 1$.


1Huishan Cai, Jintao Cao, and Ding Li, Nucl. Fusion 57, 056006 (2017).

CP11 122 Tearing mode dynamics in the RFX-mod tokamak - LUIGI CORDARO, PAOLO ZANCA, MATTEO ZUIN, FULVIO AURIEMMA, EMILIO MARTINES, BARBARA ZAN- IOL, Consorzio RFX, Corso Stati Uniti 4, Padova, Italy GIANLUCA PUCELLA, Centro Ricerche Energia ENEA Frascati, Fras-
CP11 123 Effect of Gyroviscosity on Tearing Modes in Tokamak Plasmas* RYAN WHITE, MIT Plasma Science and Fusion Center ALAN GLASSER, Fusion Theory and Computation, Inc

We present an extension of the Glasser-Greene-Johnson equations, incorporating the Braginskii gyroviscosity. It is found that the dominant terms from the gyroviscous stress are all due to poloidal variation of the equilibrium profile, implying that these physical effects are not captured in a large-aspect-ratio (cylindrical) model. Because these purely toroidal contributions dominate, we conclude that the well-known "gyroviscous cancellation" is a higher-order effect in toroidal confinement systems. We also present preliminary numerical results showing the effect of gyroviscosity on tearing mode stability.

*ORISE/DOE Fusion Energy Sciences Postdoctoral Fellowship.

CP11 124 Verification of kinetic/MHD hybrid simulation of neoclassical tearing mode in fusion plasmas KADIE WANG, CHIJIE XIAO, Peking University WENLU ZHANG, Chinese Academy of Sciences ZHIBONG LIN, University of California, Irvine XIAO QUAN, Southern Institute of Physics Simulations and predictions of the excitation threshold of neoclassical tearing mode (NTM) are challenges, since the excitation threshold depends on large-scale MHD instabilities, collisional transport, microturbulence, and energetic particle effects, etc. A hybrid simulation of NTM with gyrokinetic ions and fluid electrons has been developed and verified in the gyrokinetic toroidal code (GTC) to study this problem. An extra pressure transport equation is included to cover the pressure fattening effect. The bootstrap current is included with a simple model, \( j_{bs} = -1.46 \frac{\beta}{\sqrt{\rho}} \). In the fluid limit, it is verified that the linear growth rate of NTM is proportional to the poloidal beta \( \beta_p \) when the equilibrium profiles are fixed, and the linear and nonlinear simulation results of NTM are compared with theory and quantitatively agree with the modified Rutherford equation. The kinetic effects of thermal ions are found to reduce the linear growth rates of NTM and the finite Larmor radius effects of thermal ions have little impacts on NTM.

CP11 125 Kinetic Effects on Resistive Tearing Mode and Drift Tearing mode HAO SHI, University of Science and Technology of China WENLU ZHANG, Institute of Physics, Chinese Academy of Sciences

The kinetic effects on stability of resistive tearing mode are investigated by global simulations in cylindrical geometry using Gyrokinetic Toroidal Code (GTC). The fluid simulation of resistive tearing mode agrees well with theory prediction. Kinetic effects are found to reduce the growth rate of the tearing mode and the radial width of mode structure. The drift-tearing mode is obtained when considering density gradient, which has the frequency of the diamagnetic drift frequency. The decrease of growth rate due to the diamagnetic drift motion is observed, which agrees well with the derivation of theory. Besides, the radial mode width of the drift tearing mode is wider.

CP11 126 Two-fluid modifications on the Kelvin-Helmholtz instability in a Tokamak Plasma OMAR LOPEZ ORTIZ, LUCA GUAZZOTTO, Auburn Univ.

In a two-fluid magnetohydrodynamical description of axisymmetric equilibria stream surfaces do not exactly overlap with flux surfaces; instead, there is a relative shift which is proportional to the toroidal flow. In a reduced massless electrons scenario it is the ion’s poloidal velocity which possesses a finite component perpendicular to magnetic surfaces. Starting from a self-consistent, single-fluid analytical equilibrium derived for a high-beta, high-aspect ratio configuration with sheared flows, we obtain the two-fluid normal component of the velocity perturbatively and benchmark it against the code FLOW2 [1]. We explore the modifications that the normal component of the velocity causes for the development of a Kelvin-Helmholtz instability driven by a sheared toroidal flow.


CP11 127 Nonlinear GAM and lower kinetic TAE generation by TAE* ZHIYONG QIU, Zhejiang University LIU CHEN, Zhejiang University and UC Irvine FULVIO ZONCA, ENEA, Italy

The decay of toroidal Alfén eigenmode (TAE) [1] into a geodesic acoustic mode (GAM) [2] and a heavily damped lower kinetic TAE (LKTAE) [3], is investigated as possible mechanism for TAE saturation using nonlinear gyrokinetic theory. The equations describing the nonlinear interactions among TAE, GAM and LKTAE are derived analytically, and exhibit an interesting analogy to those describing convective cells generation by kinetic Alfén waves [4]. It is shown that the decay is induced by the anti-Hermitian part of the LKTAE dispersion function due to its strong radiative damping, analogous to the scattering due to heavilyLandau damped ion quasi-modes. Control parameters regulating the nonlinear decay are discussed. Possible diagnostics are also suggested for the experimental verification of the nonlinear process analyzed here.


Surface currents on the plasma-vacuum interface in MHD equilibria

JAMES HANSON, Auburn University

The VMEC non-axisymmetric MHD equilibrium code can compute free-boundary equilibria [1]. Since VMEC assumes that magnetic fields within the plasma form closed and nested flux surfaces, the plasma-vacuum interface is a flux surface, and the total magnetic field there has no normal component. VMEC imposes this condition of zero normal field using the potential formulation of Merkel [2], and solves a Neumann problem for the magnetic potential in the exterior region. This boundary condition necessarily admits the possibility of a surface current on the interface. While this surface current may be small in MHD equilibrium, it is readily computed in terms of the magnetic potentials in both the interior and exterior regions, evaluated on the surface. If only the external magnetic potential is known (as in VMEC), then the surface current can be computed from the discontinuity of the tangential field across the interface. Examples of the surface current for VMEC equilibria will be shown for a zero-pressure stellarator equilibrium. Field-line following of the vacuum magnetic field shows magnetic islands within the plasma region.


Exploring the limits of analytical solutions to the Grad-Shafranov equation with the Solov’yev profile

JULIO E. HERRERA-VELAZQUEZ, KASSANDRA SALGUEIRO-MARTINEZ, Instituto de Ciencias Nucleares, UNAM MIGUEL ANGEL SEGURA-RAMIREZ, None

Solutions to the Grad-Shafranov equation for the Solov’yev profiles, which are the simplest ones, can reproduce several features of the experiments, such as the average β-poloidal, the average safety factor q*, the Shafranov shift, etc., when the free parameters are appropriately chosen. This provides a flexible instrument to understand the role of the aspect ratio, elongation and triangularity on the physics of tokamaks. This work starts from the solutions proposed by Cerfon and Freidberg for the equatorially symmetric case [1], and stretches them to their limits. The starting point is the set of parameters for the spherical tokamak START, and then the consequences of varying the inverse aspect ratio ε. Similar solutions have also been proposed by Zheng et al. [2], with a different particular solutions for the homogenous Grad-Shafranov equation $\nabla \times \nabla \psi (R, Z) = 0$. We show there is a more general family of particular solutions, but the satisfaction of the boundary conditions leads to an adjustment of the coefficients in the general solution that produce the same results.


Pressure Profiles and Pressure-Driven Equilibrium Currents near Small Magnetic Islands and near Divertor Separatrixes: Resonance and Symmetry Effects

DHAHUSH RADHAKRISHNAN, NYU ALLAN REIMAN, Princeton Plasma Phys Lab

A magnetic island whose width is well below a threshold value, determined by the ratio of perpendicular to parallel transport, has only a small effect on the ambient pressure gradient. We calculate the pressure gradient, and the associated pressure driven current in the neighborhood of such an island, assuming that the pressure is determined by a diffusion equation. We similarly calculate the pressure gradient and pressure driven current in the neighborhood of a divertor separatrix. For the small magnetic island, we consider a cylindrical magnetic field with perturbed circular flux surfaces. The perturbation consists of two components, one that modulates the toroidal magnetic field strength without breaking up the flux surfaces, and a second that introduces a resonant radial component of the magnetic field at the rational surface but has little effect on the toroidal field. The relative phase between the two perturbations is varied. The Pfirsch-Schluter current near the X-line is found to be much larger when both perturbations are present and the relative phase between them breaks the stellarator symmetry than it is when these conditions are not satisfied. The calculations are consistent with previous analytical work predicting a logarithmic singularity at the X-line.

This work was supported by DOE Contracts Nos. DEAC02-76CH03073 and DE-AC02-09CH1146.

Self-consistent and robust estimation of the MHD equilibrium suitable for control-oriented models of the q-profile evolution

P. GARCIA-MARTINEZ, CONICET - Centro Atomico Barriloche P. MONTES, Instituto Balseiro E. SCHUSTER,

Lehigh University

The feasibility of controlling the q-profile using closed-loop controllers designed from first-principles-driven control-oriented models has been demonstrated in tokamaks like DIII-D. These control-oriented models typically use the magnetic diffusion equation for the poloidal magnetic flux profile evolution, combined with simplified models for other plasma quantities such as the electron density, the electron temperature, and the noninductive current-drives. The magnetic diffusion equation is expressed in flux coordinates thus requiring several geometric profiles that depend on the underlying MHD equilibrium of the plasma. In this work, a self-consistent method to improve the estimation of the MHD equilibrium and the required geometric profiles is proposed. The method combines a two-dimensional linear model, that takes into account the geometry of the flux surfaces, with a one-dimensional non-linear model that incorporates the evolution of the magnetic profiles resulting in a robust and fast strategy for MHD equilibrium estimation.

Supported by the US DOE under DE-SC0010537, DE-SC0010661, and the Fulbright-CONICET scholar program.

Fast-Time-Scale Equilibria for Rotating Nonaxisymmetric Toroidal Plasmas

LINDA SUGIYAMA, Massachusetts Institute of Technology

Toroidal fusion plasmas are strongly driven systems sustained by complicated and incompletely characterized sources and sinks. For tokamaks, basic axisymmetric ideal MHD
equilibria based on the poloidal magnetic flux are a useful first approximation to the plasma and magnetic geometry for experimental data analysis and physics studies. The large MHD terms in the plasma force balance rapidly establish a quasi-steady state, on time scales much faster than other plasma processes. Widely used equilibrium reconstruction tools, such as EFIT, usually ignore additional effects such as plasma rotation, applied nonaxisymmetry, and non-MHD processes, except for the edge bootstrap current. Good general ideal MHD configurations exist for nonaxisymmetry or rotation separately, but for the combination of the two, the single-fluid nature of MHD requires that the toroidal dependences of the plasma density, rotation, and magnetic field be related by simple expressions. These are unlikely to be satisfied over the wide range of applied heating, torque, current drive, and nonaxisymmetric fields; the mismatch is experimentally testable. This work investigates the minimal additions to basic axisymmetric ideal MHD needed to provide more consistent fast-time-scale steady states.

∗Work partially supported by U.S. DOE OFES Award DE-SC-0007883.

CP11 134 On the breakdown modes and parameter space of Ohmic Tokamak startup YANLI PENG, WEI JIANG, Huazhong University of Science & Technology YAZHANG, Wuhan University of Technology XIWEI HU, GE ZHUANG, Huazhong University of Science & Technology MARIA INNOCENTI, GIOVANNI LAPENTA, Katholieke Universiteit Leuven Tokamak plasma has to be hot. The process of turning the initial dilute neutral hydrogen gas at room temperature into fully ionized plasma is called tokamak startup. Even with over 40 years of research, the parameter ranges for the successful startup still aren’t determined by numerical simulations but by trial and errors. However, in recent years it has drawn much attention due to one of the challenges faced by ITER: the maximum electric field for startup can’t exceed 0.3 V/m, which makes the parameter range for successful startup narrower. Besides, this physical mechanism is far from being understood either theoretically or numerically. In this work, we have simulated the plasma breakdown phase driven by pure Ohmic heating using a particle-in-cell/Monte Carlo code, with the aim of giving a predictive parameter range for most tokamaks, even for ITER. We have found three situations during the discharge, as a function of the initial parameters: no breakdown, breakdown and runaway. Moreover, breakdown delay and volt-second consumption under different initial conditions are evaluated. In addition, we have simulated breakdown on ITER and confirmed that when the electric field is 0.3 V/m, the optimal pre-filling pressure is 0.001 Pa, which is in good agreement with ITER’s design.

MONDAY AFTERNOON
DI2

SESSION DI2: L/H, ZONAL
Monday Afternoon, 23 October 2017; Room: 102ABC at 15:00; Carl Schroeder, Lawrence Berkeley National Laboratory, presiding

Invited Papers

15:00
DI2 1 Rethinking wave-kinetic theory applied to zonal flows∗
JEFFREY PARKER, Lawrence Livermore National Laboratory

Over the past two decades, a number of studies have employed a wave-kinetic theory to describe fluctuations interacting with zonal flows. Recent work has uncovered a defect in this wave-kinetic formulation: the system is dominated by the growth of (arbitrarily) small-scale zonal structures. Theoretical calculations of linear growth rates suggest, and nonlinear simulations confirm, that this system leads to the concentration of zonal flow energy in the smallest resolved scales, irrespective of the numerical resolution [1,2]. This behavior results from the assumption that zonal flows are extremely long wavelength, leading to the neglect of key terms responsible for conservation of enstrophy. A corrected theory, CE2-GO, is presented; it is free of these errors yet preserves the intuitive phase-space mathematical structure [1,2]. CE2-GO properly conserves enstrophy as well as energy, and yields accurate growth rates of zonal flow. Numerical simulations are shown to be well-behaved and not dependent on box size. The steady-state limit simplifies into an exact wave-kinetic form which offers the promise of deeper insight into the behavior of wavepackets. The CE2-GO theory takes its place in a hierarchy of models as the geometrical-optics reduction of the more complete cumulant-expansion statistical theory CE2 [3,4]. The new theory represents the minimal statistical description, enabling an intuitive phase-space formulation and an accurate description of turbulence–zonal flow dynamics.

∗This work was supported by an NSF Graduate Research Fellowship, a US DOE Fusion Energy Sciences Fellowship, and US DOE Contract Nos. DE-AC52-07NA27344 and DE-AC02-09CH11466.

Concerns central to understanding turbulence and transport include: 1) Dynamics of dual cascades in EM turbulence; 2) Understanding ‘negative viscosity phenomena’ in drift-ZF systems; 3) The physics of blobby turbulence (re: SOL). Here, we present a study of a simple model – that of Cahn-Hilliard Navier-Stokes (CHNS) Turbulence – which sheds important new light on these issues. The CHNS equations describe the motion of binary fluid undergoing a second order phase transition and separation called spinodal decomposition. The CHNS system and 2D MHD are analogous [1], as they both contain a vorticity equation and a “diffusion” equation. The CHNS system differs from 2D MHD by the appearance of negative diffusivity, and a nonlinear dissipative flux. An analogue of the Alfvén wave exists in the 2D CHNS system. DNS shows that mean square concentration spectrum $H_{\psi}^k$ scales as $k^{-7/3}$ in the elastic range. This suggests an inverse cascade of $H^k$. However, the kinetic energy spectrum $E^k$ scales as $k^{-3}$, as in the direct enstrophy cascade range for a 2D fluid (not MHD!). The resolution is that the feedback of capillarity acts only at blob interfaces. Thus, as blob merger progresses, the packing fraction of interfaces decreases, thus explaining the weakened surface tension feedback and the outcome for $E^k$. We also examine the evolution of scalar concentration in a single eddy in the Cahn-Hilliard system. This extends the classic problem of flux expulsion in 2D MHD. The simulation results show that a target pattern is formed. Target pattern is a meta stable state, since the band merger process continues on a time scale exponentially long relative to the eddy turnover time. Band merger resembles step merger in drift-ZF staircases.

*This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, under Award Number DE-FG02-04ER54738.

†Collaborators: P H Diamond, and Luis Chacon.

1Phys. Rev. Fluids 1, 054403.

16:00

DI2 3 Energy Exchange Dynamics across L-H transitions in NSTX*  
AHMED DIALLO, Princeton Plasma Physics Laboratory

H-mode is planned for future devices such as ITER, and is preceded by a low (L) to high (H) transition. A key question remains. What is the mechanism behind the L-H transition? Most theoretical descriptions of the L–H transition are based on the shear of the radial electric field and coincident ExB poloidal flow shear, which is thought to be responsible for the onset of the anomalous transport suppression that leads to the L-H transition. This talk will focus on the analysis of the flow dynamics across the L-H transition in NSTX. We analyze the L-H transition dynamics using the velocimetry of 2D edge turbulence data from gas-puff imaging (GPI). We determine the velocity components at the edge across the L-H transition for 17 discharges with three types of heating power (NBI, ohmic, and RF). Using a reduced model equation of edge flows and turbulence, the energy transfer dynamics is compared with the turbulence depletion hypothesis of the predator–prey model. In order for Reynolds work to suppress the turbulence, it must deplete the total turbulent free energy, including the thermal free-energy term. For this to occur, the increase in kinetic energy in the mean flow over the L–H transition must be comparable to the pre-transition thermal free energy. However, this ratio was found to be of order $10^{-2}$. Although there are significant simplifications in the theoretical model, they are unlikely to cause inaccuracy by two orders of magnitude, suggesting that direct turbulence depletion by the Reynolds work may not be large enough to explain the L–H transition on NSTX, contrary to the predator–prey model.

*This work is supported by the US DOE Contract No. DE-AC02-09CH11466.

16:30

DI2 4 Gyrokinetic simulation of fast L-H bifurcation dynamics in a realistic diverted tokamak edge geometry*  
SEUNG-HOE KU, Princeton Plasma Physics Laboratory

We report the first observation of an edge transport barrier formation event in an electrostatic gyrokinetic simulation carried out in a low beta C-Mod like plasma in realistic diverted tokamak edge geometry [1]. The results show that the synergistic action between two multiscale dynamical phenomena, 1) the turbulent Reynolds-stress driven and 2) the neoclassical X-point orbit-loss driven sheared $E \times B$ flows, work together to quench turbulent transport and form a transport barrier just inside the last closed flux surface. The bifurcation occurs when the $E \times B$ shearing rate becomes greater than the strongest dissipative mode growth rate, which results from the dissipative trapped-electron mode in this plasma. The synergism helps reconcile experimental reports of the key role of turbulent stress in the bifurcation with other experimental observations that ascribe the bifurcation to X-point orbit-loss/neoclassical effects. The synergism is consistent with the general experimental observation that the L-H bifurcation requires more power with the ion $V B$-drift away from the single-null X-point, in which the X-point orbit-loss effect is weaker. When the ion $V B$-drift is backward, the bifurcation occurs at the same critical $E \times B$ shearing rate, but is accompanied by persistent GAM oscillations in the bifurcation layer. The effect of isotope mass on the L-H bifurcation will also be validated against DIII-D results.

*Funded by US DOE FES and ASCR, and computing resources provided by OLCF through ALCC.

SESSION EE2: UNIVERSITY FUSION ASSOCIATION GENERAL MEETING
Monday Evening, 23 October 2017
Room: 102ABC at 19:00

Contributed Papers

19:00
EE2 1 University Fusion Association General Meeting
FR1 1 Physics of the Tokamak Pedestal, and Implications for Magnetic Fusion Energy*
PHILIP SNYDER, General Atomics

High performance in tokamaks is achieved via the spontaneous formation of a transport barrier in the outer few percent of the confined plasma. This narrow insulating layer, referred to as a “pedestal,” typically results in a >30x increase in pressure across a 0.4-5cm layer. Predicted fusion power scales with the square of the pedestal top pressure (or “pedestal height”), hence a fusion reactor strongly benefits from a high pedestal, provided this can be attained without large Edge Localized Modes (ELMs), which may erode plasma facing materials. The overlap of drift orbit, turbulence, and equilibrium scales across this narrow layer leads to rich and complex physics, and challenges traditional analytic and computational approaches. We review studies employing gyrokinetic, neoclassical, MHD, and other methods, which have explored how a range of instabilities, influenced by complex geometry, and strong ExB flows and bootstrap current, drive transport across the pedestal and guide its structure and dynamics. Development of high resolution diagnostics, and coordinated experiments on several tokamaks, have validated understanding of important aspects of the physics, while highlighting open issues. A predictive model (EPED) has proven capable of predicting the pedestal height and width to ∼20-25% accuracy in large statistical studies. This model was used to predict a new, high pedestal “Super H-Mode” regime, which was subsequently discovered on DIII-D, and motivated experiments on Alcator C-Mod which achieved world record, reactor relevant pedestal pressure. We review open issues including improved formalism, particle and momentum transport, the role of neutrals and impurities, ELM control, and pedestal formation. Finally we discuss coupling pedestal and core predictive models to enable more comprehensive optimization of the tokamak fusion concept.

*Supported by the US DOE under DE-FG02-95ER54309, FC02-06ER54873, DE-FC02-04ER54698, DE-FC02-99ER54512.

GI2 1 Prediction and realization of ITER-like pedestal pressure in the high-B tokamak Alcator C-Mod*
JERRY HUGHES, MIT Plasma Science and Fusion Center

Fusion power in a burning plasma will scale as the square of the plasma pressure, which is increased in a straightforward way by increasing magnetic field: \( P_{\text{fu}} \sim p^2 \sim B^4 \). Experiments on Alcator C-Mod, a compact high-B tokamak, have tested predictive capability for pedestal pressure, at toroidal field \( B_T \) up to 8T, and poloidal field \( B_P \) up to 1T. These reactor-like fields enable C-Mod to approach an ITER predicted value of 90kPa. This is expected if, as in the EPED model, the pedestal is constrained by onset of kinetic ballooning modes (KBMs) and peeling-ballooning modes (PMB), yielding a pressure pedestal approximately as \( p_{\text{ped}} \sim B_T \times B_P \). One successful path to high confinement on C-Mod is the high-density (\( \bar{n}_e > 3 \times 10^{20} \text{m}^{-3} \)) approach, pursued using enhanced D-alpha (EDAs) H-mode. In EDA H-mode, transport regulates both the pedestal profiles and the core impurity content, holding the pedestal stationary, at just below the PBM stability boundary. We have extended this stationary ELM-suppressed regime to the highest magnetic fields achievable on C-Mod, and used it to approach the maximum pedestal predicted by EPED at high density: \( p_{\text{ped}} \approx 60 \text{kPa} \). Another approach to high pressure utilizes a pedestal limited by PBMs at low collisionality, where pressure increases with density and EPED predicts access to a higher “Super H” solution for \( p_{\text{ped}} \). Experiments at reduced density (\( \bar{n}_e < 2 \times 10^{20} \text{m}^{-3} \)) and strong plasma shaping (\( \delta > 0.5 \)) accessed these regimes on C-Mod, producing pedestals with world record \( p_{\text{ped}} \approx 80 \text{kPa} \), at \( T_{\text{ped}} \approx 2 \text{keV} \). In both the high and low density approaches, the impact of the pedestal on core performance is substantial. Our exploration of high pedestal regimes yielded a volume-averaged pressure \( \langle p \rangle > 2 \text{atm} \), a world record value for a magnetic fusion device. The results hold promise for the projection of pedestal pressure and overall performance of high field burning plasma devices.

*Supported by U.S. Department of Energy awards DE-FC02-99ER54512, DE-FC02-95ER54309, DE-FC02-06ER54873, DE-AC02-09CH11466, DE-SC0007880 using Alcator C-Mod, a DOE Office of Science User Facility.
Small non-axisymmetric magnetic field perturbations that are applied to tokamaks (dB/B~10^-4) are shown to produce 3D plasma equilibrium changes that alter the stability of microturbulence modes in the pedestal region. Measurements from the DIII-D tokamak show that the density gradient scale length in the pedestal at the outboard midplane changes with the toroidal phase of the applied 3D fields, and this change is qualitatively reproduced using two-fluid M3D-C1 modeling. This modeling shows that the density may be non-constant within flux surfaces in the pedestal region when 3D fields are applied. The pressure gradient and resulting diamagnetic rotation are large in the pedestal, so that the ion and electron fluid velocities differ significantly, necessitating the use of a two-fluid model to resolve this effect. Calculated changes to surface topology using single fluid modeling are shown to be too small to affect turbulence stability directly, through modification of the curvature and local magnetic shear, without the additional changes to the 3D density profiles that arise from two-fluid modeling. In DIII-D experiments and simulations, field-aligned helical flux tubes in the pedestal region with an increase in normalized density gradients correspond to locations with increased broadband density fluctuation amplitudes, measured using beam emission spectroscopy and Doppler backscattering. These pedestal effects may help explain the longstanding mystery of density pumpout, by which 3D fields used for control of ELMs and other properties in tokamaks lead to a rapid decrease in plasma density, and improve understanding of the heat and particle fluxes into the scrape-off layer and to the divertor.

*Work supported in part by the US DOE under contract DE-AC05-00OR22725 and DE-FC02-04ER54698.

Meticulously orchestrated non-axisymmetric fields enabled KSTAR to explore various paths to tame plasma stability and transport in a very rigorous manner. Given an extremely low level of intrinsic non-axisymmetry, KSTAR has now established high-precision 3-D field control capability that can not only robustly suppress edge localized modes using resonant magnetic perturbation (RMP), but also exclusively alter plasma rotation without invoking particle and energy transport. In highly shaped plasmas (triangularity of δ ~0.6), we have secured low-n RMP ELM suppressions in a wide range of edge safety factors at q95 = 3.4 – 6.4. One of the best n=1 RMP ELM suppressions has been sustained for more than 30 secs (comparable to wall saturation time), satisfying a low edge collisionality (υ⊥ ~0.2), close to ITER-target. Beyond a typical 3-row RMP configuration, we have newly succeeded in suppressing ELMs with n=1 off-midplane RMPs only, whose configuration is nearly orthogonal to conventional helical RMP structure. Also, a-priori calculation of ideal plasma response led us to identify an optimal window of ELM suppression distinctively separated from mode-lockings. With RMP configuration fixed, a gradual torque control between perpendicular and parallel components helped us access the onset of ELM suppression, strongly supporting a theoretical hypothesis of ω⊥,e ~0 as necessary condition for ELM-suppression, consistent with direct measurement by ECEI. Among non-resonant fields that are quite sensitive to a variation of q95 in NTV physics, a ‘most-quiescent’ configuration has been identified to fully decouple plasma rotation from particle and energy transport. In support of ITER, KSTAR has conducted a series of experiments regarding RMP misalignment impact and its compatibility with detached plasmas. Preliminary experimental analysis suggests that divertor heat flux might not be sufficiently diffused by misalignment alone, once RMP-driven ELM suppression takes place.

*Korean Ministry of Science, ICT and Future Planning.

One of the most promising applications of cold atmospheric plasma (CAP) is the cancer therapy. The uniqueness of plasma is in its ability to change composition in situ. Plasma self-organization could lead to formation of coherent plasma structures. These coherent structures tend to modulate plasma chemistry and composition, including reactive species, the electric field and charged particles. Formation of coherent plasma structures allows the plasma to adapt to external boundary conditions, such as different cells types and their contextual tissues. In this talk we will explore possibilities and opportunities that the adaptive plasma therapeutic system might offer. We shall define such an adaptive system as a plasma device that is able to adjust the plasma composition to obtain optimal desirable outcomes through its interaction with cells and tissues. The efficacy of cold plasma in a pre-clinical model of various cancer types such as lung, bladder, breast, head, neck, brain and skin has been demonstrated. Both in-vitro and in-vivo studies revealed that cold plasma selectively kill cancer cells. Recently mechanism of plasma selectivity based on aquaporin hypothesis has been proposed. Aquaporins (AQPs) are the confirmed membrane channels of H2O2 and other large molecules. We have demonstrated that the anti-cancer capacity of plasma could be inhibited by silencing the expression of AQPs. Additional possible cell feedback mechanism was recently discovered. It is associated with production of reactive species during direct CAP treatment by cancer cells. Selective production of hydrogen peroxide by different cells can lead to adaptation of chemistry
at the plasma-cell interface based on the cellular input. In particular we have found that the discharge voltage is an important factor affecting the ratio of reactive oxygen species to reactive nitrogen species in the gas phase and this correlates well with effect of hydrogen peroxide production by cells.

*This work was supported by a National Science Foundation, Grant No. 1465061.

11:30

G12 5 Novel diagnostics for direct measurements of radical densities in atmospheric pressure plasma jets*
ERIK WAGENAARS, York Plasma Institute, University of York, York, UK

Atmospheric-pressure plasma jets (APPJs) are widely studied for potential applications in industry and healthcare, e.g. surface modification of plastics, plasma medicine and photoresist removal. These plasmas can operate in open air, remain at room temperature and still have a non-equilibrium chemistry. Even though the exact mechanisms through which APPJs affect target surfaces remain largely unknown, it is clear that reactive species play a pivotal role in the success of APPJs. Therefore, reactive species diagnostics of APPJs play an important role in further developing our understanding of the plasma chemistry and will enable increases in treatment efficacy. Two-photon Absorption Laser Induced Fluorescence (TALIF) is a well-known technique for the measurement of absolute densities of atomic radicals such as O, N and H. Unfortunately, application of this technique on APPJs that are operating under realistic conditions for applications, i.e. in open air and with complex admixtures, is not straightforward. The highly collisional environment of APPJs means that collisional quenching of the laser-excited state becomes significant and needs to be taken into account. For well-controlled atmospheres and simple admixtures the effect can be estimated using quenching coefficients, however under realistic operating conditions the identity and density of the quenching partners is unknown due to the complexity of the plasma chemistry. I will present a picosecond TALIF diagnostic which uses a sub-nanosecond laser and iCCD camera that allows the measurement of the quenching-affected fluorescence decay rate directly, enabling absolute measurements of O and N density maps in the open-air effluent of an APPJ.

*The author acknowledges his collaborators at UoY, A. West, J. Bredin, S. Schroeter, K. Niemi, T. Gans, J. Dedrick and D. O’Connell and support from the UK EPSRC (EP/K018388/1 & EP/H003797/1).

12:00

G12 6 Equation of state for two-dimensional dusty plasma liquids and its applications*
YAN FENG, Soochow University

Laboratory dusty plasma consists of free electrons, free ions, and micro-sized dust particles with thousands of negative elementary charges. Due to their extremely low charge-to-mass ratio, these dust particles are strongly coupled, arranging themselves like atoms in liquids or solids. Due to the shielding effects of electrons and ions, dust particles interact with each other through the Yukawa potential, so that simulations of Yukawa liquids or solids are used to study properties of dusty plasmas. In the past two decades, the properties of liquid 2D dusty plasmas have been widely studied from experiments to theories and simulations. However, from our literature search, we have not found a quantitative and comprehensive study of properties of 2D liquid dusty plasmas over a wide range of plasma conditions. Here, from molecular-dynamics simulations of Yukawa liquids, we have obtained a concise equation of state (EOS) for the 2D liquid dusty plasmas from empirical fitting, which contains three quantities of the internal pressure, the coupling parameter, and the screening parameter. From this EOS, different therodynamical processes can be directly derived, such as isotherms, isobars and isochores. Also, various physical properties of 2D liquid dusty plasmas, like the bulk modulus of elasticity, can be analytically derived, so that the sound speeds can be obtained. Finally, an analytical expression of the specific heat for 2D liquid dusty plasmas has been achieved.

*Work supported by the National Natural Science Foundation of China under Grant No. 11505124, the 1000 Youth Talents Plan, and the startup funds from Soochow University.

SESSION G13: HOTSPOTS, APPLIED FIELDS, AND MAGLIF
Tuesday Morning, 24 October 2017; Room: 103ABC at 9:30; Ryan McBride, University of Michigan, presiding

Invited Papers

9:30

G13 1 First liquid-layer implosion experiments at the NIF*
ALEX ZYLSTRA, Los Alamos National Laboratory

Replacing the standard ice layer in an ignition design with a liquid layer allows fielding the target with a higher central vapor pressure, leading to reduced implosion convergence ratio (CR). At lower CR, the implosions are expected to be more robust to instabilities and asymmetries than standard ice-layer designs, and are also unique in that the hot spot can be primarily formed from material originating in the central fuel vapor. The first liquid-layer implosions on the National
Ignition Facility (NIF) have been performed by wicking the liquid fuel into a supporting foam that lines the inside surface of the capsule [1]. A series of shots has been conducted between CR of 12 and 20 using a HDC ablator driven by a 3-shock pulse in a near-vacuum Au hohlraum [2]. At the lowest CR the implosion performance is well predicted by 2-D radiation-hydrodynamics calculations. However, as the CR is increased the nominal simulations do not capture the experimentally observed trends. Data-based models suggest that the hot spot formation is unexpectedly suppressed at higher convergence. The data could be explained by reduced hydrodynamic coupling efficiency, or an anomalously enhanced thermal conductivity in the mixed DT/foam material. We show that the latter hypothesis can explain observed trends in several experimental metrics, including the yield, ion temperature, and burn duration.

This work was performed under the auspices of the U.S. DoE by LANL under contract DE-AC52-06NA273496.

To achieve hotspot ignition, inertial confinement fusion (ICF) implosions must achieve high hotspot internal energy that is inertially confined by a dense shell of DT fuel. To accomplish this, implosions are designed to achieve high peak implosion velocity, good energy coupling between the hotspot and implosion shell, and high areal-density at stagnation. However, experiments have shown that achieving these simultaneously is extremely challenging, partly because of inherent tradeoffs between these three interrelated requirements. The Bigfoot approach is to intentionally trade off high convergence, and therefore areal-density, in favor of high implosion velocity and good coupling between the hotspot and shell. This is done by intentionally colliding the shocks in the DT ice layer. This results in a short laser pulse which improves hohlraum symmetry and predictability while the reduced compression improves hydrodynamic stability. The results of this campaign will be reviewed and include demonstrated low-mode symmetry control at two different hohlraum geometries (5.75 mm and 5.4 mm diameters) and at two different target scales (5.4 mm and 6.0 mm hohlraum diameters) spanning 300-430 TW in laser power and 0.8-1.7 MJ in laser energy. Results of the ~10% scaling between these designs for the hohlraum and capsule will be presented. Hydrodynamic instability growth from engineering features like the capsule fill tube are currently thought to be a significant perturbation to the target performance and a major factor in reducing its performance compared to calculations. Evidence supporting this hypothesis as well as plans going forward will be presented. Ongoing experiments are attempting to measure the impact on target performance from increase in target scale, and the preliminary results will also be discussed.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Hydrodynamic instabilities and asymmetries are a major obstacle in the quest to achieve ignition as they cause pre-existing capsule perturbations to grow and ultimately quench the fusion burn in experiments at the National Ignition Facility (NIF). This talk will review recent developments of the experimental platforms and techniques to measure high-mode instabilities and low-mode asymmetries in the deceleration phase of implosions. These new platforms provide a natural link between the acceleration-phase experiments and neutron performance of layered deuterium-tritium implosions. In one innovative technique, self-emission from the hot spot was enhanced with argon dopant to “self-backlight” the shell in-flight around peak compression. Experiments with pre-imposed 2-D perturbations measured instability growth factors [1], while experiments with 3-D, “native-roughness” perturbations measured shell integrity in the deceleration phase of implosions. In a complimentary technique, the inner surface of the shell, along with its low-mode asymmetries and high-mode perturbations were visualized in implosions using x-ray emission of a high-Z dopant added to the inner surface of the capsule. These new measurements were instrumental in revealing unexpected surprises and providing improved understanding of the role of instabilities and asymmetries on implosion performance.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Experiments with Magnetized Liner Inertial Fusion (MagLIF) [1] loads have successfully demonstrated the premise of magnetized fusion [2]. While these experiments are increasingly well diagnosed, many of the measurements...
(particularly during stagnation) are time integrated, limited in spatial resolution or require additional assumptions to interpret in the context of a structured, rapidly evolving system. As such, there is some ambiguity over what may be limiting performance. Poor laser coupling in preheating the fuel prior to implosion has been suggested as a mechanism [3]. Mix of high Z contaminants that cool the fuel is also a significant concern [4]. In addition, time integrated crystal imaging has shown significant structure in the final fuel assembly indicating potential disruption from instabilities. Understanding the balance between these degradation mechanisms is vital to progress with MagLIF. We compare several sets of experimental data with synthetically generated data from systematically varied 3D resistive-MHD simulations to gain insight into the relative contributions of different degradation mechanisms. We demonstrate how some measurements strongly indicate disruption from liner material penetrating into the fuel at stagnation, and discuss the implications this has for how MagLIF targets work and scale to larger drive currents. We then explore the extent to which different combinations of instability development, current delivery, high-Z mix into the fuel and initial laser deposition can be differentiated in our existing measurements. Better determining the dominant degradation mechanisms can directly influence the direction we take to improve performance, or our confidence in scaling these targets to higher currents.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. DoE’s NNSA under contract DE-NA0003525.


11:30
GI3 5 Experiments on helical modes in magnetized thin foil-plasmas*
DAVID YAGER-ELORRIAGA, University of Michigan

This paper gives an in-depth experimental study of helical features on magnetized, ultrathin foil-plasmas driven by the 1-MA linear transformer driver at University of Michigan. Three types of cylindrical liner loads were designed to produce: (a) pure magneto-hydrodynamic (MHD) modes (defined as being void of the acceleration-driven magneto-Rayleigh-Taylor instability, MRT) using a non-imploding geometry, (b) pure kink modes using a non-imploding, kink-seeded geometry, and (c) MRT-MHD coupled modes in an unseeded, imploding geometry. For each configuration, we applied relatively small axial magnetic fields of $B_z = 0.2-2.0$ T (compared to peak azimuthal fields of 30-40 T). The resulting liner-plasmas and instabilities were imaged using 12-frame laser shadowgraphy and visible self-emission on a fast framing camera. The azimuthal mode number was carefully identified with a tracking algorithm of self-emission minima. Our experiments show that the helical structures are a manifestation of discrete eigenmodes. The pitch angle of the helix is simply $m/kR$, from implosion to explosion, where $m$, $k$, and $R$ are the azimuthal mode number, axial wavenumber, and radius of the helical instability. Thus, the pitch angle increases (decreases) during implosion (explosion) as $R$ becomes smaller (larger). We found that there are one, or at most two, discrete helical modes that arise for magnetized liners, with no apparent threshold on the applied $B_z$, for the appearance of helical modes; increasing the axial magnetic field from zero to 0.5 T changes the relative weight between the $m = 0$ and $m = 1$ modes. Further increasing the applied axial magnetic fields yield higher $m$ modes. Finally, the seeded kink instability overwheels the intrinsic instability modes of the plasma. These results are corroborated with our analytic theory on the effects of radial acceleration on the classical sausage, kink, and higher $m$ modes.

*Work supported by US DOE award DE-SC0012328, Sandia National Laboratories, and the National Science Foundation. D.Y.E. was supported by NSF fellowship Grant Number DGE 1256260. The fast framing camera was supported by a DURIP, AFOSR Grant FA9550-15-1-0419.

12:00
GI3 6 Direct observation of electrothermal instability structures on intensely Ohmically heated aluminum with current flowing in a surface skin layer
THOMAS AWE, Sandia National Laboratories

Implosions on the Z Facility assemble high-energy-density plasmas for radiation effects and ICF experiments, but achievable stagnation pressures and temperatures are degraded by the Magneto-Rayleigh-Taylor (MRT) instability. While the beryllium liners (tubes) used in Magnetized Liner Inertial Fusion (MagLIF) experiments are astonishingly smooth (10 to 50 nm RMS roughness), they also contain distributed micron-scale resistive inclusions, and large MRT amplitudes are observed. Early in the implosion, an electrothermal instability (ETI) may provide a perturbation which greatly exceeds the initial surface roughness of the liner. Resistive inhomogeneities drive nonuniform current density and Joule heating, resulting in locally higher temperature, and thus still higher resistivity. Such unstable temperature and pressure growth produce density perturbations which seed MRT. For MagLIF liners, ETI seeding of MRT has been inferred by evaluating late-time MRT, but a direct observation of ETI is not made. ETI is directly observed on the surface of 1.0-mm-diameter
solid Al rods pulsed to 1 MA in 100 ns via high resolution gated optical imaging (2 ns temporal and 3 micron spatial resolution). Aluminum 6061 alloy rods, with micron-scale resistive inclusions, consistently first demonstrate overheating from distinct, 10-micron-scale, sub-eV spots, which 5-10 ns later merge into azimuthally stretched elliptical spots and discrete strata (40-100 microns wide by 10 microns tall). Axial plasma filaments form shortly thereafter. Surface plasma can be suppressed for rods coated with dielectric, enabling extended study of the evolution of stratified ETI structures, and experimental inference of ETI growth rates. This fundamentally new and highly 3-dimensional dataset informs ETI physics, including when the ETI seed of MRT may be initiated.

**SESSION GO4: RF, STELLARATORS, STABILITY**

*Tuesday Morning, 24 October 2017*

**Room: 201AB at 9:30**

David Anderson, University of Wisconsin, presiding

**Contributed Papers**

**9:30**

GO4 1 Studies of lower hybrid current drive towards long-pulse plasma with high performance in EAST B J DING, M H LI, Institute of Plasma Physics, Chinese Academy of Sciences F NAPOLI, A CARDINALI, C CASTALDO, R CESARIO, A A TUCCILLO, Associazione EURATOM/ENEA, Centro Ricerche Frascati c.p. 65, 00044 Frascati, Italy Y C LI, Institute of Plasma Physics, Chinese Academy of Sciences P BONOLI, R PARKER, S G BAEK, MIT Plasma Science and Fusion Center, Cambridge, Massachusetts 02139, USA A EKEDAHL, M GONICHE, J HILLAIRET, Y PEYSSON, X L ZOU, CEA, IRFM, 13108 St. Paul-Ilez-Durance, France A M GAROFALO, General Atomics, San Diego, California, 92186-5606, USA A M WANG, Y YANG, H Q LIU, J F SHAN, F K LIU, X Z GONG, J G LI, B N WAN, Institute of Plasma Physics, Chinese Academy of Sciences EAST TEAM Aiming at a fusion reactor with lower hybrid current drive (LHCD), effort has been done to improve CD capability in EAST Influence of edge parameters on coupling/CD will be discussed. Effect of LH frequency (2.45/4.6GHz) on LHCD was investigated, showing higher LH frequency is preferred for LHCD at high density. The reduction in parametric instability with 4.6GHz wave seems one candidate for the improvement in driving current at higher frequency, suggesting the role and mitigation of parasitic effects of plasma edge on LHCD. Effect of LH spectrum and density on current profile were optimized-demonstrating the possibility of profile control by adjusting LH spectrum and plasma density for high performance. Repeatable LH H-mode with density up to $4.5 \times 10^{19}\text{m}^{-3}$ is obtained. With the LHCD contribution, RF dominant H-mode discharges over 100s have been achieved.

**9:42**

GO4 2 Nonlinear Simulations of Trapped Electron Mode Turbulence in Low Magnetic Shear Stellarators* B.J. FABER, M.J. PUESCHEL, P.W. TERRY, C.C. HEGNA, Univ of Wisconsin, Madison Optimized stellarators, like the Helically Symmetric eXperiment (HSX), often operate with small global magnetic shear to avoid low-order rational surfaces and magnetic islands. Nonlinear, flux-tube gyrokinetic simulations of density-gradient-driven Trapped Electron Mode (TEM) turbulence in HSX shows two distinct spectral fluctuation regions: long-wavelength slab-like TEMs localized by global magnetic shear that extend along field lines and short-wavelength TEMs localized by local magnetic shear to a single helical bad curvature region. The slab-like TEMs require computational domains significantly larger than one poloidal turn and are computationally expensive, making turbulent optimization studies challenging. A computationally more efficient, zero-average-magnetic-shear approximation is shown to sufficiently describe the relevant nonlinear physics and replicate finite-shear computations, and can be exploited in quasilinear models based on linear gyrokinetics as a feasible optimization tool. TEM quasilinear heat fluxes are computed with the zero-shear approximation and compared to experimentally-relevant nonlinear gyrokinetic TEM heat fluxes for HSX.

*Research supported by U.S. DoE Grants DE-FG02-99ER54546, DE-FG02-93ER54222 and DE-FG02-89ER53291.

**9:54**

GO4 3 Calculations of neoclassical impurity transport in stellarators ALBERT MOLLÉN, HÁKAN M. SMITH, ANDREAS LANGENBERG, YURIY TURKIN, CRAIG D. BEIDLER, PER HÉLANDER, Max Planck Inst Plasma physik MATT LANDREMAN, Institute for Research in Electronics and Applied Physics, University of Maryland SARAH L. NEWTON, CCFE, Culham Science Centre, UK JOSE M. GARCÍA-REGANO, Laboratorio Nacional de Fusión, CIEMAT, Spain MASANORI NUNAMI, National Institute for Fusion Science, Japan The new stellarator Wendelstein 7-X has finished the first operational campaign and is restarting operation in the summer 2017. To demonstrate that the stellarator concept is a viable candidate for a fusion reactor and to allow for long pulse lengths of ~30 min, i.e. “quasi-stationary” operation, it will be important to avoid central impurity accumulation typically governed by the radial neoclassical transport. The SFINCS code [1] has been developed to calculate neoclassical quantities such as the radial collisional transport and the ambipolar radial electric field in 3D magnetic configurations. SFINCS is a cutting-edge numerical tool which combines several important features: the ability to model an arbitrary number of kinetic plasma species, the full linearized Fokker-Planck collision operator for all species, and the ability to calculate and account for the variation of the electrostatic potential on flux surfaces. In the present work we use SFINCS to study neoclassical impurity transport in stellarators. We explore how flux-surface potential variations affect the radial particle transport, and how the radial electric field is modified by non-trace impurities and flux-surface potential variations.


**10:06**

GO4 4 Bayesian modelling of multiple diagnostics at Wendelstein 7-X using the Minerva framework SEHYUN KWAK, Korea Adv Inst of Sci & Tech JAKOB SVENSSON, SERGEY BOZHENKOV, HUMBERTO TRIMINO MORA, UDO HOEFEL, ANDREA PAVONE, MACIEJ KRYCHOWIAK, ANDREAS LANGENBERG, Max-Planck-Institut für Plasmaphysik YOUNG-CHUL GHIM, Korea Adv Inst of Sci & Tech W7-X TEAM TEAM Wendelstein 7-X (W7-X) is a large scale optimised stellarator designed for steady-state operation with fusion reactor relevant conditions. Consistent inference of physics parameters and their associated uncertainties requires the capability to handle the complexity of the entire system, including physics models of multiple diagnostics. A Bayesian model has been developed in the Minerva framework to infer electron temperature and density profiles from multiple
diagnostics in a consistent way. Here, the physics models predict the data of multiple diagnostics in a joint Bayesian analysis. The electron temperature and density profiles are modelled by Gaussian processes with hyperparameters. Markov chain Monte Carlo methods explore the full posterior of electron temperature and density profiles as well as possible combinations of hyperparameters and calibration factors. This results in a profile inference with proper uncertainties reflecting both statistical error and the automatic calibration for diagnostics.

10:18
GO4 5 Minerva neural network based surrogate model for real time inference of ion temperature profiles at Wendelstein 7-X ANDREA PAVONE, JAKOB SVENSSON, ANDREAS LANGENBERG, Max Planck Inst Plasmaphysik NOVIMIR PABLANT, Princeton Plasma Physics Laboratory ROBERT C. WOLF, Max Planck Inst Plasmaphysik Artificial neural networks (ANNs) can reduce the computation time required for the application of Bayesian inference on large amounts of data by several orders of magnitude, making real-time analysis possible and, at the same time, providing a reliable alternative to more conventional inversion routines. The large scale fusion experiment Wendelstein 7-X (W7-X) requires tens of diagnostics for plasma parameter measurements and is using the Minerva Bayesian modelling framework as its main inference engine, which can handle joint inference in complex systems made of several physics models. Conventional inversion routines are applied to measured data to infer the posterior distribution of the free parameters of the models implemented in the framework. We have trained ANNs on a training set made of samples from the prior distribution of the free parameters and the corresponding data calculated with the forward model, so that the trained ANNs constitute a surrogate model of the physics model. The ANNs have been then applied to 2D images measured by an X-ray spectrometer, representing the spectral emission from plasma impurities measured along a fan of lines of sight covering a major fraction of the plasma cross-section, for the inference of ion temperature profiles and then compared with the conventional inversion routines, showing that they constitute a robust and reliable alternative for real time plasma parameter inference.

10:30
GO4 6 Neural Network Computed Bootstrap Current for Real Time Control in DIII-D* ARSENE TEMA BIWOLE, Politecnico di Torino STERLING P. SMITH, ORSO MENEGHINI, EMILY BELLi, JEFF CANDY, General Atomics In an effort to provide a fast and accurate calculation of the bootstrap current density for use as a constraint in real-time equilibrium reconstructions, we have developed a neural network (NN) non-linear regression of the NEO code calculated bootstrap current $j_{BS}$. A new formulation for $j_{BS}$ in NEO allows for a determination of the coefficients on the density and temperature scale lengths. The new formulation reduces the number of inputs to the NN, and the number of output coefficients is 2 times the number of species (including electrons). The NN can reproduce the NEO and Sauter coefficients to a high degree of accuracy (< 1% error). The toroidal (not parallel) component of the bootstrap current density calculated in NEO has been used as a constraint in an offline equilibrium reconstruction for comparison to the NN calculation. The computational time of this method ($\mu$s) makes it ideal for real time calculation in DIII-D.

*Work supported by US DOE under DE-FC02-04ER54698, DE-FG2-95ER-54309, DE-SC 0012656, DE-FC02-06ER54873.

10:42
GO4 7 Influence of electron cyclotron current drive on resistive tearing modes in HL-2A and DIII-D tokamaks* JINGCHUN LI, CHUIJE XIAO, Peking University ZHIHONG LIN, University of California, Irvine DONGJIAN LIU, Sichuan University The influence of electron cyclotron current drive on the m/n=2/1 resistive tearing mode is investigated using gyrokinetic simulations in HL-2A and DIII-D configurations. The resistive tearing mode (RTM) evolution is calculated with a finite mass electron model, and the rf current source is obtained from the ray-tracing code and the Fokker-Planck code. The resistive tearing modes are shown to be stabilized completely by a continuous 1MW 68GHz X2-mode in HL-2A tokamak. While the (2/1) tearing mode in the DIII-D tokamak is only eased with the 1MW 110GHz X2-mode due to the inadequate power input. The ion kinetic effect on the resistive tearing mode stabilization is also demonstrated. It is shown, both in HL-2A and DIII-D, that the existence of ion can reduce the island width as well as the growth rate, hence enhance the resistive tearing mode stabilization with electron cyclotron wave injection.

*This work is supported by the ITER-China program (2014GB107004, 2013GB111000), and NSFC (11375053), US SciDAC GSEP.

10:54
GO4 8 Coherent current-carrying filaments during nonlinear reconnecting ELMs and VDEs* FATIMA EBRAHIMI, Princeton Plasma Physics Laboratory and Princeton University We have examined plasmoid-mediated reconnection in a spherical tokamak using global nonlinear three-dimensional resistive MHD simulations with NIMROD. We have shown that physical current sheets/layers develop near the edge as a peeling component of ELMS or during vertical displacement events (associated with the scrape-off layer currents – halo currents), can become unstable to nonaxisymmetric 3-D current-sheet instabilities (peeling- or tearing-like) and nonlinearly form edge coherent current-carrying filaments. Time-evolving edge current sheets with reconnecting nature in NSTX and NSTX-U configurations are identified [1]. In the case of peeling-like edge localized modes, the longstanding problem of quasiperiodic ELMS cycles is explained through the relaxation of edge current via direct numerical calculations of reconnecting emf terms. For the VDEs during disruption, we show that as the plasma is vertically displaced, edge halo current sheet becomes MHD unstable and forms coherent edge current filament structures, which would eventually bleed into the walls. Our model explains some essential asymmetric physics relevant to the experimental observations.

*Supported by DOE Grants DE-SC0010565, DE-AC02-09CH11466.


11:06
GO4 9 Simulation of the electromagnetic wall response to plasma wall-touching kink and vertical modes with application to ITER CALIN ATANASIU, National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania LEONID ZAKHAROV, LiWFusion, P.O. Box 2391, Princeton, NJ 08543, USA KARL LACKNER, MATTHIAS HOELZL, ERIKA STRUMBERGER, Max Planck Institute for Plasma Physics, Garching, Germany Realistic simulations of electric current excitation in three-dimensional vessel structures by the plasma touching the walls are necessary to understand plasma disruptions in tokamak. In large tokamaks like ITER, the wall-touching kink modes cause large sideway forces on the vacuum vessel determined by the sharing of asymmetric electric current between the plasma and the wall.
Our model covers both eddy currents, excited inductively by vertical modes, and source/sink currents due to current sharing between the plasma and the thin conducting wall. The developed finite element approach calculates the electromagnetic wall response to perturbation of magnetic fields and to current sharing between the plasma and the wall. The current density entering/exiting the wall surface from the plasma and the time derivative of the magnetic vector potential of the plasma are the input values. The magnetic field and the vector potential from the wall currents are returned as output. Our model has been checked against analytical examples of a multiply-connected domain of a real ITER wall.

11:18
GO4 10 Controlling runaway vortex via externally injected high-frequency electromagnetic waves ZEHUA GUO, CHRIS MCDEVITT, XIANZHU TANG, Los Alamos National Laboratory One way of mitigating runaway damage of the plasma-facing components in a tokamak fusion reactor is by limiting the runaway electron energy under a few MeV, while not necessarily reducing the runaway current appreciably. Here we describe a physics mechanism by which such momentum space engineering of the runaway distribution can be facilitated by externally injected high-frequency electromagnetic waves such as the whistler waves. The drastic impact that wave-induced scattering can have on the runaway energy distribution is fundamentally the result of its ability to control the runaway vortex in the momentum space. The runaway vortex, which is a local circulation of runaways in momentum space, is the outcome of the competition between Coulomb collisions, synchrotron radiation damping, and runaway acceleration by parallel electric field. By introducing a wave that resonantly interacts with runaways at a particular range of energy that is mildly relativistic, the enhanced scattering would reshape the vortex by cutting off the part that is highly relativistic. The efficiency of resonant scattering accentuates the requirement that the wave amplitude can be small so that the power requirement from external wave injection is practical for the mitigation scheme.

11:30
GO4 11 Stability limits in rotation and β with energetic ion, two fluid, and resistive wall effects∗ D.P. BRENNAN, Princeton University A.J. COLE, Columbia University J.M. FINN, Tibbar Plasma Technologies M.R. HALFMOOON, University of Tulsa C. PAZ-SOLDAN, General Atomics The non-ideal magnetohydrodynamic (MHD) stability of a tokamak configuration that is driven unstable to the m/n = 2/1 mode by increasing pressure is studied in a reduced model that includes many of the key physics components driving the instability: two fluid responses in various regimes at the resonant surface, a drift-kinetic slowing down distribution of trapped energetic ions, variations in the magnetic shear, plasma rotation and a resistive wall. The changes in stability are examined as the rotation varies across the Hall, Semi-Collisional and Inertial regimes, and compared with recent experiments on DIII-D for rotational limits. The energetic ion contribution to the perturbed pressure is included in the model, where energetic ions damp and stabilize the mode when orbiting in significant positive shear, and drive the mode unstable in reversed shear regions. The effect of rotation is included in the drift-kinetic ion model, where it modifies this effect. The equilibria are stable for low β and the marginal stability values in β and rotation are computed. The impact of the rotation in both the plasma layer responses, and the energetic ion response, must be taken into account to interpret the experimental results.

11:42
GO4 12 Simulation of Double Tearing Modes with plasmoids in High Lundquist Number Regime∗ J. MA, W. GUO, ASIPP A conservative perturbed MHD model [1] and a flux vector splitting (FVS) based high order of accuracy finite difference method [2] was applied to investigate the nonlinear evolution of double tearing modes (DTM) in 2D geometry with Lundquist number higher than 1.0e+4. With high spatial resolution approach, the results show the existence of multiple plasmoids generation. The effects of current sheets separation and guiding field upon secondary islands are investigated [2]. It is also find [3] that while the symmetry is well preserved during the simulation, a new quasi-stationary state with two pairs of islands can form after the explosive stage. For larger distance between rational surfaces two fast reconnections during one evolution can take place. Recently work, the numerical capability is extended to cylindrical geometry and validation during the linear and nonlinear DTM simulation in helical symmetry are performed.

∗Work supported by National Natural Science Foundation of China under Grant No. 11475219 and the Science Foundation of the Institute of Plasma Physics, Chinese Academy of Sciences (DSJJ-15-JC02).


11:54
GO4 13 Simulations and Theory of nonlinear interchange/tearing instabilities in the SOL edge of toroidal plasmas∗ WENDELL HORTON, LINJIN ZHENG, HIDEAKI MIURA, University of Texas at Austin Numerical simulations of a reduced theoretical model for the interchange/tearing instabilities are presented for the turbulence generated by the steep gradients in scrape-off-layer (SOL) edge plasmas. Plasma near the Last Closed Flux Surface (LCFS) and into the scrape-off layer (SOL), are characterized by open magnetic field lines that terminate on the divertor plates. Theoretical and numerical modeling is presented - which includes the current diffusivity ∗“which gives the turbulent transport from the pedestal into SOL. The simulations give a low-level saturated current profile in the SOL region with a current density jump across the LCFS. The nonlinear numerical simulations show that the interchange modes evolve into complex structures with a tearing mode/reconnection component that releases both pressure and current gradient energy components. These complex energy releases are consistent with earlier simulations on the current-interchange tearing modes in Zheng and Furukawa [Phys. Plasmas 2010, 2013]. The applicability of the model to the tokamak edge stability and ELM studies is discussed.

∗The work is supported by U. S. Department of Energy and the National Institute for Fusion Science, Japan.

12:06
GO4 14 The X-point effects on the peeling-ballooning stability conditions∗ LINJIN ZHENG, The University of Texas at Austin, Institute for Fusion Studies Due to the X-point singularity the safety factor tends to infinity as the last closed flux surface is approached. The usual numerical treatment of X-point singularity is to cut off a small fraction of edge region for system stability evaluation or simply use an up-down symmetric equilibrium without X-point included. This type of treatments have been used to make the peeling-ballooning stability diagram. We found that the mode

∗Supported by US DOE Grants DE-SC0014005 and DE-SC0014119.
types, peel or ballooning, can vary depending on how much the edge portion is cut off. When the cutting-off leads the edge safety factor \( (q_e) \) to become close to a mode rational number, the peeling modes dominate; otherwise the ballooning type of modes prevail. The stability condition for peeling modes with \( q_e \) being close to a rational number is much stringent than that for ballooning type of modes. Because \( q_e \) tends to infinite near the separatrix, the mode rational surfaces are concentrated in the plasma region and thus the peeling modes are basically excluded. This extrapolation indicates that the stability boundary for high edge current, which is related to the peeling modes, need to be reexamined to take into account the X-point effects.

*Supported by U. S. Department of Energy, Office of Fusion Energy Science: Grant No. DE-FG02-04ER-54742.

<table>
<thead>
<tr>
<th>SESSION GO5: LASER ACCELERATION OF PROTONS AND IONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuesday Morning, 24 October 2017</td>
</tr>
<tr>
<td>Room: 202AB at 9:30</td>
</tr>
<tr>
<td>Farhat Beg, University of California San Diego, presiding</td>
</tr>
</tbody>
</table>

**Contributed Papers**

9:30

**GO5 1 Controlling laser-ion acceleration with chirped pulses**

FELIX MACKENROTH, Max Planck Institute for the Physics of Complex Systems ARKADY GONOSKOV, MATTIAS MARK-LUND, Chalmers University of Technology

The recently proposed novel laser-ion acceleration scheme Chirped-standing-wave acceleration (CSWA) makes use of chirped high-intensity laser pulses to gain enhanced control over the accelerated ions’ phase space distribution. The first proof-of-principle analysis of this scheme promised favorable scaling properties of ion energies and densities while simultaneously offering unprecedented spatial and temporal control over the ion beam itself. In this talk we provide an extended analysis of the schemes’ further capabilities accessible through, e.g., customized laser chirps and targets. We provide quantitative estimates for existing and upcoming experimental facilities to highlight the scheme’s versatility. Furthermore, we benchmark the newly proposed scheme against conventional laser-ion acceleration schemes. To this end we use the accelerated ions’ flux as a measure for the conversion efficiency of laser energy into ion kinetic energy and provide a systematic comparison of the theoretically achievable performances of the most common laser-ion acceleration schemes. We find CSWA to be highly competitive in terms of reachable ion energies and fluxes.

9:42

**GO5 2 Proton acceleration in laser-driven megatesla magnetic fields**

ALEXEY AREFIEV, Univ of California - San Diego S. S. BULANOV, LBNL T. TONCIAN, HZDR, Germany

The next generation of laser facilities will make it possible to access laser intensities well beyond \( 10^{22} \) W/cm\(^2\). At these intensities, a laser pulse would rapidly energize electrons, making them ultra-relativistic and rendering an otherwise opaque solid material transparent. This phenomenon of relativistically-induced transparency enables a volumetric interaction between the intense laser pulse and the irradiated solid-density matter. Recent 3D simulations of this regime have demonstrated that a laser pulse can drive an unprecedented quasi-static MT-level magnetic field inside the solid-density material [1]. This talk will present a novel regime for ion acceleration enabled by the MT-level magnetic field. If the laser pulse is able to burn through a massive target, then the electrons exiting the target with the laser pulse generate a field structure that produces dense mono-energetic proton bunches (20 nC in charge and 250 MeV in energy) by an acceleration mechanism not encountered before in experimental and analytical studies [2].

*This research was supported by NSF Grant No. 1632777 and US DOE under Contract DE-AC02-05CH11231. Simulations were performed with the EPOCH code using HPC resources provided by the TACC at the University of Texas.


and manipulable, micron-scale size, highly collimated and quasi-mono-energetic ion beams can be produced by using ultra-intense ultra-short laser pulses with total laser energies less than 10 Joules. Such ion beams may find important applications in tumour therapy.

*B. Liu acknowledges support from the Alexander von Humboldt Foundation. B. Liu and H. Ruhl acknowledge support from the Gauss Centre for Supercomputing (GCS), and the Cluster-of-Excellence Munich Centre for Advanced Photonics (MAP).


10:18
GOS 5 Effects of dimensionality and laser polarization on kinetic simulations of laser-ion acceleration in the transparency regime* DAVID STARK, LIN YIN, BRIAN ALBRIGHT, FAN GUO, Los Alamos National Laboratory The often cost-prohibitive nature of three-dimensional (3D) kinetic simulations of laser-plasma interactions has resulted in heavy use of two-dimensional (2D) simulations to extract physics. However, depending on whether the polarization is modeled as 2D-S or 2D-P (laser polarization in and out of the simulation plane, respectively), different results arise. In laser-ion acceleration in the transparency regime, VPIC particle-in-cell simulations show that 2D-S and 2D-P capture different physics that appears in 3D simulations. The electron momentum distribution is virtually two-dimensional in 2D-P, unlike the more isotropic distributions in 2D-S and 3D, leading to greater heating in the simulation plane. As a result, target expansion time scales and density thresholds for the onset of relativistic transparency differ dramatically between 2D-S and 2D-P [1]. The artificial electron heating in 2D-P exaggerates the effectiveness of target-normal sheath acceleration (TNSA) into its dominant acceleration mechanism, whereas 2D-S and 3D both have populations accelerated preferentially during transparency to higher energies than those of TNSA.

*Funded by the LANL Directed Research and Development Program.


10:30
GOS 6 Stable quasi-monoenergetic ion acceleration from the laser-driven shocks in a collisional plasma SHIKHA BHADORIA, NAVEEN KUMAR, CHRISTOPH H. KEITEL, Max Planck Institute for Plasma Physics Effect of collisions on the shock formation and subsequent ion acceleration from the laser-plasma interaction is explored by the means of particle-in-cell simulations. In this setup, the incident laser pushes the laser-plasma interface inside the plasma target through the hole-boring effect and generates hot electrons. The propagation of these hot electrons inside the target excites a return plasma current, leading to filamentary structures caused by the Weibel/ filamentation instability. Weakening of the space-charge effects due to collisions results in the shock formation with a higher density jump than in a collisionless plasma. This results in the formation of a stronger shock leading to a stable quasi-monoenergetic acceleration of ions.

10:42
GOS 7 Spatiotemporal Analysis of Accelerated Protons from Sub-Micron Liquid Crystal Films* CHRISTOPHER WILLIS, Ohio State Univ - Columbus PATRICK POOLE, Lawrence Livermore National Laboratory GINEVRA COCHRAN, LINN VAN WOERKOM, DOUGLASS SCHUMACHER, Ohio State Univ - Columbus Recent studies on ion acceleration have trended towards ultra-thin (<1 μm) targets due to improved ion energies and yields from these targets. As discussed here, ultra-thin targets may exhibit unusual spatial distributions in the accelerated ions, such that ion spectrometer data may not be representative of the overall distribution. More complete characterization of the ions requires spectral unfolding of radiochromic film (RCF) data, yielding spatially dependent spectra. Spatiotemporal data will be presented from several experiments using sub-micron liquid crystal film targets at the Scarlet (OSU), Texas Petawatt (UT, Austin) and PHELIX (GSI, Darmstadt) laser facilities, including evidence of ~75 MeV protons from ~300 nm films at PHELIX. Analysis of RCF data is supported by Monte-Carlo modeling of RCF response to ions and electrons using FLUKA. Trends in the resulting ion distributions will be discussed including spatially varying slope temperature and observation of annular ring features at moderate ion energies on many shots.

*This material is based upon work supported by the AFOSR under award FA9550-14-1-0085, by the DARPA PULSE program through a Grant from AMRDEC, and by the CNSA under contract DE-NA0003107.

10:54
GOS 8 High peak current acceleration of narrow divergence ions beams with the BELLA-PW laser* SVEN STEINKE, QING JI, Lawrence Berkeley National Laboratory FRANZISKA TREFERT, Technical University of Darmstadt STEPLAN BULANOV, JIANHUI BIN, KEI NAKAMURA, ANTHONY GONSALVES, CSABA TOTH, JAEHONG PARK, Lawrence Berkeley National Laboratory MARKUS ROTH, Technical University of Darmstadt ERIC ESAREY, THOMAS SCHENKEL, WIM LEEEMANS, Lawrence Berkeley National Laboratory We present a parameter study of ion acceleration driven by the BELLA-PW laser. The laser repetition rate of 1Hz allowed for scanning the laser pulse duration, relative focus location and target thickness for the first time at laser peak powers of above 1 petawatt. Further, the long focal length geometry of the experiment (F/65) and hence, large focus size provided ion beams of reduced divergence and unprecedented charge density.

*This work was supported by Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231 and Laboratory Directed Research and Development (LDRD) funding from Lawrence Berkeley National Laboratory.

11:06
GOS 9 Generation of narrow energy spread ion beams via collisionless shock waves using ultra-intense 1 um wavelength laser systems* FELICIE ALBERT, A. PAK, Lawrence Livermore National Laboratory S. KERR, University of Alberta N. LEMOS, A. LINK, P. PATEL, B. B. POLLOCK, Lawrence Livermore National Laboratory D. HABERBERGER, D. FROULA, Laboratory of Laser Energetics M. GAUTHIER, S. H. GLENZER, SLAC National Accelerator Laboratory A. LONGMAN, L. MANZOOR, R. FEDOSEJEVS, University of Alberta S. TOCHITSKY, C. JOSHI, University of California Los Angeles F. FIUZA, SLAC National Accelerator Laboratory In this work, we report on electrostatic collisionless shock wave acceleration experiments that produced proton beams with peak energies between 10-17.5 MeV, with narrow energy spreads between Δ E / E of 10-20%, and with a total number of protons in these peaks of 1e7-1e8. These beams of ions were created by driving an electrostatic collisionless shock wave in a tailored near critical density plasma target using the ultra-intense ps duration Titan laser that operates at a wavelength of 1 um. The near critical density target was produced through the ablation of an initially 0.5 um thick Mylar foil with a separate low intensity laser. A narrow energy spread distribution of carbon / oxygen ions with...
a similar velocity to the accelerated proton distribution, consistent with the reflection and acceleration of ions from an electrostatic field, was also observed.

*This work was supported by Lawrence Livermore National Laboratory’s Laboratory Directed Research and Development program under project 15-LW-095, and the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA2734.

11:18

GO5 10 Near-critical density target experiments for ion acceleration using high-intensity laser pulses* PETER KORDELL, PAUL CAMPBELL, ANATOLY MAKSMICHUK, LOUISE WILLINGAAR, KARL KRUSHELNICK, Univ of Michigan - Ann Arbor The interaction of a short-duration, relativistic intensity laser pulse with a near-critical density plasma can produce a collisionless electrostatic shock capable of accelerating ions. This effect has already been demonstrated using CO2 laser systems ($\lambda = 10 \mu m$) where the specific plasma density profile enabled the acceleration of quasi-monoenergetic ion beams. We will present our experiments using the T-cubed laser system at the University of Michigan ($\lambda = 1.053 \mu m$, 6J, 400fs). Due to the shorter wavelength, typical of most relativistic intensity laser systems, a higher plasma density and shorter scalelengths are required to achieve the conditions for shock ion acceleration. The target design and characterization as well as preliminary experimental results will be presented.

*This work was supported by the DOE through Grant Number DE-SC0012327.

11:30

GO5 11 High repetition rate laser-driven MeV ion acceleration at variable background pressures* JOSEPH SNYDER, Miami University Regionals, Hamilton, OH GREGORY NGIRMANG, CHRIS ORBAN, The Ohio State University / Innovative Scientific Solutions, Inc. (ISSI) SCOTT FEISTER, FLASH Center for Computational Science, University of Chicago JOHN MORRISON, KYLE FRISCHEN, ISSI/ENAM CHOWDHURY, The Ohio State University / Intense Energy Solutions, LLC, W. M. ROQUEMORE, Air Force Research Laboratory, Dayton, OH Ultra-intense laser-plasma interactions (LPI) can produce highly energetic photons, electrons, and ions with numerous potential real-world applications. Many of these applications will require repeatable, high repetition rate lasers that are suitable for LPI experiments. Liquid targets can meet many of these needs, but they typically require higher chamber pressure than is used for many low repetition rate experiments. The effect of background pressure on the LPI has not been thoroughly studied. With this in mind, the Extreme Light group at the Air Force Research Lab has carried out MeV ion and electron acceleration experiments at kHz repetition rate with background pressures ranging from 30 mTorr to > 1 Torr using a submicron ethylene glycol liquid sheet target. We present these results and provide two-dimensional particle-in-cell simulation results that offer insight on the thresholds for the efficient acceleration of electrons and ions.

*This research is supported by the Air Force Office of Scientific Research under LRIR Project 17RQCORS04 under the management of Dr. Riq Parra and Dr. Jean-Luc Cambier. Support was also provided by the DOD HPCMP Internship Program.

11:42

GO5 12 Ultrathin Target Laser Ion Acceleration At Oblique Incidence* G.E. COCHRAN, The Ohio State University P.L. POOLE, Lawrence Livermore National Laboratory T. COWAN, T. KLUGE, J. METZKES, L. OBST, I. PRINCIPE, H.-P. SCHLENVOIGT, U. SCHRAMM, K. ZEIL, Helmholtz-Zentrum Dresden-Rossendorf D.W. SCHUMACHER, The Ohio State University Oblique laser incidence allows separate identification of target normal and laser axis ion acceleration mechanisms. A recent high-contrast experiment using the Draco laser ($\sim 3 \times 10^{21} W/cm^2$) at 45 degrees angle of incidence on liquid crystal targets showed predominantly target normal directed ions for all target thicknesses from 10 nm to >1 μm, with peak proton energies up to 26 MeV. We present 3D particle-in-cell simulations of this experiment which reproduce both the dominance of target normal acceleration as well as the transparency onset as a function of target thickness, with ion spectral and optical reflectivity trends in agreement with experimental observations. We find that high energy ions from the thinnest targets are accelerated volumetrically, in contrast to originating at the rear surface as in thicker targets. We discuss the acceleration mechanisms at play and the dominance of target normal ions.

*This material is based upon work supported by the AFOSR under Award Number FA9550-14-1-0085, by the NNSA under DE-NA0003107, and by computing time from the Ohio Supercomputer Center.

11:54

GO5 13 Ion acceleration via TNSA near and beyond the relativistic transparency limit* DOUGLASS SCHUMACHER, Ohio State University PATRICK POOLE, Lawrence Livermore National Laboratory GINEVRA COCHRAN, CHRISTOPHER WILLIS, Ohio State University Ultra-intense laser-based ion acceleration can proceed via several mechanisms whose fundamental operation and interplay with each other are still not well understood. The details of Relativistically Induced Transparency (RIT) and its impact on ultra-thin target acceleration are of interest for fundamental studies and to progress toward applications requiring controlled, high energy secondary radiation, e.g. hadron cancer therapy. Liquid crystal film targets formed in-situ with thickness control between 10 nm and > 50 μm uniquely allow study of how ion acceleration varies with target thickness. Several recent studies have investigated Target Normal Sheath Acceleration (TNSA) down to the thickness at which RIT occurs, with a wide range of laser conditions (energy, pulse duration, and contrast), using various ion and optical diagnostics to ascertain acceleration mechanisms and quality. Observation of target-normal directed ion acceleration enhancement at the RIT thickness onset will be discussed, including analysis of ion spatial and spectral features as well as particle-in-cell simulations investigating the underlying physical processes.

*This material is based upon work supported by the AFOSR under Award Number FA9550-14-1-0085, by the NNSA under DE-NA0003107, and by computing time from the Ohio Supercomputer Center.

12:06

GO5 14 Mono-energetic ion beams accelerated in the interaction of an ultrashort intense laser with ultra-thin solid targets* JUN LI, Center for Energy Research, Univ of California - San Diego ALEXEY AREFIEN, Center for High Energy Density Science, University of Texas, Austin CHRISTOPHER McGUFFEY, FARHAT BEG, Center for Energy Research, Univ of California - San Diego We performed particle-in-cell (PIC) simulations to study the ion acceleration by the interaction of an ultra-short (35fs) intense laser ($10^{23} W/cm^2$) with ultra-thin (6-100nm) copper targets. We aimed at investigating how ions are accelerated from thin targets, and focus on the regime in which targets remain intact and not broken through...
by the laser pulse. The target thicknesses were scanned, and we found that the ionization of copper ions to high Z states occurred during the acceleration. The mono-energetic high Z ion beams were observed only for the target thickness of 20nm with energies near 400 MeV. We conducted the particle tracking diagnostic to study the underlying physics and mechanism of the acceleration, and the details will be presented in the meeting.

* This material is based upon work supported by the Air Force Office of Scientific Research under Award Number FA FA9550-14-1-0282. This work was performed using HPC resources provided by the Texas Advanced Computing Center at the University of Texas; This work also used the Extreme Science and Engineering Discovery Environment (XSEDE), which is supported by National Science Foundation Grant Number ACI-1548562.

12:18

GO5 15 Proton and Ion Acceleration using Multi-kJ Lasers* S. C. WILKS, T. MA, A. J. KEMP, M. TABAK, A. J. LINK, C. HAEFNER, M. R. HERMANN, D. A. MARISCAL, S. RUBENCHIK, P. STERNE, LLNL, J. KIM, C. MCGUFFEY, K. BHUTWALA, F. BEG, UCSD M. WEI, GA S. M. KERR, UAlberta Y. SENTOKU, N. IWATA, OsakaU P. NORREYS, A. SEVIN, OxfordU Short (<50 ps) laser pulses are capable of accelerating protons and ions from solid (or dense gas jet) targets as demonstrated by a number of laser facilities around the world in the past 20 years accelerating protons to between 1 and 100 MeV, depending on specific laser parameters. Over this time, a distinct scaling with energy has emerged that shows a trend towards increasing maximum accelerated proton (ion) energy with increasing laser energy. We consider the physical basis underlying this scaling, and use this to estimate future results when multi-kJ laser systems begin operating in this new high energy regime. In particular, we consider the effects of laser prepulse, intensity, energy, and pulse length on the number and energy of the ions, as well as target size and composition. We also discuss potential uses of these ion beams in High Energy Density Physics Experiments.

This work was performed under the auspices of the U.S. Department of Energy (DOE) by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and funded by the LLNL LDRD program under tracking code 17-ERD-039.

SESSION GO6: ASTROPHYSICAL PLASMAS AND LABORATORY ASTROPHYSICS
Tuesday Morning, 24 October 2017
Room: 202C at 9:30
Dmitri Udzеныski, University of Colorado, presiding

Contributed Papers

9:30

GO6 1 Exploring the universe through Discovery Science on NIF* BRUCE REMINGTON, Lawrence Livermore National Laboratory New regimes of science are being experimentally studied at high energy density facilities around the world, spanning drive energies from microjoules to megajoules, and time scales from femtoseconds to microseconds. The ability to shock and ramp compress samples to very high pressures and densities allows new states of matter relevant to planetary and stellar interiors to be studied. Shock driven hydrodynamic instabilities evolving into turbulent flows relevant to the dynamics of exploding stars (such as supernovae), accreting compact objects (such as white dwarfs, neutron stars, and black holes), and planetary formation dynamics (relevant to the exoplanets) are being probed. The dynamics of magnetized plasmas relevant to astrophysics, both in collisional and collisionless systems, are starting to be studied. High temperature, high velocity interacting flows are being probed for evidence of astrophysical collisionless shock formation, the turbulent magnetic dynamo effect, magnetic reconnection, and particle acceleration. And new results from thermonuclear reactions in dense plasmas relevant to stellar and big bang nucleosynthesis are starting to emerge. A selection of examples of frontier research through NIF Discovery Science in the coming decade will be presented.

This work was performed under the auspices of U.S. DOE by LLNL under Contract DE-AC52-07NA27344.

9:42

GO6 2 Formation of High Mach-Number Magnetized Collisionless Shocks in Laser-Produced Plasmas Z WANG, J PARK, A SPITKOVSKY, Department of Astrophysical Sciences, Princeton University C HUNTINGTON, H.-S. PARK, B POLLOCK, H RINDERKNECHT, S WILKES, D RYUTOV, B REMINGTON, Lawrence Livermore National Laboratory F FIUZA, SLAC National Accelerator Laboratory ACSEL COLLABORATION Magnetized collisionless shocks commonly occur in the heliosphere and interstellar medium. Collective collisionless processes mediating such shocks can now be studied in the laboratory. We carry out an experiment to observe the formation of a high Alfvén Mach number (Ma) magnetized collisionless shock on OMEGA-EP facility. In the experiment, a laser-produced plasma flow penetrates into a pre-existing magnetized plasma. Proton radiography shows a moving region of proton deficit followed by a caustic enhancement of proton density. These features are produced by a propagating front of compressed magnetic field. We use a particle tracing code to model the proton radiography and determine the speed of the compressed field from a series of proton radiographs. Modeling of the shape of the proton deficit region allows us to constrain the amount of magnetic compression. When compared to particle-in-cell simulations of magnetized shocks, we find that the amount of observed magnetic compression is well explained by a magnetized perpendicular collisionless shock propagating with Ma=4. These experiments create a platform for further study of physical processes in the transition region of collisionless magnetized shocks.

9:54

GO6 3 Producing Beam Instabilities Relevant to Parallel Shock Formation in a Magnetized Laboratory Plasma P. V. HEUER, M. S. WEIDL, R. S. DORST, D. B. SCHAEFFER, C. G. CON-STANTIN, S. VINCENA, S. TRIPATHI, W. GEKELMAN, Univ of California - Los Angeles D. WINSKE, Los Alamos National Laboratory C. NIEMANN, Univ of California - Los Angeles Simulations have identified several electromagnetic beam instabilities that play an essential role in the formation of Alfvénic parallel shocks, but have never been studied in that context in the laboratory. We present measurements of one such instability (the Right-Hand Resonant Instability, or RHI) from a series of recent experiments at the University of California, Los Angeles. Instabilities are observed between a field-parallel super-Alfvénic ($M_i = 5$) “beam” of laser-produced plasma expanding over 80 δ, and the large, magnetized ambient plasma of the Large Plasma Device (LPD), and are diagnosed with an array of 3-axis magnetic flux ‘bdot’probes and Langmuir probes. Measurements are compared to hybrid simulations of both the experiment and of fully formed parallel shocks.
10:06
GO6 4 Investigation of Weibel-filament growth in the nonlinear regime using laser-irradiated foils of different materials* MARIO MANUEL, General Atomics - San Diego M.J.-E. MANUEL, GENERAL ATOMICS, C.M. HUNTINGTON, D.P. HIGGINS, B.B. POLLOCK, B.A. REMINGTON, H. RINDERKNECHT, J.S. ROSS, D. RYUTOV, G. SWADLING, S. WILKS, A.B. ZYLSTRA, H.-S. PARK LLNL, F. FIUZA, S. TOTORICASLAC, G. GREGORIOXOFORD, J. PARK, A. SPITKOVSKYPRINCETON, Y. SAKAWA, H. TAKABEOSAKA, H. SIOMIT, A.B. ZYLSTRAALNL. The Weibel instability is presently the leading mechanism proposed to amplify magnetic fields necessary to form 'collisionless' shocks in weakly magnetized astrophysical systems, including young supernova remnants and gamma-ray bursts. These systems rely on the presence of strong self-generated magnetic fields to mediate shock formation since the typical collisional mean-free-path is much larger than the system size. The work presented here investigates the development of the Weibel instability in the nonlinear regime through experimental variation of plasma parameters using different ion species and separation distances. Our goal is to investigate the underlying physical mechanism that may allow the formation of collisionless shocks in astrophysical objects. Recent experimental and computational results will be presented and discussed.

*This work is funded by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, Grant Number DE-NA0002956 and in collaboration with LLNL under contract DE-AC52-07NA27344.

10:18
GO6 5 Kinetic inhibition of MHD shocks in the vicinity of a parallel magnetic field ANTOINE BRET, Univ. de Castilla-La Mancha ASAF PE’ER, Physics Department, University College Cork, Cork, Ireland LORENZO SIRONI, Department of Astronomy, Columbia University, New York, NY 10027, USA RAMESH NARAYAN, Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, MA 02138, USA According to MHD, the encounter of two collisional magnetized plasmas at high velocity gives rise to shock waves. Investigations conducted so far have found that the same conclusion still holds in the case of collisionless plasmas. For the case of a flow-aligned field, MHD stipulates that the field and the fluid are disconnected, so that the shock produced is independent of the field. We present a violation of this MHD prediction when considering the encounter of two cold pair plasmas along a flow-aligned magnetic field. As the guiding magnetic field grows, isotropization is progressively suppressed, resulting in a strong influence of the field on the resulting structure. A micro-physics analysis allows us to understand the mechanisms at work. Particle-in-cell simulations also support our conclusions and show that the results are not restricted to a strictly parallel field [1].

10:30
GO6 6 The structure of low Mach number, low beta, quasi-perpendicular collisionless shocks LYNN WILSON III, NASA/GSFC ANDRIY KOVAL, NASA/GSFC and Goddard Planetary Heliophysics Inst. Univ. of Maryland Baltimore ADAM SZ-ABO, NASA/GSFC MICHAEL STEVENS, Harvard-Smithsonian Center for Astrophysics, Harvard University JUSTIN KASPER, University of Michigan, Ann Arbor CYNTHIA CATTLEL, School of Physics and Astronomy, University of Minnesota VLADIMIR KRASNOSELSKIKH, LPC2E/CNRS, University of Orleans A study of the structure of 145 low Mach number (M ⩽ 3), low beta (β ⩽ 1), quasi-perpendicular interplanetary collisionless shock waves observed by the Wind spacecraft has provided strong evidence that these shocks have large amplitude whistler precursors. The common occurrence and large amplitudes of the precursors raise doubts about the standard assumption that such shocks can be classified as laminar structures. This directly contradicts standard models. In 113 of the 145 shocks (~78%), we observe clear evidence of magnetosonic-whistler precursor fluctuations with frequencies ~0.1–7 Hz. The presence or absence of precursors showed no dependence on any shock parameter. The majority (~66%) of the precursors propagate at Θ ≈ 45° with respect to the upstream average magnetic field, most (~87%) propagate >30° from the shock normal vector, and most (~79%) propagate at least 20° from the coplanarity plane. The peak-to-peak wave amplitudes are large with a range of maximum values of ~0.2–13 nT with an average of ~3 nT. When we normalize the wave amplitudes to the upstream averaged magnetic field and the shock ramp amplitude, we find average values of ~50% and ~80%, respectively.

10:42
GO6 7 Phase-mixing of electrostatic modes in pair-ion plasma SOURAV PRAMANIK, Saha Institute of Nuclear Physics, Kolkata CHANDAN MAITY, Vivekananda Mahavidyalaya, Haripal, Hooghly-712405, India. NIHIL CHAKRABARTI, Saha Institute of Nuclear Physics, Kolkata. In a homogeneous plasma, an excited electrostatic mode can face breaking even if the perturbation amplitude is kept well below the threshold value through the process of phase-mixing. In various physical situations (for example inhomogeneous ion density background, inhomogeneous magnetic field, relativistic effects etc), associated characteristic mode frequency of the oscillation becomes space dependent and the mode is called phase-mixed. As the phase-mixed mode evolves through the space and time, particles located at different positions oscillate with different local frequencies. In next scenario, the phase difference between two adjacent oscillators begins to increase secularly with time and, finally, trajectories of the adjacent oscillators start to intersect their paths. It costs a gradual loss in the phase coherence of the constituting oscillators and eventually the relevant mode breaks. The appearance of spiky density profile signifies the occurrence of phase mixing. In our works, phase-mixing process has been studied in pair ion plasmas (fullerene-ion plasma, electron-positron plasma) and the effects of different parameters (like temperature, external magnetic field, ion concentration) on the phase-mixing process have been explored analytically.

10:54
GO6 8 On pair plasma instability due to pressure gradients in homogeneous magnetic fields* M.J. PUESCHEL, University of Wisconsin-Madison, Madison, Wisconsin 53706, USA; University of Texas at Austin, Austin, Texas 78712, USA P.W. TERRY, University of Wisconsin-Madison, Madison, Wisconsin 53706, USA B. TYZURSKA-PUESCHEL, University of Wisconsin-Madison, Madison, Wisconsin 53706, USA; German Aerospace Center, 51147 Cologne, Germany With the advent of laboratory experiments on collective effects in electron-positron plasmas, theoretical prediction of their stability properties becomes increasingly relevant. Prior work without compressional magnetic fluctuations [1] predicted complete stability of pair plasmas to density or temperature gradients in a homogeneous magnetic guide field. Here, it is shown that the inclusion of such fluctuations produces a Gradient-driven Drift Coupling (GDC) instability [2] also seen in helium plasma experiments [3]. An analytical growth rate expression applicable to a wide range of plasma parameters is derived, and a subdominant, finite-k, GDC is discussed. Overall, the GDC is shown to have a potential...
impact on systems ranging from Gamma Ray Bursts to magnetic confinement experiments like APEX, to laser-based setups. In all of these configurations, GDC growth times are much shorter than plasma lifetimes.

*Supported by DOE Grant No. DE-FG02-89ER53291.

1Helander and Connor, JPP 82, 905820301 (2016).
3Puechel et al., PPCF 59, 024006 (2017).

11:06
GO6 9 Holistic Framework for Understanding the Evolution of Stellar Coronal Plasmas* ERIC BLACKMAN, University of Rochester JAMES OWEN, Institute for Advanced Study (Princeton) Understanding how the coronal X-ray activity of stars depends on magnetic field strength, dynamo, rotation, mass loss and age is of interest not only for the basic plasma physics of stars, but also for stellar age determination and implications for habitability. Approximate relations between field strength, activity, spin down, mass loss and age have been measured, but remain to be understood theoretically. The saturation of plasma activity of the fastest rotators and the decoupling of spin-down from magnetic field strengths for slow rotators are particular puzzles. To explain the observed trends, I discuss our minimalist holistic theoretical framework that combined a Parker wind with (i) magnetic dynamo sourcing of thermal energy, wind energy and x-ray luminosity (ii) dynamo saturation based on magnetic helicity conservation and shear-induced eddy shredding and (iii) coronal equilibrium to determine how the magnetic energy divides into wind, x-ray, and thermal conduction sinks. We find conduction to be important for older stars where it can reduce the efficacy of wind angular momentum loss, offering an alternative explanation of this trend to those which require dynamo transitions. Overall, the framework shows promise and provides opportunity for further

*Grant NSF-AST1515648 is acknowledged.

11:18
GO6 10 Plasma Constraints on the Cosmological Abundance of Magnetic Monopoles and the Origin of Cosmic Magnetic Fields* MIKHAIL MEDVEDEV, KU and MIT ABRAHAM LOEB, Harvard Existing theoretical and observational constraints on the abundance of magnetic monopoles are limited. Here we demonstrate that an ensemble of monopoles forms a plasma whose properties are well determined and whose collective effects place new tight constraints on the cosmological abundance of monopoles. In particular, the existence of micro-Gauss magnetic fields in galaxy clusters and radio relics implies that the scales of these structures are below the Debye screening length, thus setting an upper limit on the cosmological density parameter of monopoles, \( \Omega_M \lesssim 3 \times 10^{-4} \), which precludes them from being the dark matter. Future detection of Gpc-scale coherent magnetic fields could improve this limit by a few orders of magnitude. In addition, we predict the existence of magnetic Langmuir waves and turbulence which may appear on the sky as “zebra patterns” of an alternating magnetic field with \( k \cdot B \neq 0 \). We also show that magnetic monopole Langmuir turbulence excited near the accretion shock of galaxy clusters may be an efficient mechanism for generating the observed intracluster magnetic fields.

*The authors acknowledge DOE partial support via Grant DE-SC0016368.

11:30
GO6 11 Astrophysical Applications of Relativistic Shear Flows EDISON LIANG, Rice University We review recent PIC simulations of relativistic collisionless shear flows in both 2D and 3D. We apply these results to spine-sheath jet models of blazars and gamma-ray-bursts, and to shear flows near the horizon of rapidly spinning black holes. We will discuss magnetic field generation, particle energization and radiation processes, and their observational consequences.

11:42
GO6 12 Magnetorotational Dynamo Action in the Shearing Box* JUSTIN WALKER, STANISLAV BOLDYREV, Univ of Wisconsin, Madison Magnetic dynamo action caused by the magnetorotational instability is studied in the shearing-box approximation with no imposed net magnetic flux. Consistent with recent studies, the dynamo action is found to be sensitive to the aspect ratio of the box: it is much easier to obtain in tall boxes (stretched in the direction normal to the disk plane) than in long boxes (stretched in the radial direction). Our direct numerical simulations indicate that the dynamo is possible in both cases, given a large enough magnetic Reynolds number. To explain the relatively larger effort required to obtain the dynamo action in a long box, we propose that the turbulent eddies caused by the instability most efficiently fold and mix the magnetic field lines in the radial direction. As a result, in the long box the scale of the generated strong azimuthal (stream-wise directed) magnetic field is always comparable to the scale of the turbulent eddies. In contrast, in the tall box the azimuthal magnetic flux spreads in the vertical direction over a distance exceeding the scale of the turbulent eddies. As a result, different vertical sections of the tall box are permeated by large-scale nonzero azimuthal magnetic fluxes, facilitating the instability.

*NSF AGS-1261659, Vilas Associates Award, NSF-Teragrid Project TG-PHY110016.

11:54
GO6 13 Transverse Cascade and Sustenance of Turbulence in Keplerian Disks with an Azimuthal Magnetic Field* D. GOGICHAISHVILI, University of Texas at Austin G. MAMAT-SASHVILI, Helmholtz-Zentrum Dresden-Rossendorf; Tbilisi State Univ.; Ilia State Univ W. HORTON, University of Texas at Austin G. CHAGELISHVILI, Ilia State Univ.; Tbilisi State Univ. G. BODO, INAF/Osservatorio Astrofisico di Torino The magnetorotational instability (MRI) in the sheared rotational Keplerian explains fundamental problems for both astrophysics and toroidal laboratory plasmas. The turbulence occurs before the threshold for the linear eigen modes. The work shows the turbulence occurs in nonzero toroidal magnetic field with a sheared toroidal flow velocity. We analyze the turbulence in Fourier k-space and x-space each time step to clarify the nonlinear energy-momentum transfers that produce the sustenance in the linearly stable plasma. The nonlinear process is a type 3D angular redistribution of modes in Fourier space — a transverse cascade — rather than the direct/inverse cascades. The turbulence is sustained an interplay of the linear transient growth from the radial gradient of the toroidal velocity (which is the only energy supply for the turbulence) and the transverse cascade. There is a relatively small “vital area in Fourier space” is crucial for the sustenance. Outside the vital area the direct cascade dominates. The interplay of the linear and nonlinear processes is generally too intertwined in k-space for a classical turbulence characterization. Subcycles occur from the interactions that maintain self-organization nonlinear turbulence. The spectral characteristics in four simulations are similar showing the universality of the sustenance mechanism of the shear flow driven MHDs-turbulence.

*Funded by the US Department of Energy under Grant DE-FG02-04ER54742 and the Space and Geophysics Laboratory at the
University of Texas at Austin. G. Mamatsashvili is supported by the Alexander von Humboldt Foundation, Germany.

12:06
GO6 14 Astrophysical ZeV acceleration in the jets from an accreting blackhole TOSHIKI TAJIMA, University of California, Irvine TOSHIKAZU EBISUZAKI, AKIRA MIZUTA, RIKEN, Japan An accreting blackhole produces extreme amplitude Alfven waves whose wavelength (wave packet) size is characterized by its clumsiness. The ponderomotive force driven by the bow wave of these Alfven waves propagates along the AGN (blazar) jet, and accelerates protons/nuclei to extreme energies beyond Zetta-electron volt (ZeV = 10^{21} eV) [1]. Such acceleration is linear and does not suffer from the multiple scattering/bending involved in cosmological filaments in the local super cluster. We will discuss the possible acceleration in an intermediate mass black hole candidate M82 X-1 and the magnetic bending in the Fermi acceleration that causes excessive synchrotron radiation loss beyond 10^{19} eV. This bow wave acceleration was confirmed one-dimensional particle-in-cell simulations [2]. General relativistic Magneto-hydrodynamics simulations also show the intermittent eruptions of electro-magnetic waves from the innermost region of the accretion disk around a black hole [3]. The production rate of ultra-high energy cosmic rays in M82 starburst galaxy is estimated from its gamma-ray luminosity and is found to be consistent with the observed flux of the northern hot spot by Telescope Array [4]. We will discuss the possible acceleration in an intermediate mass black hole candidate M82 X-1 and the magnetic bending in the cosmological filaments in the local super cluster.

1Ebisuzaki and Tajima (2014).
2Lau et al. (2015).
3Mizuta et al. (2017) priv. comm.
4Abbasi et al. (2014).

12:18
GO6 15 Observational Signatures Of The Gamma Rays From Bright Blazars And Wakefield Theory KEVORK ABAZAJIAN, NICHOLAS CANAC, TOSHIKI TAJIMA, Univ of California - Irvine TOSHIKAZU EBISUZAKI, RIKEN, Japan SHUNSAKU HORIUCHI, Virginia Tech Gamma-ray observations have detected a strong variability in blazar luminosity in the gamma ray over time scales as short as several minutes. We show, for the first time, that the correlation of spectrum with intensity is consistent with the behavior with luminosity of blazar SEDs along a blazar sequence for low synchrotron peak blazars. We show that the observational signatures of variability with μ are consistent with wakefield acceleration of electrons initiated by instabilities in the blazar accretion disk. This mechanism produces time variations as short as intervals of 100 seconds. The wakefield mechanism also predicts a reduction of electron spectral index with an increase in gamma-ray luminosity, which could be detected in higher energy observations well above the inverse Compton peak.

SESSION GO7: X-RAY DIAGNOSTICS AND MEASUREMENT TECHNIQUES
Tuesday Morning, 24 October 2017
Room: 203AB at 9:30
Kelly Hahn, Sandia National Laboratories, presiding

Contributed Papers

9:30
GO7 1 Electron temperature from x-ray continuum measurements on the NIF* LEONARD JARROT, BENJAMIN BACHMANN, ROBIN BENEDETTI, NOBUHIKO IZUMI, SHAHAB KHAN, OTTO LANDEN, TAMMY MA, SABRINA NAGEL, ARTHUR PAK, PRAV PATEL, MARILYN SCHNEIDER, PAUL SPRINGER, Lawrence Livermore Nat Lab LLNL COLLABORATION We report on measurements of the electron temperature within the hot spot of inertially confined, layered implosions on the NIF using a titanium differential filtering x-ray diagnostic. The electron temperature from x-ray emission is insensitive to non-thermal velocity flows as is the case with ion temperature measurements and is thus a critical parameter in interpreting stagnated hot spot conditions. Here we discuss measurements using titanium filters ranging from 10 μm to 1mm in thickness with a sensitivity band of 10-30keV coupled with penumbral pinholes. The use of larger pinhole diameters increases x-ray fluence improving sensitivity of photon energies with minimal attenuation from the compressed fuel/shell. This diagnostic has been fielded on a series of cryogenic shots with DT ion temperatures ranging from 2-5keV. Analysis of the measurement will be presented along with a comparison against simulated electron temperatures and x-ray spectra as well as a comparison to DT ion temperature measurements.

*This work was performed under the auspices of U.S. DoE by LLNL under Contract No. DE-AC52-07NA27344.

9:42
GO7 2 Development of a High Resolution X-ray Spectrometer on the National Ignition Facility* L. GAO, B. KRAUS, K. W. HILL, M. BITTER, P. EFTHIMION, Princeton Plasma Physics Laboratory M. B. SCHNEIDER, H. CHEN, J. AYERS, D. LIEDAHL, A. G. MACPHEE, H. P. LE, D. THORN, Lawrence Livermore National Laboratory D. NELSON, Laboratory for Laser Energetics A high-resolution x-ray spectrometer has been designed, calibrated, and deployed on the National Ignition Facility (NIF) to measure plasma parameters for a Kr-doped surrogate capsule imploded at NIF conditions. Two conical crystals, each diffracting the Heα and Heβ complexes respectively, focus the spectra onto a x-ray camera photocathode for time-resolved measurements with a temporal resolution of <20 ps. A third cylindrical crystal focuses the entire Heα to Heβ spectrum onto an image plate for a time-integrated spectrum to correlate the two streaked signals. The instrument was absolutely calibrated by the x-ray group at the Princeton Plasma Physics Laboratory using a micro-focus x-ray source. Detailed calibration procedures, including source and spectrum alignment, energy calibration, crystal performance evaluation, and measurement of the resolving power and the integrated reflectivity will be presented. Initial NIF experimental results will also be discussed.

9:54
GO7 3 The Crystal Backlighter Imager: a spherically-bent crystal imager for radiography on the National Ignition Facility GARETH HALL, Lawrence Livermore National Laboratory CHRISTINE KRAULAND, General Atomics JUSTIN BUSCHO, ROBIN HIBBARD, THOMAS MCCARVILLE, ROGER LOWEWEBB, SHANNON AYERS, DANIEL KALANTAR, THOMAS KOHUT, G. ELIJAH KEMP, DAVID BRADLEY, PERRY BELL, OTTO LANDEN, NATHANIEL BREWSTER, KENNETH PISTON, Lawrence Livermore National Laboratory The Crystal Backlighter Imager (CBI) is a quasi-monochromatic, near-normal incidence, spherically-bent crystal imager being developed for the NIF;
10:06

**GO7 4** Progress in using imaging x-ray spectroscopy to diagnose interspecies ion separation in inertial confinement fusion experiments* TIRTHA JOSHI, PETER HAKEL, SCOTT HSU, NELSON HOFFMAN, YONGHO KIM, HANS HERRMANN, GRIGORY KAGAN, Los Alamos National Laboratory, University of Nevada, Reno. We discuss the reconstruction of spatial profiles of ion densities and plasma conditions based on analyses of spatially resolved x-ray pinhole images of Ar-doped, D$_2$-filled OMEGA direct-drive ICF implosions. The targets are 15-$\mu$m spherical plastic shells filled with varying D$_2$-Ar relative and total gas pressures. Ar K-shell spectral features are observed primarily between the time of first-shock convergence and slightly before neutron bang time, using a time- and space-integrated spectrometer (XRS2), streaked crystal spectrometer (SSCA), and up to three gated neutron bang time, using a time- and space-integrated spectrometer (XRS2), streaked crystal spectrometer (SSCA), and up to three gated focal planes. The drive uniformity of OMEGA cryogenic implosions is affected by UV beamfluence variations on target, which require careful monitoring at full laser power. This is routinely performed with multiple pinhole cameras equipped with charge-injection devices (CID’s) that record the x-ray emission in the $\sim$- to 7-keV photon energy range from an Au-coated target. The technique relies on the knowledge of the relation between x-ray fluence $F_x$ and UV fluence $F_{UV}$. $F_x \sim F_{UV}^\gamma$, with a measured $\gamma$ = 3.42 for the CID-based diagnostic and 1-ns laser pulse [1]. It is demonstrated here that using a back-thinned charge-coupled-device camera with softer filtration for x-rays with photon energies $<2$ keV and well calibrated pinhole provides a lower $\gamma$ ~ 2 and a larger dynamic range in the measured UV fluence. Inferred UV fluence profiles were measured for 100-ps and 1-ns laser pulses and were compared to directly measured profiles from a UV equivalent-target-plane diagnostic. Good agreement between both techniques is reported for selected beams.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


10:18

**GO7 5** Inference of the electron temperature in ICF implosions from the hard x-ray spectral continuum* GRIGORY KAGAN, LANL O.L., LANDEN, LLNL D. SYYATSKY, LANL H. SIO, N.V. KABADI, R.A. SIMPSON, M. GATU JOHNSON, J.A. FRENJE, R.D. PETRASO, MIT R.C. SHAH, T.R. JOSHI, P. HAKEL, T.E. WEBER, LANL H.G. RINDERKNECHT, D. THORN, M. SCHNEIDER, D. BRADLEY, J. KILKENNY, LLNL. The NIF Continuum Spectrometer, scheduled to be first deployed in Fall of 2017, will infer the imploided core electron temperature from the free-free continuum self-emission spectra of photons with energies of 20 to 30 keV. However, this hard X-ray radiation is emitted by the tail of the electron distribution, which likely deviates from Maxwellian and thus obscures interpretation of the data. We investigate resulting modifications to the X-ray spectra. The logarithmic slope of the spectrum from the more realistic, non-thermal tail of the electron distribution is found to decrease more rapidly at higher photon energies, as compared to the perfectly Maxwellian case. Interpreting the spectrum with assumption of Maxwellian electrons enforced is shown to give an electron temperature that is lower than the actual one. Conversely, due to its connection with the non-thermal features in the electron distribution, hard X-ray emission can provide unprecedented information about kinetic processes in the hot DT core.

*This work was performed under the auspices of the U.S. Dept. of Energy by the Los Alamos National Security, LLC, Los Alamos National Laboratory under Contract No. DE-AC52-06NA25396.

Time-gated soft x-ray self-emission images of directly driven implosions were measured to probe the hydrodynamic conditions between the critical-density surface and the ablation front of a CH target (conduction zone) at the beginning of a laser pulse. The self-emission at each point in the coronal plasma depends on the local electron temperature and the ion density, and the intensity measured at the diagnostic plane is the line-integrated emissivity through the target. Measured 2-D images of spherically symmetric implosions were angularly averaged and compared with synthetic self-emission profiles generated from 1-D hydrodynamic simulations to benchmark the hydrodynamic parameters in the corona. This comparison was performed for a range of times early in the implosion to study the formation and evolution of the conduction zone. This measurement is significant for inertial confinement fusion since it governs the length of time that the plasma is too small to provide substantial beam smoothing through thermal conduction, determining the laser imprint efficiency. The conduction zone has previously proven challenging to probe because the density is too high for optical diagnostics and because the temperature is too high for x-ray radiography.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


The Crystal Backlighter Imager (CBI) is a very narrow bandwidth (∼10 eV) x-ray radiography system that uses Bragg reflection from a spherically-curved crystal at near normal incidence. This diagnostic has the capability to image at an ICF implosion because it only requires the brightness of the backlighter to be larger than the capsule self-emission in that narrow bandwidth. While the limited bandwidth is advantageous for this reason, it also requires that the effective energy of the backlighter atomic line is known to ∼1 eV accuracy for proper crystal alignment. Any Doppler shift in the line energy must be understood for the imaging system to work. The work presented details characterization experiments done at the Jupiter Laser Facility with a Si (8 6 2) crystal that will be used with a Selenium backlighter in the NIF CBI diagnostic. We used the spherically-bent crystals to image the backlighter to be larger than the capsule self-emission in that narrow bandwidth. While the limited bandwidth is advantageous for this reason, it also requires that the effective energy of the backlighter atomic line is known to ∼1 eV accuracy for proper crystal alignment.

11:06

GO7 11 Recent Progress in Target Metrology at General Atomics†† HAIBO HUANG, KYLE ENGELHORN, KEVIN SEQUOIA, KURT BOEHM, HONGWEI XU, JAVIER JAEUZ, ANNETTE GREENWOOD, JAY CRIPPEN, CASEY KONG, NEAL RICE, CHRISTOPHER REED, FRED ELSNER, MIKE FARRELL, General Atomics Targets are central to all ICF/HED programs. Many target specifications are so tight or specialized that the measurements cannot be performed on commercial equipment. General Atomics continues to provide on-demand target metrology development to support the evolving needs of the community. In this talk, we will present our latest efforts in new instrument design, equipment automation and data analysis technique development. Examples include a dark-field imaging algorithm to measure ablator defects down to 0.1um size required by Laboratory for Laser Energetics direct drive program, a full-surface wall-thickness mapper that enables polystyrene shell development, an integrated set up for GDP dome mapping and removal, an automated x-ray absorption spectroscopy to improve the precision and accuracy of dopant measurement, a hohlraum interior surface inspection technique, optical transmission characterization of thin metallic films for micro-dots hohlraum diagnostic platform, new high-resolution NEXIV pin-hole array characterization, etc.

11:18

GO7 12 Synthetic Pulse Dilation – PMT Model for high bandwidth gamma measurements H. GEPPERT-KLEINRATH, H. W. HERRMANN, Y. H. KIM, A. B. ZYLSTRA, K. D. MEANEY, F. E. LOPEZ, Los Alamos National Laboratory H. KHATER, Lawrence Livermore National Laboratory C. J. HORSFIELD, S. GALES, A. LEATHERLAND, Atomic Weapons Establishment T. HILSABECK, J. D. KILKENNY, General Atomics J. D. HARES, T. DYMOKO-BRADSHAW, Kentech Instruments LTD J. MILNES, Photek LTD The Cherenkov mechanism used in Gas Cherenkov Detectors (GCD) is exceptionally fast. However, the temporal resolution of GCDs, such as the Gamma Reaction History diagnostic (GRH), is limited by the current state-of-the-art photomultiplier tube (PMT) to ∼100 ps. The new pulse dilation – PMT (PD-PMT) for NIF allows for a temporal resolution comparable to that of the gas cell, or of ∼10ps. Enhanced resolution will contribute to the quest for ignition in a crucial way through precision measurement.
of reaction history and areal density ($\rho$R) history, leading to better constrained models. Features such as onset of alpha heating, shock reverberations and burn truncation due to dynamically evolving failure modes will become visible for the first time. PD-PMT will be deployed on GCD-3 at NIF in 2018. Our synthetic PD-PMT model evaluates the capabilities of these future measurements, as well as minimum yield requirements for measurements performed in a well at 3.9 m from target chamber center (TCC), and within a diagnostic inserter at $\sim$0.2m from TCC.

**SESSION GO8: ANALYTICAL AND COMPUTATIONAL TECHNIQUES, ICF AND HED**

Tuesday Morning, 24 October 2017
Room: 203C at 9:30
Andrei Simakov, Los Alamos National Laboratory, presiding

**Contributed Papers**

**9:30**

**GO8 1 A comparison of non-local electron transport models relevant to inertial confinement fusion**

MARK SHERLOCK, Lawrence Livermore National Laboratory
JONATHAN BRODRICK, CHRISTOPHER RIDGERS, University of York

We compare the reduced non-local electron transport model developed by Schurtz et al. [1] to Vlasov-Fokker-Planck simulations. Two new test cases are considered: the propagation of a heat wave through a high density region into a lower density gas, and a 1-dimensional hohlraum ablation problem. We find the reduced model reproduces the peak heat flux well in the ablation region but significantly over-predicts the coronal preheat. The suitability of the reduced model for computing non-local transport effects other than thermal conductivity is considered by comparing the computed distribution function to the Vlasov-Fokker-Planck distribution function. It is shown that even when the reduced model reproduces the correct heat flux, the distribution function is significantly different to the Vlasov-Fokker-Planck prediction. Two simple modifications are considered which improve agreement between models in the coronal region.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

**1Schurtz et al., Phys. Plasmas 7, 4238 (2000).**

**9:42**

**GO8 2 Benchmark of nonlocal transport models against Vlasov-Fokker-Planck codes in situations of immediate relevance to ICF**

DARIO DEL SORBO, JONATHAN P. BRODRICK, MARTIN P. READ, University of York
MILAN HOLEC, Cella- Univ. Bordeaux, CEA, CNRS ARNAUD DEBAYLE, PAS-CAL LOISEAU, CEA ROBERT J. KINGHAM, Imperial College
PHILIPPE NICOLAI, JEAN-LUC FEUGEAS, VLADIMIR T. TIKHONCHUK, Cella- Univ. Bordeaux, CEA, CNRS CHRISTOPHER P. RIDGERS, University of York

Hydrodynamics simulations relevant to inertial confinement fusion require a detailed description of energy transport, in particular by electrons. This may be nonlocal if, as is commonly the case, the plasma is not in local thermodynamic equilibrium (i.e. if the electron mean free path is long compared to the temperature scale-length). In this case, a kinetic model of electron thermal transport is required. Some of the most successful approaches to nonlocal transport (SNB [1] & M1 [2] models) are systematically compared [3] against Vlasov-Fokker-Planck & Particle-in-Cell codes, extending benchmarking beyond the 1D unmagnetized case and studying situations of immediate relevance to ICF.

**1Schurtz et al., Phys. Plasmas 7, 10 (2000).**
**2Del Sorbo et al., Phys. Plasmas 22, 8 (2015).**
**3Brodrick et al., arXiv:1706.04153.**

**9:54**

**GO8 3 Analytic insights into nonlocal electron thermal transport**

WALLACE MANHEIMER, DENIS COLOMBANT, Retired from NRL

Several theories of nonlocal electron thermal transport in laser target plasmas, based on a Krook model give rather different results. Sometimes these models show very little effect of fuel preheat on target gain, other calculations show enough preheat that the gain is substantially reduced. We find that there are errors in the theoretical models and very likely errors in some of their numerical implementation. Hence analytic insight is necessary. We derive approximate analytical solutions for the Krook model for nonlocal electron energy transport, ultimately finding a relatively simple formula to estimate for fuel preheat in terms of the laser and target plasma parameters. This analysis can be used as a check on the more complex fluid simulation. In addition to the Krook model being not correctly formulated, another consideration is that a Fokker Planck model gives a rather different solution for the preheat. We also derive a formula for the preheat based on a Fokker Planck model, a formula with is intuitively reasonable and predicts much less preheat than a Krook model. In either model, there can be broadening of the ablation layer which may have an effect on the Rayleigh Taylor instability growth rate.

*Work supported by NNSA.*

**10:06**

**GO8 4 Plasma simulation with a multi-scale numerical method**

LONG YANG, KUN LIU, SHUCHAO DUAN, Institute of Fluid Physics, CAEP COMPUTATIONAL PHYSICS TEAM

Multi-scale effect is widely existed in plasma. Plasma will be deviated from ideal plasma assumption when it meets external field, in which parts of electrons will gain energy from the field and become runaway electrons. Ideal MHD method can’t deal with the physical problems if the problems are closed related to those runaway electrons effect. To solve those problems, PIC (particle in cell simulation) method and hybrid fluid method were used traditionally. But those methods have their own limitations, PIC method needs a very long calculation time which limits time scale it can simulate, and hybrid method introduces some non-physical assumptions and requires dealing complex data exchange between different methods. In this paper, a multi-scale method is described, in which the evolution of plasma is referenced UGKS direct modeling method [1], and finite volume scheme is used to solve the multicomponent plasma BGK equations. And the time-varying Maxwell equations are deduced with the finite difference scheme, the magnetic field divergence is controlled by adopting the CT/CD method. This method does not require different calculation methods in calculation of different time scales. It will be degradation to kinetic scheme if the plasma average collision time is large and degradation to MHD scheme if the average plasma collision time is small automatically. The computational accuracy of this method is quite the same as that of the DSMC method, and the calculation time required is far less than that of the PIC method. The method can be applied to the simulation gas discharge plasma under extreme conditions and complex non-ideal completely ionized plasma.
from atomic inter-species diffusion to hydrodynamic instabilities. Because the interface is preheated by energy from the incoming shock, it is important to understand the dynamics before the shock arrives. The interface is in the warm dense matter phase with a deuterium/tritium fuel mixture on one side and a plastic mixture on the other. We would like to understand various aspects of the evolution, including the state of the interface when the main shock arrives, the role of electric field generation at the interface, and the character and time scales for diffusion. We present a multiscale approach to model these processes, which combines molecular dynamics to simulate the ionic degrees of freedom with orbital-free density functional theory to calculate the electronic structure. Simulation results are presented and connections to hydrodynamic models are discussed.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

10:54
GO8 8 Investigation of thermal conductivity of materials for inertial confinement fusion applications TILAK DHAKAL, BRIAN HAINES, Los Alamos National Laboratory Numerous inertial confinement fusion (ICF) capsule implosion experiments use different materials and their mixtures. To numerically simulate such experiments, one requires many plasma parameters beforehand for a wide range of temperatures and densities. Thermal conductivity is one of them, which determines the heat transport in plasma so that it plays a key role in the growth of hydrodynamic instabilities during the capsule implosion process. Analytic models such as, Spitzer model and Lee-More model have been extensively used to calculate thermal conductivity. But these models are usually not valid especially for warm dense plasma regime. Tabular EOS data, such as SESAME tables, are not available for all materials. In this talk, we investigate different analytic models, first principle calculation, tabular data to calculate thermal conductivity for most commonly used materials and their mixtures in ICF experiments such as Polystyrene (CH) and Deuterium-Tritium (DT).

11:06
GO8 9 Development of Fast and Reliable Free-Energy Density Functional Methods for Simulations of Dense Plasmas from Cold- to Hot-Temperature Regimes V. V. KARASIEV, Laboratory for Laser Energetics, U. of Rochester Free-energy density functional theory (DFT) is one of the standard tools in high-energy-density physics used to determine the fundamental properties of dense plasmas, especially in cold and warm regimes when quantum effects are essential. DFT is usually implemented via the orbital-dependent Kohn–Sham (KS) procedure. There are two challenges of conventional implementation: (1) KS computational cost becomes prohibitively expensive at high temperatures; and (2) ground-state exchange-correlation (XC) functionals do not take into account the XC thermal effects [1]. This talk will address both challenges and report details of the formal development of new generalized gradient approximation (GGA) XC free-energy functional which bridges low-temperature (ground state) and high-temperature (plasma) limits [2]. Recent progress on development of functionals for orbital-free DFT as a way to address the second challenge will also be discussed.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

10 Density-Functional-Theory–Based Equation-of-State Table of Beryllium for Inertial Confinement Fusion Applications* Y.H. DING, S.X. HU, Laboratory for Laser Energetics, U. of Rochester Beryllium has been considered a superior ablative material for inertial confinement fusion target designs. Based on density-functional-theory calculations, we have established a wide-range beryllium equation-of-state (EOS) table of density $\rho = 0.001$ to $\rho = 500$ g/cm$^3$ and temperature $T = 2000$ to $10^9$ K. Our first-principles equation-of-state (FPEOS) table [1] is in better agreement with widely used SESAME EOS table (SESAME2023) than the average-atom INFERNO model and the Paragotromodel. For the principal Hugoniot, our FPEOS prediction shows $\sim 10\%$ stiffer behavior than the last two models at maximum compression. Comparisons between FPEOS and SESAME for off-Hugoniot conditions show that both the pressure and internal energy differences are within $\sim 20\%$ between two EOS tables. By implementing the FPEOS table into the 1-D radiation–hydrodynamics code RAGE, we studied the EOS effects on beryllium target-shell implosions. The FPEOS simulation predicts up to an $\sim 15\%$ higher neutron yield compared to the simulation using the SESAME2023 EOS table.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

11 Progress towards an ab initio real-time treatment of warm dense matter* ANDREW BACZEWSKI, ATTILA CANGI, STEPHANIE HANSEN, DANIEL JENSEN, Sandia National Laboratories Time-dependent density functional theory (TDDFT) provides an accurate description of equilibrium properties of warm dense matter, such as the dynamic structure factor (Baczewski et al., Phys. Rev. Lett., 116(11), 2016). While non-equilibrium properties, such as stopping power, have also been demonstrated to be within the grasp of TDDFT, the ultrafast isochoric heating of condensed matter into the warm dense state, enabled by recent advances in XFELs, remains beyond its capabilities. In this talk, we will describe the successes of and continuing challenges for TDDFT for warm dense matter, and present progress towards a more complete ab initio treatment of isochoric x-ray heating.

*Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the DOE’s National Nuclear Security Administration under contract DE-NA0003525.

12 Implosion Simulations with a Kinetic Particle Code* IRINA SAGERT, WESLEY EVEN, TERRANCE STROther, Los Alamos National Laboratory Many problems in laboratory and plasma physics are subject to flows that move between the continuum and the kinetic regime. We discuss two-dimensional (2D) implosion simulations that were performed using a Monte Carlo kinetic particle code [1-3]. The application of kinetic transport theory is motivated, in part, by the occurrence of non-equilibrium effects in inertial confinement fusion (ICF) capsule implosions, which cannot be fully captured by hydrodynamics simulations. Kinetic methods, on the other hand, are able to describe both, continuum and rarefied flows. We perform simple 2D disk implosion simulations using one particle species and compare the results to simulations with the hydrodynamics code RAGE. The impact of the particle mean-free-path on the implosion is also explored. In a second study, we focus on the formation of fluid instabilities from induced perturbations.

*LaS acknowledges support through the Director’s fellowship from Los Alamos National Laboratory. This research used resources provided by the LANL Institutional Computing Program.

GO8 11 “Green’s function” approach & low-mode asymmetries* LAURENT MASSE, DAN CLARK, JAY SALMONSON, STEVE MACLAREN, TAMMY MA, SHAHAB KHAN, JESSE PINO, JO RALPH, C. CIAJKA, ROBERT TIPTON, OTTO LANDEN, LLNL, GEORGES KRYALA, LANL 2 TEAM, 1 TEAM Long wavelength, low mode asymmetries are believed to play a leading role in limiting the performance of current ICF implosions on NIF. These long wavelength modes are initiated and driven by asymmetries in the x-ray flux from the hohlraum; however, the underlying hydrodynamics of the implosion also act to amplify these asymmetries. The work presented here aim to deepen our understanding of the interplay of the drive asymmetries and the underlying implosion hydrodynamics in determining the final imploded configuration. This is accomplished through a synthesis of numerical modeling, analytic theory, and experimental data. In detail, we use a Green’s function approach to connect the drive asymmetry seen by the capsule to the measured inflight and hot spot asymmetries. The approach has been validated against a suite of numerical simulations. Ultimately, we hope this work will identify additional measurements to further constrain the asymmetries and increase hohlraum illumination design flexibility on the NIF. The technique and derivation of associated error bars will be presented.


GO8 14 Multi-dimensional simulation package for ultrashort pulse laser-matter interactions* ANASTASSIYA SUSLOVA, AHMED HASSANEIN, Purdue Univ Advanced simulation models recently became a popular tool of investigation of ultrashort pulse lasers (USPLs) to enhance understanding of the physics and allow minimizing the experimental costs for optimization of laser and target parameters for various applications. Our research interest is focused on developing multi-dimensional simulation package FEMTO-2D to investigate the USPL-matter interactions and laser induced effects. The package is based on solution of two heat conduction equations for electron and lattice sub-systems - enhanced two temperature model (TTM). We have implemented theoretical approach based on the collision theory to define the thermal dependence of target material optical properties and thermodynamic parameters. Our approach allowed elimination of fitted parameters commonly used in TTM based simulations. FEMTO-2D is used to simulated the light absorption and interactions for several metallic targets as a function of wavelength and pulse duration for wide range of laser intensity. The package has capability to consider different angles of incidence and polarization. It has also been used to inves-
tigate the damage threshold of the gold coated optical components with the focus on the role of the film thickness and substrate heat sink effect.

*This work was supported by the NSF, PIRE project.

**SESSION GP11: POSTER SESSION III:**
- RECONNECTION; LASER-PLASMA INTERACTIONS AND ACCELERATION; PLASMA TECHNOLOGY;
- DIII-D I; HOHLRAUM AND X-RAY CAVITY PHYSICS;
- COMPUTATION

Tuesday Morning, 24 October 2017
Exhibit Exhibit Hall D at 9:30

**GP11 1 RECONNECTION**

**GP11 2 Hard X-ray Bursts Observed in Association with Magnetic Reconnection in a Solar-Relevant Lab Experiment** RYAN S. MARSHALL, PAUL M. BELLAN, Caltech Measurements by a plastic scintillator show transient emission of a sub-microsecond pulse of 6 keV X-rays by a cold, dense MHD-driven plasma jet having a collision mean free path much shorter than the jet dimensions so that acceleration of any particles to high energy was not expected. The X-ray pulse occurs when the jet undergoes a kink instability which accelerates the jet laterally so that a fast-growing secondary Rayleigh-Taylor instability is triggered that then breaks the jet. It is proposed that despite the short collision mean free path, an inductive electric field associated with this breaking accelerates a certain subgroup of electrons to 6 keV energy without any of these electrons undergoing collisions. It is further proposed that after being accelerated to high energy, the fast electrons are suddenly decelerated via collisions and radiate X-rays. Extrapolation to both the solar corona and chromosphere predicts the acceleration of a small subset of electrons to very large super-thermal energies by sub-Dreicer electric fields.

**GP11 3 Effective Ion Heating in Guide Field Reconnection** XUE-HAN GUO, The University of Tokyo RITOKU HORIUCHI, SHUN-SUKE USAMI, National Institute for Fusion Science YASUSHI ONO, The University of Tokyo The energy conversion mechanism for ion perpendicular thermal energy is investigated by means of two-dimensional, full particle simulations in an open system. It is shown that ions gain kinetic energy due to the plasma potential drop, which is caused by the charge separation in the one pair of separatrix arms. Based on the force balance in the inflow direction, the strength of the normalized charge density can be expressed by the electric field arms. Based on the force balance in the inflow direction, the strength of the normalized charge density can be expressed by the electric field. The role of magnetic shear in altering energization and particle distributions along the turbulent magnetoshepheric separatrix is also studied. The PIC simulation results are compared to MMS observations.

**GP11 4 Plasma Transport at the Magnetopause in 3D Kinetic Simulations of MMS Reconnection Site Encounters with Varying Guide Fields** ARI LE, WILLIAM DAUGHTON, OBIOMA OHIA, LANL LI-JEN CHEN, UMD/NASA GSFC YI-HSIN LIU, NASA GSFC We present 3D fully kinetic simulations of asymmetric reconnection with plasma parameters matching MMS magnetopause diffusion region crossings with varying guide fields of $\sim 0.1$ [1], $\sim 0.4$ [2], and $\sim 1$ [3] of the reconnecting sheet field. For the weakest guide field case, drift turbulence at the magnetosheptic separatrix was found to enhance transport and parallel electron heating [4]. Here, we study how varying magnetic shear affects the morphology and plasma transport of the reconnecting magnetopause current sheet. Reconnection rates in 2D and 3D are compared using diagnostics based on particle mixing and on the magnetic field line-integrated parallel electric field. The role of magnetic shear in altering energization and particle distributions along the turbulent magnetoshepheric separatrix is also studied. The PIC simulation results are compared to MMS observations.

**GP11 5 Time domain structures in a colliding magnetic flux rope experiment** SHAWN WENJIE TANG, WALTER GEKELMAN, TIMOTHY DEHAAS, STEVE VINCENA, PATRICK PRIBYL, Univ of California - Los Angeles Electron phase-space holes, regions of positive potential on the scale of the Debye length, have been observed in auroras as well as in laboratory experiments. These potential structures, also known as Time Domain Structures (TDS), are packets of intense electric field spikes that have significant components parallel to the local magnetic field. In an ongoing investigation at UCLA, TDS were observed on the surface of two magnetized flux ropes produced within the Large Plasma Device (LAPD). A barium oxide (BaO) cathode was used to produce an 18 m long magnetized plasma column and a lanthanum hexaboride (LaB$_6$) source was used to create 11 m long kink unstable flux ropes. Using two probes capable of measuring the local electric and magnetic fields, correlation analysis was performed on tens of thousands of these structures and their propagation velocities, probability distribution function and spatial distribution were determined. The TDS became abundant as the flux ropes collided and appear to emanate from the reconnection region in between them. In addition, a preliminary analysis of the permutation entropy and statistical complexity of the data suggests that the TDS signals may be chaotic in nature.

*Work done at the Basic Plasma Science Facility (BaPSF) at UCLA which is supported by DOE and NSF.

**GP11 6 Secondary Instabilities in 3-D Magnetic Reconnection under a Strong Guide Field** XUEYI WANG, YU LIN, Auburn University LIU CHEN, University of California, Irvine 3-D magnetic reconnection is investigated using the gyrokINETIC electron and fully-kINETIC ion (GeoF) particle simulation model. The simulation is carried out for a force free current sheet with a strong guide field $B_G$ as occurring in solar and laboratory plasmas. It is found that secondary instabilities are excited in the separatrix region of the primary reconnection due to the 3-D effects associated with the finite $k_z$, where $k_z$ is the wave number along the guide field direction. The instabilities are demonstrated as being of the MHD kink type, which
lead to electron heating and acceleration in the parallel direction. The dependence of the growth rate of the secondary instabilities on the electron-ion resistivity, the ion-to-electron mass ratio $m_i/m_e$, and the half-width of the current sheet are also investigated.

GP11 7 Understanding the dynamics and the energetics of magnetic reconnection in laboratory and space plasmas* MASAKAI YAMADA, JONGSOO YOO, HANTAO JI, JON JARA-ALMOT, WILL FOX, RUSSELL KULSRUD, Princeton Plasma Physics Laboratory, Princeton University. We will present recent findings in the research of asymmetric and symmetric magnetic reconnection both in laboratory and space plasmas [1]. In spite of the huge difference ($10^5-10^6$) in physical scales, we find remarkable commonality between the properties and the dynamics of the reconnection layer in laboratory and space plasmas. The recent significant progress in diagnostics in the both fields made us possible to directly compare the observed physics processes. The experimental results on the energy conversion and partitioning are discussed and compared with quantitative estimates based on two-fluid analysis as well as space observations. We observed notable similarity in the energy partitioning in the reconnection layer of the MRX and space observations [1,2]. Furthermore, we have observed whistler waves and lower-hybrid frequency fluctuations at the lower density side of asymmetric reconnection layer on MRX [2]. The experimental results are remarkably consistent with the recent space observations from MMS [3]. We directly compare the data from the MRX and the recent MMS observations which show very similar power spectra.

*Supported by OFES, Dept. Energy.

1M. Yamada et al., PoP 23, 055402 (2016).
3L. J. Chen et al., This conf.

GP11 8 Studies of waves during asymmetric reconnection in laboratory and space* JONGSOO YOO, EVAN YERGER, JONATHAN JARA-ALMOT, MASAKAI YAMADA, HAN TAO JI, WILL FOX, Princeton Plasma Phys Lab LI-JEN CHEN, University of Maryland, College Park. Wave activities during asymmetric reconnection have been studied by directly comparing data from the Magnetic Reconnection Experiment (MRX) with data from the Magnetospheric Multiscale (MMS). The power spectrum near separatrices on the low-density (magnetosphere) side shows remarkable similarity to the high-density side observations near the EDR. The dominant wave vector satisfies $kd = 1$ for all cases. Possible excitation mechanisms for the observed whistler waves are discussed.

*This work is supported by the DOE contract No. DE-AC0209CH11466.

GP11 9 Drift Kinetic Measurements of Plasma Gradients in MMS Data* BLAKE WETHERTON, JAN EGEDAL, University of Wisconsin-Madison PETER MONTAG, Massachusetts Institute of Technology ARI LE, WILLIAM DAUGHTON, Los Alamos National Laboratory BENOIT LAVRAUD, Université de Toulouse and Centre National de la Recherche Scientifique. In magnetic reconnection, magnetic stress energy is converted into particle energy through the topological rearrangement of magnetic field lines allowed by the breakdown of ideal MHD on small spatial scales. While many models exist to explain reconnection, the crucial physics lies in a thin current layer $\sim 1 \Omega$ wide. NASA’s Magnetospheric Multiscale (MMS) mission seeks to directly investigate magnetic reconnection in Earth’s magnetosphere with a tetrahedral formation of four spacecraft. While gradients in plasma properties can be estimated through spacecraft positions, the spacing between each tends to be $\sim 1 \Omega$, causing gradients at the crucial scale to be poorly resolved. We present a drift-kinetic method for obtaining gradients in the plasma distribution function with data from a single spacecraft. This model is derived from drift kinetics, verified with a VPI C fully-kinetic simulation, and applied to MMS data to infer the geometry of the reconnection region and demonstrate gradient-scale resolution superior to finite difference methods between the four spacecraft.

*This work was supported by the Department of Energy Computational Science Graduate Fellowship Grant DE-FG02-97ER25308, NSF award 1404166, and NASA award NNX15AJ73G.

GP11 11 Plasmoid Instability in Evolving Current Sheets and Onset of Fast Reconnection* YI-MIN HUANG, LUCA COMISSO, AMITAVA BHATTACHARJEE, Princeton University. A proper description for the onset of the plasmoid instability must incorporate the evolving process of the current sheet, as a high Lundquist number current sheet usually breaks apart before it approaches the Sweet-Parker width. We carry out two-dimensional simulations and theoretical analysis of the plasmoid instability in an evolving background. The plasmoid instability disrupts the current sheet and enters nonlinear regime when the sizes of plasmoids become comparable to the inner layer width of the tearing mode. The linear growth rate, current sheet width, and dominant wavenumber at current sheet disruption depend on not only the Lundquist number, but also the initial noise amplitude. The scalings obtained from simulation can be reproduced with a phenomenological model, which incorporates the effects of linear growth and advective losses.
due reconnection outflow. Our model predicts a critical Lundquist number below which disruption does not occur. The critical Lundquist number is not a constant value but has a weak dependence on the noise amplitude.

"This work is supported by NSF, Grant Nos. AGS-1338944 and AGS-1460169, and DOE, Grant No. DE-SC0016470.

**GP11 12 3D magnetic reconnection studies in the Terrestrial Reconnection Experiment (TREX)**

ALEXANDER MILLET-AYALA, JAN EGEDAL, JOSEPH OLSON, SAMUEL GREESES, RACHEL MYERS, JOHN WALLACE, MICHAEL CLARK, CARY FOREST, *Univ of Wisconsin, Madison* Recent experimental studies on the Terrestrial Reconnection Experiment (TREX) focus on nominally 2D asymmetric magnetic reconnection configurations. In 3D reconnection, however, regions of zero magnetic fields, called magnetic nulls, become important sites of potential particle acceleration. In order to study 3D null-point reconnection in TREX, an adjustable pulsed coil (null coil) is added to the experiment to introduce magnetic nulls. Tilting the null coil relative to the existing reconnection drive and Helmholtz coils forms complex 3D magnetic field geometries, vastly different from other 2D reconnection geometries explored on TREX. To measure the effects of the added null-points, a combination of magnetic probes and Langmuir probes are used to characterize the plasma.

"This work was supported by NSF Award #1612530, and NSF/DOE award DE-SC0013032.

**GP11 13 Endogenous Magnetic Reconnection and Associated High Energy Plasma Processes**

B. COPPI, B. BASU, *MIT* The existence of an endogenous magnetic reconnection process in weakly collisional plasmas is proposed that relies on the presence of a significant electron temperature gradient [1] and a local current density gradient within the region where a drastic change of magnetic field topology is produced. The newly identified mode involves widths of the layer in which reconnection takes place that remain relevant even when large macroscopic distances are considered, such as those of interest to space and astrophysics. Given that plasmas in the Universe with considerable electron thermal energy contents are ubiquitous, it makes sense to rely on this process to generate, through magnetic field reconnection, high energy particle populations [1], momentum and angular momentum transport and, in any case, new magnetic field configurations. A depletion of magnetic energy is associated with a suppression of the current density gradient.

*Sponsored in part by the U.S. DoE.


**GP11 14 Flux-rope distribution function through a Maximum Entropy principle**

MANASVI LINGAM, Harvard University; LUCA COMISSO, AMITAVA BHATTACHARJEE, Princeton University The Principle of Maximum Entropy (MaxEnt) is utilized for inferring the distribution function of flux ropes formed through a resistive instability as a function of their mass, flux and velocity [1]. Our treatment is 3D (flux ropes) in nature, as opposed to previous works that have studied 2D structures (plasmoids) [2,3]. The distributions for the mass, width, flux and helicity are characterized by a power-law behavior with exponents of $-4/3, -2, -3$ and $-2$ respectively for small values, and display an exponential falloff for large values. The velocity distribution is shown to be flat at small values and becomes an exponential distribution function for large values with an exponent of $-7/3$. A preliminary comparison with observational evidence suggests that the predictions of the theoretical model are consistent with the latter.


**GP11 15 Survey of Waves in the Ion Diffusion Region of Asymmetric Reconnection in the Dayside Magnetopause**

EYAN YERGER, JONGSOO YOO, Princeton Plasma Phys Lab; JI-JEN CHEN, University of Maryland, College Park EUN-HWA KIM, MASAAMI YAMADA, HANTAO JI, WILL FOX, Princeton Plasma Phys Lab

Wave modes in the ion diffusion region of an active dayside reconnection site are characterized using high time-resolution data from NASA’s Magnetospheric Multiscale (MMS) mission. We observe high-amplitude, low-frequency ($< \omega_{LH}$) electrostatic fluctuations near the magnetospheric-side separatrices, which are most likely a result of the lower hybrid drift instability (LHDI). In the magnetospheric upstream region we find whistler waves with $\omega \approx \Omega_e/2$ and phase velocity near $5 \times 10^7 \text{ m/s}$ propagating toward the X-line. In the exhaust region we find a largely different set of electromagnetic waves, including an obliquely-propagating, high-frequency ($\omega > \omega_{LH}$), left-hand-polarized waves with phase velocities around $1 \times 10^6 \text{ m/s}$. Possible relationships between these waves and local distribution functions will be investigated through analysis of data from the fast plasma instrument (FPi). We will also discuss the possibility of mode conversion from electrostatic lower hybrid waves to the electromagnetic waves we observe.

*This work is supported by the DOE Contract No. DE-AC2009CH11466.

**GP11 16 FLARE: A New User Facility for Studies of Multiple-Scale Physics of Magnetic Reconnection and Related Phenomena through in-situ Measurements**


The FLARE device (Facility for Laboratory Reconnection Experiments; flare.pppl.gov) is a new laboratory experiment under construction at Princeton for the studies of magnetic reconnection in the multiple X-line regimes directly relevant to space, solar, astrophysical, and fusion plasmas, as guided by a reconnection phase diagram [1]. The whole device have been assembled with first plasmas expected in the fall of 2017. The main diagnostics is an extensive set of magnetic probe arrays, currently under construction, to cover multiple scales from local electron scales (~2 mm), to intermediate ion scales (~10 cm), and global MHD scales (~1 m), simultaneously providing in-situ measurements over all these relevant scales. The planned procedures and example topics as a user facility will be discussed.

1Ji and Daughton (2011).

**GP11 17 Onset of magnetic reconnection in a weakly collisional, high-$\beta$ plasma**

ANDREW ALT, MATTHEW KUNZ, Princeton University In a magnetized, weakly collisional plasma, the magnetic moment of the constituent particles is an adiabatic invariant. An increase of the magnetic-field strength in such a plasma thus...
leads to an increase in the thermal pressure perpendicular to the field lines. Above a $\beta$-dependent threshold, this pressure anisotropy drives the mirror instability, which produces strong distortions in the field lines and traps particles on ion-Larmor scales. The impact of this instability on magnetic reconnection is investigated using simple analytical and numerical models for the formation of a current sheet and the associated production of pressure anisotropy. The difficulty in maintaining an isotropic, Maxwellian particle distribution during the formation and subsequent thinning of a current sheet in a weakly collisional plasma, coupled with the low threshold for the mirror instability in a high-$\beta$ plasma, imply that the topology of reconnecting magnetic fields can radically differ from the standard Harris-sheet profile often used in kinetic simulations of collisionless reconnection. Depending on the rate of current-sheet formation, this mirror-induced disruption may occur before standard tearing modes are able to develop.

*This work was supported by U.S. DOE contract DE-AC02-09CH11466.

GP11 18 Experimental Investigation of Magnetic Reconnection in Weakly Ionized Plasmas JONATHAN JARA-ALMONTE, HANTAO JI, JONGSOO YOO, MASAAMI YAMADA, WILL FOX, Princeton Plasma Physics Laboratory Magnetic reconnection is a fundamental process in magnetized plasmas wherein stored magnetic energy is rapidly released. While commonly studied in fully ionized plasmas, many important systems (e.g., the chromosphere or interstellar medium) are weakly ionized, which can significantly modify reconnection physics. Recent IRIS observations have enabled detailed studies of chromospheric reconnection, highlighting its in partially ionized systems [1]. Previous experiments on the Magnetic Reconnection Experiment have qualitatively shown that reconnection is slow in partially ionized systems, in contrast to theoretical predictions, although the underlying physics is unclear [2]. Here, new experiments are performed to examine the detailed role of neutrals. An in-situ filterscope has been developed to simultaneously measure Helium line emission at 668, 706, and 728 nm from a localized, 1 cm$^3$ volume with high time-resolution. Collisional radiative modeling is used to determine the neutral density, as well as the electron density and temperature. By measuring the neutral density, the detailed neutral-plasma coupling during reconnection is studied in detail.


GP11 19 Electron phase space structure of asymmetric reconnecting current sheets with varying guide fields OBIOMA OHIA, ARI LE, WILLIAM DAUGHTON, Los Alamos National Laboratory Magnetic reconnection in asymmetric current sheets is known to produce highly structured electron velocity distributions, including crescents within the diffusion region [1] and crescents and mixed populations along the separatrices [2]. Using a series of 2D particle-in-cell simulations of asymmetric magnetic reconnection with varying guide magnetic fields, we investigate electron distribution functions in both the upstream and exhaust regions of reconnecting current sheets. Electric fields, especially those parallel to the local magnetic field, play an important role in shaping and producing beams in velocity space. We relate the electron distributions to macroscopic field and plasma structures and compare our PIC results to recent Magnetospheric Multiscale (MMS) Mission measurements during dayside magnetopause reconnection.

1Bessho et al., GRL (2016).

GP11 20 How Alfvén waves set the large scale structure of magnetic reconnection* HARSHA GURRUM, JAN EGEDAL, Univ of Wisconsin, Madison A PIC simulation of anti-parallel reconnection shows the formation of the out-of-plane or Hall magnetic field that extends hundreds of inertial lengths from the X-line. This structure is generated by field-aligned electron currents that flow outside the magnetic separatrices when ion and electrons decouple on length scales less than $d$. We observe that this Hall field propagates from the X-point to far downstream into the exhaust along the magnetic field lines at Alfvénic speed. Thus the propagation of this large scale reconnection structure can be associated with an Alfvén wave generated in the inner electron diffusion region, specifically near the X-line.

*This work was supported by NSF Award 1404166 and NASA award NNX15AJ73G.

GP11 21 Kubo Resistivity of magnetic flux ropes* WALTER GEKELMAN, TIM DEHAAS, PAT PRIBYL, STEPHEN VINCENA, BART VAN COMPERNOLLE, Department of Physics, University of California, Los Angeles RICK SYDORA, University of Alberta SHAWN WENJIE TANG, Department of Physics, University of California, Los Angeles Magnetic flux ropes are bundles of twisted magnetic fields and their associated current. They are common on the surface of the sun (and presumably all other stars) and are observed to have a large range of sizes and lifetimes. They can become unstable and resulting in coronal mass ejections that can travel to earth and indeed, have been observed by satellites. Two side by side flux ropes are generated in the LAPD device at UCLA. Using a series of novel diagnostics the following key quantities, $B$, $u$, $V_p$, $n$, $Te$ have been measured at more than 48,000 spatial locations and 7,000 time steps. Every term in Ohm’s law is also evaluated across and along the local magnetic field and the plasma resistivity derived and it is shown that Ohm’s law is non-local. The electron distribution function parallel and antiparallel to the background magnetic field was measured and found to be a drifting Kappa function. The Kubo AC conductivity at the flux rope rotation frequency, a 3X3 tensor, was evaluated using velocity correlations and will be presented. This yields meaningful results for the global resistivity. Frequency spectra and the presence of time domain structures may offer a clue to the enhanced resistivity.

*Work supported by the Department of Energy and National Science Foundation.

GP11 22 Pressure Anisotropy Measurements on the Terrestrial Reconnection Experiment* RACHEL MYERS, JAN EGEDAL, JOSEPH OLSON, SAMUEL GREESS, ALEXANDER MILLET-AYALA, MICHAEL CLARK, PAUL NONN, JOHN WALLACE, CARY FOREST, University of Wisconsin-Madison The Terrestrial Reconnection Experiment (TREX) at the Wisconsin Plasma Astrophysics Laboratory (WiPAL) studies collisionless magnetic reconnection. In this regime, electron pressure anisotropy should develop, deviating from Hall reconnection dynamics and driving large-scale current layer formation [1]. A multi-tip version of the M-probe of Shadman [2], containing 32 Langmuir probe tips and two magnetic coils, measures this anisotropy. Each tip is biased to a different potential, simultaneously measuring discrete parts of the I-V characteristic. Pulsing the coil locally increases the magnetic field near the tips, inducing a magnetic mirror force to reflect electrons with large values of $v_{\perp}/v$. The change in velocity modifies...
the I-V characteristic and can be used to infer $p_\perp/p_\parallel$. Results and analysis from the probe are presented.

*This research was conducted with support from a UW-Madison University Fellowship as well as the NSF/DOE award DE-SC0013032.


Expanding laser-produced plasmas naturally self-generate magnetic fields by the Biermann battery effect, and the collision of two plumes can drive magnetic reconnection. The National Ignition Facility at LLNL occupies a unique position for the study of magnetic reconnection driven during magnetic reconnection and particle acceleration relevant to astrophysical plasmas. Magnetic reconnection experiments have been conducted on the NIF through the NIF Discovery Science program with the first experimental shots conducted in May 2017. We will present the design of the experimental platform and results from the first experimental day. Magnetic reconnection data is obtained from proton radiography based on a DHe3 backlighter, x-ray self-emission, and a new low-energy particle spectrometer (NIF EPSS-300G) developed by the NIF Facility and Engineering and fielded for the first time on these experiments.

GP11 24 The kinetic structure of the electron diffusion region observed by MMS during asymmetric reconnection* EGEDAL JAN, BLAKE WETHERTON, UW-Madison ARI LE, WILLIAM DAUGHTON, LANL

During asymmetric magnetic reconnection in the dayside magnetopause in situ spacecraft measurements by NASA’s MMS mission provide new detailed information on the electron dynamics within the electron diffusion region. In particular, we report here on observations by MMS4 which traveled the closest to the collision of two plumes during the event. We present measurements of electron phase space densities taken on the closest encounter on the topological X-line [1] in the event on October 16, 2015, first reported by Burch et al., [2]. In addition to crescent shaped electron distributions [2,3], the measurements include electron beams flowing in toward the diffusion region. These beams of incoming electrons are formed by $E_\parallel$ acceleration along the high-density side separatrices. They penetrate across the electron diffusion region, where their directions are nearly unaffected by the rapid changes in the magnetic field geometry. Matching electron beam features are observed in 2.5D kinetic simulations, revealing their role in breaking the electron frozen-in-law through contributions to the off-diagonal stress in the electron pressure tensor.

*This work was supported by NSF GEM Award No. 1405166.


GP11 25 Impact of compressibility and a guide field on Fermi acceleration during magnetic island coalescence* PETER MON-TAG, Massachusetts Institute of Technology IAN EGEDAL, EMILY LICHKO, BLAKE WETHERTON, University of Wisconsin Madison

Previous work has shown that Fermi acceleration can be an effective heating mechanism during magnetic island coalescence, where electrons may undergo repeated reflections as the magnetic field lines contract. This energization has the potential to account for the power-law distributions of particle energy inferred from observations of solar flares. Here, we develop a generalized framework for the analysis of Fermi acceleration that can incorporate the effects of compressibility and non-uniformity along field lines, which have commonly been neglected in previous treatments of the problem. Applying this framework to the simplified case of the uniform flux tube allows us to find both the power-law scaling of the distribution function and the rate at which the power-law behavior develops. We find that a guide magnetic field of order unity effectively suppresses the development of power-law distributions.

*The work was supported by NASA Grant No. NNX14AC68G, NSF GEM Grant No. 1405166, NSF Award 1404166, and NASA Award NNX15AJ73G.

GP11 26 LASER-PLASMA INTERACTIONS AND ACCELERATION

GP11 27 Deployment of the OSIRIS EM-PIC code on the Intel Knights Landing architecture* RICARDO FONSECA, ISCTE-IUL

Electromagnetic particle-in-cell (EM-PIC) codes such as OSIRIS [1] have found widespread use in modelling the highly non-linear and kinetic processes that occur in several relevant plasma physics scenarios, ranging from astrophysical settings to high-intensity laser plasma interaction. Being computationally intensive, these codes require large scale HPC systems, and a continuous effort in adapting the algorithm to new hardware and computing paradigms. In this work, we report on our efforts on deploying the OSIRIS code on the new Intel Knights Landing (KNL) architecture. Unlike the previous generation (Knights Corner), these boards are standalone systems, and introduce several new features, include the new AVX-512 instructions and on-package MCDRAM. We will focus on the parallelization and vectorization strategies followed, as well as memory management, and present a detailed performance evaluation of code performance in comparison with the CPU code.

*This work was partially supported by Fundaçao para a Ciência e Tecnologia (FCT), Portugal, through Grant No. PTDC/FIS-PLA/2940/2014.


GP11 28 End-to-end plasma bubble PIC simulations on GPUs KAI GERMA-SCHIEWSKI, University of New Hampshire WILLIAM FOX, JACKSON MATTEUCCI, AMITAVA BHAT-TACHARJEE, Princeton Plasma Physics Laboratory Accelerator technologies play a crucial role in eventually achieving exascale computing capabilities. The current and upcoming leadership machines at ORNL (Titan and Summit) employ Nvidia GPUs, which provide vast computational power but also need specifically adapted computational kernels to fully exploit them. In this work, we will show end-to-end particle-in-cell simulations of the formation, evolution and coalescence of laser-generated plasma bubbles. This work showcases the GPU capabilities of the PSC particle-in-cell code, which has been adapted for this problem to support particle injection, a heating operator and a collision operator on GPUs.

GP11 29 Simulating The Prompt Electromagnetic Pulse In 3D Using Vector Spherical Harmonics* ALEX FRIEDMAN, BRUCE...
GP11 30 Reduced 3d modeling on injection schemes for laser wakefield acceleration at plasma scale lengths* ANTON HELM, JORGE VIEIRA, LUIS SILVA, GoLP/IPFN Instituto Superior Técnico, Lisbon, Portugal RICARDO FONSECA, GoLP/IPFN Instituto Superior Técnico, Lisbon, Portugal; ISCET - Instituto Universitario de Lisboa, Lisbon, Portugal Current modelling techniques for laser wakefield acceleration (LWFA) are based on particle-in-cell (PIC) codes which are computationally demanding. In PIC simulations the laser wavelength $\lambda_0$, in $\mu$m-range, has to be resolved over the acceleration lengths in meter-range. A promising approach is the ponderomotive guiding center solver (PGC) [1, 2] by only considering the laser envelope for laser pulse propagation. Therefore only the plasma skin depth $\lambda_p$ has to be resolved, leading to speedups of $(\lambda_0/\lambda_p)^2$. This allows to perform a wide-range of parameter studies and use it for $\lambda_0 \ll \lambda_p$ studies. We present the 3d version of a PGC solver in the massively parallel, fully relativistic PIC code OSIRIS [3]. Further, a discussion and characterization of the validity of the PGC solver for injection schemes on the plasma scale lengths, such as down-ramp injection, magnetic injection [4] and ionization injection, through parametric studies, full PIC simulations and theoretical scaling, is presented.

*This work was partially supported by Fundacaopara a Ciencia e Tecnologia (FCT), Portugal, through Grant No. PTDC/FIS-PLA/2940/2014 and PD/BD/105882/2014.

GP11 31 Convergence of the Ponderomotive Guiding Center approximation in the LWFA* THALES SILVA, JORGE VIEIRA, ANTON HELM, RICARDO FONSECA, LUIS SILVA, Instituto Superior Técnico Plasma accelerators arose as potential candidates for future accelerator technology in the last few decades because of its predicted compactness and low cost. One of the proposed designs for plasma accelerators is based on Laser Wakefield Acceleration (LWFA). However, simulations performed for such systems have to solve the laser wavelength which is orders of magnitude lower than the plasma wavelength. In this context, the Ponderomotive Guiding Center (PGC) algorithm for particle-in-cell (PIC) simulations is a potent tool. The laser is approximated by its envelope which leads to a speed-up of around 100 times because the laser wavelength is not solved. The plasma response is well understood, and comparison with the full PIC code show an excellent agreement. However, for LWFA, the convergence of the self-injected beam parameters, such as energy and charge, was not studied before and has vital importance for the use of the algorithm in predicting the beam parameters. Our goal is to do a thorough investigation of the stability and convergence of the algorithm in situations of experimental relevance for LWFA. To this end, we perform simulations using the PGC algorithm implemented in the PIC code OSIRIS. To verify the PGC predictions, we compare the results with full PIC simulations.

*This project has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant agreement No 653782.

GP11 32 Two-stage acceleration of externally injected electrons in plasma bubble derived from the combination of DLA and LWFA* VLADIMIR KHUDIK, University of Texas at Austin TIANHONG WANG, DANIEL VICUNA, Cornell University XI ZHANG, University of Texas at Austin GENNADY SHVETS, Cornell University Simultaneous interactions of accelerated electrons directly with a laser pulse and with a laser wakefield are studied using a novel quasistatic 3D particle-in-cell code. Relativistic electrons externally injected into the plasma bubble’s decelerating phase can gain significant energy through the direct laser acceleration (DLA) mechanism from the driving laser pulse [1-3], increasing the amplitude of betatron oscillations. With time, the resonant interaction condition is violated, leading to gradual dephasing between electrons and laser wave, and to eventual slipping of the electrons to the back of the plasma bubble. After that, the oscillating electrons experience the second stage of acceleration gaining energy only from the bubble wakefield. We analyze each stage of acceleration and show that electrons undergoing two stages emits much more X-ray radiation compared with those accelerated during one wakefield stage.

*This work was supported by DOE Grant DESC0007889 and by AFOSR Grant FA9550-16-1-0013.


GP11 33 Ultra-low emittance electron beam generation using ionization injection in a plasma beatwave accelerator* CARL SCHROEDER, CARLO BENEDETTI, ERIC ESAREY, WIM LEEMANS, Lawrence Berkeley National Laboratory Ultra-low emittance beams can be generated using ionization injection of electrons into a wakefield excited by a plasma beatwave accelerator. This all-optical method of electron beam generation uses three laser pulses of different colors. Two long-wavelength laser pulses, with frequency difference equal to the plasma frequency, resonantly drive a plasma wave without fully ionizing a gas. A short-wavelength injection laser pulse (with a small ponderomotive force and large peak electric field), co-propagating and delayed with respect to the beating long-wavelength lasers, ionizes a fraction of the remaining bound electrons at a trapped wake phase, generating
an electron beam that is accelerated in the wakefield. Using the beating of long-wavelength pulses to generate the wakefield enables atomically-bound electrons to remain at low ionization potentials, reducing the required amplitude of the ionization pulse, and, hence, the initial transverse momentum and emittance of the injected electrons. An example is presented using two lines of a CO₂ laser to form a plasma beatwave accelerator to drive the wake and a frequency-doubled Ti:Al₂O₃ laser for ionization injection.

*Supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

GP11 34 Emittance preservation in plasma-based accelerators with ion motion* CARLO BENEDETTI, CARL SCHROEDER, ERIC E. ESAREY, WIM LEEMANS, Lawrence Berkeley Natl Lab

In plasma-accelerator-based linear collider, the density of matched, low-emittance, high-energy particle bunches required for collider applications can be orders of magnitude above the background ion density, leading to ion motion, nonlinear focusing fields, and, hence, to beam emittance growth. By analyzing the response of the background ions to an ultra-high density beam, analytical expressions, valid for nonrelativistic ion motion, are derived for the transverse wakefield and for the final (i.e., after saturation) bunch emittance. Analytical results are validated against numerical modeling. A class of initial beam distributions are derived that are equilibrium solutions, which require head-to-tail bunch shaping, enabling emittance preservation with ion motion.

*This work was supported by the Director, Office of Science, Office of High Energy Physics, of the U.S. DOE under Contract No. DE-AC02-05CH11231.


Shaped plasmas offer the possibility of manipulating laser pulses at intensities far above the damage limits for conventional optics. An example is the plasma channel, which is a cylindrical plasma column with an on-axis density minimum. Long plasma channels have been widely used to guide intense laser pulses, particularly in laser wakefield accelerators. A new concept, the “plasma tornado”, offers the possibility of creating long plasma channels with no nearby structures and at densities lower than can be achieved by capillary discharges. A short plasma channel can focus a laser pulse in much the same manner as a conventional lens or off-axis parabola. When placed in front of the focal point of an intense laser pulse, a plasma channel lens (PCL) can reduce the effective f-number of conventional focusing optics. When placed beyond the focal point, it can act as a collimator. We will present experimental and modeling results for a new plasma tornado design, review experimental methods for generating short PCLs, and discuss potential applications.

*Supported by the Naval Research Laboratory Base Program.

GP11 36 Filtering of higher-order laser modes using plasma structures* BLAGOE DJORDJEVIC, University of California, Berkeley CARLO BENEDETTI, CARL SCHROEDER, ERIC ESAREY, WIM LEEMANS, Lawrence Berkeley National Laboratory Plasma structures based on leaky channels are proposed to filter higher-order laser mode content. The evolution and propagation of non-Gaussian laser pulses in leaky channels is studied, and it is shown that, for appropriate laser-plasma parameters, the higher-order laser mode content may be removed while the fundamental mode remains well-guided. The behavior of the multi-mode laser pulse is described analytically, including the derivation of the leakage coefficients, and compared to numerical calculations. Gaussian laser pulse propagation, without higher-order mode content, improves guiding in parabolic plasma channels, enabling extended interaction lengths for laser-plasma accelerator applications.

*This work was supported by the Director, Office of Science, Office of High Energy Physics, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

GP11 37 Spatial Control of Laser Wakefield Accelerated Electron Beams* A. MAKSIMCHUK, K. BEHM, T. ZHAO, A. S. JOGLEKAR, A. HUSSAIN, J. NEES, A. G. R. THOMAS, K. KRUSHELNICK, University of Michigan, Ann Arbor J. ELLE, A. LUCERO, Air Force Research Laboratory/Directed Energy Directorate G. M. SAMARIN, G. SARRY, J. WARWICK, Queen's University, Belfast, United Kingdom The laser wakefield experiments to study and control spatial properties of electron beams were performed using HERCULES laser at the University of Michigan at power of 100 TW. In the first experiment multi-electron beam generation was demonstrated using co-propagating, parallel laser beams with a τ-phase shift mirror and showing that interaction between the wakefields can cause injection to occur for plasma and laser parameters in which a single wakefield displays no significant injection. In the second experiment a magnetic triplet quadrupole system was used to refocus and stabilize electron beams at the distance of 60 cm from the interaction region. This produced a 10-fold increase in remote gamma-ray activation of ⁶⁷Cu using a lead converter. In the third experiment measurements of un-trapped electrons with high transverse momentum produce a 500 mrad (FWHM) ring. This ring is formed by electrons that receive a forward momentum boost by traversing behind the bubble and its size is inversely proportional to the plasma density. The characterization of divergence and charge of this electron ring may reveal information about the wakefield structure and trapping potential.


GP11 38 Investigation of the Electron Acceleration by a High-Power Laser and a Density-Tapered Mixed-Gas Cell JINJU KIM, VANESSA L.J. PHUNG, MINSEOK KIM, Gwangju Inst of Sci & Tech MIN-SUP HUR, Ulsan National Institute of Science and Technology HYYONG SUK, Gwangju Inst of Sci & Tech Plasma-based accelerators can generate about 1000 times stronger acceleration field compared with RF-based conventional accelerators, which can be done by high power laser and plasma. There are many issues in this research and one of them is development of a good plasma source for higher electron beam energy. For this purpose, we are investigating a special type of plasma source, which is a density-tapered gas cell with a mixed-gas for easy injection. By this type of special gas cell, we expect higher electron beam energies with easy injection in the wakefield. In this poster, some experimental results for electron beam generation with the density-tapered mixed-gas cell are presented. In addition to the experimental results, CFD (Computational-Fluid-Dynamics) and PIC (Particle-In-Cell) simulation results are also presented for comparison studies.

GP11 39 Wakefield simulation of solid state plasma SAHEL HAKIMI, TAM NGUYEN, DEANO FARINELLA, CALVIN LAU,
The production of relativistic positrons using ultraintense lasers can facilitate studies of fundamental pair plasma science in the relativistic regime and laboratory studies of scaled energetic astrophysical mechanisms such as gamma ray bursts. The positron densities and spatial scales required for these applications, however, are larger than current capabilities. Here, we present an overview of the experimental laser-produced positron results and their respective modeling for both the direct laser-irradiated process and the indirect process (laser wakefield accelerated electrons irradiating a high-Z converter). Conversion efficiency into positrons and positron beam characteristics are compared, including total pair yield, mean energy, angular divergence, and inferred pair density for various laser and target conditions. Prospects towards increasing positron densities and beam repetition rates will also be discussed.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, and funded by LDRD (#17-ERD-010).

GP11 42 Multi-GeV electron-positron pair generation from laser-electron scattering MARIJA VRANIC, GoLP/IPFN, Instituto Superior Tecnico, Univ. de Lisboa, Portugal ONDREJ KLIMO, GEORG KORN, STEFAN WEBER, ELI Beamlines, Fyzikalni us- tav AV CR, v. v. i., Praha Positron generation in the laboratory is of great importance, both for fundamental science and potential applications. For laboratory astrophysics, it is particularly important to produce neutral electron-positron plasma, with properties that allow studying their collective behavior. Electron-positron pairs can be generated by first emitting an energetic photon, that later decays into a pair in an intense background field (Breit-Wheeler process). Recently, several experiments demonstrated that high-frequency radiation can be generated in laser-electron beam scattering. Here we propose a new scattering configuration that can both generate electron-positron pairs, and later accelerate them to multi-GeV energies. This configuration allows obtaining an e+ e- flow with a higher energy than that of the initial electron beam. We develop an analytical model that predicts the energy cutoff. We discuss the number of pairs expected, the acceleration and the overall quality of the beam. We also study the role of pulse duration and spatiotemporal synchronization for the overall number of pairs. The work is supported by OSIRIS QED-PIC simulations, and these ideas can be tested with a new generation laser system at ELI Beamlines that will provide 10 PW peak power in a 150 fs pulse duration.

GP11 43 Plasma diagnosis using the laser-plasma tera- hertz(THz) radiation KEEKON KANG, DOGEUN JANG, HYY- ONG SUK, Gwangju Inst of Sci & Tech There has been growing interest in laser-plasma terahertz (THz) radiation as a source for plasma diagnostics for its strong radiation energy and broadband characteristics. Yet, it has not been used in actual diagnostics systems as its validity was not thoroughly investigated. In this work, we measured the plasma density in our inductively-coupled plasma (ICP) chamber with the laser-plasma THz radiation. The THz time-domain spectroscopy (THz-TDS) and single-shot detection method were used for the detection of the THz. The diagnosis results from the two different detection methods were consistent with each other, giving a possibility of the realization of the laser-plasma-THz-based plasma diagnostics.

GP11 44 Directed high-power THz radiation from transverse laser wakefield excited in an electron density filament SERGE KALMYKOV, Leidos, Albuquerque, NM 87106 ALEXANDER ENGLESBE, JENNIFER ELLE, MATTHEW DOMONKOS, ANDREAS SCHMITT-SODY, High Power Electromagnetics Division, Air Force Research Laboratory, Kirtland Air Force Base, NM 87117 A tightly focused femtosecond, weakly relativistic laser pulse partially ionizes the ambient gas, creating a string (a “filament”) of electron density, locally reducing the nonlinear index and compensating for the self-focusing effect caused by bound electrons. While maintaining the filament over many Rayleigh lengths, the pulse drives
inside it a three-dimensional (3D) wave of charge separation - the plasma wake. If the pulse waist size is much smaller than the Langmuir wavelength, electron current in the wake is mostly transverse. Electrons, driven by the wake across the sharp radial boundary of the filament, lose coherence within 2-3 periods of wakefield oscillations, and the wake decays [1]. The laser pulse is thus accompanied by a short-lived, almost aperiodic electron current coupled to the sharp index gradient. The comprehensive 3D hydrodynamic model shows that this structure emits a broad-band THz radiation, with the highest power emitted in the near-forward direction. The THz radiation pattern contains information on wake currents surrounding the laser pulse, thus serving as an all-optical diagnostic tool. The results are tested in cylindrical and full 3D PIC simulations using codes WAKE and EPOCH.


GP11 45 Terahertz Radiation from Laser Created Plasma by Applying a Transverse Static Electric Field* NOBORU YUGAMI, Department of Advanced Interdisciplinary Sciences, Center for Optical Research & Education, and Optical Technology Innovation Center, Utsonomiyu Univ TAKUYA FUKUDA, Department of Innovation Systems Engineering, Advanced Interdisciplinary Sciences Course, Utsonomiyu Univ ZHAN JIN, RYOSUKE KODAMA, Photon Pioneers Center, Osaka Univ HIDEO NAGATOMO, YASUHIKO SENTOKU, Institute of Laser Engineering, Osaka Univ HIGHTHISAKAGAMI, Fundamental Physics Simulation Research Division, National Institute for Fusion Science

Terahertz (THz) radiation, which is emitted in narrow cone in the forward direction from femtosecond laser pulse created plasma has been observed by N. Yugami et al. [1]. Additionally, T. Loffler et al. have observed that a significantly increased THz emission intensity in the forward direction when the transverse static electric field is applied to the plasma [2]. We propose the theoretical model of the THz radiation from laser created plasma by applying the transverse static electric field and conducted both experiments and 2D-PIC simulation to compared with our theory.

*JSPS Core-to-Core Program on International Alliance for Material Science in Extreme States with High Power Laser and XFEL.


GP11 46 High-efficiency gamma-ray flash generation from multiple-laser scattering ZHENHONG GONG, Peking University, China S. S. BULANOV, LLNL, A. AREFIYEV, Univ of California - San Diego X. Q. YAN, Peking University, China Gamma-ray flash generation in a near-critical-density target irradiated by four symmetrical colliding laser pulses is numerically investigated. With peak intensities about 10^{23} W/cm^2, the laser pulses boost electron energy through direct laser acceleration, while pushing them inward with the ponderomotive force. After backscattering with counter-propagating laser, the accelerated electron is trapped in the electromagnetic standing waves of the ponderomotive potential well created by the coherent overlapping of the laser pulses. Electrons emit gamma-ray photons in a multiple-laser-scattering regime, where the electrons act as a medium transferring energy from the laser to gamma-rays in the ponderomotive potential valley [1].


GP11 47 Gamma-ray Radiation From Plasma Bubble Hosing* BIFENG LEI, SERGEY RYKOVANOV, the Helmholtz Institute Jena The CEP-dominated few cycle strong laser pulse could oscillate in a underdense plasma with a period [1], where is the laser wavelength, is the laser critical density and is the initial plasma density. This oscillation further leads to the hosing-like oscillation of the formed plasma bubble [2] which, in turn, gives a very strong oscillation strength for the electrons trapped inside. With numbers of self-trapped electrons, this scheme is capable server as a strong and bright gamma-ray source. A stretched plasma bubble is achieved by firstly injecting a symmetric, moderately long and strong laser in to an underdense plasma. Then, many electrons can be self-trapped along with the bubble breaking due to the nonlinear plasma wave. The head erosion produces the few cycle pulse which enables the oscillation.

*Work supported by Helmholtz Association (Young Investigator’s Group No. VH-NG-103).


GP11 48 Temporal characterization of the wave-breaking flash in a laser plasma accelerator* BO MIAO, LINUS FEDER, ANDREW GOERS, GEORGE HINE, FATHOLAH SALEHI, JARED WAHLSTRAND, DANIEL WOODBURY, HOWARD MILCHBERG, University of Maryland, College Park Wave-breaking injection of electrons into a relativistic plasma wake generated in near-critical-density plasma by sub-terawatt laser pulses generates an intense (∼1μJ) and ultra-broadband (Δλ ≈ 300nm) radiation flash [1]. In this work we demonstrate the spectral coherence of this radiation and measure its temporal width using single-shot supercontinuum spectral interferometry (SSSI). The measured temporal width is limited by measurement resolution to 50 fs. Spectral coherence is corroborated by PIC simulations which show that the spatial extent of the acceleration trajectory at the trapping region is small compared to the radiation center wavelength. To our knowledge, this is the first temporal and coherence characterization of wave-breaking radiation.

*This work is supported by the US Department of Energy, the National Science Foundation, and the Air Force Office of Scientific Research.


GP11 49 Impact of a plasma channel on the emission of directed high-energy photons in laser-plasma interaction* OLIVER JANSEN, TAO WANG, Institute for Fusion Sciences, University of Texas in Austin TOMA TONCIAN, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany DAVID STARK, Los Alamos National Laboratory, Los Alamos, New Mexico EMANUEL D’HUMIERES, University of Bordeaux/CNRS/CEA, CELIA ALEXEY AREFIYEV, Institute for Fusion Sciences, University of Texas in Austin Compact sources of directed high-energy photons are of great interest in current research. Common sources of high-energy photons include synchrotrons and other large and expensive accelerators. Laser-plasma interactions promise sources that are significantly smaller and cheaper than conventional ones. However, they come at the cost of producing either only small number of photons or very undirected ones. A recent study [1] shows, that the use of a plasma channel is able to significantly mitigate these problems while producing a large number of high energy, well collimated photons. We provide an analysis on the physical processes, that lead to the formation of strong magnetic fields responsible for this improvement of emission. Furthermore, we investigate the channel properties in relation to a given laser pulse.
*This research was supported by the National Science Foundation under Grant No. 1632777. Simulations were performed with the EPOCH code using HPC resources provided by the TACC at the University of Texas.


GP11 50 X-Ray and electron beam source characterization from Self-Modulated Laser Wakefield Acceleration experiments at Titan* PAUL KING, Lawrence Livermore National Laboratory/University of Texas at Austin NUNO LEMOS, FELICIE ALBERT, Lawrence Livermore National Laboratory JESSICA SHAW, AVI MILDEN, Laboratory for Laser Energetics KEN MARSH, University of California Los Angeles ART PAK, Lawrence Livermore National Laboratory BJORN HEGELICH, University of Texas at Austin CHAN JOSHI, University of California Los Angeles The development of a directional, low-divergence, and short-duration (ps and sub-ps) x-ray probes with energies of tens of keV is desirable for the fields of astrophysics, High Energy Density Science and Inertial Confinement Fusion. In this work we focused the Titan laser beam (1 ps and 150 Joules) into a 4mm helium gas jet to produce an electron beam that in turn generates an x-ray beam. The measured Raman Forward Scattering satellites present in the laser spectrum after the interaction, indicate the generation of a Self-modulated laser wakefield accelerator. This accelerator produced an electron beam with energies up to 250 MeV, a divergence of 16 x 40 mrad and a total charge of 6 nC. Using this high-charge relativistic electron beam we explored the combination of three mechanisms to produce an x-ray beam: Betatron, Compton scattering and Bremsstrahlung. We show the generation of a low divergence ( mrad), small source size ( um) broadband (keV to MeV) x-ray beam that can be used as a backlighter for time-resolved spectroscopy, imaging, and Compton radiography.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. [LLNL-ABS-734746]

GP11 51 Dynamics of multiple interacting ultra-intense lasers in a plasma LUCAS SA, JORGE VIEIRA, RICARDO FONSECA,* LUIS SILVA, GoL/P/IFN, Instituto Superior Tecnico, Universidade de Lisboa, Portugal WARREN MORI, Department of Physics and Astronomy, University of California Los Angeles, Los Angeles, California, USA Although light beams do not interact in vacuum, two intense lasers can interact with each other in a nonlinear medium, forming spiraling and braiding patterns when they carry angular momentum. Here, we analyse the interaction between N laser filaments. Using a variational approach based on the Non-Linear Schrödinger Equation with the lowest order relativistic mass correction, we obtained a mechanical analog of an exponential N-body problem for the beam centroids and spot-sizes. We found that the N beams can spiral in a circular motion around the center of mass analog and determined orbital parameters and trapping criteria for this motion. Furthermore, the lasers could form a “solar system”, with N − 1 beams orbiting a high-power one. The predictions for both models were tested in Particle-in-Cell simulations, in which other effects, namely non-instantaneous spatiotemporal non-linearities, can be compared to the relativistic mass correction. Finally, the initial configuration of the beams could follow from filamentary processes, with the filamentation of an orbital angular momentum carrying laser originating the spiralling and braiding motions of the filaments.

GP11 52 Coupling the photon kinetics of soft photons with high energy photons* L. O. SILVA, GoL/P/IFN, Instituto Superior Tecnico, Universidade de Lisboa, Portugal R. BINGHAM, RAL/STFC and University of Strathclyde, U.K. The description of electromagnetic fields based on the generalized photon kinetic theory, which takes advantage of the Wigner-Moyal description for the corresponding classical field theory, is capable of capturing collective plasma dynamics in the relativistic regime driven by broadband incoherent or partially coherent sources. We explore the possibility to extend this description to include the dynamics of hard photons in the plasma, whose interaction is dominated by single scattering processes. Examples of the modification of classical plasma instabilities due to the presence of hard photons is discussed.

*Work supported by the European Research Council (ERC-AdG-2015 InPairs Grant No. 695088).

GP11 53 X-Ray Pulse Compression using Stimulated Brillouin Scattering in Plasma* MATTHEW EDWARDS, JULIA MIKHAILOVA, NATHANIEL FISCH, Princeton Univ Stimulated Brillouin scattering may allow cleaning and compression of the output from x-ray free-electron lasers, producing coherent sub-femtosecond pulses with intensities orders-of-magnitude beyond current sources. In contrast to stimulated Raman scattering, which is limited by damping at short wavelengths, particle-in-cell simulations and analytic models suggest that amplification by Brillouin scattering is possible in solid-density plasma at the wavelengths and intensities of free-electron lasers. The nonlinear amplification process is robust to quasi-incoherence in the pump beam, permitting beam cleaning in addition to compression [1].

*This work was supported by NNSA Grant No. DE-NA0002948, AFOSR Grant No. FA9550-15-1-0391, and NSF Grant No. PHY 1506372. M.R.E. acknowledges support from an NSF Graduate Research Fellowship.

diagnostics. If available, preliminary results from PETAL experiments will be discussed.

*We acknowledge the financial support from the French National Research Agency (ANR) in the framework of “the investments for the future” Programme IdEx Bordeaux-LAPHIA (ANR-10-IDEX-03-02).

GP11 55 Laser-Bioplasma Interaction: Excitation and Suppression of the Brain Waves by the Multi-photon Pulsed-operated Fiber Lasers in the Ultraviolet Range of Frequencies

V. ALEXANDER STEFAN, Institute for Advanced Physics Studies, Stefan University IAPS-TEAM TEAM

The novel study of the laser excitation-suppression of the brain waves [1] is proposed. It is based on the pulsed-operated multi-photon fiber-laser interaction with the brain parvalbumin (PV) neurons [2]. The repetition frequency matches the low frequency brain waves (5-100 Hz); enabling the resonance-scanning of the wide range of the PV neurons (the generators of the brain wave activity). The tunable fiber laser frequencies are in the ultraviolet frequency range, thus enabling the monitoring of the PV neuron-DNA, within the 10s of milliseconds. In medicine, the method can be used as an “instantaneous-on-off anesthetic.”

*Supported by Nikola Tesla Labs, Stefan University.


GP11 56 Thin film compression of a high rep rate laser: towards single-cycle pulse generation* DEANO FARINELLA, Univ of California - Irvine SERGEY MIRONOV, Institute of Applied Physics - RAS TAM NGUYEN, MATTHEW STANFIELD, FRANKLIN DOLLAR, TOSHIKI TAJIMA, Univ of California - Irvine Thin Film Compression (TFC) has been proposed [1] as a means of increasing the peak power of ultrashort laser pulses with millijoule and greater energies. As opposed to increasing peak power by increasing the energy of the pulse, TFC instead achieves an amplification in peak power by compressing laser pulse length at a fixed energy. This pulse compression is accomplished by the generation of linearly chirped bandwidth through self-phase modulation, which is then recompressed by dispersive optics. A summary of the results of laser pulse compression experiments towards the production of single-cycle pulses will be presented. Simulations show [1] that laser pulses compressed to the single-cycle regime have the potential to generate single-cycle x-ray pulses which could be used to generate wakefields in solid-density plasma with acceleration gradients of up to TeV/cm [2].

*Supported by Nikola Tesla Labs, Stefan University.


GP11 59 DIII-D

GP11 60 Developing DIII-D To Prepare For ITER And The Path To Fusion Energy* RICHARD BUTTERY, DAVID HILL, WAYNE SOLOMON, HOUYANG GUO, General Dynamics DIII-D TEAM DIII-D pursues the advancement of fusion energy through scientific understanding and discovery of solutions. Research targets two key goals. First, to prepare for ITER we must resolve how to use its flexible control tools to rapidly reach Q=10, and develop the scientific basis to interpret results from ITER for fusion projection. Second, we must determine how to sustain a high performance fusion core in steady state conditions, with minimal actuators and a plasma exhaust solution. DIII-D will target these missions with: (i) increased electron heating and balanced torque neutral beams to simulate burning plasma conditions (ii) new 3D coil arrays to resolve control of transients (iii) off axis current drive to study physics in steady state regimes (iv) divertors configurations to promote detachment with low upstream density (v) a reactor relevant wall to qualify materials and resolve physics in reactor-like conditions. With new diagnostics and leading edge simulation, this will position the US for success in ITER and a unique knowledge to accelerate the approach to fusion energy.

*Supported by the US DOE under DE-FC02-04ER54698.

GP11 61 Parameter exploration for a Compact Advanced Tokamak DEMO* D.B. WEISBERG, R.J. BUTTERY, J.R. FERRON, A.M. GAROFALO, B.B. SNYDER, A.D. TURNBULL, GA C.T. HOLCOMB, LLNL J. MCCLENNAGHAN, ORAU J. CANIK, J-M PARK, ORNL A new parameter study has explored a range of design points to assess the physics feasibility for a compact 200MWe advanced tokamak DEMO that combines high beta ($βN < 4$) and high toroidal field ($BF = 6 - 7T$). A unique aspect of this study is the use of a FASTRAN modeling suite that combines integrated transport, pedestal, stability, and heating & current drive calculations to predict steady-state solutions with neutral beam and helicon powered current drive. This study has identified a range of design solutions in a compact ($R_0 = 4m$), high-field ($BF = 6 - 7T$), strongly-shaped ($κ = 2, δ = 0.6$) device. Unlike previous proposals, C-AT DEMO takes advantage of high-beta operation as well as emerging advances in magnet technology to demonstrate net electric production in a moderately sized machine. We present results showing that the large bootstrap fraction and low recirculating power enabled by high normalized beta can achieve tolerable heat and neutron...
load with good H-mode access. The prediction of operating points with simultaneously achieved high-confinement \((H_{98} < 1.3)\), high-density \(f_{ew} < 1.3\), and high-beta warrants additional assessment of this approach towards a cost-attractive DEMO device.

*Work supported by the US DOE under DE-FC02-04ER54698.

GP11 62 A U.S. Strategy for Timely Fusion Energy Development* MICKEY WADE, General Atomics Worldwide energy demand is expected to explode in the latter half of this century. In anticipation of this demand, the U.S. DOE recently asked the National Academy of Science to provide guidance on a long-term strategic plan assuming that "economical fusion energy within the next several decades is a U.S. strategic interest." "Delivering on such a plan will require an R&D program that delivers key data and understanding on the building blocks of a) burning plasma physics, b) optimization of the coupled core-edge solution, and c) fusion nuclear science to inform the design of a cost-attractive DEMO actor in this time frame. Such a program should leverage existing facilities in the U.S. program including ITER, provide substantive motivation for an expanding R&D scope (and funding), and enable timely redirection of resources within the program as appropriate (and endorsed by DOE and the fusion community). This paper will outline a potential strategy that provides world-leading opportunities for the research community in a range of areas while delivering on key milestones required for timely fusion energy development.

*Supported by General Atomics internal funding.

GP11 63 Creating Hybrid Plasmas With Off-Axis ECCD for Radiating Divertor Studies in DIII-D* C.C. PETTY, J.R. FERRON, T.C. LUCE, T.H. OSBORNE, T.W. PETRIE, General Atomics - San Diego F. TURCO, Columbia U. C.T. HOLCOMB, LLNL K.E. THOME, ORAU A long duration, high density, high power hybrid scenario has been developed for use in radiative divertor studies in DIII-D. Using 11.2 MW of co-NBI power and 3.4 MW of ECCD, with a total injected energy of up to 56 MJ, high performance hybrid plasmas with \(\beta_p = 3.7\) and \(H_{98} \approx 1.5\) were created. The hybrid plasmas were fully non-inductive at densities of \(n \approx 4.2 \times 10^{19} \text{m}^{-3}\) with central ECCD, but the EC deposition needed to be moved to \(\rho > 0.45\) to avoid the right-hand cutoff when the density was raised to \(n \approx 5.8 \times 10^{19} \text{m}^{-3}\) for radiative divertor studies. Although moving the EC deposition to \(\rho = 0.45\) had the effect of dropping \(\tau_E\) by 10%, the energy confinement time increased with higher density like \(\tau_E \propto n^{0.3}\), allowing high beta to be maintained. While the plasma current profile displays the usual self-organizing properties of hybrids – an anomalously broad profile with \(q_{min}>1\) – local current drive can still have a measurable effect on stability, either positively or negatively. For example, hybrid discharges with radial ECH deposited at \(\rho = 0.45\) proved to be more robustly stable to \(n = 1\) modes (can be either a 1/1 or 2/1 mode) than similar discharges with co-ECCD at the same location. Interestingly, the large 1/1 mode had almost no effect on energy confinement but strongly degraded particle confinement; thus this mode needed to be suppressed to achieve the high pedestal densities required for radiative divertor studies.

*Work supported by USDOE under DE-FC02-04ER54698.

GP11 64 Energy Confinement Improvement with Density in Gas Puff Fueled High Performance Hybrid Plasmas on DIII-D* T.H. OSBORNE, T.W. PETRIE, A.W. LEONARD, T.C. LUCE, C.C. PETTY, General Atomics F. TURCO, Columbia U. M.E. FENSTERMACHER, C.J. LASNIER, LLNL J.G. WATKINS, SNL In contrast to behavior at moderate NBI heating, an increase in energy confinement is observed in high power, near double null, hybrid discharges in response to D2 gas puff fueling. This difference is tied to how the H-mode pedestal responds to fueling. At low power the pedestal width decreases with gas puff resulting in a strong reduction in the critical pressure gradient for the ballooning branch of the peeling-ballooning mode. At high power the pedestal width remains fixed and access to high pedestal pressure gradient with increased collisionality along the peeling boundary is maintained, allowing the pedestal pressure to increase with density. Access to the high pressure gradient peeling limited regime is also blocked by the ballooning boundary if the shape departs from near double null or \(q\) decreases relative to the favorable conditions: \(\text{DRSEP} \approx 2.5\text{mm}, q_{95} = 6\).

*Work supported under USDOE Cooperative Agreement DE-FC02-04ER54698.

GP11 65 Magnetic Flux Conversion in the DIII-D Steady-State Hybrid Scenario* N.Z. TAYLOR, Oak Ridge Associated Universities T.C. LUCE, R.J. LA HAYE, C.C. PETTY, General Atomics R. NAZIKIAN, PPPL The hybrid is a promising high confinement scenario for ITER. The broader current profile aids discharge sustainment by raising \(q_{min} > 1\) thereby avoiding sawtooth-triggered 2/1 tearing modes. In DIII-D hybrid scenario discharges, the rate of poloidal magnetic energy consumption is more than the rate of energy flow from the poloidal field coils. This is evidence that there is a conversion of toroidal flux to poloidal flux, which may be responsible for the anomalous broadening of the current profile known as flux pumping. The rate of poloidal flux being provided and consumed was tracked with coil and kinetic flux states [1]. During long stationary intervals (1.5 seconds) with constant stored magnetic energy, a significant flux state deficit rate > 10 mV was observed. The inequality in the evolution of the flux states was observed in hybrids that were 100% non-inductive and with successful RMP ELM suppression.

*Work supported by the US DOE under DE-FC02-04ER54698 and DE-AC05-06OR23100.

1 T. C. Luce, Nucl. Fusion 54, 093005 (2014).

GP11 66 Reduced turbulence and H-mode confinement in L-mode negative triangularity discharges on DIII-D* A. MARI-NONI, MIT M.E. AUSTIN, U. TEXAS M.L. WALKER, A.W. HYATT, C.C. PETTY, K.H. THOME, GA M. PORKOLAB, J.C. ROST, E.M. DAVIS, MIT G.R. MCKEE, UWM T.L. RHODES, C. SUNG, UCLA O. SAUTER, EPFL DIII-D TEAM, MIT PSFC COLLABORATION DIII-D has produced inner-wall limited plasmas with an L-mode edge at negative triangularity characterized by confinement and fluctuation levels comparable to those in H-mode plasmas at positive triangularity. On TCV, similar plasmas at low collisionality and with pure electron heating showed improved energy confinement, as compared to matched discharges at positive triangularity, due to modifications to the toroidal precession drift of trapped electrons. The recent DIII-D experiment used both ECH and NBI heating, thus exploring a more reactive regime where Te > Ti. Compared to matched positive triangularity discharges, the intensity of density and temperature fluctuations is reduced at negative triangularity both in ECH and in NBI dominated phases. Preliminary TGLF runs indicate the discharges are dominated by TEM modes. More detailed analysis will explore the role of the toroidal precession drift in this new regime.

*Work supported by USDOE under DE-FC02-04ER54698.
**GP11 67 Turbulent Ion Fluctuation Measurements in Negative Triangularity Plasmas**

Dinh Truong, George McKee, Zheng Yan, Raymond Fonck, University of Wisconsin - Madison Max Austin, University of Texas - Austin Alessandro Marinoni, Massachusetts Institute of Technology

DIII-D TEAM

A new detector array on the UF-CHERS (Ultra Fast Charge Exchange Recombination Spectroscopy) diagnostic at DIII-D has resulted in significantly improved signal to noise ratio and sensitivity to ion thermal fluctuations. UF-CHERS measures local, long-wavelength carbon density, ion temperature, and toroidal velocity fluctuations at turbulence-relevant spatiotemporal scales (1 \( \mu s \) time resolution, \( \sim 1 \) cm spatial resolution which is approximately the turbulence correlation length) from emission of the CVI \( n=8 \rightarrow 7 \) transition. UF-CHERS and BES fluctuation measurements were obtained in equivalent positive and negative triangularity (\( \delta \)) discharges with an L-mode edge to compare with theoretical models of turbulence-driven transport and elucidate the mechanisms for improved confinement with negative-\( \delta \). Finite coherence is observed between UF-CHERS and co-located BES channels, demonstrating that critical multifield fluctuations such as \( n^2 T_i \) and \( n^2 v_{\text{tor}} \) can be measured. Initial analysis shows positive-\( \delta \) has radially decreasing, low coherence between \( \sim 20-200 \) kHz for main ion density (BES) and carbon density, ion temperature, and toroidal rotation (UF-CHERS) fluctuations.

*Supported by DOE Grants DE-FG02-08ER54999, DE-FC02-04ER54698, and NSF GRFP Grant DGE-1256259.*

**GP11 68 A Conformal Conducting Wall for Robust Stability of High \( \beta_N \), Fully Noninductive Discharges in DIII-D**

J.R. Ferron, GA J. Bialek, J. Hanson, G. Navratil, Columbia U. J.M. Park, ORNL

A conducting surface inside the DIII-D vacuum vessel, closer to the plasma, can increase the ideal-wall MHD stability limit above the high normalized beta (\( \beta_N \)) needed for 100% noninductively-driven current at power plant relevant \( q_{55} \). In discharges modeled with the planned heating/current drive upgrades, the required \( \beta_N \) is as high as 5. This is roughly the calculated limit for \( n=1 \) ideal-wall stability, even with a broad current density profile designed to couple well to the present conducting wall. Tearing and resistive wall modes will very likely limit \( \beta_N \) to a value that is lower, but which is expected to scale with the ideal-wall limit. Conceptual designs for an axisymmetric wall that better matches the plasma shape raise the ideal-wall stability limited \( \beta_N \) above 7. Analysis with VALEN of a 3-D wall model predicts \( \beta_N \sim 6.4 \). Increased stability margins are also expected for a wide range of DIII-D discharge scenarios even without a broad current density profile.

*Work supported under USDOE Cooperative Agreement DE-FC02-04ER54698.*

**GP11 69 Developing on DIII-D a QH-mode edge solution for \( q_{95} = 10 \) in ITER**

A.M. Garofalo, C. Paz-Soldan, D.B. Weisberg, General Atomics T.M. Wilks, MIT J.M. Hanson, Columbia U. N.C. Logan, PPPL C.M. Samuell, LLNL Experiments on DIII-D are advancing toward a demonstration of access to and control of Q(uescent)H-mode at normalized performance equivalent to \( Q=10 \) in plasmas with ITER shape and collisionality, and low NBI torque throughout the pulse length. Earlier experiments had shown that ELMs return at NBI torque magnitude below \( \sim 3.5 \) Nm, which is above the expected level of normalized torque input in ITER. Recent experiments have been able to extend QH-mode operation to lower torque \( \sim 2 \) Nm and higher energy confinement by increasing the plasma-wall gap at the outboard mid-plane, and by reducing the input energy of the beam-injected ions. Two hypotheses are being tested: (a) the outer gap affects the scrape-off layer flows and thus the rotation gradient at the edge of the plasma, known to affect QH-mode access; (b) fast ion losses bombarding the wall may release impurities that affect the edge collisionality and stability making QH-mode operation more difficult.

*Supported by the US DOE under DE-FC02-04ER54698.*

**GP11 70 Mutually Exclusive Relation between High Pedestal and Large-Radius Internal Transport Barrier in High Beta Scenario on DIII-D**

Siye Ding, Jinpeng Qian, Juan Huang, Xianzu Gong, Tianyang Xia, Chengkang Pan, Guoqiang Li, QiLong Ren, WenFeng Guo, ASIPP Andrea Garofalo, GA Chris Holcomb, LLNL Joseph McClenahan, ORNL

Statistical analysis of experimental data from DIII-D high beta plasmas implies that a natural boundary exists hindering the plasma to simultaneously achieve high pedestal (electron temperature and density) and strong large-radius internal transport barrier (ITB). In the previous study, we revealed a beta threshold about 1.9 for the formation of large-radius ITB in both Te and ne channels. With strong gas puffing, we observed higher beta threshold (about 2.2) for the formation of ne-ITB that may be due to (1) the higher edge density and pedestal height and therefore high local bootstrap current; (2) the penetration of edge inductive current and turbulence. Meanwhile, the beta threshold for the formation of Te-ITB doesn’t change. The observed mutually exclusive relation in experiments is important because sustaining a large-radius ITB is favorable for developing high betap scenario with optimized confinement and stability.

*Supported in part by US DOE under DE-FC02-04ER54698 and NNSF of China under Grant No. 11575248.*

**GP11 71 Stability analysis of the high poloidal beta scenario on DIIIDowards operation athigher plasma current**

W.F. Guo, X.Z. GONG, J. HUANG, Q.L. REN, J.P. QIAN, S.Y. DING, C.K. PAN, G.Q. LI, T.Y. XIA, ASIPP A.M. GAROFALO, L. LAO, A. HYATT, J. FERRON, O. MENEGHINI, Y.Q. LIU, GA J. MCCLENAHAN, ORNL C.T. HOLCOMB, LLNL The high poloidal beta scenario with plasma current \( I_p \sim 600 \) kA and large-radius internal transport barrier (ITB) on DIII-D is subject to \( n=1 \) MHD kink modes when the current profile becomes very broad at internal inductance values \( li \sim 0.5-0.6 \). It is desirable to extend this scenario to higher plasma current \( \sim 1 \) MA for highernormalized fusionperformance. However, higher current at constant normalized beta, \( \beta_N \sim 3 \), would reduce the poloidal beta, \( \beta_p \), below the threshold for ITB sustainment, observed at \( \beta_N \sim 1.9 \). Thus, to avoid loss of the IT, \( \beta_N^{\text{TH}} \) must be increased together with \( I_p \) while avoiding the kink instability. MHD analysis is presented that explains possible paths to high \( \beta_N \) stability limit for the kink mode in this scenario.

*Work supported by National Magnetic Confinement Fusion Program of China under 2015GB110001 and 2015GB102000 - National Natural Science Foundation of China under Grant No. 1147521 and by US DOE under DE-FC02-04ER54698.*

**GP11 72 Extension of high poloidal beta scenario in DIII-D to lower \( q_{95} \) for steady state fusion reactor**

GP11 73 Central Safety Factor and Normalized Beta Control Under Near-Zero Input Torque Constraints in DIII-D* ANDRES PAJARES, WILLIAM WEHNER, EUGENIO SCHUSTER, Lehigh University KEITH BURRELL, JOHN FERRON, MICHAEL WALKER, DAVID HUMPHREYS, General Atomics LEHIGH UNIVERSITY TEAM, GENERAL ATOMICS TEAM DIII-D experiments have assessed the capability of combined central safety factor (q95) and normalized beta (βn) control under near-zero net torque to facilitate access to QH-mode with reverse Iν and normal Bt. Regulation of qν and βν can prevent magneto-hydrodynamic instabilities that deteriorate plasma performance in discharges with a monotonically increasing safety-factor profile. Zero-input-torque scenarios are of special interest because future burning plasma tokamaks such as ITER will most likely operate with very low input torque, which makes these scenarios more susceptible to locked modes. To support studies of such scenarios, a controller for simultaneous regulation of qν and βν has been developed using near-zero net input torque actuators including balanced neutral beam injection (NBI) and electron-cyclotron heating & current drive (ECH/ECCD). Experimental results show that in spite of the presence of locked modes the use of feedback control resulted in good tracking of the commanded qν and βν when both ECCD/ECH and NBI were available.

*Supported by the US DOE under DE-SC0010661 and DE-FC02-04ER54698.

GP11 74 Predictive Rotation Profile Control for the DIII-D Tokamak* W.P. WEHNER, E. SCHUSTER, Lehigh U M.D. BOYER, PPPL M.L. WALKER, D.A. HUMPHREYS, GA Control-oriented modeling and model-based control of the rotation profile are employed to build a suitable control capability for aiding rotation-related physics studies at DIII-D. To obtain a control-oriented model, a simplified version of the momentum balance equation is combined with empirical representations of the momentum sources. The control approach is rooted in a Model Predictive Control (MPC) framework to regulate the rotation profile while satisfying constraints associated with the desired plasma stored energy and/or βn limit. Simple modifications allow for alternative control objectives, such as maximizing the plasma rotation while maintaining a specified input torque. Because the MPC approach can explicitly incorporate various types of constraints, this approach is well suited to a variety of control objectives, and therefore serves as a valuable tool for experimental physics studies. Closed-loop TRANSP simulations are presented to demonstrate the effectiveness of the control approach.

*Supported by the US DOE under DE-SC0010661 and DE-FC02-04ER54698.

GP11 75 Effects of Plasma Shaping on Intrinsic Rotation in DIII-D* J.S. DEGRASSIE, T.H. OSBORNE, General Atomics B.A. GRIERSON, PPPL G.R. MCKEE, U. Wisc-Madison T.L. RHODES, UCLA Intrinsic rotation in an axisymmetric tokamak must have its source in a momentum flux that passes through the boundary of the plasma. Since it is well-known that shaping in diverted discharges modifies the pedestal in H-mode discharges [1], we have performed experiments on DIII-D in which the shaping was changed during a discharge and the accompanying change in the intrinsic rotation profile is measured. We see that the change in intrinsic rotation magnitude in the outer plasma region, ρ = 0.7, is correlated with the plasma stored energy to a large extent. At the next level of response, there are changes in the rotation profiles related to the pedestal pressure, and in the interior possibly to the q profile. An additional focus of these experiments was to make measurements of the shape-induced changes in turbulence strength and spectra with Beam Emission Spectroscopy and Doppler Back Scattering. Both show clear changes in frequency with, for example, a change in the major radius of the X-point in a single null diverted plasma.

*Work supported by US DOE under DE-FC02-04ER54698.

GP11 76 Scaling of Intrinsic Rotation with Normalized Gyroradius in DIII-D and Comparison to Intrinsic Torque Scaling* COLIN CHRYSTAL, General Atomics SHAUN HASKEY, BRIAN GRIERSON, Princeton Plasma Physics Laboratory JOHN DEGRASSIE, General Atomics CAMERON SAMUELL, Lawrence Livermore National Laboratory New experiments at DIII-D have investigated the scaling of intrinsic rotation with the normalized gyroradius, ρ*, by performing a dimensionless parameter scan in electron cyclotron heated H-mode plasmas with no external torque injection. Intrinsic rotation was measured for both the dominant impurity and the main-ion species. The main experimental result is that the Mach no. (toroidal velocity normalized to either the sound speed or the Alfvén velocity) was nearly constant or slightly increasing with decreasing ρ*. These intrinsic rotation results corroborate the previous measurements of the intrinsic torque and momentum confinement time scaling with ρ*, which indicates that the fast-ion content from significant neutral beam injection in the previous experiment did not influence those results. The potential effect of neutral particle transport in the pedestal is also investigated. Predictions of the intrinsic rotation in ITER are reviewed.

*Supported by DOE Cooperative Agreement DE-AC02-09CH11466, DE-FC02-04ER54698, DE-AC52-07NA27344.
that the momentum flux from the RS term can explain the observed momentum balance.

*Work supported under USDOE Cooperative Agreement DE-FC02-04ER54698.

**GP11 78 Collisional temperature and dependence of the edge main-ion co-current rotation profile feature on DIII-D** SHAUN HASKEY, BRIAN GRIERSON, ARASH ASHOURVAN, DEVON BATTAGLIA, Princeton Plasma Physics Laboratory COLIN CRYSTAL, KEITH BURRELL, RICHARD GROEBNER, JOHN DEGRASSIE, General Atomics LUKE STAGNER, UC Irvine TIMOTHY STOLTZFUSS-DUECK, Princeton University NOVIMIR PABLANT, Princeton Plasma Physics Laboratory A new edge main-ion (D\(^+\)) toroidal rotation from the pedestal top to the scrape off layer on DIII-D with implications for intrinsic rotation studies. A peaked co-current edge toroidal rotation is observed for the main ion species near the outboard midplane separatix with values up to 140 km/s for low collisionality QH modes. In lower power (P\(\text{keV} = 0.8\text{MW}\)) H-modes the edge rotation is still present but reduced to \(\sim 50\text{km/s}\). D\(^+\) and C6\(^+\) toroidal rotation differences are presented for a variety of scenarios covering a significant range of edge collisionality and Tc. Observations are compared with predictions from several models including collisionless ion orbit loss calculations and more complete modeling using the XGC0 code, which also predicts 140 km/s edge rotation for low collisionality QH mode cases.

*Work supported by the U.S. DOE under DE-AC02-09CH11466, No. DE-FC02-04ER54698, and DE-FC02-95ER54309.

**GP11 79 Isotope Mass Scaling of Turbulence and Transport** GEORGE MCKEE, ZHENG YAN, Univ of Wisconsin, Madison PUNIT GOHIL, TIM LUCE, General Atomics TERRY RHODES, UCLA The dependence of turbulence characteristics and transport scaling on the fuel ion mass has been investigated in a set of hydrogen (A = 1) and deuterium (A = 2) plasmas on DIII-D. Normalized energy confinement time (\(B \pm \tau_{E}\)) is two times lower in hydrogen (H) plasmas compared to similar deuterium (D) plasmas. Dimensionless parameters other than ion mass (A), including \(\rho_*, q_{95}, T_e/T_i, \beta_n, v^*, \) and Mach number were maintained nearly fixed. Matched profiles of electron density, electron and ion temperature, and toroidal rotation were well matched. The normalized turbulence amplitude (\(\tilde{\eta}/\rho\)) is approximately twice as large in H as in D, which may partially explain the increased transport and reduced energy confinement time. Radial correlation lengths of low-wavenumber density turbulence in hydrogen are similar to or slightly larger than correlation lengths in the deuterium plasmas and generally scale with the ion gyroradius, which were maintained nearly fixed in this dimensionless scan. Predicting energy confinement in D-T burning plasmas requires an understanding of the large and beneficial isotope scaling of transport.

*Supported by US DOE DE-SC0007880, DIII-D Grant Number DE-FC02-04ER54698.

**GP11 80 Impact of Magnetic Island - Turbulence Multi-Scale Interaction on Plasma Confinement and Magnetic Island Stability** L. BARDOCZI, ORAU T.A. CARTER, UCLA R.J. LA HAYE, General Atomics T.L. RHODES, UCLA G.R. MCKEE, U. Wisconsin Recent measurements [1] and gyrokinetic simulations [2] reported the reduction of turbulent density fluctuations (\(\pm \)) inside magnetic islands, and \(\pm \) increases outside magnetic islands, when the island width (W) exceeds a threshold (W\(_T\)). As the cross-field transport is dominantly driven by \(\pm \), this calls into question the conventional understanding of confinement (\(\tau_c\)) degradation and Neoclassical Tearing Mode (NTM) stability physics. We report that the increase in ion-scale \(\pm \) outside the island correlates with higher heat and particle fluxes, i.e., \(\pm \) increases temporarily when \(\tau_c\) is decreasing, while in the following stationary state \(\pm \) is comparable to before NTM onset. This indicates that the decrease of the plasma stored energy results from \(\pm -\)NTM interaction. On the other hand, simultaneous \(\pm \) reduction at the O-point has a destabilizing effect on NTMs. These observations suggest that driving \(\pm \) at the O-point could prevent small islands from growing large, allowing better plasma confinement and safer tokamak operation.

*Supported by US DOE under DE-FG02-08ER54984 and DEFC02-04ER54698.


**GP11 81 Particle transport in DIII-D plasmas** PETER KRESS, SASKIA MORDIJCK, William & Mary Coll By analyzing the plasma opacity and density evolution during the ELM cycle in DIII-D H-mode plasmas in which the amount of gas fueling was altered, we find evidence for an inward particle pinch at the plasma edge which seems to become more pronounced at higher density. Furthermore, at the plasma edge we find a correlation between the pedestal density and opacity, which measures neutral penetration depth. The changes in edge opacity during an ELM cycle were calculated by using a detailed time history of measured plasma profiles. At the same time, the density evolution during an ELM cycle was investigated. We find that if the edge density increases through an increase in gas fueling, then opacity increases and neutral fueling penetration depth decreases. We also find that density at the top of the pedestal recovers faster following an ELM when the overall density level is higher, leading to a hollow profile inside of the pedestal top. All these results indicate that there must be an inward particle pinch in the pedestal which will be crucial in the fueling of future burning plasma devices.

*Supported by US DOE DE-SC0007880, DIII-D Grant Number DE-FC02-04ER54698.

**GP11 82 Microtearing instabilities and resulting electron thermal transport in DIII-D discharges** A.H. KRITZ, T. RAFIG, Lehigh U., USA L. LUO, IBM Research, USA J. WEILAND, Chalmers U., Sweden A reduced transport model for microtearing modes (MTMs), has been developed for use in integrated predictive modeling studies. A unified fluid/kinetic approach is employed in the derivation of the nonlinear MTM dispersion relation. The dependence of the MTMs real frequency and growth rate in DIII-D like L-mode and H-mode plasma discharges is examined for a range of plasma parameters. The saturated amplitude of the magnetic fluctuations is calculated utilizing numerically determined MTM eigenvalues in the nonlinear MTM envelope equation. It is found that the electron temperature gradient in the presence of moderate collision frequency is required for MTMs to become unstable. The effects of small and large collisionality and small and large wavenumbers on MTMs are found to be stabilizing, while the effects of density gradient, plasma beta, low current density, and large magnetic shear are found to be destabilizing. The MTM growth rate, magnetic fluctuation strength, as well as electron thermal diffusivity is found to be larger in the H-mode plasma than in the L-mode plasma.
GP11 83 Extracting 3D Information from 1D and 2D Diagnostic Systems on the DIII-D Tokamak*  
MICHAEL BROOKMAN, Institute for Fusion Studies, University of Texas  
The interpretation of tokamak data often hinges on assumptions of axisymmetry and flux 
surface equilibria, neglecting 3D effects. This work discusses examples on the DIII-D tokamak where this assumption is an insufficient 
approximation, and explores the diagnostic information available to resolve 3D effects while preserving 1D profiles. Methods for ex-
tracting 3D data from the electron cyclotron emission radiometers, density profile reflectometer, and Thomson scattering system are 
discussed. Coordinating diagnostics around the tokamak shows the significance of 3D features, such as sawteeth[1] and resonant 
magnetic perturbations. A consequence of imposed 3D perturbations is a shift in major radius of measured profiles between diagnostics at dif-
ferent toroidal locations. Integrating different 3D diagnostics requires a database containing information about their toroidal, poloidal, and 
radiial locations. Through the data analysis framework OFMIT, it is possible to measure the magnitude of the apparent shifts from 3D 
effects and enforce consistency between diagnostics. Using the ex-\nisting 1D and 2D diagnostic systems on DIII-D, this process allows the effects of the 3D perturbations on 1D profiles to be addressed.

*Supported by US DOE contracts DE-FC02-04ER54698, DE-
FG03-97ER54415.

GP11 84 Measurement of internal equilibrium and fluctuating magnetic field on DIII-D by using Radial Polarimeter- 
Interferometer* JIE CHEN, WEIXING DING, DAVID BROWER, 
UCLA REJEAN BOIVIN, General Atomics  
A Faraday-effect based Radial Interferometer-Polarimeter (RIP) has been implemented on DIII-D for measurements of the magnetic equilibrium and the mag-
netic axis vertical position with fast time response that can be ex-
plotted for position and instability control. Furthermore, RIP can 
also measure internal radial magnetic fluctuations, e.g. internal kink 
- precursor to sawtooth crash, NTM seeding and plasma disruptions. By utilizing counter-rotating circular polarization technique, the diagnostic 
measures Faraday rotation and line-integrated electron density simultaneously with time response at microsecond scale and phase noise ∼0.01 degree/sqrt(kHz), corresponding to 
1 Gs/sqrt(kHz) for typical DIII-D plasma conditions. Measurement 
errors has been assessed and minimized. Systematic comparison 
between RIP measurement and MSE-constrained EFIT using a syn-
thetic diagnostic shows good agreement, manifesting consistency of 
internal magnetic field measurement between RIP and other mag-
netic diagnostics.

*Supported by US DOE Grants DE-FG03-01ER54615 and DE-
FC02-04ER54698.

GP11 85 Synthetic Diagnostic for Doppler Backscattering (DBS) Turbulence Measurements based on Full Wave Simulations* D. R. ERNST, MIT T. L. RHODES, S. KUBOTA, N. CROCKER, 
UCLA  
Plasma full-wave simulations of the DIII-D DBS system including its lenses and mirrors are developed using the GPU-based 
FDTD2D code [1], verified against the GENRAY ray-tracing code and TORBEAM paraxial beam code. Our semi-analytic description 
of the effective spot size for a synthetic diagnostic reveals new fo-
cusing and defocusing effects arising from the combined effects of the curvature of the reflecting surface and that of the Gaussian beam 
wavefront. We compute the DBS transfer function from full-wave 
simulations to verify these effects. Using the synthetic diagnostic, nonlinear GYRO simulations closely match DBS fluctuation spec-
tra with and without strong electron heating, without adjustment or change in normalization, while both GYRO and GENE also match 
fluxes in all transport channels [2]. Density gradient driven TEMs 
that are observed by the DBS diagnostic on DIII-D are reproduced by simulations as a band of discrete toroidal mode numbers which 
intensify during strong electron heating.

*Supported by US DOE under DE-FC02-04ER54698 and DE-
FG02-08ER54984.

1 B. C. Rose, S. Kubota, and W. A. Peebles, in Proc. 18th Topical 
HTPD Conference (Wildwood, N. J., 2010); J. Hillesheim et al., 

IAEA FEC paper CN-221/EX/2-3.

GP11 86 DIII-D Neutron Measurement: Status and Plan for 
Simplification and Upgrade* Y.B. ZHU, W.W. HEIDBRINK, UC 
Irvin P. L. TAYLOR, General Atomics D. FINKENTHAL, Palo-
mar College  
Neutron diagnostics play key essential roles on DIII-
D. Historically an 18-channel 2.45MeV D-D neutron measurement 
system based on 3He and BF3 proportional counters was inherited from Doublet-III including associated electronics and CAMAC data 
aquisition. Three fission chambers and two neutron scintillators were added in the 1980s and middle 1990s respectively. For Tritium 
burn-up studies, two 14MeV D-T neutron measurement systems were installed in 2009 and 2010. Operation and maintenance ex-
perience have led to a plan to simplify and upgrade these aging systems to provide a more economical and reliable solution for future DIII-D 
experiments. On simplification, most conventional expensive NIM 
and CAMAC modules will be removed. Advanced technologies like ultra-fast data acquisition and software-based pulse identification 
have been successfully tested. Significant data reduction and 
efficiency improvement will be achieved by real-time digital pulse 
identification with a field-programmable gate array. The partly re-
newed system will consist of 4 neutron counters for absolute cal-
bration and 4 relatively calibrated neutron scintillators covering a 
wide measurement range.

*Supported by US DOE under DE-FC02-04ER54698.

GP11 87 Observations of highly sheared turbulence in the H-
mode pedestal using Phase Contrast Imaging on DIII-D∗  
J.C. ROST, A. MARINONI, E.M. DAVIS, M. PORKOLAB, MIT K.H 
BURRELL, GA  
Highly sheared turbulence with short radial correlation 
lengths has been measured near the top of the H-mode pedestal, in addition to the previously measured highly-sheared turbulence 
measured in the E,well. Turbulence in regions of large velocity shear is characterized by radial correlation lengths shorter than the 
poloidal wavelength (L < λ ∼ 2 cm) and large Doppler-shifted frequ-
cencies (f > 200 kHz). The phase contrast imaging (PCI) diagnostic 
on DIII-D is ideally suited to measuring this density turbulence 
due to the measurement geometry and high frequency bandwidth. 
Radial localization is achieved by optical filtering, varying the ExB 
profile, and shifting the plasma position. Reconfiguration of the E, 
well, such as at the L-H transition or the transition to wide pedestal 
QH-mode, shows a near-instantaneous change (t < 1 ms) to the 
shaped turbulence in the E, well (∼ 1 cm inside the separatrix). In 
contrast, the sheared turbulence near the top of the pedestal (∼ 2 
cm inside the separatrix) varies over times scales of tens of ms, 
consistent with pedestal evolution.
GP11 88 Increase in turbulent transport at DIII-D pedestal top due to RMP-induced reduction of electric field shear
SAM TAIMOURZADEH, LEI SHI, Univ of California - Irvine IHOR HOLOD, LNL ZHIHONG LIN, Univ of California - Irvine RAFFI NAZIKIAN, Princeton Plasma Physics Lab. DONALD SPONG, ANDREAS WINGEN, Oak Ridge Ntl Lab. It has been demonstrated that resonant magnetic perturbations (RMPs), applied with the right conditions, suppress or mitigate edge localized modes (ELMs) in DIII-D at low, ITER-like, collisionality. Along with the RMP ELM suppression, observations in DIII-D, via BES, DBS, and other fluctuation diagnostics, show an increase in electrostatic turbulence near the top of the pedestal, where the mean radial electric field (Er) shearing rate decreases. The Gyrokinetic Toroidal Code (GTC) simulations show that there is a strong correlation between the reduction of the Er shearing rate and an increase in turbulence and transport near the pedestal top of the DIII-D shot 158103 during RMP ELM suppression at 03050 ms. A nonlinear outward spreading of the turbulence is observed, which allows a stronger microturbulence on the pedestal top during ELM suppression by RMP. For comparison, the turbulence and transport near the pedestal top remain at low levels when the plasma is ELMing, i.e. when the Er shearing rate is not decreased in the same shot at 03750 ms (ELMing w/ RMP on) and in another shot 158104 at 1350 ms (ELMing without RMP). Furthermore, GTC simulations show that the kink responses to the 3D RMP have little effects on the growth rate of electromagnetic kinetic-balloonning mode and on the turbulent transport and zonal flow damping in electrostatic turbulence.

GP11 89 Installation and Testing of ITER Integrated Modeling and Analysis Suite (IMAS) on DIII-D∗ L. LAO, M. KOSTUK, O. MENEGHINI, S. SMITH, G. STAEBLER, General Atomics R. KALLING, Kalling Software S. PINCHES, ITER A critical objective of the ITER Integrated Modeling Program is the development of IMAS to support ITER plasma operation and research activities. An IMAS framework has been established based on the earlier work carried out within the EU. It consists of a physics data model and a workflow engine. The data model is capable of representing both simulation and experimental data and is applicable to ITER and other devices. IMAS has been successfully installed on a local DIII-D server using a flexible installer capable of managing the core data access tools (Access Layer and Data Dictionary) and optionally the Kepler workflow engine and coupling tools. A general adaptor for OMFIT (a workflow engine) is being built for adaptation of any analysis code to IMAS using a new IMAS universal access layer (UAL) interface developed from an existing OMFIT EU Integrated Tokamak Modeling UAL. Ongoing work includes development of a general adaptor for EFIT and TGLF based on this new UAL that can be readily extended for other physics codes within OMFIT.

∗Work supported by US DOE under DE-SC001765, DE-FC02-04ER54698, DE-FG-2-05ER54309 and EU H2020 No 633053 FusNet.

GP11 90 Neural Network Based Models for Fusion Applications∗ ORSO MENEGHINI, GA ARSENE TEMA BIWOLE, TEOBALDO LUDA, Polito BAILEY ZYWICKI, U-Michigan CRISTINA REA, MIT STERLING SMITH, PHIL SNYDER, EMILY BELL, GARY STAEBLER, JEFF CANTY, GA Whole device modeling, engineering design, experimental planning and control applications demand models that are simultaneously physically accurate and fast. This poster reports on the ongoing effort towards the development and validation of a series of models that leverage neural-Á-network (NN) multidimensional regression techniques to accelerate some of the most mission critical first principle models for the fusion community, such as: the EPED workflow for prediction of the H-Mode and Super H-Mode pedestal structure the TGLF and NEO models for the prediction of the turbulent and neoclassical particle, energy and momentum fluxes; and the NEO model for the drift-kinetic solution of the bootstrap current. We also applied NNs on DIII-D experimental data for disruption prediction and quantifying the effect of RMPs on the pedestal and ELMs. All of these projects were supported by the infrastructure provided by the OMFIT integrated modeling framework.

∗Work supported by US DOE under DE-SC0012656, DE-FG02-95ER54309, DE-FC02-04ER54698.

GP11 91 Coupled core-pedestal simulations with self-consistent transport of impurities* G. SNOEP, Eindhoven University of Technology O. MENEGHINI, General Atomics B. GRIERSON, A. ASHOURVAN, PPPL E. BELL, J. CANDY, P.B. SNYDER, G.M. STAEBLER, General Atomics J. CITRIN, DIFFER R.J.E. JASPERS, Eindhoven University of Technology This poster reports on the ongoing development of a production tool that robustly predicts density, temperature and rotation profiles from on-axis to the separatrix. The number of free parameters and assumptions in the simulations are reduced by using physics based models that are self-consistently coupled to one another. Previous coupled core-pedestal simulations were shown to be able to reproduce experimental profiles [Meneghini PoP 2016, NP 2017], but relied on prior knowledge of the plasma Z_{eff} and pedestal rotation boundary condition. Z_{eff} is an important parameter since it influences both core performance, through transport and line radiation, and pedestal stability via its effect on the bootstrap current. To self-consistently account for the effects of impurities the previously mentioned core-pedestal workflow is iteratively coupled to the 1D impurity transport code STRAHL [Dux 2006] within the OMFIT framework. In this scheme NEO and TGLF will provide the transport fluxes used to calculate the diffusion and pinch profiles used in STRAHL. The new workflow also implements a boundary condition for the plasma rotation based on first principles [Stoltzfus-Dueck PRL 2015].

Scope supported by U.S. DOE DE-SC001765, DE-FC02-04ER54698, DE-FG-2-05ER54309 and EU H2020 No 633053 FusNet.

GP11 92 Uncertainty Propagation in OMFIT∗ STERLING SMITH, ORSO MENEGHINI, General Atomics CHOONGKI SUNG, University of California - Los Angeles A rigorous comparison of power balance fluxes and turbulent model fluxes requires the propagation of uncertainties in the kinetic profiles and their derivatives. Making extensive use of the python uncertainties package, the OMFIT framework has been used to propagate covariant uncertainties to provide an uncertainty in the power balance calculation from the ONETWO code, as well as through the turbulent fluxes calculated by the TGLF code. The covariant uncertainties arise from fitting 1D (constant on flux surface) density and temperature profiles and associated random errors with parameterized functions such as a modified tanh. The power balance and model fluxes can then be compared with quantification of the uncertainties. No effort is made at propagating systematic errors. A case study will be shown for the effects of resonant magnetic perturbations on the kinetic profiles and fluxes at the top of the pedestal. A separate attempt at modeling the random errors with Monte Carlo sampling will be compared to the method of propagating the fitting function parameter covariant uncertainties.
TUESDAY MORNING

GP11 93 Turbulence and sheared flow dynamics during q95 and density scans across the L-H transition on DIII-D* ZHENGYAN, GEORGE MCKEE, University of Wisconsin-Madison PUNIT GOHIL, General Atomic LOTHAR SCHMITZ, University of California Los Angeles DAVID ELDON, General Atomic BRIAN GRIERSON, PPL MATT KRIETE, University of Wisconsin-Madison TERRY RHODES, University of California Los Angeles CRAIG PETTY, general atoms 

Measurements of long wavelength density fluctuation characteristics have been obtained in the edge of Deuterium (D) plasmas across the L-H transition on DIII-D during density and q95 scans. The relative density fluctuation amplitude measured by Beam Emission Spectroscopy (BES) increases with higher q95. The power threshold is found to increase with plasma current (i.e., lower q95) but with complex density dependence: the largest increase of P_{TOT} occurs at n_e^\sim 3.2e19 m^{-3}. Interestingly, a dual counter-propagating mode is observed for cases when P_{tot} is low. The existence of the dual mode is correlated with increasing flow shear. Estimation of the turbulence kinetic energy transfer from turbulence to the flow increases prior to the transition. The complex behaviors of the turbulence characteristics and dual frequency modes interactions impact the flow shear generation, the transition process and the power threshold scaling.

*Supported by the US Department of Energy under DE-FG02-08ER54999, DE-AC02-09CH14466, DE-FG02-04ER54698, and DE-AC52-07NA27344.

GP11 94 L-H Transition Dynamics in ITER-Similar D, He, and H Plasmas* L. SCHMITZ, TL. RHODES, T. NEISER, L. ZENG, UCLA, Los Angeles, CA Z. YAN, G.R. MCKEE, UWisc, Madison, WI P. GOHIL, L. BARDOCZI, D. ELDON, C.C. PETTY, General Atomics, San Diego, CA B. GRIERSON, PPL, Princeton, NJ Recent work at DIII-D has revealed important differences in L-H transition trigger dynamics between deuterium (D), helium (He) and hydrogen (H) plasmas. The ion flux/polarization current induced by the Reynolds stress is shown to be decisive for the fast time evolution of the edge electric field across the L-H transition at intermediate and low plasma density in the plateau collisionality regime, in D and He plasmas. As the corresponding j × B torque increases, concomitant turbulence suppression occurs within 100-200 μs of the peak Reynolds stress gradient. H-plasmas show lower Reynolds stress and torque, and reduced toroidal correlation, of the self-organized edge flow layer, and longer transition times concomitantly with substantially higher required L-H transition threshold power. In H-plasmas, the Reynolds force is comparable in magnitude to the neoclassical bulk ion viscosity and the force due to thermal ion orbit loss, potentially explaining the increased power threshold.

*Supported by the U.S. DOE under DE-FG02-04ER54698, DE-FG02-08ER54998, DE-AC02-09CH14466 and DE-FG02-08ER54999.

GP11 95 Influence of 3D magnetic fields on turbulence at the L-H transition and across magnetic islands in DIII-D* DAVID KRIETE, GEORGE MCKEE, RAYMOND FONCK, DAVID SMITH, ZHENGYAN, University of Wisconsin-Madison LUCAS MOR-TON, Oak Ridge Associated Universities MORGAN SHAFER, Oak Ridge National Laboratory LOTHAR SCHMITZ, University of California Los Angeles Measurements of long-wavelength density fluctuations using beam emission spectroscopy (BES) reveal the significant impact of 3D magnetic fields on turbulence amplitudes and characteristics. Fluctuations are measured across an applied static m,n = 2,1 magnetic island that is rotated toroidally through the BES sightlines, providing quasi-3D measurement capability. A single unstable broadband turbulence mode is observed near the O-point, but near the X-point, this mode is accompanied by a second mode propagating in the opposite direction; fluctuation amplitudes are also much higher near the X-point than the O-point. 2D fluctuations are also measured in the L-mode edge leading up to L-H transitions with applied resonant and non-resonant magnetic perturbations. Normalized fluctuation amplitudes are ~4 times larger with resonant fields than with non-resonant fields. Additionally, dual counter-propagating modes are observed with resonant fields, while only a single mode is observed with non-resonant fields. These measurements may reveal how magnetic perturbations raise the L-H power threshold by altering turbulence-flow dynamics leading up to the transition.

*Supported by DOE Grants DE-SC0001288, DE-FG02-08ER54999, and DE-FG02-04ER54698.

GP11 96 Phase-Space Dependence of Fast-Ion Transport by Neoclassical Tearing Modes* W. HEIDBRINK, D.J. LIN, Y.B. ZHU, UCI L. BARDOCZI, ORISE C.S. COLLINS, C. MUSCATELLO, M. VANZELAND, GA G. KRAMER, M. PODESTA, PPL The fast-ion transport caused by neoclassical tearing modes (NTM) in H-mode plasmas is investigated in different parts of fast-ion phase space using the newly developed beam modulation technique and a variety of fast-ion diagnostics that are sensitive to different parts of the distribution function. As measured by electron cyclotron emission, the (m, n) = (2, 1) tearing modes have an island width of ~10 cm and change phase 180° at the q = 2 surface. (Here, m is the poloidal mode number and n is the toroidal mode number.) The fast ions are produced by deuterium neutral beam injection at 75-81 keV. To measure fast-ion transport in different parts of phase space, one neutral-beam source is modulated at 20 Hz. Flows in phase space are obtained through comparisons of measured neutron, solid-state neutral particle analyzer, and fast-ion D-alpha signals with the expected signals in the absence of wave-induced transport. In order to populate different parts of phase space, beams with six different injection geometries are modulated on successive discharges. Initial analysis indicates that the largest transport occurs for on-axis, tangentially-injected ions, while smaller transport occurs for off-axis or perpendicular injection. Simulations show similar trends.

*Supported by DOE Grants DE-SC0001288, DE-FG02-04ER54698.

GP11 97 Orbit Tomography: A Method for Determining the Population of Individual Fast-ion Orbits from Experimental Measurements* L. STAGNER, W.W. HEIDBRINK, Univ of California - Irvine Due to the complicated nature of the fast-ion distribution function, diagnostic velocity-space weight functions are used to analyze experimental data. In a technique known as Velocity-space Tomography (VST), velocity-space weight functions are combined with experimental measurements to create a system of linear equations that can be solved. However, VST (which by definition ignores spatial dependencies) is restricted, both by the accuracy of its forward model and also by the availability of spatially overlapping diagnostics. In this work we extend velocity-space weight functions to a full 6D generalized coordinate system and then show how to reduce them to a 3D orbit-space without loss of generality using an action-angle formulation. Furthermore, we show how diagnostic orbit-weight functions can be used to infer the full fast-ion distribution function, i.e. Orbit Tomography. Examples of orbit weights...
functions for different diagnostics and reconstructions of fast-ion distributions are shown for DIII-D experiments.

*This work was supported by the U.S. Department of Energy under DE-AC02-09CH11466 and DE-FC02-04ER54698.

GP11 98 Using Electron Cyclotron Emission Images to localize the drive and damping of Alfvén eigenmodes* GERRIT KRAMER, PPPL BEN TOBIAS, LLNL ALAN TURNBULL, GA CALVIN DOMIER, NEVILLE LUHMANN, UCD Alfvén Eigenmodes (AE) are routinely imaged in DIII-D with the Electron Cyclotron Emission Imaging system (ECE-I). From the ECE-I images it was found that the AE wave fronts show a clear radial phase variation, which reflects a radial plasma displacement that is induced by the AEs. We use the measured plasma displacement to extract the fluctuating electric and magnetic fields and use these fields to calculate the Poynting flux to determine radial wave-induced energy flows for saturated AEs. These energy flows arise when the drive of the mode does not coincide with the location of the damping of the mode. We will use the measured curved AE wave fronts to determine the radial energy flow that is induced by the AEs and show that the location of fast-ion drive of the AEs does not coincide with the location of the strongest damping of the mode.

*DOE Grants DE-AC02-09CH11466 & DE-FC02-04ER54698.

GP11 99 Alfvén Eigenmode Control in DIII-D* W. HU, ASIPP E. OLOFFSON, A. WELANDER, M. VAN ZEELAND, C. COLLINS, General Atomics W. HEIDBRINK, UCI Alfvén eigenmodes (AE) driven by fast ions from neutral beam and ion cyclotron heating are common in present day tokamak plasmas and are expected to be destabilized by alpha particles in future burning plasma experiments. Because these waves have been shown to cause loss and redistribution of fast ions which can impact plasma performance and potentially device integrity, developing control techniques for AEs is of paramount importance. In the DIII-D plasma control system, spectral analysis of real-time ECE data is used as a monitor of AE amplitude, frequency, and location. These values are then used for feedback control of the neutral beam power to control Alfvén waves and reduce fast ion loss. This work describes tests of AE control experiments in the current ramp up phase, during which multiple Alfvén eigenmodes are typically unstable and fast ion confinement is degraded significantly. Comparisons of neutron emission and confined fast ion profiles with and without active AE control will be made.

*Work supported by the U.S. Dept. of Energy under Award Number DE-FC02-04ER54698.

GP11 100 Optimization of DIII-D discharges to avoid AE destabilization* JACOBO VARELA, DONALD SPONG, ORNL LUIS GARCIA, Universidad Carlos III de Madrid JUAN HUANG, Institute of Plasma Physics, Chinese Academy of Science, Hefei, China MASANORI MURAKAMI, ORNL. The aim of the study is to analyze the stability of Alfvén Eigenmodes (AE) perturbed by energetic particles (EP) during DIII-D operation. We identify the optimal NBI operational regimes that avoid or minimize the negative effects of AE on the device performance. We use the reduced MHD equations to describe the linear evolution of the poloidal flux and the toroidal component of the vorticity in a full 3D system, coupled with equations of density and parallel velocity moments for the energetic particles, including the effect of the acoustic modes. We add the Landau damping and resonant destabilization effects using a closure relation. We perform parametric studies of the MHD and AE stability, taking into account the experimental profiles of the thermal plasma and EP, also using a range of values of the energetic particles β, density and velocity as well the effect of the toroidal couplings. We reproduce the AE activity observed in high poloidal β discharge at the pedestal [1] and reverse shear discharges [2].

*This material based on work is supported both by the U.S. Department of Energy, Office of Science, under Contract DE-AC05-000R22725 with UT-Battelle, LLC. Research sponsored in part by the Ministerio de Economía y Competitividad of Spain under the project.

1J. Huang, 58th APS DP/2016.

GP11 101 Experimental investigation of stability, frequency, and toroidal mode number of compressional Alfvén eigenmodes in DIII-D* S TANG, Univ of California - Los Angeles K THOM, Oak Ridge Associated Universities D PACE, General Atomics W.W. HEIDBRINK, Univ of California - Irvine T.A. CARTER, N.A. CROCKER, Univ of California - Los Angeles NSTX-U COLLABORATION, DIII-D COLLABORATION. An experimental investigation of the stability of Doppler-shifted cyclotron resonant compressional Alfvén eigenmodes (CAE) using the flexible DIII-D neutral beams has begun to validate a theoretical understanding and realize the CAE’s diagnostic potential. CAEs are excited by energetic ions from neutral beams [Heidbrink, NF 2006], with frequencies and toroidal mode numbers sensitive to the fast-ion phase space distribution, making them a potentially powerful diagnostic. The experiment also contributes to a predictive capability for spherical tokamak temperature profiles, where CAEs may play a role in energy transport [Crocker, NF 2013]. CAE activity was observed using the recently developed Ion Cyclotron Emission diagnostic—high bandwidth edge magnetic sensors sampled at 200 MS/s. Preliminary results show CAEs become unstable in BT ramp discharges below a critical threshold in the range 1.7 – 1.9 T, with the exact value increasing as density increases. The experiment will be used to validate simulations from relevant codes such as the Hybrid MHD code [Belova, PRL 2015].

*This work was supported by US DOE Grants DE-SC0011810 and DE-FC02-04ER54698.

GP11 102 Characteristics of Ion Cyclotron Emission on the DIII-D Tokamak* K.E. THOME, ORAU D.C. PACE, R.I. PINSKER, GA C. DEL CASTILLO, Stonybrook U. Y.B. ZHU, W.W. HEIDBRINK, UCI Understanding the relationship between Ion Cyclotron Emission (ICE) and the energetic particle distribution is important in modern-day tokamaks, since passive measurements of ICE in a reactor environment, such as ITER, could provide information on the alpha particle population and fast-ion losses. ICE is readily excited in DIII-D plasmas by kinetic instabilities resulting from neutral beam injection across a wide operational space, including in both helium and deuterium plasmas. A large set of ICE measurements has been collected over the past two years with multiple receiving antennas digitized at 200 Msamples/sec. The fundamental ICE frequency observed in DIII-D plasmas is in the 5-20 MHz range with typical toroidal magnetic fields of 1–2 T. Harmonics are observed up to the Nyquist limit at 100 MHz. These frequencies correspond to both core and edge locations; however, ICE is more often observed at frequencies correlated with ion cyclotron harmonics at the outboard edge. ICE dependencies on plasma and beam parameters such
as beam geometry, injection voltage, beam power, plasma density, toroidal field, neutron rate, and ion species are presented. Rapid changes of ICE during ELMs and sawteeth may provide insight into the fast evolution of the beam ion distribution due to these instabilities. Correlation of the ICE signals with the results of other fast-ion diagnostics is essential to compare with modelling of underlying kinetic instabilities.

*Work supported by US DoE under DE-FC02-04ER54698.

GP11 103 Transport of shattered pellet material during fast shutdown of DIII-D plasmas* D. SHIRAKI, J.L. HERFINDAL, L.R. BAYLOR, ORNL, N.W. EIDITIS, GA E.M. HOLLMANN, R.A. MOYER, UCSD C.J. LASNIER, LLNL A second shattered pellet injection (SPI) system has been installed on DIII-D, allowing new measurements of radial and toroidal transport of injected impurities during fast shutdown of the plasma. Toroidally separated injections from the two systems vary the impurity profiles and resulting radiative heat loads, relative to available disruption diagnostics. Infrared imaging and radiometry are used to compare heat loads near the injection port with those located toroidally away, in order to quantify radiation asymmetries. Radial transport mechanisms are studied by directing the SPI trajectory away from the magnetic axis in order to reduce the ballistic transport of solid pellet fragments to the core, which more closely matches the ITER injection geometry. The assimilation of this edge deposited SPI is compared to SPI directed towards the core, and also with massive gas injection whose assimilation is strongly dependent on thermal quench MHD mixing.

*Work supported by the U.S. DOE under DE-AC05-00OR22725, DE-FC02-04ER54698, DE-FG02-07ER54917, and DE-AC52-07N27344.

GP11 104 Variation of Argon Impurity Assimilation with Runaway Electron Current in DIII-D* ERIC HOLLMANN, University of California - San Diego I. BYKOV, R.A. MOYER, D.L. RUDAKOV, UCSB A. BRIESEMIEISTER, D. SHIRAKI, J.L. HERFINDAL, ORNL M.E. AUSTIN, UC Texas C.J. LASNIER, LLNL T.N. CARLSTROM, N.W. EIDITIS, C. PAZ-SOLDAN, M. VAN ZEELAND, GA Measurements of the effect of runaway electron (RE) pressure upon argon impurity assimilation in DIII-D are reported. Intentionally created post-disruption RE beams are ramped to different plasma currents to vary the RE pressure, while impurity levels are varied by injecting argon gas (in addition to Ar already present from the small pellet used to create the disruption). Based on comparisons of current decay rates and hard x-ray, spectroscopic, interferometer, and Thomson scattering data, it is found that argon is not mixed uniformly through the plasma radially but appears to be preferentially moved out of the center of the plasma toward the walls, relative to the main species (deuterium). This exclusion appears to be stronger at higher plasma current, indicating that this force originates from the runaway electrons.

*Supported by the US DOE under DE-FG02-07ER54917, DE-AC05-00OR22725, DE-FG02-04ER54758, DE-FC02-04ER54698, DE-AC52-07N27344, DE-FG03-95ER54309, and DE-AC52-07N27344.

GP11 105 Investigation of runaway electron dissipation in DIII-D using a gamma ray imager* A. LVOVSKY, ORAU C. PAZ-SOLDAN, N. EIDITIS, D. PACE, D. TAUSSIG, General Atomics We report the findings of a novel gamma ray imager (GRI) to study runaway electron (RE) dissipation in the quiescent regime on the DIII-D tokamak. The GRI measures the bremsstrahlung emission by RE providing information on RE energy spectrum and distribution across a poloidal cross-section. It consists of a lead pinhole camera illuminating a matrix of BGO detectors placed in the DIII-D mid-plane. The number of detectors was recently doubled to provide better spatial resolution and additional detector shielding was implemented to reduce un-collimated gamma flux and increase single-to-noise ratio. Under varying loop voltage, toroidal magnetic field and plasma density, a non-monotonic RE distribution function has been revealed as a result of the interplay between electric field, synchrotron radiation and collisional damping. A fraction of the high-energy RE population grows forming a bump at the RE distribution function while synchrotron radiation decreases. A possible destabilizing effect of Parail-Pogutse instability on the RE population will be also discussed.

*Work supported by the US DOE under DE-FC02-04ER54698.

GP11 106 Simulation of excitation of whistler waves and momentum diffusion of runaway electrons in DIII-D tokamak CHANG LIU, EERO HIRVIJOKI, Princeton Plasma Phys Lab DYLAN BRENNAN, Princeton University AMITAVA BHATTACHARJEE, GUO-YONG FU, Princeton Plasma Phys Lab DONALD SPONG, Oak Ridge National Lab In recent quiescent runaway electron experiments (QRE) experiments in DIII-D, whistler waves excited by runaway electrons have been observed and are found to be associated with the fluctuation of electron cyclotron emission (ECE) signals. To understand this connection and how the whistler instabilities affect the runaway electron distribution in momentum space, a self-consistent kinetic simulation of runaway electrons, including both the secondary generation and the quasilinear diffusion effects from the excited modes, is conducted. The results show that three different branches of waves can be excited. The low frequency whistler waves and the high frequency magnetized plasma waves are excited by runaway electrons in high energy and low energy regimes respectively, through anomalous Doppler resonance. Due to the close phase velocities of these two branches, the Landau damping of them happens at the same energy regime. These two branches of waves are not observed directly in experiments due to their high frequencies. In addition, we find a third branch of waves with wavevector almost orthogonal to the magnetic field direction, excited by the bump-on-tail distribution of the runaway electrons. These waves are in the 100-200 MHz frequency range, which agrees with the experimental observations. The cyclic behavior of excitation and damping of whistler waves associated with the fluctuations of ECE signals are also reproduced.

GP11 107 Asymmetric SOL Current in Vertically Displaced Plasma* J.D. CABRERA, G.A. NAVRATIL, J.M. HANSON, Columbia U Experiments at the DIII-D tokamak demonstrate a non-monotonic relationship between measured scrape-off layer (SOL) currents and vertical displacement event (VDE) rates with SOL currents becoming largely n=1 dominant as plasma is displaced by the plasma control system (PCS) at faster rates. The DIII-D PCS is used to displace the magnetic axis ~10x slower than the intrinsic growth time of similar instabilities in lower single-null plasmas. Low order (n≤2) mode decomposition is done on toroidally spaced current monitors to attain measures of asymmetry in SOL current. Normalized to peak n=0 response, a 2-4x increase is seen in peak n=1 response in plasmas displaced by the PCS versus previous VDE instabilities observed when vertical control is disabled. Previous inquiry shows VDE asymmetry characterized by SOL current fraction and geometric parameters of tokamak plasmas [1]. We note that, of
plasmas displaced by the PCS, short displacement time scales near the limit of the PCS temporal control appear to result in larger \( n = 1/n = 2 \) asymmetries.

*Work supported under USDOE Cooperative Agreement DE-FC02-04ER54698 and DE-FG02-04ER54761.

**Fitzpatrick 2011 Nucl. Fus. 51 053007.

GP11 108 Instability Prediction and Disruption Avoidance* A.D. TURNBULL, Y.Q. LIU, General Atomics J.M. HANSON, F. TURCO, Columbia University N.M. FERRARO, PPPL Disruption avoidance requires both a prediction of the instability proximity and an estimate of the ‘disruptability’ - the likelihood that the instability will ultimately result in a disruptive event. MHD spectroscopy is a promising option for obtaining information on the proximity of instabilities. Both the direct response and the antenna impedance provide valuable information on the low frequency global normal modes corresponding to stabilized kink modes. Data from DIII-D experiments and available nonlinear simulations are used to define quantitative criteria that signify when instabilities ultimately disrupt and when they saturate or dissipate. The key distinction in this approach is the use of physical characteristics of the modes rather than more accessible operation parameters. Simple characteristics of the linear instability for example include the linear growth or damping rate and the mode spatial extent. Criteria can also involve identifying sources of free energy in the nonlinear evolution.

*Work supported in part by the US DOE under DE-FC02-04ER54698 & DE-FG02-95ER54309.

GP11 109 Real-time plasma response control for disruption avoidance* JEREMY HANSON, FRANCESCA TURCO, GERALD NAVRATIL, Columbia University NIKOLAS LOGAN, PPPL EDWARD STRAIT, GA DIII-D TEAM DIII-D experiments demonstrate the viability of using the plasma response to applied non-axisymmetric perturbations as a real-time control variable for disruption avoidance in low-torque ITER baseline demonstration discharges. The response to long-wavelength, low-frequency perturbations like the ones used here correlates with plasma stability. Consequently, it is sensitive to key parameters that influence stability, increasing with \( \beta_N \) and decreasing with plasma rotation. In the experiments, the plasma response amplitude was used to feedback modulate the neutral beam (NB) power, and thereby the plasma stored energy and stability. While the response was being controlled, the NB torque was slowly ramped down, resulting in a decrease in stored energy as the feedback acted to keep the response constant under the changing conditions. A case where the torque was ramped through zero to \(-0.5\) Nm while maintaining stability was demonstrated, indicating that control can be maintained in the challenging ITER-like parameter regime.

*Supported by US DOE under DE-FC02-04ER54698, DE-FG02-95ER54309.

GP11 110 Disruption avoidance and fast ramp-down techniques for the DIII-D experimental scenarios* JAYSON BARR, General Atomics, Oak Ridge Assoc Univ N.W. EIDIETIS, D.A. HUMPHREYS, B. SAMMULLI, T. LUCE, General Atomics Plasma current ramp-down in ITER will continue in H-mode from 15 MA to 10 MA, and will keep a diverted shape until termination. This is in contrast to the limited ramp-down scenarios typically used in DIII-D operations. Additionally, fast emergency ramp-down scenarios for ITER and future reactors are a priority for disruption avoidance. New experiments in DIII-D use the ramp-down phase of a variety of experiments including in the ITER baseline scenario to survey and identify optimized ramp-down scenarios for both scheduled terminations and terminations triggered by off-normal event detection. Systematic scans in current ramp-rate (1-5 MA/s), neutral beam power (including \( \beta_N \) feedback) and ramp-down shaping (limited versus continued diverted) have identified fast ramp-down scenarios for Lower Single Null (LSN) and Double Null (DN) plasmas. Scenario-specific methods and their rates of successful termination will be presented and compared relative to a historical data-set of ramp-down programming in the limiter configuration. Locked modes are found to be the most significant challenge to disruption avoidance in diverted ramp-downs. Results for LSN diverted discharges that begin the rampdown with large locked-modes will also be presented. If available, results of similar experiments on EAST will be presented.

*Supported by US DOE under DE-FC02-04ER54698 and DE-SC0010685.

GP11 111 Applications of “3D” Magnetic Diagnostics in DIII-D* E.J. STRAIT, S. MUNARETTO, C. PAZ-SOLDAN, General Atomics J.M. HANSON, Columbia U N.C. LOGAN, PPPL Measurements of non-axisymmetric “3D” magnetic fields have been successfully employed in DIII-D to validate models of the plasma response to external magnetic perturbations, to validate predictions of the detailed spatial structure of unstable plasma modes, to measure damping rates of stable MHD modes, and to provide input for feedback control of resistive wall modes and of intrinsic error fields. Other possible applications that are ripe for development will be discussed, including the following. External magnetic data allows a direct measurement of the electromagnetic torque exchanged between the plasma and external coils, potentially an indicator of magnetic island onset. “3D” magnetic data in the absence of plasma may be used for direct measurement of error fields caused by coil asymmetries. Spatially resolved real-time measurements of non-axisymmetric fields can enable early detection of disruption precursors, independent of whether the instability is rotating or stationary.

*Supported by US DOE under DE-FC02-04ER54698, DE-FG02-04ER54761, and DE-AC02-09CH11466.

GP11 112 Optimization of 3D Field Design* NIKOLAS LOGAN, PPPL CAOXIANG ZHU, USTC Recent progress in 3D tokamak modeling is now leveraged to create a conceptual design of new external 3D field coils for the DIII-D tokamak. Using the IPEC dominant mode as a target spectrum, the Finding Optimized Coils Using Space-curves (FOCUS) code optimizes the currents and 3D geometry of multiple coils to maximize the total set’s resonant coupling. The optimized coils are individually distorted in space, creating toroidal “arrays” containing a variety of shapes that often wrap around a significant poloidal extent of the machine. The generalized perturbed equilibrium code (GPEC) is used to determine optimally efficient spectra for driving total, core, and edge neoclassical toroidal viscosity (NTV) torque and these too provide targets for the optimization of 3D coil designs. These conceptual designs represent a fundamentally new approach to 3D coil design for tokamaks targeting desired plasma physics phenomena. Optimized coil sets based on plasma response theory will be relevant to designs for future reactors or on any active machine. External coils, in particular, must be optimized for reliable and efficient fusion reactor designs.
GP11 113 Unlocking locked tearing-mode by applied rotating 3D field* M. OKABAYASHI, N. LOGAN, Z. WANG, Princeton Plasma Physics Laboratory, Z. TAYLOR, E. STRAIT, R. LA HAYE, General Atomics, J. HANSON, Columbia University, D. SHIRAKI, ORNL, S. INOUE, QST Tokamak reactors require control of locked tearing modes. Pre-emptive applications of a rotating 3D field controlled with (M. Okabayashi: IAEA2016) or without (D. Shiraki: APS/DPP13/P04.15) feedback have demonstrated promising pathways for recovering H-mode operation even in n=1 3D perturbed equilibria. Once a tearing mode becomes deeply locked with near-zero rotation across the radial profile, it is challenging to unlock before disruption. Preliminary observations suggest that the deeply locked state is a configuration with multiple instances of torque bifurcation and internal locking between multiple rational surfaces. Full rotation recovery was found in a narrow range of applied 3D field frequency or after one event of forced reconnection, reflecting the complex transient process of replacing the uncorrected error field with another 3D field. Initial comparison with a non-linear reduced MHD code (AEOLUS-IT) shows qualitative agreement.

*This work is supported in part by the US Department of Energy under DE-AC02-09CH11466, DE-FG02-99ER54531, DE- SC0003913, and DE-FC02-04ER54698.

GP11 114 Poloidal structure of the plasma response to n=2 perturbations* S. MUNARETTO, E.J. STRAIT, General Atomics S.R. HASKEY, N.C. LOGAN, PPPPL C. PAZ-SOLDAN, General Atomics A study of the plasma response to n=2 resonant magnetic perturbations (RMP) in DIII-D plasmas highlights the presence of two dominant modes, in good agreement with predictions from the MHD code MARS-Q. The use of RMPs offers potential benefits for nuclear fusion, for example ELM suppression or the correction of error fields, although their effect on the plasma needs to be better understood to predict how best to apply these fields. RMPs with n=2 and variable poloidal spectra are applied in plasma discharges with $q_{95} \sim 4.1$ and $\beta_N \sim 2.2$. Singular value decomposition (SVD) analysis was found to decouple the poloidal structure of the plasma response from the dependence on the spectrum of the perturbation applied. This analysis highlighted the presence of two modes, with the dominant mode peaking at the low-field-side midplane and the secondary one off-midplane, with indications of the latter being correlated with ELM suppression. The experimental observations are in good agreement with predictions of a dual-mode response from MARS-Q, improving prospects for projecting optimization of ELM control without triggering deleterious instabilities in future reactors.

*Work supported by the US Department of Energy under DE-FC02-04ER54698.

GP11 115 Demonstration of ECCD Stabilization of m/n=2/1 NTMs in the Equivalent Low-Torque ITER Baseline Scenario in DIII-D* ROBERT LA HAYE, EDWARD STRAIT, General Atomics KEJ OLOFSSON, None ANDERS WELANDER, General Atomics JEREMY HANSON, Columbia University OLIVIER SAUTER, SPC-EFPPL. Experiments in DIII-D are studying how best to minimize the average Electron Cyclotron Current Drive power directed at q=2 for stabilization of neoclassical tearing modes in discharges with the ITER shape and equivalent low-torque, low $q_{95}=3.1$ and low betaN=1.8. ITER relies on localized ECCD to stabilize NTMs that would otherwise wall-lock and lead to disruption. The work contrasts the control strategies of pre-emption by continuous ECCD at the rational surface (“Active Tracking”) vs. suppression by a pulse of ECCD whenever a growing mode is detected (“Catch & Subdue”). The large rho∼0.75 for q=2 and concomitant low Te make the EC current drive relatively weak per MW so that the EC power from 4~5 well-aligned gyrotrons of 2.5~2.8 MW, is just marginal for stabilization at about 70% of the neutral beam injection power. The low-torque makes early mode detection and good initial alignment imperative for prompt suppression before wall-locking. Requirements for stabilization will be presented.

*Work supported by the US DOE under DE-FC02-04ER54698.

GP11 116 Ideal kink and neoclassical tearing mode identification in DIII-D with ECC* HAILIN ZHAO, MAX AUSTIN, MICHALE BROOKMAN, WILLIAM ROWAN, University of Texas at Austin R.J. LA HAYE, General Atomics Detection of neoclassical tearing modes (NTMs), which can degrade plasma confinement or cause disruptions, is important in tokamaks. We have developed a code to cross-correlate ECE/magenticis data to get the amplitude and phase profiles of the electron temperature (Te) oscillation caused by the rotating magnetic island and/or a kink. It has been observed that the $\Delta$Te amplitude on the two sides of the island center can be very different in some discharges. Also, a discrepancy often exists between the location of the rational q surface according to MSE-constrained EFIT and the location of island center according to ECE; this can be an issue for ECD suppression of NTMs. We explore the possible causes of these two phenomena in terms of ECE location and calibration accuracy. By analyzing the Te fluctuation phase evolution after a large sawtooth crash which triggers an NTM, the presence of a kink-like mode before the onset of NTM can be discerned.

*Work supported by the US DOE under DE-FG02-97ER54415 and DE-FC02-04ER54698.

GP11 117 Plasma stability analysis using Consistent Automatic Kinetic Equilibrium reconstruction (CAKE)* MATTHIS ROELOFS, Technische Universiteit Eindhoven EGEMEN KOLEMEN, Princeton University, Princeton, New Jersey 08544 DAVID ELDON, General Atomics ALEX GLASSER, Princeton University, Princeton, New Jersey 08544 ORSO MENEGHINI, STERLING P. SMITH, General Atomics. Presented here is the Consistent Automatic Kinetic Equilibrium (CAKE) code. CAKE is being developed to perform real-time kinetic equilibrium reconstruction, aiming to do a reconstruction in less than 100ms. This is achieved by taking, next to real-time Motional Stark Effect (MSE) and magnetics data, real-time Thomson Scattering (TS) and real-time Charge Exchange Recombination (CER, still in development) data in to account. Electron densities and temperature are determined by TS, while ion density and pressures are determined using CER. These form, together with the temperature and density of neutrals, the additional pressure constraints. Extra current constraints are imposed in the core by the MSE diagnostics. The pedestal current density is estimated using Sauters equation for the bootstrap current density. By comparing the behaviour of the ideal MHD perturbed potential energy ($\delta W$) and the linear stability index ($\Delta \gamma$) of CAKE to magnetics-only reconstruction, it can be seen that the use of diagnostics to reconstruct the pedestal have a large effect on stability.

*Supported by U.S. DOE DE-SC0015878 and DE-FC02-04ER54698.

GP11 118 Detection of plasma stability on DIII-D, using the experimentally extracted plasma transfer function based on
Results and analysis of 3D MHD spectroscopy experiments will be presented. Though the method uses upper and lower internal coils to perform scans of frequency and poloidal mode spectrum, and measure the corresponding n=1 plasma response on 3D magnetic sensors. The transfer function is extracted, based on Padé approximation, by fitting the measured signals on different sensors simultaneously. The experimental transfer function not only points out the multi-mode plasma response but also shows the number of dominant modes and the contribution of each mode to the plasma response. The extracted damping rate of the least stable mode can be a new index indicating plasma stability quantitatively. This method has the potential to optimize ELM suppression and monitor the plasma stability in future fusion reactors. Results and analysis of 3D MHD spectroscopy experiments will be presented.

*Work supported under USDOE Cooperative Agreement DE-FC02-04ER54698, DE-AC02-09CH11466 and DE-FG02-04ER54761.

GP11 120 Development of the Pushered Single Shell Experimental Platform on NIF* JAY SALMONSON, EDUARD DEWALD, FRANK GRAZIANI, STEPHAN MACLAREN, JESSE PINO, JOSEPH RALPH, RYAN SACKS, VLADIMIR SMALYUK, ROBERT TIPTON, Lawrence Livermore National Laboratory The goal of the Pushered Single Shell (PSS) experimental campaign is to study mix of partially ionized ablator material into the hotspot. To do this we use a uniformly Si doped plastic capsule, the inner few microns of which can be doped with a few percent Ge. To diagnose mix, we use separated reactants [1]: deuterating the inner Ge-doped layer, CD/Ge, while putting Tritium into the Hydrogen capsule fill gas. Mix is then inferred by measuring the neutron yields from DD, DT, and TT reactions. In order to accentuate the cooling of the hot-spot due to Bremsstrahlung radiation when Ge is present, we require high hot-spot ion temperatures: ~3 keV. This, in turn, requires a fast, symmetric implosion. Using the Two-Shock campaign [2] as a starting point, we increased the capsule radius by ~25% to 844 μm and the peak laser power by over 10% to 475 TW. We also used a low, 0.3 mg/cc, He fill in the hohlraum to maintain control over implosion symmetry. This paper will describe the sequence of keyhole, 1DConA, 2DConA, and Syncap experiments we performed over the last year to tune the PSS implosions. We were successful in achieving our design goals; the PSS is the fastest CH capsule implosion in the laboratory, with peak velocity ~400 μm, a round hot-spot, with hotspot P2 = 0 within errors, and a hot-spot ion temperature ~3.5 keV.

This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344.


GP11 121 Rugby and elliptical-shaped hohlraums experiments on the OMEGA laser facility VERONIQUE TASSIN, MARIE-CHRISTINE MONTEIL, SYLVIE DEPIERREUX, PAUL-EDOUARD MASSON-LABORDE, FRANCK PHILIPPE, PATRICIA SEYTOR, PASCALE FREMEREY, BRUNO VILLETTE, CEA-DAM-DIF, F-91297 Arpajon, France We are pursuing on the OMEGA laser facility indirect drive implosions experiments in gas-filled rugby-shaped hohlraums in preparation for implosion plateforms on LMJ. The question of the precise wall shape of rugby hohlraum has been addressed as part of future megajoule-scale ignition designs [1]. Calculations show that elliptical-shaped hohlraum is more efficient than spherical-shaped hohlraum. There is less wall hydrodynamics and less absorption for the inner cone, provided a better control of time-dependent symmetry swings. In this context, we have conducted a series of experiments on the OMEGA laser facility. The goal of these experiments was therefore to characterize energetics with a complete set of laser-plasma interaction measurements and capsule implosion in gas-filled elliptical-shaped hohlraum with comparison with spherical-shaped hohlraum. Experiments results are discussed and compared to FCI2 radiation hydrodynamics simulations.


GP11 122 3D integrated HYDRA simulations of hohlraums including fill tubes* M. M. MARINAK, M. MILOVICH, B. A. HAMMEL, A. G. MACPHEE, V. A. SMALYUK, G. D. KERBEL, S. SEPKE, M. V. PATEL, Lawrence Livermore National Laboratory Measurements of fill tube perturbations from hydro growth radiography (HGR) experiments on the National Ignition Facility show spoke perturbations in the ablator radiating from the base of the tube [1]. These correspond to the shadow of the 10 μm diameter glass fill tube cast by hot spots at early time. We present 3D integrated HYDRA simulations of these experiments which include the fill tube. Meshing techniques are described which were employed to resolve the fill tube structure and associated perturbations in the simulations. We examine the extent to which the specific illumination geometry necessary to accommodate a backlighter in the HGR experiment contributes to the spoke pattern. Simulations presented include high resolution calculations run on the Trinity machine operated by the Alliance for Computing at Extreme Scale (ACES) partnership.

This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344.


GP11 124 Overcoming Challenges in Kinetic Modeling of Magnetized Plasmas and Vacuum Electronic Devices YURI OMELCHENKO, Triniton Research, Inc DONG-YEOP NA, FERNANDO TEIXEIRA, Ohio State University We transform the state-of-the-art of plasma modeling by taking advantage of novel computational techniques for fast and robust integration of multiscale hybrid (full particle ions, fluid electrons, no displacement current) and full-PIC models. These models are implemented in 3D HYPERS [1] and axisymmetric full-PIC CONPIC [2] codes. HYPERS is a massively parallel, asynchronous code. The HYPERS solver does not step fields and particles synchronously in time but instead executes local variable updates (events) at their self-adaptive rates while preserving fundamental conservation laws. The charge-conserving CONPIC code has a matrix-free explicit finite-element (FE) solver based on a sparse-approximate inverse (SPAI) algorithm. This explicit solver approximates the inverse FE system matrix ("mass" ma-
Numerical and experimental analysis of plasma generated on a solid target by a multi-MeV electron beam 

D’ALMEIDA, MAXIME RIBIERE, REMI MAISONNY, CEA We quantitatively investigate the interaction of a high energy, high flux electron beam with a solid target based on an approach that combines numerical and experimental characterization. The experimental study is carried out diagnosing the interaction of a multi-MeV electron beam, delivered by the CEA ASTERIX high-pulsed power driver, with an aluminum-tantalum target. The numerical analysis builds upon results from Particle-In-Cell simulations, to reproduce the electron beam dynamics and characteristics, and Monte-Carlo simulations, to simulate the interaction of the electron beam with the solid target. The main plasma features emerging from this analysis are analyzed using a 1D radiative transfer model which enabled the experimental spectra to be reproduced numerically with a good consistency. From the numerical integration of the 1D radiative transfer equation, plasma characteristics such as electron temperature and density profiles, as well as ion densities of constitutive species, are determined.

On the use of compatible discretizations with the multi-fluid plasma model 

SEAN MILLER, ERIC CYR, JOHN SHADID, EDWARD PHILLIPS, Sandia National Lab In this presentation, we discuss the advantages and disadvantages of using compatible discretizations in continuous and discontinuous finite element methods for solving the multi-fluid plasma model. Maxwell’s equations, core components to the multi-fluid plasma model, are difficult to accurately represent due to the divergence involutions governed by Gauss’ laws. Many methods have been developed to deal with these ‘divergence errors’, notably the generalized Lagrange multiplier methods discussed in Munz et al., 2000 and the vector basis discretization approach in Nedelec 1980. While the Lagrange multiplier cleaning schemes are effective and simple to implement, over long time scales the residual errors can have a large influence on the plasma. Compatible discretizations, such as those that represent the electric and magnetic fields on mixed Hcurl ‘edge’ elements and HDiv ‘face’ elements, have been shown to be especially useful in the PIC community, however, their implementation can be complex. The goal of this research is to understand the benefits of using some of these divergence handling schemes and compare them in application to finite element methods with both implicit and explicit time integration.

Efficient Implicit Plasma Simulation Using Quadrature Moment Inversion* 

DAVID LARSON, LLNL Quadrature moment inversion algorithms [1-3] are one route to reducing the computational effort required for fully implicit PIC plasma simulation. These algorithms compute a sparse quadrature representation of the velocity distribution from a set of velocity moments. A Jacobian-free Newton Krylov (JFNK) solver can then be used to concurrently solve Maxwell’s equations and the quadrature node equations of motion implicitly differenced in time using the midpoint rule [4], retaining the fully kinetic character of the overall system. The results of several test problems will be presented along with an exploration of routes to achieving convergence of the complete set of PIC particles and field equations.

This work was performed under the auspices of the U.S. DOE by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Reduction of collisional-radiative models for transient, atomic plasmas* 

RICHARD JUNE ABRANTES, ANNE KARAGOZIAN, Univ. of California - Los Angeles DAVID BILLEU, Air Force Research Laboratory HAI LE, Lawrence Livermore National Laboratory Interactions between plasmas and any radiation field, whether by lasers or plasma emissions, introduce many computational challenges. One of these computational challenges involves resolving the atomic physics, which can influence other physical phenomena in the radiated system. In this work, a collisional-radiative (CR) model with reduction capabilities is developed to capture the atomic physics at a reduced computational cost. Although the model is made with any element in mind, the model is currently supplemented by LANL’s argon database [1], which includes the relevant collisional and radiative processes for all of the ion stages. Using the detailed data set as the true solution, reduction mechanisms in the form of Boltzmann grouping [2], uniform grouping, and quasi-steady-state (QSS), are implemented to compare against the true solution. Effects on the transient plasma stemming from the grouping methods are compared. Distribution A: Approved for public release; unlimited distribution, PA (Public Affairs) Clearance Number 17449.

This work was supported by the Air Force Office of Scientific Research (AFOSR), Grant Number 17RQCOR463 (Dr. Jason Marshall).


A fully implicit, conservative, hybrid kinetic-ion fluid-electron algorithm 

ADAM STANIER, LUIS CHACÓN, GUANGYE CHEN, Los Alamos Natl Lab The hybrid model with full-orbit kinetic ions and fluid electrons is a promising approach to describe a wide range of space and laboratory plasmas [1]. Explicit hybrid algorithms typically use a predictor-corrector method with sub-cycling or a semi-implicit field solve to deal with the strict Whistler-wave CFL condition. However, these do not conserve momentum or energy, and are susceptible to numerical instability. While fully implicit methods have been recently explored [2,3] to step over such timescales in a stable manner, these studies have not considered conservation properties. Here, we present a novel particle-based non-linear hybrid algorithm that features discrete conservation of mass, momentum, energy and the solenoidal condition of the magnetic field. The scheme combines fully implicit time advance with orbit-averaging of the ion particles and the flexibility of conservative smoothing to reduce numerical noise. We verify the algorithm for a number of test problems and demonstrate the unique conservation properties.

Hamiltonian. That is derived from the second-order gyrocenter ponderomotive contains a second-order contribution to the gyrocenter current density. Here, the gyrocenter parallel-Ampère equation contains contributions from the perturbed magnetic field. We provide a metriplectic temporal and velocity-space discretization for the particle phase-space Landau collision integral that satisfies the conservation of energy, momentum, and particle densities to machine precision, as well as guarantees the existence of numerical H-theorem. The properties are demonstrated algebraically. These two result have important implications: 1) Numerical methods addressing the Vlasov-Maxwell-Landau system of equations, or its reduced gyrokinetic versions, should start from a metriplectic formulation to preserve the fundamental physical principles also at the discrete level. 2) The plasma physics community should search for a metriplectic reduction theory that would serve a similar purpose as the existing Lagrangian and Hamiltonian reduction theories do in gyrokinetics. The discovery of metriplectic formulation of collisional electrostatic gyrokinetics is strong evidence in favor of such theory and, if uncovered, the theory would be invaluable in constructing reduced plasma models.

*Supported by U.S. DOE Contract Nos. DE-AC02-09-CH11466 (EH) and DE-AC05-06OR23100 (JWB) and by European Union’s Horizon 2020 research and innovation Grant No. 708124 (MK).

GP11 131 Variational principle for the parallel-symplectic representation of electromagnetic gyrokinetic theory* ALAIN BRIZARD, Saint Michael College The nonlinear (full-f) electromagnetic gyrokinetic Vlasov-Maxwell equations are derived in the parallel-symplectic representation from an Eulerian gyrokinetic variational principle. The gyrokinetic Vlasov-Maxwell equations are shown to possess an exact energy conservation law, which is derived by Noether method from the gyrokinetic variational principle. Here, the gyrocenter Poisson bracket and the gyrocenter Jacobian contain contributions from the perturbed magnetic field. In the full-f formulation of the gyrokinetic Vlasov-Maxwell theory presented here, the gyrocenter parallel-Ampère equation contains a second-order contribution to the gyrocenter current density that is derived from the second-order gyrocenter ponderomotive Hamiltonian.

*Work supported by U.S. DoE.

GP11 132 A domain-decomposed multi-model plasma simulation of collisionless magnetic reconnection* I. A. M. DATTA, U. SHUMLAK, A. HO, S. T. MILLER, Univ of Washington Collisionless magnetic reconnection is a process relevant to many areas of plasma physics in which energy stored in magnetic fields within highly conductive plasmas is rapidly converted into kinetic and thermal energy. Both in natural phenomena such as solar flares and terrestrial aurora as well as in magnetic confinement fusion experiments, the reconnection process is observed on timescales much shorter than those predicted by a resistive MHD model. As a result, this topic is an active area of research in which plasma models with varying fidelity have been tested in order to understand the proper physics explaining the reconnection process. In this research, a hybrid multi-model simulation employing the Hall-MHD and two-fluid plasma models on a decomposed domain is used to study this problem. The simulation is set up using the WARPXM code developed at the University of Washington, which uses a discontinuous Galerkin Runge-Kutta finite element algorithm and implements boundary conditions between models in the domain to couple their variable sets. The goal of the current work is to determine the parameter regimes most appropriate for each model to maintain sufficient physical fidelity over the whole domain while minimizing computational expense.

*This work is supported by a Grant from US AFOSR.

GP11 133 Hybrid plasma model simulations of a plasma opening switch* ANDREW HO, U. SHUMLAK, I. A. M. DATTA, University of Washington Plasma models have regimes of validity that depend on local parameters. In some problems a computationally expensive model is required in a small subset of the domain while faster reduced models can adequately describe the plasma behavior everywhere else. Partitioning the domain and using the simplest plasma model that is locally valid can maintain global physical fidelity while improving computational efficiency. Coupling between the models is handled using boundary conditions to convert the variable set of one constituent model to that of another. This research investigates the coupling between MHD and two-fluid plasma models using a physics-based domain-decomposition. Comparisons are made on accuracy and performance of using a hybrid plasma model with a single conventional plasma model on the planar plasma opening switch. The setup consists of a low density background and a high density bulk plasma with a large density gradient, leading to drift instabilities which are not captured by MHD models. However, elsewhere MHD models provide sufficient accuracy. Collisional transport and non-ideal MHD effects are also investigated to determine which parameter regimes require these processes in order to gain physical fidelity.

*This research was supported by a Grant from the United States Air Force Office of Scientific Research.

GP11 134 Numerical and analytical studies of the validity of the guiding-center approximation* PATRIK OLLUS, KONSTA SARKIMAKI, Aalto University ALAIN BRIZARD, Saint Michael College Numerical studies of the validity of the guiding-center approximation are performed with the code ASCOT [1] through a careful analysis of the full-orbit and guiding-center-orbit trajectories of nonrelativistic and relativistic charged particles moving in axisymmetric and nonaxisymmetric magnetic-field geometries. The validity of the guiding-center approximation is also investigated through the exact analytical solution for the motion of a charged particle in a straight nonuniform magnetic field with a constant field gradient [2].

*Work partially funded by the Academy of Finland project No. 298126 (PO and KS) and the U.S. DoE (AJB).


GP11 135 The UPSF code: a metaprogramming-based high-performance automatically parallelized plasma simulation framework XIATIAN GAO, XIAOGANG WANG, BINHAO JIANG, Harbin Institute of Technology UPSF (Universal Plasma Simulation Framework) is a new plasma simulation code designed for maximum flexibility by using edge-cutting techniques supported
by C++17 standard. Through use of metaprogramming technique, UPSF provides arbitrary dimensional data structures and methods to support various kinds of plasma simulation models, like, Vlasov particle in cell (PIC), fluid, Fokker-Planck, and their variants and hybrid methods. Through C++ metaprogramming technique, a single code can be used to arbitrary dimensional systems with no loss of performance. UPSF can also automatically parallelize the distributed data structure and accelerate matrix and tensor operations by BLAS. A three-dimensional particle in cell code is developed based on UPSF. Two test cases, Landau damping and Weibel instability for electrostatic and electromagnetic situation respectively, are presented to show the validation and performance of the UPSF code.

**GP11 136** Exact collisional moments for plasma fluid theories DAVID PFEFFERLE, EERO HIRVIJOKI, PPPI, MANASVI LINGAM, Harvard John A. Paulson School of Engineering and Applied Sciences, Harvard University The velocity-space moments of the often troublesome nonlinear Landau collision operator are expressed exactly in terms of multi-index Hermite-polynomial moments of the distribution functions. The collisional moments are shown to be generated by derivatives of two well-known functions, namely the Rosenbluth-MacDonald-Judd-Trubnikov potentials for a Gaussian distribution. The resulting formula has a nonlinear dependency on the relative mean flow of the colliding species normalised to the root-mean-square of the corresponding thermal velocities, and a bilinear dependency on densities and higher-order velocity moments of the distribution functions, with no restriction on temperature, flow or mass ratio of the species. The result can be applied to both the classic transport theory of plasmas, that relies on the Chapman-Enskog method, as well as to deriving collisional fluid equations that follow Grad’s moment approach. As an illustrative example, we provide the collisional ten-moment equations with exact conservation laws for momentum- and energy-transfer rate.

**GP11 137** Finding the crossover from phase mixing to collisions with an integral transform J. M. HENINGER, P. J. MORRISON, University of Texas at Austin The one-dimensional linearized Vlasov-Poisson system can be exactly solved using the “G transform” [1], an integral transform based on the Hilbert transform. This transform removes the electric field, leaving a simple advection equation. We investigate how this integral transform interacts with the Fokker-Planck collision operator. The commutator of this collision operator with the G transform (the “shielding term”) is shown to be negligible. We exactly solve the advection-diffusion equation without the shielding term. This solution determines when collisions dominate and when advection (i.e. Landau damping) dominates. Introducing an energy source term that balances the energy lost to dissipation allows for the creation of a steady state distribution function that transfers energy from larger to smaller velocity scales via Landau damping. Unlike the Kolmogorov cascade, this is an energy cascade that occurs completely in velocity space: there is no nonlinearity and the spatial dependence is trivial. We hope that G transform will be used to simplify gyrokinetic codes or other kinetic models.

**GP11 138** Implementation of parallel moment equations in NIMROD HANKYU Q. LEE, ERIC D. HELD, JEONG-YOUNG JI, Utah State University As collisionality is low (the Knudsen number is large) in many plasma applications, kinetic effects become important, particularly in parallel dynamics for magnetized plasmas. Fluid models can capture some kinetic effects when integral parallel closures are adopted. The adiabatic and linear approximations are used in solving general moment equations [1] to obtain the integral closures. In this work, we present an effort to incorporate non-adiabatic (time-dependent) and nonlinear effects into parallel closures. Instead of analytically solving the approximate moment system, we implement exact parallel moment equations in the NIMROD fluid code. The moment code is expected to provide a natural convergence scheme by increasing the number of moments.

*Work in collaboration with the PSI Center and supported by the U.S. DOE under Grant Nos. DE-SC0014033, DE-SC0016256, and DE-FG02-04ER54746.


**GP11 139** Generalized approach to variational and Hamiltonian kinetic-Maxwell plasma theory CESARE TRONCI, ALEXANDER CLOSE, University of Surrey Hamiltonian and variational techniques have proved particularly helpful for constructing new kinetic and hybrid plasma models. Here, we present a geometric construction that relates these approaches for a generalized kinetic-Maxwell theory, producing Lagrangian and Eulerian variants. We then present a particular specialization, in which the well-known Maxwell-Vlasov theory is shown to emerge under appropriate choices of symplectic form and energy function.

**GP11 140** Hybrid drift-kinetic pressure coupling scheme from a variational principle ALEXANDER CLOSE, CESARE TRONCI, University of Surrey A hybrid-kinetic pressure coupling scheme (PCS) model is presented in the low-gyrofrequency approximation. This fully energy-conserving model is derived from variations of a Lagrangian over a semidirect product manifold, and produces important terms in the Vlasov equation that correct models previously appearing in the literature.

**GP11 141** Beatification: Flattening Poisson brackets for plasma theory and computation P. J. MORRISON, IFS Univ of Texas, Austin T. F. VISCONDI, I. CALDAS, Institute of Physics, University of São Paulo, São Paulo, Brazil A perturbative method called beatification [1] is presented for producing nonlinear Hamiltonian fluid and plasma theories. Plasma Hamiltonian theories, fluid and kinetic, are naturally described in terms of noncanonical variables. The beatification procedure amounts to finding a transformation that removes the explicit variable dependence from a noncanonical Poisson bracket and replaces it with a fixed dependence on a chosen state in the phase space. As such, beatification is a major step toward casting the Hamiltonian system in its canonical form, thus enabling or facilitating the use of analytical and numerical techniques that require or favor a representation in terms of canonical, or beatified, Hamiltonian variables. Examples will be given.

*U.S. D.O.E No. #DE-FG02-04ER54742.


**GP11 142** Nonlinear saturation of the ITG instability with fully kinetic ions MATTHEW MIECNIKOWSKI, Dept. of Physics, Univ. of Colorado, Boulder BENJAMIN STURDEVANT, Princeton Plasma Physics Laboratory YANG CHEN, SCOTT PARKER, Dept. of Physics, Univ. of Colorado, Boulder We study the growth and saturation of the ion-temperature-gradient (ITG) instability in simulations with fully kinetic ions and adiabatic electrons. The ion
trajectories are integrated using the full Lorentz force, fully resolving the cyclotron motion and capturing the corresponding finite Larmor radius effects. In slab geometry, the linear growth and nonlinear saturation characteristics show good agreement with analogous gyrokinetic simulations across a wide range of parameters, and the fully kinetic simulation correctly reproduces the nonlinearly generated zonal flow. We discuss our progress on the extension of this model to toroidal geometry to study more realistic turbulence. This work represents an important step towards the extension of kinetic modeling of plasma turbulence to regimes where the gyrokinetic ordering is violated or the gyrokinetic equations are questioned.

GP11 143 Stabilization approach for an explicit hybrid particle-in-cell method for bridging multiple time-scales RINAT KHAZIEV, SHANE KENILEY, DAVIDE CURRELL, Univ of Illinois - Urbana Fully-kinetic Particle-in-Cell (PIC) simulations of magnetized plasma sheaths including electrons, plasma ions, and heavy material impurities remain a big challenge because of the large discrepancy between the mass of the light species and that of the heavy species. The time-scales required for such simulations span over multiple orders of magnitude, from picoseconds for the electron dynamics, to microseconds for heavy-ion transport across the sheath. In this work, we analyze a numerical approach applicable to explicit PIC schemes that iterates between a fully-kinetic representation of the electrons and a reduced electron model; the method allows to capture fully-kinetic effects at time scales relevant to heavy-ion transport. A frequency analysis of the approach reveals the strategy required for stable operation of the method and prevent unstable drift-like behavior in the phase space. The method has been applied to plasma sheath simulations with oblique magnetic fields. In order to highlight the benefits of the method, the moments of the distribution function are compared to both long-time fully-kinetic PIC simulations, and to PIC simulations with only a reduced electron model. Finally, comparisons with a continuum Boltzmann-Poisson code solving the same problem are reported.

GP11 144 Open-source Framework for Storing and Manipulation of Plasma Chemical Reaction Data T. G. JENKINS, S. N. AVERKIN, J. R. CARY, S. E. KRUGER, Tech-X Corporation We present a new open-source framework for storage and manipulation of plasma chemical reaction data that has emerged from our in-house project MUNCHKIN. This framework consists of python scripts and C++ programs. It stores data in an SQL data base for fast retrieval and manipulation. For example, it is possible to fit cross-section data into most widely used analytical expressions, calculate reaction rates for Maxwellian distribution functions of colliding particles, and fit them into different analytical expressions. Another important feature of this framework is the ability to calculate transport properties based on the cross-section data and supplied distribution functions. In addition, this framework allows the export of chemical reaction descriptions in LaTeX format for ease of inclusion in scientific papers. With the help of this framework it is possible to generate corresponding VSim (Particle-In-Cell simulation code) and USim (unstructured multi-fluid code) input blocks with appropriate cross-sections.

GP11 145 A One-Step Variational Guiding Center Integrator using Toroidal Regularization∗ C. LEELAND ELLISON, Lawrence Livermore National Laboratory, Livermore, CA 94550 JOSHUA BURBY, Courant Institute of Mathematical Sciences, New York, NY 10012 Guiding center and gyro-center particle advances — central to test particle, drift-kinetic, and gyro-kinetic simulations — stand to benefit from symplectic integration techniques, which have had a profound impact in other physics disciplines. The non-canonical Hamiltonian formulation of these systems has kept such symplectic integration thus far elusive, except for in restricted magnetic geometries or by using computationally expensive transformations to canonical coordinates. In this work, we perform a near-identity Lie transformation to the guiding center coordinates to obtain a “toroidally regularized” Lagrangian for which symplectic integration can be more readily achieved. This transformation also eliminates the effective magnetic field appearing in the denominator of the guiding center equations and correspondingly eliminates the large parallel velocity singularities from the equations. The recently developed technique of degenerate variational integration is then applied to the regularized Lagrangian to obtain a one-step variational integrator valid for any magnetic geometry with non-zero toroidal magnetic field.

∗This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Release number: LLNL-ABS-734791.

GP11 146 A PICKSC Science Gateway for enabling the common plasma physicist to run kinetic software Q. HU, B. J. WINJUM, UCLA A. ZONCA, C. YOUN, SDSC F. S. TSUNG, W. B. MORI, UCLA Computer simulations offer tremendous opportunities for studying plasmas, ranging from simulations for students that illuminate fundamental educational concepts to research-level simulations that advance scientific knowledge. Nevertheless, there is a significant hurdle to using simulation tools. Users must navigate codes and software libraries, determine how to wrangle output into meaningful plots, and oftentimes confront a significant cyberinfrastructure with powerful computational resources. Science gateways offer a Web-based environment to run simulations without needing to learn or manage the underlying software and computing cyberinfrastructure. We discuss our progress on creating a Science Gateway for the Particle-in-Cell and Kinetic Simulation Software Center that enables users to easily run and analyze kinetic simulations with our software. We envision that this technology could benefit a wide range of plasma physicists, both in the use of our simulation tools as well as in its adaptation for running other plasma simulation software.

∗Supported by NSF under Grant ACI-1339893 and by the UCLA Institute for Digital Research and Education.

GP11 147 The Particle-in-Cell and Kinetic Simulation Software Center∗ W. B. MORI, V. K. DECYK, A. TABLEMAN, UCLA R. A. FONSECA, IST F. S. TSUNG, Q. HU, B. J. WINJUM, W. AN, T. N. DALICHAOUCH, A. DAVIDSON, L. HILDEBRAND, A. JOGLEKAR, J. MAY, K. MILLER, M. TOUATI, X. L. XU, UCLA The UCLA Particle-in-Cell and Kinetic Simulation Software Center (PICKSC) aims to support an international community of PIC and plasma kinetic software developers, users, and educators; to increase the use of this software for accelerating the rate of scientific discovery; and to be a repository of knowledge and history for PIC. We discuss progress towards making available and documenting illustrative open-source software programs and distinct production programs; developing and comparing different PIC algorithms; coordinating the development of resources for the educational use of kinetic software; and the outcomes of our first sponsored OSIRIS users workshop. We also welcome input and discussion from anyone interested in using or developing kinetic software, in obtaining access to our codes, in collaborating, in sharing their own soft-

∗Supported by NSF under Grant ACI-1339893 and by the UCLA Institute for Digital Research and Education.


GP11 148 PlasmaPy: initial development of a Python package for plasma physics∗ NICHOLAS MURPHY, Harvard-Smithsonian Center for Astrophysics ANDREW LEONARD, University of Sheffield YI-MIN HUANG, Princeton Plasma Physics Laboratory COLBY HAGGERTY, University of Delaware
PLASMAPY COLLABORATION We report on initial development of PlasmaPy: an open source community-driven Python package for plasma physics [1]. PlasmaPy seeks to provide core functionality that is needed for the formation of a fully open source Python ecosystem for plasma physics. PlasmaPy prioritizes code readability, consistency, and maintainability while using best practices for scientific computing such as version control, continuous integration testing, embedding documentation in code, and code review. We discuss our current and planned capabilities, including features presently under development. The development roadmap includes features such as fluid and particle simulation capabilities, a Grad-Shafranov solver, a dispersion relation solver, atomic data retrieval methods, and tools to analyze simulations and experiments.
We describe several ways to contribute to PlasmaPy. PlasmaPy has a code of conduct and is being developed under a BSD license, with a version 0.1 release planned for 2018. The success of PlasmaPy depends on active community involvement, so anyone interested in contributing to this project should contact the authors.

∗This work was partially supported by the U.S. Department of Energy.

†The code repository is at https://github.com/PlasmaPy/PlasmaPy.

GP11 149 Exact Energy and Momentum Conservation in Variational Macro-Particle Plasma Models B. A. SHADWICK, TIMOTHY KAWAMOTO, M. PERIN, Department of Physics and Astronomy, University of Nebraska-Lincoln We consider a class of variational macro-particle plasma models that exhibit simultaneous conservation of energy and momentum. These models retain translation invariance by using a Fourier representation of the electromagnetic fields in place of a spatial grid. That is, the Fourier amplitudes of the fields are the fundamental quantities. From the discrete Lagrangian, a canonical Hamiltonian system is obtained in the usual way, for which we introduce a symplectic integrator. We present a general formulation of the method with examples drawn from 1-1/2D studies of intense laser-plasma interactions. We comment on the relative merits of the Lagrangian vs. Hamiltonian formulations and discuss efficiency and practicality of using this technique in three dimensions.

∗Supported by the National Science Foundation under Contract No. PHY-1104683.

GP11 150 A Computational Model for Predicting Gas Breakdown∗ ZACHARY GILL, Missouri Univ of Sci & Tech
Pulsed-inductive discharges are a common method of producing a plasma. They provide a mechanism for quickly and efficiently generating a large volume of plasma for rapid use and are seen in applications including propulsion, fusion power, and high-power lasers. However, some common designs see a delayed response time due to the plasma forming when the magnitude of the magnetic field in the thruster is at a minimum. New designs are difficult to evaluate due to the amount of time needed to construct a new geometry and the high monetary cost of changing the power generation circuit. To more quickly evaluate new designs and better understand the shortcomings of existing designs, a computational model is developed. This model uses a modified single-electron model as the basis for a Mathematica code to determine how the energy distribution in a system changes with regards to time and location. By analyzing this energy distribution, the approximate time and location of initial plasma breakdown can be predicted. The results from this code are then compared to existing data to show its validity and shortcomings.

∗Supported by NSF under Grant ACI-1339893 and by the UCLA Institute for Digital Research and Education.

GP11 151 GPU Acceleration of Particle-In-Cell Methods∗ BENJAMIN COWAN, SERGEY AVERKIN, Tech-X Corporation JOHN CARY, Tech-X Corporation and University of Colorado JARROD LEDDY, SCOTT SIDES, Tech-X Corporation GREGORY WERNER, University of Colorado Graphics processing units (GPUs) have become key components in many supercomputing systems, as they can provide more computations relative to their cost and power consumption than conventional processors. However, to take full advantage of this capability, they require a strict programming model which involves single-instruction multiple-data execution as well as significant constraints on memory access. To bring the full power of GPUs to bear on plasma physics problems, we must adapt the computational methods to this new programming model. We have developed a GPU implementation of the particle-in-cell (PIC) method, one of the mainstays of plasma physics simulation. This framework is highly general and enables advanced PIC features such as high order particles and absorbing boundary conditions. The main elements of the PIC loop, including field interpolation and particle deposition, are designed to optimize memory access. We describe recent progress in these algorithms, including arbitrary grid types and multiple GPUs per node.

∗Supported by DARPA Contract No. W31P4Q-16-C-0009.

GP11 152 Recent Performance Results of VPIC on Trinity∗ W. D. NYSTROM, B. BERGEN, R. F. BIRD, Los Alamos National Laboratory K. J. BOWERS, None W. S. DAUGHTON, F. GUO, A. LE, H. LI, H. NAM, X. PANG, D. J. STARK, W. N. RUST III, L. YIN, B. J. ALBRIGHT, Los Alamos National Laboratory Trinity is a new DOE computer resource now in production at Los Alamos National Laboratory. Trinity has several new and unique features including two compute partitions, one with dual socket Intel Haswell Xeon compute nodes and one with Intel Knights Landing (KNL) Xeon Phi compute nodes, use of on package high bandwidth memory (HBM) for KNL nodes, ability to configure KNL nodes with respect to HBM model and on die network topology in a variety of operational modes at run time, and use of solid state storage via burst buffer technology to reduce time required to perform I/O. An effort is in progress to optimize VPIC [1] on Trinity by taking advantage of these new architectural features. Results of work will be presented on performance of VPIC on Haswell and KNL partitions for single node runs and runs at scale. Results include use of burst buffers at scale to optimize I/O, comparison of strategies for using MPI and threads, performance benefits using HBM and effectiveness of using intrinsics for vectorization.

∗Work performed under auspices of U.S. Dept. of Energy by Los Alamos National Security, LLC Los Alamos National Laboratory under contract DE-AC52-06NA25396 and supported by LANL LDRD program.
GP11 153 A three-dimensional particle-in-cell simulation of the diocotron instability for cylindrical geometry YOUNG HYUN JO, VLADIMIR V. MIKHAILENKO, VLADIMIR S. MIKHAILENKO, HAE JUNE LEE, Pusan National University

In a non-neutral plasma like an electron beam under a magnetic field, the diocotron instability can occur with a shear in the flow velocity of surface waves, which is a type of Kelvin-Helmholtz instability in principle. Recently, there has been advanced theories that explain the evolution of the diocotron instability using non-modal analysis considering shearing modes. In a previous study, a two-dimensional particle-in-cell simulation was performed for verification of the theory with an initially loaded cylindrical annular plasma column surrounded by a conducting boundary. The growth rates of the diocotron instability measured in the simulation agree well with the theory. As an extension of the previous work, we have extended the model to a three-dimensional cylindrical particle-in-cell simulation and compared the results with those of the two-dimensional simulation. In addition, the effect of the particle flows in the axial direction has been investigated.

GP11 154 An Approach to Radiation Hydrodynamics Within a Generalized Continuum Mixture Theory JIM REYNOLDS, GABRIELLE MILLER, MELVIN BAER, SHANE SCHUMACHER, Sandia National Laboratories

Mixed material cells have long posed challenges for radiation hydrodynamic treatments in multi-physics codes. Baer and Nunziato [1] developed a two-phase mixture formulation which is recently expanded by Baer and Schumacher to a generalized model. We present an extension to this generalized continuum mixture theory by this model incorporating energy-based gray radiation diffusion in a multi-component fluid. The extended model is presented along with a numerical approach including verification examples.

GP11 155 KEEN Wave Simulations: Comparing various PIC to various fixed grid Vlasov to Phase-Space Adaptive Sparse Tiling & Effective Lagrangian (PASTEL) Techniques* BEDROS AFEYAN, Polymath Research Inc. DAVID LARSON, Lawrence Livermore National Laboratory BRADLEY SHADWICK, University of Nebraska-Lincoln RICHARD SYDORA, University of Alberta

We compare various ways of solving the Vlasov-Poisson and Vlasov-Maxwell equations on rather demanding nonlinear kinetic phenomena associated with KEEN and KEEPN waves. KEEN stands for Kinetic, Electrostatic, Electron Nonlinear, and KEEPN, for electron-positron or pair plasmas analogs. Because these self-organized phase space structures are not steady-state, or single mode, or fluid or low order moment equation limited, typical techniques with low resolution or too much noise will distort the answer too much, too soon, and fail. This will be shown via Penrose criteria triggers for instability at the formation stage as well as particle orbit statistics in fully formed KEEN waves and KEEN-KEEN and KEEN-EPW interacting states. We will argue that PASTEL is a viable alternative to traditional methods with reasonable chances of success in higher dimensions.

*Work supported by a Grant from AFOSR PEEP.

GP11 156 Code Modernization of VPIC* ROBERT BIRD, DAVID NYSTROM, BRIAN ALBRIGHT, Los Alamos National Laboratory

The ability of scientific simulations to effectively deliver performant computation is increasingly being challenged by successive generations of high-performance computing architectures. Code development to support efficient computation on these modern architectures is both expensive, and highly complex; if it is approached without due care, it may also not be directly transferable between subsequent hardware generations. Previous works have discussed techniques to support the process of adapting a legacy code for modern hardware generations, but despite the breakthroughs in the areas of mini-app development, portable-performance, and cache oblivious algorithms the problem still remains largely unsolved. In this work we demonstrate how a focus on platform agnostic modern code-development can be applied to Particle-in-Cell (PIC) simulations to facilitate effective scientific delivery. This work builds directly on our previous work optimizing VPIC, in which we replaced intrinsic based vectorisation with compile generated auto-vectorization to improve the performance and portability of VPIC. In this work we present the use of a specialized SIMD queue for processing some particle operations, and also preview a GPU capable OpenMP variant of VPIC. Finally we include a lessons learnt.

*Work performed under the auspices of the U.S. Dept. of Energy by the Los Alamos National Security, LLC Los Alamos National Laboratory under contract DE-AC52-06NA25396 and supported by the LANL LDRD program.
Machine learning is the science of using computers to find relationships in data without explicitly knowing or programming those relationships in advance. Often without realizing it, we employ machine learning every day as we use our phones or drive our cars. Over the last few years, machine learning has found increasingly broad application in the physical sciences. This most often involves building a model relationship between a dependent, measurable output and an associated set of controllable, but complicated, independent inputs. The methods are applicable both to experimental observations and to databases of simulated output from large, detailed numerical simulations. In this tutorial, we will present an overview of current tools and techniques in machine learning – a jumping-off point for researchers interested in using machine learning to advance their work. We will discuss supervised learning techniques for modeling complicated functions, beginning with familiar regression schemes, then advancing to more sophisticated decision trees, modern neural networks, and deep learning methods. Next, we will cover unsupervised learning and techniques for reducing the dimensionality of input spaces and for clustering data. We’ll show example applications from both magnetic and inertial confinement fusion. Along the way, we will describe methods for practitioners to help ensure that their models generalize from their training data to as-yet-unseen test data. We will finally point out some limitations to modern machine learning and speculate on some ways that practitioners from the physical sciences may be particularly suited to help.

*This work was performed by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

---

**SESSION JI3: ROTATION AND FLOWS**

**Tuesday Afternoon, 24 October 2017; Room: 103ABC at 14:00; Alessandro Bortolon, Princeton Plasma Physics Laboratory, presiding**

**Invited Papers**

14:00

**JI3 1 Validation of Kinetic-Turbulent-Neoclassical Theory for Edge Intrinsic Rotation in DIII-D Plasmas**

ARASH ASHOURVAN, Princeton Plasma Physics Laboratory

Recent experiments on DIII-D with low-torque neutral beam injection (NBI) have provided a validation of a new model of momentum generation in a wide range of conditions spanning L- and H-mode with direct ion and electron heating. A challenge in predicting the bulk rotation profile for ITER has been to capture the physics of momentum transport near the separatrix and steep gradient region. A recent theory has presented a model for edge momentum transport which predicts the value and direction of the main-ion intrinsic velocity at the pedestal-top, generated by the passing orbits in the inhomogeneous turbulent field [1]. In this study, this model-predicted velocity is tested on DIII-D for a database of 44 low-torque NBI discharges comprised of both L- and H-mode plasmas. For moderate NBI powers ($P_{NBI} \approx 4$ MW), model prediction agrees well with the experiments for both L- and H-mode. At higher NBI power the experimental rotation is observed to saturate and even degrade compared to theory. TRANSP-NUBEAM simulations performed for the database show that for discharges with nominally balanced - but high powered - NBI, the net injected torque through the edge can exceed 1 N.m in the counter-current direction. The theory model has been extended to compute the rotation degradation from this counter-current NBI torque by solving a reduced momentum evolution equation for the edge and found the revised velocity prediction to be in agreement with experiment. Projecting to the ITER baseline scenario, this model predicts a value for the pedestal-top rotation ($\sim 0.9$) comparable to 4 kRad/s. Using the theory modeled - and now tested - velocity to predict the bulk plasma rotation opens up a path to more confidently projecting the confinement and stability in ITER.

*Supported by the US DOE under DE-AC02-09CH11466 and DE-FC02-04ER54698.


14:30

**JI3 2 Characterization of the core poloidal flow at ASDEX Upgrade**

ALEXANDER LEBSCHY, Max-Planck-Institut für Plasmaphysik

An essential result from neoclassical (NC) theory is that the fluid poloidal rotation ($u_{pol}$) of the main ions is strongly damped by magnetic pumping and, therefore, expected to be small ($< 2$ km/s). Despite many previous investigations, the nature of the core $u_{pol}$ remains an open question: studies at DIII-D show that at low collisionalities, $u_{pol}$ is significantly higher in the plasma core than expected. At higher collisionalities, however, a rather good agreement between experiment and theory has been found at both DIII-D and TCV. This is qualitatively consistent with the edge results from both Alcator C-Mod and ASDEX Upgrade (AUG). At AUG thanks to an upgrade of the core charge exchange recombination spectroscopy (CXRS) diagnostics, the core $u_{pol}$ can be evaluated through the inboard-outboard asymmetry of the toroidal rotation with an accuracy of 0.5-1 km/s. This measurement also provides the missing ingredient to evaluate the core ($E \times B$) velocity ($u_{E \times B}$) via the radial force balance equation. At AUG the core $u_{pol}$ ($0.35 < \rho_{tor} < 0.65$) is found to be ion-diamagnetic directed in contradiction to NC predictions. However, the edge rotation is always found to be electron-directed and in good quantitative agreement with NC codes. Additionally, the intrinsic rotation has been measured in Ohmic L-mode plasmas. From the observed data, it is clear that the gradient of the toroidal rotation is flat to slightly negative at the
critical density defining the transition from the linear to the saturated Ohmic confinement regime. Furthermore, the non-neoclassical \( u_{\text{pol}} \) observed in these plasma leads to a good agreement between the \( u_{\text{pol}} \) determined from CXRS and the perpendicular velocity measured from turbulence propagation. The difference between these two quantities is the turbulent phase velocity. The gathered dataset indicates that the transition in the turbulence regime occurs after the saturation of the energy confinement time.

\*The author thankfully acknowledges the financial support from the Helmholtz Association of German Research Centers through the Helmholtz Young Investigators Group program.

15:00

JI3 3 Measurements and modeling of viscosity in a stochastic magnetic field*

RICHARD FRIDSTROM, KTH Royal Institute of Technology

Controlled perturbation of the momentum in MST RFP plasmas has allowed the first comprehensive test of a theoretical model [1], originally derived for the tokamak, for rotation damping in a stochastic plasma. Both a resonant magnetic perturbation (RMP) and an inserted biased probe were applied, separately, to a wide variety of spontaneously rotating Ohmic plasmas with a 10-fold span in normalized magnetic fluctuation amplitude, \( b/B \). These control techniques provide measurements of the perpendicular kinematic viscosity, which is found to increase as \( (b/B)^2 \) and which agrees well with predictions from the model. The dominant magnetic fluctuations in MST are linearly unstable \( m=1 \) tearing modes resonant at multiple locations in the core. The islands associated with these modes commonly overlap, producing stochasticity. The applied RMP also has \( m=1 \), causing deceleration of the co-rotating core plasma and \( m=1 \) modes. The biased probe initially spins up the core, but when bias is turned off, the core decelerates. The viscosity is derived from the deceleration curves in both cases and reaches 50 m²/s, roughly 100 times the classical prediction in the absence of stochasticity. Applying both techniques to the same plasma conditions provides a valuable cross check. The theoretical model, targeting the tokamak edge with an applied magnetic perturbation, is based on stochastic field line diffusion, which increases as \( (b/B)^2 \) [2]. Rotation damping in the Finn model occurs as the local radial electric field is shorted out, and this damping can be characterized by an effective perpendicular viscosity. The results described here are relevant to any magnetically confined plasma, such as the tokamak and RFP, where rotation is important, and magnetic stochasticity is either intrinsic or externally imposed.

\*Work supported by USDoE.


2Rosenbluth et al., Nucl. Fusion (1966).

15:30

JI3 4 Parasitic momentum flux in the tokamak core*

T. STOLTZFUS-DUECK, Princeton University

Tokamak plasmas rotate spontaneously without applied torque. This intrinsic rotation is important for future low-torque devices such as ITER, since rotation stabilizes certain instabilities. In the mid-radius ‘gradient region,’ which reaches from the sawtooth inversion radius out to the pedestal top, intrinsic rotation profiles may be either flat or hollow, and can transition suddenly between these two states, an unexplained phenomenon referred to as rotation reversal. Theoretical efforts to explain the mid-radius rotation shear have largely focused on quasilinear models, in which the phase relationships of some selected instability result in a nondiffusive momentum flux (“residual stress”). In contrast, the present work demonstrates the existence of a robust, fully nonlinear symmetry-breaking momentum flux that follows from the free-energy flow in phase space and does not depend on any assumed linear eigenmode structure. The physical origin is an often-neglected portion of the radial ExB drift, which is shown to drive a symmetry-breaking outward flux of co-current momentum whenever free energy is transferred from the electrostatic potential to ion parallel flows [1]. The fully nonlinear derivation relies only on conservation properties and symmetry, thus retaining the important contribution of damped modes. The resulting rotation peaking is counter-current and scales as temperature over plasma current. As first demonstrated by Landau [2], this free-energy transfer (thus also the corresponding residual stress) becomes inactive when frequencies are much higher than the ion transit frequency, which allows sudden transitions between hollow and flat profiles. Simple estimates suggest that this mechanism may be consistent with experimental observations.

\*This work was funded in part by the Max-Planck/Princeton Center for Plasma Physics and in part by the U.S. Dept. of Energy, Office of Science, Contract No. DE-AC02-09CH11466.


16:00

JI3 5 Coupling of Shear Flows in a Cylindrical Plasma Device

RONGJIE HONG, Univ of California - San Diego

Spontaneous generation of parallel flows has been observed in a cylindrical plasma device. The mean parallel velocity shearing rate, \( V_z \), increases as the radial gradient of the plasma density, \( \nabla_r n_z \), exceeds a critical value. Correspondingly,
when critical density gradient is exceeded, the parallel Reynolds power, \( P_{Re}^p = -(v_\parallel)\nabla (\tilde{v}_\parallel) \), increases substantially, indicating the mean parallel flow gains more energy from ambient turbulence. Meanwhile, the shearing rate of the mean azimuthal flow, \( V_\theta \), increases with the density gradient, but soon saturates when critical density gradient is exceeded. Also, the azimuthal Reynolds power, \( P_{Re}^\theta = -(v_\theta)\nabla (\tilde{v}_\theta) \), drops at higher density gradient, implying that the mean azimuthal flow gains less energy from ambient turbulence. These results suggest that the energy of azimuthal flows may be coupled to that of parallel flows through ambient turbulence. A 4-field model is employed to explain the coupling between the azimuthal flow and the parallel flow.

16:30

**JI3 6 Velocity Space Degrees of Freedom of Plasma Fluctuations**

SEAN MATTINGLY, University of Iowa

Small scale wave modes are becoming more important in plasma physics. Examples include turbulent cascades in the solar wind [1], the energetics of fusion plasma electrostatic turbulence and transport [2,3], and low temperature basic plasma physics experiments [4]. In order to improve our understanding of these modes, I present an advance in experimental plasma diagnostics and use it to show the first measurement of a plasma ion velocity-space cross-correlation matrix. From this matrix I determine the eigenmodes of fluctuations on the ion distribution function as a function of frequency. I also determine the relative strengths of these modes - these are the velocity space degrees of freedom of plasma fluctuations. This measurement can detect the aforementioned smaller scale modes in plasmas through a localized measurement. The locality of this measurement means that it may be applied to plasmas in which a single - point velocity sensitive diagnostic is available and multipoint measurements may be difficult. Examples include in situ measurements of space plasmas, fusion plasmas, trapped plasmas, and laser cooled plasmas. This fact, combined with the new perspective it can give on small scale plasma fluctuations, means it may be used to further research on the above cited subjects. Much work remains on fully understanding this measurement. This measurement opens a velocity space interpretation of small scale plasma wave modes, and understanding this perspective from theory requires the application or invention of new mathematical tools. I discuss open problems to follow up on, which include questions from experimental, theoretical, and instrumentation perspectives.

*NSF-DOE Program Grant DE-FG02-99ERS4543.


14:12

**JO4 2 MAST Upgrade Status and Future Enhancements**

JAMES HARRISON, Culham Centre for Fusion Energy MAST UPGRADE TEAM TEAM The MAST Upgrade spherical tokamak has unique capabilities to address some of the key issues facing the development of fusion energy. Its main objectives are: 1) development of novel exhaust concepts, 2) contribution to the knowledge base for ITER and 3) to explore potential routes to smaller/cheaper fusion reactors. To fulfil these aims, it is equipped with 19 new poloidal field coils and closed divertors with Super-X capability. BT has been increased by 50% and the pulse length and Ip have increased to 3s and 2MA respectively. Auxiliary heating is provided by on and off axis NBI. The gas fuelling system allows for injection from 10 poloidal locations. The divertors are diagnosed with probes, bolometers, Thomson scattering, IR, visible imaging and spectroscopy. Fast ion physics studies are enhanced with a new fast ion loss detector. Following the construction phase, further enhancements are underway including new diagnostics, a cryoplant to serve the cryopumps and 2 additional neutral beams to increase the heating power from 5 to 10MW.

*Work supported by the RCUK Energy Programme [Grant Number EP/P012450/1] and EURATOM.

14:24

**JO4 3 Non-Solenoidal Startup Research Directions on the Pegasus Toroidal Experiment**

R.J. FONCK, M.W. BONGARD, B.T. LEWICKI, J.A. REUSCH, G.R. WINZ, University of Wisconsin-Madison The Pegasus research program has been focused on
developing a physical understanding and predictive models for non-solenoidal tokamak plasma startup using Local Helicity Injection (LHI). LHI employs strong localized electron currents injected along magnetic field lines in the plasma edge that relax through magnetic turbulence to form a tokamak-like plasma. Pending approval, the Pegasus program will address a broader, more comprehensive examination of non-solenoidal tokamak startup techniques. New capabilities may include: increasing the toroidal field to 0.6 T to support critical scaling tests to near-NSTX-U field levels; deploying internal plasma diagnostics; installing a coaxial helicity injection (CHI) capability in the upper divertor region; and deploying a modest (200–400 kW) electron cyclotron RF capability. These efforts will address scaling of relevant physics to higher $B_T$, separate and comparative studies of helicity injection techniques, efficiency of handoff to consequent current sustainment techniques, and the use of ECH to synergistically improve the target plasma for consequent bootstrap and neutral beam current drive sustainment. This has an ultimate goal of validating techniques to produce a $\sim 1$ MA target plasma in NSTX-U and beyond.

*Work supported by US DOE Grant DE-FG02-96ER54375.

14:36

JO4 4 Non-solenoidal Startup with High-Field-Side Local Helicity Injection on the Pegasus ST* J.M. PERRY, G.M. BODNER, M.W. BONGARD, M.G. BURKE, R.J. FONCK, J.L. PACHICANO, C. PIERREN, N.J. RICHNER, C. RODRIGUEZ SANCHEZ, D.J. SCHLOSSBERG, J.A. REUSCH, J.D. WEBERSKI, University of Wisconsin-Madison Local Helicity Injection (LHI) is a non-solenoidal startup technique utilizing electron current injectors at the plasma edge to initiate a tokamak-like plasma at high $I_p$. Recent experiments on Pegasus explore the inherent trade-offs between high-field-side (HFS) injection in the lower divertor region and low-field-side (LFS) injection at the outboard midplane. Trade-offs include the relative current drive contributions of HI and poloidal induction, and the magnetic geometry required for relaxation to a tokamak-like state. HFS injection using a set of two increased-area injectors ($A_{ij} = 4$ cm$^2$, $V_{ij} \sim 1.5$ kV, and $I_{ij} \sim 8$ kA) in the lower divertor is demonstrated over the full range of toroidal field available on Pegasus ($B_T \lesssim 0.15$ T). Increased PMI on both the injectors and the lower divertor plates was observed during HFS injection, and was substantively mitigated through optimization of injector geometry and placement of local limiters to reduce scrape-off density in the divertor region. $I_p$ up to 200 kA is achieved with LHI as the dominant current drive, consistent with expectations from helicity balance. To date, experiments support $I_p$, increasing linearly with helicity injection rate. The high normalized current ($I_N \geq 10$) attainable with LHI and the favorable stability of the ultra-low aspect ratio, low-$\ell$, LHI-driven plasmas allow access to high $\beta_p$—up to 100%, as indicated by kinetically-constrained equilibrium reconstructions.

*Work supported by US DOE Grant DE-FG02-96ER54375.

14:48

JO4 5 Status and Plans for NSTX-U Recovery* R.J. HAWRYLUK, S. GERHARDT, J. MENARD, C. NEUMEYER, Princeton Plasma Physics Laboratory The NSTX-U device experienced a series of technical problems; the most recent of which was the failure of one of the poloidal magnetic field coils, which has rendered the device inoperable and in need of significant repair. As a result of these incidents, the Laboratory performed a very comprehensive analysis of all of the systems on NSTX-U. Through an integrated system’s analysis approach, this process identified which actions need to be taken to form a corrective action plan to ensure reliable and predictable operation. The actions required to address the deficiencies were reviewed by external experts who made recommendations on four high-level programmatic decisions regarding the inner poloidal field coils, limitations to the required bakeout temperature needed for conditioning of the vacuum vessel, divertor and wall protection tiles and coaxial helicity injection. The plans for addressing the recommendations from the external review panels will be presented.

*This work was supported by the US DOE under Grant DE-AC02-09CH11466.

15:00

JO4 6 A first look at resistive MHD stability differences between NSTX and NSTX-U high beta discharges* L. A. MORTON, Oak Ridge Associated Universities R. J. LA HAYE, General Atomics J. W. BERKERY, Columbia University J. E. MENARD, N. M. FERRARO, Princeton Plasma Physics Laboratory D. P. BRENNAN, Princeton University S. A. SABBAGH, Columbia University L. F. DELGADO-APARICIO, Princeton University K. TRITZ, Johns Hopkins University Comparison is made of the onset, growth rate and saturation of $m/n = 2/1$ tearing modes in NSTX and NSTX-U high beta discharges. NSTX-U has stronger toroidal field, higher electron temperature (thus longer resistive diffusion time) and a larger aspect ratio (due to the expansion of the center stack). Experimental identification of the mode helicity, radial location, and width is accomplished by synergistically combining information from soft x-ray emission, Thomson scattering ($T_e$ profile), Charge Exchange Recombination ($T_e$ profile) and Mirnov diagnostics. Fitting the generalized Rutherford equation to the time-evolution of the island width allows evaluation of the different drive and stabilizing terms. Linear stability calculations have also been performed with M3D-C1. The possibility of a reduction in the stabilizing interchange effect due to curvature at somewhat larger aspect ratio in NSTX-U is one focus of the analysis.

*This work is supported by the US DOE under Grant DE-FG02-99ER54522.

15:12

JO4 7 Simulation of the internal kink-like mode driven by the toroidal rotation in spherical tokamak* G.Z. HAO, W.W. HEBD BRINK, D. LIU, UC/Irvine Y.Q. LIU, GA M. PODESTA, E. FREDRICKSON, D. DARROW, PPPL N. CROCKER, UCLA K. TRITZ, JHU Based on the L-mode discharge of NSTX, the linear simulation indicates that the internal kink-like mode can be driven by the toroidal rotation when it exceeds 25% of Alfvén velocity at magnetic axis. The predicted critical value of rotation is close to the experimental rotation at the onset of the mode. The mode frequency agrees well with the measured value (≈35 kHz). The simulated mode structure agrees with the measurement from reflectometer diagnostic which monitors the major radius larger than 120 cm from the studied case. Furthermore, in simulation, the triggering of the mode is robust and insensitive to uncertainty in the reconstructed equilibrium. The preliminary analysis of soft-x ray data suggests that the mode perturbation initially occurs in the core and moves outside during the frequency chirping process of the mode. A comparison between the simulated soft-x ray and the experiment measurement in the core region will be presented.

*This work is supported by the US DOE under Grant Nos. DE-AC02-09CH11466, DE-FG02-06ER54867, and DE-FG03-02ER54681.

Turbulent fluctuations on the electron gyro-radius length scale are thought to cause anomalous transport of electron energy in spherical tokamaks such as NSTX and MAST [1, 2] in some parametric regimes [3]. In NSTX, electron-scale turbulence is studied through a combination of experimental measurements from a high-k scattering system [4] and gyrokinetic simulations. Until now most comparisons between experiment and simulation of electron scale turbulence have been qualitative, with recent work expanding to more quantitative comparisons via synthetic diagnostic development [5,6]. In this new work, we propose two alternate, complementary ways to perform a synthetic diagnostic using the gyrokinetic code GYRO. The first approach builds on previous work [5,6] and is based on the traditional selection of wavenumbers using a wavenumber filter, for which a new wavenumber mapping was implemented for general axisymmetric geometry. A second alternate approach selects wavenumbers in real-space to compute the power spectra. These approaches are complementary, and recent results from both synthetic diagnostic approaches applied to NSTX plasmas will be presented.

*Work supported by U.S. DOE contracts DE-AC02-09CH11466 and DE-AC02-05CH11231.

1Kaye NF 2007.
2Valovic NF 2011.
3Guttenfelder PoP 2013.
4Smith RSI 2008.
5Poli PoP 2010.
6Poli APS 2010.

JO4 9 Divertor-localized fluctuations in NSTX-U L-mode discharges Filippo Scotti, V.A. Soukhanovskii, LLNL S. Zweben, PPPL J. Myra, D. Baever, Lodestar Corp. S.A. Sabbagh, Columbia University The 3-D structure of divertor turbulence is characterized in NSTX-U by means of fast camera imaging. Edge and divertor turbulence can be important in determining the heat flux width in fusion devices. Field-aligned filaments are found on the divertor legs via imaging of C III and D-α emission in NBI-heated divertor L-mode discharges, similar to observations in Alcator C-Mod and MAST. These flute-like fluctuations of up to 10-20% in RMS/mean are radially localized around the separatrix and limited to the region below the X-point. Poloidal and parallel correlation lengths are a few cm (10-50 μm) and several meters, respectively. For the outer leg filaments, poloidal correlation lengths decrease along the leg away from the strike point and typical effective toroidal mode numbers are in the range of 10-20. Opposite toroidal rotation is observed for inner (co-current rotation) and outer leg (counter-current rotation) filaments with apparent poloidal propagation of ~1 km/s. The poloidal motion of outer leg filaments is opposite to the one typically observed for NSTX upstream blobs in the scrape-off layer. The shape, dynamics and absence of correlation with upstream turbulence suggest that these fluctuations are generated and localized in the divertor region.

*Supported by US DOE DE-AC52-07NA27344, DE-AC02-09CH11466, DE-FG02-02ER54678, DE-FG02-99ER54524.

JO4 10 Characterization of boronized graphite in NSTX-U and its effect on plasma performance Felipe Bedoya, Jean Paul Allain, Univ of Illinois - Urbana Robert Kaita, Charles Skinner, Princeton Plasma Physics Laboratory University of Illinois team, Princeton Plasma Physics Laboratory Collaboration Plasma Facing Components (PFC) conditioning can have a crucial influence on plasma performance in tokamak machines. The National Spherical Torus Experiment (NSTX-U) used boronization as the main wall conditioning technique during the FY16 experimental campaign. The Materials Analysis Particle Probe (MAPP), a characterization facility, was used to investigate the surface of ATJ graphite exposed to boronization and plasma in the tokamak using X-ray Photoelectron Spectroscopy (XPS). The measurements showed that plasma induced oxidation plays a critical role in the chemical evolution of the surfaces and as a consequence in plasma performance. Additionally, ex-vessel in-situ laboratory experiments and post-mortem studies of extracted NSTX-U tiles were performed to complement the observations made with MAPP, including controlled D irradiations and XPS depth profiles. These three methodologies show congruent results where D exposures increase the oxygen concentration between 20-30%, highlighting the influence of these two species on the chemistry of the samples.

*USDOE Contract DE-AC02-09CH11466, USDOE Contract DE-SC0010717 and Award Number DE-SC0012890.

JO4 11 Elemental and topographical imaging of microscopic variations in deposition on NSTX-U and DIII-D samples C.H. Skinner, R. Kaita, PPPL B.E. Koel, Princeton U. C.P. Chrobak, GA W.R. Wampler, SNL Tokamak plasma facing components (PFCs) have surface roughness that can cause microscopic spatial variations in erosion and deposition and hence influence material migration. Previous RBS measurements showed indirect evidence for this but the spatial (0.5mm) resolution was insufficient for direct imaging. We will present elemental images at sub-micron resolution of deposition on NSTX-U and DIII-D samples that show strong microscopic variations and correlate with 3D topographical maps of surface irregularities. The elemental imaging is performed with a Scanning Auger Microprobe (SAM) that measures element-specific Auger electrons excited by an SEM electron beam. 3D topographical maps of the samples are performed with a Leica DCM 3D confocal light microscope and compared to the elemental deposition pattern. The initial results appear consistent with erosion at the downstream edges of the surface pores exposed to the incident ion flux, whereas the deeper regions are shadowed and serve as deposition traps.

*Support was provided through DOE Contract Numbers DE-AC02-09CH11466, DE-FC02-04ER54698 and DE-NA0003525.

JO4 12 Design and Modeling of a Liquid Lithium LiMIT Loop Matthew Szott, Michael Christenson, Steven Stemmler, Chisung Ahn, Daniel Andruziak, David Rusic, University of Illinois at Urbana-Champaign The use of flowing liquid lithium in plasma facing components has been shown to reduce erosion and thermal stress damage, prolong device lifetime, decrease edge recycling, reduce impurities, and increase plasma performance, all while providing a clean and self-healing surface. The Liquid Metal Infused Trench (LiMIT) system has proven the concept of controlled thermoelectric magneto-hydrodynamic driven liquid flow for use in fusion...
**16:24**

**JO4 13 On the Development of Hydrogen Isotope Extraction Technologies for a Full LiMIT-Style PFC Liquid Lithium Loop**

MICHAEL CHRISTENSON, MATTHEW SZOTT, STEVEN STEMMILEY, JEREMY METTLER, JOHN WENDEBORN, CODY MOYNihan, CHISUNG AHN, DANIEL ANDRUCZYK, DAVID RUZIC, *Univ of Illinois - Urbana*

Lithium has proven over numerous studies to improve core confinement, allowing access to operational regimes previously unattainable when using solid, high-Z divertor and limiter modules in magnetic confinement devices. Lithium readily absorbs fuel species, and while this is advantageous, it is also detrimental with regards to tritium inventory and safety concerns. As such, extraction technologies for the recovery of hydrogeinic isotopes captured by lithium require development and testing in the context of a larger lithium loop recycling system.

Proposed reclamation technologies at the University of Illinois at Urbana-Champaign (UIUC) will take advantage of the thermophysical properties of the lithium-hydrogen-lithium hydride system as the driving force for recovery. Previous work done at UIUC indicates that hydrogen release from pure lithium hydride reaches a maximum of $7 \times 10^{18} \text{ s}^{-1}$ at 665°C. While this recovery rate is appreciable, reactor-scale scenarios will require isotope recycling to happen on an even faster timescale. The ratio of isotope dissolution to hydride precipitate formation must therefore be determined, along with the energy needed to recoup trapped hydrogen isotopes.

Extraction technologies for use with a LiMIT-style loop system will be discussed and results will be presented.

*This work is supported by DOE/ALPS DE-FG02-99ER54515.

**16:36**

**JO4 14 HIDRA-MAT: A Material Analysis Tool for Fusion Devices**

DANIEL ANDRUCZYK, RABEL RIZKALLAH, FELIPE BEOYAY, AVEEK KAPAT, HANNA SCHAMIS, JEAN PAUL ALLAIN, *University of Illinois at Urbana - Champaign*

The WEGA stellarator which is now operating as HIDRA at the University of Illinois will be almost exclusively used to study the intimate relationship between the plasma interacting with surfaces of different materials. A Material Analysis Tool (HIDRA-MAT) is being designed and will be built based on the successful Material Analysis and Particle Probe (MAPP) which is currently used on NSTX-U at PPPL. This will be an in-situ material diagnostic probe, meaning that all analysis can be done without breaking vacuum. This allows surface changes to be studied in real-time. HIDRA-MAT will consist of several in-situ diagnostics including Langmuir probes (LP), Thermal Desorption Spectroscopy (TDS), X-ray Photo Spectroscopy (XPS) and Ion Scattering Spectroscopy (ISS). This presentation will outline the HIDRA-MAT diagnostic and initial design, as well as its integration into the HIDRA system.

*This work is supported by DOE/ALPS DE-FG02-99ER54515.

**16:48**

**JO4 15 Behavior of axisymmetric density fluctuations in TCV**

GABRIELE MERLO, FRANK JENKO, *University of California, Los Angeles STEPHAN BRUNNER, STEFANO CODA, ZHOUJI HUANG, LAURENT VILLARD, Swiss Plasma Center TOBIAS GOERLER, ALEJANDRO B. NAVARRO, DANIEL TOLD, Max Plank Institute* Axisymmetric density fluctuations, either with a radially coherent or dispersive nature, are routinely observed in the TCV tokamak and experimentally interpreted as Geodesic Acoustic Modes (GAMs). We use local and global GENE simulations to investigate their behavior. With a simplified physical model, neglecting impurities and using heavy electrons, simulations reproduce the observed behavior. Simulations allow to conclude that the modification of the safety factor $q$ alone cannot explain the transition between these two different fluctuation regimes, which thus appear as a consequence of variations of other parameters, including collisionality and finite machine size effects. The behavior of the radially coherent GAM is further investigated with high-realism GENE simulations. With this set-up, local simulations reproduce the experimental transport level at different radii while matching the observed GAM frequency at the location where the mode peaks. Global high-realism runs, aiming at reproducing the radial extent of the fluctuations, will be discussed as well.

*This work has been carried out within the framework of the EURopean Fusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under Grant Agreement No 633053.

---

**CONTRIBUTED PAPERS**

**14:00**

**JO5 1 Impact of Distributed Injection on Plasma Wakefield Acceleration at FACET**

NAVID VAFAEI-NAJAFABADI, *Stony Brook University*

Impact of Distributed Injection on Plasma Wakefield Acceleration at FACET. An electron-beam-driven plasma wakefield accelerator (PWFA) will sustain accelerating gradients of tens of GeV/m in a meter-scale plasma. If the transverse radius of the electron beam is not matched to the plasma, the envelope of this drive beam will execute betatron oscillations in the focusing force of the ion column. At its lowest radius in this oscillation cycle, the electric field of the beam can surpass the ionization threshold of elements, leading to ionization injection of these electrons in to the wake. Electrons from each cycle of this betatron oscillation then accumulate at the back of the wake and decrease the accelerating field. The experiments were carried out at FACET, where the drive electron beam had 3 nC of charge and an energy of 20.35 GeV. Two different plasma sources were used: a ∼30 cm self-ionized Rubidium (Rb) vapor confined by argon (Ar) gas at room-temperature and a partially pre-ionized hydrogen gas. The experimental and simulation evidence for the distributed injection of electrons and their impact on the PWFA at FACET will be presented in this talk.
JO5 2 Status and future plans for open source QuickPIC WEIMING AN, VIKTOR DECYK, WARREN MORI, Univ of California - Los Angeles QuickPIC is a three dimensional (3D) quasi-static particle-in-cell (PIC) code developed based on the UPIC framework. It can be used for efficiently modeling plasma based accelerator (PBA) problems. With quasi-static approximation, QuickPIC can use different time scales for calculating the beam (or laser) evolution and the plasma response, and a 3D plasma wake field can be simulated using a two-dimensional (2D) PIC code where the time variable is $\xi = ct - z$ and $z$ is the beam propagation direction. QuickPIC can be thousand times faster than the normal PIC code when simulating the PBA. It uses an MPI/OpenMP hybrid parallel algorithm, which can be run on either a laptop or the largest supercomputer. The open source QuickPIC is an object-oriented program with high level classes written in Fortran 2003. It can be found at https://github.com/UCLA-Plasma-Simulation-Group/QuickPIC-OpenSource.git

JO5 3 Studies of hosing of a witness beam in plasma based acceleration* LANCE HILDEBRAND, WEIMING AN, XINLU XU, WARREN MORI, UCLA A major challenge for the next generation of plasma wakefield acceleration is the preservation of emittance of the witness beam. The hosing instability is one source of emittance of the witness beam that occurs when the witness beam has a transverse offset. A general theory has been developed to describe hosing in the blow-out regime and has shown smaller growth than standard theories. However, these theories have not been rigorously tested with witness beams in the relativistic, non-adiabatic regime of interest to plasma wakefield acceleration. A modified theory using an expansion in azimuthal modes is discussed. This theory alongside 3D QuickPIC simulations are used to study perturbations to the wake structure from point charges with transverse displacements as well as witness beams optimized for beam loading.

*Work supported by NSF and DOE.

JO5 4 Plasma-optical spatiotemporal diagnostics and alignment for electron and laser beams THOMAS HEINEMANN, University of Strathclyde, DESY, University of Hamburg, The Cockcroft Institute ALEXANDER KNETSCH, DESY ANDREW BEATON, PANAGIOTIS DELINIKOLAS, FAHIM HABIB, GRACE MANAHAN, PAUL SCHERKOL, DANIEL ULLMANN, University of Strathclyde, The Cockcroft Institute ANDREW SUTHERLAND, University of Strathclyde, SLAC OLIVER KARGER, University of Hamburg JAMES ROSENZWEIG, UCLA BERNHARD HIDING, University of Strathclyde, The Cockcroft Institute The steadily increasing demand for compact accelerator-driven light sources imposes new challenges for generating compact, high-quality electron beams and concomitant $\mu$m-scale, fs-scale diagnostics. During the E210 experimental campaign at FACET (SLAC), we have amended state-of-the-art electro-optical sampling timing diagnostics and optical transition radiation spatial diagnostics with novel plasma-based techniques. By harnessing the ultrasensitive plasma response to intersecting laser and electron beams, we have developed novel diagnostic techniques which potentially enable spatiotemporal alignment with sub-fs and sub-$\mu$m accuracy. Furthermore, these diagnostics can be realized in a simple and robust layout; they are based on measuring the time-integrated plasma recombination light from tunnel ionization as well as electron impact ionization. They thus map ultrashort and small dynamics onto much longer and larger scales, such that the main diagnostic element is a simple imaging device. These techniques, the underlying physics and their potentially far-reaching impact will be presented and discussed.

JO5 5 Exploring the onset of fireball filamentation in realistic laboratory conditions NITIN SHUKLA, JORGE VIEIRA, Instituto Superior Tecnico PATRIC MUGGLI, Max Planck Institute for Physics GIANLUCA SARRI, Queen’s University of Belfast RICARDO FONSECA, LUIS SILVA, Instituto Superior Tecnico Relativistic high-density quasi-neutral electron-positron (fireball) beams have been recently generated in the laboratory [1] providing a platform to explore processes directly to address unsolved problems in astrophysics [2]. In this work, we present numerical studies [3], complemented by theoretical estimates, of the interaction of fireball beams with non-zero emittance with plasmas using beam parameters currently available in labs around the world. We show that the ratio between the density of the fireball and background plasma controls a transition between the current filamentation instability (CFI) and the competing transverse two-stream instability. When the density ratio is higher than unity the CFI can grow as long as the beam expansion rate, caused by a finite emittance, is larger than the CFI growth rate. For wide beams, we show that the CFI can also grow as long as the transverse offsets between the beam centroids are smaller than a fraction of the beam transverse dimensions. We find that the longitudinal energy spread, typical of plasma-based accelerated electron-positron fireball beams, plays a minor role in the growth of CFI.

1Sarrl (2015).
2Nakar (2011).
3Fonseca (2008).

JO5 6 Generation and acceleration of neutral atoms in intense laser plasma experiments SHEROY TATA, ANGANA MONDAL, SHOBHIK SARKAR, YASH VED, AMIT D. LAD, Tata Institute of Fundamental Research JOHN PASLEY, University of York JAMES COLGAN, Los Alamos National Laboratory M. KRISHNAMURTHY, Tata Institute of Fundamental Research The interaction of a high intensity ($\geq 10^{18}$ W/cm$^2$), high contrast ($\geq 10^9$), ultra-short (30fs) laser with solid targets generates a highly dense hot plasma. The quasi-static electric fields in such plasmas are well known for ion acceleration via the target normal sheath acceleration process. Under such conditions charge reduction to generate fast neutral atoms is almost inhibited. Improvised Thomson parabola spectrometer with improved signal to noise ratio has enabled us to measure the signals of fast neutral atoms and negative ions having energies in excess of tens of keV. A study on the neutralization of accelerated protons in plasma shows that the neutral atom to all particle ratio rises sharply from a few percent at the highest detectable energy to $\approx$ 50% at 15 keV. Using usual charge transfer reactions the generation of neutral atoms can not be explained, thus we conjecture that the neutralization of the accelerated ions is not from the hot dense region of the plasma but neutral atom formation takes place by co-propagating ions with low energy electrons enhancing the effective neutral ratio.

JO5 7 Neutron generation in deuterated nanowire arrays irradiated by femtosecond pulses of relativistic intensity* ALDEN CURTIS, CHASE CALVI, Colorado State University JIM

*This work was supported by NSF Grant No. PHY-1415386 and DOE Grant No. DE-SC0010604. Work at SLAC was supported by DOE Contract No. DE-AC02-76SF00515.

On behalf of the E200 collaboration.
TINSLEY, National Security Technologies REED HOLLINGER, SHOUJUN WANG, ALEX ROCKWOOD, CONRAD BUSS, VYACHESLAV SHLYAPTEV, Colorado State University VURAL KAYMAK, ALEXANDER PUKHOV, Heinrich-Heine-Universität YONG WANG, JORGE ROCCA, Colorado State University COLORADO STATE UNIVERSITY COLLABORATION, NATIONAL SECURITY TECHNOLOGIES COLLABORATION

Nuclear fusion is regularly created in spherical plasma compressions driven with multi-kilojoule lasers. Driving fusion reactions with compact lasers that can be fired at much higher repetition rates is also of interest. We have demonstrated a new dense fusion environment created by irradiating arrays of deuterated nanostructures with Joule–level pulses from a compact Ti:Sa laser. The irradiation of ordered deuterated polyethylene nanowires arrays with femtosecond pulses of relativistic intensity is shown to create ultra-high energy density plasmas in which deuterons are accelerated to MeV energies, efficiently driving D-D fusion reactions and ultrafast neutron pulses. We have measured up to $2 \times 10^6$ fusion neutrons/Joule, a 500 times increase respect to flat solid targets, a record yield for Joule-level lasers, and have also observed a rapid increase in neutron yield with laser pulse energy. We present results of first experiments conducted at intensities $> 1 \times 10^{21}$ W cm$^{-2}$ that generated $> 1 \times 10^7$ fusion neutrons per shot.

*Work supported by Air Force Office of Scientific Research Award Number FA9560-14-10232 and by National Security Technologies.

15:24

**JO5 8 Neutron beams driven by the Texas Petawatt laser**


Intense laser-driven ion beams produced in the relativistically-induced transparency regime have been used to generate intense γ-ray and neutron beams [1]. For neutrons, a laser-driven deuteron beam is directed at a Be disk “converter”, where deuterons split producing mainly forward-directed neutrons. The aforementioned experiments have been done at the Trident laser using a 0.5 ps laser pulse of 1 μm wavelength focused up to $10^{12}$ W/cm$^2$ onto nanofoils of deuterated-plastic (CD$_x$), where x = 1–2, making 1x10$^{10}$ neutrons/sr at ~ MeV average energies [2]. Here we report on the first experiments to explore the same regime at the Texas Petawatt (TPW) laser facility. With one plasma mirror, TPW delivers high-contrast laser pulses as short as 0.15 ps at intensities up to $2 \times 10^{21}$ W/cm$^2$. Cd and Al/CD multilayer targets of thickness in the range of 50 – 750 nm have been used. This setup has delivered up to 5x10$^8$ neutrons/sr. The dependence of neutron yield on target composition and thickness, and on laser pulse length is presented and discussed.

*This work is sponsored by the NNSA of the USDOE.

15:36

**JO5 9 Proton probing of ultra-thin foil dynamics in high intensity regime**

RAJENDRA PRASAD, ESIN AKTAN, BASTIAN AURAND, MIRELA CERCHEZ, OSWALD WILLI, Institute for laser and plasma physics, Heinrich Heine University Duesseldorf, Germany

The field of laser driven ion acceleration has been enriched significantly over the past decade, thanks to the advanced laser technologies. Already, from 100s TW class systems, laser driven sources of particles and radiations are being considered in number of potential applications in science and medicine due to their unique properties. New physical effects unearthed at these systems may help understand and conduct successful experiments at several PW class multi-beam facilities with high rep rate systems, e.g. ELI. Here we present the first experimental results on ultra-thin foil dynamics irradiated by an ultra-high intensity ($10^{20}$ W/cm$^2$), ultra-high contrast ($10^{-12}$) laser pulse at ARCTURUS laser facility at HHU Duesseldorf. By employing the elegant proton probing technique it is observed that for the circular polarization of laser light, a 100nm thin target is pushed forward as a compressed layer due to the radiation pressure of light. Whereas, the linear polarization seems to decompress the target drastically. 2D particle-in-cell simulations corroborate the experimental findings. Our results confirm the previous simulation studies investigating the fundamental role played by light polarization, finite focus size effect and eventually electron heating including the oblique incidence at the target edges.

15:48

**JO5 10 Solid-density plasma expansion in intense ultra-short laser irradiation measured on nanometer scale and in real time**

T KLUGE, J METZKES, A PELKA, A LASO GARCIA, I PRENCIPE, M BUSSMANN, K ZEIL, T SCHOENHERR, N HARTLEY, HZDR, Dresden, Germany

C GUTT, University Siegen, Germany

G E GALTIER, I NAM, HJ LEE, EE MCBRIDE, S GLENZER, SLAC U HUEBNER, Leibniz-Institute of Photonic Technology, Jena, Germany

C ROEDEL, Friedrich-Schiller-University, Jena, Germany

M NAKATSUTSUMI, European XFEL, Schenefeld, Germany

M ROEDEL, M REHWA LD, M GARTEN, M ZACHARIAS, U SCHRAMM, T.E. COWAN, HZDR, Dresden, Germany and TU-Dresden, Germany

Small Angle X-ray Scattering (SAXS) is discussed to allow unprecedented direct measurements limited only by the probe X-ray wavelength and duration. Here we present the first direct in-situ measurement of intense short-pulse laser - solid interaction that allows nanometer and high temporal resolution at the same time. A 120 fs laser pulse with energy 1 J was focused on a silicon membrane. The density was probed with an X-ray beam of 49 fs duration by SAXS. Despite prepulses, we can exclude premature bulk expansion. The plasma expansion is triggered only shortly before the main pulse, when an expansion of 10 nm within less than 200 fs was measured. Analysis of scattering patterns allows the first direct verification of numerical simulations.

*Supported by DOE FWP 100182, SF00515; EC FP7 LASERLAB-EUROPE/CHARPAC (contract 284464); German Federal Ministry of Education and Research (BMBF) under Contract Number 03Z10511; MG and MZ supported by the European Union’s Horizon 2020 No 654220.

16:00

**JO5 11 Optimum and Controllable Multi-stage Proton Acceleration Manipulated by Double Beam Image Technique**

WEN-PENG WANG, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences

With the development of ultra-intense laser technology, laser intensity can increase up to the order of $\sim 10^{22}$ W/cm$^2$ in the laboratory. Ion beams in the MeV range and even the GeV range, driven by terawatt or petawatt lasers, exhibit ultra-short pulse duration, excellent emission, and ultra-high peak current. Thus, they can potentially be applied in fast ignition of inertial confinement fusion, medical therapy, proton imaging, and pre-accelerators for conventional acceleration devices. However, the generation of quasi-monoenergetic proton beams for realistic applications is still an experimental challenge. Here, the optimum and controllable two-stage proton acceleration is realized for the first time by a novel double beam image (DBI) technique in experi-
ment. Two laser pulses are successfully tuned on two separated foils with both spatial collimation and time synchronizing, resulting in spectrum tailoring and an energy increase at the same time. Such a novel DBI technique can help us to realize the optimum two-stage acceleration in a feasible way, which opens the door for the exact manipulation of multi-stage acceleration to further improve the energy and spectra of particle beams.

16:12
We report the recent results on laser-produced relativistic electron-positron plasma jets. This includes: the prepulse [1] and material dependence of pair generation [2]; time dependent positron acceleration [3] and maximum achieved pair density [4]. We will highlight the results from recent experiments on the Omega EP laser testing nanostructured target to increase pair yield. We will also report on a newly commissioned platform using the NIF ARC lasers which was developed for efficient pair creation using 10 ps laser duration at near relativistic laser intensity.

*This work was performed under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344, and funded by LDRD (#17-ERD-010).
1Jaebum Park et al., High Power Laser Science and Engineering 4, 26 (2016).
3Shaun Kerr et al., this conference.
4Brandon Edghill et al., this conference.

16:24
JO6 13 Sheath field dynamics from time-dependent acceleration of laser-generated positrons* SHAUN KERR, ROBERT FEDOSEJEVS, University of Alberta ANTHONY LINK, JACKSON WILLIAMS, JAEBUM PARK, HUI CHEN, Lawrence Livermore National Laboratory Positrons produced in ultraintense laser-matter interactions are accelerated by the sheath fields established by fast electrons, typically resulting in quasi-monoenergetic beams [1]. Experimental results from Omega EP show higher order features developing in the positron spectra when the laser energy exceeds one kilojoule [2]. 2D PIC simulations using the LSP code were performed to give insight into these spectral features. They suggest that for high laser energies multiple, distinct phases of acceleration can occur due to time-dependent sheath field acceleration. The detailed dynamics of positron acceleration will be discussed.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344, and funded by LDRD 17-ERD-010.

16:36
JO6 14 Scaling laws for positron production in laser-electron beam collisions* TOM BLACKBURN, Chalmers University of Technology ANTON ILDERTON, University of Plymouth CHRISTOPHER MURPHY, University of York MATTIAS MARK-LUND, Chalmers University of Technology Showers of gamma rays and positrons are produced when a multi-GeV electron beam collides with a super-intense laser pulse. All-optical realisation of this geometry, where the electron beam is generated by laser-wakefield acceleration, is currently attracting much experimental interest as a probe of radiation reaction and QED effects. These interactions may be modelled theoretically in the framework of strong-field QED or numerically by large-scale PIC simulation. To complement these, we present analytical scaling laws for the electron beam energy loss, gamma ray spectrum, and the positron yield and energy that are valid in the radiation-reaction-dominated regime. These indicate that by employing the collision of a 2 GeV electron beam with a laser pulse of intensity $5 \times 10^{21}$ W cm$^{-2}$, it is possible to produce 10,000 positrons in a single shot at currently available laser facilities.

*The authors acknowledge support from the Knut and Alice Wallenberg Foundation.

SESSION JO6: WAVES AND SPACE PLASMAS
Tuesday Afternoon, 24 October 2017
Room: 202C at 14:00
Yi-Min Huang, Princeton University, presiding

Contributed Papers

14:00
JO6 1 The Dynamic Local Field Correction of Yukawa Plasmas YONGJUN CHOI, The Institute for Cyber-Enabled Research, Michigan State University GAUTHAM DHARUMAN, MICHAEL MURILLO, CMSE, Michigan State University The mean-field approximation is the cornerstone of modern statistical mechanics; therefore, unknowns are “beyond mean field” (BMF). Being tantamount to solving the complete many-body problem, however, few accurate BMF models exist even for simplified systems. Knowing the exact representation for the dynamics of a model system provides an important constraint on model validation and an exact limit. The dynamic local field correction (DLFC) is a complex function of wave vector and frequency in which all BMF information is contained. All collisional (e.g., wave damping, transport, equation of state, etc.) information is contained in the DLFC, since it represents the exact solution of the many-body problem. From these two functions (real and imaginary parts) we can validate theoretical models and compute many physical properties (e.g., wave dispersions). In this research, the DLFC will be obtained through molecular dynamics simulations on the Yukawa plasmas. The study covers full range of coupling and screening regimes.

14:12
JO6 2 Data-model comparisons of storm-time ion dynamics* AMY KEESEE, EARL SCIME, West Virginia University YU HUANG, RALUCA ILIE, University of Illinois Urbana-Champaign MICHAEL LIEHMOH, University of Michigan Plasma sheet conditions play a significant role in inner magnetosphere dynamics, particularly during periods of strong convection, such as during geomagnetic storms. To be able to accurately model the geospace environment, particularly during storm intervals, we must improve our understanding of the mechanisms that influence plasma sheet characteristics, such as ion heating, as well as the processes that transfer plasma sheet particles to the inner magnetosphere.

The global view provided by energetic neutral atom (ENA) imaging provides a way to conduct data-model comparisons with both spatial and temporal resolution. Thus, TWINS measurements can provide a useful method for determining which physical processes in a simulation yield accurate modeling of actual events. In turn, the simulations can be used to determine which processes cause
the features observed in the measurements. Recent advances in the Hot Electron and Ion Drift Integrator (HEIDI) model enable the use of more realistic magnetic field geometries. HEIDI has been incorporated as one of the inner magnetosphere components within the Space Weather Modeling Framework (SWMF) for global modeling. We present data-model comparisons of ion temperatures during the high speed stream-driven storm on 2 May 2010.

*Work supported by NASA Grant NNX16AG66G.

14:24
JO6 3 Modelling tangential discontinuities at the Magnetopause with the new Energy Conserving Momentum Implicit Method ELISABETTA BOELLA, KU Leuven ALFREDO MICERA, Politecnico di Torino DIEGO GONZALEZ-HERRERO, MARIA ELENA INNOCENTI, GIOVANNI LAPENTA, KU Leuven Kinetic modeling of heliospheric plasmas is computationally very challenging due to the simultaneous presence of micro and macroscopic scales, which are often interconnected. As a consequence, simulations are expensive and hard to deploy within the existing Particle-In-Cell techniques, being them explicit, implicit or semi-implicit. Very recently we have developed a new semi-implicit algorithm, which is perfectly energy-conserving and as such, stable and accurate over a wide range of temporal and spatial resolutions. In this work, we are going to describe the main steps that led to this great breakthrough and report the implementation of the method in a new massively parallel code, called ECsim. The new approach is then employed to investigate tangential discontinuities (TD) at the magnetopause. Two and three-dimensional simulations of TDs are carried out over MHD time scales, retaining a kinetic description for both electrons and ions with a realistic charge to mass ratio. The formation of a high-energy tail Maxwellian is observed in the distribution function of the electrons on the Earth side. This leads to a crescent-shaped distribution in the plane perpendicular to the magnetic field, in agreement with recent observations of the Magnetospheric Multiscale (MMS) mission.

14:36
JO6 4 Formation and transport of entropy structures in the magnetotail simulated with a 3-D global hybrid code* YU LIN, Auburn Univ SIMON WING, JHU/APL JAY R. JOHNSON, Andrews Univ XUEYI WANG, JOE D. PEREZ, LEI CHENG, Auburn Univ Global structure and evolution of flux tube entropy $s$, integrated over closed field lines, associated with magnetic reconnection in the magnetotail are investigated using the AuburN Global hybrid code in three dimensions (3-D), ANGIE3D. Flux tubes with decreased entropy, or “bubbles,” are found to be generated due to the sudden change of flux tube topology and thus volume in reconnection. By tracking the propagation of the entropy-depleted flux tubes, the role of the entropy structure in plasma transport to the inner magnetosphere is examined with a self-consistent global hybrid simulation for the first time. The value of $s$ first decreases due to the shortening of flux tubes and then increases due to local ion heating associated with wave turbulence around the fast flows as the bubbles are injected earthward by interchange-ballooning instability, finally oscillating around an equilibrium radial distance where $s$ is nearly the same as the ambient value. The pressure remains anisotropic and not constant along the flux tubes during their propagation with a nonzero heat flux along the field line throughout the duration of the simulation. The correlation of these bubbles with earthward fast flows and specific entropy $s$ is also studied.

*Work supported by NASA and NSF Grants.

14:48
JO6 5 Plasma-based Space Radiation Reproduction in the Laboratory* BERNHARD HIDDING, University of Strathclyde OLIVER KARGER, University of Hamburg ALEX MUROKH, RadiateBeam Technologies JAMES ROSENZEWIG, UCLA ANDREW BEATON, University of Strathclyde Space radiation is a substantial danger for electronics as well as bio-systems onboard of satellites or space vessels. This radiation comprises electrons, protons and ions in a large energy range, and typically is very broadband. The presentation reports on first plasma-based reproduction of the spectral flux of certain kinds of space radiation, such as the “killer” electron flux present e.g. on GPS orbits. In collaboration with European Space Agency, this radiation was used for radiation hardness assurance of space-grade electronics. The wider implications of this demonstrated feasibility of plasma-based radiation hardness testing of electronics, for space radiobiology and for space exploration are discussed [1].

*We thank the laser teams at the Arcturus laser at Heinrich-Heine-University Düsseldorf and at the VULCAN PW laser at the Central Laser Facility, Rutherford Appleton Laboratory.


15:00
JO6 6 Three-dimensional, ten-moment multifluid simulation of the solar wind interaction with Mercury CHUANFEI DONG, AMMAR HAKIM, PPPL LIANG WANG, UNH AMITAVA BHATTACHARJEE, PPPL KAI GERMASCHEWSKI, UNH GINA DI- BRACCIO, NASA GSFC We investigate Mercury’s magnetosphere by using Gkeyll ten-moment multifluid code that solves the continuity, momentum and pressure tensor equations of both protons and electrons, as well as the full Maxwell equations. Non-ideal effects like the Hall effect, inertia, and tensorial pressures are self-consistently embedded without the need to explicitly solve a generalized Ohm’s law. Previously, we have benchmarked this approach in classical test problems like the Orszag-Tang vortex and GEM reconnection challenge problem. We first validate the model by using MESSENGER magnetic field data through data-model comparisons. Both day- and night-side magnetic reconnection are studied in detail. In addition, we include a mantle layer (with a resistivity profile) and a perfect conducting core inside the planet body to accurately represent Mercury’s interior. The intrinsic dipole magnetic fields may be modified inside the planetary body due to the weak magnetic moment of Mercury. By including the planetary interior, we can capture the correct plasma boundary locations (e.g., bow shock and magnetopause), especially during a space weather event.

15:12
JO6 7 Time-dependent study of anisotropy in Rayleigh-Taylor instability induced turbulent flows with a variety of density ratios* YE ZHOU, WILLIAM CABOT, LLNL. This study is part of our continued effort to understand the mixing, scaling, and anisotropy of flows induced by Rayleigh-Taylor instability (RTI). In particular, we utilize three large datasets with different Atwood numbers (density ratios) from well resolved numerical simulations at moderate Reynolds number with the goal of determining the degree of departure of this inhomogeneous flow from that of homogeneous, isotropic turbulence. A number of statistical measurements are considered in detail to delineate the role played by the acceleration or gravity. For example, the normalized dissipation rate is employed to inspect the forcing of the flow in the homogeneous and gravitationalal directions. The relationship between the outer-scale and the Taylor-microscale based Reynolds numbers is also clarified. These distinctive features of the high-Atwood number RTI flows are observed during the transition to turbulence.
15:24 JO6 8 A new regime of whistler propagation in the laboratory
GARIMA JOSHI, Nirum University; G. RAVI, Institute for plasma Research
Experimental observations of a new regime of whistler propagation in the laboratory are reported in this paper. The experiments are carried out in a large laboratory unbounded uniform plasma with density $n_e \approx 10^{10} - 10^{13}$ cm$^{-3}$ and magnetic field $B_0 \approx 1 - 20$ G. Studies are performed in the electron magnetohydrodynamic regime which is governed by electron dynamics with $\tau_{el} \ll L \ll \tau_{li}$, and $\tau_i \gg \tau \gg \tau_{ce}$, where $L$ and $\tau$ are spatial and temporal scale lengths of the perturbations, $\tau_{el}$ and $\tau_{li}$ the electron & ion Larmor radii respectively and $\tau_i$ the temporal scales corresponding to the ion gyro frequency and electron gyro frequency respectively. The complete topology of the perturbed wave magnetic field is unraveled by mapping it on a two dimensional grid over repeated plasma shots. It is observed that the excited waves are elongated whistlers in the propagation direction, with the perpendicular extent limited to scale lengths of the order of natural scale length of plasma i.e. the skin depth ($\sim \omega_{pe}^{-1}$), rather than being more oblique as predicted by theory and observed in other experiments. The waves do not show any dispersive nature, contrary to the whistler characteristics, while still being able to maintain the whistler speed for the given plasma and pulsed current parameters. The above observed results are explained in terms of a new physical model.

15:36 JO6 9 Observation of multiple chirping events in electron cyclotron emission of non-equilibrium mirror-confined plasma
MIKHAIL VIKTOROV, ALEXANDER SHALASHOV, DMITRY MANSFIELD, SERGEY GOLUBEV, The Institute of Applied Physics of the Russian Academy of Sciences
Chirping frequency patterns have been observed in the electron cyclotron emission from a strongly non-equilibrium mirror-confined plasma created by powerful microwave radiation of gyrotron (37.5 GHz, 80 kW) under ECR conditions. The dynamic spectrum of emission is a set of chirping events that are highly chirped radiation bursts with both increasing and decreasing frequencies. Such patterns are typical for the formation of nonlinear phase-space structures in a proximity of the wave-particle resonances of a kinetically unstable plasma, also known as the "holes and clumps" mechanism or Berk-Breizman model [1]. Our data provide the first experimental evidence for the acting of this mechanism in the electron cyclotron frequency domain [2]. Following the Berk-Breizman model, the frequency drift within each wave packet is proportional to the instability growth rate and has a predetermined time dependence. Resulting from the analysis of the microwave emission spectrum, the value of the growth rate is consistent with previous studies of excitation of extraordinary waves at the stage of plasma decay, which confirms the applicability of the model.

16:00 JO6 11 Cinematic Characterization of Convected Coherent Structures Within an Continuous Flow Z-Pinch
THOMAS UNDERWOOD, JESSE RODRIGUEZ, KEITH LOEBNER, MARK CAPPELLI, Stanford University
In this study, two separate diagnostics are applied to a plasma jet produced from a coaxial accelerator with characteristic velocities exceeding $10^3$ m/s and timescales of $\sim 10$ $\mu$s. In the first of these, an ultra-high frame rate CMOS camera coupled to a Z-type laser Schlieren apparatus is used to obtain flow-field refractometry data for the continuous flow Z-pinch formed within the plasma deflagration jet. The 10 MHz frame rate for 256 consecutive frames provides high temporal resolution, enabling turbulent fluctuations and plasma instabilities to be visualized over the course of a single pulse. The unique advantage of this diagnostic is its ability to simultaneously resolve both structural and temporal evolution of instabilities and density gradients within the flow. To allow for a more meaningful statistical analysis of the resulting wave motion, a multiple B-dot probe array was constructed and calibrated to operate over a broadband frequency range up to 100 MHz. The resulting probe measurements are incorporated into a wavelet analysis to uncover the dispersion relation of recorded wave motion and furthermore uncover instability growth rates. Finally these results are compared with theoretical growth rate estimates to identify underlying physics.

16:12 JO6 12 Reception of Microwave Signals through a Shear Flow with Lower Hybrid Turbulence
SABA MUDALIAR, Air Force Research Laboratory
A variety of instabilities is known to be generated in plasma flows with velocity shear. We consider the case when an external magnetic field is present orthogonal to the flow direction. The scale length of the velocity shear is assumed to be considerably larger than the electron gyro radius but much smaller than the ion gyro radius. Thus, the ions are unmagnetized while the electrons are magnetized. These conditions induce lower hybrid instabilities (LHI) in the flow. Our interest is to understand the impact of such LHI on the reception microwave signals propagating through the flow. A statistical analysis is carried out by decomposing the received signal into two parts: coherent and diffuse. We find that the coherent part has the same spectrum as that of the incident signal, but undergoes dispersive attenuation. The diffuse part is obtained as a convolution (in wavenumber and frequency) of the source signal with the spectrum of electron density fluctuations. We find that the
mean free path is an important quantity for understanding the impact of the turbulent flow on the coherent and diffuse parts of the received signals. Detailed analysis is presented to investigate the physics of various scattering processes involved in this problem.

“This material is based upon work supported by the Air Force Office of Scientific Research under Award Number FA9550-15RYCOR149.”

16:24
JO6 13 Spatial Studies of Ion Beams in an Expanding Plasma
EVAN AGUIRRE, West Virginia University TIMOTHY GOOD, Gettysburg College EARL SCIME, DEREK THOMPSON, West Virginia University
We report spatially resolved perpendicular and parallel ion velocity distribution function (IVDF) measurements in an expanding argon helicon plasma. The parallel IVDFs, obtained through laser induced fluorescence (LIF), show an ion beam with \( v \sim 8 \text{ km/s} \) flowing downstream that is confined to the center of the discharge. The ion beam is confined to within a few centimeters radially and is measurable for tens of centimeters axially before the LIF signal fades, likely a result of metastable quenching of the beam ions. The axial ion beam velocity slows in agreement with collisional processes. The perpendicular IVDFs show an ion population with a radially outward flow that increases with radial location. The DC electric field, electron temperature, and the plasma density in the double layer plume are all consistent with magnetic field aligned structures. The upstream and downstream electric field measurements show clear evidence of an ion hole that maps along the magnetic field at the edge of the plasma. Current theories and simulations of double layers, which are one-dimensional, completely miss these critically important two-dimensional features.

16:36
JO6 14 Evidence of Mixed-mode oscillations and Farey arithmetic in double plasma system in presence of fireball
VRAMORI MITRA, BORNALI SARMA, ARUN SARMA, VIT University, Chennai
Plasma fireballs are luminous glowing region formed around a positively biased electrode. The present work reports the observation of mix mode oscillations (MMO) in the dynamics of plasma oscillations that are excited in the presence of fireball in a double plasma device. Source voltage and applied electrode voltage are considered as the controlling parameters for the experiment. Many sequences of distinct multi peaked periodic states reflect the presence of MMO with the variation of control parameter. The sequences of states with two patterns are characterized well by Farey arithmetic, which provides rational approximations of irrational numbers. These states can be characterized by a firing number, the ratio of the number of small amplitude oscillations to the total number of oscillations per period. The dynamical transition in plasma fireball is also demonstrated by spectral analysis, recurrence quantification analysis (RQA) and by statistical measures viz., skewness and kurtosis. The mix mode phenomenon observed in the experiment is consistent with a model that describes the dynamics of ionization instabilities.

16:48
JO6 15 Development of a methodology for deriving Plasmaspheric Total Electron Content from In-Situ electron density measurements in highly eccentric equatorial orbits
ALIYUTHUMAN SADHIQUE, ANDREW BUCKLEY,‡ PAUL GOUGH,‡ Univ of Sussex SUSSEX SPACE SCIENCE CENTRE TEAM
The contribution of the Upper Plasmasphere (defined as the altitudes above semi-synchronous orbit height to the Plasmapause height) to the TEC has been and continues to be un-quantified. The PEACE instrument in the Chinese – ESA Double Star TC1 satellite, the mission’s orbit’s high eccentricity, low perigee, high apogee and the resulting smaller incident angle while in the above altitude range provide the ideal geometric opportunity to build a methodology and to utilize its empirical in-situ electron density measurements to determine the Upper Plasmaspheric TEC component. Furthermore, the variation of the Inclination Angle of TC1 makes it a suitable equatorial mission confined to the Near-Equatorial region, ie 20° - 25° on either sides of the magnetic equator. As the most pronounced absolute TEC values and variations are within this region, it offers an excellent opportunity to build a Upper Plasmaspheric TEC database. This research generates such, first-ever database along its orbital path, using a methodology of approximation equating arcs of the orbits to straight-line TEC Bars, utilizing complex mathematics, also enabling the determination of the whole Plasmaspheric TEC from any eccentric orbital probe.

†Main Supervisor.
‡Professor Emeritus - 2nd Supervisor.
JO7 4 Signatures of Intermediate-Mode Asymmetries in OMEGA Implosions* D. PATEL, R. BETTI, K.M. WOO, D.T. MICHEL, V. GOPALASWAMY, D. CAO, J.P. KNAUER, C. STOECKL, S.P. REGAN, Laboratory for Laser Energetics, U. of Rochester On the OMEGA laser, the 60-beam port geometry creates intermediate-mode asymmetries in the illumination pattern [1] that can potentially degrade implosion performance. Recently, some x-ray images of Ge- and Cu-doped shell implosions have exhibited structures that could be related to these mid-mode nonuniformities. These images are processed to emphasize those structures using a feature in the detection algorithm that subtracts the uniform background from the image and removes the high-frequency noise. The hydrodynamic code DEC3D is being used to determine whether some of those features are produced during the deceleration or disassembly phase of the implosion. The goal of the work is to develop a method to identify and measure the magnitude of the mid-mode asymmetry resulting from the laser-port geometry and to assess its impact on the implosion performance.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


14:36

JO7 5 Nonlinear Excitation of the Ablative Rayleigh–Taylor Instability for All Wave Numbers* H. ZHANG, R. BETTI, V. GOPALASWAMY, H. ALUIE, Laboratory for Laser Energetics, U. of Rochester R. YAN, Dept. of Modern Mechanics, U. of Science and Technology of China Small-scale modes of the ablative Rayleigh–Taylor instability (ARTI) are often neglected because they are linearly stable when their wavelength is shorter than a linear cutoff. Using 2-D and 3-D numerical simulations, it is shown that linearly stable modes of any wavelength can be destabilized. This instability regime requires finite amplitude initial perturbations. Compared to 2-D, linearly stable ARTI modes are more easily destabilized in 3-D and the penetrating bubbles have a higher density because of enhanced vorticity. It is shown that for conditions found in laser fusion targets, short-wavelength ARTI modes are more efficient at driving mixing of ablated material throughout the target since the nonlinear bubble density increases with the wave number and small-scale bubbles carry a larger mass flux of mixed material.

*This work was supported by the Office of Fusion Energy Sciences Nos. DE-FG02-04ER54789, DE-SC0014318, the Department of Energy National Nuclear Security Administration under Award No. DE-NA0001944, the Ministerio de Ciencia e Innovacion of Spain (Grant No. ENE2011-28489), and the NNL LDRD program through Project Number 20150568ER.

14:48

JO7 5 Nonlinear Excitation of the Ablative Rayleigh–Taylor Instability for All Wave Numbers* H. ZHANG, R. BETTI, V. GOPALASWAMY, H. ALUIE, Laboratory for Laser Energetics, U. of Rochester R. YAN, Dept. of Modern Mechanics, U. of Science and Technology of China Small-scale modes of the ablative Rayleigh–Taylor instability (ARTI) are often neglected because they are linearly stable when their wavelength is shorter than a linear cutoff. Using 2-D and 3-D numerical simulations, it is shown that linearly stable modes of any wavelength can be destabilized. This instability regime requires finite amplitude initial perturbations. Compared to 2-D, linearly stable ARTI modes are more easily destabilized in 3-D and the penetrating bubbles have a higher density because of enhanced vorticity. It is shown that for conditions found in laser fusion targets, short-wavelength ARTI modes are more efficient at driving mixing of ablated material throughout the target since the nonlinear bubble density increases with the wave number and small-scale bubbles carry a larger mass flux of mixed material.

*This work was supported by the Office of Fusion Energy Sciences Nos. DE-FG02-04ER54789, DE-SC0014318, the Department of Energy National Nuclear Security Administration under Award No. DE-NA0001944, the Ministerio de Ciencia e Innovacion of Spain (Grant No. ENE2011-28489), and the NNL LDRD program through Project Number 20150568ER.

14:24

JO7 3 3D broadband Bubbles Dynamics for the imprinted ablative Rayleigh-Taylor Instability ALEXIS CASNER, CELIA S KHAN, LLNL C. MAILLIET, CELIA D. MARTINEZ, N. EZUMI, LLNL E. LE BEL, CELIA B.A. REMINGTON, L. MASSE, V.A. SMALYUK, LLNL We report on highly nonlinear ablative Rayleigh-Taylor growth measurements of 3D laser imprinted modulations. These experiments are part of the Discovery Science Program on NIF. Planar plastic samples were irradiated by 450 kJ of 3w laser light and the growth of 3D laser imprinted modulations is quantified through face-on radiography. The initial seed of the imprinted RTI is imposed by one beam focused in advance (~300 ps) without any optical smoothing (no CPP; no SSD). For the first time four generations of bubbles were created as larger bubbles overtake and merge with smaller bubbles because of the unprecedented long laser drive (30 ns). The experimental data, analyzed both in real and Fourier space, are compared with classical bubble-merger models [1], as well as recent theory and simulations predicting 3D bubbles reacceleration due to vorticity accumulation caused by mass ablation [2]. These experiments are of crucial importance for benchmarking 2D and 3D radiation hydrodynamics code for Inertial Confinement Fusion.


15:00

JO7 6 Finite Atwood Number Effects on Deceleration-Phase Instability in Room-Temperature Direct-Drive Implosions* S. MILLER, J.P. KNAUER, P.B. RADHA, V.N. GONCHAROV, Laboratory for Laser Energetics, U. of Rochester Performance degradation in direct-drive inertial confinement fusion implosions can be caused by several effects, one of which is Rayleigh–Taylor (RT) instability growth during the deceleration phase. In room-temperature plastic target implosions, this deceleration-phase RT growth is enhanced by the density discontinuity and finite Atwood numbers at the fuel–pusher interface. For the first time, an experimental campaign at the Omega Laser Facility systematically varied the ratio of deuterium-to-tritium (D-to-T) within the DT gas fill to change the Atwood number. The goal of the experiment was to understand the effects of Atwood number variation on observables like apparent ion temperature, yield, and variations in areal density and bulk fluid motion, which lead to broadening of neutron spectra along different lines of sight. Simulations by the hydrodynamic codes LILAC and DRACO were used to study growth rates for different D-to-T ratios and identify observable quantities effected by Atwood number variation. Results from simulations and the experiment are presented.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.
15:12


The effect of asymmetries on the inertial confinement fusion implosion yield and stagnation pressure will be presented. The asymmetries are divided into low (ℓ < 6) and intermediate (6 < ℓ < 40) modes by comparing the wavelength with the hot-spot radius. Long-wavelength modes introduce substantial nonradial motion, whereas intermediate-wavelength modes involve more cooling by thermal losses. It is found that for distorted hot spots, the measured neutron-averaged properties can be very different from the real hydrodynamic conditions. This is because mass ablation driven by thermal conduction introduces flows in the Rayleigh–Taylor bubbles that result in pressure variations, in addition to temperature variations between the bubbles and the neutron-producing region. The yield degradation—with respect to the symmetric case—results primarily from a reduction in the hot-spot pressure for low modes and from a reduction in burn volume for intermediate modes. A general expression is found relating the pressure degradation to the residual shell energy and the flow within the hot spot (i.e., the total residual energy).

∗This material is based upon work supported by the Department of Energy National Security Administration under Award Number DE-NA0001944 and by the LLNL under subcontract B614207.

15:24

JO7 8 A detailed study of bubble and spike velocities in ejecta∗ VARAD KARKHANIS, PRAVEEN RAMAPRABHU, University of North Carolina, Charlotte FRANK CHERNE, JAMES HAMMERBERG, MALCOLM ANDREWS, Los Alamos National Laboratory

We used detailed continuum hydrodynamics and molecular dynamics simulations to characterize bubble and spike growth in shock-driven ejecta. Insights from the simulations are used to suggest a modified expression for the velocity associated with ejected spike structures, while a recently proposed model [1] explains the observed bubble velocities. For spikes, existing models [2] can over-predict observed spike velocities if they do not include the modification of the initial spike growth rates due to nonlinearities. Instead, we find that using the potential flow model of [2], corrected with a suitable nonlinear prefactor leads to predictions in close agreement with our simulation data. We propose a simple empirical expression for the nonlinear correction for spike velocities that is able to reproduce results from our simulations and published experimental and simulation data over a wide range of initial conditions and Mach numbers. We verify these ideas with simulations (continuum and MD) at different amplitudes, initial perturbation shapes, and shock strength.

∗This work was supported by the Los Alamos National Laboratory.

15:36

JO7 9 Experimental platform for shock-driven Rayleigh-Taylor / Richtmeyer-Meshkov evolution before and after re-shock∗ CHANNING HUNTINGTON, SABRINA NAGEL, JASON BENDER, KUMAR RAMAN, TED BAUMANN, STEPHAN MACLAREN, SHON PRISBREY, YE ZHOU, Lawrence Livermore National Laboratory

The growth of Richtmyer-Meshkov and Rayleigh-Taylor instabilities at an interface that is impulsively accelerated, for example by the passage of a shock, have been studied in many laser-driven experiments. However, investigation of instability growth subject to a second shock (“reshock”) has to date been limited to “classical” (non-high-energy-density) shock tubes. Here we describe the results of experiments, performed on the National Ignition Facility, to directly measure the growth vs. time of the non-linear instability at a planar interface before and after reshock. In this work the unstable mixing region is directly imaged with side-on x-ray radiography, and we highlight the unique advantages of laser-driven experiments over classical shock tubes. These include precise control over the initial conditions of the instability, as well as tailored x-ray opacity to ensure accurate measurement of the entire region of material interpenetration.

∗This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344.

15:48

JO7 10 Shock-driven Rayleigh-Taylor / Richtmyer-Meshkov 2D multimode ripple evolution before and after re-shock∗ SABRINA NAGEL, CHANNING HUNTINGTON, JASON BENDER, KUMAR RAMAN, TED BAUMANN, STEPHAN MACLAREN, SHON PRISBREY, YE ZHOU, Lawrence Livermore National Laboratory

Laser-driven hydrodynamic experiments allow for the precise control over several important experimental parameters, including the timing of the laser irradiation delivered and the initial conditions of the laser-driven target. Our experimental platform at the National Ignition Facility enables the investigation of the physics of instability growth after the passage of a second shock (“reshock”). This is done by varying the laser to change the strength and timing of the secondary shock. Here we present x-ray images capturing the rapid post-reshock instability growth for a set of reshock strengths. The radiation hydrodynamics simulations used to design these experiments are also introduced.

∗This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344. LLNL-ABS-734509.

16:00

JO7 11 Computational investigation of reshock strength in hydrodynamic instability growth at the National Ignition Facility∗ JASON BENDER, KUMAR RAMAN, CHANNING HUNTINGTON, SABRINA NAGEL, BRANDON MORGAN, SHON PRISBREY, STEPHAN MACLAREN, Lawrence Livermore Natl Lab

Experiments at the National Ignition Facility (NIF) are studying Richtmyer-Meshkov and Rayleigh-Taylor hydrodynamic instabilities in multiply-shocked plasmas. Targets feature two different-density fluids with a multimode initial perturbation at the interface, which is struck by two X-ray-driven shock waves. Here we discuss computational hydrodynamics simulations investigating the effect of second-shock (“reshock”) strength on instability growth, and how these simulations are informing target design for the ongoing experimental campaign. A Reynolds-Averaged Navier Stokes (RANS) model was used to predict motion of the spike and bubble fronts and the mixing-layer width. In addition to reshock strength, the reshock ablator thickness and the total length of the target were varied; all three parameters were found to be important for target design, particularly for ameliorating undesirable reflected shocks. The RANS data are compared to theoretical models that predict multimode instability growth proportional to the shock-induced change in interface velocity, and to currently-available data from the NIF experiments.
16:12
JO7 12 3D Simulations of NIF Wetted Foam Experiments to Understand the Transition from 2D to 3D Implosion Behavior
BRIAN HAINES, RICHARD OLSON, AUSTIN YI, ALEX ZYL-STRAT, ROBERT PETERSON, PAUL BRADLEY, RAHUL SHAH, DOUG WILSON, JOHN KLINE, RAMON LEEPER, STEVE BATHA, Los Alamos National Laboratory

The high convergence ratio (CR) of layered Inertial Confinement Fusion capsule implosion capsule implosions contribute to high performance in 1D simulations yet make them more susceptible to hydrodynamic instabilities, contributing to the development of 3D flows. The wetted foam platform is an approach to hot spot ignition to achieve low-to-moderate convergence ratios in layered implosions on the NIF unobtainable using an ice layer. Detailed high-resolution modeling of these experiments in 2D and 3D, including all known asymmetries, demonstrates that 2D hydrodynamics explain capsule performance at CR > 12 but become less suitable as the CR increases. Mechanisms for this behavior and detailed comparisons of simulations to experiments on NIF will be presented. To evaluate the tradeoff between increased instability and increased performance, we present a full-scale wetted foam capsule design with 17<CR<42 and evaluate its sensitivities to asymmetries. Simulations predict that, given currently achievable levels of asymmetry, there effects negate all advantages of increased CR.


16:24
JO7 13 Depth and Extent of Gas-Ablator Mix in Symcap Implosions at the National Ignition Facility* JESSE PINO, T MA, S A MACLAREN, J D SALMONSON, D HO, S F KHAN, L MASSE, J E RALPH, C CZAJKA, D CASEY, R SACKS, V A SMALYUK, R E TIPTON, G A KYRALA, Lawrence Livermore Natl Lab

A longstanding question in ICF physics has been the extent to which capsule ablator material mixes into the burning fusion fuel and degrades performance. Several recent campaigns at the National Ignition Facility have examined this question through the use of separated reactants. A layer of CD plastic is placed on the inner surface of the CH shell and the shell is filled with a gas mixture of H and T. This allows for simultaneous neutron signals that infer the CR increases. Mechanisms for this behavior and detailed comparisons of simulations to experiments on NIF will be presented. To evaluate the tradeoff between increased instability and increased performance, we present a full-scale wetted foam capsule design with 17<CR<42 and evaluate its sensitivities to asymmetries. Simulations predict that, given currently achievable levels of asymmetry, their effects negate all advantages of increased CR.


16:36
JO7 14 Mix Models Applied to the Pushered Single Shell Capsules Fired on NIF† ROBERT TIPTON, EDUARD DEWALD, JESSE PINO, JOE RALPH, RYAN SACKS, JAY SALMONSON, Lawrence Livermore Natl Lab

The goal of the Pushered Single Shell (PSS) experimental campaign is to study the mix of partially ionized ablator material into the hotspot. To accomplish this goal, we used a uniformly Si doped plastic capsule based on the successful Two-Shock campaign [1]. The inner few microns of the capsule can be doped with a few percent Ge. To diagnose mix, we used the method of separated reactants [2]; deuterating the inner Ge-doped layer, CD/Ge, while using a gas fill of Tritium and Hydrogen. Mix is inferred by measuring the neutron yields from DD, DT, and TT reactions. The PSS implosion is fast (~400 km/sec), hot (~3KeV) and rounded (R2 ~ 0). This paper will present the calculations of RANS type mix models such as KL along with LES models such as multimcomponent Navier Stokes on several PSS shots. The calculations will be compared to each other and to the measured data.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.
†This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

important to understanding material behavior when the thermal excitation of bound electrons begins to occur. We report on experiments at the National Ignition Facility that shock compressed quartz, Mo, B$_2$C and BeO to 10-100 Mbar. Principal Hugoniot measurements of the samples were obtained using the impedance matching technique relative to a diamond standard. These new measurements can be used to constrain EOS models at previously inaccessible pressures.

*Prepared by LLNL under Contract DE-AC52-07NA27344.

14:12
JO8 2 Investigating Ta strength across multiple platforms, strain rates, and pressures† THOMAS MATTSSON, DAWN G. FLICKER, JOHN F. BENAGE, CORBETT BAUTTALIE, JUSTIN L. BROWN, J. MATTHEW D. LANE, HOJUN LIM, SANDIA NATIONAL LABORATORIES THOMAS A. ARSEN LIS, NATHAN R. BARTON, HYE-SOOK PARK, DAMIAN C. SWIFT, SHON T. PRISBREY, RYAN AUSTIN, DENNIS P. MCNABB, BRUCE A. REMINGTON, LAWRENCE LIVERMORE NATIONAL LABORATORY MICHAEL B. PRIME, GEORGE T. III GRAY, CURT A. BRONKHORST, SHUH- RONG CHEN, D.J. LUSCHER, ROBERT J. SCHARFF, SAYU J. FENSIN, MARK W. SCHRAAD, DANA M. DATTELBAUM, LOS ALAMOS NATIONAL LABORATORY STACI L. BROWN, NATIONAL SECURITY ADMINISTRATION Ta is a metal with high density and strength. We are collaborating to understand the behavior across an unprecedented range of conditions comparing strength data from Hopkinson bar, Taylor cylinder, guns, Z, Omega and the NIF using Ta from a single lot up to 380 GPa and strain rates of 10$^7$ experiments are ongoing to give more overlap between the platforms and are being simulated with models to determine the importance of specific physical processes.


14:24
JO8 3 Hugoniot Measurements of Silicon Shock Compressed to 21 Mbar* B. HENDERSON, D.N. POLSIN, T.R. BOEHLHY, M.C. GREGOR, S.X. HU, G.W. COLLINS, J.R. RYGG, LABORATORY FOR LASER ENERGETICS, U. OF ROCHESTER D.E. FRAT ANDUONO, P.M. CELLIERS, R. KRAUS, J.H. EGGERT, LLNL We present results of laser-driven shock experiments that compressed silicon samples to 21 Mbar. Impedance matching to a quartz reference provided Hugoniot data. Since silicon is opaque, a quartz witness was placed adjacent to the silicon samples; this afforded the use of the unsteady wave correction [1] to increase the precision of the transit-time measurements of shock velocity. Results are compared with both SESAME tables and quantum-molecular-dynamics calculations.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory in collaboration with the University of California, Lawrence Berkeley National Laboratory for absolute measurements of materials more opaque to x-rays.

15:00
JO8 6 Platform for absolute measurement of the compression of deuterium along isentropes to multi-TPa pressures* P. M. CELLIERS, A. FERNANDEZ-PANELLA, LAWRENCE LIVERMORE NATIONAL LABORATORY S. BRYGOO, CEA/DAM BRUYERES-L-ECHAT, FRANCE D. C. SWIFT, S. ALI, S. W. HAAN, M. MILLOT, J. H. EGGERT, D. E. FRAT ANDUONO, LAWRENCE LIVERMORE NATIONAL LABORATORY Equation of state models for deuterium and other light elements have traditionally been tested experimentally along Hugoniots, primarily the principal Hugoniot. The compression path of DT fuel in inertial confinement fusion (ICF) follows isentropes to very high density, where little experimental data measuring the compression exist. We are developing an experimental platform to compress deuterium along isentropes similar to the ICF paths using the National Ignition Facility. Our approach combines spherical geometry with multi-shock reverberation to achieve near isentropic compression to multi-TPa pressures that is diagnosed with radiographic techniques. Our plan is to measure compression paths relevant to current ICF platforms. We will describe details of the approach and preliminary data.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.
15:12
**JO8 7 Measurements of Sound Speed and Grüneisen Parameter in Polystyrene Shocked to 8.5 Mbar**
T.R. BOEHLY, J.R. RYGG, M. ZAGHOO, S.X. HU, G.W. COLLINS, Laboratory for Laser Energetics, U. of Rochester D.E. FRATANDUONO, P.M. CELLIERS, LLNL C.A. MCCOY, SNL. The high-pressure behavior of polymers is important to fundamental high-energy-density studies and inertial confinement fusion experiments. The sound speed affects shock timing and determines the amplitude of modulations in unstable shocks. The Grüneisen parameter provides a means to model off-Hugoniot behavior, especially release physics. We use laser-driven shocks and a nonsteady wave analysis to infer sound speed in shocked material from the arrival times of drive-pressure perturbations at the shock front. Data are presented for CH shocked to 8.5 Mbar and compared to models. The Grüneisen parameter is observed to drop significantly near the insulator–conductor transition—a behavior not predicted by tabular models but is observed in quantum molecular dynamic simulations.

15:24
**JO8 8 Equation of state measurements of shocked carbon foam using x-ray Thomson scattering**
PATRICK BELANCOURT, PAUL KEITER, PAUL DRAKE, University of Michigan WOLFGANG THEOBALD, SUXING HU, SEAN REGAN, Laboratory for Laser Energetics, University of Rochester PAWEL KOWIAK, West Virginia University. Simulating experiments of foams under high-energy-density physics (HEDP) conditions have been challenging due to the uncertainty of the equation of state (EOS) of foams in this regime. This motivated a recent experiment on the OMEGA EP laser system to measure the EOS of shocked 150 mg/cc carbonized resorcinol formaldehyde (CRF) foam. One OMEGA EP beam drives a shock into the CRF foam package, while the remaining three beams are used to create a nickel-He-alpha, x-ray probe. The x-ray probe penetrates the shocked foam and the imaging x-ray Thomson spectrometer (IXTS) [1] measures the scattered x-rays from the probe. The IXTS spectrally resolves the scattered x-ray beam while imaging in 1-D. This results in a temperature and ionization measurement at the shock front from the scattered x-ray spectrum and a density measurement from the imaging component. Preliminary results from this experiment will be shown.

15:36
**JO8 9 Using X-ray Thomson Scattering to Characterize Highly Compressed, Near-Degenerate Plasmas at the NIF**
TILO DOEPPNER, Lawrence Livermore National Laboratory D. KRAUS, HZDR Dresden P. NEUMAYER, GSI Darmstadt B. BACHMANN, L. DIVOL, A.L. KRITCHER, O.L. LANDEN, Lawrence Livermore National Laboratory L. FLETCHER, S.H. GLENZER, SLAC National Accelerator Laboratory R.W. FALCONE, M.J. MACDONALD, A. SAUNDERS, UC Berkeley B. WITTE, R. REDMER, University of Rostock D. CHAPMAN, R. BAGGOTT, D.O. GERICKE, University of Warwick S.A. YI, Los Alamos National Laboratory. We are developing x-ray Thomson scattering for implosion experiments at the National Ignition Facility to characterize plasma conditions in plastic and beryllium capsules near stagnation, reaching more than 20x compression and electron densities of 10^{23} cm^{-3}, corresponding to a Fermi energy of 170 eV. Using a zirc H-\alpha x-ray source at 9 keV, experiments at a large scattering angle of 120° measure non-collective scattering spectra with high sensitivity to K-shell ionization, and find higher charge states than predicted by widely used ionization models. Reducing the scattering angle to 30° probes the collective scattering regime with sensitivity to collisions and conductivity. We will discuss recent results and future plans.

15:48
**JO8 10 XFEL diffraction measurements of shocked Fe and Fe alloys for planetary science**
ANDREW KRYGIER, LLNL, Livermore, CA M HARMAND, G MORARD, R NEMSAUS, G FIQUET, IMPMC, France E MCBRIDE, K APPEL, DESY, Germany B ALBERTAZZI, A BENUZZI-MOUNAIX, M KÖNIG, T VINCI, LULI, France K KODAMA, K MIYANISHI, NOZAKI, Osaka University, Japan N HARTLEY, HZDR, Germany Z KONOPKOVA, European XFEL, Germany E GALTIER, H-J LEE, B NAGLER, SLAC, Menlo Park, CA V SVITLYK, ESRF, France. Earth's core is composed of Fe mixed with small amounts of light elements like Si, O, and C. Determining the phase relations of Fe and derivative alloys is important for understanding the cores of Earth and terrestrial exoplanets. High pressure and temperature conditions can be achieved with high power lasers, but the states are highly transient and their characterization has been limited by the lack of appropriate platforms. The recent advance of facilities with high-power lasers coupled to XFELs enables characterization of shocked states with the powerful suite of X-ray techniques used by the static community. Here we present results from recent X-ray diffraction measurements of shocked Fe alloys at the coupled XFEL-optical laser at SACLA (EHS) and LCLS (MEC).

16:00
**JO8 11 Temperature in subsonic and supersonic radiation fronts measured at OMEGA**
HEATHER JOHNS, JOHN KLINE, NICK LANIER, T. PERRY, C. FONTES, C. FRYER, Los Alamos Natl Lab COLIN BROWN, JOHN MORTON, AWE, UK. Propagation of heat fronts relevant to astrophysical plasmas is challenging in the supersonic regime. Plasma T_e changes affect opacity and equation of state without hydrodynamic change. In the subsonic phase density perturbations form at material interfaces as the plasma responds to radiation pressure of the front. Recent experiments at OMEGA studied this transition in aerogel foams driven by a hohlraum. In COAX, two orthogonal backlighters drive x-ray radiography and K-shell absorption spectroscopy to diagnose the subsonic shape of the front and supersonic T_e profiles. Past experiments used absorption spectroscopy in chlorinated foams to measure the heat front [1]; however, Cl dopant is not suitable for higher material temperatures at NIF. COAX has developed use of Sc and Ti dopants to diagnose T_e between 60-100eV and 100-180eV. Analysis with PrismSPECT using OPLIB [3] tabular opacity data [4] will
evaluate the platform’s ability to advance radiation transport in this regime.


16:12
JO8 12 Development of a Buried Layer Platform at the OMEGA Laser to Study Open L-SHELL Spectra from Coronal (non-LTE) Plasmas* EDWARD MARLEY, CHARLIE JARROT, MARILYN SCHNEIDER, ELIJAH KEMP, MARK FOORD, ROBERT HEETER, DUANE LIEDEHL, KLAUSE WIDMANN, CHRISTOPHER MAUCHE, GREG BROWN, JAMES EMIG, Lawrence Livermore National Laboratory A buried layer platform is being developed at the OMEGA laser to study the open L-shell spectra of coronal (non-LTE) plasmas (ne ~ few 10^{19}/cm³, Te ~0.8–1.2 keV) of mid Z materials. Studies have been done using a 250 μm diameter dot composed of a layer of 1200 Å thick Zn between two 600 Å thick layers of Ti, in the center of a 1000 μm diameter, 13 μm thick beryllium tamper. Lasers heat the target from both sides for up to 3 ns. The size of the microdot vs time was measured with x-ray imaging (face-on and side–on). The radiant x-ray power was measured to 3 ns. The size of the microdot vs time was measured with x-ray imaging (face-on and side–on). The radiant x-ray power was measured to 3 ns. The size of the microdot vs time was measured with x-ray imaging (face-on and side–on). The radiant x-ray power was measured to 3 ns. The size of the microdot vs time was measured with x-ray imaging (face-on and side–on). The radiant x-ray power was measured to 3 ns.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

16:24
JO8 13 Dielectronic Satellite Spectra of Na-like Mo Ions Bench-marked by LLNL EBIT with Application to HED Plasmas* A. STAFFORD, A.S. SAFRONOVA, V.I. KANTSYREV, U.I. SAFRONOVA, E.E. PETKOV, V.V. SHLYAPTESEVA, R. CHILDERS, I. SHRESTHA, University of Nevada, Reno P. BEIERSDORFER, H. HELM, G.V. BROWN, Lawrence Livermore National Laboratory Dielectronic recombination (DR) is an important process for astrophysical and laboratory high energy density (HED) plasmas and the associated satellite lines are frequently used for plasma diagnostics. In particular, K-shell DR satellite lines were studied in detail in low-Z plasmas. L-shell Na-like spectral features from Mo X-pinsches considered here represent the blend of DR and inner shell satellites and motivated the detailed study of DR at the EBIT-1 electron beam ion trap at LLNL. In these experiments the beam energy was swept between 0.6 – 2.4 keV to produce resonances at certain electron beam energies. The advantages of using an electron beam ion trap to better understand atomic processes with highly ionized ions in HED Mo plasma are highlighted.

*This work was supported by NNSA under DOE Grant DE-NA0002954. Work at LLNL was performed under the auspices of the U.S. DOE under Contract No. DE-AC52-07NA27344.

16:36
JO8 14 Non-LTE modeling of the radiative properties of high-Z plasma using linear response methodology* MARK FOORD, JUDY HARTE, HOWARD SCOTT, Lawrence Livermore National Laboratory Non-local thermodynamic equilibrium (NLTE) atomic processes play a key role in the radiation flow and energetics in highly ionized high temperature plasma encountered in inertial confinement fusion (ICF) and astrophysical applications. Modeling complex high-Z atomic systems, such as gold used in ICF hohlraums, is particularly challenging given the complexity and intractable number of atomic states involved. Practical considerations, i.e. speed and memory, in large radiation-hydrodynamic simulations further limit model complexity. We present here a methodology for utilizing tabulated NLTE radiative and EOS properties for use in our radiation-hydrodynamic codes. This approach uses tabulated data, previously calculated with complex atomic models, modified to include a general non-Planckian radiation field using a linear response methodology. This approach extends near-LTE response method [1] to conditions far from LTE. Comparisons of this tabular method with in-line NLTE simulations of a laser heated 1-D hohlraum will be presented, which show good agreement in the time-evolution of the plasma conditions.

*This work was supported by the National Science Foundation.

TUESDAY AFTERNOON

SESSION JP11: POSTER SESSION IV: EDUCATION AND OUTREACH; HIGH SCHOOL OR UNDERGRADUATE RESEARCH; C-MOD, MTF, & MFE THEORETICAL METHODS Tuesday, 24 October 2017

Exhibit Exhibit Hall D at 14:00

JP11 1 EDUCATION AND OUTREACH

JP11 2 Outreach to Underrepresented Groups in Plasma Physics* A. DOMINGUEZ, A. ZWICKER, D. ORTIZ, S.L. GRECO, PPPL. Physics, and specifically plasma physics, has a recruitment and retention problem for women and historically underrepresented minorities at all levels of their academic careers [1]. For example, women make up approximately 8% of the APS-DPP membership while making up 13% of APS membership at large. In this presentation, we describe outreach activities we have undertaken targeting retention of these groups after their undergraduate careers. These include: Targeted recruitment visits for undergraduate research internships, as well as plasma physics workshops aimed at undergraduate women in physics, faculty members of minority
serving institutions, and underrepresented undergraduates. After the first year of implementation, we have already seen results, including students reached through these programs participating in SULI undergraduate internships at PPPL.

*This work was support by a Grant from the DOE Office of Workforce Development for Teachers and Scientists (WDTS).

1AIP Physics Trends (www.aip.org/statistics).

** Pathway to STEM: Using Outreach Initiatives as a Method of Identifying, Educating and Recruiting the Next Generation of Scientists and Engineers**

**DEEDEE ORTIZ-ARIAS, ANDREW ZWICKER, ARTURO DOMINGUEZ, SHANNON GRECO, Princeton Plasma Phys Lab**

The Princeton Plasma Physics Laboratory (PPPL) uses a host of outreach initiatives to inform the general population: the Young Women’s Conference, Science Bowl, Science Undergraduate Laboratory Internship, My Brother’s Keeper, a variety of workshops for university faculty and undergraduate students, public and scheduled lab tours, school and community interactive plasma science demonstrations. In addition to informing and educating the public about the laboratory’s important work in the areas of Plasma and Fusion, these outreach initiatives, are also used as an opportunity to identify/educate/recruit the next generation of the STEM workforce. These programs provide the laboratory with the ability to: engage the next generation at different paths along their development (K-12, undergraduate, graduate, professional), at different levels of scientific content (science demonstrations, remote experiments, lectures, tours), in some instances, targeting underrepresented groups in STEM (women and minorities), and train additional STEM educators to take learned content into their own classrooms.

**The ZPIC educational code suite**

R. CALADO, M. PARDAL, P. NINHOS, A. HELM, IPFN/IST Portugal W. B. MORI, V. K. DECYK, UCLA J. VIEIRA, L. O. SILVA, IPFN/IST Portugal R. A. FONSECA, ISCTE-IUL Portugal Particle-in-Cell (PIC) codes are used in almost all areas of plasma physics, such as fusion energy research, plasma accelerators, space physics, ion propulsion, and plasma processing, and many other areas. In this work, we present the ZPIC educational code suite, a new initiative to foster training in plasma physics using computer simulations. Leveraging on our expertise and experience from the development and use of the OSIRIS PIC code, we have developed a suite of 1D/2D fully relativistic electromagnetic PIC codes, as well as 1D electrostatic. These codes are self-contained and require only a standard laptop/desktop computer with a C compiler to be run. The output files are written in a new file format called ZDF that can be easily read using the supplied routines in a number of languages, such as Python, and IDL. The code suite also includes a number of example problems that can be used to illustrate several textbook and advanced plasma mechanisms, including instructions for parameter space exploration. We also invite contributions to this repository of test problems that will be made freely available to the community provided the input files comply with the format defined by the ZPIC team. The code suite is freely available and hosted on GitHub at https://github.com/zambzamb/spic.

*Work partially supported by PICKSC.

**Terrella for Advanced Undergraduate Physics Laboratory***

JIM REARDON, DOUGLASS ENDRIZZI, CARY FOREST, STEVEN OLIVA, University of Wisconsin–Madison A terrella has been in use in the Advanced Laboratory for undergraduates in the Physics Department at the University of Wisconsin-Madison since spring 2016. Our terrella is a permanent magnet on a pedestal which may be biased in various ways. In the vacuum region B ≲ 200 gauss; for typical operation p ≲ 10⁻⁴ Torr. Plasma may be created by thermionic emission from a filament or by an S-band magnetron. Students are guided through diagnosis of the terrella plasma using spectroscopy and swept Langmuir probes. A suite of supporting experiments has been developed to introduce basic plasma phenomena, such as the Child-Langmuir law.

*Supported by NSF Grant PHY-1617602.

**Development of a Non-Contact, Inductive Depth Sensor for Free-Surface, Liquid-Metal Flows***

GERRIT BRUHAUG, Idaho State University EGEMEN KOLEMEN, Princeton Plasma Physics Lab ADAM FISCHER, Princeton University Mike HVASTA, Princeton Plasma Physics Lab This paper details a non-contact based, inductive depth measurement system that can sit behind a layer of steel and measure the depth of the liquid metal flowing over the steel. Free-surface liquid metal depth measurement is usually done with invasive sensors that impact the flow of the liquid metal, or complex external sensors that require lasers and precise alignment. Neither of these methods is suitable for the extreme environment encountered in the divertor region of a nuclear fusion reactor, where liquid metal open channel flows are being investigated for future use. A sensor was developed that used the inductive coupling of a coil to liquid metal to measure the height of the liquid metal present. The sensor was built and tested experimentally, and modeled with finite element modeling software to further understand the physics involved. Future work will attempt to integrate the sensor into the Liquid Metal eXperiment (LMX) at the Princeton Plasma Physics Laboratory for more refined testing.

*This work was made possible by funding from the Department of Energy for the Summer Undergraduate Laboratory Internship
(SULI) program. This work is supported by the US DOE Contract No.DE-AC02-09CH11466.

JP11 9 Detection of an electron beam in a high density plasma via an electrostatic probe* STEPHEN MAJESKI, Rensselaer Polytechnic Institute JONGSOO YOO, STEWART ZWEBEN, MASAAKI YAMADA, HANTAO JI, Princeton Plasma Physics Laboratory The perturbation in floating potential by an electron beam is detected by a 1D floating potential probe array to evaluate the use of an electron beam for magnetic field line mapping in the Magnetic Reconnection Experiment (MRX) plasma. The MRX plasma is relatively high density (10^{13} \text{ cm}^{-3}) and low temperature (5 \text{ eV}). Beam electrons are emitted from a tungsten filament and are accelerated by a 200 V potential across the sheath. They stream along the magnetic field lines towards the probe array. The spatial electron beam density profile is assumed to be a Gaussian along the radial axis of MRX and the effective beam width is determined from the radial profile of the floating potential. The magnitude of the perturbation is in agreement with theoretical predictions and the location of the perturbation is also in agreement with field line mapping. In addition, no significant broadening of the electron beam is observed after propagation for tens of centimeters through the high density plasma. These results demonstrate that this method of field line mapping is, in principle, feasible in high density plasmas.

*This work is supported by the DOE Contract No. DE-AC0209CH11466.

JP11 10 High-Resolution Measurement of the Turbulent Frequency-Wavenumber Power Spectrum in a Laboratory Magnetosphere* T.M. QIAN, M.E. MAUEL, Columbia University In a laboratory magnetosphere, plasma is confined by a strong dipole magnet, where interchange and entropy mode turbulence can be studied and controlled in near steady-state conditions [1]. Whole-plasma imaging shows turbulence dominated by long wavelength modes having chaotic amplitudes and phases [2]. Here, we report for the first time, high-resolution measurement of the frequency-wavenumber power spectrum by applying the method of Capon [3] to simultaneous multi-point measurement of electrostatic entropy modes using an array of floating potential probes. Unlike previously reported measurements in which ensemble correlation between two probes detected only the dominant wavenumber, Capon’s “maximum likelihood method” uses all available probes to produce a frequency-wavenumber spectrum, showing the existence of modes propagating in both electron and ion magnetic drift directions. We also discuss the wider application of this technique to laboratory and magnetospheric plasmas with simultaneous multi-point measurements.

*Supported by NSF-DOE Partnership in Plasma Science Grant DE-FG02-00ER54585.


JP11 11 Design of a laboratory platform for atmospheric pressure biomedical plasma experiments* SARAH LEE, SARA RUTZ, NATHANIEL HICKS, BRANDON BRIGGS, University of Alaska Anchorage The design of a laboratory set up for atmospheric pressure plasma (APP) experiments with biomedical applications is described. A comparison between various types of cold APP discharges (DC, RF, microwave) is presented, as well as various configurations of electrodes, dielectric materials, and gas feed conditions. Particular attention is paid to designs comprising floating electrode dielectric barrier discharges (FE-DBD) (for example as described in [1]), but atmospheric pressure plasma jets are considered as well. A plan is discussed for initial experiments on the response of bacterial populations of E. coli and Deinococcus radiodurans to APP treatment as well as to media activated by APP.

*Supported by 2017 University of Alaska Anchorage Innovate Award.


JP11 12 Towards an understanding of flows in avalanche transport phenomena* SUYING JIN, NIKOLAS RAMADAN, BART VAN COMPERNOLLE, MATT J. POULOS, GEORGE J. MORALES, Univ of California - Los Angeles Recent heat transport experiments [1] conducted in the Large Plasma Device (LAPD) at UCLA, studying avalanche phenomena at steep cross-magnetic field pressure gradients, suggest that flows play a critical role in the evolution of transport phenomena, motivating further characterization. A ring shaped electron beam source injects sub-ionization energy electrons along the strong background magnetic field within a larger quiescent plasma, creating a hollow, high pressure filament. Two distinct regimes are observed as the density decays; the first characterized by multiple small avalanches producing sudden relaxations of the pressure profile which then recovers under continued heating, and the second signaled by a permanent collapse of the density profile after a global avalanche event, then dominated by drift-Alven waves. The source is modified from previous experiments to gain active control of the flows by controlling the bias between the emitting ring and surrounding carbon masks. The results of flow measurements obtained using a Mach probe and Langmuir/emissive probe are here presented and compared. An analytical model for the behavior of the electron beam source is also in development.

*Supported by NSF Grant 1619505 and by DOE/NSF at BaPSF.


JP11 13 Microwave Interferometric Density Measurements of a Pulsed Helicon Source* ETHAN SCIME, EARL SCIME, DEREK THOMPSON, West Virginia University The intense rf environment of a helicon plasma source is problematic for electrostatic probe measurements of plasma density, particularly at low neutral pressures. Here we present measurements of the line-integrated plasma density in a helicon plasma source using a multi-frequency (20–40 GHz) microwave interferometer. The design of the diagnostic and the data acquisition system are presented, as well as a comparison to density profiles obtained with a moveable electrostatic probe. A parametric fit to the probe profile measurements is used to determine the peak density from the microwave density measurements.

*This work supported by U.S. National Science Foundation Grant No. PHY-1360278.

JP11 14 Magnet Topology and Homoclinic Tangles in Single-Null Divertor Tokamaks* AYANA CRUTCHFIELD, KESSIENA OFUNREIGN, HALIMA ALI, ALKESH PUNJABI, Hampton University Divertors are a regular feature of the modern day large tokamaks. Divertors are required for handling the plasma particle and heat exhausts on the walls in fusion plasmas. The single-null divertor can have two distinct magnetic topologies: open unbounded topology and closed compact topology. The simple map (SM) [1] generically represents open unbounded topology; and the symmetric
quartic map (SQM) [2] generically represents the closed compact topology. The parameters in the symmetric quartic map are chosen so that the magnetic geometry of the symmetric quartic map is comparable to the simple map. The new approach for calculation of homoclinic tangles of separatrices in Hamiltonian systems [3] is used. The map parameters of the SM and the SQM are used to represent the magnetic asymmetries as in the standard map. The homoclinic tangles of the primary separatrix of the single-null divertor tokamaks with the two distinct topologies are calculated, compared, and contrasted.

This work is supported by Grants DE-FG02-01ER54624, DEFG02-04ER54793, and DE-FG02-07ER54937. This research used resources of the NERSC, supported by the Office of Science, US DOE, under Contract No. DE-AC02-05CH11231.


**JP11 15 Online plasma calculator**

H. WISNIEWSKI, Whitworth University P.-A. GOURDAIN, University of Rochester

APOLLO is an online, Linux based plasma calculator. Users can input variables that correspond to their specific plasma, such as ion and electron densities, temperatures, and external magnetic fields. The system is based on a webserver where a FastCGI protocol computes key plasma parameters including frequencies, lengths, velocities, and dimensionless numbers. FastCGI was chosen to overcome security problems caused by JAVA-based plugins. The FastCGI also speeds up calculations over PHP based systems. APOLLO is built upon the WT library, which turns any web browser into a versatile, fast graphic user interface. All values with units are expressed in SI units except temperature, which is in electron-volts. SI units were chosen over cgs units because of the gradual shift to using SI units within the plasma community. APOLLO is intended to be a fast calculator that also provides the user with the proper equations used to calculate the plasma parameters. This system is intended to be used by undergraduates taking plasma courses as well as graduate students and researchers who need a quick reference calculation.

**JP11 16 An assessment of surface emissivity variation effects on plasma uniformity analysis using IR cameras**

ABIGAIL GREENHALGH, Univ. of Kentucky MELISSA SHOWERS, Univ. of Tennessee THEODORE BIEWER, Oak Ridge National Lab

The Prototype-Material Plasma Exposure eXperiment (Proto-MPEX) is a linear plasma device operating at Oak Ridge National Laboratory (ORNL). Its purpose is to test plasma source and heating concepts for the planned Material Plasma Exposure eXperiment (MPEX), which has the mission to test the plasma-material interactions under fusion reactor conditions. In this device material targets will be exposed to high heat fluxes (>10 MW/m²). To characterize the heat fluxes to the target a IR thermography system is used taking up to 432 frames per second videos. The data is analyzed to determine the surface temperature on the target in specific regions of interest. The IR analysis has indicated a low level of plasma uniformity; the plasma often deposits more heat to the edge of the plate than the center. An essential parameter for IR temperature calculation is the surface emissivity of the plate (stainless steel). A study has been performed to characterize the variation in the surface emissivity of the plate as its temperature changes and its surface finish is modified by plasma exposure.

**JP11 17 Sensitivity of wave propagation in the LHRF to initial poloidal position in finite-aspect-ratio toroidal plasmas**

J.J. LARSON, U. Iowa R.I. PINSKER, General Atomics P.T. BONOLI, M. PORKOLAB, MIT

The important effect of varying the initial poloidal wave-launching location to the core accessibility of lower hybrid slow waves in a torus of finite aspect ratio has been understood for many years [1]. Since the qualitative properties of the wave propagation of the other branch in this regime, known as the ‘whistler’, ‘helicon’ or simply the ‘fast wave’, are similar in some ways to those of the slow wave [2], we expect a dependence on launch position for this wave also. We study this problem for both slow and fast waves, first with simplified analytic models and then using the ray-tracing code GENRAY for realistic plasma equilibria. We assess the prospects of inside, top, bottom or conventional outside launch of waves on each of the two branches. Although the slow wave has been the focus of research for LHRF heating and current drive in the past, the fast wave will play a major role in burning plasmas beyond ITER where Te(0) = 10-20 keV. The stronger electron Landau damping of the slow wave will restrict the power deposition to the outer third of the plasma, while the fast wave’s weaker damping allows the wave to penetrate to the hot plasma core before depositing its power.

*Work supported in part by US DoE under the Science Undergraduate Laboratory Internship (SULI) program and under DE-FC02-04ER54698 and DE-FG02-91-ER54109.


**JP11 18 XPS investigation of depth profiling induced chemistry**

QUINN PRATT, University of San Diego CHARLES SKINNER, Princeton Plasma Physics Laboratory BRUCE KOEL, ZHU CHEN, Princeton University

Surface analysis is an important tool for understanding plasma-material interactions. Depth profiles are typically generated by etching with a monatomic argon ion beam, however this can induce unintended chemical changes in the sample. Tantalum pentoxide, a sputtering standard, and PEDOT:PSS, a polymer that was used to mimic the response of amorphous carbon-hydrogen co-deposits, were studied. We compare depth profiles generated with monatomic and gas cluster ion beam (GCIB) using X-ray photoelectron spectroscopy (XPS) to quantify chemical changes. In both samples, monatomic ion bombardment led to beam-induced chemical changes. Tantalum pentoxide exhibited preferential sputtering of oxygen and the polymer experienced significant bond modification. Depth profiling with clusters is shown to mitigate these effects. We present sputtering rates for Ta2O5 and PEDOT:PSS as a function of incident energy and flux.

*Support was provided through DOE Contract Number DE-AC02-09CH11466.

**JP11 19 Statistical characterization of surface features from tungsten-coated divertor inserts in the DIII-D Metal Rings Campaign**

JACOB ADAMS, Virginia Tech EZEKIAL UNTERBERG, Oak Ridge National Lab CHRISTOPHER CHROBAK, BRIAN STAHL, TYLER ABRAMS, General Atomics

Continuing analysis of tungsten-coated inserts from the recent DIII-D Metal Rings Campaign utilizes a statistical approach to study carbon migration and deposition on W surfaces and to characterize the pre-versus post-exposure surface morphology. A TZM base was coated
with W using both CVD and PVD and allowed for comparison between the two coating methods. The W inserts were positioned in the lower DIII-D divertor in both the upper (shell) region and lower (floor) region and subjected to multiple plasma shots, primarily in H-mode. Currently, the post-exposure W inserts are being characterized using SEM/EDX to qualify the surface morphology and to quantify the surface chemical composition. In addition, profilometry is being used to measure the surface roughness of the inserts both before and after plasma exposure. Preliminary results suggest a correlation between the pre-exposure surface roughness and the level of carbon deposited on the surface. Furthermore, ongoing in-depth analysis may reveal insights into the formation mechanism of nanoscale bumps found in the carbon-rich regions of the W surfaces that have not yet been explained.

*Work supported in part by US DoE under the Science Undergraduate Laboratory Internship (SULI) program and under DE-FC02-04ER54698.

**JP11 20 Data Analysis of the Gated-LEH X-Ray Imaging Diagnostic at the NIF**

Matthew Thibodeau, Rice Univ Hui Chen, Lawrence Livermore National Laboratory

The Gated Laser Entrance Hole (G-LEH) x-ray imaging diagnostic [1, 2] in use at the NIF offers a desirable combination of spatial and temporal resolution. By looking inside of NIF hohlraums with time resolution, G-LEH measures target features including LEH size and capsule size. A framework is presented for automated and systematic analysis of G-LEH images that measures several physical parameters of interest and their evolution over time. The results from these analyses enable comparisons with hohlraum models and allow model validation of LEH closure velocity and the extent of capsule blow-off.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.


**JP11 21 Experimental analysis of coupling between Compressional Alfvén Eigenmodes and Kinetic Alfvén Waves in NSTX**

Z Deng, NA Crocker, UCLA Y Ren, V E Belova, PPPL

In NSTX, there exists an unexplained $T_e$ profile flattening with increasing toroidal magnetic field, and neutral beam power. Core localized Compressional Alfvén Eigenmodes (CAEs) are a candidate cause. Simulations [Belova, PRL 2015] show that CAEs take energy from core energetic ions that would otherwise heat the electrons and deposit it in the edge via coupling with Kinetic Alfvén Waves (KAWs) at the Alfvén resonance location. However, this theory lacks experimental validation. To provide experimental support, we analyze high-k scattering measurements, which show signatures of CAE-KAW mode conversion. The spectrum of microwaves scattered from $6n$ fluctuations with $k_\| \rho_s \sim 1$ shows large narrow peaks at typical CAE frequencies ($f \sim 1 \text{ MHz}$), as expected. Corresponding peaks also appear at negative $f$, but their amplitudes can be much smaller, consistent with expectation for scattering. (Peaks could also result from index of refraction modulation by CAEs, but the peaks at positive and negative $f$ would have equal amplitude.) To further test that the scattering peaks are caused by fluctuations associated with CAEs, we next make sure these peaks are coherent with corresponding CAE peaks in the magnetic fluctuation spectrum, as would be expected for mode conversion. Finally, we compare the location where KAWs are detected with the location of the Alfvén resonance.

The results of the analysis seem to suggest that peaks in the high-k spectrum do indeed result from KAWs mode converted from CAEs.

*Support by DOE Grants DE-SC0011810, DE-AC02-09CH11466.

**JP11 22 Measurement of the thermal effects in the dispersion relation of the dust acoustic wave**

Joshua Hoyang, Jeremiahi Williams, Wittenberg University

A complex (dusty) plasma is a four-component plasma system composed of ions, electrons, neutral particles and charged microparticles. The charged microparticles interact with, and self-consistently modify, the surrounding plasma medium; resulting in a new and unique state of matter that can support a wide range of physical phenomena. Among these is a new wave mode known as the dust acoustic, or dust density, wave (DAW). The DAW is a low-frequency, longitudinal mode that propagates through the microparticle component of the dusty plasma system and is self-excited by the energy from the ions streaming through this component. Over the past twenty years, the dust acoustic wave has been a subject of intense study and recent studies have shown that thermal effects can, in some cases, have a significant role in the measured dispersion relation. A recent theoretical model suggests that the thermal effects are, in part, due to the finite size of the dusty plasma systems that support this wave mode. In this poster, we report the results of an experimental study examining this effect over a range of experimental conditions in a weakly-coupled dusty plasma system in an rf discharge plasma.

*This work is supported by US National Science Foundation through Grant No. PHY-1615420.

**JP11 23 Development of a time-resolved stereoscopic PIV system**

Kristin Irlam, Wittenberg.edu

Jeremiahi Williams, Wittenberg University

Over the past twenty years, a variety of particle image velocimetry (PIV) techniques have been used to characterize the particle transport and thermal state of dusty plasma systems. While the majority of these techniques required the use of a dedicated PIV system, recent advances in imaging technology have led to the development of a time-resolved two-dimensional (planar) version of this diagnostic technique which allows this diagnostic technique to be applied without the need for a dedicated PIV system. This poster will present recent work developing a relatively inexpensive time-resolved stereoscopic PIV system that can measure the full three-dimensional transport. Preliminary results will be presented.

*This work is supported by US National Science Foundation through Grant No. PHY-1615420.

**JP11 24 2D Measurements of the Balmer Series in Proto-MPEX using a Fast Visible Camera Setup**

Elizabeth G. Lindquist, Hope College

The Prototype Material Plasma Exposure eXperiment (Proto-MPEX) is a linear plasma device with densities up to $10^{20}$ m$^{-3}$ and temperatures up to 20 eV. Broadband spectral measurements show the visible emission spectra are solely due to the Balmer lines of deuterium. Monochromatic and RGB color Sanstreak SC1 Edgertronic fast visible cameras capture high speed video of plasmas in Proto-MPEX. The color camera is equipped with a long pass 450 nm filter and an internal Bayer filter to view the $\text{D}_\alpha$ line at 656 nm on the red channel and the $\text{D}_\beta$ line at 486 nm on the blue channel. The monochromatic camera has a 434 nm narrow bandpass filter to view the $\text{D}_\gamma$ intensity. In the setup, a 50/50 beam splitter is used so both cameras image the same region of the plasma discharge. Camera images were aligned...
JP11 25 Design and Control of Small Neutral Beam Arc Chamber for Investigations of DIII-D Neutral Beam Failure During Helium Operation* CARL FREMLIN, Rose-Hulman Inst of Tech JASPER BECKERS, University of Technology, Eindhoven, the Netherlands BRENDAN CROWLEY, JOSEPH RAUCH, JIM SCOVILLE, General Atomics The Neutral Beam system on the DIII-D tokamak consists of eight ion sources using the Common Long Pulse Source (CLPS) design. During helium operation, desired for research regarding the ITER pre-nuclear phase, it has been observed that the ion source arc chamber performance steadily deteriorates, eventually failing due to electrical breakdown of the insulation. A significant investment of manpower and time is required for repairs. To study the cause of failure a small analogue of the arc chamber including the PLC based operational control system for the experiment, analysis of the magnetic confinement and details of the diagnostic suite.

*Work supported in part by US DoE under the Science Undergraduate Laboratory Internship (SULI) program and under DE-FC02-04ER54698.

JP11 26 Enhancements to the Low-Energy Ion Facility at SUNY Geneseo ZACHARIAH BARFIELD, STEVEN KOSTICK, ETHAN NAGASING, KURT FLETCHER, STEPHEN PADALINO, SUNY Geneseo The Low Energy Ion Facility at SUNY Geneseo is used for detector development and characterization for inertial confinement fusion diagnostics. The system has been upgraded to improve the ion beam quality by reducing contaminant ions. In the new configuration, ions produced by the Peabody Scientific duoplasmatron ion source are accelerated through a potential, focused into a new NEC analyzing magnet and directed to an angle of 30°. A new einzel lens on the output of the magnet chamber focuses the beam into a scattering chamber with a water-cooled target mount and rotatable detector mount plates. The analyzing magnet has been calibrated for deuterons, 4He+, and 4He2+ ion beams at a range of energies, and no significant hysteresis has been observed. The system can accelerate deuterons to energies up to 25 keV to initiate d-d fusion using a deuterated polymer target. Charged particle spectra with protons, tritons, and 3He ions from d-d fusion have been measured at scattering angles ranging from 55° to 135°. A time-of-flight beamline has been designed to measure the energies of ions elastically scattered at 135°. CEM detectors initiate start and stop signals from secondary electrons produced when low energy ions pass through very thin carbon foils.

*Funded in part by the U.S. Department of Energy through the Laboratory for Laser Energetics.

JP11 27 Study of high field side/low field side asymmetry in the electron temperature profile with electron cyclotron emission* V.R. GUGLIADA, Ithaca Coll/M.E. AUSTIN, M.W. BROOKMAN, U. Texas Electron cyclotron emission (ECE) provides high resolution measurements of electron temperature profiles \( T_e(R, t) \) in tokamaks. Calibration accuracy of this data can be improved using a sawtooth averaging technique. This improved calibration will then be utilized to determine the symmetry of \( T_e \) profiles by comparing low field side (LFS) and high field side (HFS) measurements. Although \( T_e \) is considered constant on flux surfaces, cases have been observed in which there are pronounced asymmetries about the magnetic axis, particularly with increased pressure. Trends in LFS/HFS overlap are examined as functions of plasma pressure, MHD mode presence, heating techniques, and other discharge conditions. This research will provide information on the accuracy of the current two-dimensional mapping of flux surfaces in the tokamak. Findings can be used to generate higher quality EFITs and inform ECE calibration.

*This work was made possible by funding from the Department of Energy for the Summer Undergraduate Laboratory Internship (SULI) program. This work is supported by the US DOE Contract No. DE-AC02-09CH11466.

JP11 28 Building a database for statistical characterization of ELMs on DIII-D* B.J. FRITCH, University of Northern Iowa A. MARINONI, MIT A. BORTOLON, PPPL Edge localized modes (ELMs) are bursty instabilities which occur in the edge region of H-mode plasmas and have the potential to damage in-vessel components of future fusion machines by exposing the divertor region to large energy and particle fluxes during each ELM event. While most ELM studies focus on average quantities (e.g. energy loss per ELM), this work investigates the statistical distributions of ELM characteristics, as a function of plasma parameters. A semi-automatic algorithm is being used to create a database documenting trigger times of the tens of thousands of ELMs for DIII-D discharges in scenarios relevant to ITER, thus allowing statistically significant analysis. Probability distributions of inter-ELM periods and energy losses will be determined and related to relevant plasma parameters such as density, stored energy, and current in order to constrain models and improve estimates of the expected inter-ELM periods and sizes, both of which must be controlled in future reactors.

*Work supported in part by US DoE under the Science Undergraduate Laboratory Internships (SULI) program, DE-FC02-04ER54698 and DE-FG02-94ER54235.

JP11 29 Whistler wave generation by electron temperature anisotropy during asymmetric magnetic reconnection in space* JOSH SWERDLOW, Yale University JONGSOO YOO, EUNHWA KIM, MASAAKI YAMADA, HANTAO JI, Princeton Plasma Physics Laboratory Generation of whistler waves during asymmetric reconnection is studied by analyzing data from a MMS (Magnetospheric Multiscale) event [1]. In particular, the possible role of electron temperature anisotropy in excitation of whistler waves on the magnetosphere side is discussed. The local electron distribution function is fitted into a sum of bi-Maxwellian distribution functions. Then, the dispersion relation solver, WHAMP (waves in homogeneous, anisotropic, multicomponent plasmas [2]), is used to obtain the local dispersion relation and growth rate of the whistler waves. We compare the theoretical calculations with the measured dispersion relation.

*Work supported in part by US DoE under the Science Undergraduate Laboratory Internships (SULI) program, DE-FC02-04ER54698 and DE-FG02-94ER54235.
**JP11 30 Measured vs. Predicted Pedestal Pressure During RMP ELM Control in DIII-D**

**BAILEY ZYWICKI, U. Mich MAX FENSTERMACHER, LLNL RICHARD GROEBNER, ORSO MENEGHINI, GA**

From database analysis of DIII-D plasmas with Resonant Magnetic Perturbations (RMPs) for ELM control, we will compare the experimental pedestal pressure ($p_{ped}$) to EPED code predictions and present the dependence of any $p_{ped}$ differences from EPED on RMP parameters not included in the EPED model, e.g., RMP field strength, toroidal and poloidal spectrum etc. The EPED code, based on Peeling-Ballooning and Kinetic Ballooning instability constraints, will also be used by ITER to predict the H-mode $p_{ped}$ without RMPs. ITER plans to use RMPs as an effective ELM control method. The need to control ELMs in ITER is of the utmost priority, as it directly correlates to the lifetime of the plasma facing components. An accurate means of determining the impact of RMP ELM control on the $p_{ped}$ is needed, because the device fusion power is strongly dependent on $p_{ped}$. With this new collection of data, we aim to provide guidance to predictions of the ITER pedestal during RMP ELM control that can be incorporated in a future predictive code.

*Work supported in part by US DoE under the Science Undergraduate Laboratory Internship (SULI) program and under DE-FC02-04ER54698, and DE-AC52-07NA27344.

**JP11 31 Origin of Non-Gaussian Spectra Observed via the Charge Exchange Recombination Spectroscopy Diagnostic in the DIII-D Tokamak**

**ALEX SULYMAN, UC Davis COLIN CHRYSAL, General Atomics SHAUN HASKEY, Princeton Plasma Physics Laboratory KEITH BURRELL, General Atomics BRIAN GRIERSON, Princeton Plasma Physics Laboratory**

The possible observation of non-Maxwellian ion distribution functions in the pedestal of DIII-D will be investigated with a synthetic diagnostic that accounts for the effect of finite neutral beam size. Ion distribution functions in tokamak plasmas are typically assumed to be Maxwellian, however non-Gaussian features observed in impurity charge exchange spectra have challenged this concept [1]. Two possible explanations for these observations are spatial averaging over a finite beam size and a local ion distribution that is non-Maxwellian. Non-Maxwellian ion distribution functions could be driven by orbit loss effects in the edge of the plasma [2], and this has implications for momentum transport and intrinsic rotation. To investigate the potential effect of finite beam size on the observed spectra, a synthetic diagnostic has been created that uses FIDAsim to model beam and halo neutral density. Finite beam size effects are investigated for vertical and tangential views in the core and pedestal region with varying gradient scale lengths.

*Work supported in part by US DoE under the Science Undergraduate Laboratory Internship (SULI) program, DE-FC02-04ER54698, and DE-AC52-09CH11466.

**JP11 32 Operations Studies of the Gyrotrons on DIII-D**

**STEPHEN STORMENT, University of Arkansas - Fayetteville JOHN LOHR, MIRELA CENGHER, YURI GORELOV, DAN PONCE, ANTONIO TORREZAN, General Atomics**

The gyrotrons are high power vacuum tubes used in fusion research to provide high power density heating and current drive in precisely localized areas of the plasma. Despite the increasing experience with both the manufacture and operation of these devices, individual gyrotrons with similar design and manufacturing processes can exhibit important operational differences in terms of generated rf power, efficiency and lifetime. This report discusses differences in the performance of several gyrotrons in operation at DIII-D and presents the results of a series of measurements that could lead to improved the performance of single units based on a better understanding of the causes of these differences. The rf power generation efficiency can be different from gyrotron to gyrotron. In addition, the power loading of the collector can feature localized hot spots, where the collector can locally be close to the power deposition limits. Measurements of collector power loading provide maps of the power deposition and can provide understanding of the effect of modulation of the output rf beam on the total loading, leading to improved operational rules increasing the safety margins for the gyrotrons under different operational scenarios.

*Work supported by US DoE under DE-FC02-04ER54698.

**JP11 33 Hydrodynamic instabilities at an oblique interface: Experiments and Simulations**

**E. DOUGLAS-MANN, C. FIEDLER KAWAGUCHI, Bryn Mawr College, University of Michigan M. A. TRANTHAM, University of Michigan G. MALAMUD, Nuclear Research Center, University of Michigan W.C. WAN, S. R. KLEIN, C. C. KURANZ, University of Michigan**

Hydrodynamic instabilities are important phenomena that occur in high-energy-density systems, such as astrophysical systems and inertial confinement fusion experiments, where pressure, density, and velocity gradients are present. Using a ~30 ns laser pulse from the Omega EP laser system, a steady shock wave is driven into a target. A Spherical Crystal Imager provides high-resolution x-ray radiographs to study the evolution of complex hydrodynamic structures. This experiment has a light-to-heavy interface at an oblique angle with a precision-machined perturbation. The incident shock wave deposits shear and vorticity at the interface causing the perturbation to grow via Richtmyer-Meshkov and Kelvin-Helmholtz processes. We present results from analysis of radiographic data and hydrodynamics simulations showing the evolution of the shock and unstable structure.

*This work is supported by the NNSA-DS and SC-OSES Joint Program in High-Energy-Density Laboratory Plasmas, Grant Number DE-NA0002956 and the National Science Foundation through the Basic Plasma Science and Engineering program and LILAC.

**JP11 34 An Illustrative Guide to the Minerva Framework**

**ERIK FLOM, Univ. of Oklahoma PATRICK LEONARD, UW-Madison UDO HOEFFEL, SEHYUN KWAK, ANDREA PAVONE, JAKOB SVENSSON, MACIEJ KRYCHOWIAK, Max Planck Institute for Plasma Physics WENDELSTEIN 7-X TEAM COLLABORATION**

Modern physics experiments require tracking and modelling data and their associated uncertainties on a large scale, as well as the combined implementation of multiple independent data streams for sophisticated modelling and analysis. The Minerva Framework offers a centralized, user-friendly method of large-scale physics modelling and scientific inference. Currently used by teams at multiple large-scale fusion experiments including the Joint European Torus (JET) and Wendelstein 7-X (W7-X), the Minerva framework provides a forward-model friendly architecture for developing and implementing models for large-scale experiments. One aspect of the framework involves so-called data sources, which are nodes in the graphical model. These nodes are supplied with engineering and physics parameters. When end-user level code calls a node, it is
checked network-wide against its dependent nodes for changes since its last implementation and returns version-specific data. Here, a filterscope data node is used as an illustrative example of the Minerva Framework’s data management structure and its further application to Bayesian modelling of complex systems.

“This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under Grant Agreement No. 633053.

*DoE, NSF.

**This material is based upon work supported by the U.S. Department of Energy Office of Science, Office of Fusion Energy Sciences program under Award Numbers DE-FC02-05ER54814 and DE-SC0015474.

JP11 35 Ion Temperature and Velocity Measurements using Fabry-Perot Spectroscopy* MEGAN TABBUTT, KEN FLANAGAN, MARK D. NORNBERG, FRED L. ROESLER, CARY B. FOREST, Univ. of Wisconsin, Madison

Wisconsin Plasma Astrophysics Laboratory Team A Fabry-Perot spectrometer system has been used to measure ion temperature and velocity in flowing, astrophysical plasmas at the Wisconsin Plasma Astrophysics Laboratory (Wipal). Wipal research seeks weakly magnetized, fast flowing, plasmas in order to study basic low-flux driven MHD instabilities. The Fabry-Perot spectrometer images the ion-velocity distribution function (IVDF) of both Argon (488 nm ion line) and Helium (468.6 nm ion line complex) plasmas. Electron temperatures range from 5 eV to 15 eV; plasma densities range from 10^11 to 10^12 cm^-3; ion temperatures range from 0.5 eV to 2 eV and flows can reach 10 km/s. Beyond the increased resolving power compared to grating spectrometers, the Fabry-Perot’s 2D interference pattern can be summed to give a large signal-to-noise increase.

*DoE ARPA-E ALPHA Program.


Previous research on the Large Plasma Device (LAPD) has shown that biased rotation of the plasma can aid confinement. However, the same rotation which aids confinement can also generate waves (and thus turbulence) that can hinder the effectiveness of that confinement. There are multiple wave candidates in the LAPD which may be interacting, including drift, rotational interchange, and Kelvin-Helmholtz waves. Interaction was determined using a bispectral analysis, which scans Fourier spectra for frequencies that exhibit non-linear coupling. Analysis was performed on ion saturation current data at bias voltages ranging from 80-200V.


In the Swarthmore Spheromak Experiment (SSX), compact toroidal plasmas are launched from a plasma gun and evolve into minimum energy twisted Taylor states. The plumes initially have a velocity ~ 40 km/s, density ~ 0.4 x 10^16 cm^-3, and proton temperature ~ 20 eV. After formation, the plumes are accelerated by pulsed pinch coils with rise times τ_{pinc} = (π/2)/√LC less than 1 μs and currents I_{pinc} = V_0/2 = V_0/√L/C on the order of 10^4 A. The accelerated Taylor States are abruptly stagnated in a copper flux conserver, and ITER states are abruptly stagnated in a copper flux conserver, and density values in the SSX device approach about 10^-10 cm^-3.

E = μ0B^2/2

B = 10 T

τ < 10 μs, adiabatic compression is observed. The magnetothermodynamics of this compression do not appear to be dictated by the MHD equation of state d/dt(P/N^2) = 0. Rather, the compression appears to evolve according to the Chew-Goldberger-Low (CGL) double adiabatic model. CGL theory presents two equations of state, one corresponding with particle motion perpendicular to magnetic field in a plasma, the other to particle motion parallel to the field. We observe Taylor state compression most in agreement with the parallel equation of state: d/dt(P/N^2) = 0.


Studying magnetic turbulence in the laboratory requires measurements of magnetic fluctuations at high frequencies, but probe diagnostics, such as magnetic pickup coils, can run into inductance issues at such high frequencies. Careful calibration is necessary to be able to report on the proper scaling of power. B-dot probes and Hall effect sensors are used in the measurement of time varying magnetic fields. In the case of a B dot probe, current is induced in a coil as a result of the varying magnetic field. The coil then produces an output voltage that is proportional to dB/dt. The output voltage of a Hall effect sensor changes in response to the transverse force produced by the magnetic field. For measurements at the Bryn Mawr Plasma Laboratory, both B-dot probes and Hall effect probes are calibrated using an Accel Instruments TS250 power amplifier to drive current up to 2A from 100Hz to 10MHz.

JP11 39 Ross filter development for absolute measurement of Al line radiation on MST** N. LAUERSDORF, L. M. REUSCH, D. J. DEN HARTOG, J. A. GOETZ, University of Wisconsin-Madison

P. FRANZ, Consorzio RFX P. VANMETER, University of Wisconsin-Madison

The MST has a two-color soft x-ray tomography (SXT) diagnostic that, using the double-filter technique, measures electron temperature (Te) from the slope of the soft x-ray (SXR) continuum. Because MST has an aluminum plasma-facing surface, bright Al line radiation occurs in the SXR spectrum. In past application of the double-filter technique, these lines have been filtered out using thick Be filters (~400μm and ~800μm), restricting the measurement temperature range to > 1 keV due to the signal strength having a positive correlation with Te. Another way to deal with the line radiation is to explicitly include it into the SXR spectrum analysis from which Te is derived. A Ross filter set has been designed to measure this line radiation, and will enable the absolute intensities of the aluminum lines to be quantified and incorporated into the analysis. The Ross filter will be used to measure Al+11 and Al+12 lines, occurring between 1.59 and 2.04 keV. By using multiple detectors with filters made of varying element concentrations, we create spectral bins in which the dominant transmission is the line radiation. Absolute measurement of Al line intensities will enable use of thinner filters in the SXT diagnostic and accurate measurement of Te < 1 keV.

**This work has been carried out within the framework of the EU-ROFusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under Grant Agreement No. 633053.

JP11 40 Precision Electron Density Measurements in the SSX MHD Wind Tunnel** EMAA M. SUEN-LEWIS, LUKE J. BARBANO, JARON E. SHROCK, MANJIT KAUR, Swarthmore College

DAVID A. SCHAFFNER, Bryn Mawr College

MICHAEL R. BROWN, Swarthmore College

We characterize fluctuations of the line averaged electron density of Taylor states produced by the magnetized coaxial plasma gun of the SSX device using a HeNe laser interferometer. The analysis method uses the electron density dependence of the refractive index of the plasma to determine the electron density of the Taylor states. Typical magnetic field and density values in the SSX device approach about B ≤ 0.3 T and...
n = 0.4 × 10^{16} \text{cm}^{-3}$. Analysis is improved from previous density measurement methods by developing a post-processing method to remove relative phase error between interferometer outputs and to account for approximately linear phase drift due to low-frequency mechanical vibrations of the interferometer. Precision density measurements coupled with local measurements of the magnetic field will allow us to characterize the wave composition of SSX plasma via density vs. magnetic field correlation analysis, and compare the wave composition of SSX plasma with that of the solar wind [1]. Preliminary results indicate that density and magnetic field appear negatively correlated.

*Work supported by DOE ARPA-E ALPHA program.

JPP 41  A Phoswich Detector System to Measure Sub-Second Half-Lives using ICF Reactions\footnote{1} MICAH COATS, KATELYN COOK, MARK YULY, Houghton College STEPHEN PADALINO, State University of New York at Geneseo CRAIG SANGSTER, SEAN REGAN, Laboratory for Laser Energetics  The $^3\text{H}(t,\gamma)^3\text{He}$ cross section has not been measured at any bombarding energy due to the difficulties of simultaneously producing both a tritium beam and target at accelerator labs. An alternative technique may be to use an ICF implosion on the OMEGA Laser Facility. The $^4\text{He}$ cross section could be determined in situ by measuring the beta decay of $^4\text{He}$ beginning a few milliseconds after the shot along with other ICF diagnostics. A de-E-phoswich system capable of surviving in the OMEGA target chamber was tested using the SUNY Geneseo pelletron to create neutrons via $^3\text{H}(d,n)^3\text{He}$ and subsequently $^4\text{He}$ via $^5\text{Be}(n,\alpha)^4\text{He}$ in a beryllium target. The phoswich de-E detector system was used to select beta decay events and measure the 807 ms half-life of $^4\text{He}$. It is composed of a thin, 2 ns decay time de scintillator optically coupled to a thick, 285 ns E scintillator, with a linear gate to separate the short de pulse from the longer E tail.

*Work funded in part by the DOE through the Laboratory for Laser Energetics.

JPP 42  Two-point modeling of SOL losses of HHFW power in NSTX\footnote{2} AYDEN KISH, Auburn Univ. RORY PERKINS, PPPL JOON-WOOK AHN, ORNL AHMED DIALLO, PPPL TRAVIS GRAY, ORNL JOEL HOSEA, MICHAEL JAWORSKI, GERRIT KRAMER, BENOIT LEBLANC, PPPL STEVE SABBAGH, Columbia Univ.  High-harmonic fast-wave (HHFW) heating is a heating and current-drive scheme on the National Spherical Torus eXperiment (NSTX) complimentary to neutral beam injection. Previous experiments suggest that a significant fraction, up to 50\%, of the HHFW power is promptly lost to the scrape-off layer (SOL). Research indicates that the lost power reaches the divertor via wave propagation and is converted to a heat flux at the divertor through RF rectification rather than heating the SOL plasma at the midplane [1]. This counter-intuitive hypothesis is investigated using a simplified two-point model [2], relating plasma parameters at the divertor to those at the midplane. Taking measurements at the divertor region of NSTX as input, this two-point model is used to predict midplane parameters, using the predicted heat flux as an indicator of power input to the SOL. These predictions are compared to measurements at the midplane to evaluate the extent to which they are consistent with experiment.

*This work was made possible by funding from the Department of Energy for the Summer Undergraduate Laboratory Internship (SULI) program. This work is supported by the US DOE Contract No. DE-AC02-09CH11466.

\begin{footnotesize}
\begin{enumerate}
\end{enumerate}
\end{footnotesize}

JPP 43 Using Rutherford Backscattering Spectroscopy to Characterize Targets for MTW\footnote{3} GUNNAR BROWN, BARAK STOCKLER, RYAN WARD, CHARLIE FREEMAN, STEPHEN PADALINO, SUNY Geneseo COLLIN STILLMAN, STEVEN IVANIC, S.P. REAGAN, T.C. SANGSTER, Laboratory for Laser Energetics  A study is underway to determine the composition and thickness of targets used at the Multiterawatt (MTW) laser facility at the Laboratory for Laser Energetics (LLE) using Rutherford backscattering spectroscopy (RBS). In RBS, an ion beam is incident on a sample and the scattered ions are detected with a surface barrier detector. The resulting energy spectra of the scattered ions can be analyzed to determine important parameters of the target including elemental composition and thickness. Proton, helium and deuterium beams from the 1.7 MV Pelletron accelerator at SUNY Geneseo have been used to characterize several different targets for MTW, including CH and aluminum foils of varying thickness. RBS spectra were also obtained for a cylindrical iron buried-layer target with aluminum dopant which was mounted on a silicon carbide stalk. The computer program SIMNRA is used to analyze the spectra.

*This work was funded in part by a Grant from the DOE through the Laboratory for Laser Energetics.

JPP 44 Characterizing the volume of a compressed Taylor state object in the SSX plasma\footnote{4} L. J. BARBANO, E. M. SUENLEWIS, J. E. SHROCK, M. KAUR, Swarthmore College D. A. SCHAFFNER, Bryn Mawr College M. R. BROWN, Swarthmore College  A cookbook of numerical techniques (namely wavelet transforms, smoothing filters, and spline interpolations) is applied to characterize the length of a stagnating Taylor state object in SSX. This length analysis uses magnetic field data from a linear array of 20 evenly spaced 2-D $B$ probes positioned along the compression can axis. A 3-D animation of the Taylor state object’s magnetic field in the compression volume reveals the object’s wavelet-like magnetic structure in space. In order to localize the object in space and characterize its length, a continuous wavelet transform is performed. The most dominant spatial frequency given by the resulting frequency-space spectrum is taken to be the length of the object in the compression volume. This analysis is performed at every time in the $B$ time series to give some measure of the Taylor state object’s length as a function of time. This length, in conjunction with the cross-sectional area of the compression can, gives the object’s volume. Information about the object’s volume as a function of time allows us to identify instances of compressive heating and investigate the magnetothermodynamic (MTD) properties of the SSX plasma.

*Work supported by DOE ARPA-E ALPHA program.

JPP 45 Opacplot2: Enabling tabulated EoS and opacity compatibility for HEDLP simulations with the FLASH code JORDAN LAUNE, PETROS TZEFERACOS, SCOTT FEISTER, MILAD FATENEJAD, University of Chicago ROMAN YURCHAK, Laboratoire pour l’Utilisation des Lasers Intenses NORBERT FLOCHE, KLAUS WERNER, DONALD LAMB, University of Chicago  Thermodynamic and opacity properties of materials are necessary to accurately simulate laser-driven laboratory experiments. Such data are compiled in tabular format since the thermodynamic range that needs to be covered cannot be described...
with one single theoretical model. Moreover, tabulated data can be made available prior to runtime, reducing both compute cost and code complexity. This approach is employed by the FLASH code. Equation of state (EoS) and opacity data comes in various formats, matrix-layouts, and file-structures. We discuss recent developments on opacplot2, an open-source Python module that manipulates tabulated EoS and opacity data. We present software that builds upon opacplot2 and enables easy-to-use conversion of different table formats into the IONINX format, the native tabular input used by FLASH. Our work enables FLASH users to take advantage of a wider range of accurate EoS and opacity tables in simulating HELP experiments at the National Laser User Facilities.

**JP11 46 Investigating Trapped Particle Asymmetry Modes and Temperature Effects in the Lawrence Non-neutral Torus II**

R. NIRWAN, P. SWANSON, M.R. STONEKING, Lawrence University, Appleton WI 54911

Electron plasma is confined in the Lawrence Non-Neutral Torus II using a purely toroidal magnetic field \( (R_t = 18 \text{ cm}, B < 1 \text{ kG}) \) for confinement times exceeding 1 second. The LNT II can be configured for fully toroidal traps or variable-length partial toroidal traps. The behavior of the plasma is observed by monitoring the image charge on isolated wall sectors. The plasma is excited by application of a sinusoidal tone burst to the sides of the grid. Preliminary analysis of the moments of the IVDFs and to initiate self-assembly of semiconductor nanostructures. To do so, we present a description of the parameters and first results from a new experimental facility designed to

\[ T_e \approx 3 \times 10^5 \text{cm}^{-3} \]
provide exceptional optical access for these ion beam experiments. We will describe the vacuum chamber design, the LIF optics, and initial LIF measurements of argon plasma.

"This work was supported by U.S. National Science Foundation Grant No. PHY-1617880.

**JP11 51 The Effect of Background Pressure on Electron Acceleration from Ultra-Intense Laser-Matter Interactions** MANH LE, Ohio State Univ - Columbus and University of Dayton Research Institute GREGORY NGIRMANG, Ohio State Univ - Columbus and Innovative Scientific Solutions, Inc. CHRIS ORBAN, Ohio State Univ - Columbus JOHN MORRISON, Innovative Scientific Solutions, Inc. ENAM CHOWDHURY, Ohio State Univ - Columbus and Intense Energy Solutions, LLC. WILLIAM ROQUEMORE, Air Force Rsch Lab - WPAFB, WPAFB We present two-dimensional particle-in-cell (PIC) simulations that investigate the role of background pressure on the acceleration of electrons from ultra intense laser interaction at normal incidence with liquid density ethylene glycol targets. The interaction was simulated at ten different pressures varying from 7.8 mTorr to 26 Torr. We calculated conversion efficiencies from the simulation results and plotted the efficiencies with respect to the background pressure. The results revealed that the laser to >100 keV electron conversion efficiency remained flat around 0.35% from 7.8 mTorr to 1.2 Torr and increased exponentially from 1.2 Torr onward to about 1.47% at 26 Torr. Increasing the background pressure clearly has a dramatic effect on the acceleration of electrons from the target. We explain how electrostatic effects, in particular the neutralization of the target by the background plasma, allows electrons to escape more easily and that this effect is strengthened with higher densities. This work could facilitate the design of future experiments in increasing laser to electron conversion efficiency and generating substantial bursts of electrons with relativistic energies.

"This research is supported by the Air Force Office of Scientific Research under LIR Project 17RQCOR504 under the management of Dr. Riq Parra and Dr. Jean-Luc Cambier. Support was also provided by the DOD HPCMP Internship Program.

**JP11 52 Characterizing Scintillator Response with Neutron Time-of-Flight** KEVIN PALMISANO, HANNAH VISCA, LOUIS CAVES, COREY WILKINSON, HANNAH MCCLOW, STEPHEN PADOWALINO, State Univ of NY - Genesco CHAD FORREST, JOE KATZ, CRAIG SANGSTER, SEAN REGAN, Laboratory of Laser Energetics Neutron scintillator diagnostics for ICF can be characterized using the neutron time-of-flight (nTOF) line on Genesee’s 1.7 MV Tandem Pelletron Accelerator. Neutron signals can be differentiated from gamma signals by employing a coincidence method called the associated particle technique (APT). In this measurement, a 2.1 MeV beam of deuterons incident on a deuterated polyethylene target produces neutrons via the d(d,n)3He reaction. A BC-412 plastic scintillator, placed at a scattering angle of 152°, detects 1.76 MeV neutrons in coincidence with the 2.56 MeV 3He ions at an associated angle of 10°. The APT is used to identify the 1.76 MeV neutron while the nTOF line determines its energy. By gating only mono-energetic neutrons, the instrument response function of the scintillator can be determined free from background scattered neutrons and gamma rays.

JP11 53 Mach Probe Measurements in a Large-Scale Helicon Plasma M.W. HATCH, R.F. KELLY, D.M. FISHER, M. GILMORE, R.H. DWYER, Univ of New Mexico A new six-tipped Mach probe, that utilizes a fused-quartz insulator, has been developed and initially tested in the HelCat dual-source plasma device at the University of New Mexico. The new design allows for relatively long duration measurements of parallel and perpendicular flows that suffer less from thermal changes in conductivity and surface build-up seen in previous alumina-insulated designs. Mach probe measurement will be presented in comparison with ongoing laser induced fluorescence (LIF) measurements, previous Mach probe measurements, ExB flow estimates derived from Langmuir probes, and fast-frame CCD camera images, in an effort to better understand previous anomalous ion flow in HelCat. Additionally, Mach probe-LIF comparisons will provide an experimentally obtained Mach probe calibration constant, K, to validate sheath-derived estimates for the weakly magnetized case.

"Supported by U.S. National Science Foundation Award 1500423.

**JP11 54 Simulation of an expanding plasma using the Boris algorithm** LUKE NEAL, EVAN AGUIRRE, THOMAS STEINBERGER, Department of Physics and Astronomy, West Virginia University TIMOTHY GOOD, Department of Physics, Gettysburg College EARL SCIME, Department of Physics and Astronomy, West Virginia University We present a Boris algorithm simulation in a cylindrical geometry of charged particle motion in a helicon plasma confined by a diverging magnetic field. Laboratory measurements of ion velocity distribution functions (ivdfs) provide evidence for acceleration of ions into the divergent field region in the center of the discharge. The increase in ion velocity is inconsistent with expectations for simple magnetic moment conservation given the magnetic field mirror ratio and is therefore attributed to the presence of a double layer in the literature. Using measured electric fields and ivdfs (at different radial locations across the entire plasma column) upstream and downstream of the divergent magnetic field region, we compare predictions for the downstream ivdfs to measurements. We also present predictions for the evolution of the electron velocity distribution function downstream of the divergent magnetic field.

"Supported in part by a Grant from the DOE, through the Laboratory for Laser Energetics.

**JP11 55 Computational Study of Plasma Response to Higher Order RF Multipole** AMANDA BOWMAN, KATARINA GODEN, NATHANIEL HICKS, University of Alaska Anchorage Initial results are presented from a computational plasma physics study of radio-frequency (RF) multipole structures containing various quasi-neutral plasma conditions. A particle-in-cell code is used to model a 2D cross section of the structure and enclosed plasma. Multipole orders including n = 2 (quadrupole), n = 4 (octupole), n = 8 (hexadecapole) and so on are compared, along with the corresponding effects on shape of the pseudopotential well that traps particles and the interaction between the external field and plasma, including the formation of the RF plasma sheath. The simulation results are guiding the design of experiments to test some of these multipole configurations in the laboratory.

*Supported by U.S. National Science Foundation Grant No. PHY-1360278.
TUESDAY AFTERNOON

JP11 56 Stability of an axisymmetric, non-paraxial mirror and its applications for a fusion neutron source* ROGER WALEFFE, ETHAN PETERSON, VLADIMIR MIRNOV, CARY FOREST, Univ of Wisconsin, Madison. Interchange stability analysis is underway for the design and development of an axisymmetric, non-paraxial (spherical) mirror. Such a system takes advantage of favorable magnetic field line curvature to stabilize the m = 1 flute mode, corresponding to a radial displacement of the plasma as a whole. Our results indicate the presence of a “stability ring” at intermediate values of magnetic flux inside the separatrix. As a result, any pressure distribution inside such a region is also stable. Optimizations for maximum stable volume peak where \( \frac{B_{\text{spherical}}}{B_{\text{torus}}} \approx 0.1 \) at the origin, independent of cylindrical Z location or mirror coil shape. An eigenvalue solver in the ballooning approximation has been developed and applied to the spherical mirror equilibria: it exhibits stability with respect to high-m modes for inner portions of the plasma volume. The stability limit is seen to decrease with increasing plasma beta and is heavily dependent on the pressure profile. Inherent MHD stability, coupled with high-temperature superconducting technology promises a promising path forward for the resurgence of axisymmetric mirrors. Work is ongoing to model a standalone high-field spherical mirror as a fusion neutron source using the GENRAY ray tracing and CQL3D wave deposition codes.

*This work is supported by the DoE, the NSF, and the Hilldale Undergraduate Research Fellowship.

JP11 57 Schlieren Technique Applied to Magnetohydrodynamic Generator Plasma Torch* NIRBHAV CHOPRA, JACOB PEARCY, MICHAEL JAWORSKI, Princeton Plasma Physics Lab Magnetohydrodynamic (MHD) generators are a promising augmentation to current hydrocarbon based combustion schemes for creating electrical power. In recent years, interest in MHD generators has been revitalized due to advances in a number of technologies such as superconducting magnets, solid-state power electronics and materials science as well as changing economics associated with carbon capture, utilization, and sequestration. We use a multi-wavelength schlieren imaging system to evaluate electron density independently of gas density in a plasma torch under conditions relevant to MHD generators. The sensitivity and resolution of the optical system are evaluated alongside the development of an automated analysis and calibration program in Python. Preliminary analysis shows spatial resolutions less than 1 mm and measures an electron density of \( n_e = 1 \times 10^{16} \text{ cm}^{-3} \) in an atmospheric microwave torch.

*Work supported by DOE contract DE-AC02-09CH11466.

JP11 58 A Lithium Vapor Box Divertor Similarity Experiment* ROBERT A. COHEN, Princeton University ERIC D. EMDEE, ROBERT J. GOLDSTON, MICHAEL A. JAWORSKI, JACOB A. SCHWARTZ, Princeton Plasma Physics Laboratory A lithium vapor box divertor offers an alternate means of managing the extreme power density of divertor plasmas by leveraging gaseous lithium to volumetrically extract power. The vapor box divertor is a baffled slot with liquid lithium coated walls held at temperatures which increase toward the divertor floor. The resulting vapor pressure differential drives gaseous lithium from hotter chambers into cooler ones, where the lithium condenses and returns. A similarity experiment was devised to investigate the advantages offered by a vapor box divertor design. We discuss the design, construction, and early findings of the vapor box divertor experiment including vapor can construction, power transfer calculations, joint integrity tests, and thermocouple data logging. Heat redistribution of an incident plasma-based heat flux from a typical linear plasma device is also presented.

*This work supported by DOE Contract No. DE-AC02-09CH11466 and The Princeton Environmental Institute.

JP11 59 Quench and stress coupled analysis of high temperature superconducting coils JESSICA LI, Columbia Univ YUHU ZHAI, Princeton Plasma Phys Lab High-temperature superconductors (HTS) are promising candidates for compact next step fusion reactor designs due to their low power loss, higher margin and ability to carry extremely high current densities at high magnetic fields. However, unlike their low-temperature counterparts, HTS coils are much more vulnerable to damage during quench events under severe mechanical loading at high field magnet operation. It has been shown that the intensity of quench events may be mitigated by installing inductively coupled inserts around the superconducting coils. To this end, some previously explored designs of force-balanced coils which minimize stress in coil winding packs are reviewed for better stress management in HTS coils for quench mitigation. We use analytic models in FORTRAN and MATLAB to calculate the magnetic fields and resultant forces for various solenoid-like configurations of both high- and low-temperature superconducting coils. We then simulate their thermal, electric, and magnetic behaviors during quench-like events to identify optimal designs for both stability and quench protection.

JP11 60 Simulations of Atmospheric Plasma Arcs* JACOB PEARCY, NIRBHAV CHOPRA, MICHAEL JAWORSKI, Princeton Plasma Physics Laboratory We present the results of computer simulation of cylindrical plasma arcs with characteristics similar to those predicted to be relevant in magnetohydrodynamic (MHD) power conversion systems. These arcs, with core temperatures on the order of 1 eV, place stringent limitations on the lifetime of conventional electrodes used in such systems, suggesting that a detailed analysis of arc characteristics will be crucial in designing more robust electrode systems. Simulations utilize results from NASA’s Chemical Equilibrium with Applications (CEA) program to solve the Elenbaas-Heller equation in a variety of plasma compositions, including approximations of coal-burning plasmas as well as pure gas discharges. The effect of carbon dioxide injection on arc characteristics, emulating discharges from molten carbonate salt electrodes, is also analyzed. Results include radial temperature profiles, composition maps, and current-voltage (IV) characteristics of these arcs.

*Work supported by DOE contract DE-AC02-09CH11466.

JP11 61 Predicting high-current disruptions on NSTX with stacked regression trees* NATHANIEL BARBOUR, Yale University KORNEE KLEIJWEGT, Eindhoven University of Technology LEONARD LUPIN-JIMENEZ, Stanford University EGEMEN KOLEMEM, Princeton University Disruption mitigation and avoidance are critical objectives for the successful operation of ITER. Of particular interest is the prospect of predicting disruptions during its first high-plasma-current experiments, when only low-current data will be available. Toward achieving those objectives, data from an initial sample of 1,000 shots are separated into two groups by plasma current. Four regression tree algorithms are then used as disruption predictors: AdaBoost, random forests, extremely randomized trees, and bootstrap aggregating (“bagging”). Each algorithm is trained...
using data from low-current shots and used to predict disruptions in the sample of high-current shots. To improve prediction accuracy, multiple methods of scaling the input signal data are examined. The creation of a meta-estimator from the predictions of the four regression tree algorithms is explored. A future extension is to predict high-current disruptions on other devices using a meta-estimator trained with low-current data from NSTX and NSTX-U.

*Supported by the US DOE Contract No. DE-AC02-09CH11466.

**JP11 62 Photon Throughput Calculations for a Spherical Crystal Spectrometer**

C. J. GILMAN, Davidson College M. BITTER, L. DELGADO-APARICIO, P. C. EFTHIMION, K. HILL, B. KRAUS, L. GAO, N. PABLANT, Princeton Plasma Physics Laboratory X-ray imaging crystal spectrometers of the type described in Refs. [1,2] have become a standard diagnostic for Doppler measurements of profiles of the ion temperature and the plasma flow velocities in magnetically confined, hot fusion plasmas. These instruments have by now been implemented on major tokamak and stellarator experiments in Korea, China, Japan, and Germany and are currently also being designed by PPPL for ITER. A still missing part in the present data analysis is an efficient code for photon throughput calculations to evaluate the chord-integrated spectral data. The existing ray tracing codes cannot be used for a data analysis between shots, since they require extensive and time consuming numerical calculations. Here, we present a detailed analysis of the geometrical properties of the ray pattern. This method allows us to minimize the extent of numerical calculations and to create a more efficient code.

*This work was performed under the auspices of the U.S. Department of Energy by Princeton Plasma Physics Laboratory under contract DE-AC02-09CH11466.


**JP11 63 Intrinsic Flow Behavior During Improved Confinement in MST Reversed-field Pinch**

E. TAN, D. CRAIG, B. SCHOTT, Wheaton College J. BOGUSKI, Z.A. XING, M.D. NORNBERG, J.K. ANDERSON, University of Wisconsin-Madison We used active charge exchange recombination spectroscopy to measure impurity ion flow velocity in high-current plasmas during periods of improved confinement. Velocity measurements throughout the core reveal that ion flow parallel to the magnetic field is dominant compared to the perpendicular flow. The poloidal flow profile reverses at r/a = 0.6, and the flow near the core is larger on outboard positions compared to the inboard positions. A strong shear in the toroidal flow develops near the axis as PPCD proceeds. In the past, the mode velocity has been used to infer the toroidal flow based on the ‘no-slip’ assumption that the mode and local plasma co-rotate. We tested this assumption with direct measurements near the n = m = 1, n = 6 resonant surface. Inboard flow measurements are consistent with the no-slip condition and exhibit a time dependence where the flow decreases together with the n = 6 mode velocity. The outboard flow is consistent in magnitude with the no-slip condition but the variations in time and across shots do not correlate well with the n = 6 mode velocity. Possible reasons why the inboard and outboard flow exhibit different behavior are discussed.

*This work has been supported by the US DOE and the Wheaton College summer research program.

**JP11 64 Accelerating CR-39 Track Detector Processing by Utilizing UV**

JONATHAN SPARLING, STEPHEN PADALINO, JAMES MCLEAN, State Univ of NY at Geneseo CRAIG SANGSTER, SEAN REGAN, Lab for Laser Energetics, University of Rochester The use of CR-39 plastic as a Solid State Nuclear Track Detector is an effective technique for obtaining data in high energy particle experiments including inertial confinement fusion. To reveal particle tracks after irradiation, CR-39 is chemically etched in NaOH at 80°C, producing micron-scale signal pits at the nuclear track sites. It has been shown that illuminating CR-39 with UV light prior to etching increases bulk and track etch rates, especially when combined with elevated temperature. Spectroscopic analysis for amorphous solids has helped identify which UV wavelengths are most effective at enhancing etch rates. Absorption peaks found in the near infrared range provide for efficient sample heating, and may allow targeting cooperative IR-UV chemistry. Avoiding UV induced noise can be achieved through variations in absorption depths with wavelength. Vacuum drying and water absorption tests allow measurement of the resulting variation of bulk etch rate with depth.

*Supported by the NSF and an Department of Energy Grant through the Lab of Laser Energetics.

**JP11 65 Ballistic dynamics of a relativistic electron beam for mapping of the magnetosphere**

MICHAEL GREKLE-MCKEON, Princeton Plasma Physics Laboratory ANDREW T. POWIS, Princeton University IGOR D. KAGANOVICE, PETER PORAZIK, Princeton Plasma Physics Laboratory JAY JOHNSON, JAKE WILLARD, Andrews University ENNIO SANCHEZ, SRI International Relativistic electrons fired from an orbiting satellite will propagate along the field lines of the magnetosphere. When the electrons impact the Earth’s atmosphere, they produce a characteristic signature that is detectable by ground stations. Such a diagnostic would enable direct validation of magnetospheric models, and assist in answering outstanding questions on auroral arcs. We determine the loss cone of a relativistic electron beam at various injection points within the Earth's magnetosphere during the stages of a prominent geomagnetic event. We then study the degree of beam spreading during propagation to determine the viability of signal detection at the top of the atmosphere. This verification, using realistic magnetic field data, demonstrates that an electron beam emitted from a satellite can be fired into the loss cone of the Earth’s atmosphere and create an observable signal on the ground.

*Supported by the US DOE Contract No. DE-AC02-09CH11466.

**JP11 66 RF Antenna Design for a Helicon Plasma Source**

KATARINA GODDEN, BRENDAN STASSEL, DANIEL WARTA, ISAAC YEP, NATHANIEL HICKS, JENS MUNK, University of Alaska Anchorage A helicon plasma source is under development for the new Plasma Science and Engineering Laboratory at the University of Alaska Anchorage. The helicon source is of a type [1] comprising Pyrex and stainless steel cylindrical sections, joined to an ultrahigh vacuum chamber. A radio frequency (RF) helical antenna surrounds the Pyrex chamber, as well as DC solenoidal magnetic field coils. This presentation focuses on the design of the RF helical antenna and RF matching network, such that helicon wave power is coupled to argon plasma with minimal reflected power to the RF amplifier. The amplifier output is selectable between 2-30 MHz, with forward c.w. power up to 1.5 kW. Details and computer simulation of the antenna geometry, materials, and power matching will be presented, as well as the matching network of RF transmission line, tuning capacitors, and cooling system. An initial computational study of power coupling to the plasma will also be described.

*Supported by the US DOE Contract No. DE-AC02-09CH11466.
TUESDAY AFTERNOON

JP11 67 FLASH Interface; a GUI for managing runtime parameters in FLASH simulations* CHRISTOPHER WALKER, PETROS TZEFERACOS, KLAUS WEIDE, DONALD LAMB, NORBERT FLOCKE, SCOTT FEISTER, Univ of Chicago We present FLASH Interface, a novel graphical user interface (GUI) for managing runtime parameters in simulations performed with the FLASH code. FLASH Interface supports full text search of available parameters; provides descriptions of each parameter’s role and function; allows for the filtering of parameters based on categories; performs input validation; and maintains all comments and non-parameter information already present in existing parameter files. The GUI can be used to edit existing parameter files or generate new ones. FLASH Interface is open source and was implemented with the Electron framework, making it available on Mac OSX, Windows, and Linux operating systems. The new interface lowers the entry barrier for new FLASH users and provides an easy-to-use tool for experienced FLASH simulators.


JP11 68 Design and Calibration of a Dispersive Imaging Spectrometer Adaptor for a Fast IR Camera on NSTX-U* RICHARD REKSOATOMODJO, College of William and Mary TRAVIS GRAY, Oak Ridge National Laboratory PRINCETON PLASMA PHYSICS LABORATORY TEAM A dispersive spectrometer adaptor was designed, constructed and calibrated for use on a fast infrared camera employed to measure temperatures on the lower divertor tiles of the NSTX-U tokamak. This adaptor efficiently and evenly filters and distributes long-wavelength infrared photons between 8.0 and 12.0 microns across the 128x128 pixel detector of the fast IR camera. By determining the width of these separated wavelength bands across the camera detector, and then determining the corresponding average photon count for each photon wavelength, a very accurate measurement of the temperature, and thus heat flux, of the divertor tiles can be calculated using Planck’s law. This approach of designing an exterior dispersive adaptor for the fast IR camera allows accurate temperature measurements to be made of materials with unknown emissivity. Further, the relative simplicity and affordability of this adaptor design provides an attractive option over more expensive, slower, dispersive IR camera systems.

*This work was made possible by funding from the Department of Energy for the Summer Undergraduate Laboratory Internship (SULI) program. This work is supported by the US DOE Contract No. DE-AC02-09CH11466.

JP11 69 Analysis Tools for the Ion Cyclotron Emission Diagnostic on DIII-D* C. A. DEL CASTILLO, SUNY Stony Brook K. E. THOME, ORAU R. I. PINSKER, O. MENEGHINI, D. C. PACE, General Atomics Ion cyclotron emission (ICE) waves are excited by suprathermal particles such as neutral beam particles and fusion products. An ICE diagnostic is in consideration for use at ITER, where it could provide important passive measurement of fast ion location and losses, which are otherwise difficult to determine. Simple ICE data analysis codes had previously been developed, but more sophisticated codes are required to facilitate data analysis. Several terabytes of ICE data were collected on DIII-D during the 2015-2017 campaign. The ICE diagnostic consists of antenna straps and dedicated magnetic probes that are both digitized at 200 MHz. A suite of Python spectral analysis tools within the OMFIT framework is under development to perform the memory-intensive analysis of this data. A fast and optimized analysis allows ready access to data visualizations as spectrograms and as plots of both frequency and time cuts of the data. A database of processed ICE data is being constructed to understand the relationship between the frequency and intensity of ICE and a variety of experimental parameters including neutral beam power and geometry, local and global plasma parameters, magnetic fields, and many others.

*Work supported in part by US DoE under the Science Undergraduate Laboratory Internship (SULI) program and under DE-FC02-04ER54698.

JP11 70 Identification of a localized core mode in a helicon plasma DANIEL A. GREEN, Swarthmore College, Swarthmore, PA 19081, USA SAIAKT CHAKRABORTY THAKUR, Center for Energy Research, University of California San Diego, La Jolla, CA 92093, USA GEORGE R. TYNAN, Department of Mechanical and Aerospace Engineering and Center for Energy Research, University of California San Diego, La Jolla, CA 92093, USA ADAM D. LIGHT, Swarthmore College, Swarthmore, PA 19081, USA We present imaging measurements of a newly observed mode in the core of the Controlled Shear Decorrelation Experiment - Upgrade (CSDX-U). CSDX-U is a well-characterized linear machine producing dense plasmas relevant to the tokamak edge (Te ~ 3 eV, n~ 1013/cc). Typical fluctuations are dominated by electron drift waves, with evidence for Kelvin-Helmholtz vortices appearing near the plasma edge. A new mode has been observed using high-speed imaging that appears at high magnetic field strengths and is confined to the inner third of the plasma column. A cross-spectral phase technique allows direct visualization of dominant spatial structures as a function of frequency. Experimental dispersion curve estimates are constructed from imaging data alone, and allow direct comparison of theoretical dispersion relations to the observed mode. We present preliminary identification of the mode based on its dispersion curve, and compare the results with electrostatic probe measurements.

JP11 71 Spherical 3-Axis Hall Probe Array Calibration and Implementation for The Big Red Ball* JACOB LYNN, Univ of Wisconsin, Madison E. PETERSON COLLABORATION, D. ENDRIZZI COLLABORATION, M. CLARK COLLABORATION, C. B. FOREST COLLABORATION A 3-axis Helmholtz coil capable of producing 100 G magnetic fields at frequencies ranging from DC to 1 kHz has been built to calibrate an array of 3-axis hall probes. Accurate magnetic field measurements are necessary for diagnosing plasma equilibria and the presence of any MHD instabilities. The array will consist of three single-axis Hall sensors mounted orthogonally, each of which has a frequency response of 100 kHz and a sensitivity of 28 mV. These probes will be placed on the inner surface of the machine to create a spherical array of sensors. Such an array will provide the necessary data to constrain plasma equilibrium parameters, such as current density and plasma pressure from \( \nabla P = J \times B \). Understanding the plasma equilibrium, and large-scale magnetic fields is critical to understanding the dynamics involved in many phenomena, like the dynamo. Details on the design, calibration, and implementation of the three-axis Helmholtz coil and Hall sensors will be presented.
JP11 72 Einzel lens calculation and design for the ALPHA Experiment  
B. G. COLE, Marquette University  
W. A. BERTSCHE, M. A. JOHNSON, University Of Manchester And The Cockcroft Institute  
T. D. THARP, Marquette University  
ALPHA COLLABORATION  
An Einzel lens can be made from a series of hollow, cylindrical conductors charged to different electric potentials. The electric fields within the cylinders can be arranged to electrostatically focus a beam of non-neutral plasma to a certain focal point. Using electric field simulation tools, we explore possible modes of operation of this configuration to see what kinds of geometry and potentials are most favorable for future deployment in the ALPHA antihydrogen experiment at CERN.

JP11 73 Properties of large amplitude Alfvén waves in a magnetized, order-unity β laboratory plasma  
CHRISTINA MIGLIORE, Northeastern University  
TROY CARTER, University of California Los Angeles  
STEVE VINCENA, vin@physics.ucla.edu  
SHREEKRISHNA TRIPATHI, SETH DORFMAN, DAVID HAMILTON, University of California Los Angeles  
Alfvén waves play an important role in magnetized plasmas in the laboratory, e.g. in fusion plasmas, and in space and astrophysical settings, e.g. in the solar wind. The Large Plasma Device (LAPD) at UCLA has been used to study the linear and nonlinear properties of these important waves, however in a low-beta plasma (β ~ 1 x 10^{-4}). A new LaB₆ cathode source has been installed in LAPD, allowing the generation of much higher pressure plasmas; with lowered magnetic field, magnetized plasmas with β ~ 1 can be generated. New theoretical work by Squire suggests that the firehose instability limits the possible amplitude of Alfvén waves in higher β plasmas [1]. We will report on experiments with large amplitude waves in β ~ 1 plasmas in LAPD aiming to test this theory and look for other processes that might limit wave amplitude, such as decay instabilities [2].


JP11 74 Nonneutral plasma diagnostic commissioning for the ALPHA Antihydrogen experiment  
S. KONEWKO, Marquette University  
T. FRIESEN, Aarhus University  
T. D. THARP, Marquette University  
ALPHA COLLABORATION  
The ALPHA experiment at CERN creates antihydrogen by mixing antiproton and positron plasmas. Diagnostic measurements of the precursor plasmas are performed using a diagnostic suite, colloquially known as the “stick.” This stick has a variety of sensors and is able to move to various heights to align the desired diagnostic with the beamline. A cylindrical electrode, a faraday cup, an electron gun, and a microchannel-plate detector (MCP) are regularly used to control and diagnose plasmas in ALPHA. We have designed, built, and tested a new, upgraded stick which includes measurement capabilities in both beamline directions.

JP11 75 Using Divertor Strike Point Splitting to Study Plasma Response and Its Sensitivity to Equilibrium Uncertainties*  
ABRAHAM TEKLU, Oregon State University  
Resonant magnetic perturbations (RMPs) from 3D coils have been varied to modify the splitting of the divertor strike points in DIII-D. This splitting is imaged in filtered visible and infrared emission from the divertor to determine the particle and heat flux patterns on the target plates. The observed splitting is compared to vacuum and plasma response modeling in discharges where a subset of the RMP coils were ramped to shift the divertor footprints from dominantly n = 3 to n = 2 pattern. These results will be used to determine if the plasma response model can be validated with the measured splitting. We will also study the sensitivity of the modeled splitting to details of the 2D equilibrium. This RMP ramp technique could be used in ITER to spread out the heat flux while avoiding excessive forces on the RMP coils.

*Work supported by U.S. DOE under the Science Undergraduate Laboratory Internship (SULI) program and DE-FG02-04ER54698, DE-FG02-07ER54917, DE-FG02-05ER54809 and DE-AC52-07NA27344.

JP11 76 Direct comparison of neutral velocity distribution measurements and simulations in the vicinity of an absorbing boundary oblique to a magnetic field  
MIGUEL F. HENRIQUEZ, DEREK S. THOMPSON, West Virginia University  
Department of Physics and Astronomy  
SHANE KENILEY, DAVIDE CURREL, University of Illinois Urbana-Champaign  
Department of Nuclear, Plasma, and Radiological Engineering  
THOMAS E. STEINBERGER, DAVID D. CARON, ANDREW J. JEMIOLO, JACOB W. MCLAUGHLIN, MIKAL T. DUFOUR, LUKE A. NEAL, EARL E. SCIME, West Virginia University  
Department of Physics and Astronomy  
UMAIR SIDIQUI, Phase Four Inc.  
Plasma-boundary interactions are strongly affected by the sheath and presheath structures that form near the boundary surface. Recent measurements have observed ion transport across magnetic field lines in regions where the surface is oblique to the background magnetic field (ψ > 74°). In these boundary regions, charge exchange collisions may provide a mechanism through which neutral particles interact with the long distance presheath electric field. We report efforts to directly compare Boltzmann and particle-in-cell simulations with 3D neutral velocity distribution functions (NVDFs) using laser induced fluorescence (LIF) in a magnetized plasma boundary region. We present a novel LIF method for measuring Ar-II metastable velocity distributions, in which we observe the 738.9167 nm fluorescence (2π to 1s₃) in Paschen’s notation), that results from absorption of the 706.9167 nm (1s₃ metastable to 2π₃) pump laser, providing neutral temperatures and flows. We additionally describe electrostatic probe measurements in the same region.

JP11 77 Progress On The Thomson Scattering Diagnostic For The Helicon Plasma Experiment (HPX)*  
CGAPL TEAM  
A high-performance spectrometer utilizing volume-phase-holographic (VPH) grating and a charge coupled device (CCD) camera with a range of 380-1090 nm and resolution of 1024x1024 has been assembled on HPX at the Coast Guard Academy Plasma Laboratory (CGAPL). This spectrometer will collect doppler shifted photons, emitted from the plasma by the first harmonic (1064 nm) of a 2.5 J Nd:YAG laser. Direct measurements of the plasma’s temperature and density will be determined using HPX’s Thomson Scattering (TS) single spatial point diagnostic system. A zero order half wave plate rotates the polarization of the second harmonic TS laser beam when operating at a wavelength of 532 nm. A linear actuated periscope has been constructed to remotely redirect the beam so that 532 and 1064 nm wavelengths can both be used. TS has the capability of determining plasma properties on short time scales and will be used to create a robust picture of the internal plasma parameters. Operating at both
532 and 1064 nm results in a self-consistent measurement and better use our existing spectrometer and soon to be constructed polychrometer. A prototype spectrometer has been explored to assess the Andor CCD camera’s resolution and sensitivity. The current status of the diagnostic development, spectrometer, and collection optics system will be reported.

*Supported by U.S. DEPS Grant [HEL-JTO] PRWJFY17.

JP11 78 Progress on the Development of Low Pressure High Density Plasmas on the Helicon Plasma Experiment (HPX)*

R.W. JAMES, A. CHAMBERLIN, P. AZZARI, P. CRILLY, T. EMAMI, J. HOPSON, J. KARAMA, A. GREEN, R.N. PAOLINO, E. SANDRI, J. TURK, M. WICKE, U.S. Coast Guard Academy CGAPL TEAM The small Helicon Plasma Experiment (HPX) at the Coast Guard Academy Plasma Lab (CGAPL), continues to progress toward utilizing the reputed high densities \( (10^{13} \text{ cm}^{-3} \text{ and higher}) \) at low pressure (0.1 T) \cite{1} of helicons, for eventual high temperature and density diagnostic development in future laboratory investigations. HPX is designed to create repeatedly stable plasmas \( (~20-30 \text{ ns}) \) induced by an RF frequency in the 10 to 70 MHz range. HPX has constructed a protected Langmuir probe where raw data will be collected, compared to the RF compensated probe and used to measure the plasma’s density, temperature, and behavior during experiments. Our 2.5 J YAG laser Thomson Scattering system backed by a 32-channel Data Acquisition (DAQ) system is capable 12 bits of sampling precision at 2 MS/s for HPX plasma property investigations are being integrated into the existing diagnostics and control architecture. Progress on the construction of the RF coupling system, Helicon Mode development, and magnetic coils, along with observations from the Thomson Scattering, particle, and electromagnetic scattering diagnostics will be reported.

*Supported by U.S. DEPS Grant [HEL-JTO] PRWJFY17.

JP11 79 EBT-XD Radiochromic Film Sensitivity Calibrations Using Proton Beams from a Pelletron Accelerator* BARAK STOCKLER, SUNY Geneseo ALEXANDER GRUN, Gettysburg GUNNAR BROWN, MATTHEW KLEIN, JACOB WOOD, ANTHONY COOPER, RYAN WARD, CHARLIE FREEMAN, STEPHEN PADALINO, SUNY Geneseo S.P. REGAN, T.C. SANGSTER, Laboratory for Laser Energetics Radiochromic film (RCF) is a transparent detector film that permanently changes color following exposure to ionizing radiation. RCF is used frequently in medical applications, but also has been used in a variety of high energy density physics diagnostics. RCF is convenient to use because it requires no chemical processing and can be scanned using commercially available document scanners. In this study, the sensitivity of Gafchromic® EBT-XD RCF to protons and x-rays was measured. Proton beams produced by the SUNY Geneseo Pelletron accelerator were directed into an evacuated target chamber where they scattered off a thin gold foil. The scattered protons were incident on a sample of RCF which subtended a range of angles around the scattering center. A new analysis method, which relies on the variation in scattered proton fluence as a function of scattering angle in accordance with the Rutherford scattering law, is currently being developed to speed up the proton calibrations. Samples of RCF were also exposed to x-ray radiation using an X-RAD 160 x-ray irradiator, allowing the sensitivity of RCF to x-rays to be measured.

*Supported by USDOE.

JP11 80 C-MOD

JP11 81 The High Field Path to Practical Fusion Energy ROBERT MUMGAARD, D. WHYTE, M. GREENWALD, Z. HARTTWIG, D. BRUNNER, B. SORBOM, E. MARMAR, J. MINNIVERNI, P. BONOLI, J. IRBY, B. LABOMBARD, J. TERRY, R. VIEIRA, S. WUKITCH, MIT PSFC We propose a faster, lower cost development path for fusion energy enabled by high temperature superconductors, devices at high magnetic field, innovative technologies and modern approaches to technology development. Timeliness, scale, and economic-viability are the drivers for fusion energy to combat climate change and aid economic development. The opportunities provided by high-temperature superconductors, innovative engineering and physics, and new organizational structures identified over the last few years open new possibilities for realizing practical fusion energy that could meet mid-century decarbonization needs. We discuss re-factoring the fusion energy development path with an emphasis on concrete risk retirement strategies utilizing a modular approach based on the high-field tokamak that leverages the broader tokamak physics understanding of confinement, stability, and operational limits. Elements of this plan include development of high-temperature superconductor magnets, simplified immersion blankets, advanced long-leg divertors, a compact divertor test tokamak, efficient current drive, modular construction, and demountable magnet joints. An R&D plan culminating in the construction of an integrated pilot plant and test facility modeled on the ARC concept is presented.

JP11 82 High Performance Regimes in Alcator C-Mod at High Magnetic Field* E.S. MARMAR, Massachusetts Institute of Technology ALCATOR C-MOD TEAM Alcator is the only divertor tokamak in the world capable of operating at magnetic fields up to 8 T, equaling and exceeding that planned for ITER. Using RF and microwave tools for auxiliary heating and current drive, C-Mod accesses high pressure, high density, reactor-relevant regimes with no external torque and equilibrated electrons and ions, with exclusive use of high-Z metal plasma-facing components. The 2016 experimental campaign focused on naturally ELM-suppressed, enhanced energy confinement regimes (including I-mode and EDA H-mode, and approaches to super-H-mode), with emphasis on operation at the highest fields (5 < B_t < 8 T). Results include extension of pedestal stability studies to 8T, including characterization of edge relaxation mechanisms and comparisons with theory, evaluation of the window for steady-state I-mode access, as well as confirmation of the Eich scaling for SOL power widths \( (L_q \propto 1/B_t) \) for \( B_t \) up to 1.3T. On the final operation day of the campaign, a new world record for average confined-plasma pressure (> 2 atm.) was achieved. Taken together, combined with previous results from C-Mod and the world tokamak database, these results form a strong foundation for the high field, compact approach to achieving fusion energy production. New advances in high temperature, high field superconductors open the possibilities for practical development of this path for commercial fusion.

*Supported by USDOE.

JP11 83 Conceptual design study for heat exhaust management in the ARC fusion pilot plant C.A. DENNETT, N.M. CAO, A.J.
CREELY, J. HECLA, H. HOFFMAN, A.Q. KUANG, M. MAI JOR, J. RUIZ RUIZ, R.A. TINGUELY, E.A. TOLMAN, D. BRUN NER, B. LABOMBARD, B.N. SORBOM, D.G. WHYTE, MIT P. GROVER, C. LAUGHMAN, MERL The ARC pilot plant conceptual design study [1] has been extended to explore solutions for managing heat exhaust resulting from ~525 MW of fusion power in a compact (R ~ 3.3 m) tokamak. Superconducting poloidal field coils are configured to produce double-null equilibria that support X-point target divertors while maintaining the original core plasma shape and toroidal field coil size. Long outer divertor legs are appended to the original vacuum vessel, providing both large surface areas for surface dissipation of radiative heat and significantly reduced neutron damage for divertor components. A molten salt FLiBe blanket adequately shields all superconductors and functions as a tritium breeder, with advanced neutronics calculations indicating a tritium breeding ratio of ~1.08. In addition, FLiBe is used as the active coolant for the entire vessel. A tungsten swirl-tube cooling channel is implemented in the divertor, capable of exhausting 12 MW/m² heat flux while keeping total FLiBe pumping power below 1% of fusion power. Finally, three novel diagnostics are explored: Cherenkov radiation emitted in FLiBe to measure fusion reaction rate, microwave interferometry to measure divertor detachment front location, and IR imaging through the FLiBe blanket to monitor selected divertor “hotspots.”

J.P. Manz, Hybrid Range of Frequencies Actuators JP11 84 Integrated, Reactor Relevant Solutions for Lower Hybrid Range of Frequencies Actuators* S SHIRAIWA, P.T. BONOLI, Y LIN, G.M. WALLACE, S.J. WUKITCH, PSFC, MIT RF (radiofrequency) actuators with high system efficiency (wall-plug to plasma) and ability for continuous operation have long been recognized as essential tools for realizing a steady state tokamak. A number of physics and technological challenges to utilization remain including current drive efficiency and location, efficient coupling, and impurity contamination. In a reactor environment, plasma material interaction (PMI) issues associated with coupling structures are similar to the first wall and have been identified as a potential show-stopper. High field side (HFS) launch of LHRF power represents an integrated solution that both improves core wave physics and mitigates PMI/coupling issues. For HFS LHRF, wave penetration is vastly improved because wave accessibility scales as 1/B allowing for launching the wave at lower n° (parallel refractive index). The lower n° penetrate to higher electron temperature resulting in higher current drive efficiency (1/n°×). HFS RF launch also provides for a means to dramatically improve launcher robustness in a reactor environment. On the HFS, the SOL is quiescent; local density profile is steep and controlled through magnetic shape; fast particle, neutron, turbulent heat and particle fluxes are eliminated or minim

1B. N. Sorbom et al., Fusion Engineering and Design 100, 378 (2015).

“Work supported by the U.S. DoE under DE-FC02-99ER54512 and US DoE Contract No. DE-FC02-01ER54648 under a Scientific Discovery through Advanced Computing Initiative.

JP11 84 Integrated, Reactor Relevant Solutions for Lower Hybrid Range of Frequencies Actuators* S SHIRAIWA, P.T. BONOLI, Y LIN, G.M. WALLACE, S.J. WUKITCH, PSFC, MIT RF (radiofrequency) actuators with high system efficiency (wall-plug to plasma) and ability for continuous operation have long been recognized as essential tools for realizing a steady state tokamak. A number of physics and technological challenges to utilization remain including current drive efficiency and location, efficient coupling, and impurity contamination. In a reactor environment, plasma material interaction (PMI) issues associated with coupling structures are similar to the first wall and have been identified as a potential show-stopper. High field side (HFS) launch of LHRF power represents an integrated solution that both improves core wave physics and mitigates PMI/coupling issues. For HFS LHRF, wave penetration is vastly improved because wave accessibility scales as 1/B allowing for launching the wave at lower n° (parallel refractive index). The lower n° penetrate to higher electron temperature resulting in higher current drive efficiency (1/n°×). HFS RF launch also provides for a means to dramatically improve launcher robustness in a reactor environment. On the HFS, the SOL is quiescent; local density profile is steep and controlled through magnetic shape; fast particle, neutron, turbulent heat and particle fluxes are eliminated or minim

1B. N. Sorbom et al., Fusion Engineering and Design 100, 378 (2015).

“Work supported by the U.S. DoE under DE-FC02-99ER54512 and US DoE Contract No. DE-FC02-01ER54648 under a Scientific Discovery through Advanced Computing Initiative.

JP11 84 Separation of particle and energy transport in the I-mode regime* A.E. HUBBARD, MIT PSFC I. CZIEGLER, York Plasma Inst. T. HAPPEL, IPP Garching J.W. HUGHES, MIT PSFC P. MANZ, IPP Garching J.E. RICE, T. WILKS, MIT PSFC ALCA TOR C-MOD TEAM, ASDEX UPGRADE TEAM The I-mode regime is distinct among regimes of improved tokamak energy confinement in that it clearly separates particle and energy transport; I-mode has L-mode particle (main ion and impurity) confinement but high (H-mode-like) energy confinement. The phenomenology of the regime is well measured, and very similar, on both Alcator C-Mod and ASDEX Upgrade. A broad peak in fluctuations at a few hundred kHz, called the Weakly Coherent Mode, is observed. A fluctuating flow at the GAM frequency exchanges energy with the WCM and helps to broaden it. Transport in I-mode is observed to be more intermittent or ‘bursty’ than in L-mode. An Er well exists in I-mode which is deeper than in L-mode but weaker than in some H-modes. The transition from L-mode to I-mode is typically more gradual than the L-H transition and likely not the same type of bifurcation. The reason for the separation of transport channels is less clear. Possible physics mechanisms, and some initial simulations of underlying instabilities, will be discussed.

*Work supported by the U.S. DOE under DE-FC02-99ER54512 and DE-SC0014264.

JP11 86 Impact of magnetic field and heating power on Er profile and fluctuations in I-mode pedestals in C-Mod* JERRY HUGHES, T.M. WILKS, MIT I. THEILER, EPFL A.E. HUBbard, S.-G. BAEK, MIT M. CHURCHILL, PPL I. CZIEGLER, YPI E. EDLUND, J. RICE, E. TOLMAN, MIT C-MOD TEAM Cross machine comparisons of I-mode show robust stationary ELM suppressed plasmas over broad operating conditions, suggesting the potential for the regime to be utilized in future reactors. I-modes typically exhibit separation of particle and energy transport channels, often associated with the weakly coherent mode (WCM) coupled to a GAM-like fluctuation in the edge pedestal region. C-Mod I-mode pedestals are analyzed over varied magnetic fields (2.8-5.8T) and auxiliary power (1.5-4.6 MW) to determine trends in the edge radial electric field, ExB shear, rotation, and fluctuations. In a controlled power ramp, the radial electric field well increases with power before reaching its maximum before the I-H transition. With increased input power, preliminary observations show an increase in the fluctuation frequencies, followed by a frequency reversal associated with an increase in mid-spectrum fluctuations. Previous research has explored the L-I and I-H power thresholds dependence on plasma density, surface area and magnetic field, allowing us to examine pedestal ExB shear as a function of proximity to these thresholds.

*Work supported by the U.S. DOE under DE-FC02-99ER54512 and DE-SC0014264.

JP11 87 Turbulence phase transitions involving I-mode states in Alcator C-Mod* ISTVAN CZIEGLER, University of York AMANDA HUBBARD, JERRY HUGHES, JAMES TERRY, PSFC, MIT The edge turbulence dynamics of the low- to high-confinement transition has recently been characterized as spectral transfer suppressing turbulence while driving zonal flows (ZF). The I-mode, an alternative regime combining high heat confinement with low particle and impurity confinement, exhibits geodesic-acoustic modes (GAM), which couple nonlinearly to the regime’s characteristic edge fluctuation, the “weakly coherent mode” (WCM). Although this suggests that ZF and GAM may play similar roles, their dynamics in transitions are not well understood. Fluctuations in and leading up to I-mode were studied with a focus on the interaction between turbulence and flows. Results offer an insight into the background of the range of plasma parameters in which I-modes can be maintained (“I-mode window”) as one of nonlinear dynamics. Trends of nonlinearities are analyzed in L- and I-modes, as well as the dynamics in L-I and I-H transitions. The L-I dynamics appear markedly different from L-H transitions, while the I-H transition (like the L-H case) is dominated by ZF phenomena.
**JP11 88 Gyrokinetic and experimental investigations of multiscale turbulence in Alcator C-Mod and DIII-D plasmas**


Extensive comparisons of high physics fidelity, multi-scale gyrokinetic simulations \((m_i/m_e = 1, \beta_N = 1.9, q95 = 3.3, Te/Ti \sim 2.5-5.0)\) documented possible signatures of cross-scale coupling in the wavenumber spectrum of intermediate-\(k (k \rho_s \sim 2.5-5.0)\) density fluctuations measured with the Doppler backscattering (DBS) diagnostic. Results from multi-scale simulations of Alcator C-Mod plasmas and progress on analysis and simulation of the DIII-D experiments will be presented.

*Supported by US DOE Grant DEFC02-99ER54512-CMOD and DE-FC02-04ER54698.*

**JP11 89 Flux-driven turbulence GDB simulations of the IWL Alcator C-Mod L-mode edge compared with experiment**

MANAMURE FRANCISQUEZ, BEN ZHU, BARRETT ROGERS, Dartmouth College

Prior to predicting confinement regime transitions in tokamaks one may need an accurate description of L-mode profiles and turbulence properties. These features determine the heat-flux width upon which wall integrity depends, a topic of major interest for research aid to ITER. To this end our work uses the GDB model to simulate the Alcator C-Mod edge and contributes support for its use in studying critical edge phenomena in current and future tokamaks. We carried out 3D electromagnetic flux-driven two-fluid turbulence simulations of inner wall limited (IWL) C-Mod shots spanning closed and open flux surfaces. These simulations are compared with gas puff imaging (GPI) and mirror Langmuir probe (MLP) data, examining global features and statistical properties of turbulent dynamics. GDB reproduces important qualitative aspects of the C-Mod edge regarding global density and temperature profiles, within reasonable margins, and though the turbulence statistics of the simulated turbulence follow similar quantitative trends questions remain about the code’s difficulty in exactly predicting quantities like the autocorrelation time A proposed breakpoint in the near SOL pressure and the posited separation between drift and ballooning dynamics it represents are examined

*This work was supported by DOE-SC-0010508. This research used resources of the National Energy Research Scientific Computing Center (NERSC).*

**JP11 90 Validation of TGLF in C-Mod and DIII-D using machine learning and integrated modeling tools**

P RODRIGUEZ-FERNANDEZ, AE WHITE, NM CAO, AJ CREELEY, MJ GREENWALD, MIT BA GRIERSON, PPPL NT HOWARD, MIT O MENEGHINI, CC PETTY, GA JE RICE, F SCIORTINO, MIT X YUAN, PPPL Predictive models for steady-state and perturbative transport are necessary to support burning plasma operations. A combination of machine learning algorithms and integrated modeling tools is used to validate TGLF in C-Mod and DIII-D. First, a new code suite, VITALS, is used to compare SAT1 and SAT0 models in C-Mod. VITALS exploits machine learning and optimization algorithms for the validation of transport codes. Unlike SAT0, the SAT1 saturation rule contains a model to capture cross-scale turbulence coupling. Results show that SAT1 agrees better with experiments, further confirming that multi-scale effects are needed to model heat transport in C-Mod L-modes. VITALS will next be used to analyze past data from DIII-D: L-mode “Shortfall” plasma and ECH swing experiments. A second code suite, PRIMA, allows for integrated modeling of the plasma response to Laser Blow-Off cold pulses. Preliminary results show that SAT1 qualitatively reproduces the propagation of cold pulses after LBO injections and SAT0 does not, indicating that cross-scale coupling effects play a role in the plasma response. PRIMA will be used to “predict-first” cold pulse experiments using the new LBO system at DIII-D, and analyze existing ECH heat pulse data.

*Work supported by DE-FC02-99ER54512, DE-FC02-04ER54698.*

**JP11 91 Bayesian Inference of H-mode Impurity Transport in Alcator C-Mod**


The investigation of impurity transport offers a compelling pathway for the validation of turbulence models, in particular through the computation of radial profiles of impurity transport coefficients. Such validation effort requires a rigorous computation of uncertainties, which we approach in a Bayesian framework using Gaussian Process Regression and the MultiNest algorithm to sample from multi-dimensional, potentially multi-modal posterior distributions. For the first time, we applied such analysis to determine experimental impurity transport in an Alcator C-Mod EDA H-mode plasma, where impurity confinement times are expected to be larger than in previously analyzed L-mode conditions. Using spatially resolved measurements of Ca +18 provided by an X-ray Imaging Crystal Spectrometer (XICS) and the STRAHL impurity transport code, radial profiles of experimental diffusion and convection coefficients were obtained following the injection of impurities via Laser Blow-Off (LBO). These results constitute the first steps towards constructing an impurity transport experimental database that will be used to provide constraints for gyrokinetic model validation.

*Supported by US DoE Grants DEFC02-99ER54512-CMOD, DE-FG02-91-ER54109.*

**JP11 92 Electron Profile Stiffness and Critical Gradient Length Studies in the Alcator C-Mod Tokamak**

SAEID HOUSH-MANDYAR, DAVID R. HATCH, KENNETH T. LIAO, BINGZHE ZHAO, PERRY E. PHILLIPS, WILLIAM L. ROWAN, Institute for Fusion Studies, The University of Texas at Austin NORMAN CAO, DARIN E. ERNST, JOHN E. RICE, Plasma Science and Fusion Center, MIT

Electron temperature profile stiffness was investigated at Alcator C-Mod L-mode discharges. Electrons were heated by ion cyclotron range of frequencies (ICRF) through minority heating. The intent of the heating mechanism was to vary the heat flux and simultaneously, gradually change the local gradient. The electron
temperature gradient scale length \( (L_{\tau}^T = |\nabla T|/T) \) was accurately measured through a novel technique, using the high-resolution radiometer ECE diagnostic [1]. The TRANSP power balance analysis \((Q/Q_{rad})\) and the measured scale length \((a/L_{\tau})\) result in critical scale length measurements at all major radius locations. These measurements suggest that the profiles are already at the critical values. Furthermore, the dependence of the stiffness on plasma rotation and magnetic shear will be discussed. In order to understand the underlying mechanism of turbulence for these discharges, simulations using the gyrokinetic code, GENE, were carried out. For linear runs at electron scales, it was found that the largest growth rates are very sensitive to \(a/L_{\tau}\) variation, which suggests the presence of ETG modes, while the sensitivity studies in the ion scales indicate ITG/TEM modes.

*Supported by USDoE awards DE-FG03-96ER54373 and DE-FC02-99ER45412.


**JP11 93 The Multi-Spectral Imaging Diagnostic on Alcator C-Mod and TCV** B. L. LINEHAN, R. T. MUMGAARD, MIT PSFC B. P. DUVAL, C. G. THEILER, EPFL SPC TCV TEAM The Multi-Spectral Imaging (MSI) diagnostic is a new instrument that captures simultaneously spectrally filtered images from a common sight view while maintaining a large tendue and high spatial resolution. The system uses a polychromator layout where each image is sequentially filtered. This procedure yields a high transmission for each spectral channel with minimal vignetting and aberrations. A four-wavelength system was installed on Alcator C-Mod and then moved to TCV. The system uses industrial cameras to simultaneously image the divertor region at 95 frames per second at \#8 2.8 via a coherent fiber bundle (C-Mod) or a lens-based relay optic (TCV). The images are absolutely calibrated and spatially registered enabling accurate measurement of atomic line ratios and absolute line intensities. The images will be used to study divertor detachment by imaging impurities and Balmer series emissions. Furthermore, the large field of view and an ability to support many types of detectors opens the door for other novel approaches to optically measuring plasma with high temporal, spatial, and spectral resolution. Such measurements will allow for the study of Stark broadening and divertor turbulence. Here, we present the first measurements taken with this cavity imaging system.

*Supported by USDoE awards DE-FC02-99ER45412 and award DE-AC05-06OR23100, ORISE, administered by ORAU.

**JP11 94 Universality in scrape-off layer plasma fluctuations: Comparison of experiment to numerical simulations** RALPH KUBE, ODD ERIK GARCIA, AUDUN THEODORSEN, UIT-The Arctic University of Norway DAN BRUNNER, BRIAN LABOMBARD, JAMES TERRY, MIT Plasma Science and Fusion Center MATTHIAS WIESENBERGER, Technical University of Denmark Particle density time series, sampled in the outboard mid-plane scrape-off layer, are interspersed by large amplitude bursts due to radial propagation of plasma blobs. GPI and Langmuir probe time series measured in the Alcator C-Mod tokamak suggest that conditionally averaged wave forms of large amplitude bursts are well described by a double exponential function. Furthermore remains the ratio of the rise and fall \(e\)-folding time of the conditionally averaged wave form constant over a range of line-averaged plasma densities. In this contribution we compare this finding to results from numerical simulations. A two-dimensional drift-fluid model has been used to simulate the propagation of seeded plasma blobs in scrape-off layer plasmas for various initial amplitudes and cross-field sizes. Time traces of the particle density, sampled at a single point, are compared to the conditionally averaged waveform of the experimental data time series. The results are interpreted in the framework of a stochastic model which relates the statistical properties of the SOL fluctuations to the profile scale length.

*Supported by USDoE award DE-FC02-99ER45412.

**JP11 96 Synchrotron emission in Alcator C-Mod: spectra at three magnetic fields, visible camera images, and polarization data** R ALEX TINGUELY, ROBERT GRANETZ, MIT Plasma Science and Fusion Center MATHIAS HOPPE, OLA EMBREUS, ADAM STAHL, TUNDE FULOP, Chalmers University of Technology Alcator C-Mod’s high magnetic field allows runaway electron synchrotron emission to be observed in the visible wavelength range. Visible spectrometers were used to measure synchrotron spectra at three magnetic fields: 2.7, 5.4, and 7.8 T. Both a test-particle model [1] and kinetic solver CODE (Collisional Distribution of Electrons) [2,3] explore the energy evolution of the runaway population and the impact of magnetic-field-dependent synchrotron radiation as a power loss mechanism. Additionally, distortion-corrected visible camera images capture the spatial distribution and evolution of synchrotron emission in C-Mod. Initial results show good agreement between experiment and the new synthetic diagnostic SOFT (Synchrotron-detecting Orbit-Following Toolkit) [4]. Finally, a first look at synchrotron polarization data is presented.

2 M. Landreman et al., CPC 185 (2014).
3 A. Stahl et al., NF 56 (2016).
4 M. Hoppe et al., in progress.

**JP11 97 An assessment of methods to compute secondary electron emission for tungsten and molybdenum and implications**
for plasma potential measurements by Langmuir probes in Alcator C-Mod* WILLIAM MCCARTHY, BRIAN LABOMBARD, DAN BRUNNER, ADAM KUANG, Massachusetts Inst of Tech-MIT Plasma potentials measured by Langmuir probes rely on a method to compute secondary electron emission (SEE) yield. However, significant variations exist among published models for SEE and the datasets used to evaluate them. As a means to critically assess SEE evaluation methods, two of four tungsten electrodes on a Langmuir-Mach probe head were replaced with molybdenum and exposed to high temperature (>50 eV) plasmas in this situation. Plasma potentials computed for either material should be identical, with the SEE evaluation method properly accounting for significant differences in SEE yields. Of the six methods to compute SEE examined, two are found to produce consistent results (Sternglass-Bronstein and Young-Decker-Bronstein). In contrast, the method previously used for C-Mod data analysis (Sternglass-Kollath) was found to be inconsistent. We have since adopted Young-Decker-Bronstein. An important consequence is that values for plasma potential, electric field and ExB flow shear near the LCFS in Alcator C-Mod is substantially increased compared to what had been reported previously.

*This work was supported by DoE Contract DE-FC02-99ER54512 on Alcator C-Mod, a DoE Office of Science user facility.

JP11 98 Fluctuations measured by flush mounted versus proud divertor Langmuir probes – why are they different?" O.E. GARCIA, UIT A.Q. KUANG, D. BRUNNER, B. LABOMBARD, MIT PSFC R. KUBE, UIT A flush-mounted, toroidally-elongated, and field-aligned divertor ‘rail’ Langmuir probe array was installed in Alcator C-Mod in 2015. This geometry is heat flux tolerant and effectively mitigates shear expansion effects to incident field line angles of 0.5 degree [1]. Further complications have arisen that cannot be explained by shear-expansion. In particular, the ‘rail’ probe geometry measures significantly higher plasma fluctuation levels in the common flux region compared to traditional proud probes, whereas they are similar in the private flux zone. In some instances, the amplitudes of ion saturation current fluctuations normalized to the mean are a factor of 2 higher; probability distribution functions correspondingly record large amplitude events that are not seen by the proud probes. This discrepancy also appears to depend on divertor plasma regime. For example, fluctuations become similar near the strikepoint when the electron temperature is low. To ensure that these discrepancies were not due to perturbations caused by the voltage bias or currents collected by the probes, the two Langmuir probe systems were left to ‘float’ and the fluctuation statistics analyzed. Yet, even in this non-perturbative situation, there exist clear differences in the fluctuation characteristics. The raises two questions: how does the probe geometry affect plasma fluctuations measurements and what are the true plasma fluctuations experienced by the divertor surface?

*Supported by USDoe awards DE-FC02-99ER54512.


JP11 100 Mode conversion in ICRF experiments on Alcator C-Mod* Y. LIN, S.J. WUKITCH, E. EDLUND, P. ENNEVER, A.E. HUBBARD, M. PORKOLAB, J. RICE, J. WRIGHT, MIT PSFC In recent three-ion species (majority D and H plus a trace level of 3He) ICRF heating experiment on Alcator C-Mod [1], double mode conversion on both sides of the 3He cyclotron resonance has been observed using the phase contrast imaging (PCI) system. The MC locations are used to estimate the species concentrations in the plasma. Simulation using TORIC shows that with the 3He level <1%, most RF power is absorbed by the 3He ions and the process can generate energetic 3He ions. In recent mode conversion flow drive experiment in D(3He) plasma at 8 T, MC waves were also monitored by PCI. The MC ion cyclotron wave (ICW) amplitude and wavenumber kR have been found to correlate with the flow drive force. The MC efficiency, wave-number k of the MC ICW and their dependence on plasma parameters like TDr are shown to play important roles. Based on the experimental observation and numerical study of the dispersion solutions, a hypothesis of the flow drive mechanism has been proposed.

*Supported by USDoe awards DE-FC02-99ER54512.


JP11 101 MST

JP11 102 Overview of MST Research* B.E. CHAPMAN, UW-Madison MST progress in advancing the RFP for (1) fusion plasma confinement with ohmic heating and minimal external magnetization, (2) predictive capability in toroidal confinement physics, and (3) basic plasma physics is summarized. Validation of key plasma models is a program priority, which is enhanced by programmable power supplies (PPS) to maximize inductive capability. The existing PPS enables access to very low plasma current, down to Ip=0.02 MA. This greatly expands the Lundquist number range S=107-108 and allows nonlinear, 3D MHD computation using NIMROD and DEBS with dimensionless parameters that overlap those of MST plasmas. A new, second PPS will allow simultaneous PPS control of the Bp and Bt circuits. The PPS also enables MST tokamak operation, thus far focused on disruptions and RMP suppression of runaway electrons. Gyrokinetic modeling with GENE predicts unstable
TEM in improved-confinement RFP plasmas. Measured fluctuations have TEM properties including a density-gradient threshold larger than for tokamak plasmas. Turbulent energization of an electron tail occurs during sawtooth reconnection. Probe measurements hint that drift waves are also excited via the turbulent cascade in standard RFP plasmas. Exploration of basic plasma science frontiers in MST RFP and tokamak plasmas is proposed as part of WiPPL, a basic science user facility.

*Work supported by USDoE.

**JP11 103 Intrinsic Flow and Momentum Transport during Improved Confinement in MST** D. CRAIG, E. TAN, B. SCHOTT, Wheaton College, Wheaton IL USA J.K. ANDERSON, J. BOGUSKI, M.D. NORNBERG, Z.A. XING, University of Wisconsin - Madison, WI USA Progress in absolute wavelength calibration of the Charge Exchange Recombination Spectroscopy (CHERS) system on MST has enabled new observations and analysis of intrinsic flow and momentum transport. Localized toroidal and poloidal flow measurements with systematic accuracy of +/- 3 km/s have been obtained during improved confinement Pulsed Parallel Current Drive (PPCD) plasmas at high plasma current (400-500 kA). The magnetic activity prior to and during the transition to improved confinement tends to increase the flow and sets the initial condition for the momentum profile evolution during improved confinement where intrinsic flow drive appears to weaken. Inboard flows change in time during PPCD, consistent with changes in the core-resonant m=1, n=6 tearing mode phase velocity. Outboard flows near the magnetic axis are time-independent, resulting in the development of a strongly sheared toroidal flow in the core and asymmetry in the poloidal flow profile. The deceleration of the n=6 mode during the period of improved confinement correlates well with the n=6 mode amplitude and is roughly consistent with the expected torque from eddy currents in the conducting shell. The level of Dα-emission and secondary mode amplitudes (n=7-10) do not correlate with the mode deceleration suggesting that the momentum loss from charge exchange with neutrals and diffusion due to residual magnetic stochasticity are not significant in PPCD.

*This work has been supported by the U.S.D.O.E.

**JP11 104 Ion energy balance in enhanced-confinement reversed-field pinch plasmas** Z. A. XING, M.D. NORNBERG, J. BOGUSKI, University of Madison-Wisconsin D. CRAIG, Wheaton College D.J. DEN HARTOG, K. MCCOLLAM, University of Madison-Wisconsin Testing the applicability of collisional ion transport theory using tearing suppressed RFP plasma in MST achieved through Pulsed Poloidal Current Drive (PPCD), we find that the ion temperature dynamics in the core to be well-predicted by classical and collisional terms. Prior work demonstrated that impurity ion particle transport in PPCD plasmas is classical. Neoclassical effects on ions in the RFP are small and the stochastic transport is greatly suppressed during PPCD. Recent neutral modelling with DEGAS2 suggests higher core neutral temperatures than expected due to the preferential penetration of higher temperature neutrals generated by charge exchange. Further, investigations through equilibrium reconstruction point to the existence of an inward pinch flow associated with ExB drift. The heat balance model pulls together a wide range of diagnostic data to forward model T_e evolution in PPCD, which is then compared to charge exchange spectroscopy measurements of T_e. Ion power balance is mostly driven by classical effects including compressional heating, electron collisional heating, and charge exchange transport. This understanding provides a good baseline for investigations of anomalous heating in plasmas with tearing mode activity.

*This work is supported by US DOE.

**JP11 105 Measurements of Impurity Particle Transport Associated with Drift-Wave Turbulence in MST** TAKASHI NISHIZAWA, MARK NORNBERG, JOHN BOGUSKI, University of Wisconsin, Madison DARREN CRAIG, Wheaton College, IL DANIEL DEN HARTOG, M.J. PUESCHEL, JOHN SARFF, PAUL TERRY, ZACH WILLIAMS, ZICHUAN XING, University of Wisconsin, Madison Understanding and controlling impurity transport in a toroidal magnetized plasma is one of the critical issues that need to be addressed in order to achieve controlled fusion. Gyrokinetic modeling shows turbulence can drive impurity transport, but direct measurements of the turbulent flux have not been made. Particle balance is typically used to infer the presence of turbulent impurity transport. We report, for the first time in a toroidal plasma, direct measurements of turbulence-driven impurity transport. Trapped electron mode (TEM) turbulence appears in MST plasmas when MHD tearing fluctuations are suppressed. Impurity ion-Doppler spectroscopy is used to correlate impurity density and radial velocity fluctuations associated with TEM. Small Doppler shifts associated with the radial velocity fluctuations (rms 1km/s) are resolved with the use of a new linearized spectrum correlation analysis method, which improves the rejection of Poisson noise. The method employs frequency-domain correlation analysis to expose the fluctuation and transport spectrum. The C^∗^2 impurity transport velocity driven by turbulence is found to be 48m/s (inward), which is sufficiently large to impact an impurity flux balance in MST improved-confinement plasmas.

*This work is supported by the US DOE.

**JP11 106 Measurement of ion velocities in the locked Single Helical Axis state in MST RFP plasmas** J. BOGUSKI, M. D. NORNBERG, B. E. CHAPMAN, Univ of Wisconsin, Madison M. CIANCIOISA, Oak Ridge National Laboratory D. J. DEN HARTOG, Univ of Wisconsin, Madison D. CRAIG, Wheaton College K. J. MCCOLLAM, T. NISHIZAWA, Z. A. XING, Univ of Wisconsin, Madison Charge Exchange Recombination Spectroscopy (CHERS) provides the first core-localized measurements of the 3D ion flow structure in Single Helical Axis (SHAs) plasmas. In high-current and low-density (large Lundquist number) RFP plasmas, the island associated with the innermost resonant tearing mode can grow to large amplitude and envelop the magnetic axis creating a 3D equilibrium. Measurements of the flow profile with various orientations (phases) of the helical structure relative to the CHERS diagnostic were achieved by locking the plasma with resonant magnetic perturbations. The flows persist despite mode locking, and are correlated with the amplitude and phase of the innermost resonant tearing mode. At mid-radius, a dominantly m=2 poloidal flow structure appears relative to the phase of the helical core. Near the core, non-axisymmetric flows become less pronounced, and cannot be distinguished at the innermost radii. These results place more significant constraints on the nature of the flow structure than previous line-integrated spectroscopy measurements and challenge predictions of visco-resistive MHD models of these helical RFP plasmas.

*This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences program under Award No. DE-FC02-05ER54814.
JP11 107 Validation of MHD Models using MST RFP Plasmas* C.M. JACOBSON, B.E. CHAPMAN, D.J. DEN HARTOG, K.J. MCCOLLAM, J.S. SARFF, C.R. SOVINEC, University of Wisconsin-Madison Rigorous validation of computational models used in fusion energy sciences over a large parameter space and across multiple magnetic configurations can increase confidence in their ability to predict the performance of future devices. MST is a well-diagnosed reversed-field pinch (RFP) capable of operation with plasma current ranging from 60 kA to 500 kA. The resulting Lundquist number $S$, a key parameter in resistive magnetohydrodynamics (MHD), ranges from $4 \times 10^4$ to $8 \times 10^4$ for standard RFP plasmas and provides substantial overlap with MHD RFP simulations. MST RFP plasmas are simulated using both DEBS, a nonlinear single-fluid visco-resistive MHD code, and NIMROD, a nonlinear extended MHD code, with $S$ ranging from $10^5$ to $10^6$ for single-fluid runs, and the magnetic Prandtl number $Pm = 1$. Validation metric comparisons are presented, focusing on how normalized magnetic fluctuations at the edge $b$ scale with $S$. Preliminary results for the dominant $n = 6$ mode are $b \sim S^{-0.20 \pm 0.02}$ for single-fluid NIMROD, $b \sim S^{-0.25 \pm 0.05}$ for DEBS, and $b \sim S^{-0.20 \pm 0.02}$ for experimental measurements, however, there is a significant discrepancy in mode amplitudes. Preliminary two-fluid NIMROD results are also presented.

*Work supported by US DoE.

JP11 108 Synthetic Camera Diagnostics for Edge Modeling in MST* RYAN NORVAL, HEINKE FERRICH, JOHN GOETZ, OLIVER SCHMITZ, Univ of Wisconsin, Madison A nearly full coverage camera system on MST aids power balance studies by measuring of spatially resolved $D_n$, other Balmer lines, or broadband visible emission. Camera measurements have found the wall recycling in MST to be asymmetric both in standard RFP mode and Quasi-Single Helically (QSH) mode operation. The EIRENE code is used to interpret the measured light and estimate the neutral density from the Balmer lines and a background plasma. A synthetic camera module for EIRENE is currently being implemented which allows comparison between the images that would result from the simulation to the actual images observed by the cameras. Additional diagnostic data from line integrated $D_n$ detectors, and an edge Langmuir probe will help constrain the model. It is expected that an iterative technique to match simulated images to real images will result in more accurate neutral density estimates as well as constraining the relatively unknown edge parameters. This increased accuracy of the neutral profile and edge parameters of MST will allow for better comparison between the standard RFP and the QSH mode with respect to neutral particles acting as an energy loss pathway via charge exchange and radiative losses.

*Supported by US DOE.

JP11 109 Measurements of fast ion spatial dynamics during magnetic activity in the RFP* J.A. GOETZ, J.K. ANDERSON, P. BONOFIGLO, J. KIM, M. MCCONNELL, UW - Madison R.M. MAGEE, TriAlpha Energy, Inc. Fast ions in the RFP are only weakly affected by a stochastic magnetic field and behave nearly classically in concentration too low to excite Alfvenic activity. At high fast ion concentration sourced by NBI in 300kA RFP discharges, a substantial drop in concentration localized high pitch fast ions is observed during bursts of coupled EPM and IAE (magnetic island-induced Alfven eigenmode) activity (100-200kHz) through neutral particle analysis. Sourcing instead fast deuterium with NBI, the DD fusion products can measure the dynamics of the fast ion density profile. Both a collimated neutron detector and a new 3MeV fusion proton detector loaded by TriAlpha Energy measure the fast ion density profile with ~5cm spatial resolution and 100μs temporal resolution. In D-NBI, the bursting EPM is excited at slightly lower frequency and the IAE activity is nearly absent, likely due to an isotope effect and loss of wave-particle interaction. In these cases, neutral particle analysis shows little change in the core-localized high pitch fast ion content, and the fusion product profile indicates little change in the fast ion density profile, leaving unexplained the mechanism removing EPM drive. We measure a substantial redistribution of the fast ion profile due to strong lower-frequency (~30kHz) MHD activity that accompanies the current profile relaxation in the RFP. Profile flattening is strongest in low bulk density discharges, which often occur with a total increase in global neutron flux from acceleration of the beam ions.

*Work supported by US DoE.

JP11 110 Anisotropic and asymmetric fast ion distribution generated by magnetic reconnection in MST plasmas* JUNGHA KIM, JAY ANDERSON, PHILLIP BONOFIGLO, Univ of Wisconsin, Madison ROBERT HARVEY, CompX JOHN SARFF, Univ of Wisconsin, Madison Magnetic reconnection is important in particle transport and energization in both astrophysical and laboratory plasmas. Global reconnection events in MST spontaneously generate an anisotropic ion distribution with a high energy tail extending up to 30x thermal energy, likely through a multi-step process that involves multiple physical scale lengths. First, thermal ions are heated by a mechanism that operates preferentially perpendicular to the magnetic field. Second, the higher energy portion of the thermal ion distribution moves into orbits that drift off the stochastic background magnetic field. In the reversed field pinch (RFP) configuration, these drift velocities contribute to stable fast ion orbits that are low in diffusivity and favorable to confinement. These fast ions, separated from the background magnetic field, are unaffected by fluctuation-based, dynamo-like emfs that reduce the total electric field to 0.5 V/m. Finally, a parallel electric field (~80 V/m), induced by the fast change in the equilibrium during magnetic relaxation, accelerates these fast ions, resulting in an ion distribution that favors high energy, parallel-streaming ions. Work is underway to model the time evolution of the fast ion distribution using CQL3D (Fokker-Planck equation solver) and RIO (full orbit tracer).

*Work supported by US DOE.

JP11 111 Fast Ion Transport in the Three-Dimensional Reversed Field Pinch* P. J. BONOFIGLO, J. K. ANDERSON, University of Wisconsin - Madison E. PARKE, University of California Los Angeles M. GOBBIN, Consorzio RFX J. KIM, J. EGEDAL, University of Wisconsin - Madison The reversed field pinch (RFP) provides a unique environment to study fast ion confinement and transport in both 2D and 3D geometries. In the axisymmetric RFP, guiding center drifts are along flux surfaces, resulting in naturally well-confined fast ions. At sufficiently high Lundquist number, the innermost tearing mode can grow and envelop the magnetic axis, creating a helical axis and 3D equilibrium. Experiments on MST reveal reduced confinement of fast ions with the transition to this quasi-single helicity (QSH) state. Current work aims to probe the dynamics of fast ion transport during QSH. Energetic particle modes (EPMs) upshift in frequency with increasing core tearing mode amplitude, disappear in high current QSH plasmas, and depend on NBI isotope. Additionally, FIR interferometry has resolved electron density perturbations associated with EPMs. The FIR measurements show the upshifting EPMs moving radially outward as they grow in frequency, indicating transport associated with the transition to QSH. The Hamiltonian
guiding center code ORBIT corroborates rapid fast ion loss times in QSH and is being actively used to simulate diffusion coefficients and particle orbits for examining neoclassical transport.

*This research is supported by US DOE.

**JP11 112 Measurement of beam-driven Alfvénic instabilities in MST and comparison to predictions** E. PARKE, UCLA J. K. ANDERSON, J. BOGUSKI, P. J. BONOFIGLIO, UW-Madison D. L. BROWER, W. X. DING, UCLA Neutral beam injection in MST drives a variety of energetic particle modes (EPMs) and Alfvénic modes (AEs). These instabilities can lead to avalanche processes with enhanced fast ion transport, the most commonly observed avalanche involving coupling between modes with toroidal number n = 5, 4, and −1. Density fluctuations correlated with these avalanches, as well as internal magnetic fluctuations associated with the dominant, n = 5 EPM, have previously been characterized with the FIR interferometer-polarimeter. However, the n = 4 and −1 AEs were too weak to observe with polarimetry. Recent upgrades to the interferometer-polarimeter have further reduced the noise floor for fluctuation measurements. The upgraded system allows clear identification of Faraday rotation fluctuations associated with the n = −1 AE. These fluctuations are highly localized, with narrow structure peaking at the same location as the density fluctuations. Previous work has established that the n = 4 and −1 fluctuations are consistent with island-induced AEs (IAEs). Measured structures are compared to predictions for IAIs as well as helicity-induced AEs, and ongoing work to resolve the dependence of observed structures on tearing mode island phase and identify n = 4 correlated fluctuations is presented.

*This work supported by U.S. DOE.

**JP11 113 Core Localized Anisotropic Electron Energization During Magnetic Reconnection in RFP Plasma** ALEXANDER SCHERER, ABDULGADER ALCAGRI, MIHIR PANDYA, AMI DUBOIS, University of Wisconsin-Madison We investigate the generation of an anisotropic electron tail during magnetic reconnection events in the MST RFP device. We have observed a strong, high-energy tail in the electron bremsstrahlung x-ray spectrum for a view perpendicular to the toroidal magnetic field and a relatively weak tail in the x-ray spectra for parallel and antiparallel views [1]. Runaway mechanisms are ruled out for this energization due to symmetry between the parallel and antiparallel spectra. These experimental observations have been reproduced by a bremsstrahlung calculation using the CQL3D code in which a distribution function with a large \( v_x \) tail is input and localized to a core with a 9 cm radius around the magnetic axis [1]. An experiment to isolate the spatial extent of this core region is performed by scanning a fast response x-ray detector over the reversal surface and a series of radial, chord-like views. The presence of a strong tail in the chord spectra determines the extent of this core region. Spectra viewing the poloidal magnetic field near the reversal surface are also investigated for runaway energization and compared with toroidal results.

*Work supported by the US DOE.


**JP11 114 Dissipation Range of Anisotropic Magnetic Fluctuations in MST plasmas** JAMES TITUS, Florida A&M Univ AB-DUL ALCAGRI, JOHN SARFF, PAUL TERRY, University of Wisconsin - Madison EPHREM MEZONLIN, Florida A&M Univ Previous measurements of broadband magnetic fluctuations in the MST reversed field pinch (RFP) revealed a turbulent cascade that is anisotropic with respect to the large-scale (equilibrium) magnetic field and characterized by a power spectrum with exponential falloff at scales larger than expected for classical processes. The cascade is supported by tearing instabilities at the global scale that undergo strong nonlinear coupling, especially through poloidal mode n = 1 and m = 0 fluctuations. The non-classical dissipation feature may be indicative of the powerful non-collisional ion heating observed in MST plasmas. The previous measurements were done with pickup coils separated in both the toroidal and poloidal directions that allowed a resolution of \( |k| < 0.1 \text{ cm}^{-1} \). We report new measurements with increased spatial resolution, from increasing the number of coil sets (from 2 to 7). This enables an increase in the amount of two-point correlated spectra to be ensemble. Calibration analysis show the new probe measurements agree with the previous probe measurements at the same insertion depth. As the new probe is inserted deeper into the plasma, towards the reversal surface, the exponential component dominates as the power law component goes to zero. This is either due to stronger dissipation or the change in wavenumber resistivity.

*Work supported by DOE and NSF.

**JP11 115 Observation of Electron Bernstein Wave Heating in the RFP** ANDREW SELTZMAN, JAY ANDERSON, JOHN GOETZ, CARY FOREST, Univ of Wisconsin, Madison The first observation of RF heating in a reversed field pinch (RFP) using the electron Bernstein wave (EBW) has been demonstrated on MST. Efficient mode conversion of an outboard-launched X mode wave at 5.5 GHz leads to Doppler-shifted resonant absorption \( (\alpha_{ef} = n_{eo} \pm k_{th} v_o) \) for a broad range \( (n=1-7) \) of harmonics. The dynamics of EBW-heated electrons are measured using a spatial distribution of solid targets with diametrically opposed x-ray detectors. EBW heating produces a clear supra-thermal electron tail in MST. Radial deposition of the EBW is controlled with \( |B| \) and is measured using the HXR flux emitted from an insertable probe. In the thick-shelled MST RFP, the radial accessibility of EBW is limited to \( r/a > 0.8 (\sim 10 \text{ cm}) \) by magnetic field error induced by the porthole necessary for the antenna. Experimental measurements show EBW propagation inward through a stochastic magnetic field. EBW-heated test electrons are used as a direct probe of edge \( (r/a > 0.9) \) radial transport, showing a modest transition from ‘standard’ to reduced-delaying EBW operation. Electron loss is too fast for collisional effects and implies a large non-collisional radial diffusivity. EBW heating has been demonstrated in reduced magnetic stochastic plasmas with \( \beta = 15-20\% \).

*Work supported by USDOE.

**JP11 116 Advanced control for inductive programming of MST plasmas** I. R. GOUMIRI, K. J. MCCOLLAM, A. SQUITIERI, D. J. HOLLY, J. S. SARFF, C. M. JACOBSON, University of Wisconsin, Madison MST is a reversed field pinch whose poloidal and toroidal magnetic fields (Bp and Bt) can be sourced by IGBT-based programmable power supplies. In order to provide real-time simultaneous control of both Bp and Bt circuits, a time-dependent integrated modeling code is developed. Relaxed-state RFP physics simulations provide prediction and interpretive analysis of MST experimental data. The actuators considered for the control are the Bp and Bt primary currents. However, the physical quantities which MST operators want to demand can vary for different experiments and can have complicated dependences on the two actuator quantities as well as time. To develop our advanced control system, we choose to focus on two demand quantities, the plasma current Ip, directly related to Bp, and the reversal parameter F, closely related to Bt. To understand the response of Ip and F to the actuators and to
enable systematic design of control algorithms, a linearized dynamic response model is generated using a system identification method. A multi-variable model based control scheme that accounts for the coupled dynamics of the system while mitigating the effect of actuator limitations is designed. A series of experiments are planned to test our controllers and validate our modeling.

*This work is supported by the U.S. DoE.

**JP11 117 Density-Gradient-Driven trapped-electron-modes in improved-confinement RFP plasmas** JAMES DUFF, JOHN SARFF, University of Wisconsin - Madison WEIXING DING, DAVID BROWER, ELI PARKE, UCLA BRETT CHAPMAN, PAUL TERRY, M.J. PUESCHEL, ZACH WILLIAMS, University of Wisconsin - Madison Short wavelength density fluctuations in improved-confinement MST plasmas exhibit multiple features characteristic of the trapped-electron-mode (TEM). Core transport in the RFP is normally governed by magnetic stochasticity stemming from long wavelength tearing modes that arise from current profile peaking, which are suppressed via inductive control for this work. The improved confinement is associated with an increase in the pressure gradient that can destabilize drift waves. The measured density fluctuations have \( f \sim 50 \text{ kHz}, k_g \rho_i < 0.1 \), and propagate in the electron drift direction. Their spectral emergence coincides with a sharp decrease in global tearing mode associated fluctuations, their amplitude increases with local density gradient, and they exhibit a density-gradient threshold at \( R/L_c \sim 15 \). The GENE code, modified for the RFP, predicts the onset of density-gradient-driven TEM for these strong-gradient plasma conditions. While nonlinear analysis shows a large Dimits shift associated with predicted strong zonal flows, the inclusion of residual magnetic fluctuations, comparable to experimental magnetic fluctuations, causes a collapse of the zonal flows and an increase in the predicted transport to a level close to the experimentally measured heat flux.

*Work supported by US DOE.

**JP11 119 Soft X-ray studies on MST: Measuring the effects of toroidicity on tearing mode phase and installation of a multi-energy camera** PATRICK VAN METER, LISA REUSCH, Univ. of Wisconsin, Madison PAOLO FRANZ, Consorzio RFX JOHN SARFF, JOHN GOETZ, Univ. of Wisconsin, Madison LOUIS DELGADO-APARICIO, Princeton Plasma Physics Laboratory DANIEL DEN HARTOG, Univ. of Wisconsin, Madison The soft X-ray tomography (SXT) system on MST uses four cameras in a double-filter configuration to measure the emitted brightness along forty distinct lines of sight. These measurements can then be inverted to determine the emissivity, which depends on physical properties such as temperature, density, and impurity content. The SXR emissivity should correspond to the structure of the magnetic field; however, there is a discrepancy between the phase of the emissivity inversions and magnetic field reconstructions when using the typical cylindrical approximation to interpret the signal from the toroidal magnetic array. This discrepancy was measured for two distinct plasma conditions using all four SXT cameras, with results supporting the interpretation that it emerges from physical effects of the toroidal geometry. In addition, a new soft x-ray measurement system based on the PILATUS3 photon counting detector will be installed on MST. Emitted photons are counted by an array of pixels with individually adjustable energy cutoffs giving the device more spectral information than the double-filter system.

*This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences program under Award Numbers DE-FC02-05ER54814 and DE-SC0015474.

**JP11 120 Improvements to the MST Thomson Scattering Diagnostic** D.T. ADAMS, M.T. BORCHARDT, D.J. DEN HARTOG, D.J. HOLLY, T. KILE, S.Z. KUBALA, C.M. JACOBSON, M.A. THOMAS, J.P. WALLACE, W.C. YOUNG, Univ of Wisconsin, Madison MST THOMSON SCATTERING TEAM Multiple upgrades to the MST Thomson Scattering diagnostic have been implemented to expand capabilities of the system. In the past, stray laser light prevented electron density measurements everywhere and temperature measurements for \( z/a > 0.75 \). To mitigate stray light, a new laser beamline is being commissioned that includes a longer entrance flight tube, close-fitting apertures, and baffles. A polarizer has been added to the collection optics to further reduce stray light. An absolute density calibration using Rayleigh scattering in argon will be performed. An insertable integrating sphere will provide a full-system spectral calibration as well as maps optical fibers to machine coordinates. Reduced transmission of the collection optics due to coatings from plasma-surface interactions is regularly monitored to inform timely replacements of the first lens. Long-wavelength filters have been installed to better characterize non-Maxwellian electron distribution features. Previous work has identified residual photons not described by a Maxwellian distribution during \( m=0 \) magnetic bursts. Further effort to characterize the distribution function will be described.

*This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences program under Award No. DE-FC02-05ER54814.

**JP11 121 Absolute brightness modeling for improved measurement of electron temperature from soft x-rays on MST** L. M. REUSCH, University of Wisconsin - Madison P. FRANZ, Consorzio
JP11 122 An Integrated Data Analysis model to determine ion effective charge from beam attenuation and charge exchange emission measurements∗ M.D. NORNBERG, D.J. DEN HARTOG, L.M. REUSCH, Univ of Wisconsin-Madison We have created a forward model for charge-exchange impurity density measurements that incorporates neutral beam attenuation measurements self-consistently for determining the ion effective charge Z_{eff} in MST PPCD plasmas. Detailed knowledge of Z_{eff} is critical to determining the resistive dissipation of hot plasmas and requires knowledge of the impurity content and dynamics. Previously, Z_{eff} profiles were determined from soft-x-ray brightness measurements by using charge-exchange impurity density measurements as prior information using an Integrated Data Analysis (IDA) method. The model is extended to include a self-consistent calculation of the neutral beam attenuation and includes measurements of the beam Doppler-shift spectrum and shine-through particle flux. Methods of experimental design are employed to calculate the information gained from different diagnostic combinations. The analysis shows that while attenuation measurements alone do not provide a unique impurity density measurement in the case of a multi-species inhomogeneous plasma, they do provide a valuable measurement of the Z_{eff} profile and constrain the range of contributing impurity densities.

∗Supported by US DOE.

JP11 125 Comparing magnetic fluctuation dynamics in non-linear MHD simulations of low-aspect-ratio RFPs to RELAX experiments∗ K.J. Mccollam, D.J. Den Hartog, C.M. Jacobson, C.R. Sovinec, University of Wisconsin-Madison S. Masamune, A. Sanpe, Kyoto Institute of Technology We present comparisons of magnetic tearing fluctuation activity between RFP experiments on the low-aspect-ratio RELAX device (R/a ≈ 2) and nonlinear simulations of zero-beta, single-fluid MHD using the NIMROD code in both cylindrical and toroidal geometries at a Lundquist number of S = 10^4, nearly as high as experimental values. Time-average fluctuation amplitudes observed in the simulations are similar to those from the experiments, but more rigorous comparisons versus spectral mode numbers are in progress. We also focus on how the spatiotemporal dynamics of the fluctuations vary with RFP equilibrium parameters. Interestingly, at shallow reversal, cylindrical simulations show a relatively uncoupled spectrum of nearly quiescent modes periodically varying in time, whereas the corresponding toroidal cases show a fully chaotic spectrum of strongly nonlinearly interacting modes. We describe this
to the geometric $n = 1$ coupling present in the toroidal but not the cylindrical case. We present initial results from convergence studies with increased spatial resolution for both geometries. Simulations at higher $S$ are planned.

*This work is supported by the U.S. DOE and by the Japan Society for the Promotion of Science.

**JP11 126 THEORETICAL METHODS**

**JP11 127 Eulerian approach to bounce-transit and drift resonance with magnetic drifts in tokamaks** KER CHUNG SHAING, National Cheng Kung University; I. SEOL, National Fusion Research Institute, Korea; M. S. CHU, Institute of Plasma Physics, China; S. A. SABBAGH, Columbia University, USA

Bounce-transit and drift resonance can be important to plasma confinement in tokamaks with broken symmetry, and can have implications on the wave-particle resonance. Usually, the resonance is either treated by integrating along the unperturbed orbits or calculated using an action-angle approach. An Eulerian approach has been developed so that momentum conservation property of the Coulomb collision operator can be taken into account. The parallel flows appear in the thermodynamic forces in the Eulerian approach. However, in the existing theory, only $E \times B$ drift is kept; the magnetic drifts are neglected by adopting the large aspect ratio assumption. Here, $E$ is the electric field, and $B$ is the magnetic field. The importance of the magnetic drifts in finite aspect ratio tokamaks is demonstrated in [1]. Here, the Eulerian approach is extended to include the magnetic drifts to calculate neoclassical toroidal plasma viscosity in finite aspect ratio tokamoks. The relation to the nonlinear plasma viscosity in the plateau regime [2] will also be discussed.

*This work was supported by Taiwan Ministry of Science and Technology under Grant No. 100-2112-M-006-004-MY3, and Republic of Korea MSIP (Ministry of Science, ICT and Future Planning) under KSTAR program.


**JP11 128 A multigrid method for drift-kinetic calculations in stellarators and rippled tokamaks** MATT LANDREMAN, University of Maryland; HAKAN SMITH, IPP-Greifswald

Important phenomena such as the bootstrap current and collisional transport in stellarators, and neoclassical toroidal viscosity in tokamaks, must be computed by numerical solution of the drift-kinetic equation in nonaxisymmetric geometry. This equation has the form of a linear, inhomogeneous, advection-dominated advection-diffusion PDE with recirculating flow, internal boundary layers, and a null space, with typically five coupled dimensions (poloidal and toroidal angle, speed, velocity pitch angle, and species.) While multigrid algorithms are a preferred method for efficient solution of some PDEs, multigrid smoothers are typically unstable for accurate discretizations of the drift-kinetic equation due to the absence of any physical diffusion in the spatial dimensions, and the dominance of advection over diffusion in the velocity dimensions. In this work we demonstrate a high-order-accurate multigrid solution of the drift-kinetic equation in nonaxisymmetric geometry. A defect correction approach is used: solution of a high-order discretized problem is preconditioned by a multigrid cycle in which a low-order upwind discretization is used for smoothing. Compared to a direct solver, the multigrid method can reduce the memory requirement by several orders of magnitude.

*Supported by US DoE FES award DE-FG02-93ER54197.

**JP11 129 A New Parallel Boundary Condition for Turbulence Simulations in Stellarators** MIKE F MARTIN, MATT LANDREMAN, WILLIAM DORLAND, University of Maryland; PAVLOS XANTHOPOULOS, Max-Planck-Institut für Plasmaphysik

For gyrokinetic simulations of core turbulence, the “twist-and-shift” parallel boundary condition (Beer et al., PoP, 1995), which involves a shift in radial wavenumber proportional to the global shear and a quantization of the simulation domain’s aspect ratio, is the standard choice. But as this condition was derived under the assumption of axisymmetry, “twist-and-shift” as it stands is formally incorrect for turbulence simulations in stellarators. Dreicer fields, low-shear stellarators like W7X and HSX, the use of a global shear in the traditional boundary condition places an inflexible constraint on the aspect ratio of the domain, requiring more grid points to fully resolve its extent. Here, we present a parallel boundary condition for “stellarator-symmetric” simulations that relies on the local shear along a field line. This boundary condition is similar to “twist-and-shift”, but has an added flexibility in choosing the parallel length of the domain based on local shear consideration in order to optimize certain parameters such as the aspect ratio of the simulation domain.

**JP11 130 A conservative, relativistic Fokker-Planck solver for runaway electrons** LUIS CHACON, W. TAITANO, X. TANG, Z. GUO, C. MCDEVITT, LANL

Relativistic runaway electrons develop when electric fields surpass a critical electric field [1], $E = E_D \left(\frac{E_{DR}}{E_D}\right)^2$, with $E_D$ the Dreicer field (which is the electric field at which the whole thermal electron population runs away). Above this critical field, electron tails accelerate relativistically until they are arrested by radiative processes [2]. In regimes above this critical electric field (but below the Dreicer field) for low-shear stellarators like W7X and HSX, the use of a global shear in the traditional boundary condition places an inflexible constraint on the aspect ratio of the domain, requiring more grid points to fully resolve its extent. Here, we present a parallel boundary condition for “stellarator-symmetric” simulations that relies on the local shear and the runaway tail is key, and demands a full nonlinear relativistic Fokker-Planck treatment. In this presentation, we report on progress towards a fully conservative, implicit, adaptive implementation of the relativistic electron Fokker-Planck equation. Strict conservation properties, as well as positivity preservation, are a must to avoid spurious numerical effects, and to be able to capture tenuous electron runaway tails for fields just above $E_D$.


**JP11 131 A backward Monte Carlo method for efficient computation of runaway probabilities in runaway electron simulation** GUANNAN ZHANG, DIEGO DEL-CASTILLO-NEGROTE, Oak Ridge National Laboratory

Kinetic descriptions of RE are usually based on the bounced-averaged Fokker-Planck model that determines the PDFs of RE. Despite of the simplification involved, the Fokker-Planck equation can rarely be solved analytically and direct numerical approaches (e.g., continuum and particle-based Monte Carlo (MC)) can be time consuming specially in the computation of asymptotic-type observable including the runaway probability, the slowing-down and runaway mean times, and the energy limit probability. Here we present a novel backward MC approach to these problems based on backward stochastic differential equations (BSDEs). The BSDE model can simultaneously describe the PDF of RE and the runaway probabilities by means of the well-known Feynman-Kac theory. The key ingredient of the backward MC algorithm is to place all the particles in a runaway state and simulate
them backward from the terminal time to the initial time. As such, our approach can provide much faster convergence than the brute-force MC methods, which can significantly reduce the number of particles required to achieve a prescribed accuracy. Moreover, our algorithm can be parallelized as easy as the direct MC code, which paves the way for conducting large-scale RE simulation.

“This work is supported by DOE FES and ASCR under the Contract Numbers ERKJ320 and ERAT77.

JP11 132 Application of electron closures in extended MHD* ERIc HELD, Brett Adair, Trevor TAYLOR, Utah State University Rigorous closure of the extended MHD equations in plasma fluid codes includes the effects of electron heat conduction along perturbed magnetic fields and contributions of the electron collisional friction and stress to the extended Ohms law. In this work we discuss application of a continuum numerical solution to the Chapman-Enskog-like electron drift kinetic equation [1] using the NIMROD code. The implementation is a tightly-coupled fluid/kinetic system that carefully addresses time-centering in the advance of the fluid variables with their kinetically-computed closures. Comparisons of spatial accuracy, computational efficiency and required velocity space resolution are presented for applications involving growing magnetic islands in cylindrical and toroidal geometry. The reduction in parallel heat conduction due to particle trapping in toroidal geometry is emphasized.

“Work supported by DOE under Grant Nos. DE-FC02-08ER54973 and DE-FG02-04ER54746.


JP11 133 NIMROD modeling of poloidal flow damping in tokamaks using kinetic closures* J. R. JEPSON, C. C. HEGNA, Univ of Wisconsin, Madison E. D. HELD, Utah State University Calculation of poloidal flow damping in a tokamak are undertaken using two different implementations of the ion drift kinetic equation (DKE) in the extended MHD code NIMROD. The first approach is hybrid fluid/kinetic and uses a Chapman Enskog-like (CEL) Ansatz. Closure of the evolving lower-order fluid moment equations for n, V, and T is provided by solutions to the ion CEL-DKE written in the macroscopic flow reference frame [1]. The second implementation solves the DKE using a delta-f approach. Here, the delta-f distribution describes all of the information beyond a static, lowest-order Maxwellian. We compare the efficiency and accuracy of these two approaches for a simple initial value problem that monitors the relaxation of the poloidal flow profile in high- and low-aspect-ratio tokamak geometry. The computation results are compared against analytic predictions of time dependent closures for the parallel viscous force [2,3].

“Supported by DoE Grants DE-FG02-86ER53218 and DE-FG02-04ER54746.


JP11 134 Parallel closure theory for toroidally confined plasmas* JEONG-YOUNG JI, ERIC D. HELD, Utah State University We solve a system of general moment equations [1] to obtain parallel closures for electrons and ions in an axisymmetric toroidal magnetic field. Magnetic field gradient terms are kept and treated using the Fourier series method. Assuming lowest order density (pressure) and temperature to be flux labels, the parallel heat flow, friction, and viscosity are expressed in terms of radial gradients of the lowest-order temperature and pressure, parallel gradients of temperature and parallel flow, and the relative electron-ion parallel flow velocity. Convergence of closure quantities is demonstrated as the number of moments and Fourier modes are increased. Properties of the moment equations in the collisionless limit are also discussed. Combining closures with fluid equations parallel mass flow and electric current are also obtained.

“Work in collaboration with the PSI Center and supported by the U.S. DOE under Grant Nos. DE-SC0014033, DE-SC0016256, and DE-FG02-04ER54746.


JP11 135 Energy Conservation and Conversion in NIMROD Computations of Magnetic Reconnection* J. A. MADDOX, C. R. SOVINEC, UW Madison Previous work modeling magnetic relaxation during non-inductive start-up at the Pegasus spherical tokamak indicates an order of magnitude gap between measured experimental temperature and simulated temperature in NIMROD. Potential causes of the plasma temperature gap include: insufficient transport modeling, too low modeled injector power input, and numerical loss of energy, as energy is not algorithmically conserved in NIMROD simulations. Simple 2D nonlinear MHD simulations explore numerical energy conservation discrepancies in NIMROD because understanding numerical loss of energy is fundamental to addressing the physical problems of the other potential causes of energy loss. Evolution of these configurations induces magnetic reconnection, which transfers magnetic energy to heat and kinetic energy. The kinetic energy is eventually damped so, magnetic energy loss must correspond to an increase in internal energy. Results in the 2D geometries indicate that numerical energy loss during reconnection depends on the temporal resolution of the dynamics.

“Work support from U.S. Department of Energy through a subcontract from the Plasma Science and Innovation Center.

JP11 136 Confinement properties of tokamak plasmas with extended regions of low magnetic shear J. P. GRAVES, W. A. COOPER, A. KLEINEr, M. RAGHUNATHAN, E. NETO, T. NICOLAS, S. LANTHALER, H. PATTen, Ecole Polytechnique Federale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne D. PEFFERLE, Princeton Plasma Physics Laboratory (PPPL), Princeton NJ, 08543-0451, USA D. BRUNETTI, Istituto di Fisica del Plasma ‘P. Caldirola’ CNR, Milano, Italy H. LUTIENs, Centre de Physique Theorique - Ecole Polytechnique, CNRS, Palaiseau, France Extended regions of low magnetic shear can be advantageous to tokamak plasmas. But the core and edge can be susceptible to non-resonant ideal fluctuations due to the weakened restoring force associated with magnetic field line bending. This contribution shows how saturated non-linear phenomenology, such as 1/1 Long Lived Modes, and Edge Harmonic Oscillations associated with QH-modes, can be modelled accurately using the non-linear stability code XTOR, the free boundary 3D equilibrium code VMec, and non-linear analytic theory. That the equilibrium approach is valid is particularly valuable because it enables advanced particle confinement studies to be undertaken in the ordinarily difficult environment of strongly 3D magnetic fields. The VENUS-LEVIS code exploits the Fourier description of the VMEC equilibrium fields, such that full Lorentzian and guiding centre approximated differential operators in curvilinear angular coordinates can be evaluated analytically. Consequently, the confinement properties of minority ions such as energetic particles and high Z impu-
rities can be calculated accurately over slowing down timescales in experimentally relevant 3D plasmas.

**JP11 137 Investigation of flow-induced numerical instability in a mixed semi-implicit, implicit leapfrog time discretization**

JA-COB KING, SCOTT KRUGER, Tech-X Corporation

Flow can impact the stability and nonlinear evolution of range of instabilities (e.g. RWMs, NTMs, sawteeth, locked modes, PBMs, and high-k turbulence) and thus robust numerical algorithms for simulations with flow are essential. Recent simulations of DIII-D QH-mode [King et al., Phys. Plasmas and Nucl. Fus. 2017] with flow have been restricted to smaller time-step sizes than corresponding computations without flow. These computations use a mixed semi-implicit, implicit leapfrog time discretization as implemented in the NIMROD code [Sovinec et al., JCP 2004]. While prior analysis has shown that this algorithm is unconditionally stable with respect to the effect of large flows on the MHD waves in slab geometry [Sovinec et al., JCP 2010], our present Von Neumann stability analysis shows that a flow-induced numerical instability may arise when ad-hoc cylindrical curvature is included. Computations with the NIMROD code in cylindrical geometry with rigid rotation and without free-energy drive from current or pressure gradients qualitatively confirm this analysis. We explore potential methods to circumvent this flow-induced numerical instability such as using a semi-Lagrangian formulation instead of time-centered implicit advection and/or modification to the semi-implicit operator.

*This work is supported by the DOE Office of Science (Office of Fusion Energy Sciences).

**JP11 138 Non-symmetric steady ideal magnetohydrodynamic flows in a non-symmetric topological torus**

HAROLD WEITZNER, WRICK SENGUPTA, New York University

Previous work [1], on expansions of ideal magnetohydrodynamic equilibria in a topological torus is extended and modified to allow the addition of steady flows of leading order in the formal expansion parameter. The leading order flow and magnetic field depend on one coordinate direction only and have components in the other two coordinate directions. It is shown that an expansion can be carried out to all orders in a parameter which measures the amplitude of the “helical” flows and fields. Resonances appear, but can be resolved exactly as in the previous work by the addition of appropriate lower order flows and fields. The resonance conditions involve two different linear combination of the lowest order flows and fields. As in the earlier work the elimination of the resonances requires that the boundaries of the domain of the steady flow be chosen correctly. Although the expansion may be carried to all orders, convergence is not proven.

*Work Supported bt DE-FG-02-86ER53223.


**JP11 139 Numerical optimization of the ramp-down phase with the RAPTOR code**

ANNA TEPLUKHINA, OLIVIER SAUTER, Ecole Polytechnique Federale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland FEDERICO FELICI, Eindhoven University of Technology, POBox 513, 5600MB Eindhoven, The Netherlands THE TCV TEAM,∗ THE ASDEX-UPGRADE TEAM,∗ THE EUROFUSION MSTI TEAM∗ The ramp-down optimization goal in this work is defined as the fastest possible decrease of a plasma current while avoiding any disruptions caused by reaching physical or technical limits. Numerical simulations and preliminary experiments on TCV and AUG have shown that a fast decrease of plasma elongation and an adequate timing of the H-L transition during current ramp-down can help to avoid reaching high values of the plasma internal inductance. The RAPTOR code (F. Felici et al., 2012 PPCF 54; F. Felici, 2011 EPFL PhD thesis), developed for real-time plasma control, has been used for an optimization problem solving. Recently the transport model has been extended to include the ion temperature and electron density transport equations in addition to the electron temperature and current density transport equations, increasing the physical applications of the code. The gradient-based models for the transport coefficients (O. Sauter et al., 2014 PPCF 21; D. Kim et al., 2016 PPCF 58) have been implemented in RAPTOR and tested during this work. Simulations of the AUG and TCV entire plasma discharges will be presented.

*See the author list of S. Coda et al., Nucl. Fusion 57 2017 102011.

†See the author list of A. Kallenbach et al., Nucl. Fusion 57 2017 102015.

‡See the author list of H. Meyer et al., Nucl. Fusion 57 2017 102014.

**JP11 140 Validation and Continued Development of Methods for Spheromak Simulation**

THOMAS BENEDETT, University of Washington

The HIT-Si experiment has demonstrated stable sustenance of spheromaks. Determining how the underlying physics extrapolate to larger, higher-temperature regimes is of prime importance in determining the viability of the inductively-driven spheromak. It is thus prudent to develop and validate a computational model that can be used to study current results and study the effect of possible design choices on plasma behavior. An extended MHD model has shown good agreement with experimental data at 14 kHz injector operation. Efforts to extend the existing validation to a range of higher frequencies (36, 53, 68 kHz) using the PSI-Tet 3D extended MHD code will be presented, along with simulations of potential combinations of flux conserver features and helicity injector configurations and their impact on current drive performance, density control, and temperature for future SIHI experiments.

*Work supported by USDoE.

**JP11 141 Modeling MHD Equilibrium and Dynamics with Non-Axisymmetric Resistive Walls in LTX and HBT-EP**

C. HANSEN, University of Washington J. LEVESQUE, Columbia University D. P. BOYLE, P. HUGHES, Princeton Plasma Physics Laboratory

In experimental magnetized plasmas, currents in the first wall, vacuum vessel, and other conducting structures can have a strong influence on plasma shape and dynamics. These effects are complicated by the 3D nature of these structures, which dictate available current paths. Results from simulations to study the effect of external currents on plasmas in two different experiments will be presented: 1) The arbitrary geometry, 3D extended MHD code PSI-Tet is applied to study linear and non-linear plasma dynamics in the High Beta Tokamak (HBT-EP) focusing on toroidal asymmetries in the adjustable conducting wall. 2) Equilibrium reconstructions of the Lithium Tokamak eXperiment (LTX) in the presence of non-axisymmetric eddy currents. An axisymmetric model is used to reconstruct the plasma equilibrium, using the PSI-Tri code, along with a set of fixed 3D eddy current distributions in the first wall and vacuum vessel [C. Hansen et al., PoP Apr. 2017]. Simulations of detailed experimental geometries are enabled by use of the PSI-Tet code, which employs a high order finite element method on unstructured tetrahedral grids that are generated directly from CAD models. Further development of PSI-Tet and PSI-Tri will also be presented.

*This work supported by US DOE contract DE-SC0016256.
JP11 142 Computational optimization of global gyrokinetic particle code GTS* ADITYA KRISHNA SWAMY, STEPHANE ETHIER, WEIXING WANG, EDWARD STARTSEV, WEI-LI LEE, Princeton Plasma Physics Lab RAJARAMAN GANESH, Institute for Plasma Research, Gandhinagar

Electromagnetic microturbulence is an important source of anomalous ion and electron transport in tokamak plasmas. Gyrokinetic Tokamak Simulation (GTS), a global PIC code presents a first-principles based method to understand and predict such transport. Recently, the double-split-weight scheme that avoids the high-beta “cancelation problem” has been developed and implemented in GTS to study electromagnetic turbulence. Use of magnetic coordinates and a field-line following grid in GTS provides a highly efficient means to resolve a relatively larger set of modes in the same run. The misalignment of the field-line following grid with cylindrical grid, however, makes Fourier-filtering of single mode highly inefficient, and therefore makes benchmarking of linear modes with other codes time consuming. Recent algorithmic optimizations to align this subroutine with the 2-d domain have resulted in a significant performance improvement of ∼20x, with an overall code speedup of ∼3x. These and further improvements to the filtering capability, along with linear benchmarks of electromagnetic instabilities such as MTM and KBM will be discussed.

* SERB Indo-US Research Fellowship.

JP11 143 Progress on Schwarz-type coupling of core- and edge-region tokamak simulations for whole device modeling* LEE RICKETSON, Lawrence Livermore Natl Lab AMMAR HAKIM, Princeton Plasma Physics Lab JEFFREY HITTINGER, Lawrence Livermore Natl Lab

The edge and core regions of a tokamak differ drastically on many fronts – geometry and collisionality, to name only two among many. It is thus natural that different numerical methods are optimally suited to the simulation of each region. However, this creates a challenge for the pursuit of whole device modeling (WDM): How can one self-consistently couple two distinct codes to achieve a uniformly accurate description of the entire tokamak? In support of the ECP goal of coupling the codes GENE (core) and XGC (edge) for whole device modeling, we present such a coupling scheme inspired by classical additive Schwarz methods. While traditional Schwarz schemes require iteration to convergence inside a single time step, this is computationally intractable in the context of 5-D gyrokinetic simulations. We give evidence – both analytic and empirical – that if one is interested only in long-time (e.g. transport-scale) averages, then this expensive iteration can be avoided while retaining the scheme’s convergence properties. We present numerical results from tests on both a 1-D model problem and 2-D simulations of the Hasegawa-Wakatani equations.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

JP11 144 Bringing global gyrokinetic turbulence simulations to the transport timescale using a multiscale approach* JEFFREY PARKER, LYNDA LODESTRO, LNL DANIEL TOLD, Max-Planck-Institut fur Plasmaphysik, Garching GABRIELE MERLO, UCLA LEE RICKETSON, ALEJANDRO CAMPOS, LNL FRANK JENKO, UCLA JEFFREY HITTINGER, LNL

Predictive whole-device simulation models will play an increasingly important role in ensuring the success of fusion experiments and accelerating the development of fusion energy. In the core of tokamak plasmas, a separation of timescales between turbulence and transport makes a single direct simulation of both processes computationally expensive. We present the first demonstration of a multiscale-timescale method coupling global gyrokinetic simulations with a transport solver to calculate the self-consistent, steady-state temperature profile. Initial results are highly encouraging, with the coupling method appearing robust to the difficult problem of turbulent fluctuations. The method holds potential for integrating first-principles turbulence simulations into whole-device models and advancing the understanding of global plasma behavior.


The development of multi-scale time integration methods for XGC is reported, including a recent implementation of an equation-free algorithm for XGCa. In this work, XGCa is used to evolve a 4D distribution function over short time intervals. The distribution function is then restricted to a set of low-order fluid moments, which are projected over a large time step. Finally, the fluid moments are transformed back to a fine-scale 4D distribution function to restart the simulation at the next time step. By enabling the use of a time step size much larger than in standard PIC methods, this algorithm has promise for large computational savings in transport time scale simulations. For the tokamak edge, however, the use of low-order fluid moments is inadequate, since the distribution function can be far from Maxwellian. In this case, coupling between a fine-scale kinetic code and a coarse-scale kinetic code is of interest. A key tool for accurate kinetic-kinetic coupling is particle resampling. Recent methods for particle resampling have been developed which accurately preserve low-order velocity moments and local features of a kinetic distribution function [1]. We include plans to further develop this work for kinetic-kinetic coupling.

1Faghihi et al., arXiv:1702.05198.

JP11 146 Implementation of non-axisymmetric mesh system in the gyrokinetic PIC code (XGC) for Stellarators TOSEO MORI-TAKA, National Institute for Fusion Science ROBERT HAGER, MICHEAL COLE, CHOONG-SEOCK CHANG, SAMUEL LAZERSON, SEUNG-HOE KU, Princeton Plasma Physics Laboratory

SEIJI ISHIGURO, National Institute for Fusion Science Gyrokinetic simulation is a powerful tool to investigate turbulent and neo-classical transports based on the first-principles of plasma kinetics. The gyrokinetic PIC code XGC has been developed for integrated simulations that cover the entire region of Tokamaks. Complicated field line and boundary structures should be taken into account to demonstrate edge plasma dynamics under the influence of X-point and vessel components. XGC employs gyrokinetic Poisson solver on unstructured triangle mesh to deal with this difficulty. We introduce numerical schemes newly developed for XGC simulation in non-axisymmetric Stellarator geometry. Triangle meshes in each poloidal plane are defined by PEST poloidal angle in the VMEC equilibrium so that they have the same regular structure in the straight field line coordinate. Electric charge of marker particle is distributed to the triangles specified by the field-following projection to the neighbor poloidal planes. 3D spline interpolation in a cylindrical mesh is also used to obtain equilibrium magnetic field at the particle position. These schemes capture the anisotropic plasma dynamics and resuling potential structure with high accuracy. The triangle meshes can smoothly connect to unstructured meshes in the edge and core regions of a tokamak.

*For the Exascale Computing Project (17-SC-20-SC).
edge region. We will present the validation test in the core region of Large Helical Device and discuss about future challenges toward edge simulations.

**JP11 147** A symbiotic approach to fluid equations and non-linear flux-driven simulations of plasma dynamics\(^*\) FEDERICO HALPERN, General Atomics. The fluid framework is ubiquitous in studies of plasma transport and stability. Typical forms of the fluid equations are motivated by analytical work dating several decades ago, before computer simulations were indispensable, and can be, therefore, not optimal for numerical computation. We demonstrate a new first-principles approach to obtaining manifestly consistent, skew-symmetric fluid models, ensuring internal consistency and conservation properties even in discrete form. Mass, kinetic, and internal energy become quadratic (and always positive) invariants of the system. The model lends itself to a robust, straightforward discretization scheme with inherent non-linear stability. A simpler, drift-ordered form of the equations is obtained, and first results of their numerical implementation as a binary framework for bulk-fluid global plasma simulations are demonstrated.

\(^*\)This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, Theory Program, under Award No. DE-FG02-95ER54309.

**JP11 148** Introducing a distributed unstructured mesh into gyrokinetic particle-in-cell code, XGC\(^*\) EISUNG YOON, MARK SHEPHARD, E.SEEGYOUNG SEOL, KAUSHIK KALYANARAMAN, Rensselaer Polytechnic Inst XGC has shown good scalability for large leadership supercomputers. The current production version uses a copy of the entire unstructured finite element mesh on every MPI rank. Although an obvious scalability issue if the mesh sizes are to be dramatically increased, the current approach is also not optimal with respect to data locality of particles and mesh information. To address these issues we have initiated the development of a distributed mesh PIC method. This approach directly addresses the base scalability issue with respect to mesh size and, through the use of a mesh entity centric view of the particle mesh relationship, provides opportunities to address data locality needs of many core and GPU supported heterogeneous systems. The parallel mesh PIC capabilities are being built on the Parallel Unstructured Mesh Infrastructure (PUMI) [1]. The presentation will first overview the form of mesh distribution used and indicate the structures and functions used to support the mesh, the particles and their interaction. Attention will then focus on the node-level optimizations being carried out to ensure performant operation of all PIC operations on the distributed mesh.

\(^*\)Partnership for Edge Physics Simulation (EPSI) Grant No. DE-SC0008449 and Center for Extended Magnetohydrodynamic Modeling (CEMM) Grant No. DE-SC0006618.


**JP11 149** Resistive MHD Stability Analysis in Near Real-time\(^*\) ALEXANDER GLASSER, EGEMEN KOLEMEN, Princeton Plasma Physics Laboratory We discuss the feasibility of a near real-time calculation of the tokamak \(\Delta\) matrix, which summarizes MHD stability to resistive modes, such as tearing and interchange modes. As the operational phase of ITER approaches, solutions for active feedback tokamak stability control are needed. It has been previously demonstrated that an ideal MHD stability analysis is achievable on a sub-C(Ts) timescale, as is required to control phenomena comparable with the MHD-evolution timescale of ITER. In the present work, we broaden this result to incorporate the effects of resistive MHD modes. Such modes satisfy ideal MHD equations in regions outside narrow resistive layers that form at singular surfaces. We demonstrate that the use of asymptotic expansions at the singular surfaces, as well as the application of state transition matrices, enable a fast, parallelized solution to the singular outer layer boundary value problem, and thereby rapidly compute \(\Delta\).

\(^*\)Supported by US DOE Grants DE-SC0015878 and DE-FC02-04ER54698.

**JP11 150** Diagnosis of Acceleration, Reconnection, Turbulence, and Heating\(^*\) MIKAL T. DUFOR, ANDREW J. JEMIOLO, AMY KEESEE, PAUL CASSAK, WEICHAO TU, EARL E. SCIME, West Virginia University, Department of Physics and Astronomy The DARTH (Diagnosis of Acceleration, Reconnection, Turbulence, and Heating) experiment is an intermediate-scale, experimental facility designed to study magnetic reconnection at and below the kinetic scale of ions and electrons. The experiment will have non-perturbative diagnostics with high temporal and three-dimensional spatial resolution, giving it the capability to investigate kinetic-scale physics. Of specific scientific interest are particle acceleration, plasma heating, turbulence and energy dissipation during reconnection. Here we will describe the magnetic field system and the two plasma guns used to create flux ropes that then merge through magnetic reconnection. We will also describe the key diagnostic systems: laser induced fluorescence (LIF) for ion vdf measurements, a 300 GHz microwave scattering system for sub-mm wavelength fluctuation measurements and a Thomson scattering laser for electron vdf measurements. The vacuum chamber is designed to provide unparalleled access for these particle diagnostics. The scientific goals of DARTH are to examine particle acceleration and heating during, the role of three-dimensional instabilities during reconnection, how reconnection ceases, and the role of impurities and asymmetries in reconnection.

\(^*\)This work was supported by the by the O’Brien Energy Research Fund.

**JP11 151** Error field locking of real frequency tearing modes\(^*\) A.J. COLE, Columbia University J.M. FINN, Tibbar Plasma Technologies, Los Alamos D.P. BRENNAN, Princeton University It has been shown [1] that the Maxwell torque on the plasma in the presence of an applied error field is modified significantly for tearing modes having real frequencies near marginal stability. In this poster we derive the tearing mode dispersion relation with pressure gradient, field line curvature and parallel dynamics both with and without perpendicular resistivity in the resistive-inertial (RI) and visco-resistive regimes, neglecting the divergence of the \(E \times B\) drift. We find the usual Glasser effect, which involves real frequencies, is retained in this simplified model in both regimes, and that the existence of tearing modes with complex frequencies is related to nearby electrostatic resistive interchange modes. The interchange modes themselves are found to move into the sound wave continuum (for the case with no perpendicular resistivity) as the sound speed is increased. Results are also presented for the case of parallel dynamics with perpendicular resistivity, to investigate the tearing mode behavior when the sound wave continuum is discretized into a finite set of modes on the stable side of the frequency space.

\(^*\)Supported by US DOE Grants DE-SC0014005 and DE-SC0014119.
JP11 152 Experimental Demonstration of Magnetic Reconnection in a Laboratory Scale with Guide Field* HYUNSUE KIM, JAN EGEDAL, JOE OLSEN, DOUGLASS ENDRIZZI, JOHN WALLACE, Univ of Wisconsin, Madison TREX TEAM

Through a process called magnetic reconnection, the opposing solar wind and Earth magnetic fields annihilate and allow energetic solar particles to enter the magnetosphere. This energetic plasma can cause major disturbances to satellite communication networks and navigation systems, as well as electrical power grids. To better understand this process and prevent significant economic losses, NASA has launched the MMS Mission in 2015, a cluster of spacecraft which directly probes the reconnection sites in the magnetosphere. Though in situ measurements of reconnection in space are essential to our understanding of the process, the mission comes at a cost of over $1 billion. Thus, smaller laboratory experiments become essential to complement the data acquired by MMS at relatively low cost.

The Terrestrial Reconnection Experiment (TREX) currently aims to probe a similar configuration to dayside reconnection by adding a toroidal guide magnetic field, where under the right conditions, high frequency turbulent fluctuations are expected. Using a set of fast Langmuir probes to diagnose the fluctuations, the global structure of the plasma turbulence can be reconstructed. In this poster, an overview of the upgraded experiment and design progress of the fast Lprobe will be provided.

*NSF/DOE award DE-SC0013032.

---

Invited Papers

15:00

K12 1 Fluorescence and absorption spectroscopy for warm dense matter studies and ICF plasma diagnostics*

STEPHANIE HANSEN, Sandia National Laboratories

The burning core of an inertial confinement fusion (ICF) plasma at stagnation is surrounded by a shell of warm, dense matter whose properties are difficult both to model (due to a complex interplay of thermal, degeneracy, and strong coupling effects) and to diagnose (due to low emissivity and high opacity). We demonstrate a promising technique to study the warm dense shells of ICF plasmas based on the fluorescence emission of dopants or impurities in the shell material. This emission, which is driven by x-rays produced in the hot core, exhibits signature changes in response to compression and heating. High-resolution measurements of absorption and fluorescence features can refine our understanding of the electronic structure of material under high compression, improve our models of density-driven phenomena such as ionization potential depression and plasma polarization shifts, and help diagnose shell density, temperature, mass distribution, and residual motion in ICF plasmas at stagnation.

*Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-NA-0003525. This work was supported by the U.S. Department of Energy, Office of Science Early Career Research Program, Office of Fusion Energy Sciences under FWP-14-017426.

15:30

K12 2 Warm Dense Matter Demonstrating Non-Drude Conductivity from Observations of Nonlinear Plasmon Damping*

BASTIAN B. L. WITTE, University of Rostock, SLAC National Accelerator Laboratory

The thermal and electrical conductivity, equation of state and the spectral opacity in warm dense matter (WDM) are essential properties for modeling, e.g., fusion experiments or the magnetic field generation in planets. In the last decade it has been shown that x-ray Thomson scattering (XRTS) is an effective tool to determine plasma parameters like temperature and density in the WDM regime [1]. Recently, the electrical conductivity was extracted from XRTS experiments for the first time [2]. The spectrally resolved scattering data of aluminum, isochorically heated by the Linac Coherent Light Source (LCLS), show strong dependence on electron correlations. Therefore, the damping of plasmons, the collective electron oscillations, has to be treated beyond perturbation theory. We present results for the dynamic transport properties in warm dense aluminum using density-functional-theory molecular dynamics (DFT-MD) simulations. The choice of the exchange-correlation (XC) functional, describing the interactions in the electronic subsystem, has significant impact on the ionization energy of bound electrons and the dynamic dielectric function. Our newly developed method for the calculation of XRTS signals including plasmon and bound-free transitions is based on transition matrix elements together with ionic contributions using uniquely DFT-MD simulations. The results show excellent agreement with the LCLS data if hybrid functionals are applied [3]. The experimental finding of nonlinear plasmon damping is caused by the non-Drude conductivity in warm dense aluminum. Here, we show further validation by comparing with x-ray absorption data. These findings enable new insights into the impact of XC functionals on calculated properties of WDM and allow detailed predictions for future experiments at the unprecedented densities on the NIF.

*NSF/DOE award DE-SC0013032.
Aluminum is ideal for testing theoretical first-principles calculations because of the relative simplicity of its atomic structure. Density functional theory (DFT) calculations predict that Al transforms from an ambient-pressure, face-centered-cubic (fcc) crystal to the hexagonal close-packed (hcp) and body-centered-cubic (bcc) structures as it is compressed. Laser-driven experiments performed at the University of Rochester’s Laboratory for Laser Energetics and the National Ignition Facility (NIF) ramp compressed Al samples to pressures up to 540 GPa without melting. Nanosecond in-situ x-ray diffraction was used to directly measure the crystal structure at pressures where the solid–solid phase transformations of Al are predicted to occur. Laser velocimetry provided the pressure in the Al. Our results show clear evidence of the fcc→hcp and hcp→bcc transformations at 216 ± 9 GPa and 321 ± 12 GPa, respectively. This is the first experimental in-situ observation of the bcc phase in compressed Al and a confirmation of the fcc→hcp transition previously observed under static compression at 217 GPa. The observations indicate these solid–solid phase transitions occur on the order of tens of nanoseconds time scales. In the fcc→hcp transition we find the original texture of the sample is preserved; however, the hcp→bcc transition diminishes that texture producing a structure that is more polycrystalline. The importance of this dynamic is discussed. The NIF results are the first demonstration of x-ray diffraction measurements at two different pressures in a single laser shot.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.
Contributed Papers

17:30
LE3 1 Women in Plasma Physics

Contributed Papers

18:15
LE4 1 Student Appreciation Reception
SESSION MR1: REVIEW: BRINGING SPACE DOWN TO EARTH: EXPLORING THE PHYSICS OF SPACE PLASMAS IN THE LABORATORY
Wednesday Morning, 25 October 2017; Room: Ballroom C at 8:00; Amy Keesee, West Virginia University, presiding

Invited Papers

8:00

MR1 1 Bringing Space Down to Earth: Exploring the Physics of Space Plasmas in the Laboratory*
GREGORY G. HOWES, University of Iowa

Laboratory experiments provide a valuable complement to explore the fundamental physics of space plasmas without the limitations inherent to spacecraft measurements. Specifically, experiments overcome the restriction that spacecraft measurements are made at only one (or a few) points in space, enable greater control of the plasma conditions and applied perturbations, can be reproducible, and are orders of magnitude less expensive than launching spacecraft. I will highlight key open questions about the physics of space plasmas and identify the aspects of these problems that can potentially be tackled in laboratory experiments, reviewing past successes in the laboratory investigation of the physical processes at play in different space environments, including the solar corona, solar wind, planetary magnetospheres, and outer boundary of the heliosphere. A strategy for future laboratory investigations of space physics will be outlined, with explicit connections to specific space environments.

*NSF/DOE Partnership Grant No. DE-SC0014599.

SESSION NI2: RECONNECTION: EXPERIMENTS AND OBSERVATIONS
Wednesday Morning, 25 October 2017; Room: 102ABC at 9:30; Nuno Loureiro, Massachusetts Institute of Technology, presiding

Invited Papers

9:30

NI2 1 Anomalous heating and plasmoid formation in pulsed power driven magnetic reconnection experiments*
JACK HARE, Imperial College London

Magnetic reconnection is an important process occurring in various plasma environments, including high energy density plasmas. In this talk we will present results from a recently developed magnetic reconnection platform driven by the MAGPIE pulsed power generator (1 MA, 250 ns) at Imperial College London [1,2]. In these experiments, supersonic, sub-Alfvénic plasma flows collide, bringing anti-parallel magnetic fields into contact and producing a well-defined, elongated reconnection layer. This layer is long-lasting (>200 ns, >10 hydrodynamic flow times) and is diagnosed using a suite of high resolution, spatially and temporally resolved diagnostics which include laser interferometry, Thomson scattering and Faraday rotation imaging. We observe significant heating of the electrons and ions inside the reconnection layer, and calculate that the heating must occur on time-scales far faster than can be explained by classical mechanisms. Possible anomalous mechanisms include in-plane electric fields caused by two-fluid effects, and enhanced resistivity and viscosity caused by kinetic turbulence. We also observe the repeated formation of plasmoids in the reconnection layer, which are ejected outwards along the layer at super-Alfvénic velocities. The O-point magnetic field structure of these plasmoids is determined using in situ magnetic probes, and these plasmoids could also play a role in the anomalous heating of the electrons and ions. In addition, we present further modifications to this experimental platform which enable us to study asymmetric reconnection or measure the out-of-plane magnetic field inside the plasmoids.

*This work was supported in part by the Engineering and Physical Sciences Research Council (EPSRC) Grant No. EP/N013379/1, and by the U.S. Department of Energy (DOE) Awards No. DE-F03-02NA00057 and No. DE-SC-0001063.


10:00

NI2 2 Experimental demonstration of collisionless plasmoids at the electron scale during high Lundquist number magnetic reconnection*
JOSEPH OLSON, University of Wisconsin-Madison
The dynamics of magnetic reconnection can vary greatly depending on the collisionality of the plasma. While resistivity alone provides force balance during collisional reconnection, it cannot account for the reconnection rate during collisionless reconnection. As the collisionality decreases, kinetic processes, such as electron pressure anisotropy [1] can develop unimpeded and provide pressure balance across the current sheet [2]. Recent PIC simulations have shown that more unique structures, driven by pressure anisotropy, can develop only if the electrons do not collide as they traverse the reconnection region [3]. More precisely, this collisionless regime exists when the characteristic Lundquist number is 

\[ S \gg 10^4 \left( m_e / m_i \right) L / d_i \] (for anti-parallel reconnection), where \( \epsilon < 1 \) is an experimental scale factor and \( L \) is the system size. The Terrestrial Reconnection Experiment (TREX) has been specifically designed to operate in this regime, where the Lundquist number is set by the applied reconnection drive. Early experiments in low collisional plasmas with \( S \sim 10 \) showed evidence of magnetic island formation (plasmoids) occurring below characteristic ion length scales [4]. The experiments demonstrate that the plasmoid instability is still active for relatively small system size compared to predictions from either extended MHD or fully kinetic PIC simulations. Furthermore, in recent experiments with \( S > 10^4 \), we document a transition to a regime where the current sheet shrinks to the electron scale, \( \delta_j \sim 2 - 4c/\omega_pe \), consistent with results from kinetic simulations showing that such electron layers are related to strong pressure anisotropy.

This work was supported by the NSF/DOE award DE-SC0013032.


10:30

NI2 3 Electron heating and acceleration during magnetic reconnection

JOEL DAHLIN, NASA Goddard Space Flight Center

Magnetic reconnection is thought to be an important driver of energetic particles in a variety of astrophysical phenomena such as solar flares and magnetospheric storms. However, the observed fraction of energy imparted to a nonthermal component can vary widely in different regimes. We use kinetic particle-in-cell (PIC) simulations to demonstrate the important role of the non-reversing (guide) field in controlling the efficiency of electron acceleration in collisionless reconnection. In reconnection where the guide field is smaller than the reconnecting component, the dominant electron accelerator is a Fermi-type mechanism that preferentially energizes the most energetic particles. In strong guide field reconnection, the field-line contraction that drives the Fermi mechanism becomes weak. Instead, parallel electric fields are primarily responsible for driving electron heating but are ineffective in driving the energetic component of the spectrum. Three-dimensional simulations reveal that the stochastic magnetic field that develops during 3D guide field reconnection plays a vital role in particle acceleration and transport. The reconnection outflows that drive Fermi acceleration also expel accelerating particles from energization regions. In 2D reconnection, electrons are trapped in island cores and acceleration ceases, whereas in 3D the stochastic magnetic field enables energetic electrons to leak out of islands and freely sample regions of energy release. A finite guide field is required to break initial 2D symmetry and facilitate escape from island structures. We show that reconnection with a guide field comparable to the reconnecting field generates the greatest number of energetic electrons, a regime where both (a) the Fermi mechanism is an efficient driver and (b) energetic electrons may freely access acceleration sites. These results have important implications for electron acceleration in solar flares and reconnection-driven dissipation in turbulence.

11:00

NI2 4 Anisotropic Electron Tail Generation during Tearing Mode Magnetic Reconnection

AMI DUBOIS, University of Wisconsin - Madison

Magnetic reconnection (MR) plays an important role in particle transport, energization, and acceleration in space, astrophysical, and laboratory plasmas. In the MST RFP, discrete MR events release large amounts of energy from the equilibrium magnetic field, a large fraction of which is transferred to the ions in a non-collisional process. Key features are anisotropic heating, mass and charge dependence, and energetic ion tail formation. Unlike the ions, the thermal electron temperature decreases at MR events, which is consistent with enhanced electron heat transport due to increased magnetic stochasticity. However, new high-speed x-ray spectrum measurements reveal transient formation of a non-Maxwellian energetic electron tail during MR. The energetic tail is characterized by a power-law, \( E \sim \gamma \), with the spectral index \( \gamma \) decreasing from 4.2 to 2.2 at MR, and then increasing rapidly to 6.8 due to increased stochastic transport. The x-ray emission peaks in a radial view and is symmetric in the toroidal direction, indicating an anisotropic electron tail is generated. The toroidal symmetry of the electron tail implies runaway acceleration is not a dominant process, consistent with the net emf, \( v_\| \), being smaller than the Dreicer field. Modeling of bremsstrahlung emission shows that a power-law electron tail distribution that is localized near the magnetic axis will yield strong perpendicular anisotropy, consistent with x-ray measurements in the radial and toroidal views. A strong correlation between high energy x-ray flux and tearing mode dynamics suggests a tur-
bulous mechanism is active. This implies that the electron tail formation most likely results from a turbulent wave-particle interaction.

∗This work is supported by the US DOE and NSF.

11:30
NI2 5 Experimental verification of the role of electron pressure in fast magnetic reconnection with a guide field
W. FOX, Princeton Plasma Physics Laboratory

Magnetic reconnection enables explosive conversion of magnetic field energy to plasma kinetic energy in space and laboratory plasmas. In many reconnecting plasmas in space, solar, and laboratory plasmas, reconnection proceeds in the presence of a finite guide field (GF) such that the magnetic field lines meet at an angle less than 180°, and in magnetic fusion devices the guide field can be the largest component of the field. We report detailed laboratory observations of the structure of reconnection current sheets in a two-fluid plasma regime with a guide magnetic field. We observe and quantitatively analyze the quadrupolar electron pressure variation in the ion-diffusion region, as originally predicted by extended magnetohydrodynamics simulations. The projection of the electron pressure gradient parallel to the magnetic field contributes significantly to balancing the parallel electric field, and the results demonstrate how parallel and perpendicular force balance are coupled in guide field reconnection and confirm basic theoretical models of the importance of electron pressure gradients for obtaining fast magnetic reconnection. I discuss connections to observations of reconnection with finite guide field by spacecraft missions, and implications for two-fluid reconnection in magnetic fusion devices.

12:00
NI2 6 Diffusion region in magnetopause reconnection observed by the MMS mission∗
LI-JEN CHEN, NASA/Goddard Space Flight Center, University of Maryland at College Park

The diffusion region is the primary location where the plasmas are energized to dissipate the magnetic energy in reconnection. The NASA Magnetospheric Multiscale (MMS) mission, capable of resolving sub-gyroscales of both electrons and ions, has created new frontiers in the state-of-the-art understanding of the diffusion region. The MMS detection of reconnection at Earth’s magnetopause will be discussed to highlight the roles of demagnetized particle orbits and wave fluctuations in the reconnection dynamics. When the guide field is significantly weaker than the reconnecting magnetic field, the reconnection current layer is gyro-resistive and the electron distribution functions exhibit strong finite-gyroradius effects with crescent and counterstreaming characteristics. When the guide field is comparable to the reconnecting component, the electron jets are mainly the E cross B drift due to the polarization electric field and the guide magnetic field, and the energy conversion at the jet reversal is dominated by the wave electric field near the lower hybrid frequency. Insensitive to the guide-field, the dense magnetosheath electrons in the reconnection exhaust are transported, by wave turbulence, across the magnetospheric separatrix to modify the plasma properties and field structures in the magnetosphere. The MMS results will be compared with available laboratory measurements from the Magnetic Reconnection Experiment in Princeton, and challenges in diffusion region physics will be discussed.

∗The MMS and MRX teams are acknowledged. Work is supported by NASA, DOE, and NSF.

SESSION NI3: DISRUPTIONS AND ENERGETIC PARTICLES
Wednesday Morning, 25 October 2017; Room: 103ABC at 9:30; Eric Hollmann, UCSD, presiding

Invited Papers

9:30
NI3 1 The ins and outs of modelling vertical displacement events
DAVID PFEFFERLE, PPPL

Of the many reasons a plasma discharge disrupts, Vertical Displacement Events (VDEs) lead to the most severe forces and stresses on the vacuum vessel and Plasma Facing Components (PFCs). After loss of positional control, the plasma column drifts across the vacuum vessel and comes in contact with the first wall, at which point the stored magnetic and thermal energy is abruptly released. The vessel forces have been extensively modelled in 2D [1] but, with the constraint of axisymmetry, the fundamental 3D effects that lead to toroidal peaking, sideways forces, field-line stochastisation and halo current rotation have been vastly overlooked. In this work, we present the main results of an intense VDE modelling activity using the implicit 3D extended MHD code M3D-C1 and share our experience with the multi-domain and highly non-linear physics encountered. At the culmination of code development by the M3D-C1 group over the last decade, highlighted by the inclusion of a finite-thickness resistive vacuum vessel within the computational domain [2], a series of fully 3D non-linear simulations are performed using realistic transport coefficients based on the reconstruction of
10:00

NI3 3 Physics of the interaction between runaway electrons and the background plasma of the current quench in tokamak disruptions∗

CEDRIC REUX, CEA, IRFM, 13108, Saint-Paul-les-Durance, France

Runaway electrons are created during disruptions of tokamak plasmas. They can be accelerated in the form of a multi-MA beam at energies up to several 10’s of MeV. Prevention or suppression of runaway electrons during disruptions will be essential to ensure a reliable operation of future tokamaks such as ITER. Recent experiments showed that the suppression of an already accelerated beam with massive gas injection was unsuccessful at JET, conversely to smaller tokamaks. This was attributed to a dense, cold background plasma (up to several 10\(^20\) m\(^{-3}\)) accompanying the runaway beam. The present contribution reports on the latest experimental results obtained at JET showing that some mitigation efficiency can be restored by changing the features of the background plasma. The density, temperature, position of the plasma and the energy of runaways were characterized using a combined analysis of interferometry, soft X-rays, bolometry, magnetics and hard X-rays. It showed that lower density background plasmas were obtained using smaller amounts of gas to trigger the disruption, leading to an improved penetration of the mitigation gas. Based on the observations, a physical model of the creation of the background plasma and its subsequent evolution is proposed. The plasma characteristics during later stages of the disruption are indeed dependent on the way it was initially created. The sustainment of the plasma during the runaway beam phase is then addressed by making a power balance between ohmic heating, power transfer from runaway electrons, radiation and atomic processes. Finally, a model of the interaction of the plasma with the mitigation gas is proposed to explain why massive gas injection of runaway beams works only in specific situations. This aims at pointing out which parameters bear the most importance if this mitigation scheme is to be used on larger devices like ITER. Acknowledgement: This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

High-energy relativistic runaway electrons (RE) can be produced during magnetic disruptions due to electric fields generated during the thermal and current quench of the plasma. Understanding this problem is key for the safe operation of ITER because, if not avoided or mitigated, RE can severely damage the plasma facing components. In this presentation we report on RE simulation efforts centered in two complementary approaches: (i) Full orbit (6-D phase space) relativistic numerical simulations in general (integrable or chaotic) 3-D magnetic and electric fields, including radiation damping and collisions, using the recently developed particle-based Kinetic Orbit Runaway electron Code (KORC) and (ii) Backward Monte-Carlo (MC) simulations based on a recently developed efficient backward stochastic differential equations (BSDE) solver. Following a description of the corresponding numerical methods, we present applications to: (i) RE synchrotron radiation (SR) emission using KORC and (ii) Computation of time-dependent runaway probability distributions, RE production rates, and expected slowing-down and runaway times using BSDE. We study the dependence of these statistical observables on the electric and magnetic field, and the ion effective charge. SR is a key energy dissipation mechanism in the high-energy regime, and it is also extensively used as an experimental diagnostic of RE. Using KORC we study full orbit effects on SR and discuss a recently developed SR synthetic diagnostic that incorporates the full angular dependence of SR, and the location and basic optics of the camera. It is shown that oversimplifying the angular dependence of SR and/or ignoring orbit effects can significantly modify the shape and overestimate the amplitude of the spectra. Applications to DIII-D RE experiments are discussed.

11:30
NI3 5 Suppression of Alfvénic modes through modification of the fast ion distribution*
ERIC FREDRICKSON, PPPL

Experiments on NSTX-U have shown for the first time that small amounts of high pitch-angle, low $\rho_L$ beam ions can strongly suppress the counter-propagating Global Alfvén Eigenmodes (GAE) [1]. GAE have been implicated in the redistribution of fast ions and modification of the electron power balance in previous experiments on NSTX. The ability to predict the stability of Alfvén modes, and development of methods to control them, is important for fusion reactors like ITER, which like NSTX, will be heated with a large population of non-thermal, super-Alfvénic ions (unlike the normal operation of conventional tokamaks). The suppression of the GAE by adding a small population of high-pitch resonant fast ions is qualitatively consistent with an analytic model of the Doppler-shifted ion-cyclotron resonance drive responsible for GAE instability [2]. The model predicts that fast ions with $k_\perp \rho_L < 1.9$ are stabilizing, which is in good agreement with the experimental observations. A quantitative analysis was done using the HYM stability code [3] of one of the nearly 100 identified examples of GAE suppression. The simulations find remarkable agreement with the observed mode numbers and frequencies of the unstable GAE prior to suppression. Adding the population of high pitch-angle, low $\rho_L$ beam ions to the HYM fast ion distribution function predicts complete suppression of the GAE. TRANSP/NUBEAM calculations for the example analyzed with HYM suggest that the additional beam source increases the population of resonant fast ions with $k_\perp \rho_L < 1.9$ by roughly a factor of four.

*Work supported by U.S. DOE Contract DE-AC02-09CH11466.

12:00
NI3 6 Manipulating Energetic Ion Velocity Space to Control Instabilities and Improve Tokamak Performance*
DAVID C. PACE, General Atomics - San Diego

The first-ever demonstration of independent current (I) and voltage (V) control of high power neutral beams in tokamak plasma shots has successfully reduced the prevalence of instabilities and improved energetic ion confinement in experiments at the DIII-D tokamak. Energetic ions drive Alfvén eigenmode (AE) instabilities through a resonant energy exchange that can increase radial diffusion of the ions, thereby reducing beam heating and current drive efficiency. This resonance is incredibly sensitive to the ion velocity and orbit topology, which then allows changes in beam voltage (keeping the injected power constant through compensating changes in current) to remove nearly all instability drive. The implementation of temporal control of beam current and voltage allows for a reduction in the resonant energetic ion velocity space while maintaining the ability to inject maximum power. DIII-D low confinement (L-mode) plasmas demonstrate a nearly complete avoidance of AE activity in plasmas with 55 kV beam injection compared to the many AE that are observed in plasmas featuring similar total beam power at 70 kV. Across the experimental range of beam settings, resulting increases in beam divergence have been inconsequential. High performance steady-state scenarios featuring equilibria that are conducive to dense arrays of Alfvén waves benefit the most from instability control mechanisms. One such scenario, the so-called high qmin scenario, demonstrates improved confinement and equilibrium evolution when the injected beam voltage begins at lower values (i.e., fewer resonances) and then increases as the plasma reaches its stationary period. These results suggest a future in which plasma confinement and performance is improved through continuous feedback control.
of auxiliary heating systems such that the energetic ion distribution is constantly adapted to produce an optimal plasma state.

*Work supported by US DOE under DE-FC02-04ER54698.

SESSION NO4: KSTAR
Wednesday Morning, 25 October 2017
Room: 201AB at 9:30
Zheng Yan, General Atomics, presiding

Contributed Papers

9:30
NO4 1 Research Progress and Future Plan of the KSTAR*
YEOONG-KOOK OH, NRFI H.K. PARK, UNIST S.W. YOON, J.G. KWAG, Y. CHU, K.R. PARK, NRFI KSTAR TEAM TEAM, KSTAR RESEARCH COLLABORATORS COLLABORATION Unique capabilities of the Korean Superconducting Tokamak Advanced Research (KSTAR) have been fully capitalized for steady state operation of high beta plasmas and fundamental physics research. The KSTAR is ideal for study of the tokamak plasma symmetry on stability and confinement study owing to the lowest error field and magnetic ripple. Versatile magnetic perturbation tool with n=1,2 in-vessel control coils has been extensively used in control of the harmful MHD such as the ELMs and toroidal rotation through NTV. Advanced 2D/3D microwave imaging diagnostics for undisputed measurements for theory and modeling. In 2016 and 2017 campaigns, KSTAR has achieved a record low operation (34s) of a ELM-crash-free as well as long ELMy (70s) H-mode operation. A predictive capability as well as the underlying physics of the resonant magnetic perturbations (RMP) have been demonstrated. This talk will address the advances in research and vision toward the high beta long pulse operation in KSTAR together with the upgrade plan.

*This work is supported by MSIP of Korea under KSTAR project and NRF of Korea under Contract No. NRF-2014M1A7A1A03029865.

9:42
NO4 2 Scenario development toward high beta steady-state operation at KSTAR S. W. YOON, Y. M. JEON, H. S. KIM, M. H. WOO, S. H. HAHN, Y. S. BAE, J. S. KANG, National Fusion Research Institute Y. S. NA, Seoul National University Y. K. OH, H. K. PARK.* National Fusion Research Institute KSTAR TEAM Solving issues for high-beta long-pulse operation is one of the essential topics for superconducting tokamaks and sustainment of a fully non-inductive H-mode discharge with high performance is successfully demonstrated up to record-long ~70 seconds at KSTAR. Typical plasma parameters are 0.4MA(\(I_p\)), max 5MW (NBi+ECH), \(\beta_p\sim3, f_{\text{TAE}}\sim0.5, H_{95}\sim1.3\) and in a wide range of \(q_{95}=6\sim12\). Though an internal transport barrier is not identified yet, the developed scenario has many features in common with the so called ‘high \(\beta_p\) discharge’ at DIII-D. The thermal confinement is sensitive on the deposition layer of the central ECH heating suggesting strong interaction TAE with fast ion transport. Based on the transport/stability analysis on the present discharge, improved performance is also estimated with higher NBi+ECH heating power envisaged in near future.

*Ulsan National Institute of Science and Technology.

9:54
NO4 3 Distinctive dependence of RMP-ELM coupling on plasma shape, and its optimization for robust ELM control in KSTAR
Y.M. JEON, Y. IN, National Fusion Research Institute J.-K. PARK, Princeton Plasma Physics Laboratory Y. M. JEON, Y. IN, National Fusion Research Institute J.-W. AHN, Oak Ridge National Laboratory G. Y. PARK, H. S. HAN, S.W. YOON, National Fusion Research Institute KSTAR TEAM In recent KSTAR experiments, a critical dependence of RMP-ELM coupling on plasma shape was found to be as important as \(q_{95}\). In application of low-n RMPs, small variations of lower triangularity (\(\delta_{\text{Lower}}\)) made dramatic changes on RMP coupling. Specifically, as \(\delta_{\text{Lower}}\) increases, the coupling to plasma core appears weakened, while the edge coupling gets strengthened effectively for ELM suppression. So far, such \(\delta_{\text{Lower}}\) dependence window for RMP-ELM suppression is surprisingly narrow (\(\Delta\delta_{\text{Lower}} = 0.08\)), while the other shape dependence is unclear. In 2017, a further investigation reveals that such a strict condition can be relaxed by allowing a small up-down asymmetry on plasma shape. Applying this new optimized plasma shape made substantial improvements on the reliability and robustness of RMP-ELM control. As results, the ELM suppressions were successfully demonstrated in a wide range of \(q_{95}\) (4.0-6.4 for \(n=1\) and 3.3-3.8 for \(n=2\) RMPs) even with a fixed RMP phasing, achieving a record-long sustained operation of ELM-suppression (>30sec).

*This work was partly supported by the JSPS-NRF-NFSC A3 Fore-site Program in the field of Plasma Physics.

10:06
NO4 4 Decoupling edge and core RMPs for ELM suppression in KSTAR*
J.-K. PARK, Princeton Plasma Physics Laboratory Y. M. JEON, Y. IN, National Fusion Research Institute J.-W. AHN, Oak Ridge National Laboratory G. Y. PARK, J. KIM, H. S. KIM, National Fusion Research Institute N. C. LOGAN, Z. WANG, R. NAZIKIAN, Princeton Plasma Physics Laboratory KSTAR RESEARCH TEAM Resonant magnetic perturbations (RMPs) can suppress edge-localized-modes (ELMs) in tokamaks when carefully optimized, in particular for the resonant response in the edge pedestal while minimizing other unnecessary resonances or degradations in the core. KSTAR has been unique in testing these RMP decoupling and optimizing principles, by its 3 rows of in-vessel coils and independent \(n=1\) control at each row. A recent experiment on a special subset of that multi-dimensional coil configuration space in KSTAR clearly suggests the importance of 3D MHD response to RMPs, as both IPEC and MARS codes were greatly successful in predicting ELM suppression windows whereas vacuum approximation was entirely misleading. The linear 3D MHD predictions were often surprisingly accurate in details, as validated by various dynamic RMP applications and ELM responses. This predictive RMP capability played an important role in guiding experiments later and finding non-standard RMPs, leading to the first demonstration of the \(n=1\) ELM suppression without using the mid-plane coils and also the RMP ELM suppression in high \(q_{95}>6\) in high-\(\beta\) KSTAR plasmas.

*This work was supported by DOE Contract DE-AC02-09CH11466.

10:18
NO4 5 Evidence of perpendicular flow bifurcation at the onset of ELM-crash suppression
*JAEHYUN LEE, Ulsan National Institute of Science and Technology YOUNGMU JEON, YONGKYOON IN, National Fusion Research Institute GUNSU YUN, Pohang University of Science and Technology MINWOO KIM, Ulsan National
WEDNESDAY MORNING

Institute of Science and Technology MINJUN CHOI, GUNYOUNG PARK, National Fusion Research Institute HYEON K. PARK, Unsan National Institute of Science and Technology KSTAR TEAM

The evidence of perpendicular electron flow ($v_{\perp,e}$) bifurcation at the onset of ELM-crash suppression has been measured using electron cyclotron emission imaging (ECEI) system [1] for the first time in KSTAR. The ECEI has shown that (1) resonant magnetic perturbation (RMP) enhances small scale turbulent fluctuations in the edge toward the ELM-crash suppression phase, (2) the induced turbulence regulates growth of the ELM filament via nonlinear interaction between them [2]. Cross spectra and correlation analysis among the ECEI channels revealed that the ELM crashes get suppressed along with a rapid reduction of $v_{\perp,e}$ close to zero (small but finite value) together with decrease of its shear. The $v_{\perp,e}$~0 km/s is sustained during the ELM-crash suppression even under a large variation of RMP current and external torque and when this condition is violated, ELM crashes are reappeared.

*This work was supported by National Research Foundation of Korea under Grants No. NRF-2014M1A7A1A03029865, No. NRF-2017M1A7A1A03064231.


10:30

NO4 6 Compatibility of RMP ELM control with divertor heat flux dispersal and detachment in KSTAR* JOONWOOK AHN, ORNL YONGYOOK IN, National Fusion Research Institute ALBERTO LOARTE, ITER Organization JUN GYO BAK, BIN CAO, YOUNGMO JEON, JAYHYUN KIM, HYUNG HO LEE, GUNYOUNG PARK, National Fusion Research Institute JONG-KYU PARK, Princeton Plasma Physics Laboratory SUK HO HONG, WON HA KO, SI WOO YOON, National Fusion Research Institute RMP ELM suppression can help avoid transient peak heat flux problem in tokamaks but the steady state heat flux should be also effectively dispersed over the divertor surface, either by profile broadening or divertor detachment. Low-n RMPs were utilized to address the effect of B-field structure, including intentionally misaligned RMP configuration, and divertor gas puffing on both heat and particle flux footprints. Particularly, full ELM suppression for $n=\pm 2$ at $q_{95}=3.4$ was successfully sustained even with the strong gas puffing and the subsequent density ramp up until the plasma finally disrupted due to the apparent radiative loss. On the other hand, as for the $n=1$ RMP ELM suppression at $q_{95}=5$, both heat and particle fluxes were reduced significantly near the outer strike point (OSP) with divertor gas puffing (indicative of partial detachment) but the ELM suppression itself was not sustained. Overall, good progress in high-density ELM suppression for $n=\pm 2$ was made and this needs to be combined with the stable divertor detachment, which was demonstrated for $n=1$. Detailed analyses with various plasma parameters and response to RMPs will be discussed.

*Work supported by the U.S. DOE, contract # DE-AC05-00OR22725.

10:42

NO4 7 Observation of the Generalized Noceological Toroidal Viscosity Offset Rotation Profile in KSTAR* S.A. SABBAGH, Y.S. PARK, Columbia U. J. KIM, W.H. KO, S.H. HAHN, Y. IN, Y.K. OH, NRFI K.C. SHAING, National Cheng Kung U. Y. SUN, ASIPP A beneficial effect of Neoclassical Toroidal Viscosity [1] that may be important in slowly rotating plasmas as expected in ITER is the inherent or “offset” rotation created by an applied 3D field. Past experiments and associated theory have only considered that the NTV offset rotation can occur in the direction opposite to the plasma current. More recently, the NTV offset rotation profile, $V_{\perp,e}^\text{NTV}$, was directly measured and studied in the KSTAR tokamak that has shown for the first time strong, controlled rotation in the $\ell_1$ direction at high electron temperature. This result is expected from generalized NTV theory that allows for electron and ion torques. A field with dominant $n=2$ component was applied to produce $V_{\perp,e}^\text{NTV}$.

Rotation in the plasma outer region exceeded 12 krad/s, quite significant compared to projections for ITER of approximately 2 krad/s in the pedestal region. Also, the $V_{\perp,e}^\text{NTV}$ rotation profile shear is 15 times greater than measured in the intrinsic rotation profile (without 3D field). Experiments at higher $T_e$ produced the strong co-rotation and rotation shear while higher density and lower $T_e$ reduced these characteristics.

*Supported by US DOE Contracts DE-FG02-99ER54524 and DE-SC0016614.


10:54

NO4 8 Comparison of MHD simulation codes for understanding nonlinear ELMs dynamics in KSTAR H-mode plasma* M. KIM, J. LEE, UNIST H. K. PARK, UNIST, NRFI G. S. YUN, POSTECH X. XU, LLNL S. C. JARDIN, PPPL M. BECOULET, KSTAR electron cyclotron emission imaging (ECEI) systems have contributed to understanding the fundamental physics of ELMs by high-quality 2D and quasi-3D images of ELMs. However, in the highly nonlinear phase of ELM dynamics, the interpretation of ECE signals becomes complicated intrinsically. Theoretical and numerical approaches are necessary to enhance the understanding of ELM physics. Well-established MHD codes (BOUT++, JOREK, and M3D-C1) are introduced for comparative study with the observations. The nonlinear solutions are obtained using the same equilibrium of the KSTAR H-mode plasma. Each code shows the partial difference in mode evolution, probably, due to the difference in optimized operation window of initial conditions. The nonlinear simulation results show that low-$n$ ($n < 5$) modes become dominant close to pedestal collapse. The mode evolution in the simulations qualitatively matches with the recent ECEI observation just before ELM-crash, or excitation of non-modal solitary perturbation (typically, $n = 1$) [1] which is highly localized in poloidal and toroidal. Regardless of differences in details, qualitative similarity can provide inspiration to understand the triggering of ELM-crash.

*Supported by NRF of Korea under Contract No. NRF-2014M1A7A1A03029865.


11:06

NO4 9 Modulation method as a tool to measure three dimensional magnetic field structures in toroidal plasmas KATSUMI IDA, TATSUYA KOBAYASHI, National Institute for Fusion Science, Toki, 509 5292, Japan WONHA KO, HYUNGHO LEE, YONGYOOK IN, HYUNSEOK KIM, National Fusion Research Institute, Daejeon 34133, Korea Three dimension (3D) magnetic field applied by external coils is modified by the 3D current produced by plasma (plasma response). For example, the magnetic island produced by the external field and resonant or non-resonant magnetic perturbation (NRMP or RMP) field applied usually differ from the vacuum magnetic field due to the plasma response. Therefore, it is important to determine the 3D magnetic field experimentally, not based on the magnetic field calculation. Two modulation techniques applied to various toroidal plasmas to measure 3D magnetic field structure are discussed. One is the modulation electron cyclotron
heating (MECH) to measure the size of magnetic island by taking advantage of bi-directional (inward and outward) heat pulse propagation excited by MECH inside magnetic island. Recently, the modulation of NRMP or RMP field is applied to measure the penetration length of the 3D perturbation magnetic field using the modulation amplitude profile of the toroidal rotation gradient. In this talk, 1) bifurcation phenomena of magnetic island in LHD [1] and DIII-D [2] plasmas and 2) non-linearity of the penetration of 3D magnetic field in KSTAR H-mode plasma will be presented.

11:18
NO4 10 Control advances for achieving the ITER baseline scenario on KSTAR* N.W. EIDETIS, General Atomics J. BARR, Oak Ridge Associated Universities S.H. HAHN, National Fusion Research Institute D.A. HUMPHREYS, General Atomics Y.K. IN, Y.M. JEON, National Fusion Research Institute M.J. LANCTOT, US DOE D. MUELLER, Princeton Plasma Physics Laboratory M.L. WALKER, General Atomics Control methodologies developed to enable successful production of ITER baseline scenario (IBS) plasmas on the superconducting KSTAR tokamak are presented: decoupled vertical control (DVC), real-time feedforward (rtFF) calculation, and multi-input multi-output (MIMO) X-point control. DVC provides fast vertical control with the in-vessel control coils (IVCC) while sharing slow vertical control with the poloidal field (PF) coils to avoid IVCC saturation. rtFF compensates for inaccuracies in offline PF current feedforward programming, allowing reduction or removal of integral gain (and its detrimental phase lag) from the shape controller. Finally, MIMO X-point control provides accurate positioning of the X-point despite low controllability due to the large distance between coils and plasma. Combined, these techniques enabled achievement of IBS parameters ($q_{95} = 3.2$, $\beta_N = 2$) with a scaled ITER shape on KSTAR. $n=2$ RMP response displays a strong dependence upon this shaping.

*Work supported by the US DOE under Award DE-SC0010685 and the KSTAR project.

†Formerly General Atomics.
from the measurements and linear simulations are comparable with each other, and this seems to be due to low collisionality of the plasmas where the quasi-coherent fluctuations were measured. Group velocities of the fluctuations in the plasma frame are all in the ion diamagnetic drift direction for the NBI L-mode plasmas, and this agrees well with the linear simulation results. For ECH L-mode plasmas, however, the group velocities from the measurements are not clearly recognized.

*Supported by DOE/NNSA.


9:42

**NO5 2 Three dimensional calculation of thermonuclear ignition conditions for magnetized targets**

ROSS CORTEZ, JASON CASSIBRY, University of Alabama in Huntsville MICHAEL LAPOINTE, ROBERT ADAMS, NASA Fusion power balance calculations, often performed using analytic methods, are used to estimate the design space for ignition conditions. In this paper, fusion power balance is calculated utilizing a 3-D smoothed particle hydrodynamics code (SPFMax) incorporating recent stopping power routines. Effects of thermal conduction, multigroup radiation emission and nonlocal absorption, ion/electron thermal equilibration, and compressional work are studied as a function of target and liner parameters and geometry for D-T, D-D, and 3LI-D fuels to identify the potential ignition design space. Here, ignition is defined as the condition when fusion particle deposition equals or exceeds the losses from heat conduction and radiation. The simulations are in support of ongoing research with NASA to develop advanced propulsion systems for rapid interplanetary space travel.


9:54

**NO5 3 Streaked Thomson Scattering on Laboratory Plasma Jets**

JACOB BANASEK, TOM BYVANK, SOPHIA ROCCO, BRUCE KUSSE, DAVID HAMMER, Cornell University Streaked Thomson scattering measurements have been performed on plasma jets created from a 15 μm thick radial Al or Ti foil load on COBRA, a 1 MA pulsed power machine. The goal was to measure the electron temperatures inside the center of the plasma jet created by the radial foil. The laser used for these measurements had a maximum energy of 10 J at 526.5 nm in a 3 ns duration pulse. Early experiments showed using the full energy significantly heats the $5 \times 10^{18}$ cm$^{-3}$ jet by inverse bremsstrahlung radiation. Here we used a streak camera to record the scattered spectrum and measure the evolving temperature of this laser heated jet. Analysis of the streak camera image showed that the electron temperature of the Al jet was increased from about 25 eV to 80-100 eV within about 2 ns. The Ti jets showed even stronger interaction with the laser, being heated to over 150 eV, and showed some heating even when only 1 J of laser energy was used. Also, the ion-acoustic peaks in the scattered spectrum from the Ti jets were significantly narrower than those from Al jets. Initial results will also be presented with scattered spectra taken at two different times within a single experiment by splitting the probe beam.

*This research is supported by the NNSA Stewardship Sciences Academic Programs under DOE Cooperative Agreement DE-NA0001836.

10:06

**NO5 4 Simulations of a dense plasma focus on a high impedance generator**

ANDREY BERESNYAK, JOHN GIULIANI, STUART JACKSON, STEVE RICHARDSON, STEVE SWANEKAMP, JOE SCHUMER, ROBERT COMMISSO, Naval Research Laboratory DAVE MOSHER, Syntek Technologies BRUCE WEBER, ALEXANDER VELIKOVICH, Naval Research Laboratory We study the connection between plasma instabilities and fast ion acceleration for neutron production on a Dense Plasma Focus (DPF). The experiments will be performed on the HAWK generator (665 kA), which has fast rise time, 1.2 $\mu$s, and a high inductance, 607 nH. It is hypothesized that high impedance may enhance the neutron yield because the current will not be reduced during the collapse resulting in higher magnetization. To prevent upstream breakdown, we will inject plasma far from the insulator stack. We simulated rundown and collapse dynamics with Athena – Eulerian 3D, unsplit finite volume MHD code that includes shock capturing with Riemann solvers, resistive diffusion and the Hall term. The simulations are coupled to an equivalent circuit model for HAWK. We will report the dynamics and implosion time as a function of the initial injected plasma distribution and the implications of non-ideal effects. We also traced test particles in MHD fields and confirmed the presence of stochastic acceleration, which was limited by the size of the system and the strength of the magnetic field.

*Supported by DOE/NNSA and the Naval Research Laboratory Base Program.

10:18

**NO5 5 Advanced Design Concepts for Dense Plasma Focus Devices at LLNL**

ALEXANDER POVILUS, YURI PODPALY,
CHRISTOPHER COOPER, BRIAN SHAW, STEVE CHAPMAN, JAMES MITRANI, MICHAEL ANDERSON, ARIC PEARSON, ENRIQUE ANAYA, ED KOH, STEVE FALABELLA, TONY LINK, ANDREA SCHMIDT, LAWRENCE LIVERMORE NATL LAB

The dense plasma focus (DPF) is a z-pincher device where a plasma sheath is accelerated down a coaxial railgun and ends in a radial implosion, pinch phase. During the pinch phase, the plasma generates intense, transient electric fields through physical mechanisms, similar to beam instabilities, that can accelerate ions in the plasma sheath to MeV-scale energies on millimeter length scales. Using kinetic modeling techniques developed at LLNL, we have gained insight into the formation of these accelerating fields and are using these observations to optimize the behavior of the generated ion beam for producing neutrons via beam-target interactions for kilojoule to megajoule-scale devices. Using a set of DPF’s, both in operation and in development at LLNL, we have explored critical aspects of these devices, including plasma sheath formation behavior, power delivery to the plasma, and instability seeding during the implosion in order to improve the absolute yield and stability of the device.

*Prepared by LLNL under Contract DE-AC52-07NA27344. Computing support for this work came from the LLNL Institutional Computing Grand Challenge program.

10:30

**NO5 6 Overview of pulsed-power-driven high-energy-density plasma research at the University of Michigan**


ional Labs

The Michigan Accelerator for Inductive Z-pinch Experiments (MAIZE) is a 3-m-diameter, single-cavity Linear Transformer Driver (LTD) at the University of Michigan (UM). MAIZE supplies a fast electrical pulse (0–1 MA in 100 ns for matched loads) to various experimental configurations, including wire-array z-pinches and cylindrical foil loads. This talk will report on projects aimed at upgrading the MAIZE facility (e.g., a new power feed and new diagnostics) as well as various physics campaigns on MAIZE (e.g., radiation source development, power flow, implosion instabilities, and other projects relevant to the MagLIF program at Sandia). In addition to MAIZE, UM is constructing a second, smaller LTD facility consisting of four 1.25-m-diameter cavities. These cavities were previously part of Sandia’s 21-cavity Ursa Minor facility.

The status of the four Ursa Minor cavities at UM will also be presented.

*This research was funded in part by the University of Michigan, a Faculty Development Grant from the Nuclear Regulatory Commission, the NNSA under DOE Grant DE-NA0003047 for UNR, and Sandia National Laboratories under DOE-NNSA contract DE-NA0003525.

10:42

**NO5 7 Implosion dynamics and radiative properties of W planar wire arrays influenced by Al wires on University of Michigan’s LTD generator**


The results of new experiments with W Double Planar Wire Arrays (DPWA) at the University of Michigan’s Linear Transformer Driver (LTD) generator are presented that are of particular importance for future work with wire arrays on 40-60 MA LTDs at SNL. A diagnostic set similar to the previous campaigns comprised filtered x-ray diodes, a Faraday cup, x-ray spectrometers and pinhole cameras, but had an ultra-fast 12-frame self-emission imaging system. Implosion and radiative characteristics of two DPWAs of the same mass (60 μg/cm) and geometry (two planes with 8 wires each at the distance of 6 mm and an inter-wire gap of 0.7 mm) with one plane of W wires and another either of W wires (1) or of Al wires (2) were compared in detail. The substantial differences between two cases are observed: 1) precursor formation and intense hard x-ray characteristic emission of W (“cold” L lines) caused by electron beams; 2) no precursor, standing shocks at the W plane side that lasted up to a hundred of ns, fast ablation and implosion of Al wires, and suppression of hard x-ray “cold” L lines of W. In addition, the evolution of self-emission in a broad period of time up to 400 ns is analyzed for the first time.

*Research supported by NNSA under DOE Grant DE-NA0003047.

11:06

**NO5 9 Shock ignition targets: gain and robustness vs ignition threshold factor**

STEFANO ATZENI, LUCA ANTONELLI, ANGELO SCHIAVI, SILVIA PICONE, STEFANO ATZENI, LUCA ANTONELLI, ANGELO SCHIAVI, SILVIA PICONE, 1 GIAN MARCO VOLPONI, 1 Dipartimento SBAI, Universita’ di Roma “La Sapienza”, Italy ALBERTO MAROCCHINO, LNF, INFN, Frascati, Italy

Shock ignition [1] is a laser direct-drive inertial confinement fusion scheme, in which the stages of compression and hot spot formation are partly separated. The hot spot is created at the end of the implosion by a converging shock driven by a final “spike” of the laser pulse. Several shock-ignition target concepts have been proposed and relevant gain curves computed (see, e.g. [2]). Here, we consider both pure-DT targets and more facility-relevant targets with plastic ablators. The investigation is conducted with 1D and 2D hydrodynamic...
simulations. We determine ignition threshold factors ITF's (and their dependence on laser pulse parameters) by means of 1D simulations [3]. 2D simulations indicate that robustness to long-scale perturbations increases with ITF. Gain curves (gain vs laser energy), for different ITF's, are generated using 1D simulations.

*Work partially supported by Sapienza Project C26A15YTMA, Sapienza 2016 (n. 257584), Eurofusion Project AWP17-ENR-IFEC-CEA-01.

1Student.
2Student.

2S. Atzeni et al., Nucl. Fusion 54, 054008 (2014).

11:18
NO5 10 Laser plasma instabilities and hot electron generation from multi-kilojoule shock ignition relevant high-intensity IR and UV lasers* S. ZHANG, J. LI, F. N. BEG, Univ of California - San Diego C. M. KRAULAND, S. MULLER, N. ALEXANDER, General Atomicities C. REN, W. THEOBALD, D. TURNBULL, D. HABERBERGER, R. BETTI, E. M. CAMPBELL, ILE, Univ of Rochester D. BATANI, J. SANTOS, P. NICOLAI, CELIA, Univ of Bordeaux M. S. WEI, General Atomicities As an alternative ignition scheme, shock ignition uses a strong convergent shock driven by a high-intensity laser (~10^{16} \text{ W/cm}^2) on a pre-compressed fuel to achieve ignition. Moderately energetic hot electrons (<100 keV) generated from the laser plasma instabilities (LPI) can strengthen the ignition shock by deposits energy at the compressed outer shell increasing ablation pressure. In our previous experiments on OMEGA-EP, 90 keV collimated hot electrons were observed from a 100 ps, 2.5 kJ IR laser interacting with SL long scale length hot plasmas (L_e \approx 200 \text{ - 500 } \mu \text{m}, T_e > 1 \text{ keV}, produced by low-intensity UV beams). To further characterize hot electron generation and investigate the related LPI's, we have extended the experiments with high-intensity, multi-kJ IR and UV lasers (both at normal incidence, up to 2 \times 10^{16} \text{ W/cm}^2). Two IR beams in co-propagation extend the pulse duration to 200 ps, closer to required ignition pulse duration. The scattered light is spectrally resolved to identify the LPI. Angular filter refractometer images from 4ω probe show the details of the laser propagation and interaction. The divergence, energy, and temperature of the hot electrons are diagnosed by measuring the bremsstrahlung and Cu Ka emission. Details of the experimental results will be presented.

*This work is supported by the U. S. DOE under contracts DE-NA0003600 (NLUF) and DE-SC0014666 (HEDLP).

11:30
NO5 11 Compact Fast Ignition experiments using Joule-class tailored drive pulses under counterbeam configuration YOSHITAKA MORI, RYOHEI HANAYAMA, KATSUHIRO ISHII, YONEYOSHI KITAGAWA, GPI TAKASHI SEKINE, YASUKI TAKEUCHI, TAKASHI KURITA, YOSHINORI KATO, NAKAHIRO SATOHI, NORIO KURITA, TOSHIYUKI KAWASHIMA, Hamamatsu Photonics K. K. OSAMU KOMEDA, Toyota motor Corp. TATSUMI HIOKI, TOMOYOSHI MOTO-HIRO, Nagoya Univ, ATSUHI SUNAHARA, Purdue Univ, YASUHIKO SENTOKU, Osaka Univ, EISUKE MIURA, AIST AKI-FUMI IWAMOTO, HITOSHI SAKAGAMI, NIFS Fast ignition (FI) is a form of inertial confinement fusion in which the ignition step and the compression step are separate processes resulting in a reduction of the symmetry requirement for hot spot generation. One of the problems of FI so far are the accessibility of an ignition laser pulse into the assembled core in which the driver energy is converted into relativistic electrons produced in the laser-plasma interaction. We have experimentally demonstrated that a tailored-pulse-assembled core with a diameter of 70 μm, originally a deuterated polystyrene spherical shell of 500 μm diameter, is flashed by directly counter irradiating 0.8 J/110 fs laser pulses [Y. MORI et al., PRL 2016]. This result indicates that once the assembled core is squeezed into the target center, the heating lasers can access the core’s edges and deposit their energy into the core. In this talk, we will discuss the heating effects in relation to formation of the assembled core.

11:42
NO5 12 Two-colors-laser-plasma interaction for enhancing hot electron generation to drive strong shock in a dense matter* SHINSUKE FUJIOKA, SEUNGHO LEE, HIDETAKA KISHIMOTO, HIROKI MORITA, YUIJ FUKUYAMA, SYOHEI SAKATA, KAZUKI MATSUO, KING FAI FARLEY LAW, YUGO OCHIAI, KEISUKE KOGA, YASUNOBU ARIKAWA, KEISUKE SHIGEMORI, AKIFUMI YOGO, HIROAKI NISHIMURA, ILE, Osaka Univ, Japan KUNIKO MIMA, GPI, Japan HIROSHI AZECHI, NATSUMI IWATA, TAKAYOSHI SANØ, HIDEO NAGATOMO, YASUHIKO SENTOKU, RYOSUKE KODAMA, ILE, Osaka Univ, Japan Localized heating of an overdense plasma by hot electrons is being studied as a scheme to drive strong shock in a matter. One of the challenges in this scheme is efficient energy conversion from laser light to hot electrons through laser-plasma interactions. Here we have demonstrated experimentally that mixture of 1.053 μm and 0.53 μm intense laser beams results in one order of magnitude enhancement of this efficiency. Number and energy distribution of hot electrons were measured by using two spectrometers of Bremsstrahlung X-ray and characteristic X-ray from Cu tracer embedded targets. Dependences of the energy conversion on laser intensity ratio and relative polarization were clearly observed. Spectrum of the backscattered light indicates change of electron plasma waves by the two-color lasers irradiation. Comparison between the experiment and simulation will also be presented.

*This work is supported by JSPS, NIFS and ILE, Osaka University.

11:54
NO5 13 Diffusion of external magnetic fields into the cone-in-shell target in the fast ignition ATSUHI SUNAHARA, CMUXE, Purdue University HIROKI MORITA, Institute of Laser Engineering, Osaka University TOMOYUKI JOHZAKI, Hiroshima University HIDEO NAGATOMO, SHINSUKE FUJIOKA, Institute of Laser Engineering, Osaka University AHMED HASSANEIN, CMUXE, Purdue University FIREX PROJECT TEAM We simulated the diffusion of externally applied magnetic fields into cone-in-shell target in the fast ignition. Recently, in the fast ignition scheme, the externally magnetic fields up to kilo-Tesla is used to guide fast electrons to the high-dense imploded core. In order to study the profile of the magnetic field, we have developed 2D cylindrical Maxwell equation solver with Ohm’s law, and carried out simulations of diffusion of externally applied magnetic fields into a cone-in-shell target. We estimated the conductivity of the cone and shell target based on the assumption of Saha-ionization equilibrium. Also, we calculated the temporal evolution of the target temperature heated by the eddy current driven by temporal variation of magnetic fields, based on the accurate equation of state. Both, the diffusion of magnetic field and the increase of target temperature interact with each other. We present our results of temporal evolution of the magnetic field and its diffusion into the cone and shell target.
Contributed Papers

9:30
NO6 1 Blast-Wave Generation and Propagation in Rapidly Heated Laser-Irradiated Targets∗ S.T. IVANCIC, C.R. STILLMAN, P.M. NILSON, A.A. SOLODOV, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester Time-resolved extreme ultraviolet (XUV) spectroscopy was used to study the creation and propagation of a >100-Mbar blast wave in a target irradiated by an intense (>10^35 W/cm^2) laser pulse. Blast waves provide a platform to generate immense pressures in the laboratory. A temporal double flash of XUV radiation was observed when viewing the rear side of the target, which is attributed to the emergence of a blast wave following rapid heating by a fast-electron beam generated from the laser pulse. The time-history of XUV emission in the photon energy range of 50 to 200 eV was recorded with an x-ray streak camera with 7-ps temporal resolution. The heating and expansion of the target was simulated with an electron transport code coupled to 1-D radiation–hydrodynamics simulations. The temporal delay between the two flashes measured in a systematic study of target thickness and composition was found to evolve in good agreement with a Sedov–Taylor blast-wave solution.

∗This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and Department of Energy Office of Science Award Number DE-SC-0012317.

9:42
NO6 2 Characterization of short-pulse laser-produced x-rays for diagnosing magnetically driven cylindrical isentropic compression HIROSHI SAWADA, TYLER DAYKIN, BRUNO BAUER, Univ of Nevada - Reno FARHAT BEG, University of California San Diego We have developed an experimental platform to study material properties of magnetically compressed cylinder using a 1 MA pulsed power generator Zebra and a 50 TW subpicosecond short-pulse laser Leopard at the UNR’s Nevada Terawatt Facility. According to a MHD simulation, strong magnetic fields generated by 100 ns rise time Zebra current can quasi-isentropically compress a material to the strongly coupled plasma regime. Taking advantage of the cylindrical geometry, a metal rod can be brought to higher pressures than that in the planar geometry. To diagnose the compressed rod with high precision x-ray measurements, an initial laser-only experiment was carried out to characterize laser-produced x-rays. Interaction of a high-intensity, short-pulse laser with solids produces broadband and monochromatic x-rays with photon energies high enough to probe dense metal rods. Bremsstrahlung was measured with Imaging plate-based filter stack spectrometers and monochromatic 8.0 keV Cu K-alpha was recorded with an absolutely calibrated Bragg crystal spectrometer. The broadband x-ray source was applied to radiography of thick metal objects and different filter materials were tested. The experimental results and a design of a coupled experiment will be presented.

9:54
NO6 3 Physics of Short Laser Pulse Heated Solid Targets Revealed by Code Comparisons∗ RICHARD LONDON, ANDREAS KEMP, MARK SHERLOCK, Lawrence Livermore National Laboratory NATHAN SIRCOMBE, MARTIN RAMSAY, AWE Aldermaston Physical properties of hot dense plasmas, such as opacity and equation-of-state, are increasingly being studied with solid targets heated by short-pulse lasers. In the conventional scenario, an intense laser pulse produces hot electrons, which then heat the bulk of the target. However, there remain many unanswered questions about the physics of the energy coupling and transport in such targets. To answer these questions, we have embarked on a project to compare simulation results produced by several independent computer codes. We describe the role of pre-plasma scale length in determining the hot electron spectra and the importance of various coupling mechanisms between hot electrons and the bulk plasma. We discuss plans to identify optimal simulation methods to better utilize short pulse heated targets for studying hot dense matter.

∗This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

10:06
NO6 4 Ultrafast nonequilibrium electron dynamics of aluminium interacting with an ultra-intense x-ray pulse CHENG GAO, JIAOLOONG ZENG, JIANMIN YUAN, National University of Defense Technology Ultrafast nonequilibrium dynamics of free electrons in an ultra-intense and ultrafast x-ray pulse interacting with a solid-density aluminium is investigated by solving Pokker-Planck equation. X-ray propagation through aluminium is determined by solving a one-dimensional radiative transfer equation which is coupled with a time-dependent rate equation. Although high energy electrons are evidently nonequilibrium, they account for a small population fraction in the total free electrons. The transmission of an ultra-intense x-ray pulse through a 1 um thick solid-density aluminium sample is calculated and compared with a recent experiment, where good agreement is found and saturable absorption is evidently observed.

10:18
NO6 5 Modeling dynamic plasmas driven by ultraintense nano-focused x-ray laser pulses in solid iron targets∗ RYAN ROYLE, University of Oxford YASUHIKO SENTOKU, Institute of Laser Engineering, Osaka University ROBERTO MANCINI, University of Nevada, Reno The hard x-ray free electron laser has proven to be a valuable tool for high energy density (HED) physics as it is able to produce well-characterized samples of HED matter at exactly solid density and homogeneous temperatures. However, if the x-ray pulses are focused to sub-micron spot sizes, where peak intensities can exceed 10^20 W/cm^2, the plasmas driven by sources of non-thermal photoelectrons and Auger electrons can be highly dynamic and so cannot be modeled by atomic kinetics or fluid codes. We apply the 2D/3D particle-in-cell code, PICLS—which has been extended with numerous physics models to enable the simulation of XFEL-driven plasmas—to the modeling of such dynamic plasmas driven by nano-focused XFEL pulses in solid iron targets. In the case of the smallest focal spot investigated of just 100 nm in diameter, keV plasmas induce strong radial E-fields that accelerate keV ions radially as well as sheath fields that accelerate surface ions to hundreds of keV. The heated spot, which is initially larger than the laser spot due to the kinetic nature of the fast Auger electrons, expands as ion and electron waves propagate radially, leaving a low density region along the laser axis.

∗This research was supported by the US DOE-OFES under Grant No. DE-SC0008827, the DOE-NNSA under Grant No. DE-NA0002075, and the JSPS KAKENHI under Grant No. JP15K21767.
10:30 NO6 6 Proton radiography of relativistic magnetic reconnection driven by ultra-high intensity lasers∗ PAUL T. CAMPBELL, A. RAYMOND, University of Michigan C. A. J. PALMER, Y. MA, Lancaster University H. CHEN,1 LLNL Y. KATZIR, RAL C. MILHAME, P. M. NILSON, LLE C. P. RIDGERS, University of York A. G. R. THOMAS, University of Michigan E. R. TUBMAN, Imperial College London M. S. WEI, General Atomics G. J. WILLIAMS, LLNL N. WOOLSEY, University of York L. WILLINGALE, K. KRUSHELNICK, University of Michigan In recent experiments conducted with the OMEGA-EP laser facility at LLE and the Vulcan laser at RAL, proton radiography was used to observe in detail the magnetic field dynamics associated with magnetic reconnection driven by ultra-high intensity, short pulse lasers. Two configurations were investigated: one with two short pulses focused on target in close proximity and another with a short pulse fired near a relatively slowly evolving long pulse produced plasma. The proton radiography results, along with x-ray imaging and angularly resolved electron spectra will be presented.

∗This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-0002727.

1. H. Chen and G. J. Williams were supported under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

10:42 NO6 7 Magnetic field generation in intense laser-plasma interaction and their impact on ion acceleration∗ ROHINI MISHRA, MAXENCE GAUTHIER, SLAC National Accelerator Laboratory CHANDRA CURRY, University of Alberta, Edmonton, Alberta, CANADA JONGJIN KIM, SIEGFRIED GLNZEN, FREDERICO FIUZA, SLAC National Accelerator Laboratory Mass limited targets can bring advantages to laser-driven ion acceleration including enhanced laser absorption and higher proton energy. However, these targets can be subject to pre-expansion due to the laser pre-pulse and form low-density plasma in the rear side of the target. We have investigated the generation of magnetic fields in pre-expanded targets and the role of these fields on the ion beams. Multidimensional (2D and 3D) particle-in-cell (PIC) simulations motivated by ion acceleration experiments show two dominant magnetic fields generation mechanisms: i) Weibel or current-filamentation instability associated with the background return current and ii) Biermann Battery or fountain effect (associated with fast electron dynamics). They can both contribute to modulate the ion beams. The interplay between these two mechanisms depends on the pre-plasma scale length present at the rear surface of the target. We also present an analytical model to estimate the magnetic fields based on proton energies and modulations observed in the experiments, which is consistent with the PIC simulation results.

∗This work is supported by DOE FES under FWP 100182 and FWP 100237.

10:54 NO6 8 Probing the onset of laser-induced relativistic transparency in massive targets∗ TAO WANG, CRAIG WAGNER, CHEDS, Univ. of Texas, Austin TOMA TONCIAN, Helmholtz-Zentrum Dresden-Rossendorf, Germany GILLIS DYER, CHEDS, Univ. of Texas, Austin ALEXEY AREFIEV, University of California, San Diego TODD DITMIER, CHEDS, Univ. of Texas, Austin We have investigated a novel approach of using harmonics of the laser frequency generated in the plasma to detect the onset of relativistic transparency induced by an intense laser pulse. The onset of the transparency is directly associated with a forward motion of a relativistically adjusted critical surface. The corresponding velocity is relativistic, so the harmonics generated at this critical surface are noticeably shifted. Using particle-in-cell simulations, we have confirmed that the resulting shift greatly exceeds the shift produced during a hole-boring process when the relativistic transparency plays no role, which allows us to clearly identify the onset of the relativistic transparency. Experiments that we have carried out at the Texas Petawatt laser showcase this approach. The 3rd harmonic signal detected in experiments with massive targets irradiated at laser intensities around 1020 W/cm² has a pronounced shift associated with the relativistic transparency. The shift represents a recession of the relativistically adjusted critical surface with a velocity close to 0.2 c. This approach opens a new possibility of detecting changes in the optical properties of matter induced by intense laser pulses even when no transmission of the laser pulse takes place.

∗This research was supported part by NSF (Grant No. 1632777) and NNSA (Cont. No. DE-NA0002008). Simulations were performed using HPC resources at TACC at the University of Texas.

11:06 NO6 9 Microwave Emission Spectroscopy of Short Pulse Laser-Produced Plasma in Air∗ ALEXANDER ENGBLES, University of Michigan, Air Force Research Laboratory JENNIFER ELLE, REMINGTON REID, ADRIAN LUCERO, HUGH POHLE, SERGE KALMYKOV, MATTHEW DOMONKOS, ANDREAS SCHMITT-SODY, Air Force Research Laboratory KARL KRUSHELNICK, University of Michigan Measuring the radiated power spectral density of microwaves from plasmas has long been used to infer details about plasma behavior. We apply this technique to plasma generated via ultra-short pulse laser ionization. The impulsive interaction of the laser with the plasma drives current, which couples to radiated fields and is a source of broadband terahertz and microwave radiation. We measure the radiated spectrum and angular distribution in the far field over a frequency range of 1-40 GHz. The spectrum of the microwaves is sampled using calibrated, tunable heterodyne receivers. We show that neutral gas pressure significantly alters the amplitude of microwave emissions from the plasma. The spectrum as a function of background neutral density is used to infer information about the free electron density of the plasma. Experimental results are compared to a moving dipole model, with good agreement over a limited parameter range.

∗This material is based upon work supported by the Air Force Office of Scientific Research under Award Number FA9550-16RCOR325.

11:18 NO6 10 Laser pulse sharpening with electromagnetically induced transparency in plasma∗ KENAN QU, NATHANIEL FISCH, Department of Astrophysical Sciences, Princeton University, Princeton, New Jersey 08544, USA We propose a laser-controlled plasma shutter technique to generate sharp laser pulses using a process analogous to electromagnetically induced transparency in atoms. The shutter is controlled by a laser with moderately strong intensity, which induces a transparency window below the cutoff frequency, and hence enables propagation of a low frequency laser pulse. Numerical simulations demonstrate that it is possible to generate a sharp pulse waveform (sub-ps) using two broad pulses in high density plasma. The technique can work in a regime that is not accessible by plasma mirrors when the pulse pedestals are stronger than the ionization intensity.

∗This work was supported by NNSA Grant No. DENA0002948, and AFOSR Grant No. FA9550-15-1-0391.
Field creation may find applications in charged beam collimation in-cell simulations using EPOCH. This new method of magnetic analytical predictions are confirmed in three-dimensional particle-plasma (ps scale). It is different from Inverse Faraday effects. Our magnetic field (up to 0.4 MG), which persists over a long time in the there is a net rotating current leading to the onset of an intense axial the electrical current based on particle motion. To the second order, in the transverse plane has some special characteristics. We present (TRPW). The distribution and evolution of density and electric field oscillate elliptically in the transverse plane with an azimuthally de- frequency and also different twist index. In this plasma wave, particles driven by co-propagating Laguerre-Gaussian (LG) beating orbital angular momentum (OAM) laser beams with both a different frequency and also different twist index. In this plasma wave, particles oscillate elliptically in the transverse plane with an azimuthally dependent phase. We therefore call it a transverse rotating plasma wave (TRPW). The distribution and evolution of density and electric field in the transverse plane has some special characteristics. We present a linear fluid model of TRPW and also a high order analysis of the electrical current based on particle motion. To the second order, there is a net rotating current leading to the onset of an intense axial magnetic field (up to 0.4 MG), which persists over a long time in the plasma (ps scale). It is different from Inverse Faraday effects. Our analytical predictions are confirmed in three-dimensional particle-in-cell simulations using EPOCH. This new method of magnetic field creation may find applications in charged beam collimation and controlled fusion.

*Dr Yin Shi is a Newton International Fellow. This work is supported by the Royal Society. This work used the ARCHER UK National Supercomputing Service.

11:42
NO6 12 The role of plasma density scale length on the laser pulse propagation and scattering in relativistic regime MA-SOUD PISHDAST, SEYED ABOLFAZL GHASEMI, JAMAL ALDIN YAZDANPANAH, Plasma and Fusion Research School, NSTRI, Tehran, Iran The role of plasma density scale length on two short and long laser pulse propagation and scattering in under dense plasma have been investigated in relativistic regime using 1D PIC simulation. In our simulation, different density scale lengths and also two short and long pulse lengths with temporal pulse duration \(t_2 = 60\ \text{fs}\) and \(t_2 = 300\ \text{fs}\) have been used. It is found that laser pulse length and density scale length have considerable effects on the energetic electron generation. The analysis of total radiation spectrum reveals that, for short laser pulses and with reducing density scale length, more unstable electromagnetic modes grow and strong longitudinal electric field generates which leads to the generation of more energetic plasma particles. Meanwhile, the dominant scattering mechanism is Raman scattering and tends to Thomson scattering for longer laser pulse.

Contributed Papers

9:30
NO7 1 Kinetic Energy Transfer Process in a Double Shell Leading to Robust Burn* D.S. MONTGOMERY, W.S. DAUGHTON, B.J. ALBRIGHT, D.C. WILSON, E.N. LOOMIS, E.C. MERRITT, E.S. DODD, R.C. KIRKPATRICK, R.G. WATT, Los Alamos National Laboratory M.D. ROSEN, Lawrence Livermore National Laboratory A goal of double shell capsule implosions is to impart sufficient internal energy to the D-T fuel at stagnation in order to obtain robust \(\alpha\)-heating and burn with low hot spot convergence, C.R. < 10. A simple description of the kinetic energy transfer from the outer shell to the inner shell is found using shock physics and adiabatic compression, and compares well with 1D modeling. An isobaric model for the stagnation phase of the inner shell is used to determine the ideal partition of internal energy in the D-T fuel. Robust burn of the fuel requires, at minimum, that \(\alpha\)-heating exceeds the rate of cooling by expansion of the hot spot so that the yield occurs before the hot spot disassembles, which is then used to define a minimum requirement for robust burn. One potential advantage of a double shell capsule compared to single shell capsules is the use of a heavy metal pusher, which may lead to a longer hot spot disassembly time. We present these analytic results and compare them to 1D and 2D radiation-hydrodynamic simulations.

*Work performed under the auspices of DOE by LANL under contract DE-AC52-06NA25396.

9:42
NO7 2 Investigating the importance of low-mode symmetry on double shell performance ERIC LOOMIS, DOUG WILSON, DAVID MONTGOMERY, ELIZABETH MERRITT, WILLIAM DAUGHTON, EVAN DODD, JOSHUA SAUPPE, DRU RENNER, SASI PALANIYAPPAN, STEVE BATHA, Los Alamos Natl Lab Implosions of hohlraum-driven double shell targets as an alternative inertial confinement fusion (ICF) concept are underway at the National Ignition Facility. The double shell system relies on a series of efficient energy transfer processes starting from thermal x-ray absorption by the outer shell, followed by collisional transfer of kinetic energy to an inner shell, and final conversion to fuel internal energy. Beyond these zero-dimensional processes double shells must also be designed for robust performance against hydrodynamic instability growth, engineering features, and implosion asymmetry. In this talk we will present simulation results on the shape transfer process between the outer shell and inner shell during collision. We will discuss the mechanisms involved in the shape transfer process and give numerical predictions on their importance to double shell designs.

9:54
NO7 3 NIF Double Shell outer/inner shell collision experiments* E. C. MERRITT, E. N. LOOMIS, D. C. WILSON, T. CARDENAS, D. S. MONTGOMERY, W. S. DAUGHTON, E. S. DODD, T. DESJARDINS, D. B. RENNER, S. PALANIYAPPAN, S. H. BATHA, Los Alamos National Lab S. F. KHAN, V. SMALYUK, Y. PING, P. AMENDT, Lawrence Livermore National Lab M. SCHOFF, M. HOPPE, General Atomics Double shell capsules are a potential low convergence path to substantial alpha-heating and ignition on NIF, since they are predicted to ignite and burn at relatively low temperatures via volume ignition. Current LANL NIF double shell designs consist of a low-Z ablator, low-density foam cushion, and high-Z inner shell with liquid DT fill. Central to the Double Shell concept is kinetic energy transfer from the outer to inner shell via collision. The collision determines maximum energy available for compression and implosion shape of the fuel. We present results of a NIF shape-transfer study: two experiments comparing shape and trajectory of the outer and inner shells at post-collision times. An outer-shell-only target shot measured the no-impact shell conditions, while an 'imaging' double shell shot measured shell conditions with impact. The 'imaging' target uses a low-Z inner shell and is designed to perform in similar collision physics space to a high-Z double shell but can be radiographed at 16keV, near the viable 2DConA BL energy limit.
NO7 4 Double shell planar experiments on OMEGA* E. S. DODD, E. C. MERRITT, S. PALANIYAPPAN, D. S. MONTGOMERY, W. S. DAUGHTON, D. W. SCHMIDT, T. CARDENAS, D. C. WILSON, E. N. LOOMIS, S. H. BATHA, LANL, Y. PING, V. A. SMALYUK, P. A. AMENDT, LLNL The double shell project is aimed at fielding neutron-producing capsules at the National Ignition Facility (NIF), in which an outer low-Z ablative collides with an inner high-Z shell to compress the fuel. However, understanding these targets experimentally can be challenging when compared with conventional single shell targets. Halfbraun-driven planar targets at OMEGA are being used to study physics issues important to double shell implosions outside of a convergent geometry. Both VISAR and radiography through a tube have advantages over imaging through the hohlraum and double-shell capsule at NIF. A number of physics issues are being studied with this platform that include 1-d and higher dimensional effects such as defect-driven hydrodynamic instabilities from engineering features. Additionally, the use of novel materials with controlled density gradients require study in easily diagnosed 1-d systems. This work ultimately feeds back into the NIF capsule platform through manufacturing tolerances set using data from OMEGA.

*Supported under the US DOE by the LANS, LLC under contract DE-AC52-06NA25396. LA-UR-17-25386.

NO7 5 Evaluation of the Revolver Ignition Design at the National Ignition Facility Using Polar-Direct-Drive Illumination* P.W. MCKENTY, T.J.B. COLLINS, J.A. MAROZAS, E.M. CAMPBELL, Laboratory for Laser Energetics, U. of Rochester K. MOLVIG, M. SCHMITT, LLNL The direct-drive ignition design Revolver[1] employs a triple-shell target using a beryllium ablator, a copper driver, and an eventual gold pusher. Symmetrical numerical calculations indicate that each of the three shells exhibit low convergence (~3 to 5) resulting in a modest gain (G ~4) for ~1.7 MJ of incident laser energy. Studies are now underway to evaluate the robustness of this design employing polar direct drive (PDD) at the National Ignition Facility. Integral to these calculations is the leveraging of illumination conditioning afforded by research done to demonstrate ignition for a traditional PDD hot-spot target design. [2] Two-dimensional simulation results, employing nonlocal electron-thermal transport and cross-beam energy transport, will be presented that indicate ignition using PDD. A study of the allowed levels of long-wavelength perturbations (target offset and power imbalance) not precluding ignition will also be examined.

This work was performed under the auspices of the U. S. DOE by LLNL under contract DE-AC52-06NA25396.


NO7 6 Enhancing Ignition Probability and Fusion Yield in NIF Indirect Drive Targets with Applied Magnetic Fields* L. JOHN PERKINS, B. GRANT LOGAN, DARWIN HO, GEORGE ZIMMERMAN, MARK RHODES, DONALD BLACKFIELD, STEVEN HAWKINS, Lawrence Livermore National Laboratory Imposed magnetic fields of tens of Tesla that increase to greater than 10 kT (100 MGauss) under capsule compression may relax conditions for ignition and propagating burn in indirect-drive ICF targets. This may allow attainment of ignition, or at least significant fusion energy yields, in presently-performing ICF targets on the National Ignition Facility that today are sub-marginal for thermonuclear burn through adverse hydrodynamic conditions at stagnation. Results of detailed 2D radiation-hydrodynamic-burn simulations applied to NIF capsule implosions with low-mode shape perturbations and residual kinetic energy loss indicate that such compressed fields may increase the probability for ignition through range reduction of fusion alpha particles, suppression of electron heat conduction and stabilization of higher-mode RT instabilities. Optimum initial applied fields are around 50 T. Off-line testing has been performed of a hohlraum coil and pulsed power supply that could be integrated on NIF; axial fields of 58T were obtained. Given the full plasma structure at capsule stagnation may be governed by 3-D resistive MHD, the formation of closed magnetic field lines might further augment ignition prospects. Experiments are now required to assess the potential of applied magnetic fields to NIF ICF ignition and burn.

*Work performed under auspices of U.S. DOE by LLNL under Contract DE-AC52-07NA27344.

NO7 7 Scaling of Liquid DT Layer Capsules to an ICF Burning Plasma* R. E. OLSON, R. R. PETERSON, B. M. HAINES, S. A. YI, P. A. BRADLEY, A. B. ZYLSTRA, J. L. KLINE, R. J. LEEPER, S. H. BATHA, LANL Recent experiments at the NIF demonstrated cryogenic liquid DT layer ICF implosions [1]. Unlike DT ice layer implosions, DT liquid layer designs can operate with low-to-moderate convergence ratio (12 < CR < 25), with a hot spot formed mostly or entirely from DT mass originating within the central, spherical volume of DT vapor [2]. With reduced CR, hot spot formation is expected to have improved robustness to instabilities and asymmetries [3]. In addition, the hot spot pressure (P) required for self-heating is reduced if the hot spot radius (Rhs) is increased (P ∝ R2hs). With a reduction in the hot spot Pr requirement, the implosion velocity and fuel ablation requirements are relaxed. On the other hand, with larger hot spot size, the hot spot energy requirement for self-heating (Ehs) is increased (Ehs ∝ R2hs), and the required capsule-absorbed energy is increased. In this presentation, we will discuss the hot spot energy, hot spot pressure, cold fuel ablation, and capsule-absorbed energy requirements for achieving self-heating and propagating burn with hot spot CR < 20.

This work was performed under the auspices of the U. S. DOE by LANL under contract DE-AC52-06NA25396.


NO7 8 Capsule physics comparison of different ablators for NIF implosion designs* DANIEL CLARK, ANDREA KRITCHER, Lawrence Livermore National Laboratory AUSTIN YI, ALEX ZYLSTRA, Los Alamos National Laboratory STEVEN HAAN, JOSEPH RALPH, CHRISTOPHER WEBER, Lawrence Livermore National Laboratory Indirect drive implosion experiments on the National Ignition Facility (NIF) have now tested three different ablator materials: glow discharge polymer (GDP) plastic, high density carbon (HDC), and beryllium. How do these different ablator choices compare in current and future implosion experiments on NIF? What are the relative advantages and disadvantages of each? This talk compares these different ablator options in capsule-only simulations of current NIF experiments and proposed future designs. The simulations compare the impact of the capsule fill tube,
support tent, and interface surface roughness for each case, as well as all perturbations in combination. According to the simulations, each ablator is impacted by the various perturbation sources differently, and each material poses unique challenges in the pursuit of ignition.

11:06
NO7 9 Subscale HDC implosions driven at high radiation temperature using advanced hohlraums* D. HO, P. AMENDT, O. JONES, L. BERZAK HOPKINS, S. LE PAPE, LLNL. Implosions using HDC ablators have received increased attention because of shorter pulse length and can access higher implosion velocity than CH ablators [1]. Recent HDC midscale (979 m radius) implosion experiments have achieved DT neutron yields of 1.5e16 [2]. Our 2D simulations show that subscale (890 m radius) HDC capsules can achieve robust high-yield performance if driven at high enough radiation temperature 330 eV, because the penalty for less fuel mass can be offset by higher implosion velocity. To achieve 330 eV will likely require the use of innovative hohlraum concepts, e.g., sub-scale rugby-shaped hohlraum [3] using 1.3 MJ of laser energy without incurring a risk of high laser backscatter. Radiation symmetry is currently under study. Confidence in our modeling of HDC implosions is high in part because our 2D modeling of recent HDC implosions experiments show good agreement with data.

*Work performed under auspices of U.S. DOE by LLNL under 15-ERD-058.

2L. Berzak Hopkins, S. Le Pape et al., this conference and paper forthcoming.

11:18
NO7 10 Beryllium implosion experiments at high case-to-capsule ratio on the National Ignition Facility* ALEX ZYLSTRA, AUSTIN YI, JOHN KLINE, GEORGE KYRALA, ERIC LOOMIS, TERRY, RAHUL SHAH, STEVE BATHA, Los Alamos National Laboratory STEVE MACLAREN, JOE RALPH, JAY SALMONSON, LAURENT MASSE, ABBAS NIKROO, MICHAEL STADERMANN, DEBBIE CALLAHAN, OMAR HURRICANE, Lawrence Livermore National Laboratory NEAL RICE, HAIBO HUANG, CASEY KONG, General Atomics. Using beryllium as an ablator material has several potential advantages for inertial fusion because of its low opacity and thus higher ablation rate. This could enable novel designs taking advantage of the reduced ablation-front growth rate, or operating at lower radiation temperature. To investigate the integrated performance of beryllium implosions, we conducted a tuning campaign leading into DT layered implosions using a 900um radius capsule in a 6.72mm diameter hohlraum (case-to-capsule ratio CCR=3.7); the large CCR enables direct study of the 1-D implosion performance. The tuning campaign shots demonstrate excellent control over the shock timing and implosion symmetry at this CCR. Performance data from the DT experiments will also be discussed.

*This work performed under the auspices of the U.S. DoE by LANL under contract DE-AC52-06NA25396.

11:30
NO7 11 Quantifying design trade-offs of beryllium targets on NIF* S.A. YI, A.B. ZYLSTRA, J.L. KLINE, E.N. LOOMIS, G.A. KYRALA, R.C. SHAH, T.S. PERRY, R.J. KANZLEITER, S.H. BATHA, LANLSA. MACLAREN, J.E. RALPH, E.P. MASSE, J.D. SALMONSON, R.E. TIPTON, D.A. CALLAHAN, O.A. HURRICANE, LLNL. An important determinant of target performance is implosion kinetic energy, which scales with the capsule size. The maximum achievable performance for a given laser is thus related to the largest capsule that can be imploded symmetrically, constrained by drive uniformity. A limiting factor for symmetric radiation drive is the ratio of hohlraum to capsule radii, or case-to-capsule ratio (CCR). For a fixed laser energy, a larger hohlraum allows for driving bigger capsules symmetrically at the cost of reduced peak radiation temperature ($T_r$). Beryllium ablators may thus allow for unique target design trade-offs due to their higher ablation efficiency at lower $T_r$. By utilizing larger hohlraum sizes than most modern NIF designs, beryllium capsules thus have the potential to operate in unique regions of the target design parameter space. We present design simulations of beryllium targets with a large CCR = 4.3 ~ 3.7. These targets are scaled surrogates of large hohlraum low-Tr beryllium targets, with the goal of quantifying symmetry tunability as a function of CCR.

*This work performed under the auspices of the U.S. DOE by LANL under contract DE-AC52-06NA25396, and by LLNL under Contract DE-AC52-07NA27344.

11:42
NO7 12 Relationship between symmetry and laser pulse shape in low-fill hohlraums at the National Ignition Facility* STEVE MACLAREN, LLNL A.B. ZYLSTRA, A. YI, J.L. KLINE, G.A. KYRALA, L.B. KOT, E.N. LOOMIS, T.S. PERRY, R.C. SHAH, LANL L.P. MASSE, J.E. RALPH, S.F. KHAN, LLNL. Typically in indirect-drive inertial confinement fusion (ICF) hohlraums cryogenic helium gas fill is used to impede the motion of the hohlraum wall plasma as it is driven by the laser pulse. A fill of ~1 mg/cc has been used to significantly suppress wall motion in ICF hohlraums at the National Ignition Facility (NIF); however, this level of fill also causes laser-plasma instabilities (LPI) which result in hot electrons, time-dependent symmetry swings and reduction in drive due to increased backscatter. There are currently no adequate models for these phenomena in codes used to simulate integrated ICF experiments. A better compromise is a fill in the range of 0.3~0.6 mg/cc, which has been shown to provide some reduction in wall motion without incurring significant LPI effects [1]. The wall motion in these low-fill hohlraums and the resulting effect on symmetry due to absorption of the inner cone beams by the outer cone plasma can be simulated with some degree of accuracy with the hydrodynamics and inverse Bremsstrahlung models in ICF codes. We describe a series of beryllium capsule implosions in 0.3 mg/cc He fill hohlraums that illustrate the effect of pulse shape on implosion symmetry in the “low-fill” regime. In particular, we find the shape of the beginning or “foot” of the pulse has significant leverage over the final symmetry of the stagnated implosion.

*This work performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344.

Wednesday Morning, 25 October 2017
Room: 202DE at 9:30
Felix Mackenroth, Max Planck Institute for the Complex Systems, presiding

Contributed Papers

9:30 NM9 1 Strong field physics enabled by a 100 PW laser LIANG JI, Shanghai Institute of Optics and Fine Mechanics A 100 PW laser can support focal intensities beyond 10^{23} W/cm^{2}, which will drive the interaction into the strong relativistic regime and create QED-featured plasma. In the former, charged particles can be accelerated to the unprecedented GeV to tens-of-GeV level via laser-driven wakefield acceleration. The concept of laser-driven table-tap accelerators can be significantly advanced. Further, interaction in the near-QED regime will exhibit exotic new effects such as gamma photons emission, radiation-reaction effect and QED cascade. A most exciting prospect is combining a 100 PW laser with a hard X-ray free-electron laser (XFEL) facility. It will lead the chasing on the discovering vacuum birefringence-a prominent strong field QED effect of vacuum. The proposed scientific activities and experimental design are introduced for a 100 PW laser system.

9:50 NM9 2 Laser-Plasma experiments at ELI-NP PETRU GHENUCHE, FLORIN NEGOITA, BOGDAN DIACONESCU, Extreme Light Infrastructure-Nuclear Physics (ELI-NP), IFIN-HH, Romania DAN STUTMAN, Extreme Light Infrastructure-Nuclear Physics (ELI-NP), IFIN-HH, Johns Hopkins University Recent advances in ultra-high power lasers architecture brings unprecedented intensity and pressure regimes within our reach. Extreme Light Infrastructure – Nuclear Physics (ELI-NP) is a new large laser facility, part of the ELI European research infrastructure that will benefit from these upgrades in the next years. It has the ambitious goal to use extreme electromagnetic fields generated by two 10 PW laser beams for a broad range of research topics in fundamental physics at the frontier of plasma physics, nuclear physics and astrophysics, together with applied research in materials and life sciences. Here we describe the facility implementation status and challenges and the commissioning experiments related with laser-plasma interaction [1].

10:10

NM9 3 High-intensity research infrastructure at ELI Beamlines∗ ONDREJ KLIMO,1 ELI Beamlines, Institute of Physics of the ASCR The L4 laser (10 PW, 150 fs) at ELI Beamlines is expected to provide focused intensities approaching 1022W/cm2 and thus herald a new era of research in ultra-high intensity laser matter interaction. This talk will describe the progress in enabling the associated technological infrastructure - including the laser system, beam transport, diagnostics and the experimental chamber [1]. Synergistic experimental and theoretical programs are also developing tools for such research. The talk will also briefly describe these research areas like development of dedicated diagnostic equipment, efforts toward obtaining ultra-high intensities using tight-focusing search areas like development of dedicated diagnostic equipment, efforts toward obtaining ultra-high intensities using tight-focusing.

∗Supported from European Regional Development Funds - projects High Field Initiative (CZ.02.1.01/0.0/0.0/15_003/0000449) and ELI - phase 2 (CZ.02.1.01/0.0/0.0/15_008/0000162).

1on behalf of the R5 and R6 teams of ELI Beamlines.


10:30

NM9 4 Experimental observation of strong radiation reaction in the field of an ultra-intense laser G. SARRI, Queen’s University Belfast, University Road, Belfast BT7 1NN, UK K. PODER, Blackett Laboratory, Imperial College London, London SW72BZ, UK M. TAMBURINI, A. DI PIAZZA, C. H. KEITEL, Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany M. ZEPF, Queen’s University Belfast, University Road, Belfast BT7 1NN, UK Describing radiation reaction in an electromagnetic field is one of the most fundamental outstanding problems in electrodynamics [1]. It consists of determining the dynamics of a charged particle fully taking into account self-forces (loosely referred to as radiation reaction) resulting from the radiation fields generated by the particle whilst it is accelerated. Radiation reaction has only been invoked to explain the radiative properties of powerful astrophysical objects, such as pulsars and quasars [2]. From a theoretical standpoint, this phenomenon is subject of fervent debate [1, 3] and this impasse is worsened by the lack of experimental data, due to extremely high fields required to trigger these effects. Here, we report on the first experimental evidence of strong radiation reaction during the interaction of an ultra-relativistic electron beam with an intense laser field, beyond a purely classical description.


10:50

NM9 5 Ultra-bright GeV photon source via controlled electromagnetic cascades in laser-dipole waves ARKADY GONOSKOV, Chalmers University of Technology, Sweden ALEXEY BASHINOV, EVGENY EFIMENKO, ALEXANDER MURAVIEV, ARKADY KIM, Institute of Applied Physics, RAS, Russia ANTON ILDERTON, University of Plymouth, UK SERGEY BASTRAKOV, IOSIF MEYEROV, Lobachevsky State University of Nizhni Novgorod, Russia MATTHIAS MARKLUND, Chalmers University of Technology, Sweden ALEXANDER SERGEEV, Institute of Applied Physics, RAS, Russia The prospect of achieving conditions for triggering strong-field QED phenomena at upcoming large-scale laser facilities raises a number of intriguing questions. What kind of new effects and interaction regimes can be accessed by basic QED phenomena? What are the minimal (optimal) requirements to trigger these effects and enter these regimes? How can we, from this, gain new fundamental knowledge or create important applications? The talk will concern the prospects of producing high fluxes of GeV photons by triggering a special type of self-sustaining cascade in the field of several colliding laser pulses that form a dipole wave [1]. Apart from reaching the highest field strength for a given total power of laser pulses, the dipole wave enables anomalous radiative trapping that favors pair production and high-energy photon generation. An extensive theoretical analysis and 3D QED-PIC simulations indicate that the concept is feasible at upcoming large-scale laser facilities of 10 PW level and can provide an extraordinary intense source of GeV photons for novel experimental studies in nuclear and quark-nuclear physics.

1Gonoskov et al., arXiv:1610.06404.

11:10

NM9 6 Extreme states of electron-positron plasma in multi-petawatt laser fields EVGENY EFIMENKO, ALEKSEI BASHINOV, ARKADY GONOSKOV, ALEXANDER MURAVIEV, ARKADY KIM, ALEXANDER SERGEEV, Institute of Applied Physics, Russian Academy of Sciences, 46 Ulyanov Street, 603950, Nizhny Novgorod, Russia The next generation of high-intensity laser facilities, such as ELI and XCELS, will allow reaching intensities sufficient for triggering strong-field QED phenomena. In particular, dense electron-positron-pair plasma can be created through vacuum breakdown by means of QED cascades. We analyze theoretically different nonlinear regimes of electron-positron plasma dynamics in multi-beam laser fields. First, we show that for laser powers of up to 20 PW QED-plasma with extra-high particle densities and fluxes, as well as ultra-bright bursts of GeV photons are produced. This could serve for unique sources of intense gamma rays and dense antimatter. This regime is governed by a current instability, which causes transformation of small plasma density perturbations into thin sheets with extreme current. Second, at higher laser powers created QED-plasma enters a self-compression stage driven by the generated magnetic field and reaches unprecedented pair densities on a short time scale. We call this regime a pinch regime and attribute such complex dynamics to inherent interaction of QED-plasma currents produced by counter-streaming electrons and positrons.

11:30

NM9 7 Impact of extreme laser-driven magnetic fields on photon emission and electron acceleration A. AREFIEV, Univ. of California - San Diego D. STARK, LANL T. WANG, O. JANSEN, CHEDS, Univ. of Texas E. D’HUMIERES, Univ. of Bordeaux, France T. TONCIAN, HZDR, Germany Newly constructed facilities such as ELI are expected to deliver unprecedented laser intensities. A solid density matter irradiated at these intensities will be able to generate strong currents and, as a result, sustain previously inaccessible in laboratory magnetic fields. We have examined the conditions required for the magnetic field generation and the impact that this magnetic field has on photon emission and electron acceleration in the presence of an ultra-intense laser pulse. Generation of extreme quasi-static magnetic fields can ultimately offer an extra ‘control knob’ for exploring QED effects in experiments with high-intensity lasers.

11:50

NM9 8 Gamma beams generation with high intensity lasers for two photon Breit-Wheeler pair production EMMAUEL D’HUMIERES, XAVIER RIBEYRE, OLIVER JANSEN, LEO EUNAULT, SOPHIE JEQUIER, JEAN-LUC DUBOIS, SEBASTIEN HULIN, VLADIMIR TIKHONCHUK, Univ. Bordeaux-CNRS-CEA, France ALEX AREFIEV, TOMA TONCIAN, Univ. of Texas,
NP11 3 Fluctuation-Induced Bistability: A Model of Heat Flux Hysteresis and Avalanching in Confined Plasmas
ZHIBIN GUO, WEIXIN GUO, LU WANG, HUZHONG UNIVERSITY OF SCIENCE & TECHNOLOGY

We propose a theory-based model which explains the observation of heat flux hysteresis in the absence of a transport barrier. This study also strikes at the fundamental question of ‘what is an avalanche?’ We show that multiscale coupling between mesoscopic and microscopic fluctuations can induced bistability of the local turbulence intensity and system state bifurcation. For the subcritical scenario, i.e., the temperature gradient below its linear threshold, if the intensity of the mesoscale temperature gradient exceeds a certain threshold, the system transitions from a metastable ‘laminar’ state to an absolutely stable excited state. Correspondingly, the effective thermal conductivity jumps from a value close to the neoclassical value to an anomalous value. By reducing the external drive, the excited state returns to the laminar one. Therefore, it is the bistability of the turbulence intensity that induces the heat flux hysteresis. The scaling of the hysteresis strength is obtained. Incorporating turbulent viscosity effect, a stable front of turbulence intensity is formed. This front connects the excited and laminar states, and propagates as an avalanche. Hysteresis and turbulence intensity avalanche speed are estimated in a unified theoretical framework.

NP11 4 Impurity transport driven by parallel velocity shear instabilities
WEIXIN GUO, LU WANG, HUZHONG UNIVERSITY OF SCIENCE & TECHNOLOGY

The instability driven by large parallel velocity shear (PVS) is by D’Angelo and P. J. Catto. CT-6B tokamak also reported the existence of PVS driven turbulence in the edge plasma. There are also extensive theoretical investigations, especially, the momentum-energy transport [1], thermal transport [2] as well as inward particular transport [3] are studied, but impurity (non-hydrogenic ions) transport in plasmas with large PVS is never addressed. Impurity accumulation in internal transport barrier (ITB) discharges is reported in JET, JT-6U and DIII-D, especially for the heavier or metal impurities. What’s more, the PVS instability has also been discussed in ITB plasmas [4-6]. Therefore, the PVS turbulence could be a mechanism for mitigating the degree of impurity accumulation in ITB plasmas. The present paper thus studied the impurity effects on PVS instability and the associated impurity transport.

NP11 5 Catastrophic global-avalanche of a hollow pressure filament

B. Van Compernolle, M. J. Poulos, G. J. Morales, University of California, Los Angeles

New results are presented of a basic heat transport experiment performed in the Large Plasma Device at UCLA. A ring-shaped electron beam source injects low energy electrons along a strong magnetic field into a preexisting, large and cold plasma. The injected electrons are thermalized by Coulomb collisions within a short distance and provide an off-axis heat source that results in a long, hollow, cylindrical region of elevated plasma pressure. The off-axis source is active for a period long compared to the density decay time, i.e., as time progresses the power per particle increases. Two distinct regimes are observed to take place, an early regime dominated by multiple avalanches [1], identified as a sudden intermittent rearrangement of the pressure profile that repeats under sustained heating, and a second regime dominated by broadband drift-Alfvén fluctuations. The transition between the two regimes is sudden and global, both radially and axially. The initial regime is characterized by peaked density and temperature profiles, while only the peaked temperature profile survives in the second regime. Recent measurements at multiple axial locations provide new insight into the axial dynamics of the global avalanche.

* Sponsored by NSF Grant 1619505 and by DOE/NSF at BaPSF.


NP11 6 Current driven by electromagnetic ETG turbulence

Wen He, Lu Wang, Shuitao Peng, Huazhong University of Science & Technology

Recently, there has been intensive investigation of turbulence induced spontaneous rotation in tokamak. Naturally, current driven by turbulence has also been considered such as the electron temperature gradient (ETG) instability with a fluid mode [1]. The electrostatic gyrokinetic simulation [2] shows that the ETG turbulence driven current density corresponds to 20% of the local bootstrap current density. In this paper, the quasi-linear version of the current evolution equation in the presence of electromagnetic (EM) ETG turbulence is presented using EM gyrokinetic equation. There are two types of current driving mechanisms. The first type is the divergence of stress, while the second type is called turbulent acceleration source. Finally, we compare the turbulent driven current to the background bootstrap current. The results demonstrate that the EM effect is important for the turbulent driven current. And the source term contributes a little to the total current. The modification of current due to EM ETG turbulence is not dramatic in today’s tokamak. However, it may play a significant role in future device.

S. Tiwari et al., IAEA (2014).

NP11 9 Theoretical explanations of impurity removal in I-mode and poloidal pedestal asymmetries

Silvia Espinosa, Peter J. Catto, MIT Plasma Science and Fusion Center

We have developed the first self-consistent theoretical model retaining the impurity diamagnetic flow and the 2D features it implies due to its associated non-negligible radial flow. It successfully explains the experimental impurity density and temperature, and radial electric field, in-out asymmetries neo-classically. Moreover, it provides a means of calculating the neoclassical impurity radial flow from currently available measurements, providing insight on optimal tokamak operation to prevent impurity accumulation. In particular, it predicts outward neoclassical impurity flux, and therefore inward fueling, occurs for I-mode operation in C-Mod.

NP11 7 Transport increase and confinement degradation caused by MARFE

Peng Shi, Huazhong University of Science & Technology

Recently, the MARFE phenomenon associated with high density plasmas has been observed on J-TEXT Ohmically heated discharges. The MARFE on J-TEXT is characterized by the poloidally local region at high field side (HFS) edge with high density and strong radiation. At the almost same time of MARFE appearance, the density peaking factor and sawtooth oscillation reach maximum and decrease with density increasing, infers that the plasma confinement is saturated. By analyzing the far-forward scattering signals from polarimeter-interferometer, it is found that the local radial density turbulence at high field edge increases significantly after MARFE onset. It is inferred that the local particle transport at MARFE affected region (HFS edge) is enhanced. The enhancement of radial transport at MARFE affected region is considered as the possible reason for confinement saturation on J-TEXT. Furthermore, the trapped electron mode (TEM) with quasi-coherent characteristics is measured by far-forward scattering. The TEMs are always observed in plasmas with low density, and disappear after the plasma density exceeds a threshold. The density threshold of TEM disappearance is consistent with the density threshold of MARFE onset. The evolution of turbulence affirms that the MARFE may be the cause of energy confinement transition from LOC to SOC.

NP11 8 Competition of Perpendicular and Parallel Flows in a Straight Magnetic Field

Jiacong Li, Patrick Diamond, Rongjie Hong, George Tynan, Univ of California - San Diego

In tokamaks, intrinsic rotations in both toroidal and poloidal directions are important for the stability and confinement. Since they compete for energy from background turbulence, the coupling of them is the key to understanding the physics of turbulent state and transport bifurcations, e.g., L-H transition. $V_\perp$ can affect the parallel Reynolds stress via cross phase and energetics, and thus regulates the parallel flow generation. In return, the turbulence driven $V_\parallel$ plays a role in the mean vorticity flux, influencing the generation of $V_\perp$. Also, competition of intrinsic azimuthal and axial flows is observed in CSDX-a linear plasma device with straight magnetic fields. CSDX is a well diagnosed venue to study the basic physics of turbulence-flow interactions in straight magnetic fields. Here, we study the turbulent energy branching between the turbulence driven parallel flow and perpendicular flow. Specifically, the ratio between parallel and perpendicular Reynolds power decreases when the mean perpendicular flow increases. As the mean parallel flow increases, this ratio first increases and then decreases before the parallel flow shear hits the parallel shear flow instability threshold. We seek to understand the flow states and compare with CSDX experiments.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, under Award Number DE-FG02-04ER54738.
NP11 10 Influence of zonal vorticity on the cross phase \textsc{Chan-}
\textsc{Yong An, Byunghoon Min, Chang-bae Kim, Soongsil University} The study of the evolution of the cross phase $\delta$ between the
electron pressure and the potential in the resistive-drift-Afven turbulence under the sheared magnetic field lines are reported. The
linear cross phase is established by both the drift-wave dynamics and the Ohm's law and it is vanishingly small in the modes with
low $k_l$. The nonlinearly saturated cross phase is correspondingly different from the linear $\delta$ mainly due to the $E \times B$ flux. Numeri-
cal computations are performed in order to investigate the roles of
$E \times B$ nonlinearity when the self-consistent zonal flow exists on
$\delta$ by using BOUT++ platform. In this work, the influence of the non-uniformity of the zonal flow, the gradient and the curvature, on
$\delta$ and transport is presented and the departure of $\delta$ from the linear
state is particularly highlighted.

NP11 11 Relationship of the cross phase and the zonal
flow in electrostatic ion-temperature-gradient turbulence
\textsc{Byunghoon Min, Chan-yong An, Chang-bae Kim, Soongsil University} The cross phase $\delta$, that is the phase difference
between the electric potential and the ion pressure, is examined in the
electrostatic ion-temperature-gradient fluid turbulence. It is im-
portant to study the cross phase because the thermal transport $\Gamma$
is roughly proportional to $\sin \delta$. Three-dimensional numerical sim-
ulations are performed in the BOUT++ platform with the shifted
metric coordinate system. The cross phase seems to show an inter-
esting feature such that it is almost constant when the zonal flow $V$ is
in the direction of the electron diamagnetic drift and the time evo-
lution of the cross phase oscillates near zero at low poloidal wave
number and $\Gamma$ is small. These phenomena are closely correlated
with the fluctuation level and depend closely on the curvature $V''$
of the zonal flow.

NP11 12 Dynamics of Staircase Formation and Evolution
\textsc{in a Reduced Model of Beta Plane Turbulence}\textsuperscript{*} \textsc{Thomas Bradly, Mikhail Malkov, Patrick Diamond, UCSD} Staircase dynamics relevant to both beta-plane geostrophic and drift-
wave plasma turbulence is studied numerically and analytically. It ev-
olves an averaged potential vorticity (PV) whose flux is both
driven by and regulates enstrophy field. The model's closure uses
a mixing length concept. Its link with bistability, vital to staircase
formation, is analyzed and verified by integrating the equations nu-
erically. The staircase evolves through meta-stable quasi-periodic
 configurations, lasting for hundreds of time units, yet interspersed
with abrupt mergers of adjacent steps in the staircase. The mergers
occur at the staircase lattice defects where it is not completely re-
laxed to a strictly periodic solution that can be obtained analytically.
The other types of stationary solutions are the solitons and kinks in
the PV gradient and enstrophy - profiles. The waiting time between
mergers increases with decreasing number of steps in the staircase,
because of the exponential decrease in their coupling strength with
growing space. The long-time staircase dynamics is numerically
shown to be local to the adjacent steps. The merger reveals itself
through the explosive growth of the turbulent PV-flux which, how-
ever, abruptly drops to its global constant value when the merger is
completed.

\textsuperscript{*}This research was supported by the Department of Energy under
Award No. DE-FG02-04ER54738.

NP11 13 Evidence for Particle Inward Transport, Theoretical
prediction and Importance for Reacting Plasmas\textsuperscript{*} \textsc{N. Sharky, Retired B. Coppi, MIT C. Mazzotta, ENEA} The fact that parti-
cle transport cannot be described by a diffusion equation but by one
[1,2] that would include an inflow term, involving transport in the
direction of the density gradient, was evidenced by experiments on
magnetically confined plasmas in which the central plasma density
was observed to increase as a result of gas injection at the edge of
the plasma column. The validity of the proposed equation has
been repeatedly confirmed over the years and limitations for the
occurrence of particle inflow in a variety of experimental conditions
have been uncovered. The direct experimental observation of the
inward propagating particle cloud leading to a profile peaking [3] is
described and the effects of different degrees of density peaking in
fusion burning plasmas are analyzed.

\textsuperscript{*}Sponsored in part by the U.S. DoE.

3C. Mazzotta et al., Proceedings of the 44th EPS Conference on

NP11 14 Simulation of ITG instabilities with fully kinetic ions
and drift-kinetic electrons in tokamaks\textsuperscript{*} \textsc{Youn Jun Huh, Yang
Chen, Scott Parker, Univ of Colorado - Boulder} A turbulence
simulation model with fully kinetic ions and drift-kinetic electrons
is being developed in the toroidal electromagnetic turbulence code
GEM. This is motivated by the observation that gyrokinetic ions are
not well justified in simulating turbulence in tokamak edges with
steep density profile, where $\rho_i/L$ is not small enough to be used
a small parameter needed by the gyrokinetic ordering (here $\rho_i$
is the gyro-radius of ions and $L$ is the scale length of density profile).
In this case, the fully kinetic ion model may be useful. Our model
uses an implicit scheme to suppress high-frequency compressional
Alfven waves and waves associated with the gyro-motion of ions.
The ion orbits are advanced by using the well-known Boris scheme,
which reproduces correct drift-motion even with large time-step
comparable to the ion gyro-period. The field equation in this model
is Ampere's law with the magnetic field eliminated by using an
implicit scheme of Faraday's law. The current contributed by ions
are computed by using an implicit $\delta f$ method. A flux tube approx-
imation is adopted, which makes the field equation much easier to
solve. Numerical results of electromagnetic ITG obtained from this
model will be presented and compared with the gyrokinetic results.

\textsuperscript{*}This work is supported by U.S. Department of Energy, Office of
Fusion Energy Sciences under Award No. DE-SC0008801.

NP11 15 Modelling Axial Flow Generation and Profile Evolution
\textsuperscript{*} \textsc{in CSDX Linear Device} \textsc{Rima Hajjar, Patrick H Diamond, George
Tynan, Hong Rongjie, Thakur Saiak, Univ of California - San Diego} We report on developments in reduced
modelling of profile evolution in CSDX. The model includes effects
of turbulence driven axial flows important for enhanced confine-
ment in ITER. Recent studies revealed existence of such flows in
CSDX, historically associated with non-vanishing parallel resid-
ual stress in the momentum flux. Studies also showed transition to
enhanced confinement and amplification of mean axial flow shear
as $B$ increases. The model addresses the relation between perpen-
dicular transport and axial flow dynamics and tracks time-space
evolution of four fields: density $n$, axial and azimuthal flow profiles
$v_x$ and $v_\phi$, energy $\epsilon = (\partial \phi^2 + \partial \phi^2 + (\nabla \phi)^2)/2$. With total energy
conserved, parallel compressibility couples parallel and perpendicular
directions allowing for the system to access the $V_n$ free
energy, thus amplifying the parallel flow shear and depleting turbulent
fluctuations. In this model, the particle flux is purely diffusive, while residual components are added to the Reynolds stresses. The model addresses: i) Vn steepening with B, ii) the relation between v’i and v’s, iii) the surge in parallel Reynolds work indicating coupling of fluctuating energy and parallel flow.

NP11 16 Intermittency in the Helimak, a simple magnetic torus* E.I. TAYLOR, W.L. ROWAN, K.W. GENTLE, W. HORTON, T. BERNARD, IFS, UT Austin Irregularly-spaced, large-amplitude bursts are observed in the Helimak plasma turbulence with sufficient definition to investigate their physical basis and possibly improve understanding of the induced particle transport. The Helimak is an experimental realization of a sheared cylindrical slab that generates and heats a plasma with microwaves and confines it in a helical magnetic field. Although it is MHD stable, the plasma is always in a nonlinearly saturated state of microturbulence. The intermittency in this turbulence manifests itself in highly skewed PDFs of the normalized electron density. Cross-conditional averaging exposes large amplitude structures propagating down the density gradient at a few hundred meters per second. Introduction of a radial electric field via bias plates appears to suppress these intermittent transport events (ITEs) for Er pointing down the density gradient. In addition, the cross-conditionally averaged waveforms are relatively unchanged as connection length is varied. Within certain regimes, our measurements are consistent with the predictions of a stochastic model that represents the plasma fluctuations as a random sequence of burst events. Furthermore, we attempt to gain insight into the physical origin of these ITEs by searching for similar statistical behavior in fluid and gyrokinetic simulations.

*This material is based upon work supported by the U.S. Department of Energy Office of Science, Office of Fusion Energy Sciences under Award Number DE-FG02-04ER5476.

NP11 17 Two species continuum kinetic simulation of plasma turbulence* D.W. CREWS, I.A.M. DATTA, U. SHUMLAK, Univ of Washington We numerically investigate a problem of plasma turbulence decay in the solar wind using the continuum kinetic Vlasov-Maxwell system. While a previous investigation [1] has used an electron fluid model with highly resolved PIC ions, recent results in collisionless problems with kinetically resolved electrons indicate that plasma dynamics result in non-Maxwellian electron distributions. In this approach both ion and electron species are resolved kinetically. Following Franci, a uniform two-dimensional geometry with an out-of-plane magnetic field is considered, where an equipartitioned spectrum of magnetic and kinetic energy fluctuations is initialized on a scale well above an ion scale length. A newly implemented kinetic modeling capability in University of Washington’s WARPX code is used, via a RKDG finite element method with an unstructured physical space and a cartesian velocity space.

*This work is supported by a Grant from US AFOSR.


NP11 18 A unified theory of the magnetized collision term for plasmas* CHAO DONG, DING LI, WENLU ZHANG, Institute of Physics, Chinese Academy of Sciences Recently, the general form of the magnetized Fokker-Planck equation and coefficients have been derived for plasmas. To calculate the magnetized Fokker-Planck coefficients accurately, a unified theory is developed here. The basic idea is to divide the collision area into two regions: (i) 0 < b < b1; (ii) b > b1. Here b is the impact parameter and b1 is chosen to be much larger than the Landau length and much smaller than the inter-particle distance and particles’ thermal gyro-radii. For region (i), the collective effects are unimportant and the magnetic field does not affect the collision process, so the usual binary collision theory without magnetic field is employed to calculate the Fokker-Planck coefficients. For region (ii), the wave theory taking account of the magnetic field effects is employed to calculate the magnetized Fokker-Planck coefficients. Synthesize of the results of the two regions will give the exact magnetized Fokker-Planck coefficients and thus the exact magnetized collision term which includes, in a rather complete manner, the collective effects, the magnetic field effects, and the contribution from close collisions.

*Supported by Strategic Priority Research Program of Chinese Academy of Sciences and National Natural Science Foundation of China.

NP11 19 Edge transport bifurcation in plasma resistive interchange turbulence CONG MENG, XUEYUN WANG, BO LI, Peking University Transport bifurcation and mean E×B shear flow generation in resistive interchange turbulence are explored with self-consistent fluid simulations in a flux-driven system with both closed and open field line regions. The nonlinear evolution of resistive interchange modes shows the presence of two confinement regimes characterized by low and high mean E×B shear flows. By increasing the heat flux above a threshold, large-amplitude fluctuations are induced in the plasma edge region and a transition to the state of reduced turbulent transport occurs as the Reynolds power exceeds the fluctuation energy input rate for a sufficient time period. The flux-gradient relationship shows a sharp bifurcation in the plasma edge transport [1].


NP11 20 Dynamics of edge transport bifurcation induced by external biasing BO LI, XUEYUN WANG, PENGFEI LI, CONG MENG, Peking University Transport bifurcation and flow generation induced by external biasing at the plasma edge are explored with self-consistent turbulence simulations in a flux-driven system with both closed and open magnetic field lines. With no biasing, the nonlinear evolution of pressure-gradient-driven interchange instabilities produces large-scale turbulent eddies, leading to high levels of convective transport in the edge region. By applying a sufficient biasing at the plasma edge, the turbulent flux abruptly decreases to a much lower level, indicating a strong bifurcation in transport.

NP11 21 Multi-scale interaction between magnetic island, plasma flow and turbulence in HL-2A ohmic plasmas MIN JIANG, W.L. ZHONG, Southwestern Institute of Physics Y. XU, Southwest Jiaotong University Z.B. SHI, W. CHEN, X.T. DING, X.Q. JI, Z.C. YANG, P.W. SHI, J. CHENG, Y. LIU, Q.W. YANG, M. XU, Southwestern Institute of Physics HL-2A TEAM Improved understanding of multi-scale physics such as interaction between tearing modes with plasma flows and turbulence can lead to improved control of plasma performance, and thus, have important implication for ITER. The radial profiles of perpendicular flows and density fluctuations in the presence of the m/n=2/1 magnetic island were firstly measured in the HL-2A ohmic plasmas by hopping the work frequency of the Doppler backward scattering (DBS) reflectometer system along with a two-dimensional electron cyclotron...
emission imaging (ECEI) diagnostic identifying the island locations. It has been observed that across the O-point cut the perpendicular flow is quite small at the center of the island and strongly enhanced around the boundary of the island, resulting in a large increase of the flow shear at the island boundary, while across the X-point cut the flow is almost flat in the whole island region. Meanwhile it was found that the density fluctuations are generally weakened inside the island. The results indicate that the perpendicular flow, flow fluctuation and the density fluctuation level were all modulated by the naturally rotating tearing mode across the whole island region.

NP11 22 Turbulence experiments on the PKU Plasma Test (PPT) device∗ TIANCHAO XU, CHUJIE XIAO, XIAOYI YANG, YIHANG CHEN, Peking University YI YU, University of Science and Technology of China MIN XU, Southwestern Institute of Physics LONG WANG, Chinese Academy of Sciences CHEN LIN, Peking University XIAOGANG WANG, Harbin Institute of Technology The PKU Plasma Test (PPT) device is a linear plasma device in Peking University, China. It has a vacuum chamber with 1000mm length and 500mm diameter. A pair of Helmholtz coils can generate toroidal magnetic field up to 2000 Gauss, and plasma was generated by a helicon source. Probes and fast camera were used to diagnose the parameters and got the turbulence spectrums, coherent structure, etc. The dynamics of turbulence, coherent structure and parameter profiles have been analyzed, and it has been found that the turbulence states are related to the equilibrium profiles; Some coherent structures exist and show strongly interactions with the background turbulences; The spatial and temporal evolutions of these coherent structures are related to the amplitude of the density gradient and electric field. These results will help on further studies of plasma transport.

*This work was supported by the National Natural Science Foundation of China under 11575014 and 11375053, CHINA MOST under 2012YQ030142 and ITER-CHINA program 2015GB120001.

NP11 23 Towards Multiscale Interactions Between tearing Modes and Microturbulence∗ Z.R. WILLIAMS, M.J. PUESCHEL, P.W. TERRY, University of Wisconsin, Madison Work on the Madison Symmetric Torus Reversed-Field Pinch (RFP) has shown that large-scale tearing modes present in standard operation are highly detrimental to confinement. These tearing modes, even when reduced in improved confinement regimes of operation, significantly affect zonal flow activity and play a large role in setting microturbulent-induced transport levels. Previous gyrokinetic work has shown that a small but finite tearing fluctuation amplitude is necessary to produce transport values in agreement with experimental measurements of flows have been difficult to reconcile with simple expectations, such as azimuthal flows being dominated by $E\times B$ rotation. Therefore, recent measurements have focused on understanding plasma flows, and the role of neutral dynamics.

NP11 24 Shear-Flow Instability Saturation by Stable Modes: Hydrodynamics and Gyrokinetics∗ ADRIAN FRASER, M.J. PUESCHEL, P.W. TERRY, E.G. ZWEIBEL, University of Wisconsin-Madison, Madison, Wisconsin We present simulations of shear-driven instabilities, focusing on the impact of nonlinearly excited, large-scale, linearly stable modes on the nonlinear cascade, momentum transport, and secondary instabilities. Stable modes, which have previously been shown to significantly affect instability saturation [Fraser et al. PoP 2017], are investigated in a collisionless, gyrokinetic, periodic zonal flow using the GENE code by projecting the results of nonlinear simulations onto a basis of linear eigenmodes that includes both stable and unstable modes. Benchmarking growth rates against previous gyrokinetic studies and an equivalent fluid system demonstrates comparable linear dynamics in the fluid and gyrokinetic systems. Cases of driven and decaying shear-flow turbulence are compared in GENE by using a Krook operator as an effective forcing. For comparison with existing hydrodynamic and MHD shear-flow instability studies, we present results for the shear layer obtained by similar means with the code Dedalus.

*Supported by U.S. DOE Grant No. DE-FG02-89ER53291, the NSF, and UW-Madison.

NP11 25 Bicoherence Analysis of Electrostatic Interchange Mode Coupling in a Turbulent Laboratory Magnetosphere∗ M.C. ABLER, A. SAPERSTEIN, J.R. YAN, M.E. MAUEL, Columbia University Plasmas confined by a strong dipole field exhibit interchange and entropy mode turbulence, which previous experiments have shown respond locally to active feedback [1]. On the Collisionless Terrella Experiment (CTX), this turbulence is characterized by low frequency, low order, quasi-coherent modes with complex spectral dynamics. We apply bicoherence analysis [2] to study nonlinear phase coupling in a variety of scenarios. First, we study the self-interaction of the naturally occurring interchange turbulence; this analysis is then expanded to include the effects of driven modes in the frequency range of the background turbulent oscillations. Initial measurements of coupling coefficients are presented in both cases. Driven low frequency interchange modes are observed to generate multiple harmonics which persist throughout the plasma, becoming weaker as they propagate away from the actuator in the direction of the electron magnetic drift. Future work is also discussed, including application of wavelet bicoherence analysis, excitation of interchange modes at multiple frequencies, and applications to planetary magnetospheres.

*Supported by NSF-DOE Partnership for Plasma Science Grants DE-DE-FG02-00ER54585.


NP11 26 Experiment-Model Comparisons of Turbulence, Transport, and Flows in a Magnetized Linear Plasma Using a Global Two-Fluid Braginskii Solver∗ M. GILMORE, D.M. FISHER, R.F. KELLY, M.W. HATCH, University of New Mexico B.N. ROGERS, Dartmouth College Ongoing experiments and numerical modeling of the dynamics of electrostatic turbulence and transport in the presence of flow shear are being conducted in helicon plasmas in the linear HelCat (Helicon-Cathode) device. Modeling is being done using GBS, a 3D, global two-fluid Braginskii code that solves self-consistently for plasma equilibrium as well as fluctuations. Past experimental measurements of flows have been difficult to reconcile with simple expectations, such as azimuthal flows being dominated by $E\times B$ rotation. Therefore, recent measurements have focused on understanding plasma flows, and the role of neutral dynamics.
In the model, a set of two-fluid drift-reduced Braginskii equations are evolved using the Global Braginskii Solver Code (GBS). For low-field helicon-sourced Ar plasmas a non-negligible cross-field thermal collisional term must be added to shift the electric potential in the ion momentum and vorticity equations as the ions are unmagnetized. Significant radially and axially dependent neutral profiles are also included in the simulations to try and match those observed in HelCat. Ongoing simulations show a mode dependence on the axial magnetic field along with strong axial variations that suggest drift waves may be important in the low-field case.

*Supported by U.S. National Science Foundation Award 1500423.

NP11 27 Thermal Resonator Experiments Using A Magnetized Electron Temperature Filament* SCOTT KARBASHEWSKI, RICHARD SYDORA, University of Alberta BART VAN COMPERNOLLE, MATT POULOS, GEORGE MORALES, University of California, Los Angeles We present results from basic heat transport experiments of a magnetized electron temperature filament that behaves as a thermal resonator. Experiments are performed in the Large Plasma Device at UCLA. A CeB₆ cathode injects low energy electrons along a magnetic field into the center of a pre-existing plasma forming a hot electron filament embedded in a colder plasma. Previous work reported that the filament exhibits spontaneous excitation of thermal waves [1] and temperature gradient driven drift-Alfvén waves that enhance cross-field transport [2]. We have added to the cathode a bias of a series of low amplitude pulse trains tuned to the thermal resonance of the filament that externally excite thermal waves. Langmuir probe measurements allow for the determination of the phase velocity and radial decay length of the thermal mode. These results are used to compute the axial and transverse thermal conductivities of the magnetized plasma and compare with those given by classical theory. Agreement of the axial conductivity provides a measurement of electron temperature; deviation of the transverse conductivity suggests anomalous transport or non-uniform excitation.

*Work Supported by NSERC, Canada and NSF-DOE, USA.


NP11 28 Differential Impurity Transport in the Presence of an External Potential* ELIJA KOLMES, IAN OCHS, NATHANIEL FISCH, Princeton Univ We discuss a generalization of the classical impurity pinch to include the effects of external potentials. This allows us to describe a smooth transition between the behavior of different particle species in thermodynamic equilibrium and the pinch that we encounter in a magnetically confined system. It also allows us to predict the behavior of a variety of systems that are in steady state but not in thermodynamic equilibrium; external potentials can either increase or mitigate the pinch, depending on the context. These effects could have practical implications for a variety of different plasma devices. We are particularly interested in the effects of rotation and of electrostatic potentials.

*DOE Contract No. DE-AC02-09CH1-1466.

NP11 29 Dynamical transitions associated with turbulence in a helicon plasma ADAM D. LIGHT, LI TIAN, Swarthmore College, Swarthmore, PA 19081, USA SAIKAT CHAKRABORTY THAKUR, Center for Energy Research, University of California San Diego, La Jolla, CA 92093, USA GEORGE R. TYNAN, Department of Mechanical and Aerospace Engineering and Center for Energy Research, University of California San Diego, La Jolla, CA 92093, USA Diagnostic capabilities are often cited as a limiting factor in our understanding of transport in fusion devices. Increasingly advanced multichannel diagnostics are being applied to classify transport regimes and to search for “trigger” features that signal an oncoming dynamical event, such as an ELM or an L-H transition. In this work, we explore a technique that yields information about global properties of plasma dynamics from a single time series of a relevant plasma quantity. Electrostatic probe data from the Controlled Shear Decorrelation eXperiment (CSDX) is analyzed using recurrence quantification analysis (RQA) in the context of previous work on the transition to weak drift-wave turbulence. The recurrence characteristics of a phase space trajectory provide a quantitative means to classify dynamics and identify transitions in a complex system. We present and quantify dynamical variations in the plasma variables as a function of the background magnetic field strength. A dynamical transition corresponding to the emergence of broadband fluctuations is identified using RQA measures.

*This work was performed at UCLA’s Basic Plasma Science Facility, which is supported by the DOE and NSF.

NP11 30 Production of Alfven Daughter Waves Through Nonlinear Interactions of Counterpropagating Alfven Waves* DAVID HAMILTON, SETH DORFMAN, Univ of California - Los Angeles GREGORY HOWES, Univ of Iowa - Iowa City TROY CARTER, Univ of California - Los Angeles The current theoretical understanding of astrophysical turbulence is based largely upon the nonlinear interactions between counterpropagating Alfven waves. These interactions are the fundamental building block used to model energy transfer from large to small scales. We present current experimental findings obtained in a laboratory plasma at the Large Plasma Device (LAPD), in which counterpropagating Alfven waves with crossed polarizations interacted with each other after being generated by antennas at the two ends of the device. This work is largely based off of previous efforts conducted at the LAPD by G. G. Howes, et al., but with differing key parameters, such as the amplitudes and frequencies of the two waves. We expect to find a daughter wave produced by the nonlinear interactions of the two parent waves. Additionally, ongoing analysis may reveal the same phenomenon to occur between the main daughter wave and either of the two parent waves; this effect has not yet been observed in the laboratory. This work may assist in furthering our understanding of the energy cascade effect in astrophysical turbulence.

*This work was supported by the DOE and NSF.

NP11 31 Transport of particles in chaotic, time dependent, magnetic fields* B. DASGUPTA, CSPAR, Univ of California - Los Angeles M. S. JANAKI, S. SAMANTA, P. K. SHAW, SINP, India Magnetic fields in regions of low plasma pressure and large currents, such as in interstellar space and gaseous nebulae, are force-free as the Lorentz force vanishes. The three-dimensional Arnold-Beltrami-Childress (ABC) field is an example of three-dimensional, force-free, helical, chaotic magnetic field [1]. However, the ABC field is chaotic only if all three coefficients describing the field are non-zero. Otherwise, the field lines are regular and well behaved. The ABC fields correspond to Beltrami flows. The characteristic motion of particles in the chaotic ABC field is superdiffusive in space [1]. We consider the dynamics of particles when the ABC field is superimposed onto a larger amplitude uniform magnetic field. We further assume the ABC field to have sinusoidal time dependence, with a prescribed frequency. In this case the particles not only undergo cross-field diffusion but also gain energy.

*Supported by DOE Contract No. DE-AC02-09CH1-1466.

NP11 32 Analysis of dynamical transitions in tokamaks* TROY CARTER, Univ of California - Los Angeles The characteristic motion of particles in the chaotic ABC field is superdiffusive in space [1]. We consider the dynamics of particles when the ABC field is superimposed onto a larger amplitude uniform magnetic field. We further assume the ABC field to have sinusoidal time dependence, with a prescribed frequency. In this case the particles not only undergo cross-field diffusion but also gain energy.

*Supported by DOE Contract No. DE-AC02-09CH1-1466.
We present results on the cross-field diffusion of particles and on their energization and compare to the case when the ABC field is not chaotic.

*Supported in part by DoE Grant DE-FG02-91ER-54109.


NP11 32 Axial plasma detachment in helicon plasmas during a global transition due to spontaneous self organization: instabilities, bifurcation and the helicon core formation SAIKAT CHAKRABORTY THAKUR, RONGJIE HONG, GEORGE TY-NAN, Univ of California - San Diego We observe axial plasma detachment in a helicon plasma device that occurs simultaneously along with a spontaneous, self-organized global transition in the plasma dynamics via a transport bifurcation with strong hysteresis, at a certain $B_{\text{crit}}$ [1]. For $B < B_{\text{crit}}$, the plasma is dominated by density gradient driven resistive drift waves. For $B > B_{\text{crit}}$, the plasma exhibits steepened density and ion temperature gradients, strong shearing in the azimuthal and parallel velocities, and multiple, simultaneously present, radially separated plasma instabilities. The axial detachment also follows the same hysteresis curves associated with the transport bifurcation that led to the transition. The value of $B_{\text{crit}}$ depends on the source parameters (pressure, gas flow rate, rf power etc.). This study allows access to new regimes to study plasma turbulence and transport as well as plasma detachment and helicon core formation. We find that the plasma can exist in more than one type of helicon modes.

1L. Cui et al., PoP 23, 055704 (2016).

NP11 33 Magnetic reconnection as a trigger for sub-proton-scale cascade in magnetized plasma turbulence LUCA FRANCI, University of Florence SILVIO SERGIO CERRI, University of Pisa PRINCETON University FRANCESCO CALIFANO, University of Pisa SIMONE LANDI, EMANUELE PAPINI, ANDREA VERDINI, University of Florence LORENZO MATTEINI, Imperial College London FRANK JENKO, UCLA PETR HELLINGER, Astronomical Institute Prague We provide the first numerical evidences that the development of power-law energy spectra below the so-called ion break can be related to the occurrence of magnetic reconnection, regardless of the actual state of the turbulent cascade at MHD scales. This mechanism is investigated via high-resolution two-dimensional hybrid-kinetic simulations employing complementary approaches (Lagrangian vs Eulerian) and with completely different mechanisms to feed the turbulent dynamics (freely-decaying Alfvénic fluctuations vs continuously-driven compressible fluctuations). In both cases, the reconnection-mediated kinetic spectrum of parallel magnetic fluctuations develops a spectral slope of $-2.8$ whether or not an MHD cascade has already developed, without changes even after a successive formation of a power law at larger scales. Once a quasi-steady turbulent state is reached, the total magnetic spectrum exhibits a slope of $-5/3$ in the MHD range and of $-3$ below the ion scales. Based on this and on the analysis of the turbulent and reconnection characteristic time scales, we therefore suggest a scenario where magnetic reconnection may represent a relevant non-local transfer mechanism simultaneously at play in addition to the classical local turbulent energy transfer.

NP11 34 High Energy Particle Populations and Momentum Transport Associated with Collisionless Reconnection Processes* B. BASU, B. COPPI, MIT In the two-fluid description [1] of reconnection processes a new type of “magneto-thermal” mode producing reconnection is found [2,3] when the longitudinal electron thermal conductivity is relatively large. The mode is associated with the electron temperature gradient and can have a phase velocity in either directions of the electron or the ion diamagnetic velocity. High-energy particle populations are proposed to be produced as a result of reconnection events through mode-particle resonances that transfer the energy of the reconnecting mode to super-thermal particle populations. The spatial near-singularity of the perturbed electron temperature, that can enhance the thermal energy of particles in one region while depleting that of particles in the adjacent region, may be an additional contributing factor in this context. The modes can extract momentum from the plasma body and in an axisymmetric toroidal confinement configuration could sustain a “spontaneous rotation” [4] of the plasma column by carrying away angular momentum of the opposite sign.

*Supported in part by the U.S. DoE.

1B. Coppi, Phys. Fluids 8, 2273 (1965).

NP11 35 HEDP I

NP11 36 Spectroscopic diagnostics of NIF ICF implosions using line ratios of Kr dopant in the ignition capsule* ARATI DASGUPTA, NICHOLAS OUART, JOHN GIULIANI, ROBERT CLARK, Naval Research Laboratory MARYLYN SCHNEIDER, HOWARD SCOTT, HUI CHEN, TAMMY MA, Lawrence Livermore National Laboratory X ray spectroscopy is used on the NIF to diagnose the plasma conditions in the ignition target in indirect drive ICF implosions [1]. A platform is being developed at NIF where small traces of krypton are used as a dopant to the fuel gas for spectroscopic diagnostics using krypton line emissions. The fraction of krypton dopant was varied in the experiments and was selected so as not to perturb the implosion. Our goal is to use X-ray spectroscopy of dopant line ratios produced by the hot core that can provide a precise measurement of electron temperature. Simulations of the krypton spectra using a 1 in $10^8$ atomic fraction of krypton in direct-drive exploding pusher with a range of electron temperatures and densities show discrepancies when different atomic models are used. We use our non-LTE atomic model with a detailed fine-structure level atomic structure and collisional-radiative rates to investigate the krypton spectra at the same conditions. Synthetic spectra are generated with a detailed multi-frequency radiation transport scheme from the emission regions of interest to analyze the experimental data with 0.02% Kr concentration and compare and contrast with the existing simulations at LLNL.

*Work supported by DOE/NNSA; Part of this work was also done under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.


NP11 37 Calibration of a High Resolution X-ray Spectrometer for High-Energy-Density Plasmas on NIF* B. KRAUS, L. GAO, K. W. HILL, M. BITTER, P. EFTHIMION, Princeton Plasma Physics Laboratory M. B. SCHNEIDER, H. CHEN, J. AY-
ERS, P. BEIERSDORFER, D. LIEDAHL, A. G. MACPHEE, D. B. THORN, R. BETTENCOURT, R. KAUFFMAN, H. LE, Lawrence Livermore National Laboratory D. NELSON, Laboratory for Laser Energetics A high-resolution, DIM-based (Diagnostic Instrument Manipulator) x-ray crystal spectrometer has been calibrated for and deployed at the National Ignition Facility (NIF) to diagnose plasma conditions and mix in ignition capsules near stagnation times. Two conical crystals in the Hall geometry focus rays from the Kr He-α, Ly-α, and He-β complexes onto a streak camera for time-resolved spectra, in order to measure electron density and temperature by observing Stark broadening and relative intensities of dielectronic satellites. Signals from these two crystals are correlated with a third crystal that time-integrates the intervening energy range. The spectrometer has been absolutely calibrated using a microfocus x-ray source, an array of CCD and single-photon-counting detectors, and K- and L-absorption edge filters. Measurements of the integrated reflectivity, energy range, and energy resolution for each crystal will be presented. The implications of the calibration on signal levels from NIF implosions and x-ray filter choices will be discussed.

This work was performed under the auspices of the U.S. DoE by Princeton Plasma Physics Laboratory under contract DE-AC02-09CH11466 and by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344.

NP11 38 Calibration of a Multipurpose Bragg-Crystal Spectrometer* NICHOLAS AYBAR, Univ of California - San Diego ED MARLEY, JIM EMIG, MARILYN SCHNEIDER, Lawrence Livermore National Laboratory X-ray spectroscopy is an important diagnostic tool in understanding key parameters in high energy density science. The radiative properties of material in ICF implosions carries important information about the temperature and density of the generated plasma. To obtain absolute measurements of x-ray flux, a measurement of the energy-dependent response of the diagnostic is necessary. The calibration of a multipurpose Bragg-crystal spectrometer (MSPEC) is presented. This spectrometer was designed at Lawrence Livermore National Lab and utilizes a variety of geometrical configurations to record x-ray spectra in the 1.0 - 9.0 keV range. A laboratory x-ray source is measured at two symmetric locations: the MSPEC and a Si detector. The resolved spectrum from the MSPEC is recorded onto a CCD and compared to the signal recorded with the Si detector to give the energy dependent response of the MSPEC. The response of different crystals (PET, KAP, CsAP) and different elliptical geometries is measured and discussed.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

NP11 39 Absolute calibration of a compact gamma-ray spectrometer for high intensity laser plasma experiments S. SINGH, ELI Beamlines, Prague, Czech Republic A. GARCIA, A. FERRARI, M. MOLODTSOVA, R. SCHWENNGER, Institute for Radiation Physics, HZDR, Germany L. MOREJON, R. VERSACI, D. KUMAR, ELI Beamlines, Prague, Czech Republic T. COWAN, Institute for Radiation Physics, HZDR, Germany Copyious amounts of gamma rays are generated in high intensity laser matter experiments, either by bremsstrahlung or by inverse Compton scattering. Measurements of multi-MeV gamma rays in such experiments provide direct indication of hot electrons generated during the interaction. A spectrometer based on forward Compton scattering was recently tested by Espy et al. [1]. We report on an improved design of a similar spectrometer which is significantly more compact (70 cm x 25 cm x 25 cm) and thus extremely convenient to use in laser plasma experiments. In this presentation, we describe the design considerations and recent results of an absolute calibration of the gamma-ray spectrometer. The calibration was performed using a bremsstrahlung source at different electron energies, i.e. 11, 13, 15 and 18 MeV [2]. Experimental spectra show a systematic increase of the maximum cut-off energy, temperature and flux. The results indicate that the spectrometer is effective for an energy range of 4–20 MeV with 5-10% energy resolution.

1M. A. Espy, A. Gehring, A. Belian et al., Proc. SPIE 9783, 97834V.

NP11 40 Proton deflectometry of laser-driven relativistic electron jet from thin foil target* CHENGKUN HUANG, S. PALANIYAPPAN, D. C. GAUTIER, R. P. JOHNSON, T. SHIMADA, J. C. FERNANDEZ, Los Alamos Natl Lab F. S. TSUNG, W. B. MORI, UCLA Near critical density relativistic electron jets from laser solid interaction carry currents approaching the Alfvén-limit and tens of kilo-Tesla magnetic fields. Such jets are often found in kinetic simulations with low areal density targets, but have not been confirmed experimentally. They may be used for X/gamma-ray generation and is also important for the understanding of post-transparency plasma dynamics. With a short-pulse probe beam at the Trident laser facility, we employed proton deflectometry to infer the jet’s properties, structure and the long-time dynamics. We develop corresponding GEANT4 simulation model of the proton deflectometry, with input from the kinetic PIC simulations in 2D and quasi-3D geometry, to compare with the experimental radiography images. Detail comparison of the experimental and simulation features in the deflectometry will be discussed.

*Work supported by the LDRD program at LANL.

NP11 41 Measuring the temperature history of isochorically heated warm dense metals* CHRIS MCGUFFEY, University of California San Diego J KIM, UCSD J PARK, J MOODY, J EMIG, B HEETER, LLNL M DOZIERES, FN BEG, UCSD HS MCLEAN, LLNL A pump-probe platform has been designed for soft X-ray absorption spectroscopy near edge structure measurements in isochorically heated Al or Cu samples with temperature of 10s to 100s of eV. The method is compatible with dual picosecond-class laser systems and may be used to measure the temperature of the sample heated directly by the pump laser or by a laser-driven proton beam Knowledge of the temperature history of warm dense samples will aid equation of state measurements. First, various low- to mid-Z targets were evaluated for their suitability as continuum X-ray backlighters over the range 200-1800 eV using a 10 J picosecond-class laser with relativistic peak intensity Alloys were found to be more suitable than single-element backlighters. Second, the heated sample package was designed with consideration of target thickness and tamp layers using atomic physics codes. The results of the first demonstration attempts will be presented.

*This work was supported by the U.S. DOE under Contract No. DE-SC0014600.

NP11 42 High-resolution imaging of a shock front in plastic by phase contrast imaging at LCLS* M. BECKWIT, S. JIANG, Y. ZHAO, Lawrence Livermore National Lab A. SCHROPP, Deutsches Elektronen-Synchrotron DESY A. FERNANDEZ-PANELLA, H. G. RINDERKNECHT, S. WILKS,
K. FOURNIER, Lawrence Livermore National Lab E. GALTIER, Z. XING, E. GRANADOS, E. GAMBOA, S. H. GLENZER, P. HEIMANN, SLAC National Accelerator Laboratory U. ZASTRAU, European XFEL B. I. CHO, Gwangju Institute of Science and Technology J. H. EGGERT, G. W. COLLINS, Y. PING, Lawrence Livermore National Lab Understanding the propagation of shock waves is important for many areas of high energy density physics, including inertial confinement fusion (ICF) and shock compression science. In order to probe the shock front structures in detail, a diagnostic capable of detecting both the small spatial and temporal changes in the material is required. Here we show the experiment using hard X-ray phase contrast imaging (PCI) [1] to probe the shock wave propagation in polycrystalline with submicron spatial resolution. The experiment was performed at the Matter in Extreme Conditions (MEC) endstation of the Linac Coherent Lightsource (LCLS). PCI together with the femtosecond time scales of x-ray free electron lasers enables the imaging of optically opaque materials that undergo rapid temporal and spatial changes. The result reveals the evolution of the density profile with time.

"Work performed under DOE Contract No. DE-AC52-07NA27344 with support from OFES Early Career and LLNL LDRD program.


NP11 43 Additions and improvements to the high energy density physics capabilities in the FLASH code* D. LAMB, A. BOGATE, S. FEISTER, N. FLOCKE, C. GRAZIANI, B. KHIAR, J. LAUNE, P. TZEFERACOS, C. WALKER, K. WEIDE, Flash Center for Computational Physics, University of Chicago FLASH is an open-source, finite-volume Eulerian, spatially-adaptive radiation magnetohydrodynamics code that has the capabilities to treat a broad range of physical processes. FLASH performs well on a wide range of computer architectures, and has a broad user base. Extensive high energy density physics (HEDP) capabilities exist in FLASH, which make it a powerful open toolset for the academic HEDP community. We summarize these capabilities, emphasizing recent additions and improvements. We describe several non-ideal MHD capabilities that are being added to FLASH, including the Hall and Narment effects, implicit resistivity, and a circuit model, which will allow modeling of Z-pinch experiments. We showcase the ability of FLASH to simulate Thomson scattering polariometry, which measures Faraday due to the presence of magnetic fields, as well as proton radiography, proton self-emission, and Thomson scattering diagnostics. Finally, we describe several collaborations with the academic HEDP community in which FLASH simulations were used to design and interpret HEDP experiments.

*This work was supported in part at U. Chicago by DOE NNSA ASC through the Argonne Institute for Computing in Science under FWP 57789; DOE NNSA under NLCU Grant DE-NA0002724; DOE SC OFES Grant DE-SC0016566; and NSF Grant PHY-1619573.

NP11 44 Modeling experimental plasma diagnostics in the FLASH code: proton radiography* NORBERT FLOCKE, KLAUS WEIDE, SCOTT FEISTER, PETROS TZEFERACOS, DONALD LAMB, Univ of Chicago Proton radiography is an important diagnostic tool for laser plasma experiments and for studying magnetized plasmas. We describe a new synthetic proton radiography diagnostic recently implemented into the FLASH code. FLASH is an open-source, finite-volume Eulerian, spatially-adaptive radiation magnetohydrodynamics and magneto-hydrodynamics code that incorporates capabilities for a broad range of physical processes. Proton radiography is modeled through the use of the (relativistic) Lorentz force equation governing the motion of protons through 3D domains. Both instantaneous (one time step) and time-resolved (over many time steps) proton radiography can be simulated. The code module is also equipped with several different setup options (beam structure and detector screen placements) to reproduce a variety of experimental proton radiography designs. FLASH’s proton radiography diagnostic unit can be used either during runtime or in post-processing of simulation results. FLASH is publicly available at flash.uchicago.edu.

*U.S. DOE NNSA, U.S. DOE NNSS ASC, U.S. DOE Office of Science and NSF.

NP11 45 Modeling experimental plasma diagnostics in the FLASH code: Thomson scattering* KLAUS WEIDE, NORBERT FLOCKE, SCOTT FEISTER, PETROS TZEFERACOS, DONALD LAMB, Univ of Chicago Spectral analysis of the Thomson scattering of laser light sent into a plasma provides an experimental method to quantify plasma properties in laser-driven plasma experiments. We have implemented such a synthetic Thomson scattering diagnostic unit in the FLASH code, to emulate the probe-laser propagation, scattering and spectral detection. User-defined laser rays propagate into the FLASH simulation region and experience scattering (change in direction and frequency) based on plasma parameters. After scattering, the rays propagate out of the interaction region and are spectrally characterized. The diagnostic unit can be used either during a physics simulation or in post-processing of simulation results. FLASH is publicly available at flash.uchicago.edu.

*U.S. DOE NNSA, U.S. DOE NNSS ASC, U.S. DOE Office of Science and NSF.

NP11 46 Recent Developments in the VISRAD 3-D Target Design and Radiation Simulation Code JOSEPH MACFARLANE, IGOR GOLOVKIN, JAMES SEBALD, Prism Computational Sciences The 3-D view factor code VISRAD is widely used in designing HEDP experiments at major laser and pulsed-power facilities, including NIF, OMEGA, OMEGA-EP, ORION, Z, and LMJ. It simulates target designs by generating a 3-D grid of surface elements, utilizing a variety of 3-D primitives and surface removal algorithms, and can be used to compute the radiation flux throughout the surface element grid by computing element-to-element view factors and solving power balance equations. Target set-up and beam pointing are facilitated by allowing users to specify positions and angular orientations using a variety of coordinates systems, and can be used to generate image sequences for animations. We will discuss recent improvements to conveniently assess beam capture on target and beam clearance of diagnostic components, as well as plans for future developments.

NP11 47 New Set of Prism Atomic Data, EOS and Opacity tables IGOR GOLOVKIN, JOSEPH MACFARLANE, Prism Computational Sciences, Inc. We present a new set of atomic data tables generated with the updated data from the latest release of NIST atomic database. The new set also includes corrections for known inconsistencies in atomic structure calculations. Prism’s ATBASE suite
of atomic physics codes was used to generate high-quality atomic data for simulating the spectral properties and ionization dynamics of plasmas over a wide range of conditions. Atomic energy levels and oscillator strengths are computed using Hartree-Fock and configuration interaction models. Photoionization cross-sections from Hartree-Fock calculations are utilized for both valence-shell and inner-shell transitions. Radiative recombination rate coefficients are calculated from the photoionization cross-sections. Distorted-wave calculations are performed to generate electron collisional excitation and ionization cross-sections and rate coefficients. Autoionization rates include configuration interaction models. For dielectronic recombination related to K-shell spectra (Li-like ions and higher), electron capture rates are computed using autoionization rates and the detailed balance relationship. For lower ionization stages, total dielectronic recombination rate coefficients are based on semi-empirical models. A new set of EOS and opacity tables is generated with PROPACEOS code based on the new atomic data. We will discuss details of the calculations and demonstrate application of the new data to the analysis of several sets of experimental data.

NP11 48 SpectraPLOT, Visualization Package with a User-Friendly Graphical Interface JAMES SEBALD, JOSEPH MACFARLANE, IGOR GOLOVKIN, Prism Computational Sciences SpectraPLOT is a collisional-radiative spectral analysis package designed to compute detailed emission, absorption, or x-ray scattering spectra, filtered images, XRD signals, and other synthetic diagnostics. The spectra and images are computed for virtual detectors by post-processing the results of hydrodynamics simulations in 1D, 2D, and 3D geometries. SpectraPLOT can account for a variety of instrumental response effects so that direct comparisons between simulations and experimental measurements can be made. SpectraPLOT is a user-friendly graphical interface for viewing a wide variety of results from SPECT3D simulations, and applying various instrumental effects to the simulated images and spectra. We will present SpectraPLOT’s ability to display a variety of data, including spectra, images, light curves, streaked spectra, space-resolved spectra, and drilldown plasma property plots, for an argon-doped capsule implosion experiment example. Future SpectraPLOT features and enhancements will also be discussed.

NP11 52 Higher-Order Advection-Based Remap of Magnetic Fields in an Arbitrary Lagrangian-Eulerian Code* BRIAN CORNILLE, University of Wisconsin-Madison DAN WHITE, Lawrence Livermore National Laboratory We will present methods formulated for the Eulerian advection stage of an arbitrary Lagrangian-Eulerian code for the new addition of magneto-hydrodynamic (MHD) effects. The various physical fields are advanced in time using a Lagrangian formulation of the system. When this Lagrangian motion produces substantial distortion of the mesh, it can be difficult or impossible to progress the simulation forward. This is overcome by relaxation of the mesh while the physical fields are frozen. The code has already successfully been extended to include evolution of magnetic field diffusion during the Lagrangian motion.
stage. This magnetic field is discretized using an H(div) compatible finite element basis. The advantage of this basis is that the divergence-free constraint of magnetic fields is maintained exactly during the Lagrangian motion evolution. Our goal is to preserve this property during Eulerian advection as well. We will demonstrate this property and the importance of MHD effects in several numerical experiments. In pulsed-power experiments magnetic fields may be imposed or spontaneously generated. When these magnetic fields are present, the evolution of the experiment may differ from a comparable configuration without magnetic fields.

*Work supported by the LANL ASC and Science programs.

NP11 53 Multi-species ion transport in ICF relevant conditions* ERIK VOLD, GRIGORY KAGAN, ANDREI SIMAKOV, KIM MOLVIG, LIN YIN, BRIAN ALBRIGHT, Los Alamos National Laboratory Classical transport theory based on Chapman-Enskog methods provides self consistent approximations for kinetic fluxes of mass, heat and momentum for each ion species in a multi-ion plasma characterized with a small Knudsen number. A numerical method for solving the classic forms of multi-ion transport, self-consistently including heat and species mass fluxes relative to the center of mass, is given in [Kagan-Baalrud, arXiv ’16] and similar transport coefficients result from recent derivations [Simakov-Molvig, PoP, ’16]. We have implemented a combination of these methods in a standalone test code and in xRage, an adaptive-mesh radiation hydrodynamics code, at LANL. Transport mixing is examined between a DT fuel and a CH capsule shell in ICF conditions. The four ion species develop individual self-similar density profiles under the assumption of P-T equilibrium in 1D and show interesting early time transient pressure and center of mass velocity behavior when P-T equilibrium is not enforced. Some 2D results are explored to better understand the transport mix in combination with convective flow driven by macroscopic fluid instabilities at the fuel-capsule interface. Early transient and some 2D behaviors from the fluid transport are compared to kinetic code results.

*Work performed under the auspices of the U.S. DOE by the Los Alamos National Security, LLC Los Alamos National Laboratory and supported by the ASC and Science programs.

NP11 54 Plasma kinetic effects on atomistic mix in one dimension and at structured interfaces (I)* L. YIN, B. J. ALBRIGHT, E. L. VOLD, W. TAITANO, L. CHACON, A. SIMAKOV, Los Alamos National Laboratory Kinetic effects on interfacial mix are examined using VPIC simulations. In 1D, comparisons are made to the results of analytic theory in the small Knudsen number limit. While the bulk mixing properties of interfaces are in general agreement, differences arise near the low-concentration fronts during the early evolution of a sharp interface when the species’ perpendicular scattering rate dominates over the slowing down rate. In kinetic simulations, the diffusion velocities can be larger or comparable to the ion thermal speeds, and the Knudsen number can be large. In pulsed-power experiments magnetic fields may be imposed or spontaneously generated. When these magnetic fields are present, the evolution of the experiment may differ from a comparable configuration without magnetic fields.

NP11 55 Plasma kinetic effects on atomistic mix in one dimension and at structured interfaces (II)* BRIAN ALBRIGHT, LIN YIN, JAMES COOLEY, JEFFREY HAACK, MELISSA DOUGLAS, Los Alamos Natl Lab The Marble campaign seeks to develop a platform for studying mix evolution in turbulent, inhomogeneous, high-energy-density plasmas at the NIF. Marble capsules contain engineered CD foams, the pores of which are filled with hydrogen and tritium. During implosion, hydrodynamic stirring and plasma diffusivity mix tritium fuel into the surrounding CD plasma, leading to both DD and DT fusion neutron production. In this presentation, building upon prior work [1], kinetic particle-in-cell simulations using the VPIC code are used to examine kinetic effects on thermonuclear burn in Marble-like settings. Departures from Maxwellian distributions are observed near the interface and TN burn rates and inferred temperatures from synthetic neutron time of flight diagnostics are compared with those from treating the background species as Maxwellian.

*Work performed under the auspices of the U.S. DOE by the Los Alamos National Security, LLC Los Alamos National Laboratory and supported by the ASC and Science programs.

NP11 56 Plasma Ion Stratification by Weak Planar Shocks* A. N. SIMAKOV, B. D. KEENAN, W. T. TAITANO, L. CHACON, Los Alamos National Laboratory We derive fluid equations for describing steady-state planar shocks of a moderate strength (0<\textit{M}<1 with \textit{M} the shock Mach number) propagating through an unmagnetized quasineutral collisional plasma comprising two separate ion species. In addition to the standard fluid quantities, such as the total mass density, mass-flow velocity, and electron and average ion temperatures, the equations describe shock stratification in terms of variations in the relative concentrations and temperatures of the two ion species along the shock propagation direction. We have solved these equations analytically for weak shocks (0<\textit{M}<1), with the results depending on \textit{M}, ratios of the ion masses and charges, and the upstream mass fraction of one of the ion species. These analytical results are instrumental for gaining understanding in the behavior of weak shocks, and they have been used to verify kinetic simulations of shocks in multi-ion plasmas.

*Work supported by the US Department of Energy.

NP11 57 Resolving Controversies Concerning the Kinetic Structure of Multi-Ion Plasma Shocks* BRETT KEENAN, ANDREI SIMAKOV, LUIS CHACON, WILLIAM TAITANO, Los Alamos National Laboratory Strong collisional shocks in multi-ion plasmas are featured in several high-energy-density environments, including Inertial Confinement Fusion (ICF) implosions. Yet, basic structural features of these shocks remain poorly understood (e.g., the shock width’s dependence on the Mach number and the plasma ion composition, and temperature decoupling between ion species), causing controversies in the literature; even for stationary shocks in planar geometry [cf., Ref. [1] and Ref. [2]]. Using a LANL-developed, high-fidelity, 1D-2V Vlasov-Fokker-Planck code (iFP) [3], as well as direct comparisons to multi-ion hydrodynamic simulations and semi-analytic predictions, we critically examine steady-state, planar shocks in two-ion species plasmas and put forward resolutions to these controversies.
of state that includes cold, thermal ion/lattice, and thermal electron
similar solutions of the Noh problem in cylindrical and spherical
an arbitrary equation of state, we demonstrate the existence of self-
the converging gas. After that, a constant-velocity accretion shock
condition similar to the classic solution but with a finite pressure of
such a flow produces a uniform gas whose velocity at each point is
rounding the center or axis of symmetry. At the moment of collapse
of a finite-amplitude sound wave into a uniform resting gas sur-
vised in low density gas under a quasi-planar geometry and diagnosed
by broadband proton radiography. The broad proton spectrum al-
ows energy-dependent measurements of deflection from which one
can quantitatively constrain the electrical potential and field thick-
ness. Three UV beams delivering up to 6.4 kJ energy in 2ns were
used for shock generation and a short laser pulse of energy up to
850 J, 10 ps duration, was used to accelerate the broadband pro-
ton beam for point-projection radiography. Observations show the
existence of electric fields with potential
∼
300 V at the front of a
Mach 9 shock in helium gas. A Mach 16 shock is also studied, from
which both the field thickness and electric potential are reproduced.
Simultaneously spatially resolved soft-x-ray spectroscopy provided
additional measurements of shock velocity, particle velocity and
thermal emission.

This work was performed under DOE contract DE-AC52-07NA27
344 with support from OFES Early Career program and LLNL
LDRD program. This work has been partially supported by the
University of California Office of the President Lab Fee Grant
Number LFR-17-449059.

New generalized Noh solutions for HEDP hydrocode
verification
* A. L. VELIKOVICH, J. L. GIULIANI, Plasma
Physics Division, Naval Research Laboratory S. T. ZALESAK,
V. TANGRI, Berkeley Research Associates The classic Noh solu-
tion describing stagnation of a cold ideal gas in a strong accretion
shock wave has been the workhorse of compressible hydrocode
verification for over three decades. We describe a number of its gen-
eralizations available for HEDP code verification. First, for an ideal
gas, we have obtained self-similar solutions that describe adiabatic
convergence either of a finite-pressure gas into an empty cavity or
of a finite-amplitude sound wave into a uniform resting gas sur-
rounding the center or axis of symmetry. At the moment of collapse
such a flow produces a uniform gas whose velocity at each point is
constant and directed towards the axis or the center, i.e. the initial
condition similar to the classic solution but with a finite pressure of
the converging gas. After that, a constant-velocity accretion shock
propagates into the incident gas whose pressure and velocity pro-
files are not flat, in contrast with the classic solution. Second, for
an arbitrary equation of state, we demonstrate the existence of self-
similar solutions of the Noh problem in cylindrical and spherical
geometry. Examples of such solutions with a three-term equation of
state that includes cold, thermal ion/lattice, and thermal electron
contributions are presented for aluminum and copper. These ana-
lytic solutions are compared to our numerical simulation results as
an example of their use for code verification.

NP11 60 Analytic Analysis of Convergent Shocks to Multi-
Gigabar Conditions*
J. J. RUBY, J. R. RYGG, G. W. COLLINS, Labora-
yory for Laser Energetics, U. of Rochester B. BACHMANN,
D. DOEPPNER, Y. PING, J. GAFNEY, A. LAZICKI, A. L.
KRITCHER, D. SWIFT, J. NILSEN, O. L. LANDEN, R. HATARIK,
M. MASTERS, S. NAGEL, P. STERNE, T. PARDINI, S. KHAN,
P. M. CELLIERS, P. PATEL, LLNL. GERICKE, University of War-
wick R. F. RALFONE, University of California, Berkeley The gigabar
experimental platform at the National Ignition Facility is designed
to increase understanding of the physical states and processes that
dominate in the hydrogen at pressures from several hundreds of
Mbar to tens of Gbar. Recent experiments using a solid Cd2 ball
reached temperatures and densities of order 10^7 K and several tens
of g/cm^2, respectively. These conditions lead to the production of
D-D fusion neutrons and x-ray bremsstrahlung photons, which al-
low us to place constraints on the thermodynamic states at peak
compression. We use an analytic model to connect the neutron and
x-ray emission with the state variables at peak compression. This
analytic model is based on the self-similar Guderley solution of
an imploding shock wave and the self-similar solution of the point
explosion with heat conduction from Reinicke. Work is also being
done to create a fully self-similar solution of an imploding shock
wave coupled with heat conduction and radiation transport using a
general equation of state.

This material is based upon work supported by the Department of
Energy National Nuclear Security Administration under Award
Number DE-NA0001944.

NP11 61 A Platform for X-Ray Thomson Scattering
Measurements of Radiation Hydrodynamics Experiments on the NIF
HEATH LEFEVRE, KEVIN MA, PATRICK BELANCOURT, Univ
of Michigan - Ann ArborMICHAEL MACDONALD, University of
California - BerkeleyTILO DOEPPNER, Lawrence Livermore Na-
tional Laboratory PAUL KEITER, CAROLYN KURANZ, Univ
of Michigan - Ann Arbor A recent experiment on the National Ignition
Facility (NIF) radiographed the evolution of the Rayleigh-Taylor (RT)
instability under high and low drive cases. This experiment
showed that under a high drive the growth rate of the RT instability
is reduced relative to the low drive case. The high drive launches
a radiative shock, increases the temperature of the post-shock re-
region, and ablates the spikes, which reduces the RT growth rate.
The plasma parameters must be measured to validate this claim.
We present a target design for making X-Ray Thomson Scattering
(XRTS) measurements on radiation hydrodynamics experiments on
NIF to measure the electron temperature of the shocked region in the
above cases. Specifically, we show that a previous fielded NIF ra-
diation hydrodynamics platform can be modified to allow sufficient
signal and temperature resolution for XRTS measurements.

This work is funded by the NNSA-DS and SC-OFES Joint Pro-
gram in High-Energy-Density Laboratory Plasmas, Grant Number
DE-NA0002956 and the National Science Foundation through the
Basic Plasma Science and Engineering program.

NP11 62 Modeling and design of radiative hydrodynamic ex-
periments with X-ray Thomson Scattering measurements on
NEDESDAY MORNING, NP11

NP11 66 Detachment experiments in new DIII-D upper divertor∗ A.L. MOSER, A.W. LEONARD, R.J. GROEBNER, H. GUO, G4 H. WANG, ORAU J.G. WATKINS, SNL A.G. MCLEAN, M.E. FENSTERMACHER, LLNL M.W. SHAFER, A.R. BRIESE-MEISTER, ORNL E.T. HINSON, UWM Installation of the Small Angle Slot (SAS) in the upper divertor of DIII-D enables new studies of the effect of target and baffle geometry on divertor detachment. This structure provides a more-closed upper divertor as well as the SAS divertor itself. Initial SAS experiment results indicate that divertor detachment occurs at a lower line-averaged density than in the more-open, lower single null divertor configurations on DIII-D. In contrast, the increased divertor closure of the new installation did not reduce the upstream density required for detachment beyond that achieved with the previous upper divertor structure. Particle pumping in the upper divertor structure is found to produce a ≈10% reduction in the pedestal density required for detachment compared to the case with no pumping. Comparisons focus on both the onset of detachment (measured by in-target Langmuir probes) as a function of upstream density, as well as the effect of the new divertor configurations on pedestal density profiles.

∗Work supported by US DOE under DE-FC02-04ER54698, DE-AC05-00OR22725, DE-AC04-94AL85000, DE-AC52-07NA27344, and DE-SC00013911.

NP11 67 Simulation of DIII-D experiments on detachment and divertor closure∗ ERIC MEIER, William and Mary AUNA MOSER, TONY LEONARD, General Atomics While divertor detachment is necessary to control the heat flux to divertor targets in ITER and future tokamak fusion devices, detachment is often associated with high pedestal density, which can be problematic for core plasma performance. Divertor closure experiments on DIII-D have shown that the pedestal electron density at detachment is reduced by ~35% for a configuration with a high degree of outer divertor closure, compared to an open outer divertor configuration. In this work, SOLPS-ITER modeling, with full drift physics engaged, is used to evaluate the experimental open and closed configurations. Realistic power and particle fluxes are assumed at the core boundary. Predicted 2D ionization profiles will be presented, and sensitivity of detachment behavior to particle and thermal diffusivities, cryopump efficiency, and wall pumping assumptions will be addressed. Initial simulations show a 20% decrease in pedestal density at detachment for the closed configuration, and a similar reduction in the pedestal ionization source.

∗Supported by the U.S. DOE, through NNSA Grants DE-NA0002956 (SSAA) and DE-NA0002719 (NLUF), by the LLE under DE-NA0001944, and by the LLNL under subcontract B614207, and was performed under the auspices of the U.S. DOE by LLNL under Contract No. DE-AC52-07NA27344.
NP11 68 Effects of Magnetic Coil Misalignments on the SAS Divertor* G.L. TREVISAN, B.C. LYONS, Oak Ridge Associated Universities L.L. LAO, T.E. EVANS, H.Y. GUO, Y. LIU, W. WU, General Atomic D.M. ORLOV, University of California-San Diego A. WINGEN, Oak Ridge National Laboratory A new Small Angle Slot (SAS) divertor has recently been installed and tested in DIII-D, promising easier plasma detachment and lower target temperatures. Previous SAS analyses focused on the accuracy of the 2D reconstructed strike geometry and 3D “vacuum” analyses of RMs on the lobes and on the strike point modulation. The present work introduces a kinetic EFIT 2D equilibrium reconstructed from a recent 2017 SAS experiment. The kinetic EFIT and its “vacuum” topology due to 3D error and perturbation fields are compared to the previous analyses based on a synthetic equilibrium, showing similar results. The magnetic lobes remain confined within the SAS and the toroidal modulation of the strike point position is only slightly affected. Further simulations of a possible shift of the toroidal field coil are carried out through 3D field-line tracing. The effects of such misalignments including plasma response on the SAS are discussed, together with the corresponding implications for the design of the next envisaged SAS upgrade.

*Work supported by US DOE under DE-FC02-04ER54698 and DE-FG02-95ER54309.

NP11 69 Numerical exploration of non-axisymmetric divertor closure in the small angle slot (SAS) divertor at DIII-D∗ HEINKE FRERICHS, OLIVER SCHMITZ, Univ. of Wisconsin, Madison BRENT COVELE, HOUYANG GUO, DAVID HILL, General Atomic YUHE FENG, Max-Planck-Institut fuer Plasmafysik In the Small Angle Slot (SAS) divertor in DIII-D, the combination of misaligned slot structure and non-axisymmetric perturbations to the magnetic field causes the strike point to vary radially along the divertor slot and even leave it at some toroidal locations. This effect essentially introduces an opening in the divertor slot from where recycling neutrals can easily escape, and thereby degrade performance of the slot divertor. This effect has been approximated by a finite gap in the divertor baffle. Simulations with EMC3-EIRENE show that a toroidally localized loss of divertor closure can result in non-axisymmetric divertor densities and temperatures. This introduces a density window of 10-15% on top of the nominal threshold separatrix density during which a non-axisymmetric onset of local detachment occurs, initially leaving the gap and up to 60 deg beyond that still attached. Conversely, the impact of such toroidally localized divertor perturbations on the toroidal symmetry of midplane separatrix conditions is small.

*This work has been funded by the U.S. Department of Energy under Early Career Award Grant DE-SC0013911, and Grant DE-FC02-04ER54698.

NP11 70 Maximizing Heat Dissipation via Target Optimization of the Small-Angle Slot Divertor* BRENT COVELE, FEDERICO HALPERN, General Atomic LIVIA CASALI, Oak Ridge Associated Universities JOHN CANIK, Oak Ridge National Laboratory DAN THOMAS, HOUYANG GUO, General Atomic The planned SAS 2 divertor uses a combination of grazing target angles and closure to direct recycling neutrals near the strike point, thus facilitating detachment onset. SAS 2 should also provide adequate pumping efficiency to be consistent with high-power steady-state scenarios on DIII-D. Initial SOLPS results indicate significantly higher neutral densities and lower electron temperatures in the SAS 2 slot, compared to a closed reference divertor model with baseline plasma profiles appropriate for high power. A systematic optimization of the parameterized SAS 2 target shape is performed in SOLPS to further reduce target heat fluxes and temperatures at lowest upstream density. To speed up the target optimization process, target neutral densities calculated by Eirene act as a performance metric by proxy for detachment facilitation. The efficacy of this proxy metric is discussed. Results are also presented from SAS 2 neutral pumping simulations in Eirene with a stationary background plasma. The feasibility of mutually satisfactory particle control and detachment control is discussed.

*Work supported under USDOE Cooperative Agreements DE-FC02-04ER54698 and DE-AC05-00OR22725.

NP11 71 Impact of Cross-field Drifts on Detachment in DIII-D* A.E. JAERVINEN, S.L. ALLEN, A.G. MCLEAN, T.D. Rognlien, C.M. Samuell, G.D. PORTER, L.M. Groth, Aalto D.N. Hill, A.W. Leonard, GA Simulations of DIII-D plasmas have revealed the strong role of E×B-drifts in the low field side (LFS) detachment structure. High confinement modes (H-mode) with the VB-drift towards the X-point (fwd B_v) enter detachment at 20% higher upstream density n_e,sep than plasmas with the VB-drift away from the X-point (rev B_v). In contrast, low confinement modes (L-mode) enter detachment at 10% lower n_e,sep in fwd B_v. Despite this, both L- and H-modes detached plasmas show strong target flux J_zAT, reduction with increasing n_e,sep in fwd B_v, while only a modest reduction occurs in rev B_v. In fwd B_v H-mode, a step-wise transition from attached to strongly detached conditions is observed with increasing n_e,sep. UEDGE simulations indicate that the strong poloidal E×B-drift in the private flux region in H-mode drives the difference for the detachment onset relative to L-mode. In fwd B_v, the dependence of this poloidal E×B-drift on the divertor conditions can reinforce the plasma into either attached or strongly detached state. In rev B_v, radial E×B-drift depletes strike-line n_e, limiting the degree of detachment.

*Work supported by the US DOE under DE-FC02-04ER54698, DE-AC52-07NA27344, and LNL, LDRD project 17-ERD-020.

NP11 72 Parallel Energy Transport in Detached DIII-D Divertor Plasmas† A.W. LEONARD, General Atomic J.D. Lore, J.M. Canik, ORNL A.G. McLean, M.A. Makowski, LNL A comparison of experiment and modeling of detached divertor plasmas is examined in the context of parallel energy transport. Experimental estimates of power carried by electron thermal conduction versus plasma convection are experimentally inferred from power balance measurements of radiated power and target plate heat flux combined with Thomson scattering measurements of T_e profile along the divertor leg. Experimental profiles of T_e exhibit relatively low gradients with T_e < 15 eV from the X-point to the target implying transport dominated by convection. In contrast, fluid modeling with SOLPS produces sharp T_e gradients for T_e > 3 eV, characteristic of transport dominated by electron conduction through the bulk of the divertor. This discrepancy with experimental transport dominated by convection and modeling by conduction has significant implications for the radiative capacity of divertor plasmas and may explain at least part of the difficulty for fluid modeling to obtain the experimentally observed radiative losses. Comparisons are also made for
helium plasmas where the match between experiment and modeling is much better.

*Work supported by the US DOE under DE-FC02-04ER54698.

NP11 73 2-D Laser-Calibrated Doppler Images of Helium and CII Emission on DIII-D* S.L. ALLEN, CAMERON SAMUELL, W.H. MEYER, Lawrence Livermore National Lab Recent improvements to the DIII-D CIS system have reduced the error bars of the inferred Doppler velocity by over an order of magnitude, i.e. to \( \sim 0.1 \) km/s. Coherence imaging of plasma emission superimposes an interferogram on the plasma image, and the interferometer phase is a sensitive measure of the central wavelength of the emission. A tunable diode laser calibration image at \( \sim 465 \) nm is automatically acquired between plasma shots and provides the rest wavelength in the lab frame; the wavelength is measured with a wavemeter to 0.01 pm. The interferometer is stabilized mechanically and thermally with a unique system so that the interferometer drift between calibrations is small. These improvements have enabled tomographically inverted images of main ion He II parallel flow in the divertor during He plasma operation. The parallel flow, as expected, is observed to depend on the direction of the \( B \times VB \) drift, which is reversed by changing the direction of the toroidal field. For many conditions, the C III Doppler velocity is also in the same direction as the main ion.

*Work supported by the US DOE under DE-FC02-04ER54698 and DE-AC52-07NA27344. LLNL-ABS-88688.

NP11 74 Divertor extreme ultraviolet (EUV) survey spectroscopy in DIII-D* ADAM MCLEAN, STEVE ALLEN, RON ELLIS, AARO JARVINEN, VLAD SOUKHANOVS KII, Lawrence Livermore Natl Lab REJEAN BOVIN, EDUARDO GONZALES, IAN HOLMES, JAMES KULCHAR, ANTHONY LEONARD, BOB WILLIAMS, DOUG TAUSSIG, DAN THOMAS, General Atomics GRANT MARCY, University of California, San Diego An extreme ultraviolet spectrograph measuring resonant emissions of D and C in the lower divertor has been added to DIII-D to help resolve an \( \sim 2 \times \) discrepancy between bolometrically measured radiated power and that predicted by boundary codes for DIII-D, JET and ASDEX-U. With 290 and 450 gr/mm gratings, the DivSPRED spectrometer, an 0.3 m flat-field McPherson model 251, measures ground state transitions for D (the Lyman series) and C (e.g., C IV, 155 nm) which account for \( \sim 75\% \) of radiated power in the divertor. Combined with Thomson scattering and imaging in the DIII-D divertor, measurements of position, temperature and fractional power emission from plasma components are made and compared to UEDGE/SOLPS-ITER. Mechanical, optical, electrical, vacuum, and shielding aspects of DivSPRED are presented.

*Work supported under USDOE Cooperative Agreement DE-FC02-04ER54698 and DE-AC52-07NA27344, and by the LLNL Laboratory Directed R&D Program, project #17-ERD-020.

NP11 75 Development of an EMC3-EIRENE Synthetic Imaging Diagnostic* WILLIAM MEYER, STEVE ALLEN, CAMERON SAMUELL, Lawrence Livermore Natl Lab JEREMY LORE, Oak Ridge Natl Lab 2D and 3D flow measurements are critical for validating numerical codes such as EMC3-EIRENE. Toroidal symmetry assumptions preclude tomographic reconstruction of 3D flows from single camera views. In addition, the resolution of the grids utilized in numerical code models can easily surpass the resolution of physical camera diagnostic geometries. For these reasons we have developed a Synthetic Imaging Diagnostic capability for forward projection comparisons of EMC3-EIRENE model solutions with the line integrated images from the Doppler Coherence Imaging diagnostic on DIII-D. The forward projection matrix is 2.8 Mpixel by 6.4 Mcells for the non-axisymmetric case we present. For flow comparisons, both simple line integral, and field aligned component matrices must be calculated. The calculation of these matrices is a massive embarrassingly parallel problem and performed with a custom dispatcher that allows processing platforms to join mid-problem as they become available, or drop out if resources are needed for higher priority tasks. The matrices are handled using standard sparse matrix techniques.

*Prepared by LLNL under Contract DE-AC52-07NA27344. This material is based upon work supported by the U.S. DOE, Office of Science, Office of Fusion Energy Sciences. LLNL-ABS-734800.

NP11 76 Examining Diagnostic Capability for Determining Divertor Neutral Sourcing to the Pedestal on DIII-D* MOR-GAN SHAFER, ALEXIS BRIESEMEISTER, JOHN CANIK, JIN MYUNG PARK, EZEKIAL UNTERBERG, Oak Ridge National Laboratory ANTHONY LEONARD, HOUYANG GUO, AU NA MOSER, General Atomics Neutral fueling from the divertor plays a key role in setting the density pedestal, but can not yet be predicted via numerical models and thus remains a crucial variable in predictive core-edge coupling. New neutral diagnostics are planned to address this issue by constraining predictions of neutral density from the divertor through the SOL into the pedestal: (a) Lyman-alpha imaging and (b) extended poloidal coverage of neutral pressure gauges. Forward modeling diagnostic responses across expected pedestal neutral fueling rates is used to estimate the diagnostic sensitivity and range of applicability. Modeled neutral source rates are obtained through interpretive modeling with the OEDGE code of experiments performed across the range of DIII-D divertor baffling configurations and gas puffing rates that result in a range of density profiles. Additional forward modeling with the core/edge coupling code CESOL will be used and compared against interpretive analysis.

*Work supported by US DOE under DE-AC05-00OR22725, DE-FC02-04ER54698.

NP11 77 Understanding tungsten divertor sourcing and SOL transport using multiple poloidally-localized sources in DIII-D ELM-y H-mode discharges* EA UNTERBERG, ORNL D DONOVAN, UT-K J BARTON, WR WAMPLER, SNI T ABRAMS, DM THOMAS, T PETRIE, HY GUO, GA PG STANGEBY, JD ELDER, U-Toronto D RUDAKOV, UCSD B GRIERSON, PPPL B VICTOR, LLNL Experiments using metal inserts with novel isotopically-enriched tungsten coatings at the outer divertor strike point (OSP) have provided unique insight into the ELM-induced sourcing, main-SOL transport, and core accumulation control mechanisms of W for a range of operating conditions. This experimental approach has used a multi-head, dual-facing collector probe (CP) at the outboard midplane, as well as W-I and core W spectroscopy. Using the CP system, the total amount of W deposited relative to source measurements shows a clear dependence on ELM size, ELM frequency, and strike point location, with large ELMs depositing significantly more W on the CP from the far-SOL source. Additionally, high spatial (\( \sim 1 \)mm) and ELM resolved spectroscopic measurements of W sourcing indicate shifts in the peak erosion rate. Furthermore, high-performance discharges with rapid ELMs show core W concentrations of \( \sim \)few \( 10^{-5} \), and the CP deposition profile indicates W

NP11 78 Measurements and modeling of intra-ELM tungsten sputtering and transport in DIII-D∗ T. ABRAMS, A.W. LEONARD, D.M. THOMAS, GA A.G. MCLEAN, M.A. MAKOWSKI, LNL H. WANG, ORAU E.A. UNTERBERG, A.R. BRIESEMIEISTER, ORNL D.L. RUDAKOV, I. BYKOV, UCSD D. DONOVAN, UTK Intra-ELM tungsten erosion profiles in the DIII-D divertor, acquired via W I spectroscopy with high temporal and spatial resolution, are consistent with SDTrim.SP sputtering modeling using measured ion saturation currents and impact energies during ELMs as input and an ad-hoc 2% C\textsuperscript{2+} impurity flux. The W sputtering profile peaks close to the OSP both during and between ELMs in the favorable B\textsubscript{T} direction. In reverse B\textsubscript{T} the W source peaks close to the OSP between ELMs but strongly broadens and shifts outboard during ELMs, heuristically consistent with radially outward ion transport via ExB drifts. Ion impact energies during ELMs (inferred taking the ratio of divertor heat flux to the ion saturation current) are found to be approximately equal to T\textsubscript{e,ped}, lower than the 4\textsuperscript{th}T\textsubscript{e,ped} value predicted by the Fundamanski/Moulton free streaming model. These impact energies imply both D main ions and C impurities contribute strongly to W sputtering during ELMs on DIII-D. This work represents progress towards a predictive model linking upstream conditions (i.e., pedestal height) and SOL impurity levels to the ELM-induced W impurity source at both the strike-point and far-target regions in the ITER divertor. Correlations between ELM size/frequency and SOL W fluxes measured via a midplane deposition probe will also be presented.

∗Work supported by US DOE under DE-SC0015877 & DE-FC02-04ER54698.

NP11 79 Modifications of W and Mo leading edges under plasma loads in DIII-D divertor∗ D.L. RUDAKOV, I. BYKOV, R.A. MOYER, UCSD T. ABRAMS, C.P. CHROBAK, H.Y. GUO, B. STAHL, D.M. THOMAS, GA J.L. BARTON, R.E. NYGREN, J.G. WATKINS, SNL C.J. LASNIER, LNL ANDREY LITNOVSKY, FZJ P.C. STANGEBY, UTDAS E.A. UNTERBERG, ORNL Cracking and melting of W and Mo leading edges were observed in the lower divertor of DIII-D during experiments with intentionally misaligned W monoblocks (MBs) and in the course of the Metal Rings Campaign involving W-coated Mo tile inserts (TIs). MBs were exposed near the attached outer strike point during deuterium and helium L- and H-mode discharges using DiMES. Two of the MBs were misaligned by 0.3 mm and 1 mm, forming leading edges. Particular ejection from a 1 mm leading edge was observed during the exposure, and evidence of melting and cracking was found post mortem. Two toroidal rings of TIs were installed in the lower outer divertor, the inner one at the floor and the outer one at the shelf. The floor TIs bowed during plasma exposure forming leading edges up to 1.2 mm high; about 40% of these edges experienced melting. Resolidified melt layers up to 1 mm thick were observed, their shape being consistent with motion in the jxB direction with j driven by electron emission.

∗Work supported by US DOE under DE-FC02-04ER54698, DE-FG02-07ER54917, DE-AC04-94AL85000, DE-AC52-07NA27344, and DE-AC05-00OR22725.

NP11 80 Measurements of W Erosion using UV Emission from DIII-D and CTH∗ CURTIS JOHNSON, DAVID ENNIS, STUART LOCH, Auburn University CONNOR BALANCE, Queen’s University BELFAST BRIAN VICTOR, STEVE ALLEN, CAMERON SAMUELL, LNL TYLER ABRAMS, GA EZEKIEL UNTERBERG, ORNL of Plasma Facing Components (PFCs) will play a critical role in establishing the performance of reactor-relevant fusion devices, particularly for tungsten (W) divertors. Erosion can be diagnosed from spectral line emission together with atomic coefficients representing the ionizations per photon (S/XB). Erosion from W is most intense in the UV region. Thus, UV survey spectrometers (200–400 nm) are used to diagnose W PFCs erosion in the DIII-D divertor and from a W tipped probe in the CTH experiment. Nineteen W emission lines in the UV region are identified between the two experiments, allowing for multiple S/XB erosion measurements. Initial W erosion lines in the UV region are identified between ELMs and giving a potential metastable diagnostic. New atomic coefficients depend upon calculated W I photon emissivities and effective ionization rate coefficients, each of which can be influenced by long lived metastable states. A review of progress in new atomic calculations for W excitation and ionization is given, along with a description of the remaining challenges. The new data is used to investigate the sensitivity of W I emission and ionization to metastable populations. The metastable-resolved data is generated using a collisional-radiative model. A comparison with W I measured spectra from DIII-D and Auburn CTH plasmas are given. Each spectral line can be associated with a single driving metastable population, simplifying the modeling considerably and giving a potential metastable diagnostic. New atomic coefficients are also generated for use in ERO modeling and compared with previously used data.

∗Work supported by USDOE Grants DE-SC0015877 & DE-FC02-04ER54698.

NP11 81 The role of neutral W metastable states in tungsten spectral line emission and erosion diagnostics.* SD LOCH, MS PINDZOLA, CA JOHNSON, C FAVREAU, DA ENNIS, Auburn University R SMYTH, M TURKINGTON, CP BALANCE, Queen’s University of Belfast W I spectral emission has been widely used to measure influx rates from W PFCs via S/XB coefficients. These coefficients depend upon calculated W I photon emissivities and effective ionization rate coefficients, each of which can be influenced by long lived metastable states. A review of progress in new atomic calculations for W excitation and ionization is given, along with a description of the remaining challenges. The new data is used to investigate the sensitivity of W I emission and ionization to metastable populations. The metastable-resolved data is generated using a collisional-radiative model. A comparison with W I measured spectra from DIII-D and Auburn CTH plasmas are given. Each spectral line can be associated with a single driving metastable population, simplifying the modeling considerably and giving a potential metastable diagnostic. New atomic coefficients are also generated for use in ERO modeling and compared with previously used data.

∗Work supported by USDOE Grants DE-FC02-04ER54698, DE-SC0015877.

NP11 82 Application of Laser Ablation Inductively Coupled Plasma Mass Spectrometry and Enriched Tungsten Isotopes to Nuclear Fusion Impurity Transport Research∗ JONAH DURAN, JACK NOWATARSKI, DAVID DONOVAN, Univ of Tennessee, Knoxville EZEKIEL UNTERBERG, MIKE ZACH, Oak Ridge National Laboratory During the DIII-D Metal Rings Campaign of 2016, one divertor tile-array was coated in natural tungsten (W) (26.5% W-182) and the other array was coated with 93.5% isotopically enriched W-182. The unique ‘isotopic fingerprint’ of the
enriched W-182 coating enabled the eroded W to act as tracer particles. Graphite collector probes (CPs) were inserted into the plasma scrape-off-layer (SOL) at the outboard midplane during operations to sample W escaping the divertor region. The use of W tracer particles and isotopic analysis of the CPs provides unique information on how various plasma operating configurations affect impurity production from the divertor and transport within the SOL. Laser Ablation Mass Spectrometry (LA-MS) is used in order to measure isotopic ratios of the W deposited on the CPs. Initial tests have revealed enrichment on the probes up to nearly 93% which corresponds with sourcing of impurities from the enriched W-182 tile-array. Additional empirical evidence is provided for understanding divertor high-Z sourcing and transport through trace plasma material interaction studies with low-Z walls. With the Stable Isotopic Mixing Model, relative contribution from each W source is also provided.

*Work supported by US DOE under DE-SC0016318 (UTK), DE-AC05-00OR22725 (ORNL) and DIII-D contract #DE-FC02-04ER54698.

NP11 83 Deposition Profile Analysis from DIII-D Metal Rings Campaign Outer-Midplane Collector Probe Diagnostic and Utilization of Enriched Isotopic Tungsten Tracer Particles* D.C. DONOVAN, J. DURAN, S. ZAMPERINI, S. LEE, (UTK) E.A. UNTERBERG, (ORNL) W.R. WAMPLER, (SNL) D.L. RUDAKOV, (UCSD) D. ELDER, P.C. STANGEBY, (UTIAS) T. ABRAMS, (GA) The DIII-D Metal Rings Campaign used isotopically-enriched, W-coated divertor tiles coupled with dual-facing midplane collector probes (CPs) in the far Scrape-off Layer (SOL). Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) results are presented characterizing the isotopic ratios of deposited W on the CPs and which give quantitative information on the transport of W from specific poloidal locations within the lower outer divertor region having different isotopically-marked tiles. Rutherford Backscattering Spectrometry (RBS) of these CPs has provided areal densities of elemental W content. These resultant W deposition profiles were compared with DIVIMP modelling of the far-SOL to better understand impurity transport in the edge plasma. CPs were exposed for 37 distinct operating configurations (L-mode/H-mode, forward/reverse Bias, strikepoint position). Radial decay lengths (RDLs) between 5 and 50 mm were observed with consistently narrower RDL and higher peak W content on the side of the probes connected along field lines to the inner divertor, indicating a concentration of W in the upstream plasma. Correlations are discussed between peak W content, RDL, and isotopic profiles on the CPs over a wide range of conditions.

*Work supported by US DOE under DE-AC05-00OR22725, DE-FG02-07ER54917, DE-FC02-04ER54698, DE-NA0003525.

NP11 84 OEDGE Modeling of Collector Probe measurements in L-mode from the DIII-D tungsten ring campaign* J.D. ELDER, Elder Fusion Incorporated P.C. STANGEBY, UofToronto Z. UNTERBERG, ORNL D. DONOVAN, UTK W.R. WAMPLER, J. WATKINS, SNL T. ABRAMS, GA A.G. MCLEAN, LLNL. During the tungsten ring campaign on DIII-D, a collector probe system with multiple diameter, dual-facing collector rods was inserted into the far scrape off layer (SOL) near the outer midplane to measure the plasma tungsten content. For most probes more tungsten was observed on the side connected along field lines to the inner divertor, with the larger probes showing largest divertor-facing asymmetries. The OEDGE code is used to model the tungsten erosion, transport and deposition. It has been enhanced with (i) a peripheral particle transport and deposition model to record the impurity content in the peripheral region outside the regular mesh, and (ii) a collector probe model. The OEDGE results approximately reproduce both the divertor-facing asymmetries and the radial decay of each collector probe profile. The effect of changing impurity transport assumptions and wall location are examined. The measured divertor-facing asymmetries imply a higher tungsten density in the plasma upstream of the probe; this was expected theoretically from the effect of the parallel ion temperature gradient force driving upstream transport of tungsten from the outer divertor and was also found in the code analysis.

*Work supported by the US Department of Energy under DE-FC02-04ER54698, DE-NA0003525, DE-AC05-00OR22725, and DE-AC52-07NA27344.

NP11 85 Development of Surface Eroding Thermocouples in DIII-D P. WATKINS, JR REN, T. ABRAMS, D. DONOVAN, UTK JON WATKINS, SANDIA NATIONAL LABORATORY Thomas HUIQIAN WANG, ORAU DMITRY RUDAKOV, UCSD CHRISTOPHER MURPHY, GA EZEKIEL UNTERBERG, ORNL DAN THOMAS, REJEAN BOIVIN, GA The Surface Eroding Thermocouple (SETC) is a specialized diagnostic for characterizing the surface temperature evolution with a high temporal resolution (~1ms) which is especially useful in areas unobservable by line-of-sight diagnostics (e.g. IR cameras). Recently, SETCs were tested in DiMES and successfully acquired temperature signals during strike point sweeps on the lower divertor shelf. We observed that the SETCs have a sub-10 ms time response and is sufficient to resolve ELM heat pulses. Preliminary analysis shows heat fluxes measured by SETCs and IR camera agree within 20%. Comparison of SETCs, calorimeters and Langmuir probe also show good agreement. We plan to implement an array of SETCs embedded in the tiles forming the new DIII-D small angle slot (SAS) divertor. Strategies to improve the SNR of these SETCs through testing in DiMES before the final installation will be discussed.

*This work was supported by the US Department of Energy under DE-SC0016318 (UTK), DE-AC05-00OR22725 (ORNL), DE-FG02-07ER54917 (UCSD), DE-FC02-04ER54698 (GA), DE-AC04-94AL85000 (SNL).

NP11 86 High Performance Double-null Plasma Operation Under Radiating Divertor Conditions* T.W. PETRIE, T. OSBORNE, A.W. LEONARD, T.C. LUCE, C.C. PETTY, General Atomics M.E. FENSTERMACHER, C.J. LASNIER, Lawrence Livermore National Laboratory F. TURCO, Columbia University J.G. WATKINS, Sandia National Laboratory We report on heat flux reduction experiments in which deuterium/neon- or deuterium/argon-based radiating mantle/divertor approaches were applied to high performance double-null (DN) plasmas (H98=1.4-1.7, Beta_E=4, q95=6) with a combined neutral beam and ECH power input P_n ≈ 15 MW. When the radial location of the ECH deposition is close to the magnetic axis (e.g., ρ ≤ 0.20), the radial profiles of both injected and intrinsic impurities are flat to somewhat hollow. For deposition farther out (e.g., ρ = 0.45), the impurity profiles are highly peaked on axis, which would make high performance DN operation with impurity injection more problematic. Comparison of neon with argon ‘seeding’ with respect to core dilution, energy confinement, and heat flux reduction under these conditions favors argon. Conditions that lead to an improved τE as predicted previously from ELITE code analysis, i.e., very high P_n, proximity to magnetic balance, and higher q95, are largely consistent with this data.

*Work supported by the US DOE under DE-FC02-04ER54698, DE-AC52-07NA27344, DE-FG02-04ER54761, and DE-AC04-94AL85000.
NP11 87 Nonlinear MHD study on the influence of E×B flow in QH-mode plasma of DIII-D∗ FENG LIU, Université Côte d’Azur & CASTOR/Inria Sophia-Antipolis, France GUIDO HUIMANS, CEA, IRFM, F-13108 Saint-Paul-Lez-Durance, France ALBERTO LOARTE, ITER organization ANDREA GAROFALO, WAYNE SOLOMON, General Atomics, P.O. Box 85608, San Diego, California 92186-5608, USA BONIFACE NKONGA, Université Côte d’Azur & CASTOR/Inria Sophia-Antipolis, France MATTHIAS HOELZL, 6Max Planck Institute for Plasma Physics, 85748 Garching, Germany In QH-mode experiments with zero-net NBI torque show that there remains a finite E×B rotation in the pedestal region implying that a minimum E×B flow or flow shear is required for the plasma to develop the Edge Harmonic Oscillation (EHO), which is a saturated KPM (kink-peeling mode) characteristic of the QH-mode. To understand the roles of E×B flow and its shear in the saturation of KPMs, non-linear MHD simulations of DIII-D QH-mode plasmas including toroidal mode numbers n = 0 to 10 with different E×B rotation speed have been performed. These simulation show that E×B rotation strongly stabilizes high-n modes but destabilizes low-n modes (particularly the n=2 mode) in the linear growth phase, which is consistent experimental observations and previous linear MHD modeling.

∗US DOE under DE-FC02-04ER54698.

NP11 88 Investigating electromagnetic effects on transport and turbulence in DIII-D QH-modes∗ WALTER GUTTENFELDER, B.A. GRIERSON, PPPPL T.L. RHODES, UCLA K.H. BURRELL, G.M. STAEBLER, GA D.R. ERNST, MIT Previous experiments and gyrokinetic simulations in the core (ρ = 0.3) of QH-modes have found that the coupling of electrostatic turbulence to magnetic fluctuations (dB) at finite beta is very stabilizing to ITG/TEM turbulence [1]. As expected from theory, the electromagnetic (EM) effects are significant as the profile is locally within ~90% of the kinetic ballooning mode (KBM) threshold. Additional gyrokinetic and TGLF simulations have been run in advance of a planned QH-mode experiment aiming to directly measure core dB using cross polarization scattering (CPS). These “predict first” simulations will be shown to highlight the expected strength of EM effects, the scaling of the predicted amplitude of dB, and the proximity of profiles to the KBM threshold.

∗This work supported in part by the U.S. Department of Energy under DE-AC02-09CH11466 and DE-FC02-04ER54698.

NP11 89 Recent Progress in BOUT++ boundary plasma turbulence simulations X.Q. XU, LLNL BOUT++ TEAM BOUT++ has been developed and applied for a range of problems that impact on boundary plasma turbulence and transport. A summary of simulation progress and results will be presented including, but not limited to: (1) Modeling tokamak boundary plasma turbulence and understanding its role in setting divertor heat flux widths; (2) Self-consistent calculation of the radial electric field with ion orbit loss mechanism; (3) Simulating the DIII-D and EAST grassy ELM regime; (4) Simulation comparison of EHO state and broadband MHD phase in near-zero torque QH-mode on DIII-D; (5) Simulation of the ELMs triggering by lithium pellet on EAST tokamak; (6) Ideal MHD Stability and Characteristics of Edge Localized Modes on CFETR. Our latest transport module solves a set of transport equations with quasi-neutral constraint using vorticity formulation under the BOUT++ framework. This new capability enables BOUT++ team to simulate boundary plasma transport across the separatrix with self-consistent electric and magnetic drifts, ion orbit loss, and sheath boundary conditions in the scrape-off-layer. Preliminary results of the coupled turbulence and transport simulations will also presented.

∗Prepared by LLNL under Contract DE-AC52-07NA27344.

NP11 90 Observations of ELM stabilization during neutral beam injection in DIII-D∗ ALESSANDRO BORTOLON, GER-RIT KRAMER, AHMED KLOKNER, RAJESH MAINGI, RAFFI NAZIKIAN, Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA JOHN DEGRASSIE, THOMAS OSBORNE, General Atomics, San Diego, CA 92121, USA Edge localized modes (ELMs) are generally interpreted as peeling-ballooning instabilities, driven by the pedestal current and pressure gradient, with other subdominant effects possibly relevant close to marginal stability. We report observations of transient stabilization of type-I ELMs during neutral beam injection (NBI), emerging from a combined dataset of DIII-D ELM My h-mode plasmas with moderate heating obtained through pulsed NBI waveforms. Statistical analysis of ELM onset times indicates that, in the selected dataset, the likelihood of onset of an ELM lowers significantly during NBI modulation pulses, with the stronger correlation found with counter-current NBI. The effect is also found in rf-heated H-modes, where ELMs appear inhibited when isolated diagnostic beam pulses are applied. Coherent average analysis is used to determine how plasma density, temperature, rotation as well as beam ion quantities evolve during a NB modulation cycle, finding relatively small changes (∼3%) of pedestal Te and ne and toroidal and poloidal rotation variations up to 5 km/s. The effect of these changes on pedestal stability will be discussed.

∗Work supported by US DOE under DE-FC02-04ER54698, DE-AC02-09CH11466.

NP11 91 Modeling ELM Pellet Padding with M3D-C1∗ S.J. DIEM, ORNL N. FERRARO, PPPPL L. BAYLOR, ORNL M3D-C1, a code for solving the linear or non-linear extended-MHD equations in toroidal geometry, is currently being used for modeling pellet ELM triggering in DIII-D ITER-like plasmas. Initial M3D-C1 results run in linear mode show that the localized perturbation due to the pellet destabilizes peeling-ballooning modes. For these simulations the pellet was modeled as a 2D density ring perturbation and the total pressure was kept constant. Calculations of linear peeling-ballooning stability as a function of pellet size and deposition have shown for an initial number of particles ∼4e17, only nω > 20 is unstable. Increasing the number of particles to 1e19 leads to unstable edge modes at the pellet ablation location, suggesting that the 2-D pellet density ring underestimates the effects of the pellet. Linear simulations also suggest that the destabilization seems to be a resistive effect. Placing the density perturbation further inside the pedestal destabilizes nω > 10. Recent M3D-C1 modeling efforts have focused on 3D, 2-fluid nonlinear simulations for ELM pellet pacing.

∗This work was supported by the U.S. D.O.E contract DE-AC05-00OR22725 and under US DOE Award DE-FC02-04ER54698.

The pedestal height and width in the DIII-D high-betap EAST-demonstration plasmas are compared with the EPED1 model. It shows that the pedestal height and width agree with the EPED1 prediction for cases with no/weak ITB, while the pedestal height is much lower than the EPED1 prediction when there is strong ITB. For a couple of similar discharges, when the operation conditions are varied slightly, the ELM frequency change is large. The high frequency ELM cases have low pedestal height and strong ITB, while the low frequency cases have high pressure pedestal height and no ITB appears. The time evolution of the kinetic profiles shows that the pedestal structure correlates with the ITB strength at large radius. As the ITB emerges and builds up, the pedestal height decreases.

*Work supported by National Magnetic Confinement Fusion Program of China under 2014GB106001 and 2015GB102000, and by US DOE under DE-FC02-04ER54698.

NP11 93 Interactions of Fast Ion Losses and MHD During an ELM Cycle† Ryan Chaban, Saskia Mordick, William & Mary Coll David Pace, General Atomics. This work focuses on empirically determining correlations between different types of MHD activity in the pedestal region in DIII-D H-modes and fast ion losses to guide future work on discovering the interaction mechanisms between these two phenomena. Using conditional averaging, data of the energetic ion energy-pitch angle distribution, pedestal measurements, and ELM crashes was analyzed to track fast ion and MHD development over the ELM cycle. Prior research has focused on understanding MHD precursors to ELMs and how these magnetic precursors, and separately energetic ion losses, grow before an ELM crash. Later, we observe that during the ELM crash, energetic ion losses occur at uncommon energy - pitch angle phase space.

The fast ion losses that occur during the ELM crash have very high pitch angles and relatively low energy, implying a loss of confined ions that could not yet deposit their energy. After the ELM crash, when there is little MHD activity, there is also a lack of consistent fast ion losses, indicating that MHD activity at the plasma edge may enhance fast ion losses.

*Work supported by US DOE under DE-FC02-04ER54698.

NP11 94 ECE Imaging upgrade for ELM imaging measurement on DIII-D† Yilun Zhu, Yan Wang, University of California at Davis Benjamin Tobias, Los Alamos National Lab Joon-Han Yu, Anh-Vu Pham, Calvin Domier, Chen Luo, University of California at Davis Ahmed Diallo, Gerrit Kramer, Yang Ren, Raffi Nazikian, Princeton Plasma Physics Laboratory Ming Chen, Neville LuHmann Jr., University of California at Davis. DIII-D ECE1 uses liquid crystal polymer (LCP) substrates to combine System-on-Chip receivers with on-board LO multiplication and amplification inside a fully shielded, modular package. It improves x30 sensitivity compared to existing one, while significantly reducing EM interference, environmental noise, and radiation bursts, thereby improving ELM studies in the most ITER relevant, low-collisional regimes on DIII-D. Noise bursts that have been troublesome for ECEI of ELMS have been classified into different types: some indicate important processes involving reconnection and the acceleration of non-thermal electrons, while out-of-band interference had been removed. The upgrade facilitates studies on disruption avoidance during RF heating by static and not rotating MHD. The upgraded system can be used to infer RF heating deposition profiles with absolutely calibrated Te measurements.

*Work supported by US DOE under DE-AC02-09CH11466, DE-FC02-04ER54698, DE-FG02-99ER54531 and DE-SC0012551.

NP11 95 SOLPS modeling of inter/intra-ELM W transport DIII-D A.C. Sontag, E.A. Unterberg, J.M. Canik, L.W. Owen, ORNL T. Abrams, GA J. Watkins, SNL. SOLPS will be used for interpretive modeling of SOL tungsten transport in DIII-D to determine the roles of the friction force and the ion temperature gradient force on impurity transport. Modeling will be performed comparing discharges with the outer strike point on each tungsten divertor ring. A gas source with the measured tungsten source rate is placed at the location of each ring in the model to simulate sputtering, allowing for individual rings to source for comparison to tracer isotope studies. Anomalous thermal and particle transport coefficients are adjusted to match the upstream deuterium profiles while impurities use the same transport coefficients. An outer midplane deposition probe provides additional data on the SOL tungsten density. ELM averaged pedestal profiles covering the last 20% of the ELM cycle are used to determine the inter-ELM transport, while individual pedestal profiles measured during the ELM cycle are used to examine intra-ELM tungsten transport. ELM resolved source flux measurements are used to model the inter-ELM transport.

NP11 96 Prediction of Pressure and Temperature Gradients in the Tokamak Plasma Edge† W.M. Stacey, Georgia Tech. An extended plasma fluid theory [1,2] that takes into account kinetic ion orbit loss and electromagnetic forces in the continuity, momentum and energy balances, as well as atomic physics and radiation, has been used to reveal the explicit dependence of the temperature and pressure gradients in the tokamak edge plasma on these various factors. Combining the ion radial momentum balance and the Ohm’s Law expression for E, reveals the dependence of the radial ion pressure gradient on VxS forces driven by radial particle fluxes, which depend on ion orbit loss, and other factors. The strong temperature gradients measured in the H-mode edge pedestal could certainly be associated with radiative and atomic physics edge cooling effects and the strong reduction in ion and energy fluxes due to ion orbit loss, as well as to the possible reductions in thermal diffusivities that is usually assumed to be the cause.

*Work supported by USDOE under DE-FC02-04ER54698.


NP11 97 GTEDGE-2 A new predictive and interpretive edgeline boundary transport capability E.W. Deshazer, M.D. Hill, W.M. Stacey, Georgia Tech. A new code is being assembled for the tokamak plasma and neutral particle transport in the plasma edge, Scrape-Off Layer (SOL) and divertor. The new code will differ from existing codes by including ion orbit loss of thermalized ions and retaining electromagnetic “pinch” forces in the momentum balance, thus conserving particles, momentum and energy. Edge plasma transport is based on a 1D Flux-Surface Averaged (FSA) transport solution of the extended fluid theory incorporating ion orbit loss and electromagnetic particle pinch [1], with flux surface compression-expansion effects of gradients and Shafranov shift accounted for using the Miller model [2]. SOL-divertor plasma transport is initially based on a 1-D solution of the particle, momentum and energy equations in the core and edge plasma [3]. Neutral particle transport is based on the GTNEUT interface current balance code [4].
Theoretical models for the Code structure, integration and iteration issues are discussed.

1 Nucl. Fusion 57, 066034 (2017).

NP11 98 Edge Mechanisms for Power Excursion Control in Burning Plasmas∗ M.D. HILL, W.M. STACEY, Georgia Tech ITER must have active and preferably also passive control mechanisms that will limit inadvertent plasma power excursions which could trigger runaway fusion heating. We are identifying and investigating the potential of ion-orbit loss, impurity seeding, and various divertor “choking” phenomena to control or limit sudden increases in plasma density or temperature by reducing energy confinement, increasing radiation loss, etc., with the idea that such mechanisms could be tested on DIII-D and other existing tokamaks.

We are assembling an edge-divertor code (GTEDGE-2) with a neutral transport model and a burn dynamics code, for this purpose. One potential control mechanism is the enhanced ion orbit loss from the thermalized ion distribution that would result from heating of the thermalized plasma ion distribution. Another possibility is impurity seeding with ions whose emissivity would increase sharply if the edge temperature increased. Enhanced radiative losses should also reduce the thermal energy flux across the separatrix, perhaps dropping the plasma into the poorer L-mode confinement regime. We will present some initial calculations to quantify these ideas.

∗Work supported by US DOE under DE-FC02-04ER54698.

NP11 99 Calculation of rotation and poloidal asymmetries in DIII-D∗ R.W. KING, W.M. STACEY, Georgia Tech The Braginski rate-of-strain tensor model of viscosity, extended to toroidal geometry [1] and arbitrary collisionality [2], predicted central toroidal rotation within an order of magnitude of experiment [3,4] using a circular flux surface model to calculate poloidal asymmetries that determine the magnitude of the Braginski toroidal gyroviscosity. Refinement of the poloidal asymmetry calculation using a Miller model flux surface led to an order of magnitude improvement in agreement with experimental toroidal velocity in the central region of DIII-D [5]. An orthogonalized flux-surface aligned localized coordinate frame [6] has been developed to improve calculations of poloidal asymmetries. We extend this system to calculate poloidal asymmetries and velocities to evaluate how well an accurate calculation of the extended Braginski gyroviscosity can describe the toroidal momentum damping in the central regions of DIII-D.

∗Work Partially supported by US DOE under DE-FC02-04ER54698.

NP11 100 Changes in Ion Orbit Loss, Intrinsic Rotation and Particle Pinch across the L-H Transition in DIII-D Plasmas∗ N.A. PIPER, W.M. STACEY, Georgia Tech R.J. GROEBNER, General Atomics Two interesting new L-H phenomena have been observed in a series of DIII-D discharges. 1) The measured C co-Ip toroidal rotation inside of $\rho < 0.94$ was observed to increase the L-H transition, but actually decreased for $\rho > 0.94$. A particle-momentum-energy balance shows that the preferential ion orbit loss of ctr-Ip ions causes a co-Ip intrinsic rotation for $\rho > 0.94$ which is greater in L-mode than in H-mode, thus causing the drop in total measured rotation for $\rho > 0.94$ at the L-H transition. 2) In two of the three shots the electromagnetic pinch velocity went from weakly inward in L-mode to strongly inward in H-mode for $\rho > 0.96$, consistent with improved particle confinement in H-mode associated with inward electromagnetic forces on the ions. The calculated edge neutral density, which is proportional to the radial particle flux, drag frequency, and therefore pinch velocity, is greater in H-mode than in L-mode for the two shots with a strongly inward pinch in H-mode of $\rho > 0.96$, but not for the third shot in which the inward pinch in H-mode was weaker than in L-mode.

∗Work supported by US DOE under DE-FC02-04ER54698.

NP11 101 Interpretation of thermal conduction and toroidal momentum transport in DIII-D, taking into account IOL and pinch velocity∗ J.J. ROVETO, W.M. STACEY, Georgia Tech R.J. GROEBNER, General Atomics The capability of the Georgia Tech GTEDGE edge transport interpretation code has been upgraded to include improved ion-orbit-loss models for neutral beam and thermalized ions in the edge plasma. We are undertaking a new comparison of various theoretical thermal diffusivity models with the improved interpretation of experimental edge transport now possible. The experimental values are being compared with various theoretical models, including paleoclassical, neoclassical, ITG, drift ballooning mode, TEM, and ETG. An improved interpretation of viscous drag considering ion orbit loss is considered and compared to that without ion-orbit-loss effects. This effort is examining two H-mode DIII-D shots, #144977 and #123302. The improved interpretation leads to quite different experimental thermal diffusivity profiles in the edge than previously reported when ion-orbit-loss effects are included (as much as 50% lower at the separatrix for shot #123302).

∗Work supported by US DOE under DE-FC02-04ER54698.

NP11 102 Installation and initial operation of a 117.5 GHz gyrotron on DIII-D∗ JOHN LOHR, RIGO BRAMBILA, MIRELA CENGHER, YURI GORELOV, BILL GROSNICKLE, DAN PONCE, General Atomics STEPHEN STORMENT, University of Arkansas ANTONIO TORREZAN, General Atomics A new gyrotron operating at 117.5 GHz and generating in excess of 1.5 MW for short pulses has been installed at DIII-D and is being prepared for operations. The tube was designed and manufactured by CPI in Palo Alto, CA. At the limit of the CPI test set, the gyrotron generated pulses up to 10 sec in length at about 550 kW output power. The GA installation permits full output power at pulse lengths up to 5 sec, the administrative limit, to be used in testing. This will be the first gyrotron in the DIII-D complex to be operated for conditioning from the outset using FPGA based pulse control. This allows the tube to be restarted after a fault in many cases relevant to the conditioning activity. The progress of the conditioning program with the new pulse control hardware will be compared with previous ab initio testing and the current status will be presented.

∗Work supported by US DOE under DE-FC02-04ER54698.

NP11 103 Dependence of Helicon Antenna Loading on the Antenna/Plasma Gap and $n_m$ in DIII-D Experiments∗ R.I. PINSKER, C.P. MOELLER, General Atomics A comprehensive set of measurements of the plasma loading of a 12-element antenna array, designed to launch helicon waves (i.e., very-high-harmonic
fast waves), were performed on DIII-D in 2016. The antenna, operated in the 466 – 486 MHz band, is prototypical of a wider array for a 1-MW-level experiment planned for 2018-9. The dependence of the antenna loading on antenna/plasma gap is of great practical significance, as the gap must be kept greater than a minimum distance to suppress deleterious plasma-material interactions, while the loading must be high enough to retain good efficiency of power transfer to the plasma. While the loading in all examined plasma regimes, including both limited and diverted L-mode discharges and H-mode discharges, decayed exponentially with increasing gap in agreement with simple theory, the characteristic decay length was in all cases larger than expected, motivating the development of a more realistic model. Furthermore, the characteristic decay length did not depend on the launched $n_a$, though the absolute level of loading at a given gap increased as $n_a$ was decreased from 4 to 2. After the antenna was removed from DIII-D, measurements of the loading produced by a 100 $\Omega$/sq resistive film were carried out on the bench. Both the antenna/film gap and $n_a$ were scanned varied and the results compared with calculations done with the QuickWave FDTD electromagnetics solver. Very good agreement was found in this case.

*Work supported by the US DOE under DE-FC02-04ER54698.

NP11 104 Full wave simulations of helicon wave losses in the scrape-off-layer of the DIII-D tokamak* C. HOLLCOMB, R. BERTETTI, Princeton Plasma Physics Laboratory ROBERT PINSKER, General Atomics Helicon waves have been recently proposed as an off-axis current drive actuator for DIII-D. Previous modeling using the hot plasma, full wave code AORSA, has shown good agreement with the ray tracing code GENRAY for helicon wave propagation and absorption in the core plasma. AORSA, and a new, reduced finite-element-model show discrepancies between ray tracing and full wave occur in the scrape-off-layer (SOL), especially at high densities. The reduced model is much faster than AORSA, and reproduces most of the important features of the AORSA model. The reduced model also allows for larger parametric scans and for the ease of arbitrary tokamak geometry. Results of the full wave codes, AORSA and COMSOL, will be shown for helicon wave losses in the SOL are shown for a large range of parameters, such as SOL density profiles, $n_a$, radial and vertical locations of the antenna, and different tokamak vessel geometries.

*This work was supported by DE-AC05-00OR22725, DE-AC02-09CH11466, and DE-FC02-04ER54698.

NP11 105 Prospects for Off-axis Current Drive via High Field Side Lower Hybrid Current Drive in DIII-D* S.J. WUKITCH, S. SHIRAIWA, G.M. WALLACE, P.T. BONOLI, MIT PSFC C. HOLCOMB, LLNL J.M. PARK, ORNL R.I. PINSKER, GA. An outstanding challenge for an economical, steady state tokamak is efficient off-axis current drive scalable to reactors. Previous studies have focused on high field side (HFS) launch of lower hybrid waves for current drive (LHCD) in double null configurations in reactor grade plasmas [1]. The goal of this work is to find a HFS LHCD scenario for DIII-D that balances coupling, power penetration and damping. The higher magnetic field on the HFS improves wave accessibility, which allows for lower $n_a$ waves to be launched. These waves penetrate farther into the plasma core before damping at higher $T_e$, yielding a higher current drive efficiency. Utilizing advanced ray tracing and Fokker Planck simulation tools (GENRAY+CQL3D), wave penetration, absorption and drive current profiles in high performance DIII-D H-Mode plasmas were investigated. We found LH scenarios with single pass absorption, excellent wave penetration to $r/a = 0.6-0.8$, FWHM $r/a = 0.2$ and driven current up to 0.37 MA/MW coupled. These simulations indicate that HFS LHCD has potential to achieve efficient off-axis current drive in DIII-D and the latest results will be presented.

*Work supported by U.S. Dept. of Energy, Office of Science, Office of Fusion Energy Sciences, using User Facility DIII-D, under Award No. DE-FC02-04ER54698 and Contract No. DE-FC02-01ER45468 under Scientific Discovery through Advanced Computing Initiative.

1P. T. Bonoli, IAEA (2016).

NP11 106 High Field Side Lower Hybrid Current Drive Launcher Design for DIII-D* G.M. WALLACE, R. LECCACORI, J. DOODY, R. VIEIRA, S. SHIRAIWA, S.J. WUKITCH, MIT PSFC C. HOLCOMB, LLNL R.I. PINSKER, GA. Efficient off-axis current drive scalable to reactors is a key enabling technology for a steady-state tokamak. Simulations of DIII-D discharges have identified high performance scenarios with excellent lower hybrid (LH) wave penetration, single pass absorption and high current drive efficiency. The strategy was to adapt known launching technology utilized in previous experiments on C-Mod (poloidal splitter) and Tore Supra (bi-junction) and remain within power density limits established in JET and Tore Supra. For a 2 MW source power antenna, the launcher consists of 32 toroidal apertures and 4 poloidal rows.

NP11 107 Real Time Computer Control of Neutral Beam Energy and Current During a DIII-D Tokamak Shot* C.J. PAWLEY, D.C. PACE, J.M. RAUCH, J.T. SCOVILLE, General Atomics A new control system has been implemented on DIII-D neutral beams which has been used during the 2016 and 2017 experimental campaign to directly change the beam acceleration voltage (V) and beam current (I) by the Plasma Control System (PCS) during a shot. Small changes in the beam voltage of 1-2 kV can be made in 1 msec or larger changes of up to 20 kV in 0.5 seconds. The beam current can be modified by as much as ±20% at a fixed beam voltage. Since both can be independently and simultaneously changed it is possible to change beam power (IV) at fixed voltage, keep constant power while sweeping beam voltage, or to maintain minimum beam divergence during a beam voltage sweep by changing I simultaneously to keep a constant beam perveance. The limitations of the variability will be presented with required changes in equipment to extend either the speed or range of the controls. Some of the effects on fast ion plasma instabilities or other plasma mode changes made possible by this control will also be presented (see also D.C. Pace, this conference).
NP11 108 Investigation of Neutral Beam Arc Chamber Failure During Helium Operations at DIII-D∗ JASPER BECKERS, University of Technology, Eindhoven, The Netherlands BRENDAN CROWLEY, J.T. SCOVILLE, General Atomics ROGER JASPERS, ANA SOBOTA, University of Technology, Eindhoven, The Netherlands The Neutral Beam system on the DIII-D tokamak consists of eight ion sources using the Common Long Pulse Source (CLPS) design. During helium operation, desired for research regarding the ITER pre-nuclear phase, it has been observed that the ion source arc performance steadily deteriorates, eventually failing due to electrical breakdown across the insulation. This poster presents the details and preliminary results of an experimental effort to replicate the problem in a bench top ion source with similar plasma parameters. The initial aim of the experiment is to test the hypothesis that during helium operation there is increased tungsten evaporation and sputtering due to ion bombardment of the hot cathodes, leading to the deposition of filament material on the insulation and subsequent short circuits. Ultimately the aim of the experiment is to find methods to ameliorate the problems associated with helium operation at DIII-D.

∗Work supported by U.S. DOE under DE-FC02-04ER54698.

NP11 109 COMPACT TORUS

NP11 110 Overview of the HIT-SI3 spheromak experiment∗ A.C. HOSSACK, T.R. JARBOE, R.N. CHANDRA, K.D. MORGAN, D.A. SUTHERLAND, C.J. EVerson, J.M. PENNA, B.A. NELSON, University of Washington The HIT-SI and HIT-SI3 spheromak experiments (n = 25 cm) study efficient, steady-state current drive for magnetic confinement plasmas using a novel method which is ideal for low aspect ratio, toroidal geometries. Sustained spheromaks show coherent, imposed plasma motion and low plasma-generated mode activity, indicating stability. Analysis of surface magnetic fields in HIT-SI indicates large n = 0 and 1 mode amplitudes and little energy in higher modes. Within measurement uncertainties all the n = 1 energy is imposed by the injectors, rather than being plasma-generated. The fluctuating field imposed by the injectors is sufficient to sustain the toroidal current through dynamo action whereas the plasma-generated field is not (Hossack et al., Phys. Plasmas, 2017). Ion Doppler spectroscopy shows coherent, imposed plasma motion inside r ≈10 cm in HIT-SI and a smaller volume of coherent motion in HIT-SI3. Coherent motion indicates the spheromak is stable and a lack of plasma-generated n = 1 energy indicates the maximum q is maintained below 1 for stability during sustainment. In HIT-SI3, the imposed mode structure is varied to test the plasma response (Hossack et al., Nucl. Fusion, 2017). Imposing n = 2, n = 3, or large, rotating n = 1 perturbations is correlated with transient plasma-generated activity.

∗Work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, under Award Number DE-FG02-96ER54361.

NP11 111 Progress on FIR interferometry and Thomson Scattering measurements on HIT-SI3 CHRISTOPHER EVERSON, THOMAS JARBOE, KYLE MORGAN, Univ of Washington Spatially resolved measurements of the electron temperature (Te) and density (n_e) will be fundamental in assessing the degree to which HIT-SI3 demonstrates closed magnetic flux and energy confinement. Further, electron temperature measurements have not yet been made on an inductively-driven spheromak. Far infrared (FIR) interferometer and Thomson Scattering (TS) systems have been installed on the HIT-SI3 spheromak. The TS system currently implemented on HIT-SI3 was originally designed for other magnetic confinement experiments, and progress continues toward modifying and optimizing for HIT-SI3 plasmas. Initial results suggest that the electron temperature is of order 10 eV. Plans to modify the TS system to provide more sensitivity and accuracy at low temperatures are presented. The line-integrated n_e is measured on one chord by the FIR interferometer, with densities near 5 × 10^{19} m^{-3}. Four cylindrical volumes have been added to the HIT-SI3 apparatus to enhance passive pumping. It is hoped that this will allow for more control of the density during the 2 ms discharges. Density measurements from before and after the installation of the passive pumping volumes are presented for comparison.

NP11 112 Two-fluid (plasma-neutral) Extended-MHD simulations of spheromak configurations in the HIT-SI experiment with PSI-Tet D.A. SUTHERLAND, C.J. HANSEN, T.R. JARBOE, University of Washington A self-consistent, two-fluid (plasma-neutral) dynamic neutral model [1] has been implemented into the 3-D, Extended-MHD code PSI-Tet. A monatomic, hydrogenic neutral fluid reacts with a plasma fluid through elastic scattering collisions and three inelastic collision reactions: electron-impact ionization, radiative recombination, and resonant charge-exchange. Density, momentum, and energy are evolved for both the plasma and neutral species. The implemented plasma-neutral model in PSI-Tet is being used to simulate decaying spheromak configurations in the HIT-SI experimental geometry, which is being compared to two-photon absorption laser induced fluorescence measurements (TALIF) made on the HIT-SI3 experiment. TALIF is used to measure the absolute density and temperature of monatomic deuterium atoms. Neutal densities on the order of 10^{19} m^{-3} and neutral temperatures between 0.6-1.7 eV were measured towards the end of decay of spheromak configurations with initial toroidal currents between 10-12 KA. Validation results between TALIF measurements and PSI-Tet simulations with the implemented dynamic neutral model will be presented. Additionally, preliminary dynamic neutral simulations of the HIT-SI/HIT-SI3 spheromak plasmas sustained with inductive helicity injection will be presented. Lastly, potential benefits of an expansion of the two-fluid model into a multi-fluid model that includes multiple neutral species and tracking of charge states will be discussed.


NP11 113 NI MROD Simulations of the HIT-SI and HIT-SI3 Devices∗ KYLE MORGAN, TOM JARBOE, AARON HOSSACK, RIAN CHANDRA, CHRIS EVerson, University of Washington The Helicity Injected Torus with Steady Inductive helicity injection (HIT-SI) experiment uses a set of inductively driven helicity injectors to apply non-axisymmetric current drive on the edge of the plasma, driving an axisymmetric spheromak equilibrium in a central confinement volume. Significant improvements have been made to extended MHD modeling of HIT-SI, with both the resolution of disagreement at high injector frequencies in HIT-SI in addition to successes with the new upgraded HIT-SI3 device. Previous numerical studies of HIT-SI, using a zero-beta eMHD model, focused on operations with a drive frequency of 14.5 kHz, and found reduced agreement with both the magnetic profile and current amplification at higher frequencies (30-70 kHz). HIT-SI3 has three helicity
injectors which are able to operate with different mode structures of perturbations through the different relative temporal phasing of the injectors. Simulations that allow for pressure gradients have been performed in the parameter regimes of both devices using the NIMROD code and show improved agreement with experimental results, most notably capturing the observed Shafranov-shift due to increased beta observed at higher $f_{\omega}$ in HIT-SI and the variety of toroidal perturbation spectra available in HIT-SI3.

*This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences under Award Number DE-FG02-96ER54361.

NP11 114 NIMROD simulations and physics assessment of possible designs for a next generation Steady Inductive Helicity Injection HIT device JAMES PENNA, KYLE MORGAN, ISAAC GRUBB, THOMAS JARBOE, University of Washington The Helicity Injected Torus - Steady Inductive 3 (HIT-SI3) experiment forms and maintains spheromaks via Steady Inductive Helicity Injection (SIHI) using discrete injectors that inject magnetic helicity via a non-axisymmetric perturbation and drive toroidally symmetric current. Newer designs for larger SIHI-driven spheromaks incorporate a set of injectors connected to a single external manifold to allow more freedom for the toroidal structure of the applied perturbation. Simulations have been carried out using the NIMROD code to assess the effectiveness of various imposed mode structures and injector schema in driving current via Imposed Dynamo Current Drive (IDCD). The results are presented here for varying flux conservor shapes on a device approximately 1.5 times larger than the current HIT-SI3 experiment. The imposed mode structures and spectra of simulated spheromaks are analyzed in order to examine magnetic structure and stability and determine an optimal regime for IDCD sustainment in a large device. The development of scaling laws for manifold operation is also presented, and simulation results are analyzed and assessed as part of the development path for the large scale device.


NP11 115 Using Algebraic Space Curves to Investigate Magnetic Helicity and Its Application to the Spheromak R. E. WILLIAMS, R. L. WILLIAMS, Florida A. & M. University The goal of this research is to study magnetic helicity and the topology of magnetic flux tubes using the homotopy groups of braids, knots, links and tangles. Flux tubes are represented as real algebraic curves in three dimensional space. We are interested in developing a stochastic, dynamic group of curves representing knotted, braided, and tangled flux tubes that evolve around and converge onto a torus. The group will be modeled using a computer algebra system. Using our model, we propose to define helicity, writhe and linking number parameters to analyze their ratio to the time for magnetic relaxation and confinement.

NP11 116 Progress of STPX Discharges and Diagnostic Systems R. WILLIAMS, J. CLARK, J. B. TITUS, C. AKPOVO, E. THOMAS, Auburn University The Spheromak Turbulent Physics Experiment (STPX) at Florida A&M University is currently ramping up plasma operations and diagnostic testing. STPX is a large radius (1.5m), magnetic confinement device, capable of creating fusion-relevant and astrophysical-related spheromak plasmas. We have measurements and simulations of the formation banks and bias magnetic field coils. dB/dt coils provided by WVU have been calibrated and a Langmuir triple probe developed by Auburn University is providing density and temperature measurements with a saturation coil array providing a rough density profile. A CO$_2$ interferometer has been installed to corroborate the density measurements and a mechelle spectrometer is providing spectral line data. CORSICA simulations of STPX plasmas have begun.

NP11 117 Electron density measurements in STPX plasmas JERRY CLARK, R. WILLIAMS, J. B. TITUS, E. D. MEZONLIN, C. AKPOVO, Florida A & M University E. THOMAS, Auburn University Diagnostics have been installed to measure the electron density of Spheromak Turbulent Physics Experiment (STPX) plasmas at Florida A. & M. University. An insertable probe, provided by Auburn University, consisting of a combination of a triple-tipped Langmuir probe and a radial array consisting of three ion saturation current / floating potential rings has been installed to measure instantaneous plasma density, temperature and plasma potential. As the ramp-up of the experimental program commences, initial electron density measurements from the triple-probe show that the electron density is on the order of $10^{19}$ particles/m$^3$. For a passive measurement, a CO$_2$ interferometer system has been designed and installed for measuring line-averaged densities and to corroborate the Langmuir measurements. We describe the design, calibration, and performance of these diagnostic systems on large volume STPX plasmas.

NP11 118 Plasma driven by helical electrodes* CIHAN AKCAY, JOHN FINN, RICHARD NEBEL, DANIEL BARNES, NEAL MARTIN, Tibbar Plasma Technologies We present a plasma state driven by helically symmetric electrodes $(m, n)$ in the presence of a uniform axial magnetic field in a periodic cylinder [1], with applications as an electrical transformer or for tailoring the current profile in a tokamak or RFP. For strong drive there is a $(m, n)$ state with mean-field current density and flat $q_0 \approx m/n = 1$ in the interior. It has large helical flows, a bi-directional parallel current density $\lambda$, and an $O-$ line encircled by all of the field lines. We show a Cowling-like theorem $(q_0 B^\parallel) = 0$ and discuss the relationship with magnetic helicity. The transient stage is discussed. Integration of the current density streamlines is used to quantify primary-to-secondary leakage for the transformer application. Results varying $(m, n)$ the plasma length are presented. Sensitivity studies to (a) boundary conditions, (b) resistivity profile, and (c) electrode shape are presented. Results with finite $(m, n)$ radial magnetic field are introduced, showing high transformer efficiencies. 3D studies of finite length plasmas are presented.

*DOE ARPA-E Grant DE- AR000067.


NP11 119 3D Resistive MHD Simulations of Formation, Compression, and Acceleration of Compact Tori* SIMON WOODRUFF, THOMAS MEYER, JAMES STUBER, Woodruff Scientific Inc CARLOS ROMERO-TALAMAS, University of Maryland Baltimore County MICHAEL BROWN, Swarthmore MANJIT KAUR, Swarthmore DAVID SCHAFFNER, Bryn Mawr We present results from extended resistive 3D MHD simulations (NIMROD [1]) pertaining to a new formation method for toroidal plasmas using a reconnection region that forms in a radial implosion, and results from the acceleration of CTs along a drift tube that are accelerated by a coil and then allowed to go tilt unstable and form a helical minimum energy state. The new formation method results from a reconnection...
region that is generated between two magnetic compression coils that are ramped to 320kV in 2μs. When the compressing field is aligned anti-parallel to a pre-existing CT, a current sheet and reconnection region forms that accelerates plasma radially inwards up to 500km/s which stagnates and directed energy converts to thermal, raising temperatures to 500eV. When field is aligned parallel to the pre-existing CT, the configuration can be accelerated along a drift tube. For certain ratios of magnetic field to density, the CT goes tilt-unstable forming a twisted flux rope, which can also be accelerated and stagnated on an end wall, where temperature and field increases as the plasma compresses. We compare simulation results with adiabatic scaling relations.

*Work supported by ARPA-E ALPHA program and DARPA.


NP11 120 UEDGE Simulations for Power and Particle Flow Analysis of FRC Rocket* FRED ZHENG, Princeton Univ EU-GENE S. EVANS, Princeton Plasma Physics Laboratory NICK MCGREIVY, University of Pennsylvania ALAN KAPTANOGLU, Stanford University OLIVIER IZACARD, SAMUEL A. COHEN, Princeton Plasma Physics Laboratory The field-reversed configuration (FRC) is under consideration for use in a direct fusion drive (DFD) rocket propulsion system for future space missions. To achieve a rocket configuration, the FRC is embedded within an asymmetric magnetic mirror, in which one end is closed and contains a gas box, and the other end is open and incorporates a magnetic nozzle. Neutral deuterium is injected into the gas box, and flows through the scrape-off layer (SOL) around the core plasma and out the magnetic nozzle, both cooling the core and serving as propellant. Previous studies have examined a range of operating conditions for the SOL of a DFD using UEDGE, a 2D fluid code; discrepancies on the order of ~5% were found during the analysis of overall power balance. This work extends the analysis of the previously-studied SOL geometry by updating boundary conditions and conducting a detailed study of power and particle flows within the simulation with the goals of modeling electrical power generation instead of thrust and achieving higher specific impulse.

*This work was supported, in part, by DOE Contract Number DE-AC02-09CH11466 and Princeton Environmental Institute.

NP11 121 Results from an 8 Joule RMF-FRC Plasma Translation Experiment for Space Propulsion CARRIE HILL, NOLAN UCHIZONO, ERC, Inc. MICHAEL HOLMES, U.S. Air Force Research Laboratory Field-Reversed Configuration (FRC) thrusters are attractive for advanced in-space propulsion technology as their projected performance, low specific mass, and propellant flexibility offer significant benefits over state-of-the-art thrusters. A benchtop experiment to evaluate FRC thruster behavior using a Rotating Magnetic Field (RMF) formation method was constructed at the Air Force Research Laboratory. This experiment generated an RMF-FRC in a conical geometry and accelerated the plasma into a field-free drift region, using 8 J of input energy. Downstream plasma probes in a time-of-flight array measured the exhaust contents of the plasma plume. Results from this diagnostic demonstrated that the ejected mass and ion exit velocities fell short of the desired specific impulse and momentum. Two high-speed cameras were installed to diagnose the gross plasma behavior from two perspectives. Results from these images are presented here. These images show that the plasma generated in the formation region for several different operating conditions was highly non-uniform and did not form a stable closed-field topology that is expected from RMF-FRC plasmas.

NP11 122 High Efficiency push-pull class E amplifiers for fusion rocket engines* GABRIEL GAITAN, ERIC HAM, Princeton Univ S.A. COHEN, CHARLES SWANSON, PPPL MINJIE CHEN, Princeton Univ CHRISTOPHER BRUNKHORST, PPPL In a Field Reversed Configuration fusion reactor, ions in the plasma are heated by an antenna operating at RF frequencies. This paper presents how push-pull class E amplifiers can be used to efficiently drive this antenna in the MHz range, from 0.5MHz to 4 MHz, while maintaining low harmonic content in the output signal. We offer four different configurations that present a trade-off between efficiency and low harmonic content. The paper presents theoretical values and breadboard results from these configurations, which operate at a power of around 100W. For a practical design, multiple amplifiers would be linked in parallel and would power the RF antenna at around 1MW. These designs provide multiple different options for reactor systems that could be used in a variety of applications, from power plants on the ground to rocket engines in space.

*This work was supported, in part, by DOE Contract Number DE-AC02-09CH11466 and Princeton Environmental Institute.

NP11 123 Particle-in-cell studies of fast-ion slowing-down rates in cool tenuous magnetized plasma using LSP* EUGENE S. EVANS, ERIJAH KOLMES, SAMUEL A. COHEN, Princeton Plasma Physics Laboratory DALE R. WELCH, Voss Scientific TOM ROGNLIEN, BRUCE COHEN, Lawrence Livermore National Laboratory ERC, Inc. ALAN KAPTANOGLU, University of Washington We present particle-in-cell (PIC) simulations of fast-ion slowing down rates in cool, weakly-magnetized plasma (where \( \rho_i < \lambda_D e \) and \( v_{fi} > v_{th,e} \)) using the fully electromagnetic PIC code LSP. These simulations use explicit algorithms, resolving \( \rho_i \) and \( \lambda_D e \) spatially and the electron cyclotron and plasma frequencies temporally. Scaling studies of the slowing-down time, \( \tau_{sd} \), versus fast-ion charge and background plasma density are in good agreement with unmagnetized slowing-down theory; a small anisotropy is observed between \( \tau_{sd} \) in the perpendicular- and parallel-field directions. Furthermore, scaling of the fast-ion charge is confirmed as a viable way to reduce the required computational time for each simulation. The implications of slowing down processes in this regime are described for one magnetic-confinement fusion concept, the small field-reversed configuration device.

*This work was supported, in part, by DOE Contract Number DE-AC02-09CH11466.

NP11 124 SiC MOSFET Switching Power Amplifier Project Summary* KENNETH E. MILLER, TIMOTHY ZIEMBA, JAMES PRAGER, ILJA SLOBODOV, ALEX HENSON, Eagle Harbor Technologies, Inc. Eagle Harbor Technologies has completed a Phase I/II program to develop SiC MOSFET based Switching Power Amplifiers (SPA) for precision magnet control in fusion science applications. During this program, EHT developed several units that have been delivered to the Helicity Injected Torus (HIT) experiment at the University of Washington to deliver both the voltage and flux circuits of the helicity injectors. These units are capable of switching 700 V at 100 kHz with an adjustable duty cycle from 10 – 90% and a combined total output current of 96 kA for 4 ms (at max current). The SPAs switching is controlled by the microcontroller at HIT, which adjusts the duty cycle to maintain a specific waveform in the injector. The SPAs include overcurrent and shoot-through...


NP11 125 Study of Dislocation Loops in Ion-Irradiated Tungsten Using X-Ray Diffuse Scattering* PEIHAO SUN, High Energy Density Science Division, SLAC National Accelerator Laboratory; Department of Physics, Stanford University PHILIP HEIMANN, SLAC National Accelerator Laboratory YONGJIANG WANG, Los Alamos National Laboratory MUNGO FROST, High Energy Density Science Division, SLAC National Accelerator Laboratory CHRISTOPHER SCHONWALDER, High Energy Density Science Division, SLAC National Accelerator Laboratory; Friedrich-Alexander University ABRAHAM LEVITAN, MIANZHEN MO, ZHIJIANG CHEN, High Energy Density Science Division, SLAC National Accelerator Laboratory JEROME HASTINGS, SLAC National Accelerator Laboratory SIEGFRIED GLENZER, High Energy Density Science Division, SLAC National Accelerator Laboratory

As the material of choice for the divertor wall in tokamak fusion reactors, tungsten is exposed to high levels of radiation. As a result, a large amount of defects form inside the crystal, leading to significant changes in its thermal-mechanical properties. Therefore, it is important to understand the types and sizes of radiation-induces defects. X-ray diffuse scattering around Bragg peaks has been developed as a technique to solve this problem. By applying this technique to ion-irradiated tungsten, we have obtained quantitative data on the size-distribution of dislocation loops under different radiation levels.

*This work is supported by DOE FES under FWP 100182.

NP11 126 LOW TEMPERATURE PLASMAS


The electric breakdown of gases is one of the fundamental phenomena of gas discharge physics. It has been studied for a long time but still attracts incessant interest of researchers. Besides the interesting physics, breakdown is important for many applications including development of reliable electric insulation in electric grids and the study of different aspects of gas discharge physics. In this work an experimental study of the electric breakdown in helium gas for the plane–parallel electrode configuration has been conducted using a copper cathode and a variety of anode materials: copper, aluminum, stainless steel, graphite, platinum-plated aluminum and gold-plated aluminum. According to the Paschen law for studied electrode configuration, the breakdown voltage is a function of the product of gas pressure and inter-electrode gap. The breakdown processes on the left, lower pressure side of the Paschen curve have been the subject of this investigation. For those pressures, the Paschen curve may become multi-valued, where any given pressure corresponds to three levels.

NP11 128 Diamagnetism and neutrals depletion in low temperature plasma* AMNON FRUCHTMAN, Holon Inst of Technology SHUNJIRO SHINOHARA, DAI SUKE KUWAHARA, Tokyo University of Agriculture and Technology Recent study has shown that diamagnetism may be suppressed in low temperature plasma due to neutrals depletion [1]. Diamagnetism and neutrals depletion in low temperature plasma are explored here theoretically. Cylindrical plasma is considered with radial cross-field transport. Conditions are found for either diamagnetism or neutrals depletion being dominant. An unexpected non-monotonic variation of the plasma density with the plasma particle flux is demonstrated. It is shown that as plasma generation (and particle flux) increase, the plasma density first increases, as expected, but then, as particle flux is increased further, the plasma density surprisingly decreases. The decrease follows a decrease of plasma confinement due to increased plasma diamagnetism. In addition, it is shown that an increase of the magnetic field as the plasma density is kept constant results in a decrease of neutrals depletion, as suggested previously [2], while an increase of the magnetic field as the plasma particle flux is kept constant results in constant neutrals depletion.

*Supported by JSPS under Contract No. S14033, by the ISF, Grants No. 765/11 and 1581/16, and by NIFS budget code NIFS17KBA.

NP11 129 Characterization of the Electron Energy Distribution Function in a Penning Discharge* VALENTIN SKOUTNEV, PAUL DOURBAL, YEVGENY RAITSES, Princeton Plasma Physics Laboratory Slow and fast sweeping Langmuir probe diagnostics were implemented to measure the electron energy distribution function (EEDF) in a cross-field Penning discharge undergoing rotating spoke phenomenon. The EEDF was measured using the Druyvesteyn method [1]. Rotating spoke occurs in a variety of ExB devices and is characterized primarily by azimuthal light, density, and potential fluctuations on the order of a few kHz, but is theoretically still not well understood [2,3]. Characterization of a time-resolved EEDF of the spoke would be important for understanding physical mechanisms responsible for the spoke and its effects on Penning discharges, Hall thrusters, sputtering magnetrons, and other ExB devices. In this work, preliminary results of measurements of the EEDF using slow and fast Langmuir probes that sweep below and above the fundamental spoke frequency will be discussed.

*This work was supported by the Air Force Office of Scientific Research (AFOSR).

NP11 130 Removal of DLC film on polymeric materials by low temperature atmospheric-pressure plasma jet DAICHI KOBA YASHI, FUMIYUKI TANAKA, YOSHIIYUKI KASAI, JUNKI SAHARA, TOMOHIKO ASA I, Nihon University MASANORI HIRATSUKA, Nanotech Corp. MIKIO TAKATSU, Heiwa Electric Co., Ltd HARUHISA KO GUCHI, National Institute of Advanced Industrial Science and Technology Diamond-like carbon (DLC) thin film has various excellent functions. For example, high hardness, abrasion resistance, biocompatibility, etc. Because of these functionalities, DLC has been applied in various fields.
Removal method of DLC has also been developed for purpose of microfabrication, recycling the substrate and so on. Oxygen plasma etching and shot-blast are most common method to remove DLC. However, the residual carbon, high cost, and damage onto the substrate are problems to be solved for further application. In order to solve these problems, removal method using low temperature atmospheric pressure plasma jet has been developed in this work. The removal effect of this method has been demonstrated for DLC on the SUS304 substrate. The principle of this method is considered that oxygen radical generated by plasma oxidize carbon constituting the DLC film and then the film is removed. In this study, in order to widen application range of this method and to understand the mechanism of film removal, plasma irradiation experiment has been attempted on DLC on the substrate with low heat resistance. The DLC was removed successfully without any significant thermal damage on the surface of polymeric material.

NP11 131 Cross-field electron transport inside an insulating cylinder of a baffled probe∗ YEYGENY RAITSES, ANDREW ALT, Princeton Plasma Phys Lab Plasma-immersed wall experiments have been performed in a magnetized xenon plasma in a cross-field Penning configuration with density around \(10^{12}\) cm\(^{-3}\) and an electron temperature around a few eV. A cylinder with an open end and diameter of 1.4 mm was placed across field lines so that electrons were blocked from reaching a wire recessed behind the shield while ions were unimpeded. The reduction of electron current to the wire causes it to float closer to the plasma potential, possibly making a device that can passively measure plasma potential. However, the measured electron current was much higher than expected even when the wire was recessed several electron gyroradii behind the baffle. Possible mechanisms for this electron conduction causing the short circuiting to the bulk plasma have been studied with numerical approaches and with a dedicated experiment designed to isolate this short circuit effect. The obtained results may be important for cross-field transport in a variety of other configurations in magnetized, low-temperature plasmas.

∗This work was supported by DOE contract DE-AC02-09CH11466.

NP11 132 Experimental and Numerical Study of the Carbon Arc: Plasma Properties in the Region of Nanotube Synthesis∗ VLADISLAV VEKELMAN, ALEXANDER KHRABRY, IGOR KAGANOVICH, BRENTLEY STRATTON, YEYGENY RAITSES, Princeton Plasma Phys Lab A carbon arc for nanomaterial synthesis was comprehensively studied using spectroscopic techniques and electrical measurements and modeled by specially modified computationally fluid dynamic (CFD) code ANSYS. The carbon arc plasma is generated and sustained by ablation of the graphite anode. In this study the plasma and carbon composition is fully characterized in the synthesis region that is important for understanding of synthesis of carbon nanomaterials by the arc method. We applied planar laser induced fluorescence (LIF) diagnostic to obtain instantaneous distribution of \(\text{C}_2\) in carbon arc. In addition, the arc was characterized by optical emission spectroscopy (OES) and fast filtered imaging. Results of the current work revealed two main arc plasma regions defined as the arc core and the arc periphery different by composition of carbon species. The core represents the dense and hot plasma region conducting most of the discharge current which is self-consistently sustained. The arc periphery is colder and characterized by intensive formation of carbon molecules. The resulting radial distribution of carbon molecules has a distinguished hollow profile structure which is preserved regardless of the arc stochastic motion realized in some modes. These results are in agreement with results of two dimensional CFD simulations of the carbon arc under operating conditions used in experiments.

∗This work was supported by DOE Contract No. DE-AC02-09CH11466.

NP11 133 Development of SSUBPIC code for modeling the neutral gas depletion effect in helicon discharges∗ JEFFREY KOLLASCH, CARL SOVENIC, OLIVER SCHMITZ, University of Wisconsin – Madison The SSUBPIC (steady-state unstructured-boundary particle-in-cell) code is being developed to model helicon plasma devices. The envisioned modeling framework incorporates (1) a kinetic neutral particle model, (2) a kinetic ion model, (3) a fluid electron model, and (4) an RF power deposition model. The models are loosely coupled and iterated until convergence to steady-state. Of the four required solvers, the kinetic ion and neutral particle simulation can now be done within the SSUBPIC code. Recent SSUBPIC modifications include implementation and testing of a Coulomb collision model (Lemons et al., JCP, 228(5), pp. 1391-1403) allowing efficient coupling of kinetic-treat ions to fluid electrons, and implementation of a neutral particle tracking mode with charge-exchange and electron impact ionization physics. These new simulation capabilities are demonstrated working independently and coupled to “dummy” profiles for RF power deposition to converge on steady-state plasma and neutral profiles. The geometry and conditions considered are similar to those of the MARIA experiment at UW-Madison. Initial results qualitatively show the expected neutral gas depletion effect in which neutrals in the plasma core are not replenished at a sufficient rate to sustain a higher plasma density.

∗This work is funded by the NSF CAREER award PHY-1455210 and NSF Grant PHY-1206421.

NP11 134 Investigation of Dusts Effect and Negative Ion in DC Plasmas by Electric Probes HYE TAEK OH, INJE KANG, MIN-KEUN BAE, INSUN PARK, SEUNGHWA LEE, SEOJIN JEONG, KYU-SUN CHUNG, Department of Electrical Engineering, Hanyang University Dust is typically negatively charged by electron attachment whose thermal velocities are fast compared to that of the heavier ions. The negatively charged particles can play a role of negative ions which affect the quasi-neutrality of background plasma. To investigate effect of metal dusts and negative ion on plasma and materials, metal dusts are injected into background Ar plasma which is generated by tungsten filament using dust dispenser on Cubical Plasma Device (CPD). The CPD has following conditions: size=24x24x24cm\(^3\), plasma source=DC filament plasma (\(n_e \approx 1X10^{10}\), \(T_e \approx 2\text{eV}\)), background gas=Ar, dusts=tungsten powder (diameter \(\approx 1.89\text{micron}\)). The dust dispenser is developed to quantitate of metal dust by ultrasonic transducer. Electronegative plasmas are generated by adding \(\text{O}_2+\text{Ar}\) plasma to compare negative ion and dust effect. A few microns of micron-sized dusts are placed in the dust dispenser which is located at the upper side of the Cubical Plasma Device. The falling particles by dust dispenser are mainly charged up by the collection of the background plasma. The change in parameters due to negative ion production are characterized by measuring the floating and plasma potential, electron temperature and negative ion density using electric probes.

NP11 135 Control of radical and ion production in chlorine plasma∗ DAVID CARON, EARL SCIIME, West Virginia University COSTEL BILOIU, Applied Materials Chlorine gas is widely used
in the nanochip industry for ion etching of silicon wafers. As feature sizes on chips shrink, greater control of ion production is needed. Despite its popularity as an etching gas, it is difficult to control the dissociation and densities of ions and radicals. In this work, rare gas actinometry is used to determine an absolute number density for Cl₂. Plasma parameters are then varied to control chlorine densities. We focus on obtaining the measurements using an argon or krypton dopant while confirming previous work done with xenon. Density measurements are achieved by comparing the relative peak intensities produced in an inductively coupled chlorine plasma mixed with 5% rare gas. The plasma is sampled using line-of-sight spectroscopy in the source and across a blank silicon wafer. The benefit of creating a scheme for these rare gases is that argon and krypton provide stronger spectral lines and are cheaper than xenon. This work demonstrates a method for chlorine ion and radical production that will allow the precise control needed for nanochip etching.

*This work was supported by U.S. National Science Foundation Grant No. PHY-1617880.

NP11 136 Electron density measurement of non-equilibrium atmospheric pressure plasma using dispersion interferometer*

SHINJI YOSHIMURA, HIROSHI KASAHARA, TSUYOSHI AKIYAMA, National Institute for Fusion Science, National Institutes of Natural Sciences Medical applications of non-equilibrium atmospheric plasmas have recently been attracting a great deal of attention [1], where many types of plasma sources have been developed to meet the purposes. For example, plasma-activated medium (PAM), which is now being studied for cancer treatment [2], has been produced by irradiating non-equilibrium atmospheric pressure plasma with ultrahigh electron density to a culture medium [3]. Meanwhile, in order to measure electron density in magnetic confinement plasmas, a CO₂ laser dispersion interferometer has been developed and installed on the Large Helical Device (LHD) at the National Institute for Fusion Science, Japan [4]. The dispersion interferometer has advantages that the measurement is insensitive to mechanical vibrations and changes in neutral gas density. Taking advantage of these properties, we applied the dispersion interferometer to electron density diagnostics of atmospheric pressure plasmas produced by the NU-Global HUMAP-WSAP-50 device, which is used for producing PAM.

*This study was supported by the Grant of Joint Research by the National Institutes of Natural Sciences (NINS).


NP11 137 Characterization of a plasma photonic crystal using a multi-fluid plasma model* W.R. THOMAS, U. SHUMLAK, Univ of Washington B. WANG, F. RIGHETTI, M.A. CAPPELLI, Stanford Plasma Physics Laboratory S.T. MILLER, Sandia National Laboratories Plasma photonic crystals have the potential to significantly expand the capabilities of current microwave filtering and switching technologies by providing high speed (μs) control of energy band/gap/pass characteristics in the GHz through low THz range. While photonic crystals consisting of dielectric, semiconductor, and metallic matrices have seen thousands of articles published over the last several decades, plasma-based photonic crystals remain a relatively unexplored field. Numerical modeling efforts so far have largely used the standard methods of analysis for photonic crystals (the Plane Wave Expansion Method, Finite Difference Time Domain, and ANSYS finite element electromagnetic code HFSS), none of which capture nonlinear plasma-radiation interactions. In this study, a 5N-moment multi-fluid plasma model is implemented using University of Washington’s WARPXM finite element multiphysics code. A two-dimensional plasma-vacuum photonic crystal is simulated and its behavior is characterized through the generation of dispersion diagrams and transmission spectra. These results are compared with theory, experimental data, and ANSYS HFSS simulation results.

*This research is supported by a Grant from United States Air Force Office of Scientific Research.

NP11 138 Particle-in-Cell Modeling of Magnetron Sputtering Devices JOHN R. CARY, University of Colorado T. G. JENKINS, N. CROSSETTE, PETER H. STOLTZ, Tech-X Corporation J. M. MCGUGAN, Northrop Grumman In magnetron sputtering devices, ions arising from the interaction of magnetically trapped electrons with neutral background gas are accelerated via a negative voltage bias to strike a target cathode. Neutral atoms ejected from the target by such collisions then condense on neighboring material surfaces to form a thin coating of target material; a variety of industrial applications which require thin surface coatings are enabled by this plasma vapor deposition technique. In this poster we discuss efforts to simulate various magnetron sputtering devices using the Verpal PIC code in 2D axisymmetric cylindrical geometry. Field solves are fully self-consistent, and discrete models for sputtering, secondary electron emission, and Monte Carlo collisions are included in the simulations. In addition, the simulated device can be coupled to an external feedback circuit. Erosion/deposition profiles and steady-state plasma parameters are obtained, and modifications due to self-consistency are seen. Computational performance issues are also discussed.

*and Tech-X Corporation.

NP11 139 Plasma Modeling with Speed-Limited Particle-in-Cell Techniques* THOMAS G. JENKINS, Tech-X Corporation G. R. WERNER, University of Colorado J. R. CARY, University of Colorado/Tech-X Corporation P. H. STOLTZ, Tech-X Corporation Speed-limited particle-in-cell (SLPIC) modeling is a new particle simulation technique [1] for modeling systems wherein numerical constraints, e.g. limitations on timestep size required for numerical stability, are significantly more restrictive than is needed to model slower kinetic processes of interest. SLPIC imposes artificial speed-limiting behavior on fast particles whose kinetics do not play meaningful roles in the system dynamics, thus enabling larger simulation timesteps and more rapid modeling of such plasma discharges. The use of SLPIC methods to model plasma sheath formation and the free expansion of plasma into vacuum will be demonstrated. Wall-clock times for these simulations, relative to conventional PIC, are reduced by a factor of 2.5 for the plasma expansion problem and by over 6 for the sheath formation problem; additional speedup is likely possible. Physical quantities of interest are shown to be correct for these benchmark problems. Additional SLPIC applications will also be discussed.

*Supported by US DoE SBIR Phase II Award DE-SC0015762.

NP11 140 Physical processes in high field insulating liquid conduction* MICHAEL MAZARAKIS, MARK...
KIEFNER, JOSHUA LECKBEE, DELMAR ANDERSON, FRANK WILKINS, ROBERT OBREGON, Sandia National Laboratories In the power grid transmission where a large amount of energy is transmitted to long distances, High Voltage DC (HVDC) transmission of up to 1MV becomes more attractive since is more efficient than the counterpart AC. However, two of the most difficult problems to solve are the cable connections to the high voltage power sources and their insulation from the ground. The insulating systems are usually composed of transformer oil and solid insulators. The oil behavior under HVDC is similar to that of a weak electrolyte. Its behavior under HVDC is dominated more by conductivity than dielectric constant. Space charge effects in the oil bulk near high voltage electrodes and impeded plastic insulators affect the voltage oil hold-off. We have constructed an experimental facility where we study the oil and plastic insulator behavior in an actual HVDC System. Experimental results will be presented and compared with the present understanding of the physics governing the oil behavior under very high electrical stresses.


NP11 143 Three-Dimensional FEM-PIC Simulation of Ion Extraction with CEX Collision* TAO HUANG, XIAOLIN JIN, MEIYU LIU, BIN LI, University of Electronic Science and Technology of China Electric propulsion has the characters of high specific impulse and total efficiency, which results in a reduction in the amount of propellant required for a given space mission or application compared to other conventional propulsion methods. Over the past few decades, its use in spacecraft has grown steadily worldwide, and the modeling and simulation techniques have been playing a more and more important role in developing advanced electric thrusters. In this paper, the ion extraction in the optics system of ion thruster was described, which solves particle trajectory, CEX collision, space charge, the Poisson’s equation self-consistently, as the three dimensional FEM-PIC method. The single and seven grid apertures models were considered, respectively. The spatiotemporal distributions of the total ion beam current and the generation of CEX ions were obtained, and the effects of CEX collision on ion extraction process were discussed.

*Fundamental Research Funds for the Central Universities (Grant Nos. ZYGX2016J065).

NP11 144 Multi-Fluid Simulations of Field Reversed Configuration Formation* EDER SOUSA, ERC Inc, AFRL ROBERT MARTIN, AFRL The use of field reversed configuration (FRC) have been studied extensively for fusion application but here we investigate them for propulsion purposes. FRCs have the potential to produce highly variable thrust and specific impulse using different gases as propellant. Aspects of the FRC formation physics, using a rotating magnetic field (RMF) at low power, are simulated using a multi-fluid plasma model. Results are compared with experimental observations with emphasis in the development of instabilities and robustness of the field reversal. The use of collisional radiative models are used to help compare experiment versus simulation results. Distribution A: Approved for public release; distribution unlimited; Clearance No. 17445.

*This work is supported by the Air Force Office of Scientific Research Grant Number 17RQCOR465.

NP11 142 Numerical Simulation of Discharge in the Ion Thruster Using BUMBLEBEE-EP Code* XIAOLIN JIN, SHENGLONG GUO, MINGJUAN YANG, TAO HUANG, BIN LI, University of Electronic Science and Technology of China Due to high efficiency, high specific impulse, long lifetime and high reliability, ion thrusters have already become the research focus of the electrical propulsion. Up to now, the numerical simulation of the ionization characteristics in the discharge chamber of ion thruster was mainly based on electrostatic model, which cannot give the important information on the electromagnetic radiation features and the self-consistent interaction between charged particles and time-varying electromagnetic fields. The 2D3V PIC/MCC code ‘BUMBLEBEE-EP’ was developed based on the electromagnetic model for the research of ion thruster. In this paper, the discharge process of the ion thruster was simulated using BUMBLEBEE-EP. The complete Maxwell’s equations were solved and the effects of the electromagnetic fields on the charged particles were taken into account in the self-consistent way. The spatiotemporal distribution of the charged particles and electromagnetic fields were obtained in detail.

*Fundamental Research Funds for the Central Universities (Grant Nos. ZYGX2016J065).

NP11 145 Current Driven Instabilities and Anomalous Mobility in Hall-effect Thrusters* JONATHAN TRAN, University of California, Los Angeles DANIEL ECKHARDT, ROBERT MARTIN, Air Force Research Laboratory Edwards AFB Due to the extreme cost of fully resolving the Debye length and plasma frequency, hybrid plasma simulations utilizing kinetic ions and quasi-steady state fluid electrons have long been the principle workhorse methodology for Hall-effect thruster (HET) modeling. Plasma turbulence and the resulting anomalous electron transport in HETs is a promising candidate for developing predictive models for the observed anomalous transport. In this work, we investigate the implementation of an anomalous electron cross field transport model for hybrid HET simulations such a HPHall. A theory for anomalous transport in HETs and current driven instabilities has been recently studied by
Lafleur et al. This work has shown collective electron-wave scattering due to large amplitude azimuthal fluctuations of the electric field. We will further adapt the previous results for related current driven instabilities to electric propulsion relevant mass ratios and conduct a preliminary study of resolving this instability with a modified hybrid (fluid electron and kinetic ion) simulation with the hope of integration with established hybrid HET simulations.

*This work is supported by the Air Force Office of Scientific Research award FA9550-17RQCOR465.

NP11 146 Improvement of Thrust Characteristics of Helicon Plasma Thruster using Local Gas Fueling Method* DAISUKE KUWAHARA, KOSUKE AMMA, YUICHI ISHIGAMI, AKIHIKO IGARASHI, SHINICHI NISHIMOTO, SHUNJIRO SHINOHARA, Tokyo Univ. of Agri. & Tech. JUNICHI MIYAZAWA, National Institute for Fusion Science A helicon plasma thruster is proposed as a long-lifetime electric thruster which has non-direct contact electrodes. Here, a neutral particle, e.g., H2, Ar, and Xe works, as a fuel gas. In most cases, these gases are supplied into a discharge tube by the use of a simple nozzle. Therefore, the neutral particle fills a discharge tube homogenously. However, there are two problems in this configuration. First, there is a limitation of an electron density increase, due to a neutral particle depletion in the central region of the high-density helicon plasma [1]. This limitation reduces the thrust performance directly. Second, the high-density plasma causes an erosion of an inner discharge tube wall. For the future MW class thruster, this problem will become serious because the particle and heat fluxes of the plasma will increase drastically. To solve above-mentioned problems, we have proposed local fueling method for the high-density helicon plasma. In this presentation, we will show the methods and experimental results using a fueling tube, inserted in a plasma directly.

*This work is supported by JPSP KAKENHI Grant Number 16K17843 and NIFS Collaboration Research program (NIF-SKBAF016).


NP11 147 High Frequency, Low Pressure, Plasma Generation using Extremely Small Diameter Tube TOMOYA YAMASE, HIROTAKA HORIZA, KOYUKO SATO, DIBYESH SATPATHY, KIIT Univ., India DAISUKE KUWAHARA, SHUNJIRO SHINOHARA, Tokyo Univ. of Agri. & Tech. Electrodeless electric propulsion method has a very long life compared with conventional electric propulsion method, because electrode and plasma do not have a direct contact each other, leading to no wear of the electrode [1]. In addition, miniaturization of the plasma generation unit is desired as one of important propulsion objectives. The generation of electrodeless plasma in a quartz tube with an inner diameter down to only 3 mm has already been succeeded by changing rf frequency, but there remains a problem of a high pressure (Lower limit 100 Pa range) operation [2]. Therefore, plasma generation under lower pressure (Lower limit 2 Pa range) by improving the experimental setup external parameters were performed. Here, the plasma characteristics was investigated, using the SHD device [3]. Furthermore, rf plasma generation has been performed with a diameter of only 1 mm.


NP11 148 Plasma Acceleration by Rotating Magnetic Field Method using Helicon Source* TAKERU FURUKAWA, KAICHISHIMURA, DAISUKE KUWAHARA, SHUNJIRO SHINOHARA, Tokyo Univ. of Agri. & Tech. Electrodeless plasma thrusters are very promising due to no electrode damage, leading to realize further deep space exploration. As one of the important proposals, we have been concentrating on Rotating Magnetic Field (RMF) [1] acceleration method [2,3]. High-density plasma (up to 1017 cm−3) can be generated by using a radio frequency (rf) external antenna, and also accelerated by an antenna wound around outside of a discharge tube. In this scheme, thrust increment is achieved by the axial Lorentz force caused by non linear effects. RMF penetration condition into plasma can be more satisfied than our previous experiment [4], by increasing RMF coil current and decreasing the RMF frequency, causing higher thrust and fuel efficiency. Measurements of AC RMF component s have been conducted to investigate the acceleration mechanism and the field penetration experimentally.

*This study has been partially supported by Grant-in-Aid for Scientific Research (B: 17H02995) from the Japan Society for the Promotion of Science.


NP11 149 Electrodeless Plasma Acceleration Using m = 0 Coil SHUICHI NISHIMURA, DAISUKE ARAI, TAKUYA YAMAGUCHI, DAISUKE KUWAHARA, SHUNJIRO SHINOHARA, Tokyo Univ. of Agri. & Tech. We have been investigating electrodeless plasma acceleration method by the Lorentz force, using m = 0 coil (m is an azimuthal mode number) without electrode erosion condition, which leads to a deep space exploration in future [1,2]. The Lorentz force of j-theta * Br is composed of two factors; the m = 0 coil can generate the azimuthal current j-theta by supplying an AC current (over 100 A) and the externally magnet make the static radial magnetic field Br in divergent field configuration. In the past m = 0 coil experiment using the SHD [3], we have found increases of ion velocity and electron density by a factor of 2.5 and 3, respectively. In this research, detailed measurement have been done as to ion velocity, electric density and the azimuthal current to clarify the effect of m = 0 coil method on plasma acceleration.


NP11 150 Graphene as a Coating for Plasma Facing Components* MARCOS NAVARRO, MARZIYEH ZAMIRI, GERALD KULCINSKI, MAX LAGALLY, JOHN SANTARIUS, University of Wisconsin-Madison This research explores the protection by graphene of plasma facing materials bombarded with energetic ions of helium. Few studies have shown that graphene can act as a protective layer against sputtering due to energetic ions. In the presence of such irradiation, plasma facing components (PFC’s) tend to develop surface morphologies that lead to the sputtering of wall material, potentially diminishing the lifetime of the PFC’s and plasma performance. Since plasmas have broad applications and the quality of transferred and grown graphene is different, we have used a chemical vapor deposition method to grow on other substrates. We have also shown that graphene can reduce changes on surface morphology due to energetic helium. After irradiation, in the case of graphene-covered tungsten, our results show that, compared to the uncovered W, graphene suppresses these morphologies that form on the surface of hot W. Using Raman spectroscopy as a diagnostic, the graphene coating shows little sign of damage after being irradiated, indicating that there is little to no sputtering of carbon impurities.
from the surface. We have determined that the mass losses in W have been reduced significantly, which may lead to an improved plasma performance and longer PFC lifetimes.

*Supported by DHS Project 2015-DN-077-ARI095 and the Grainger Foundation.

NP11 151 Thermomechanical and chemical properties of porous W/liquid Li hybrid systems as plasma-facing self-healing surfaces* AVEEK KAPAT, ERIC LANG, ANTON NEFF, JEAN PAUL ALLAIN, Department of Nuclear, Plasma and Radiological Engineering, University of Illinois, Urbana, IL The environmental conditions at the plasma-material interface of a future nuclear fusion reactor interacting will be extreme. The incident plasma will carry heat fluxes of the order of 100’s of MWm$^{-2}$ and particle fluxes that can average $10^{24}$ m$^{-2}$s$^{-1}$. The fusion reactor wall would need to operate at high temperatures near 800 C and the incident energy of particles will vary from a few eV ions to MeV neutrons. A hybrid system, inspired by self-healing solid-state concepts, combines the ductile phase of liquid Li within a solid phase porous W. The liquid Li serves to control hydrogen retention and provide vapor shielding, within the framework of a tunable porosity to optimize edge plasma conditions [2]. Additionally, the porous interface can also provide for effective defect sinks for high duty cycle neutron damage. The surface chemistry of liquid Li on a porous surface varied with D irradiation is studied and its effect on retention. Prior results with refractory alloys have demonstrated effective wetting properties [3]. These hybrid systems, as well as traditional W samples, are bombarded with 500eV D$_2^+$ and Ar$^+$ at 230°C and 300°C. The Li, O, and C XPS peaks were examined and compared to controls. Additionally, the porous W is characterized for thermo-mechanical properties.

*Work supported by USDOE Contract DE- DE-SC0014267.

NP11 152 Non-equilibrium electron energy distribution in oxygen plasma: observation with optical emission spectroscopy* JOHN BOFFARD, NATHANIEL LY, SHICONG WANG, COLIN SWEE, CHUN C. LIN, AMY WENDT, University of Wisconsin-Madison Partially ionized inductively-coupled RF oxygen plasmas are in widespread use for materials processing, and non-invasive diagnostics are of interest for the optimization and control of the degrees of ionization and dissociation. Our initial study involves a 2-5% admixture of argon for optical emission spectroscopy (OES) of the oxygen plasma glow. The Ar 420.1/419.8 nm line intensity ratio, previously used in other mixtures to compute electron temperature, when $< 1$, is also an indicator of a significant population of high energy ( > 35 eV) electrons [1]; the latter is observed under conditions of low power and high pressure in the oxygen plasma. We tentatively attribute the increase in energetic electrons to a transition to capacitive coupling, leading to electron acceleration to high energy in the sheaths adjacent to the powered electrode, which in this system is a spiral flat antenna separated from the plasma by a dielectric window. Investigations of OES methods involving additional species, including other trace rare gases [2], O, and O$_2^+$, to determine oxygen plasma properties such as non-Maxwellian electron energy distributions will also be described.

*Supported by NSF Grants PHY-1617602 and PHY-1068670.

1J. B. Boffard et al., PSST 24 (2015).

NP11 153 Mini-conference Posters: Bridging the Divide Between Space and Laboratory Plasma Physics

NP11 154 Laboratory Study of Wave Generation Near Diplorization Fronts* ERIK TEJERO, LON ENLOE, BILL AMATUCCI, CHRIS CRABTREE, GURU GANGULI, US Naval Research Laboratory Experiments conducted in the Space Physics Simulation Chamber at the Naval Research Laboratory (NRL) studying instabilities generated by small-scale plasma flows use plasma equilibrium that replicate those found in dipolarization fronts. It has previously been shown that these small-scale flows can generate waves in the lower hybrid range. Recent experiments at NRL have demonstrated that these flows can also generate electromagnetic waves in the whistler band. These waves are large amplitude, bursty waves that exhibit frequency chirps similar to whistler mode chorus. Recent results from these experiments will be presented.

*Work supported by the US Naval Research Laboratory Base Program and NASA Grant No. NNH17AE70L.

NP11 155 Exploring the role of Alfvén waves in heating the solar corona* SAYAK BOSE, Columbia University W. GEKELMAN, University of California at Los Angeles M. HAHN, Columbia University S. VINCENA, University of California at Los Angeles D.W. SAVIN, Columbia University The solar corona, the outer atmosphere of the Sun, is ~ 200 times hotter than the underlying visible surface of the Sun. Recent coronal observations find Alfvén wave damping at unexpectedly low heights in the corona, suggesting that Alfvén waves may contribute to the heating of the corona to temperatures of ~ 10^8 K. Dissipation of wave energy may occur due to gradients in the Alfvén speed along the coronal magnetic field lines. These gradients may cause wave reflection, which subsequently generates turbulence. Furthermore, the presence of gradients in the Alfvén speed across the magnetic field line may lead to phase mixing, which can promote additional nonlinear damping mechanisms.

We are studying various wave dissipation processes under conditions similar to the solar corona, using the Large Plasma Device (LAPD) at the University of California, at Los Angeles. Here we will present the results of our initial experiments exploring the effectiveness of gradients in the Alfvén speed along the magnetic field in reflecting Alfvén waves and reducing the amplitude of Alfvén waves transmitted across a gradient.

*This work is supported, in part, by the DoE, NSF, and NASA. The Basic Plasma Science facility is supported by the DoE OFES and the NSF.

NP11 156 Numerical Support for Applying Field-Particle Correlations to Space and Laboratory Plasmas KRISTOPHER KLEIN, Univ of Michigan - Ann Arbor GREGORY HOWES, University of Iowa FRANCESCO VALENTINI, Universita della Calabria Determining the mechanisms that transfer energy between electromagnetic fields and plasma particles, eventually leading to heating, is an important task in the study of a wide variety of plasma systems. Many different mechanisms have been proposed to mediate the energy transfer, which can be broadly classified as resonant, non-resonant, and intermittent. Each mechanism will preferentially en-
ergize particles with different velocities; such distinct features make the identification of energy transfer mechanisms possible assuming the velocity-space structure of the phase-space energy density transfer can be measured. Based upon the structure of the field-particle interaction term in the Vlasov equation, we construct a correlation using field and particle distribution timeseries from a single point in space which tracks the phase-space energy density transfer. We present such field-particle correlations calculated using data from a variety of turbulent kinetic simulations with the aim of eventual application of these correlations to space and laboratory plasma observations. Even in the presence of strong turbulence, we show that field-particle correlations calculated from a single-point data set can be used to determine the mechanisms responsible for the energy transfer.

NP11 157 Observational Evidence for Field-Particle Energy Transfer in the Earth’s Magnetosheath CHRISTOPHER CHEN, Queen Mary University of London KRIS KLEIN, University of Michigan GREG HOWES, University of Iowa One of the unanswered questions in space plasma turbulence is how the energy is dissipated at the small scale end of the turbulent cascade. To help address this, a technique was recently developed (Klein & Howes 2016 ApJL, Howes et al. 2017 JPP) to allow the field-particle energy transfer to be determined as a function of velocity space, enabling the different heating mechanisms to be distinguished, each of which has a characteristic signature. Here, we present the first application of this technique to data from the MMS mission in and around the Earth’s magnetosheath region. The velocity space energy transfer between the electromagnetic fields and plasma particles is measured and compared to theoretical predictions and numerical simulations of the different dissipation mechanisms, to determine which ones are taking place.

NP11 158 Using Field-Particle Correlations to Show that Landau Damping Leads to Spatially Intermittent Particle Energization in Current Sheets* GREGORY G. HOWES, ANDREW J. MCCUBBIN, University of Iowa KRISTOPHER G. KLEIN, University of Michigan Understanding the removal of energy from turbulent fluctuations in a magnetized plasma and the consequent energization of the constituent plasma particles is a major goal of heliophysics and astrophysics. Previous work has shown that nonlinear interactions among counterpropagating Alfvén waves—or Alfvén wave collisions—are the fundamental building block of astrophysical plasma turbulence and naturally generate current sheets in strong turbulence. A nonlinear gyrokinetic simulation of a strong Alfvén wave collision is used to examine the damping of the electromagnetic fluctuations and the associated energization of particles that occurs in self-consistently generated current sheets. A simple model explains the flow of energy due to the collisionless damping and the associated particle energization, as well as the subsequent thermalization of the particle energy by collisions. Using the recently developed field-particle correlation technique, we show that particles resonant with the Alfvén waves in the simulation dominate the energy transfer, demonstrating conclusively that Landau damping plays a key role in the spatially intermittent damping of the electromagnetic fluctuations and consequent energization of the particles in this strongly nonlinear simulation.

*NP11 159 Velocity-space cross-correlation matrix measurements and potential applications to space plasmas SEAN MATTINGLY, FRED SKIFF, University of Iowa We summarize a recent laboratory measurement of a velocity-space cross-correlation matrix. This matrix can be decomposed into a set of eigenmodes that can be compared to plasma kinetic fluctuation modes. The measurement is a local measurement that may be applied with any velocity-sensitive measurement technique. In the laboratory, this measurement is achieved with laser induced fluorescence. In the spirit of this miniconference, we discuss the criteria a velocity-sensitive measurement must fulfill for a velocity-space cross-correlation measurement to be taken in situ in space plasma.

NP11 160 Towards a turbulent magnetic dynamo platform KIRK FLIPPO, ALEXANDER RASMUS, HUILI SHENGTAI LI, Los Alamos National Laboratory CAROLYN KURANZ, JOSEPH LEVESQUE, SALLEE KLEIN, University of Michigan PETROS TZEFERACOS, University of Chicago It is known through astronomical observations that most of the Universe is ionized, magnetized, and often turbulent and filled with jets. One theorized process to create strong magnetic fields and jets is the turbulent magnetic dynamo. The magnetic dynamo is a fundamental process in plasma physics, taking kinetic energy and converting it to magnetic energy and is very important to planetary physics and astrophysics. We report on recent Omega EP experiments to produce platform with a turbulent plume of magnetized material with which to study the turbulent magnetic dynamo process. The laser interaction with the target can seed magnetic fields that can be advected into the plume and amplified to saturation by the turbulent magnetic dynamo process. The experimentally measured plume characteristics are compared to hydro code calculations.

NP11 161 Kinetic Theory and Fast Wind Observations of the Electron Strahl KONSTANTINOS HORAITES, Univ of Wisconsin, Madison STANISLAV BOLDYREV, Univ of Wisconsin, Madison; Space Science Institute LYNN B. WILSON III, ADOLOFO F. VIÑAS, NASA Goddard Space Flight Center JAN MERKA, NASA Goddard Space Flight Center; University of Maryland, Baltimore County, Goddard Planetary Heliophysics Institute Measurements of the electron velocity distribution function (vEFD) in the solar wind exhibit a high-energy, field-aligned beam of electrons, known as the “strahl”. We develop a kinetic model for the strahl population, based on the solution of the electron drift-kinetic equation at heliospheric distances where the plasma density, temperature, and the strength of the magnetic field decline as power-laws of the distance along a magnetic flux tube. We compare our model with the vEFD measured by the Wind satellite’s SWE strahl detector. The model is successful at predicting the angular width of the strahl for the Wind data at 1 AU, in particular, the scaling of the width with particle energy and background density. We report on recent Omega EP experiments to produce platform in colliding laser-produced plasmas* GENNADY FIKSEL, University of Michigan, Ann Arbor; MJ W. FOX, PPPL, Princeton, NJ S.X. HU, LLE, Rochester; NY M. ROSENBERG, LLNL, Livermore, CA D.B. SCHAEFFER, J. MATTEUCCI, A. BHATTACHARJEE, Princeton University, Princeton, NJ Magnetic reconnection experiments are conducted in a low-collisonality regime at the OMEGA EP facility. Magnetic fields are generated in expanding plasmas by the Biermann battery effect. Collision of multiple plasma bubbles produces a magnetic reconnection current sheet and drives magnetic reconnection. A novel aspect of these experiments is that a gap is introduced between the targets lowering the plasma density at the reconnection layer, and allowing high resolution proton radiography.

Proton radiography reveals, for the first time, a cascade of plasmoid instabilities from short wavelength to long wavelength. The initial short-wavelength tearing is strongly modified by plasma anisotropy driven by the counter-streaming flows forming the current sheet, and is a hybrid of Weibel and tearing instability. The results have implications for magnetic reconnection driven in low-collisionality, compressive systems such as planetary magnetospheres and the heliosheath. Results on particle energization during reconnection will be reported.

“*This work is supported by the Department of Energy (DOE) through Grants No. DE-NA0002731 and No. DE-SC0016249.

NP11 163 Magnetic Reconnection during Turbulence: Statistics of X-Lines and Heating COLBY HAGGERTY, MICHAEL SHAY, TULASI PARASHAR, WILLIAM MATTHAEUS, YAN YANG, University of Delaware MINPING WAN, South University of Science and Technology of China SERGIO SERVIDIO, University della Calabria PIN WU, Queens University Magnetic reconnection is a ubiquitous plasma phenomenon that has been observed in turbulent plasma systems. It is an important part of the turbulent dynamics and heating of space, laboratory and astrophysical plasmas. Recent simulation and observational studies have detailed how magnetic reconnection heats plasma and this work has developed to the point where it can be applied to larger and more complex plasma systems. We examine the statistics of magnetic reconnection in fully kinetic PIC simulations to quantify the role of magnetic reconnection on energy dissipation and plasma heating. We examine the distribution of reconnection rates at the x-points found in the simulation and find that their distribution is broader than the MHD counterpart, and the average value is approximately 0.1. Reconnection heating predictions are applied to the regions surrounding the identified x-points and this is used to study the role of magnetic reconnection in turbulent heating of plasma. The ratio of ion to electron heating rates is found to be consistent with magnetic reconnection predictions.

NP11 164 Partition of Heating During Magnetic Reconnection: Role of Exhaust Velocity MICHAEL SHAY, COLBY HAGGERTY, University of Delaware JAMES DRAKE, University of Maryland TAI PHAN, University of California Berkeley RUNGPOLOY PHAN KIEOKAEW, University of Exeter KITTIPAT MALAKIT, Thammasat University, Thailand Understanding how magnetic reconnection heats the plasma and how the energy is partitioned between electrons and ions is an important problem that has recently become under intense scrutiny in both space and laboratory studies of reconnection. In the strong magnetic shear limit of magnetic reconnection (low guide field), the production of counterstreaming beams due to magnetic field line contraction plays an important role in heating the plasma. The contraction velocity or outflow velocity controls both the magnitude of the heating and partition of the heating between electrons and ions. However, although it is known that often the outflow velocity is less than the upstream Alfvén speed, an understanding of why this is so is lacking. We show that the outflow velocity in reconnection is reduced by the ion exhaust temperature and derive a scaling relationship for this effect. Both kinetic PIC simulations and satellite observations are used to test this scaling prediction. The reduction in outflow speed is shown to be due to the firehose instability, which is suppressed for large guide field cases where the outflow speed matches the inflowing Alfvén speed. This scaling for the outflow is then applied to a general theory for plasma heating during magnetic reconnection.

NP11 165 Role of electron trapping during reconnection in laboratory are space plasmas∗ JAN EGEDAL, UW-Madison Experiments in VTF catalyzed an analysis of electron trapping, showing that electron pressure anisotropy will develop in the reconnection region [1]. The results inspired a kinetic model for anisotropic electron distributions recorded by the Wind spacecraft in the deep magnetotail [2]. The model was subsequently used to formulate a closure to the electron fluid equations, where the resulting Equations of State [3] permit electron trapping to be retained in two-fluid simulations [4]. Trapping has fundamental implications for the reconnection process, where it is the main driver of electron jets [4,5]. In the talk I will present the trapping model and how the circle between research in the laboratory, simulations, theory and spacecraft observations, now is being closed with observations of the narrow electron jets in the Terrestrial Reconnection Experiment (TREX) at UW-Madison [6].

∗This work was supported by NSF/DOE award DE-SC0013032 and NSF GEM award 1405166.


NP11 166 Electron Pressure Anisotropy in the Terrestrial Reconnection Experiment and the Magnetospheric Multiscale Mission∗ RACHEL MYERS, JAN EGEDAL, JOSEPH OLSON, SAMUEL GREESS, ALEXANDER MILLET-AYALA, MICHAEL CLARK, PAUL NONN, JOHN WALLACE, CARY FOREST, University of Wisconsin-Madison The NASA Magnetospheric Multiscale (MMS) Mission seeks to measure heating and motion of charged particles from reconnection events in the magnetotail and dayside magnetopause. MMS is paralleled by the Terrestrial Reconnection Experiment (TREX) at the Wisconsin Plasma Astrophysics Laboratory (WiPAl) in its study of collisionless magnetic reconnection. In the regimes seen by TREX and MMS, electron pressure anisotropy should develop, driving large-scale current layer formation [1]. MMS has witnessed anisotropy, but the spatial coverage of the data is too limited to determine how the pressure anisotropy affects jet and current layer creation [2]. Measurements of pressure anisotropy on TREX will be presented, and implications for reconnecting current layer structure in the magnetosphere, as measured by MMS, will be discussed.

∗This research was conducted with support from a UW-Madison University Fellowship as well as the NSF/DOE award DE-SC0013032.


NP11 167 Accessing the Asymmetric Collisionless Reconnection Regime in the Terrestrial Reconnection Experiment (TREX)∗ SAMUEL GREESS, JAN EGEDAL, JOSEPH OLSON, ALEXANDER MILLET-AYALA, RACHEL MYERS, JOHN WALLACE, MICHAEL CLARK, CARY FOREST, University of Wisconsin-Madison Kinetic effects are expected to dominate the collisionless reconnection regime, where the mean free path is large enough that the anisotropic electron pressure can develop without being damped away by collisional pitch angle scattering. In simulations,
the anisotropic pressure drives the formation of outflow jets [1]. These jets are expected to play a role in the reconnection layer at the Earth's magnetopause, which is currently being explored by Magnetospheric Multiscale Mission (MMS) [2]. Until recently, this regime of anisotropic pressure was inaccessible by laboratory experiments, but new data from the Terrestrial Reconnection Experiment (TREX) shows that fully collisionless reconnection can now be achieved in the laboratory. Future runs at TREX will delve deeper into this collisionless regime in both the antiparallel and guide-field cases.

*Supported in part by NSF/DOE award DE-SC0013032.

1A. Le et al., JPP, 81(1), doi: 10.1017/S0022377814000907.

NP11 168 Energy conversion in the asymmetric reconnection diffusion region SHAN WANG, LI-JEN CHEN, NAOKI BESSHO, University of Maryland College Park, Goddard Space Flight Center MICHAEL HESSE, University of Bergen, Norway MMS TEAM The energy conversion in the diffusion region during asymmetric reconnection is studied using two-dimensional particle-in-cell (PIC) simulations. The energy partition is region-dependent and varies with the guide field strength. Without a guide field, within the central electron diffusion region, the input magnetic energy is mostly converted to electron thermal energies; half of the input energy to the region from the X-line to the peak ion outflow location is converted to the plasmas energy, with approximately equal partition between ions and electrons, similar to the laboratory results from the Magnetic Reconnection Experiment (MRX); over the entire ion diffusion region, about half of the energy goes to ions, and 20% goes to electrons. Electrons obtain energies mainly from the reconnect electric field (E_r), while the in-plane electrostatic fields (E_p) have a net negative contribution. For the ion total energy gain in the diffusion region, about 2/3 is from E_0 and 1/3 is from E_b. Adding a guide field tends to reduce the plasmas energy gain. The energy partition in the diffusion region observed by the Magnetospheric Multiscale (MMS) Mission will be estimated and compared with the PIC and MRX results.

NP11 169 Issues in Space Physics in Need of Reconnection with Laboratory Physics* B. COPPL, MIT Predicted space observations, such as the “foot” in front of collisionless shocks or the occurrence of magnetic reconnection in the Earth’s magnetotail leading to auroral substorms, have highlighted the fruitful connection of laboratory and space plasma physics. The emergence of high energy astrophysics has then benefitted by the contribution of experiments devised for fusion research to the understanding of issues such as that of angular momentum transport processes that have a key role in allowing accretion of matter on a central object (e.g. black hole). The theory proposed for the occurrence of spontaneous rotation in toroidal plasmas was suggested by that developed for accretion. The particle density values, ρ ≃ 10^15 cm^-3 that are estimated to be those of plasmas surrounding known galactic black holes have in fact been produced by the Alcator and other machines. Collective modes excited in the presence of high energy particle populations in laboratory plasmas (e.g. when the “slide away” regime has been produced) have found successful applications in space. Magnetic reconnection theory developments and the mode particle resonances associated with them have led to envision new processes for novel high energy particle acceleration.

NP11 170 Kinetic instabilities and reconnection in flux ropes under laboratory and space conditions GIOVANNI LAPENTA, KU Leuven PAOLO PIOVESAN, IGI-CNR ALEJANDRO ALVAREZ LAGUNA, KU Leuven and Von Karman Institut ELISA BETTA BOELLA, STEFANAS POEDTS, KU Leuven Reconnection converts magnetic energy forming hot flows of matter and Poynting fluxes. Reconnection happens in laboratory either by design (in experiments designed to study it) or as byproduct of other experiments (e.g. sawtooths in tokamaks). Reconnection is also often observed in situ or remotely in space systems. Among the conditions leading to reconnection, the kinking of a flux rope is amongst the most observed: in the solar corona, the Earth magnetosphere and in laboratory plasmas. We consider here specifically two conditions of current interest. First, the conditions expected in the DIII-D device where kinking can be induced with appropriate setup [1] and the flux ropes observed by the NASA mission MMS in the Earth magnetopause [2]. In both cases, flux ropes become unstable to a number of competing modes, drift modes and kink modes [3]. We investigate the relative importance and interplay of these two families of modes and their impact on reconnection. Our approach will be taking into account observational data and computer simulation making a direct comparison of the two.

1DIII-D Frontier Science Campaign, https://tinyurl.com/ya5o9z7m.

NP11 171 Formation and Evolution of Laser-Driven, High-Mach-Number Magnetized Collisionless Shocks DEREK SCHAEFFER, Princeton University WILL FOX, Princeton Plasma Physics Laboratory GENNADY FIKSEL, University of Michigan, Ann Arbor AMITAVA BHATTACHARJEE, Princeton University, Princeton Plasma Physics Laboratory DUSTIN FROULA, DAN HABERBERGER, DAN BARNAK, SUXING HU, Laboratory for Laser Energetics, University of Rochester KAI GERMASCHEWSKI, University of New Hampshire, Durham Recent experiments [1] demonstrated the laboratory generation of high-Mach-number, magnetized collisionless shocks through the interaction of a laser-driven piston plasma with a pre-formed magnetized ambient plasma. We present additional results on collisionless shock formation, structure, and evolution from new experiments and numerical simulations. These include angular filter refractometry and Thomson scattering measurements of the density and temperature of the piston and ambient plasmas and their interaction, and proton radiography measurements of the dynamics of the magnetic field. Related studies on the role of collisionless coupling, magnetic field overshoots, particle heating, and the MHD jump conditions in piston-driven shocks were undertaken with the 2D particle-in-cell code PSC. The results provide improved understanding of laboratory-generated magnetized collisionless shocks and their relationship to shocks in astrophysical systems.


NP11 172 Magnetized jet creation using a ring laser and applications EDISON LIANG, Rice University IAN GAO, Princeton University YINGCHAO LU, Rice University HANTAO JI, Princeton University RUSS FOLLETT, DUSTIN FROULA, LLNL ROCHESTER PETROS TZEFERACOS, DONALD LAMB, University of Chicago ANDREW BICKEL, HONG SIO, CHI KIANG LI, RICHARD PE-
TRASSO, MIT MINGSHEUNG WEI, General Atomic WEN FU, LILY HAN, Rice University We have recently demonstrated a new robust platform of magnetized jet creation using 20 OMEGA beams to form a hollow ring. We will present the latest experimental results and their theoretical interpretation, and explore potential applications to laboratory astrophysics, fundamental plasma physics and other areas. We will also discuss the scaling of this platform to future NIF experiments.

NP11 173 Scaling Arguments for Magnetically Affected Shock Experiments∗ R. P. YOUNG, C. C. KURANZ, University of Michigan C. K. LI, Massachusetts Institute of Technology P. HARTIGAN, A. LIAO, Rice University D. FROULA, Laboratory for Laser Energetics G. FIKSEL, University of Michigan J. S. ROSS, Lawrence Livermore National Laboratory P. Y. CHANG, Laboratory for Laser Energetics M. J.-E. MANUEL, General Atomics J. M. LEVESQUE, S. KLEIN, University of Michigan A. ZYLSTRA, Los Alamos National Laboratory H. W. SIO, Massachusetts Institute of Technology D. BARNAK, Laboratory for Laser Energetics In this talk we will discuss general scaling arguments applicable to magnetically affected shock experiments and their inherent challenges. This genre of experiments is rapidly growing and holds enormous promise for the field of laboratory astrophysics, but universally faces two basic constraints. First, the conditions must be right for a shock to form, and, second, the magnetic field strength must be strong enough to affect the structure and/or evolution of the shock. We will present the ramifications of these constraints, their effect on recent experiments we fielded, and current efforts underway to overcome them.

∗This work is funded by the U.S. Department of Energy, through the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, Grant Number DE-NA0002956, and the National User Facility Program, Grant Number DE-NA0002719, and for the Laboratory for Laser Energetics, University of Rochester by the NNSA/OICF under Cooperative Agreement No. DE-NA0001944.

NP11 174 Quasi-nonlinear approach to the Weibel instability∗ MIKHAIL MEDVEDEV, KU and MIT Astrophysical and high-energy-density laboratory plasmas often have large-amplitude, sub-Larmor-scale electromagnetic fluctuations excited by various kinetic-streaming or anisotropy-driven instabilities. The Weibel (or the filamentation) instability is particularly important because it can rapidly generate strong magnetic fields, even in the absence of seed fields. Particles propagating in collisionless plasmas with such small-scale magnetic fields undergo stochastic deflections similar to Coulomb collisions, with the magnetic pitch-angle diffusion coefficient representing the effective “collision” frequency. We show that this effect of the plasma “quasi-collisionality” can strongly affect the growth rate and evolution of the Weibel instability in the deeply nonlinear regime. This result is especially important for understanding cosmic-ray-driven turbulence in an upstream region of a collisionless shock of a gamma-ray burst or a supernova. We demonstrate that the quasi-collisions caused by the fields generated in the upstream suppress the instability slightly but can never shut it down completely. This confirms the assumptions made in the self-similar model of the collisionless foreshock.

∗The authors acknowledge DOE support via Grant DE-SC0016368.

NP11 175 Driving Fast Flows with Volumetric Current Drive∗ JASON MILHONE, D. ENDRIZZI, K. FLANAGAN, M.D. NORMBERG, E.E. PETERSON, C.B. FOREST, University of Wisconsin-Madison Volumetric current drive has been shown to be an efficient method for driving fast flows with high Rm for studying the onset of flow-driven plasma instabilities. High performance plasmas are produced with 20 kW of electron cyclotron heating (ECH) and thermally emissive lanthanum hexaboride cathodes. Plasma flow is achieved by injecting current through the plasma across an externally applied weak magnetic field setting up a J × B body force on the plasma volume. Two scenarios for volumetric current drive have been demonstrated. The first injects current across a weak uniform axial magnetic field driving a Keplerian-like flow for magneto-rotational instability (MRI) studies. The second injects current across a weak quadrupole magnetic field for driving a von Karman-like flow for dynamo studies. First results measuring velocity and ion temperature profiles measured by a Fabry-Perot interferometer are shown. Detailed mach probe flow measurements show stronger flow shear in volumetric current drive compared to previous edge-driven plasma flow experiments.

∗Work funded by NSF and DOE.

NP11 176 Equilibrium and Stability Properties of Low Aspect Ratio Mirror Systems: from Neutron Source Design to the Parker Spiral∗ ETHAN PETERSON, JAY ANDERSON, MIKE CLARK, JAN EGEDAL, DOUGLAS ENDRIZZI, KEN FLANAGAN, Univ of Wisconsin, Madison ROBERT HARVEY, CompX JACOB LYNN, JASON MILHONE, JOHN WALLACE, ROGER WALEFFE, VLADIMIR MIRONOV, CARY FOREST, Univ of Wisconsin, Madison Equilibrium reconstructions of rotating magnetospheres in the lab are computed using a user-friendly extended Grad-Shafranov solver written in Python and various magnetic and kinetic measurements. The stability of these equilibria are investigated using the NIMROD code with two goals: understand the onset of the classic “wobble” in the heliospheric current sheet and demonstrating proof-of-principle for a laboratory source of high-β turbulence. Using the same extended Grad-Shafranov solver, equilibria for an axisymmetric, non-paraxial magnetic mirror are used as a design foundation for a high-field magnetic mirror neutron source. These equilibria are numerically shown to be stable to the m=1 flute instability, with higher modes likely stabilized by FLR effects; this provides stability to gross MHD modes in an axisymmetric configuration. Numerical results of RF heating and neutral beam injection (NBI) from the GENRAY/CQL3D code suite show neutron fluxes promising for medical radioisotope production as well as materials testing. Synergistic effects between NBI and high-harmonic fast wave heating show large increases in neutron yield for a modest increase in RF power.

∗Work funded by DOE, NSF, NASA.

NP11 177 Observations of magnetic pumping in the solar wind using MMS data∗ EMILY LICHKO, JAN EGEDAL, University of Wisconsin - Madison WILLIAM DAUGHTON, Los Alamos National Laboratory JUSTIN KASPER, University of Michigan The turbulent cascade is believed to play an important role in the energization of the solar wind plasma. However, there are characteristics of the solar wind that are not readily explained by the cascade, such as the power-law distribution of the solar wind speed. Starting from
the drift kinetic equation, we have derived a magnetic pumping model, similar to the magnetic pumping well-known in fusion research, that provides an explanation for these features. In this model, particles are heated by the largest scale turbulent fluctuations, providing a complementary heating mechanism to the turbulent cascade. We will present observations of this mechanism in the bow shock region using data from the Magnetospheric MultiScale mission.

*This research was conducted with support from National Defense Science and Engineering Graduate (NDSEG) Fellowship, 32 CFR 168, as well as from NSF Award 1404166 and NASA award NNX15AJ73G.

NP11 178 Interaction of a Relativistic Electron Beam with Magnetized Plasma* SETH DORFMAN, University of California, Los Angeles VADIM ROYERTSHTEYN, Space Science Institute CYNTHIA CATTELL, University of Minnesota BART VAN COMPERNOLLE, University of California, Los Angeles GIAN LUCA DELZANNO, Los Alamos National Laboratory The interaction between relativistic electron beams and a magnetized plasma is a fundamental and practical problem that is relevant to many challenging issues in space physics and astrophysics. For example, it is well known that energetic particles in the Earth’s radiation belts pose a danger to communication satellites. Compact electron beam sources may be used on future spacecraft to generate waves that would remove the energetic particles from the radiation belt region. A full understanding of the physics of these waves may also shed light on the mechanism for type II/III solar radio emissions. This talk will discuss experiments proposed to further advance understanding of the physical mechanisms governing beam-plasma interactions. The experiments and supporting simulations will investigate in detail the types of waves (whistler, Langmuir, etc.) produced by high-energy beams, beam stability, and feasibility for future space-based experiments. Experiments will be conducted on the Large Plasma Device (LAPD) at UCLA using a unique variable-energy electron beam recently developed at Los Alamos. We will discuss the proposed experimental setup as well as ongoing feasibility studies conducted using theoretical estimates and kinetic simulations.

*Supported by NSF.

NP11 179 How to emit a high-power electron beam from a magnetospheric spacecraft? FEDERICO LUCCO CASTELLO, GIAN LUCA DELZANNO, Los Alamos National Laboratory JOSEPH BOROVSKY, Space Science Institute GRANT MIARS, OMAR LEON, BRIAN GILCHRIST, University of Michigan The idea of using high-power electron beams to actively probe magnetic-field-line connectivity in space has been discussed since the 1970’s. It could solve longstanding questions in magnetospheric/ionospheric physics by establishing connectivity and causality between phenomena occurring in the magnetosphere and their image in the ionosphere [1]. However, this idea has never been realized onboard a magnetospheric spacecraft because the tenuous magnetospheric plasma cannot provide the return current necessary to keep the spacecraft charging under control. Recently, we have used Particle-In-Cell simulations to propose a spacecraft-charging mitigation scheme that would enable the emission of a high-power electron beam from a magnetospheric spacecraft [2]. In this work, we will present an overview of the concept and of our theoretical, computational and experimental effort to establish this idea conclusively.

NP11 180 Modeling-challenge paradigm using design of experiments for spacecraft immersed in nonstationary, between-regimes, flowing plasma ME KOEPKE, West Virginia Univ R MARCHAND, Univ of Alberta A conducting sphere and cylinder under the conditions of nonstationary, between-regimes, flowing plasma is adopted as a test case for a modeling-challenge paradigm based on design of experiments (DOE) methodology that merges numerical simulation and testing. This model/simulation development platform facilitates a red-team/blue-team style challenge aimed at a tailored set of standard experimental conditions and measurements addressing specific questions in spacecraft-environment interactions and assessing the capability of models to describe those conditions. The goal is streamlining the Model/Simulation development process. A byproduct is an enhancement of the interrelationship between experiments in the laboratory and in space. Here, we conceptualize the advantage of the model-challenge over conventional validation in advancing whole-device modeling objectives in basic and applied plasma science.

NP11 181 Laboratory observation of multiple double layer resembling space plasma double layer PRINCE ALEX, SARA-VANAN ARUMUGAM, SURAJ SINHA, Pondicherry University Perceptible double layer consisting of more than one layers were produced in laboratory using a double discharge plasma setup. The confinement of oppositely charged particles in each layer with sharply defined luminous boarder is attributed to the self-organization scenario. This structure is generated in front of a positively biased electrode when the electron drift velocity ($v_d$) exceeds 1.3 times the electron thermal velocity ($v_{te}$). Stable multiple double layer structures were observed only between $1.3 v_{te} \leq v_d \leq 3 v_{te}$. At $v_d = 1.3 v_{te}$, oscillations were excited in the form of large amplitude burst followed by a high frequency stable oscillation. Beyond $v_d = 3 v_{te}$, multiple double layer begins to collapse which is characterized by an emergence in turbulence. Long range dependence in the corresponding electrostatic potential fluctuations indicates the role of self-organized criticality in the emergence of turbulence. The algebraic decaying rate of the autocorrelation function and power law behavior in the power spectrum are consistent with the observation.

NP11 182 Experimental Simulation of Solar Wind Interactions with Magnetic Dipole Fields above Insulating Surfaces* TO-BIN MUNSAT, JAN DECA, JIA HAN, MIHALY HORANYI, XU WANG, GREG WERNER, LI HSIA YEO, University of Colorado DOMINIC FUENTES, California State University, East Bay Magnetic anomalies on the surfaces of airless bodies such as the Moon interact with the solar wind, resulting in both magnetic and electrostatic deflection of the charged particles and thus localized surface charging. This interaction is studied in the Colorado Solar Wind Experiment with large-cross-section (~300 cm²) high-energy flowing plasmas (100-800 eV beam ions) that are incident upon a magnetic dipole embedded under various insulating surfaces. Measured 2D plasma potential profiles indicate that in the dipole lobe regions, the surfaces are charged to high positive potentials due to the collection of unmagnetized ions, while the electrons are magnetically shielded. At low ion beam energies, the surface potential follows the beam

*Supported by NSF.
energy in eV. However, at high energies, the surface potentials in the electron-shielded regions are significantly lower than the beam energies. A series of studies indicate that secondary electrons are likely to play a dominant role in determining the surface potential. Early results will also be presented from a second experiment, in which a strong permanent magnet with large dipole moment (0.55 T, 275 A²m²) is inserted into the flowing plasma beam to replicate aspects of the solar wind interaction with the earth’s magnetic field.

*This work is supported by the NASA SSERVI program.

NP11 183 How high energy fluxes may affect Rayleigh-Taylor instability growth in young supernova remnants* C.C. KURANZ, University of Michigan H.-S. PARK, C.M. HUNTINGTON, A.R. MILES, B.A. REMINGTON, Lawrence Livermore National Laboratory R.P. DRAKE, M.A. TRANTHAN, T.A. HANDY, D. SHVARTS, University of Michigan G. MALAMUD, A. SHIMONY, Nuclear Research Center D. SHVARTS, University of Michigan J. KLINE, K.A. FLIPPO, F.W. DOSS, Los Alamos National Laboratory T. PLEWA, Florida State University Energy-transport effects can alter the structure that develops as a supernova evolves into a supernova remnant. The Rayleigh Taylor instability is thought to produce structure at the interface between the stellar ejecta and the circumstellar matter, based on simple models and hydrodynamic simulations. Simulations predict that RT produces structures at this interface, having a range of spatial scales. When the CSM is dense enough, as in the case of SN 1993J, the hot shocked matter can produce significant radiative fluxes that affect the emission from the SNR. Here we report experimental results from the National Ignition Facility to explore how large energy fluxes, which are present in supernovae such as SN 1993J, might affect this structure. We present data and simulations from Rayleigh-Taylor instability experiments in high- and low-energy flux experiments performed at the National Ignition Facility. We also will discuss the apparent, larger role of heat conduction when we closely examined the comparison between the experimental results, and the SNR observations and models.

*This work is funded by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, Grant Number DE-NA0002956.

Invited Papers

14:00

PT2 1 Experiments and models of MHD jets and their relevance to astrophysics and solar physics* PAUL BELLAN, Caltech

MHD-driven flows exist in both space and lab plasmas because the MHD force-balance equation \( \mathbf{J} \times \mathbf{B} - \nabla P = 0 \) can only be satisfied in situations having an unusual degree of symmetry. In the normal situation where such symmetry does not exist, an arbitrary magnetic field \( \mathbf{B} \) and its associated current \( \mathbf{J} = \mu_0^{-1} \nabla \times \mathbf{B} \) provide a magnetic force \( \mathbf{F} = \mathbf{J} \times \mathbf{B} \) having the character of a torque, i.e., \( \nabla \times \mathbf{F} \neq 0 \). Because \( \nabla \times \nabla P = 0 \) is a mathematical identity, no pressure gradient can balance this torque so a flow is driven. Additionally, since ideal MHD has magnetic flux frozen into the frame of the moving plasma, the flow converges frozen-in magnetic flux. If the flow slows and piles up, both the plasma and the frozen-in magnetic flux will be compressed. This magnetic flux compression amplifies both the frozen-in \( \mathbf{B} \) and its associated \( \mathbf{J} \). Slowing down thus increases certain components of \( \mathbf{F} \), in particular the pinch force associated with the electric current in the flow direction. This increased pinching causes the flow to self-collimate if the leading edge of the flow moves slower than the trailing part so there is compression in the flow frame. The result is that the flow self-collimates and forms a narrow jet. Self-collimating jets with embedded electric current and helical magnetic field are analogous to the straight cylindrical approximation of a tokamak, but now with the length of the cylinder continuously increasing and the radius depending on axial position. The flows are directed from axial regions having small radius to axial regions...
having large radius. The flow velocity is proportional to the axial electric current and is a significant fraction of the Alfvén velocity. Examples of these MHD-driven flows are astrophysical jets, certain solar coronal situations, and the initial plasma produced by the coaxial magnetized plasma guns used for making spheromaks. The above picture has been developed from laboratory measurements, analytic models, and numerical simulations. Upon attaining a critical length, laboratory jets develop a complex but resolvable sequence of instabilities which is effectively a cascade from the large-scale MHD regime to the small-scale two-fluid and kinetic regimes. This cascade involves kinking, Rayleigh-Taylor instabilities, magnetic reconnection, whistler waves, ion and electron heating, and generation of hard X-rays. An extended model shows how clumps of particles in a weakly ionized accretion disk move like a metaparticle having its charge to mass ratio reduced from that of an ion by the fractional ionization. These weakly charged metaparticles follow an inward spiral trajectory that is neither a cyclotron nor a Kepler orbit and accumulate at small radius where they produce a disk-plane radial EMF that drives astrophysical jets.

*Supported by DOE, NSF, and AFOSR.
instability (MRI). As the MRI saturates into strong turbulence, it also generates ordered magnetic fields, acting as a magnetic dynamo powered by the background shear flow. However, despite its importance for astrophysical accretion processes, basic aspects of MRI turbulence—including its saturation amplitude—remain poorly understood. In this talk, I will outline progress towards improving this situation, focusing in particular on the nonlinear shear dynamo and how this controls the turbulence. I will discuss how novel statistical simulation methods can be used to better understand this shear dynamo, in particular the distinct mechanisms that may play a role in MRI turbulence and how these depend on important physical parameters.

15:30
PI3 4 A New Scaling for Divertor Detachment∗
ROBERT GOLDSTON, Princeton Plasma Physics Laboratory

The ITER design and future fusion power plant designs depend on divertor detachment, whether partial, pronounced or complete, both to limit heat flux to plasma-facing components and to limit surface erosion due to sputtering. Generally the parallel heat flux, estimated as proportional to $P_{sep}/R$ or $P_{sep} B/R$, is used as a proxy for the difficulty of achieving detachment. Here we argue that the impurity cooling required for detachment is strongly dependent on the upstream separatrix density, which is limited by Greenwald scaling. Taking this into account self-consistently, along with the Heuristic Drift (HD) model for the SOL width, and using a Lengyel radiation model that includes non-coronal effects, we find [1] that the relative impurity concentration, $c_t \equiv n_t/n_e$, required for detachment scales dominantly as $c_t \propto P_{sep}/B R (n_{sep}/n_{GW})^2$. The absence of any explicit favorable size scaling is concerning, as $P_{sep}$ must increase by an order of magnitude from present experiments to an economic fusion power system, while increases in the poloidal magnetic field strength are limited by magnet technology and MHD stability. This result should not be surprising, as it follows from the simplest scaling, $P_{sep} \propto c_t n_e^2 V_{SOL}$, taking into account the Greenwald density limit and the HD SOL volume scaling. Reinke [2] has combined a similar approach with the requirement to maintain H-mode, which sets a lower limit on $P_{sep}$, and also arrives at an incentive for high field and disincentive for large size. These results should be challenged by comparison with 2D divertor codes and with measurements on existing experiments. In particular measurements are required for extrinsic divertor impurity concentration over a range of power and density conditions far from the regime where detachment can be achieved with deuterium puffing and intrinsically impurities alone. Nonetheless, these results suggest that higher magnetic field, stronger shaping, double-null operation, ‘advanced’ divertor magnetic and baffle configurations, as well as lithium vapor targets merit greater attention.

‘This work supported by the US DOE under contract DE-AC02-09CH11466.


16:00
PI3 5 Effects of Density and Impurity on Edge Localized Modes in Tokamaks∗
PING ZHU, University of Science and Technology of China, University of Wisconsin-Madison

Plasma density and impurity concentration are believed to be two of the key elements governing the edge tokamak plasma conditions. Optimal levels of plasma density and impurity concentration in the edge region have been searched for in order to achieve the desired fusion gain and divertor heat/particle load mitigation. However, how plasma density or impurity would affect the edge pedestal stability may have not been well known. Our recent MHD theory modeling and simulations using the NIMROD code have found novel effects of density and impurity on the dynamics of edge-localized modes (ELMs) in tokamaks. First, previous MHD analyses often predict merely a weak stabilizing effect of toroidal flow on ELMs in experimentally relevant regimes. We find that the stabilizing effects on the high-$n$ ELMs from toroidal flow can be significantly enhanced with the increased edge plasma density [1]. Here $n$ denotes the toroidal mode number. Second, the stabilizing effects of the enhanced edge resistivity due to lithium-conditioning on the low-$n$ ELMs in the high confinement (H-mode) discharges in NSTX have been identified. Linear stability analysis of the experimentally constrained equilibrium shows that the change in the equilibrium plasma density and pressure profiles alone due to lithium-conditioning may not be sufficient for a complete suppression of the low-$n$ ELMs. The enhanced resistivity due to the increased effective electric charge number $Z_{eff}$ after lithium-conditioning provides additional stabilization of the low-$n$ ELMs [2]. These new effects revealed in our theory analyses may help further understand recent ELM experiments and suggest new control schemes for ELM suppression and mitigation in future experiments. They may also pose additional constraints on the optimal levels of plasma density and impurity concentration in the edge region for H-mode tokamak operation.

∗Supported by National Magnetic Confinement Fusion Science Program of China Grants 2014GB124002 and 2015GB101004, the 100 Talent Program of the Chinese Academy of Sciences, and U.S. Department of Energy Grants DE-FG02-86ER53218 and DE-FC02-08ER54975.

WEDNESDAY AFTERNOON

PO4 1 Superposition of dual shattered pellet injections for disruption mitigation∗ J.L. HERFINDAL, D. SHIRAKI, L.R. BAYLOR, ORNL, E.M. HOLLMANN, R.A. MOYER, UCSD, C.J. LASNIER, LLNL, N.W. EIDETIS, GA Experiments on DIII-D have injected multiple shattered pellets at different toroidal locations for the first time, as is planned for the ITER disruption mitigation system. Systematically varying the relative timing of the two pellets demonstrate that simultaneous pellets may mitigate less effectively than a single pellet injecting similar neon quantities. Thermal quench (TQ) radiation fractions measured near the injection are reduced with the dual pellets, possibly as a result of a more rapid shutdown due to a broader impurity distribution over multiple flux tubes. However, radiation measured away from the injection does not share this trend, indicating asymmetries may exist. Mitigation of current quench (CQ) loads at little similar reduced in the dual pellet cases, consistent with the observed reduction in TQ mitigation. However, pellets entering the plasma after (or during) the TQ initiated by the other pellet, can still contribute to CQ mitigation.∗Supported by the US DOE under DE-AC05-00OR22725, DE-FG02-07ER54917, DE-AC52-07N27344, and DE-FG02-04ER54758.

PO4 2 Predicting the necessary impurity quantities for thermal quench mitigation in ITER disruptions RYAN SWEENEY, MICHAEL LEHNEN, DI HU, JOSEPH SNIPES, ITER Organization During a thermal quench (TQ) in a 15 MA scenario in ITER, heat fluxes can significantly exceed melt limits. It is planned to inject neon (Ne) atoms to radiate > 90% of the thermal energy in this scenario. However, an upper-limit on the current quench rate prohibits the use of more than 4 × 10^{22} Ne atoms. Previous simulation work found the required Ne quantity for ITER TQ mitigation is marginal with respect to this limit, however a cross-machine validation of this simulation is missing, and thus its accuracy is unknown. Scaling laws and 0D and pseudo-1D models of varying complexity are developed to compare estimates of the required Ne quantity for TQ mitigation. The physics considered in these models includes atomic radiation with non-coronal equilibrium effects, the scaling of the TQ duration with the minor radius, dilution cooling, and radial localization of the impurities. These models are compared with published data on the “minimum necessary injected impurity quantity” for TQ mitigation. The published data are converted to quantities assimilated before the TQ, using measured efficiencies and 1D simulations of gas flow in injection pipes. Implications on the required Ne quantity for ITER TQ mitigation will be discussed.


PO4 3 Fast Time Response Electromagnetic Particle Injection System for Disruption Mitigation∗ ROGER RAMAN, W-S. LAY, T.R. JARBOE, University of Washington J.E. MENARD, M. ONO, PPPL Predicting and controlling disruptions is an urgent issue for ITER. In this proposed method, a radiative payload consisting of micro spheres of Be, BN, B, or other acceptable low-Z materials would be injected inside the q=2 surface for thermal and runaway electron mitigation. The radiative payload would be accelerated to the required velocities (0.2 to > 1km/s) in an Electromagnetic Particle Injector (EPI). An important advantage of the EPI system is that it could be positioned very close to the reactor vessel. This has the added benefit that the external field near a high-field tokamak dramatically improves the injector performance, while simultaneously reducing the system response time. A NSTX-U / DIII-D scale system has been tested off-line to verify the critical parameters - the projected system response time and attainable velocities. Both are consistent with the model calculations, giving confidence that an ITER-scale system could be built to ensure safety of the ITER device.

∗This work is supported by U.S. DOE Contracts: DE-AC02-09CH11466, DE-FG02-99ER54519-AM08, and DE-SC0006757.

PO4 4 Shattered Pellet Injection Simulations With NIMROD∗ CHARLSON KIM, SLS2 Consulting PAUL PARKS, LANG LAO, General Atomics MICHAEL LEHNAN, ALBERTO LOARTE, ITER VALERIE IZZO, University of California, San Diego NIMROD TEAM Shattered Pellet Injection (SPI) will be the Disruption Mitigation System in ITER. SPI propels a cryo-pellet of high-Z and deuterium into a sharp bend of the flight tube, shattering the pellet into a plume of shards. These shards are injected into the plasma to quench it and mitigate forces and heat loads that may damage...
in-vessel components. We use NIMROD to perform 3-D nonlinear MHD simulations of SPI to study the thermal quench. This work builds upon prior Massive Gas Injection (MGI) studies by Izzo [1]. A Particle-in-Cell (PIC) model is implemented to mimic the shards, providing a discrete moving source. Observations indicate that the quench proceeds in two phases. Initially, the outer plasma is shed via interchange-like instabilities while preserving the core temperature. This results in a steep gradient and triggers the second phase, an external kink-like event that collapses the core. We report on the radiation efficiency and toroidal peaking as well as fueling efficiency and other metrics that assess the efficacy of the SPI system.

"Work supported by GA ITER Contract ITER/CT/14/4300001108 and US DOE DE-FG02-95ER54309.

V. A. Izzo et al., NF 55, 073032.

14:48

PO4 5 Plasma response control using advanced feedback techniques* MITCHELL CLEMENT, JAMES BIALEK, JEREMY HANSON, GERALD NAVRATIL, Columbia Univ Recent DIII-D experiments show that a new, advanced algorithm improves resistive wall mode (RWM) stability control in high performance discharges using external coils. DIII-D can excite strong, locked or nearly locked kink modes whose rotation frequencies do not evolve quickly and are slow compared to their growth rates. Simulations and experiments have shown that modern control techniques will perform better, using 77% less current, than classical techniques when using coils external to the vacuum vessel for RWM feedback. ITER will have to deal with such modes, especially in steady state operation, and it is unclear whether or not rotation alone will be sufficient to counteract these modes. VALEN models the perturbed magnetic field from a single MHD instability and its interaction with surrounding conducting structures as a series of coupled circuit equations. RWM feedback based on VALEN outperformed a classical control algorithm using external coils to suppress the normalized plasma response to a rotating n=1 perturbation applied by internal coils over a range of frequencies.

*Work supported by the U.S. DOE under DE-FC02-04ER54698 and DE-FG02-04ER54761.

15:00

PO4 6 Development of a real-time system for ITER first wall heat load control HIMANK ANAND, PETER DE VRIES, YURI GRIBOV, RICHARD PITTS, JOSEPH SNIPES, LUCA ZABEO, ITER organization The steady state heat flux on the ITER first wall (FW) panels are limited by the heat removal capacity of the water cooling system. In case of off-normal events (e.g. plasma displacement during H-L transitions), the heat loads are predicted to exceed the design limits (2-4.7 MW/m²). Intense heat loads are predicted on the FW, even well before the burning plasma phase. Thus, a real-time (RT) FW heat load control system is mandatory from early plasma operation of the ITER tokamak. A heat load estimator based on the RT equilibrium reconstruction has been developed for the plasma control system (PCS). A scheme, estimating the energy state for prescribed gaps defined as the distance between the last closed flux surface (LCFS)/separatrix and the FW is presented. The RT energy state is determined by the product of a weighted function of gap distance and the power crossing the plasma boundary. In addition, a heat load estimator assuming a simplified FW geometry and parallel heat transport model in the scrape-off layer (SOL), benchmarked against a full 3-D magnetic field line tracer is also presented.

15:12

PO4 7 Comprehensive Assessment of Damage Effects during Transient Events in ITER* AHMED HASSANEIN, VALERYI SIZYUK, Purdue Univ During abnormal operations in tokamaks, the incident particle and heat fluxes during disruptions and ELMs are quickly generate a secondary plasma composed mainly from divertor plate materials. This mini-plasma will then absorb the incoming disruptive plasma and convert its energy to intense radiation fluxes to nearby components. HEIGHTS simulations showed significant increase of radiation fluxes and components heat load for high-Z (i.e., tungsten) generated secondary plasma. These radiation can seriously damage hidden components such as umbrella tubes and dome structure. In fact, simulation showed that during longer disruption times the evolving mini-plasma can damage parts of Be first wall. We have enhanced previous HEIGHTS models and implemented efficient models for photon and particle transport in evolving secondary plasma during transients. HEIGHTS now simulates full 3D detail ITER geometry to assess various damage of these components during plasma instabilities. HEIGHTS predicted again, for the first time, details of heat loads and temperatures evolution of divertor and nearby components including first wall. Current ITER divertor design needs to be modified to withstand the damage produced from disruptions. A single unmitigated disruption event can cause serious damage to components that were not directly exposed to disruptions including dome, stainless steel tubes, and parts of Be first wall.

*Supported by National Science Foundation, PIRE Project.

15:24

PO4 8 Prototype testing of the ITER Toroidal Interferometer and Polarisimeter (TIP) on DIII-D* T.N. CARLSTROM, M.A. VAN ZEELAND, A. GAITUSO, R. O’NEILL, J. VASQUEZ, GA D.E. FINKENTHAL, R.A. COLIO, PSI D. JOHNSON, PPPD D. BROWER, J. CHEN, W.-X. DING, UCLA A 10.6 micron CO2 laser based ITER TIP system has been designed and tested for density measurements on DIII-D. Features include vibration compensation using a 5.22 micron Quantum Cascade Laser, real-time measurements at 1 kHz with <1% error at expected ITER operating densities, 500 kHz bandwidth density fluctuation measurements, active feedback alignment with auto signal recovery capabilities, fringe skip correction using polarimetry measurements, and a novel three-frequency heterodyne technique with real-time digital phase demodulation. A 120 m path length laboratory prototype was used to test components, demonstrate active feedback alignment capabilities, and determine noise floor capabilities. Phase errors of 1.5 degrees for the interferometer and 0.06 degrees for the polarimeter have been demonstrated for 1000 seconds. The system is now installed on the DIII-D tokamak, using a geometry and path length similar to that planned for ITER and has successfully demonstrated the ITER requirements for accuracy and time resolution.

*Work supported by U.S. DOE Cooperative Agreement DE-FC02-04ER54698 and Contract Number DE-AC-02-09CH11466.

15:36

PO4 9 Divertor Heat Flux Control with 3D Stochastic Magnetic Fields during ELM Suppression* DM ORLOV, RA MOYER, IO BYKOV, UCSD TE EVANS, W WU, GA A LOARTE, ITER A TEKLU, Oregon State U JG WATKINS, SNL H WANG, BC LYONS, GL TREVISAN, ORAU MA MAKOWSKI, C LASNIER, ME FENSTERMACHER, LLNL. Experiments in DIII-D have been performed to modify the divertor heat and particle flux pattern during suppression of ELMs with resonant magnetic perturbation (RMP) fields. In this work, we assessed the impact of small current
modulations in a subset of DIII-D I-coils on pedestal profiles, transport and stability as well as divertor conditions. Different I-coil subset ramps were performed allowing for a slow transition of the divertor footprints from \( n = 3 \) to \( n = 2 \) and \( n = 1 \) distributions. We obtained long periods of RMP ELM suppression with slow I-coil quartet ramps. Strong divertor particle flux splitting was observed in these discharges as well as modulation of the divertor heat flux due to changes in toroidal spectrum of applied perturbation. Experimental results are compared to the TRIP3D modeling and to linear M3D-C1 simulations to understand the role of the plasma response on quantitative predictions of the divertor flux splitting.

\*Work supported by US DOE under DE-FC02-04ER54698 and DE-FG02-05ER54809.

15:48

PO4 10 Enhancement of Helium exhaust by resonant magnetic perturbations in DIII-D\(^*\)


Clear evidence of enhanced He exhaust during RMP ELM suppression has been obtained for the first time in a series of lower single null H-mode discharges with and without RMP in DIII-D. During RMP, reduced midplane He density measurements from CER and faster neutral He decay times after a 100ms He puff provided evidence for faster outward transport. Additionally, during RMP, neutral He pressure in the lower pumping plenum increased, while \( D_\parallel \) pressure was similar to the no RMP case. A spectrometer viewing the divertor shelf in the scrape off layer measured consistently increased He-I light during RMP ELM suppression. These two measurements indicate an improved retention of He in the unconfined region, which is important for enhanced He removal. Consequently, the effective helium confinement time, \( \tau^*_{\text{He},\text{ec}} \), measured for conditions in this work was reduced by \( > 35\% \) when RMP ELM suppression was obtained.

\*Work supported by US DOE DE-FC02-04ER54698, DE-SC00013911, DE-FG02-07ER54917, DE-AC52-07NA27344, DE-AC05-00OR22725, DE-AC04-94AL85000.

16:00

PO4 11 Expansion of Parameter Space for Wide-Pedestal, Quiescent H-mode Plasmas in DIII-D\(^*\)

KEITH BURRELL, General Atomics

QH-mode is an attractive operating regime for future devices since it has excellent energy confinement time and operates without ELMs at zero net NBI torque. The recently discovered wide pedestal QH-modes exhibit an increase in the pedestal pressure height and width and increased global energy confinement associated with a bipolar change in the ExB shear [1]. Experiments in 2017 have investigated the underlying physics by expanding the parameter space for wide pedestal QH-mode. It has now been created in LSN discharges with \( d \text{Resp} \geq -1.5 \text{ cm} \) and sustained with \( d \text{Resp} \geq -3.5 \text{ cm} \); previous experiments required balanced DN plasmas or USN with \( d \text{Resp} \leq 1 \text{ cm} \). A wide range of NBI torque was used to sustain the wide pedestal, from \(-2.5 \text{ Nm (counter-Ip) to 1.9 Nm (co-Ip)}\); this greatly exceeds the ITER-equivalent torque range. The wide pedestal state with broadband MHD can be created directly from standard ELM-free conditions without the presence of the coherent EHO in plasmas using \(-1.5 \text{ Nm NBI torque}\). The time integrated torque required to reach and sustain the wide pedestal state has been reduced by over 90\%, limited by core tearing modes. This is an important step on the road to use QH-mode in future devices with much lower equivalent NBI torque.

\*Supported by US DOE under DE-FC02-04ER54698.


16:12

PO4 12 Non-linear MHD simulations of pellet triggered ELM for ITER plasma scenarios\(^*\)

SHIMPEI FUTATANI, Barcelona Supercomputing Center GUIDO HUUSMANS, CEA, IREM ALBERTO LOARTE, ITER Organization MERV I MANTSINEN, Barcelona Supercomputing Center STANISLAS PAMELA, LUCA GARZOTTI, EURATOM/CCFE, Fusion Association, Culham Science Centre

The non-linear MHD simulations with the JOREK code have been performed to study the dependence of the pellet size required to trigger an ELM in ITER plasma, and also the dependency of the threshold on the pedestal plasma pressure when the pellet is injected. Based on the observation that the pedestal pressure leading to spontaneous ELM triggering is 150 kPa by JOREK simulation, pedestal pressure of 75 kPa and 112.5 kPa have been studied. The JOREK simulation results show that it is necessary to increase the pellet size by a factor of 1.5 of the number of particles in the pellet to trigger ELMs for a pedestal pressure of 75 kPa compared to 112.5 kPa in ITER 15MA/5.3T plasma. In these simulations it has also been found that the magnitude of the ELM energy loss is strongly correlated with the pedestal plasma pressure rather than with the size of the pellet that is required for triggering. The JOREK simulation shows the toroidally asymmetric profile of the heat flux on the outer divertor target due to the pellet triggered ELM which is consistent with the experiment observation of JET. The work contributes the estimation of the requirement of the pellet injection condition to control ELMs in ITER 15MA operation scenarios.

\*The views and opinions expressed herein do not necessarily reflect either those of the European Commission or those of the ITER Organization.

16:24

PO4 13 Pellet Fueling of ELM Mitigated ITER Baseline Scenario Plasmas on DIII-D\(^*\)

L.R. BAYLOR, Oak Ridge National Laboratory

ITER has been designed to employ HFS pellet fueling to operate at high density using pellets that produce less than a 10\% density perturbation and that penetrate to just beyond the top of the pedestal. DIII-D ITER-like plasmas with ELM mitigation provided by either pellet ELM pacing or RMPs have been fueled with small shallow penetrating HFS pellets. In DIII-D, large normal ELMS dramatically reduce the effective fueling efficiency of the HFS pellets to nearly 0 within the time scale of a few large ELMs. In the ELM paced plasmas, the pellets trigger ELMs that are no more intense than the paced ELMs and the resulting fueling efficiency is > 80\%. In RMP ELM mitigated plasmas, the efficient fueling from HFS pellets results in pedestal collisionality increases that can reduce the ELM mitigation. New experiments have shown that edge ECH can decrease pedestal collisionality and will be combined with the HFS pellets to better mimic the ITER fueling scenario. These fueling results from pellet pacing and RMP ELM mitigation will be presented and implications for ITER discussed.

\*Supported by the US DOE under DE-AC05-00OR22725, DE-FC02-04ER54698, DE-AC52-07NA27344 & DE-FG02-07ER54917.

16:36

PO4 14 Exploring an Alternate Approach to Q=10 in ITER\(^*\)

T.C. LUKE, General Atomics F. TURCO, Columbia U.

The ITER Research Plan envisions a stepwise approach in B and I due to heating system constraints to the objective of 500 MW fusion power with \( Q = 10 \) for \( >300 \text{ s} \), but always reaching \( q_{95} = 3 \) at each B. An
alternating approach goes directly to 5.3 T, then raises I. This approach reduces disruption risk because q is higher and perhaps the goal is realized at lower I. DIII-D experiments explored this path with co-NBI heating and NBI heating with 0 Nm applied torque. For the first time, stable plasmas in the ITER shape (including aspect ratio) at the ITER baseline scenario conditions ($q_{95} \approx 3$, $\beta_N \approx 2$) have been obtained with 0 Nm applied torque. At equivalent currents to 9-17 MA in ITER ($q_{95} \approx 5.7-2.8$), the maximum stable $\beta$ and the $r_e$ have been measured as a function of applied torque. The equivalent $\beta$ for 500 MW of fusion power is obtained at about 13.5 MA for 0 Nm, indicating significant stability margin. However, confinement is less than predicted by the H-mode scaling at 15 MA because linear confinement scaling with I is not seen above 12.5 MA at all levels of applied torque, indicating this is not due to ExB shearing effects. These results indicate that the risk of operation in ITER at low $q_{95}$ and specifically at 15 MA may not be warranted.

*Work supported under USDOE Cooperative Agreement DE-FC02-04ER54698 and DE-FG02-04ER54761.

16:48

PO4 15 Safety factor profiles from spectral motional Stark effect for ITER applications* JINSEOK KO, JINIL CHUNG, HAN MIN WI, Natl Fusion Res Inst Depositions on the first mirror and multiple reflections on the other mirrors in the labyrinth of the optical system in the motional Stark effect (MSE) diagnostic for ITER are regarded as one of the main obstacles to overcome. One of the alternatives to the present-day conventional photoelastic-modulation-based MSE principles is the spectroscopic analyses on the motional Stark emissions where either the ratios among individual Stark multiplets or the amount of the Stark split are measured based on precise and accurate atomic data and models to ultimately provide the critical internal constraints in the magnetic equilibrium reconstruction. Equipped with the PEM-based conventional MSE hardware since 2015, the KSTAR MSE diagnostic system is capable of investigating the feasibility of the spectroscopic MSE approach particularly via comparative studies with the PEM approach. Available atomic data and models are used to analyze the beam emission spectra with a high-spectral-resolution spectrometer with a patent-pending dispersion calibration technology. Experimental validation on the atomic data and models is discussed in association with the effect of the existence of mirrors, the Faraday rotation in the relay optics media, and the background polarized light on the measured spectra.

*Work supported by the Ministry of Science, ICT and Future Planning, Korea.

PO4 15 Safety factor profiles from spectral motional Stark effect for ITER applications* JINSEOK KO, JINIL CHUNG, HAN MIN WI, Natl Fusion Res Inst Depositions on the first mirror and multiple reflections on the other mirrors in the labyrinth of the optical system in the motional Stark effect (MSE) diagnostic for ITER are regarded as one of the main obstacles to overcome. One of the alternatives to the present-day conventional photoelastic-modulation-based MSE principles is the spectroscopic analyses on the motional Stark emissions where either the ratios among individual Stark multiplets or the amount of the Stark split are measured based on precise and accurate atomic data and models to ultimately provide the critical internal constraints in the magnetic equilibrium reconstruction. Equipped with the PEM-based conventional MSE hardware since 2015, the KSTAR MSE diagnostic system is capable of investigating the feasibility of the spectroscopic MSE approach particularly via comparative studies with the PEM approach. Available atomic data and models are used to analyze the beam emission spectra with a high-spectral-resolution spectrometer with a patent-pending dispersion calibration technology. Experimental validation on the atomic data and models is discussed in association with the effect of the existence of mirrors, the Faraday rotation in the relay optics media, and the background polarized light on the measured spectra.

*Work supported by the Ministry of Science, ICT and Future Planning, Korea.

**Contributed Papers**

14:00

PO4 15 Safety factor profiles from spectral motional Stark effect for ITER applications* JINSEOK KO, JINIL CHUNG, HAN MIN WI, Natl Fusion Res Inst Depositions on the first mirror and multiple reflections on the other mirrors in the labyrinth of the optical system in the motional Stark effect (MSE) diagnostic for ITER are regarded as one of the main obstacles to overcome. One of the alternatives to the present-day conventional photoelastic-modulation-based MSE principles is the spectroscopic analyses on the motional Stark emissions where either the ratios among individual Stark multiplets or the amount of the Stark split are measured based on precise and accurate atomic data and models to ultimately provide the critical internal constraints in the magnetic equilibrium reconstruction. Equipped with the PEM-based conventional MSE hardware since 2015, the KSTAR MSE diagnostic system is capable of investigating the feasibility of the spectroscopic MSE approach particularly via comparative studies with the PEM approach. Available atomic data and models are used to analyze the beam emission spectra with a high-spectral-resolution spectrometer with a patent-pending dispersion calibration technology. Experimental validation on the atomic data and models is discussed in association with the effect of the existence of mirrors, the Faraday rotation in the relay optics media, and the background polarized light on the measured spectra.

*Work supported by the Ministry of Science, ICT and Future Planning, Korea.

**Contributed Papers**

14:00

PO4 15 Safety factor profiles from spectral motional Stark effect for ITER applications* JINSEOK KO, JINIL CHUNG, HAN MIN WI, Natl Fusion Res Inst Depositions on the first mirror and multiple reflections on the other mirrors in the labyrinth of the optical system in the motional Stark effect (MSE) diagnostic for ITER are regarded as one of the main obstacles to overcome. One of the alternatives to the present-day conventional photoelastic-modulation-based MSE principles is the spectroscopic analyses on the motional Stark emissions where either the ratios among individual Stark multiplets or the amount of the Stark split are measured based on precise and accurate atomic data and models to ultimately provide the critical internal constraints in the magnetic equilibrium reconstruction. Equipped with the PEM-based conventional MSE hardware since 2015, the KSTAR MSE diagnostic system is capable of investigating the feasibility of the spectroscopic MSE approach particularly via comparative studies with the PEM approach. Available atomic data and models are used to analyze the beam emission spectra with a high-spectral-resolution spectrometer with a patent-pending dispersion calibration technology. Experimental validation on the atomic data and models is discussed in association with the effect of the existence of mirrors, the Faraday rotation in the relay optics media, and the background polarized light on the measured spectra.

*Work supported by the Ministry of Science, ICT and Future Planning, Korea.

**Contributed Papers**

14:00

PO4 15 Safety factor profiles from spectral motional Stark effect for ITER applications* JINSEOK KO, JINIL CHUNG, HAN MIN WI, Natl Fusion Res Inst Depositions on the first mirror and multiple reflections on the other mirrors in the labyrinth of the optical system in the motional Stark effect (MSE) diagnostic for ITER are regarded as one of the main obstacles to overcome. One of the alternatives to the present-day conventional photoelastic-modulation-based MSE principles is the spectroscopic analyses on the motional Stark emissions where either the ratios among individual Stark multiplets or the amount of the Stark split are measured based on precise and accurate atomic data and models to ultimately provide the critical internal constraints in the magnetic equilibrium reconstruction. Equipped with the PEM-based conventional MSE hardware since 2015, the KSTAR MSE diagnostic system is capable of investigating the feasibility of the spectroscopic MSE approach particularly via comparative studies with the PEM approach. Available atomic data and models are used to analyze the beam emission spectra with a high-spectral-resolution spectrometer with a patent-pending dispersion calibration technology. Experimental validation on the atomic data and models is discussed in association with the effect of the existence of mirrors, the Faraday rotation in the relay optics media, and the background polarized light on the measured spectra.

*Work supported by the Ministry of Science, ICT and Future Planning, Korea.

**Contributed Papers**

14:00

PO4 15 Safety factor profiles from spectral motional Stark effect for ITER applications* JINSEOK KO, JINIL CHUNG, HAN MIN WI, Natl Fusion Res Inst Depositions on the first mirror and multiple reflections on the other mirrors in the labyrinth of the optical system in the motional Stark effect (MSE) diagnostic for ITER are regarded as one of the main obstacles to overcome. One of the alternatives to the present-day conventional photoelastic-modulation-based MSE principles is the spectroscopic analyses on the motional Stark emissions where either the ratios among individual Stark multiplets or the amount of the Stark split are measured based on precise and accurate atomic data and models to ultimately provide the critical internal constraints in the magnetic equilibrium reconstruction. Equipped with the PEM-based conventional MSE hardware since 2015, the KSTAR MSE diagnostic system is capable of investigating the feasibility of the spectroscopic MSE approach particularly via comparative studies with the PEM approach. Available atomic data and models are used to analyze the beam emission spectra with a high-spectral-resolution spectrometer with a patent-pending dispersion calibration technology. Experimental validation on the atomic data and models is discussed in association with the effect of the existence of mirrors, the Faraday rotation in the relay optics media, and the background polarized light on the measured spectra.

*Work supported by the Ministry of Science, ICT and Future Planning, Korea.

**Contributed Papers**

14:00

PO4 15 Safety factor profiles from spectral motional Stark effect for ITER applications* JINSEOK KO, JINIL CHUNG, HAN MIN WI, Natl Fusion Res Inst Depositions on the first mirror and multiple reflections on the other mirrors in the labyrinth of the optical system in the motional Stark effect (MSE) diagnostic for ITER are regarded as one of the main obstacles to overcome. One of the alternatives to the present-day conventional photoelastic-modulation-based MSE principles is the spectroscopic analyses on the motional Stark emissions where either the ratios among individual Stark multiplets or the amount of the Stark split are measured based on precise and accurate atomic data and models to ultimately provide the critical internal constraints in the magnetic equilibrium reconstruction. Equipped with the PEM-based conventional MSE hardware since 2015, the KSTAR MSE diagnostic system is capable of investigating the feasibility of the spectroscopic MSE approach particularly via comparative studies with the PEM approach. Available atomic data and models are used to analyze the beam emission spectra with a high-spectral-resolution spectrometer with a patent-pending dispersion calibration technology. Experimental validation on the atomic data and models is discussed in association with the effect of the existence of mirrors, the Faraday rotation in the relay optics media, and the background polarized light on the measured spectra.

*Work supported by the Ministry of Science, ICT and Future Planning, Korea.
2-temperature density-functional-theory molecular-dynamic simulations show good agreement, that can not be achieved by standard theories of plasma physics.

*This work is supported by DOE FES under FWP 100182.

14:36
PO5 4 Isochoric heating and adiabatic expansion of WDM with intense relativistic electrons* JOSH COLEMAN, J. COLGAN, N.B. RAMEY, T. SCHMIDT, H.L. ANDREWS, J.O. PERRY, Los Alamos Natl Lab D.R. WELCH, Voss Scientific A ∼100-ns-long electron bunch with an energy of 19.8 MeV and current of 1.7 kA has been used to isochorically heat thin foils of Cu or Ti to T_e, >1 eV. Adiabatic expansion of these warm dense plasmas has been observed, which fits well with the analytical point source solution. After 100 ns of heating, the plasma expands and the opacity drops emitting Ti-I or Cu-I, which indicates the measured density ranges from 1-3 x 10^{17} cm^{-3}. Additional efforts are underway to model the hydrodynamic expansion and deploy several diagnostics to measure the WDM. These include a Bragg spectrometer for K-shell emission, a PDV probe for hydro disassembly time and an indirect measurement of the plasma pressure, and a single pass density diagnostic. Preliminary measurements will be presented which are critical for characterizing the warm dense phase and providing a map of the EOS across a density range of 10^{16} ≤ n_e (cm^{-3}) < 10^{23}

*This work was supported by the National Nuclear Security Administration of the U.S. Department of Energy under Contract No. DE-AC52-06NA25396.

14:48
PO5 5 X-Ray Thomson Scattering and Radiography from Spherical Implosions on the OMEGA Laser* A. M. SAUNDERS, University of California Berkeley A. LAZIKI-JENEL, T. DOEPPNER, O. L. LANDEN, Lawrence Livermore National Laboratory M. MACDONALD, University of California Berkeley J. Nilsen, D. Swift, Lawrence Livermore National Laboratory R. W. Falcone, University of California Berkeley X-ray Thomson scattering (XRTS) is an experimental technique that directly probes the physics of warm dense matter by measuring electron density, electron temperature, and ionization state [1]. XRTS in combination with x-ray radiography offers a unique ability to measure an absolute equation of state (EOS) from material under compression [1,2]. Recent experiments highlight uncertainties in EOS models and the predicted ionization of compressed matter, suggesting more validation of models is needed [3,4]. We present XRTS and x-ray radiography measurements taken at the OMEGA Laser Facility from directly-driven solid carbon spheres at densities on the order of 1 x 10^{25} g cm^{-3} and temperatures on the order of 30 eV. The results shed light on the equations of state of matter under compression.

*This work performed under auspices of the US Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and under the Stewardship Science Graduate Fellowship, Grant Number DE- NA0002135.


15:00
PO5 6 First-Principles Equation of State and Shock Compression of Warm Dense Aluminum and Hydrocarbons* KEVIN DRIVER, FRANCOIS SOUBIRAN, SHUAI ZHANG, BURKHARD MILITZER, Univ. California, Berkeley Theoretical studies of warm dense plasmas are a key component of progress in fusion science, defense science, and astrophysics programs. Path integral Monte Carlo (PIMC) and density functional theory molecular dynamics (DFT-MD), two state-of-the-art, first-principles, electronic-structure simulation methods, provide a consistent description of plasmas over a wide range of density and temperature conditions. Here, we combine high-temperature PIMC data with lower-temperature DFT-MD data to compute coherent equations of state (EOS) for aluminum and hydrocarbon plasmas. Subsequently, we derive shock Hugoniot curves from these EOSs and extract the temperature-density evolution of plasma structure and ionization behavior from pair-correlation function analyses. Since PIMC and DFT-MD accurately treat effects of atomic shell structure, we find compression maxima along Hugoniot curves attributed to K-shell and L-shell ionization, which provide a benchmark for widely-used EOS tables, such as SESAME and LEOs, and more efficient models. LLNL-ABS-734424. Funding provided by the DOE (DE-SC0010517) and in part under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Computational resources provided by Blue Waters (NSF AC1164076) and NERSC.

*K. Driver’s and S. Zhang’s current address is Lawrence Livermore Natl. Lab, Livermore, CA, 94550, USA.

15:12
PO5 7 Toward Sodium X-Ray Diffraction in the High-Pressure Regime* X. GONG, D.N. POLSIN, J.R. RYGG, T.R. BOEHLY, L. CRANDALL, B.J. HENDERSON, S.X. Hu, M. HUFF, R. SAHA, G.W. COLLINS, Laboratory for Laser Energetics, U. of Rochester R. SMITH, J. EGGERT, A.E. LAZICKI, LLNL M. MCMAHON, Dept. of Physics, U. of Edinburgh We are working to quasi-sisentropically compress sodium into the terapascal regime to test theoretical predictions that sodium transforms to an electride [1,2]. A series of hydrodynamic simulations have been performed to design experiments to investigate the structure and optical properties of sodium at pressures up to 500 GPa. We show preliminary results where sodium samples, sandwiched between diamond plates and lithium-fluoride windows, are ramp compressed by a gradual increase in the drive-laser intensity. The low sound speed in sodium makes it particularly susceptible to forming a shock; therefore, it is difficult to compress without melting the sample. Powder x-ray diffraction [3] is used to provide information on the structure of sodium at these high pressures.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


15:24
PO5 8 Stopping Power of Warm Dense Matter from Ehrenfest Molecular Dynamics ATITLA CANGI, DANIEL S. JENSEN, STEPHANIE B. HANSEN, ANDREW D. BACZEWSKI, Sandia National Laboratories Recent experimental advances enabled the precise measurement of the stopping power of fusion products in warm dense matter. We assess the ability of real-time dependent density functional theory to reproduce these results. Our approach facilitates the prediction of the stopping power in future experiments from first principles and advances our empirical and phenomenological understanding of transport properties in this technologically challenging thermodynamic regime.
15:36
PO5 9 Optical conductivity of magnetized warm dense matter using time-dependent density functional theory* DANIEL JENSEN, ANDREW BACZEWSKI, ATTILA CANGI, STEPHANIE HANSEN, Sandia Natl Labs In magnetized liner inertial fusion (MagLIF), matter is subjected to 10-30 T magnetic fields that are then flux compressed to strengths greater than 1 kT [1]. The determination of transport properties in such extreme fields and the warm dense regime are of vital importance to experimental design. We show how time-dependent density functional theory (TDDFT) can be used to extract optical conductivities in and beyond the linear response regime. Building on work studying scalar linear perturbations to warm dense matter [2], we present the necessary theoretical modifications as well as some preliminary results.

*Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy’s National Nuclear S.

15:48
PO5 10 First Principles Simulation of the Dynamics of Warm Dense Matter during Femtosecond Laser Damage using a Particle-in-Cell Method with Pair-Potential Interactions and Direct Comparison to Experiment* ALEX RUSSELL, Ohio State University KYLE KAFKA, University of Rochester ENAM CHOWDHURY, DOUGLASS SCHUMACHER, Ohio State University Understanding of the warm dense matter (WDM) state is of fundamental importance in the modeling of femtosecond laser damage because laser electron coupling and subsequent electron lattice coupling can rapidly increase the material temperature at the laser focal region to on the order of an eV, producing WDM not well described by standard liquid and solid equations of state. By modifying the particle-in-cell formalism designed for plasmas to include a pair-potential interaction model, we have created the first fundamental simulation method for modelling ultrashort pulse laser damage that can treat large scale (micron sized) damage morphology and resolves dynamics spanning over six orders of magnitude in time from the femtosecond to the nanosecond scale. We confirm the accuracy of our algorithm by comparing simulated crater profiles on copper against those produced from precision experiment and then show the dynamics of transient warm dense matter formation in aluminum.

*This material is based upon work supported by the Air Force Office of Scientific Research under Award Number FA9550-16-1-0069 and computing time from the Ohio Supercomputer Center.

16:00
PO5 11 Magnetic anvil cells driven by pulsed-power generators* P.-A. GOURDAIN, M. B. ADAMS, M. EVANS, University of Rochester R. D. MCBRIDE, University of Michigan A. B. SEFFOW, University of Rochester C. E. SEYLER, Cornell University G. COLLINS, University of Rochester Magnetic anvil cells (MAC) use a gas, foam or solid damper to compress a material sample via magnetic pinch forces. Unlike diamond anvil cells (DAC), which are limited by the material strength of diamond, MAC have no mechanical limits. Only the amount of current that can be delivered to the MAC limits the final pressure at which a material sample can be compressed. Another main advantage of MAC over DAC is the ability to heat the sample, allowing to produce warm dense matter. The damper that surrounds the material sample has several functions. Initially, it diverts the current away from the sample, preventing electrothermal instabilities inside the sample. When the damper has fully imploded, the current commutes from the damper to the sample in less than 10 ns. Since the current is already on its way to reach a maximum, hundreds of kilobars are suddenly applied to the sample, limiting plasma ablation and surface inhomogeneity, which can later seed magnetic Rayleigh-Taylor instabilities. This work shows that the phase and chemical composition of the damper is critical to the homogeneity of the compressed sample and will change depending on the current level required to reach the final pressure.

*Research supported by DOE Stockpile Stewardship Academic Alliance Program, Grant DE-FG52-10NA29656, and NASA Earth and Space Science Fellowship Program, Award NNX14AP17H.
The phase dynamics of dense hydrogen is much interesting. Since now, first principles molecular dynamics is the most important method to study it in theory. Nuclear quantum effects and van der Waals interactions can be included, but many-body effects such as self-interactions and non-local exchange correlation effects are difficult to include because of extremely expensive computational costs. We study the liquid-liquid phase transition (LLPT) of dense hydrogen using first-principles molecular dynamics with improved rVV10 functional, with self-interaction correlations. The path integral molecular dynamics is employed to consider the nuclear quantum effects, which play an important role in LLPT of dense hydrogen. By including nuclear quantum effects and van der Waals interactions with hybrid functional in DFT calculations, the molecular dissociation is described as much accurately as conventional DFT calculations. We obtain the temperature-pressure boundary of LLPT based on analysis of radial distribution function and vibrational spectra of hydrogen molecules, and the phase transition from molecular phase to atomic phase is expected to change much.

16:48

PO5 15 Thermal conductivity measurements of proton-heated warm dense aluminum* A. MCKELVEY, G. KEMP, P. STERENE, A. FERNANDEZ, R. SHEPHERD, M. MARINAK, A. LINK, G. COLLINS, LLNL. H. SIO, MIT J. KING, R. FREEMAN, OSU/R. HUA, C. MCGUFFEY, J. KIM, F. BEG, UCSD Y. PING, LLNL. We present the first thermal conductivity measurements of warm dense aluminum at 0.5-2.7 g/cc and 2-10 eV, using a recently developed platform of differential heating. A temperature gradient is induced in an Au/Al dual-layer target by proton heating, and subsequent heat flow from the hotter Au to the Al rear surface is detected by two simultaneous time-resolved diagnostics. A systematic data set allows for constraining both thermal conductivity and equation-of-state models. Simulations using Purgatorio model or Sesame S27314 for constraining both thermal conductivity and equation-of-state simultaneously. An approach developed with the goal of extending the reach of kinetic models to the fluid scales. Kinetic models are a higher order description and fluid effects are included in them. However, the cost in terms of computing power is much higher and it has been so far prohibitively expensive to treat space weather events fully kinetically. We have now designed a new method capable of reducing that cost by several orders of magnitude making it possible for kinetic models to study macroscopic systems [1].

http://www.deep-projects.eu/.

1Lapenta et al., JCP 334, 349 (2017); JPP 83, 2 (2017).

14:12

PO6 2 Algorithm implementation and testing to ensure consistency of Gauss’s law in OSIRIS* KYLE MILLER, Univ of California - Los Angeles PAUL ELIAS, Office National d’Etudes et Recherches Aerospatiales RICARDO FONSECA, Instituto Superior Tecnico BENJAMIN WINJUM, FRANK TSUNG, VIKTOR DECYK, WARREN MORI, Univ of California - Los Angeles Electromagnetic particle-in-cell (PIC) simulations compute the trajectories of particles as they interact via fields calculated by numerically solving Maxwell’s equations on a grid using currents (and charge densities) from the particles. Within PICKSC, UCLA maintains a variety of open-source and open-access codes. These include OSIRIS—developed in partnership with IST—and UPIC-EMMA. Standard OSIRIS uses a rigorous charge-conserving current deposit to ensure the consistency of Gauss’s law together with a finite-difference (FD) solution to Maxwell’s equations. It also contains options for spectral (FFT) and hybrid (FFT and FD) field solvers, as well as a customized, higher-order FD field solver to help mitigate the numerical Cerenkov instability. The standard charge conserving current deposit is only valid for second-order accurate FD solvers. Another option for maintaining the consistency of Gauss’s law is the Boris correction, where a “direct” current deposit is used and the electric field is corrected through the use of a Poisson solve. The Boris correction—with both exact and iterative multigrid Poisson solves—has been implemented into OSIRIS. Preliminary analyses of timing and fluctuations levels will be presented, including the effects of different particle orders.

*Work supported by NSF and DOE.
device/host data allocation to minimize memory access and data communication per operation. Successful implementation has resulted in an order of magnitude increase in simulation speed for a test-case involving multiple binary collisions using the null collision method.

*Work supported by DARPA under contract W31P4Q-16-C-0009.

14:36
PO6 4 The utility of continuum simulations for direct current and microwave microplasmas VENKATTRA MAN AYYASWAMY, ARGHAVAN ALAMATSAZ, ABHISHEK KUMER VERMA, University of California Merced State-of-the-art microplasma devices have contributed to several challenges that require a fundamental understanding of the various mechanisms involved in order to achieve optimal operation for a given application. In this context, the role of computations cannot be stressed enough. Historically, the computational techniques used for simulating plasmas belong to two categories “continuum/fluid and kinetic methods. The primary goal of the current work is to perform an exhaustive comparison of continuum and kinetic simulations for a range of operating conditions. Kinetic simulations using the particle-in-cell with Monte Carlo collisions (PIC-MCC) method and continuum simulations using the full-momentum equation are performed at various operating conditions. It is shown that using the electron energy distribution function (EEDF) predicted by BOLSIG+ in continuum simulations of direct current microplasmas leads to a significant under-prediction of plasma densities. The discrepancy between kinetic and continuum simulations is attributed to the presence of hot electrons created as a result of secondary emission. On the other hand, continuum simulations performed for a microwave microplasma operating at 0.5 GHz showed excellent agreement with kinetic simulations.

14:48
PO6 5 A Lagrangian code for simulating compressible large deformation multi-material MHD processes BO XIAO, HAI-BO ZHAO, JIN-SONG BAI, GANGHUA WANG, Institute of Fluid Physics, CAEP COMPUTATIONAL PHYSICS TEAM A 2-dimensional Lagrangian code, named TriAngels-MHD, is made for the simulation of compressible large deformation multi-material MHD processes. The Lagrangian scheme is built on pure triangular mesh. The MHD simulation is split into a hydrodynamic step (ideal MHD step) and a magnetic diffusion step. For the hydrodynamic step, to conquer the mesh distortion problem in a Lagrangian scheme, a dynamic local remeshing algorithm is designed. And to mitigate the checkerboard oscillation problem that is typical for a triangular mesh based Lagrangian simulation, a matter flow term is introduced for each grid edge, which compensates for the non-bending of a grid edge. For the magnetic diffusion step, the Joule heat is calculated based on a formula of $\frac{\partial T}{\partial t} = \nabla \cdot \left( \frac{1}{\rho} \mathbf{B} \times (\nabla \times \mathbf{B}) \right) - \frac{1}{\rho} \mathbf{B} \cdot \mathbf{B} \cdot \mathbf{B}$. This scheme insures the equality of the total Joule heat production and the total electromagnetic energy loss in the system. Typical simulations are carried out to test the performance of the Lagrangian code, including the pure hydrodynamic processes of Nah explosion test problem and triple-point problem and the MHD process of magneto-Rayleigh-Taylor instability evolution.

15:00
PO6 6 Block Preconditioning to Enable Physics-Compatible Implicit Multifluid Plasma Simulations EDWARD PHILLIPS, JOHN SHADDID, ERIC CYR, SEAN MILLER, Sandia Natl Labs Multifluid plasma simulations involve large systems of partial differential equations in which many time-scales ranging over many orders of magnitude arise. Since the fastest of these time-scales may set a restrictively small time-step limit for explicit methods, the use of implicit or implicit-explicit time integrators can be more tractable for obtaining dynamics at time-scales of interest. Furthermore, to enforce properties such as charge conservation and divergence-free magnetic field, mixed discretizations using volume, nodal, edge-based, and face-based degrees of freedom are often employed in some form. Together with the presence of stiff modes due to integrating over fast time-scales, the mixed discretization makes the required linear solvers for implicit methods particularly difficult for black box and monolithic solvers. This work presents a block preconditioning strategy for multifluid plasma systems that segregates the linear system based on discretization type and approximates off-diagonal coupling in block diagonal Schur complement operators. By employing multilevel methods for the block diagonal subsolves, this strategy yields algorithmic and parallel scalability which we demonstrate on a range of problems.

15:12
PO6 7 Second Energy Variation for Heterogeneous Systems with Electrostatic and Magnetostatic Interaction MICHAEL GREENFIELD, US Army Resch Lab - Aberdeen PAVEL GREENFIELD, Drexel University Systems carrying electric charges and magnetic dipoles are widespread in nature and applications. Variational principles and methods play key role in modelling these systems, and they have been developed for a couple of centuries (see, Landau, L.D. and Lifshitz, E.M. Electrodynamics of Continuous Media, Pergamon, 1963). Nonetheless, even a quick glance at the literature shows that the variational approach remains unfinished. In particular, in terms of calculus of variations, all the studies are based on the analysis of first energy variations (i.e., analysis of ponderomotive forces and conditions of equilibrium.) The analysis of the second variation, the cornerstone of the stability analysis, is not even touched in a systematic manner. We partially fixed this gap in (Grinfeld, M., Grinfeld, P., A Variational Approach to Electrostatics of Polarizable Heterogeneous Substances, Advances in Mathematical Physics, Article ID 659127, 2015). In this paper, we present corresponding results relating to the problems of plasma physics.

15:24
PO6 8 Bayesian equilibrium inference in the Minerva framework JAKOB SVENSSON, OLIVER FORD, Max-Planck-Institut für Plasmaphysik, Teilinstitut Greifswald, D-17491 Greifswald, Germany SEHYUN KWAK, Department of Nuclear and Quantum Engineering, KAIST, Daejeon 34141, Korea LYNTON APPEL, 3CCFE, Culham Science Centre, Abingdon OX14 3DB, United Kingdom KIAN RAHBARNIA, JOACHIM GEIGER, JONATHAN SCHILLING, Max-Planck-Institut für Plasmaphysik, Teilinstitut Greifswald, D-17491 Greifswald, Germany The Minerva framework is a scientific modelling system based on Bayesian forward modelling and is used at a number of experiments. The structure of the framework makes it possible to combine flux function based, axisymmetric or full 3D models. A general modularity approach makes it easy to replace underlying physics models, such as the model for force balance and corresponding current distribution. We will give an overview of the different models within Minerva for inference of equilibrium field and flux surfaces, for both tokamaks and stellarators. For axisymmetric devices, three methods of increasing complexity, Gaussian process based Current Tomography (CT), an iterative Grad-Shafranov solver, and a full nonlinear Grad-Shafranov based model, will be demonstrated for the JET device. The novel nonlinear Grad-Shafranov model defines a proper posterior distribution for the equilibrium problem thus defnes the space
of possible equilibrium solutions, and has the capacity to include any nonlinear constraints (e.g. from models of profile diagnostics). The Bayesian approach further allows uncertainties on the equilibrium parameters to be calculated. For the W7-X stellarator, two models based on the VMEC 3D solver and a fast function parameterization approximation will be demonstrated.

Contributed Papers


Post NIC (2012), more stable and lower convergence implosions were developed and used as part of a ‘basecamp’ strategy to identify obstacles to further performance. From 2013-2015 by probing away from a conservative working implosion in steps towards conditions of higher velocity and compression, ‘Fuel Gain’ and alpha-heating were obtained. In the process, performance cliffs unrelated to ‘mix’ were identified the most impactful of which were symmetry control of the implosion and hydro seeded by engineering features. From 2015-2017 we focused on mitigating poor symmetry control and engineering improvements on fill-tubes and capsule mounting techniques. The results were more efficient implosions that can obtain the same performance levels as the earlier implosions, but with less laser energy. Presently, the best of these implosions is poised to step into a burning plasma state. Here, we describe the next step in our strategy that involves using the data we’ve acquired across parameter space to make a step to the largest symmetric implosions that can be fielded on NIF with the energy available. We describe the key principles that form the foundation of this approach.

**Work performed under the auspices of the U.S. D.O.E. by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.


Improvements to the hohlraum for CH implosions [1] have resulted in near-record hot spot pressures, ~225 Gbar. Implosion symmetry and laser energy coupling are improved by using a hohlraum that, compared to the previous high gas-fill hohlraum [2], is longer, larger, at lower gas fill density, and is fielded at zero wavelength separation to minimize cross-beam energy transfer [3]. With a capsule at 90% of its original size in this hohlraum, implosion symmetry changes from oblate to prolate, at 33% cone fraction. Simulations highlight improved inner beam propagation as the cause of this symmetry change. These implosions have produced the highest yield for CH ablator at modest power and energy, i.e., 360 TW and 1.4 MJ. Upcoming experiments focus on continued improvement in shape as well as an increase in implosion velocity. Further, results and future plans on an increase in capsule size to improve margin will also be presented.

*Work performed under the auspices of the U.S. D.O.E. by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.


We have demonstrated nearly 3x alpha-heating at the National Ignition Facility by using tungsten-doped High-Density Carbon (HDC) capsules in low gas fill, unlined, uranium (DU) hohlraums. Shot N170601 achieved a primary neutron yield of 1.5 x 10^{16} neutrons with a Deuterium-Tritium ion temperature of 4.7 keV. Predecessor experiments demonstrated high-performing, efficient performance, as noted through high neutron yield production per laser energy input. Building on these ‘subscale’ results, follow-on experiments utilize an 8% larger target than the predecessor campaign, to increase the capsule surface area and absorbed energy. The capsule fill tube has been reduced in size from 10 to 5 micron diameter, and the laser design implements a new, “drooping” technique for the end of the pulse, to reduce the time between laser shut-off and capsule peak emission while still maintaining capsule mass remaining. Design of the current platform as well as avenues to potentially improve performance based on these experiments will be discussed.

*Work performed under the auspices of the U.S. D.O.E. by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.


Building on our experimental and modelling effort over the last three years, we have found a capsule/hohlraum combination enabling us to drive a symmetrical implosion to convergence 27 with minimal Laser Plasma Interaction (LPI). The experimental platform consists of a low gas fill unlined DU hohlraum driving a W-doped High-Density Carbon (HDC) capsule. With the symmetry in control, the campaign is now moving forward on increasing the neutron yield by increasing the energy absorbed by the capsule. A series of experiments have been carried out first to test how the symmetry of the implosion was preserved at larger capsule and hohlraum scale.
and then to test the performance of the high convergence cryogenic DT-layered implosion. Using this platform, a record primary neutron yield of $1.47 \times 10^{16}$, with a DSR of 3.29% an ion temperature of 4.7 keV at 1.55 MJ was achieved (shot N170601). Details of the implosion conditions of the high performer shot will be presented.

*This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344.

14:48
PO7 5 Assessment of the impact that the capsule fill tube has on implosions conducted with high density carbon ablators* ARTHUR PAK, L.R. BENEDETTI, L. F. BERZAK HOPKINS, D. CLARK, L. DIVOL, E. L. DEWALD, D. FITTINGHOFF, N. IZUMI, S. F. KHAN, O. LANDEN, S. LEPANE, T. MA, E. MARLEY, S. NAGEL, Lawrence Livermore National Laboratory P. VOLEGOV, Los Alamos National Laboratory C. WEBER, D. K. BRADLEY, D. CALLAHAN, G. GRIM, O. A. HURRICANE, P. PATEL, M. B. SCHNEIDER, M. J. EDWARDS, Lawrence Livermore National Laboratory In recent inertial confinement implosion experiments conducted at the National Ignition Facility, bright and spatially localized x-ray emission within the hot spot at stagnation has been observed. This emission is associated with higher Z ablator material that is injected into the hot spot by the hydrodynamic perturbation induced by the 5-10 um diameter capsule fill tube. The reactivity of the DT fuel and subsequent yield of the implosion are strongly dependent on the density, temperature, and confinement time achieved throughout the stagnation of the implosion. Radiative losses from higher Z ablator material that mixes into the hot spot as well as non-uniformities in the compression and confinement induced by the fill tube perturbation can degrade the yield of the implosion. This work will examine the impact to conditions at stagnation that results from the fill tube perturbation. This assessment will be based from a pair of experiments conducted with a high density carbon ablator where the only deliberate change was reduction in fill tube diameter from 10 to 5 um. An estimate of the radiative losses and impact on performance from ablator mix injected into the hot spot by the fill tube perturbation will be presented.

*This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344.

15:00
PO7 6 Symmetry control strategies in low gas-fill hohlraum* CLEMENT GOYON, S. LE PAPE, L. F. BERZAK HOPKINS, L. DIVOL, N. B. MEEZAN, E. DEWALD, D. D. HO, C. WEBER, S. F. KHAN, T. MA, J. L. MILOVICH, A. S. MOORE, R. BENEDETTI, A. E. PAK, J. S. ROSS, S. R. NAGEL, G. P. GRIM, Lawrence Livermore Natl Lab P. VOLEGOV, Los Alamos National Laboratory J. BIENER, A. NIKROO, D. A. CALLAHAN, O. A. HURRICANE, W. W. HSING, R. P. TOWN, M. J. EDWARDS, Lawrence Livermore Natl Lab The primary neutron yield record, to-date, for an ICF implosion on the NIF $(1.47 \times 10^{16})$ has been achieved using a doped HDC capsule ($D = 1.82$ mm) in an unlined DU hohlraum ($D = 6.20$ mm, $L = 11.3$ mm) filled with a low He gas-fill (0.3 mg/cc). This platform uses a new “drooping” pulse designed to keep high remaining mass and short cooling time. Prior to the high convergence (27x) cryogenic DT implosion, our ability to tune hot spot symmetry using this new pulse was tested at lower convergence (15x) using DD gas-filled capsules. Hot spot symmetry was tuned using beam pointing, gas-fill density, and power balance between outer and inner beams. The main metrics to assess the efficiency of each change are the implosion shape (time resolved X-ray emission of the hot spot) and DD neutron yield. In addition, we will describe the irradiation pattern obtained in each case using X-ray (soft and hard) diagnostics and the laser coupling to the hohlraum.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

15:12
PO7 7 Testing low-mode symmetry control with low-adiabat, extended pulse-lengths in BigFoot implosions on the National Ignition Facility MATTHIAS HOHENBERGER, D. T. CASEY, C. A. THOMAS, K. L. BAKER, B. K. SPEARS, S. F. KHAN, O. A. HURRICANE, D. CALLAHAN, Lawrence Livermore Natl Lab The Bigfoot approach to indirect-drive inertial confinement fusion (ICF) has been developed as a compromise trading high-convergence and areal densities for high implosion velocities, large ablatad and hydrodynamic stability. Shape control and predictability are maintained by using relatively short laser pulses and merging the shocks within the DT-ice layer. These design choices ultimately limit the theoretically achievable performance, and one strategy to increase the 1-D performance is to reduce the shell adiabat by extending the pulse shape. However, this can result in loss of low-mode symmetry control, as the hohlraum “bubble,” the high-Z material launched by the outer-cone beams during the early part of the laser pulse, has more time to expand and will eventually intercept inner-cone beams preventing them from reaching the hohlraum waist, thus losing equatorial capsule drive. We report on experimental results exploring shape control and predictability with extended pulse shapes in BigFoot implosions. Prepared by LLNL under Contract DE-AC52-07NA27344.

15:24
PO7 8 Improved Understanding of Implosion Symmetry through New Experimental Techniques Connecting Hohlraum Dynamics with Laser Beam Deposition* JOSEPH RALPH, JAY SALMONSON, EDUARD DEWALD, BENJAMIN BACHMANN, JOHN EDWARDS, FRANK GRAZIANI, OMAR HURRICANE, OTTO LANDEN, TAMMY MA, LAURENT MASSE, STEPHEN MACLAREN, NATHAN MEEZAN, JOHN MOODY, Lawrence Livermore National Laboratory NICHOLAS PARRILLA, Case Western Reserve University JESSE PINO, RYAN SACKS, ROBERT TIPTON, Lawrence Livermore National Laboratory Understanding what affects implosion symmetry has been a challenge for scientists designing indirect drive inertial confinement fusion experiments on the National Ignition Facility (NIF). New experimental techniques and data analysis have been employed aimed at improving our understanding of the relationship between hohlraum dynamics and implosion symmetry. Thin wall imaging data allows for time-resolved imaging of $\sim 10$ keV Au l-band x-rays providing for the first time on the NIF, a spatially resolved measurement of laser deposition with time. In the work described here, we combine measurements from the thin wall imaging with time resolved views of the interior of the hohlraum. The measurements presented are compared to hydrodynamic simulations as well as simplified physics models. The goal of this work is to form a physical picture that better explains the relationship of the hohlraum dynamics and capsule ablator on laser beam propagation and implosion symmetry.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344.
Simultaneous visualization of hohlraum-wall motion and inner-cone beam transport using mid-Z tracers and thin-wall patches at the National Ignition Facility* NOBUHIKO IZUMI, N. MEEZAN, S. JOHNSON, O. JONES, O. JONES, O. LAN- DEN, J. J. KROLL, S. VONHOF, A. NIKROO, Lawrence Livermore Natl Lab J. JAQUEZ, General Atomics C. BAILEY, M. HARDY, R. EHRLICH, J. RALPH, R. PJ. TOWN, D. E. HINKEL, J. D. MOODY, Lawrence Livermore Natl Lab The shorter drive of the High-density carbon (HDC) ablator design allows us to use Intermediate gas-Fill Hohlraums (IFH, 0.3 ~0.6 mg/cc). Due to its reduced initial electron density, IFHs have lower backscatter, lower hot-electrons, and do not require CBET for radiation symmetry control. However, reduced tamping by the hohlraum gas allows more expansion of the hohlraum wall and the ablator. Therefore, the beam transport can be affected by the plasma filling of the hohlraum and the drive symmetry can be altered dynamically. We developed a method to visualize the energy deposition of the inner-cone beams by using thin-wall patches on the hohlraum. The inner-cone beams absorbed on the gold wall create ~11 keV x-rays which are imaged through the thin-wall patches on the equator of the hohlraum. Clipping and absorption of the inner cone beams in the hohlraum is clearly observed with temporal resolution. Comparison of experimental data and rad-hydro simulation will be presented.

*Prepared by LLNL under Contract DE-AC52-07NA27344.

Characterizing NIF hohlraum energy and particle transport using mid-Z spectroscopic tracer materials* J. D. MOODY, LLNL M. A. BARRIOS, Insight Datascience K. WID-MANN, L. J. SUTER, D. A. LIEDAHL, M. B. SCHNEIDER, D. B. THORN, W. A. FARMER, O. L. LANDEN, R. L. KAUFF-MAN, C. JARROTT, M. W. SHERLOCK, H. CHEN, O. JONES, S. A. MACLAREN, D. EDER, D. J. STROZZI, N. B. MEEZAN, A. NIKROO, J. J. KROLL, S. JOHNSON, LLNL J. JAQUEZ, H. HUANG, GA Line emission from mid-Z dopants placed at several spatial locations is used to determine the electron temperature (Te) and plasma flow in NIF hohlraums. Laser drive ablates the dopant and launches it on a trajectory recorded with a framing camera. Analysis of temporally streaked spectroscopy provides an estimate of the time-resolved Te. The estimated temperature gradients show evidence for significantly restricted thermal conduction. Non-local thermal conductivity can account for part of this; additional effects due to magnetic fields, return-current instabilities, ion acoustic turbulence and other physics are considered. We describe our findings and discuss interpretations.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Experimental study of the plasma conditions in gas-filled hohlraum YONGKUN DING, ZHICHAO LI, Research Center of Laser Fusion, China Academy of Engineering Physics XIN LI, Institute of Applied Physics and Computational Mathematics HANG ZHAO, Research Center of Laser Fusion, China Academy of Engineering Physics CHANGSHU WU, Institute of Applied Physics and Computational Mathematics TAO GONG, DONG YANG, XIAO-HUA JIANG, Research Center of Laser Fusion, China Academy of Engineering Physics WUDI ZHENG, SHIYANG ZOU, Insitute of Applied Physics and Computational Mathematics SHENYE LIU, SHAOEN JIANG, Research Center of Laser Fusion, China Academy of Engineering Physics JIAN ZHENG, University of Science and Technology of China Hohlraum plasma and its kinetic behavior are vital to study the laser heated hohlraum, affecting the temporal, spatial and spectral features of the x-ray source. Accurate measurements of the plasma conditions in gas-filled hohlraums have been achieved using the recently set-up 4° Thomson scattering diagnostic at Shenguang-III prototype laser facility. The plasma evolution and kinetic behavior for different locations inside the hohlraum are explored through comparing the theoretical Thomson-scattering spectra based on radiation hydrodynamic code to the experiment result.

Spherical hohlraum energetics studies on the SG series laser facility WENYI HUO, Institute of Applied Physics and Computational Mathematics ZHICHAO LI, XUFEI XIE, Research Center of Laser Fusion, China Academy of Engineering Physics YAOHUA CHEN, GUO LI, JIE LIU, KE LAN, Institute of Applied Physics and Computational Mathematics The integrated experiments at the National Ignition Facility indicates that the radiation asymmetry control in the cylindrical hohlraums is an extremely challenging problem in achieving ignition by using indirect drive. Recently, Lan et al. proposed the octahedral spherical hohlraum which has the natural superiority in providing high radiation symmetry. As new and promising hohlraums, the performance of spherical hohlraum attracts much research interests. Hohlraum energetics is one of the fundamental problems in indirect drive inertial confinement study. We report on the spherical hohlraum experiments performed at the SG series laser facility. At the SGIII-prototype laser facility, we performed the first spherical energetics experiment. The radiation temperature is measured by using an array of flat-response x-ray detectors through a laser entrance hole at different angles. The radiation temperature and M-ban fraction inside the hohlraum are determined by the shock wave technique. At the SGIII laser facility, we performed the first octahedral spherical hohlraum energetics experiment. The 32 of 48 laser beams enter the hohlraum through six laser entrance holes. The radiation flux is measured by 5 FXRDs at different angles. And the radiation temperature inside the hohlraum is determined by the shock wave technique. The repetition of the experimental results is excellent.

BigFoot: a program to reduce risk for indirect drive laser fusion* CLIFF THOMAS, Lawrence Livermore Natl Lab The conventional approach to inertial confinement fusion (ICF) with indirect drive is to design for high convergence (40), DT areal density, and target gain. By construction, this strategy is challenged by low-mode control of the implosion (Legendre P2 and P4), instability, and difficulties interpreting data. Here we consider an alternative - an approach to ICF that emphasizes control. To begin, we optimize hohlraum predictability, and coupling to the capsule. Rather than focus on density, we work on making a high-energy hotspot we can diagnose and “tune” at low convergence (20). Though gain is reduced, this makes it possible to study (and improve) stagnation physics in a regime relevant to ignition (1E16-1E17). Further improvements can then be made with small, incremental increases in areal density, target scale, etc. Details regarding the “BigFoot” platform and pulse are reported, including recent findings. Work that could enable additional improvements in capsule stability and hohlraum control will also be discussed.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
PO7 14 Low fuel convergence path to ignition on the NIF


A novel concept for achieving ignition on the NIF is proposed that obviates current issues plaguing single-shell high-convergence capsules. A large directly-driven Be shell is designed to robustly implode two nested internal shells by efficiently converting 1.7MJ of laser energy from a 6 ns, low intensity laser pulse, into a 1 ns dynamic pressure pulse to ignite and burn a central liquid DT core after a fuel convergence of only 9. The short, low intensity laser pulse mitigates LPI allowing more uniform laser drive of the target and eliminates hot e-, preheat and laser zooming issues. Preliminary rad-hydro simulations predict ignition initiation with 90% maximum inner shell velocity, before deceleration Rayleigh-Taylor growth can cause significant pusher shell mix into the compressed DT fuel. The gold inner pusher shell reduces pre-ignition radiation losses from the fuel allowing ignition to occur at 2.5keV. Further 2D simulations show that the short pulse design results in a spatially uniform kinetic drive that is tolerant to variations in laser cone power. A multi-pronged effort, in collaboration with LLE, is progressing to optimize this design for NIF’s PDD laser configuration.

*Work performed under the auspices of the U.S. Dept. of Energy by the Los Alamos National Security, LLC, Los Alamos National Laboratory under contract DE-FG02-05ER54810.

SESSION PO8: MAGNETO-INERTIAL FUSION I
Wednesday Afternoon, 25 October 2017
Room: 203C at 14:00
Uri Shumlak, University of Washington, presiding

Contributed Papers

14:00

PO8 1 Stagnation morphology in Magnetized Liner Inertial Fusion experiments


In Magnetized Liner Inertial Fusion (MagLIF) experiments on the Z Facility, an axial current of 15-20 MA is driven through a thick metal cylinder containing axially-magnetized, laser-heated deuterium fuel. The cylinder implodes, further heating the fuel and amplifying the axial B-field. Instabilities, such as magneto-Rayleigh-Taylor, develop on the exterior of the liner and may feed through to the inner surface during the implosion. Monochromatic x-ray emission at stagnation shows the stagnation column is quasi-helical with axial variations in intensity. Recent experiments demonstrated that the stagnation emission structure changed with modifications to the target wall thickness. Additionally, applying a thick dielectric coating to the exterior of the target modified the stagnation column. A new version of the x-ray self-emission diagnostic has been developed to investigate stagnation with higher resolution.


14:12

PO8 2 Quantification of MagLIF stagnation morphology using the Mallat Scattering Transformation


The morphology of the stagnated plasma resulting from MagLIF is measured by imaging the self-emission x-rays coming from the multi-keV plasma. Equivalent diagnostic response can be derived from integrated rad-hydro simulations from programs such as Hydra and Gorgon. There have been only limited quantitative ways to compare the image morphology, that is the texture, of the simulations to that of the experiments, to compare one experiment to another, or to compare one simulation to another. We have developed a metric of image morphology based on the Mallat Scattering Transformation, a transformation that has proved to be effective at distinguishing textures, sounds, and written characters. This metric has demonstrated excellent performance in classifying an ensemble of synthetic stagnation images. A good regression of the scattering coefficients to the parameters used to generate the synthetic images was found. Finally, the metric has been used to quantitatively compare simulations to experimental self-emission images.

*Sandia National Laboratories is a multi-mission laboratory managed and operated by NTESS, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the USDoeS NNSA under contract DE-NA0003525.

14:24

PO8 3 Diagnosing the Stagnation Conditions of MagLIF Implosions Using Co and Kr Dopants


Recent experiments on the Z-machine tested several new diagnostic techniques for investigating the stagnation conditions and the origins of the mix present in a Magnetized Liner Inertial Fusion (MagLIF) target. For the first time we have collected K-shell spectra from a low-concentration, Kr dopant placed in the gaseous D2 fuel. In addition, thin Co coatings were strategically applied to three different internal surfaces of the target in order to assess which surfaces actively contribute to the contamination of the fuel. Both imaging spectroscopy and narrow-band crystal imaging were used to identify the location of He-like Co ions. The Tex and ne of the Co is inferred by fitting the He-alpha lines and the near-by Li-like satellites. The Te and ne of the Co is inferred by fitting the He-alpha lines and the near-by Li-like satellites. The experimental measurements and the challenges associated with the analysis will be discussed.

*Sandia Natl Lab is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. DOE NNSA under contract DE-NA-0003525.

14:36

PO8 4 Multi-Objective data analysis using Bayesian Inference for MagLIF experiments

P. Knapp, M. Glinsky, Sandia National Laboratories M. Evans, J. Harvey-Thompson, Sandia National Laboratories

Being able to accurately predict implosion outcomes is essential for the path to ignition of the National Ignition Facility (NIF). The goal of this work is to develop a model that is capable of predicting the stagnation conditions in high performance MagLIF implosions. Using multi-objective Bayesian inference, we are able to learn the space of possible stagnation conditions that lead to the observed stagnation images. This approach allows us to model uncertainties in our diagnostic measurements and to constrain the stagnation conditions through the use of data from other experiments. We have developed a metric that characterizes the texture of the simulations to compare one experiment to another, or to compare one simulation to another. We have developed a metric of image morphology based on the Mallat Scattering Transformation, a transformation that has proved to be effective at distinguishing textures, sounds, and written characters. This metric has demonstrated excellent performance in classifying an ensemble of synthetic stagnation images. A good regression of the scattering coefficients to the parameters used to generate the synthetic images was found. Finally, the metric has been used to quantitatively compare simulations to experimental self-emission images.

15:12

PO8 6 A New Laser Preheat Protocol For MagLIF* M.R. WEIS, A.J. HARVEY-THOMPSON, M. GEISSEL, C.A. JENNINGS, K.J. PETERSON, M.E. GLINSKY, T.J. AWE, D.E. BLISS, M.R. GOMEZ, E.C. HARDING, S.B. HANSEN, M.W. KIMMEL, P.F. KNAPP, S.M. LEWIS, G.A. ROCHAU, M. SCHOLLMIEIER, J. SCHWARZ, J.E. SHORES, S.A. SLUTZ, D.B. SINARS, I.C. SMITH, C.S. SPEAS, Sandia Natl Labs Previous Magnetized Liner Inertial Fusion experiments at Sandia National Labs have preheated the fuel with the unsmoothed 2ω Z-Beamlet Laser. A new low intensity laser configuration, using phase plate smoothing and a low-power pulse shape, improved laser propagation and reduced stimulated Brillouin scattering in offline laser experiments. This allows for more efficient use of laser energy and better spot reproducibility. The new laser protocol is estimated to couple at least 650 J to the fuel, sufficient to produce comparable neutron yields with the previous unsmoothed configuration. Mid-Z dopants were also fielded on the underside of the window. Observation of these dopants provided evidence of window material mixing into the fuel with both the unsmoothed and smoothed beam, consistent with MHD simulation predictions.


University of Rochester MATTH GOM, STEPHANIE HAN, ERIC HARDING, STEVE SLUTZ, KELLY HAHN, ADAM HARVEY-THOMPSON, MATTHIAS GEISSEL, DAVID AMPLEFORD, CHRISTOPHER JENNINGS, PAUL SCHMIT, IAN SMITH, JENS SCHWARZ, KYLE PETERSON, BRENT JONES, GREGORY ROCHAU, DANIEL SINARS, Sandia National Laboratories The MagLIF concept [1] has recently demonstrated Gbar pressures and confinement of charged fusion products at stagnation [2,3]. We present a new analysis methodology that allows for integration of multiple diagnostics including nuclear, x-ray imaging, and x-ray power to determine the temperature, pressure, liner areal density, and mix fraction. A simplified hot-spot model is used with a Bayesian inference network to determine the most probable model parameters that describe the observations while simultaneously revealing the principal uncertainties in the analysis.

*MRI and operation funded by the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

15:00

PO8 5 MagLIF Pre-Heat Optimization on the PECOS Surrogacy Platform* MATTHIAS GEISSEL, A.J. HARVEY-THOMPSON, D. AMPLEFORD, T.J. AWE, D.E. BLISS, M.E. GLINSKY, M.R. GOMEZ, E. HARDING, S.B. HANSEN, C. JENNINGS, M.W. KIMMEL, P.F. KNAPP, S.M. LEWIS, K. PETERSON, G.A. ROCHAU, M. SCHOLLMIEIER, J. SCHWARZ, J.E. SHORES, S.A. SLUTZ, D.B. SINARS, I.C. SMITH, C.S. SPEAS, R.A. VESEY, M.R. WEIS, J.L. PORTER, Sandia Natl Labs Sandia’s MagLIF Program is using the PECOS target area as a platform to optimize the coupling of laser energy into the fuel. After developing laser pulse shapes that reduced SBS and improved energy deposition (presented last year), we will report on the effect on inter-pulse stabilities (LPI) using 2ω (527 nm) and 3ω (351 nm) lasers with intensity in the range of (1-5)×10¹⁴ Wcm⁻². The laser beam (1-1.5 ns square pulse) enters the gas-filled plastic liner though a 2-μm thick polyimide window to heat an underdense Ar-doped deuterium gas and increase with laser intensity and the 2ω beam produces more hard x-ray diagnostics. The 2ω beam propagation shows a noticeable larger lateral spread than the 3ω beam, indicating laser spray due to filamentation. LPI is observed to increase with laser intensity and the 2ω beam produces more hot electrons compared with the 3ω beam under similar conditions.

*Work supported by the U.S. DOE ARPA-E and NNSA.
the spatial distributions of heat flow and inverse bremsstrahlung absorption in the plasma.

*This work was supported by a contract from SNL.

15:36
PO8 9 Experimental Observation of the Stratified Electrothermal Instability on Dielectric-Coated Thick Aluminum TREVOR HUTCHINSON, University of Nevada, Reno THOMAS AWE, Sandia National Laboratories BRUNO BAUER, University of Nevada, Reno KEVIN YATES, University of New Mexico EDMUND YU, WILLIAM YELTON, Sandia National Laboratories STEPHAN FUELLING, University of Nevada, Reno The first direct observation of the stratified electrothermal instability on the surface of thick metal is reported. Aluminum rods coated with 70 um Parylene-N were driven to 1 MA in approximately 100 ns, with the metal thicker than the skin depth. The dielectric coating suppressed plasma formation, prolonging the observability of discrete azimuthally-correlated stratified structures perpendicular to the current. Assuming blackbody emission, radiometric calculations indicate strata are temperature perturbations that grow exponentially with rate 0.04/ns in 3000-10,000 K aluminum.

15:48
PO8 10 Development of the striation and filament form of the electrothermal instability* EDMUND YU, T.J. AWE, W.G. YELTON, B.B. MCKENZIE, K.J. PETERSON, Sandia National Labs B.S. BAUER, T.M. HUTCHINSON, University of Nevada S. FUELLING, Sandia National Labs K.C. YATES, G. SHIPLEY, University of New Mexico Magnetically imploded liners have broad application to ICF, dynamic material property studies, and flux compression. An important consideration in liner performance is the electrothermal instability (ETI), an Ohmic heating instability that manifests in 2 ways: assuming vertical current flow, ETI forms hot, horizontal bands (striations) in metals, and vertical filaments in plasmas. Striations are especially relevant in that they can develop into density perturbations, which then couple to the dangerous magnetic Rayleigh-Taylor (MRT) instability during liner acceleration. Recent visible emission images of Ohmically heated rods [1] show evidence of both the striation and filament form of ETI, suggesting several questions: (1) can simulation qualitatively reproduce the data? (2) If so, what seeds the striation ETI, and how does it transition to filaments? (3) Does the striation develop into a strong density perturbation, important for MRT? In this work, we use analytic theory and 3D MHD simulation to study how isolated resistive inclusions, embedded in a perfectly smooth rod and communicating through current redistribution, can be used to address the above questions.

*Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. DOE NNSA under contract DE-NA0003525.


16:00
PO8 11 Experimental Study of Magnetic Field Production and Dielectric Breakdown of Auto-Magnetizing Liners* GABRIEL SHIPLEY, THOMAS AWE, Sandia National Laboratories TREVOR HUTCHINSON, University of Nevada, Reno BRIAN HUTSEL, STEPHEN SLUTZ, DEREK LAMPPA, Sandia National Laboratories AutoMag liners premagnetize the fuel in MagLIF targets and provide enhanced x-ray diagnostic access and increased current delivery without requiring external field coils [1]. AutoMag liners are composite liners made with discrete metallic helical construction paths separated by insulating material. First, a low dI/dt “foot” current pulse (1 MA in 100 ns) premagnetizes the fuel. Next, a higher dI/dt pulse with larger induced electric field initiates breakdown on the composite liner’s surface, switching the current from helical to axial to implode the liner. Experiments on MYKONOS have tested the premagnetization and breakdown phases of AutoMag and demonstrate axial magnetic fields above 90 Tesla for a 550 kA peak current pulse. Electric fields of 17 MV/m have been generated before breakdown. AutoMag may enhance MagLIF performance by increasing the premagnetization strength significantly above 30 T, thus reducing thermal-conduction losses and mitigating anomalous diffusion of magnetic field out of hotter fuel regions, by, for example, the Nernst thermoelectric effect.

*This project was funded in part by Sandia’s Laboratory Directed Research and Development Program (Projects No. 200169 and 195306).


16:12
PO8 12 Enhancing Neutron Yield in Cylindrical Implosions with an Applied Magnetic Field* J.L. PEEBLES, J.R. DAVIES, D.H. BARNAK, R. BETTI, Y.YU. GLEBOV, J.P. KNAUER, Laboratory for Laser Energetics, U. of Rochester Laser-driven MagLIF (magnetized liner inertial fusion) is being developed on the OMEGA laser; multiple experimental campaigns have been conducted that have examined yield dependence on magnetic field, preheat energy, and fill pressure. Magnetic fields were generated in the region of interest using coils driven by current from the mageto-inertial fusion electrical discharge system (MIFEDS). A variety of coil designs were used and current was varied to generate different levels of magnetic field without impeding the path of the 40 implosion beams. We demonstrate a large enhancement of neutron yield by applying an initial field of 10 T along the axis of a cylindrical implosion.

*The work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0000568 and the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

16:24
PO8 13 Fuel Areal-Density Measurements in Laser-Driven Magnetized Inertial Fusion from Secondary Neutrons* J.R. DAVIES, D.H. BARNAK, R. BETTI, Y.YU. GLEBOV, J.P. KNAUER, J.L. PEEBLES, Laboratory for Laser Energetics, U. of Rochester Laser-driven magnetized liner inertial fusion is being developed on the OMEGA laser to provide the first data at a significantly smaller scale than the Z pulsed-power machine in order to test scaling and to provide more shots with better diagnostic access than Z. In OMEGA experiments, a 0.6-mm-outerior-diam plastic cylinder filled with 11 atm of D2 is placed in an axial magnetic field of ~10 T, the D2 is preheated by a single beam along the axis, and then the cylinder is compressed by 40 beams. Secondary DT neutron yields provide a measurement of the areal density of the compressed D2 because the compressed fuel is much smaller than the mean free path and the Larmor radius of the T produced in D-D fusion. Measured secondary yields confirm theoretical predictions that preheating and magnetization reduce fuel compression. Higher fuel compression is found to consistently lead to lower neutron yields, which is not predicted by simulations.

*The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0000568.
and the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

SESSION PM9: MINI-CONFERENCE ON LASER-MATTER INTERACTIONS: THE NEXT GENERATION II
Wednesday Afternoon, 25 October 2017
Room: 202DE at 14:00
Arkady Gonoskov, Chalmers University of Technology, presiding

Contributed Papers

14:00
PM9 1 Exploring extreme plasma physics in the laboratory and in astrophysics* L. O. SILVA, T. GRISMAIER, R. A. FONSECA, F. CRUZ, F.D. GAUDIO, J.L. MARTINS, J. VIEIRA, M. VRANIC, GoLP/IPFN, Instituto Superior Tecnico, Universidade de Lisboa, Portugal
The interaction of ultra intense fields with plasmas is at the confluence of several sub-fields ranging from QED, and nuclear physics to high energy astrophysics, and fundamental plasma processes. It requires novel theoretical tools, highly optimised numerical codes and algorithms tailored to these complex scenarios, where physical mechanisms at very disparate temporal and spatial scales are self-consistently coupled in multidimensional geometries. The key developments implemented in Osiris will be presented along with some examples of problems, relevant for laboratory or astrophysical scenarios, that are being addressed resorting to the combination of massively parallel simulations with theoretical models. The relevance for near future experimental facilities such as ELI will also be presented.

PM9 2 Quantum regime in new collider configurations THOMAS GRISMAIER, MARIJA VRANIC, FABRIZIO DEL GAUDIO, GoLP/Instituto de Plasmas e Fusao Nuclear, University of Lisbon, Portugal
The interaction of ultra intense fields with plasmas is at the confluence of several sub-fields ranging from QED, and nuclear physics to high energy astrophysics, and fundamental plasma processes. It requires novel theoretical tools, highly optimised numerical codes and algorithms tailored to these complex scenarios, where physical mechanisms at very disparate temporal and spatial scales are self-consistently coupled in multidimensional geometries. The key developments implemented in Osiris will be presented along with some examples of problems, relevant for laboratory or astrophysical scenarios, that are being addressed resorting to the combination of massively parallel simulations with theoretical models. The relevance for near future experimental facilities such as ELI will also be presented.

*Work supported by the European Research Council (ERC-AdG-2015 InPairs Grant No. 695088).

14:20
PM9 3 Second order nonlinear QED processes in ultra-strong laser fields FELIX MACKENROTH, Max Planck Institute for the Physics of Complex Systems
The interaction of ultra-intense laser fields with matter the ever increasing peak laser intensities render nonlinear QED effects ever more important. For long, ultra-intense laser pulses scattering large systems, like a macroscopic plasma, the interaction time can be longer than the scattering time, leading to multiple scatterings. These are usually approximated as incoherent cascades of single-vertex processes. Under certain conditions, however, this common cascade approximation may be insufficient, as it disregards several effects such as coherent processes, quantum interferences or pulse shape effects. Quantifying deviations of the full amplitude of multiple scatterings from the commonly employed cascade approximations is a formidable, yet unaccomplished task. In this talk we are going to discuss how to compute second order nonlinear QED amplitudes and relate them to the conventional cascade approximation. We present examples for typical second order processes and benchmark the full result against common approximations. We demonstrate that the approximation of multiple nonlinear QED scatterings as a cascade of single interactions has certain limitations and discuss these limits in light of upcoming experimental tests.

PM9 4 Strong-field QED processes in laser and plasma environments SEBASTIAN MEUREN,* CHRISTOPH H. KEITEL, ANTONINO DI PIAZZA, Max Planck Institute for Nuclear Physics, Heidelberg, Germany
Highly relativistic probes can explore the QED critical field if they propagate through strong electromagnetic fields, e.g., in a plasma environment [1]. In this regime nonlinear and nonperturbative QED effects become important and thus a complicated interplay between strong-field QED and plasma physics takes place. To render numerical calculations in this regime feasible the so-called QED-PIC approach has been developed [2], which is based on the semiclassical approximation. Recently, we have investigated the validity of the semiclassical approximation by examining the nonlinear Breit-Wheeler process (electron-positron photoproduction) inside a plane-wave laser field in detail [3]. In the talk the difference between classical and quantum absorption of laser energy, the importance of interference effects and the possibility of recoil processes [4] will be discussed.

*Now at Princeton University, Princeton, NJ.

1Di Piazza et al., Rev. Mod. Phys. 84, 1177 (2012).

15:00
PM9 5 Influence of the ion mass on quantum electrodynamics processes with the next generation high power lasers* REMI CAPEDESSUS, PAUL MCKENNA, Department of Physics SUPA, University of Strathclyde
The construction of a number of new multi-petawatt laser facilities in Europe, USA and China has generated intense interest in the exploration of new physical regimes involving ultra-strong electromagnetic fields in which a significant amount of the laser energy is converted into high energy synchrotron radiation and in which electron-positron pairs can be produced. These new laser facilities will enable experimental exploration of this science for the first time. From an ultra-intense...
laser pulse ($I > 10^{21}$ W/cm$^2$) interacting with a plasma, we bring out the impact of the ion collective dynamics on the basic quantum electrodynamics processes such as high energy synchrotron radiation generation and the production of electron-positron pairs in the non-linear Breit-Wheeler process. Relevant cases are qualitatively discussed as well as potential future experiments.

This work is supported by EPSRC (Grant No. EP/P007082/1).

PM9 6 Possibilities to observe Delbrück scattering at next generation laser facilities

JAMES KOGA, TAKEHITO HAYAKAWA, Natl Inst for Quantum & Radiological Science & Tech (QST)

We have previously shown that by using high-flux linearly polarized laser Compton gamma-ray sources the contribution of the vacuum component, Delbrück scattering, to the elastic scattering of the gamma-rays off nuclei could be nearly isolated at photon energies of 1.1 MeV [1]. Since for photon energies below the electron-positron pair creation threshold of 1.022 MeV the complex Delbrück scattering amplitude is real and measures only the contribution from virtual pairs [2], it is of interest to measure it for the properties of vacuum. We present our calculations for sub-MeV photon energies and discuss the possibility of measuring Delbrück scattering at new ultra-high power laser and X-ray Free Electron Laser facilities.


PM9 7 Spin polarization of electrons by ultra-intense lasers

DARIO DEL SORBO, University of York DANIEL SEIPT, Cockcroft Institute/Lancaster University TOM G. BLACK-BURN, Chalmers University of Technology ALEXANDER G. R. THOMAS, Cockcroft Institute/Lancaster University CHRISTOPHER D. MURPHY, University of York JOHN G. KIRK, Max Planck Institut für Kernphysik CHRISTOPHER RIDGERS, University of York

At the intensities accessible by the soon to be completed Extreme Light Infrastructure, laser-matter interactions are predicted to reach a new regime characterized by the interplay of relativistic plasma kinetics and non-linear QED processes. In order to understand the dynamics of this QED-plasmas, it is necessary to have an accurate description of the micro-dynamics of particles undergoing QED processes in the strong background field of the laser. Standard treatments average over the spin degree of freedom. However, Sokolov and Ternov demonstrated that ultra-relativistic electrons and positrons spin polarize up to 92.4%, in a strong magnetic field, after a characteristic time. We show that electron spin-polarization can also occur in the electromagnetic fields of next-generation lasers. In particular, we study the case of electrons orbiting in a rotating electric field - a configuration that may be realized at the magnetic node of two colliding, circularly-polarized laser pulses. The spin-polarization of the electrons by high-intensity lasers can occur very rapidly, we predict on the femtosecond time scale [1].


PM9 8 Vlasov simulations of electron beam-laser collisions

ALEXANDER THOMAS, University of Michigan / Lancaster University CHRIS RIDGERS, University of York DANIEL SEIPT, Lancaster University DARIO DEL SORBO, University of York

We present numerical calculations of the interaction of a GeV electron beam with an intense laser pulse ($\sim 10^{21}$ W cm$^{-2}$ at 0.8 nm) using a 1D1.5P Eulerian-Vlasov model that includes strong field QED processes, including photon emission and pair production. Using a Vlasov treatment allows accurate modeling of the highest energy but low probability components of the particle distributions, which disproportionally contribute to QED processes.

PM9 9 Flying relativistic mirrors for nonlinear QED studies*

STEPAN BULANOV, CARL SCHROEDER, ERIC ESAREY, WIM LEEMANS, Lawrence Berkeley National Laboratory Recent progress in laser technology has led to a dramatic increase of laser power and intensity. As a result, the laser-matter interaction will happen in the radiation dominated regimes. In a strong electromagnetic field, electrons can be accelerated to such high velocities that the radiation reaction starts to play an important role. The radiation effects change drastically the laser-plasma interaction leading to fast energy losses. Moreover, previously unexplored regimes of the interaction will be entered into, in which quantum electrodynamics (QED) can occur. Depending on the laser intensity and wavelength, either classical or quantum mode of radiation reaction prevail. In order to study different regimes of interaction as well as the transition from one into another the utilization of flying relativistic mirrors, which can generate electromagnetic pulses with varying frequency and intensity, is proposed. The scheme is demonstrated for multiphoton Compton scattering.

*Work supported by U.S. DOE under Contract No. DE-AC02-05CH11231.

PP11 1 HEDP II

Development of a compact 30 T magnetic field system for OMEGA

G. FIJKSEL, R. BACKHUS, P. MCNALLY, E. VIGES, M. VILLALTA, University of Michigan, Ann Arbor; M/I/D. JACOBS-PERKINS, R. BETTI, LLE, University of Rochester, NY. Aiming at conducting studies of magnetized high-energy density plasmas in a high magnetic field, we are developing a compact system capable of creating a pulsed magnetic field of about 30T in a volume of several cubic centimeters. The system prototype will be tested at the University of Michigan and will be adopted afterwards for use at the OMEGA facility of the Laboratory for Laser Energetics (LLE) of the University of Rochester, NY. The system consists of a pulsed power supply situated outside of the Omega vacuum chamber and a magnetic coil inserted into the chamber with a diagnostic inserter. The power supply is based on a 50μF/20kV storage capacitor and is capable of driving a pulse of current of up to 50kA through the coil. The power supply is connected with the coil via a low-inductive chain of power cables and a strip transmission line. The system electrical, magnetic, and thermal analysis will be presented along with the results of initial testing.

*This work is supported in part through a DOE-OFES award DE-SC0016258 and a University of Michigan research Grant U051442.

PP11 2 HEDP II

Development of a compact 30 T magnetic field system for OMEGA

G. FIJKSEL, R. BACKHUS, P. MCNALLY, E. VIGES, M. VILLALTA, University of Michigan, Ann Arbor; M/I/D. JACOBS-PERKINS, R. BETTI, LLE, University of Rochester, NY. Aiming at conducting studies of magnetized high-energy density plasmas in a high magnetic field, we are developing a compact system capable of creating a pulsed magnetic field of about 30T in a volume of several cubic centimeters. The system prototype will be tested at the University of Michigan and will be adopted afterwards for use at the OMEGA facility of the Laboratory for Laser Energetics (LLE) of the University of Rochester, NY. The system consists of a pulsed power supply situated outside of the Omega vacuum chamber and a magnetic coil inserted into the chamber with a diagnostic inserter. The power supply is based on a 50μF/20kV storage capacitor and is capable of driving a pulse of current of up to 50kA through the coil. The power supply is connected with the coil via a low-inductive chain of power cables and a strip transmission line. The system electrical, magnetic, and thermal analysis will be presented along with the results of initial testing.

*This work is supported in part through a DOE-OFES award DE-SC0016258 and a University of Michigan research Grant U051442.
PP11 3 Solenoid for Laser Induced Plasma Experiments at Janus SALLEE KLEIN, HEATH LEFEBVRE, University of Michigan GREGORY KEMP, DEREK MARISCAL, Lawrence Livermore National Laboratory ALEX RASMUS, University of Michigan, Los Alamos National Laboratory JACKSON WILLIAMS, Lawrence Livermore National Laboratory ROBB GILLESPIE, University of Michigan MARIO MANUEL, General Atomics CAROLYN KURANZ, PAUL KEITER, R DRAKE, University of Michigan Inventing and maintaining a magnetized implosion environment for experiments involving laser-induced plasmas is particularly challenging due to the high voltages at which the solenoid must be pulsed. Creating a solenoid resilient enough to survive through large numbers of voltage discharges, enabling it to endure a campaign lasting several weeks, is exceptionally difficult. Here we present a solenoid that is robust through 40 μs pulses at a ∼13 kV potential. This solenoid is a vast improvement over our previously fielded designs in peak magnetic field capabilities and robustness. Designed to be operated at small-scale laser facilities, the solenoid housing allows for versatility of experimental set-ups among diagnostic and target positions. Within the perpendicular field axis at the center there is 300 degrees of clearance which can be easily modified to meet the needs of a specific experiment, as well as an ∼0.3 cone for transmitted or backscattered light. After initial design efforts, these solenoids are relatively inexpensive to manufacture.

PP11 4 Characterization of cylindrically imploded magnetized plasma by spectroscopy and proton probing* M. DOZIERES, P. FORESTIER-COLLEONI, Univ of California - San Diego M. S. WEI, General Atomics - San Diego P-A GOURDAIN, J. R. DAVIES, Univ of Rochester - New York S. FUJIOKA, Univ of Osaka - Japan J. PEEBLES, M. CAMPBELL, Univ of Rochester - New York J. J. SANTOS, D. BATANI, Univ of Bordeaux - France C. MCGUFFEY, F. N. BEG, Univ of California - San Diego Understanding the role of magnetic field in relativistic electron beam transport and energy deposition is important for several applications including fast ignition inertial confinement fusion. We report the development of a cylindrically compressed target platform with externally applied magnetic fields on OMEGA. As a first step, we performed an experiment to characterize the imploded plasma and compressed field condition. The implosion of the target was performed using 36 UV beams (400 J per beam, 1.5 ns square pulse), and the magnetic field was measured by proton deflection using mono-energetic protons produced from D3He capsule implosion. The target was a CH foam cylinder doped with 1% chlorine in order to detect the time-resolved 1s-2p Cl absorption structures, using a gold foil as a broadband backlighter source. A Cu foil at the beginning of the foam cylinder and a Zn foil at the end, allowed us to measure the Kr and the 1s-2p transitions of He-like and Li-like ions for both elements. The emission and absorption spectroscopic data are compared to atomic physics codes to determine the plasma temperature and density under the influence of the magnetic field.

PP11 5 Hybrid Fluid/Kinetic Modeling Of Magnetized High Energy Density Plasmas* DAVID HANSEN, ERIC HELD, Utah State University JACOB KING, PETER STOLTZ, Tech-X Corp ROBERT MASTI, BHUVANA SRINIVASAN, Virginia Tech NATHANIEL FISCH, Princeton University The magnetic field influences the linear and coronal regions distort distribution functions and likely lead to non-local transport effects in a plasma which varies from weakly to strongly coupled. In this work, we discuss using effective potential theory [1] along with a Chapman-Enskog-like (CEL) formalism to develop hybrid fluid/kinetic modeling capabilities for these plasmas. Effective potential theory addresses the role of Coulomb collisions on transport across coupling regimes and the CEL approach bridges the gap between full-blown kinetic simulations and the EOS tables, which only depend locally on density and temperature. Quantitative results on the Spitzer problem across coupling regimes will be presented as a first step.

*DOE Grant No. DE-SC0016525.


PP11 6 Enhancing Understanding of Magnetized High Energy Density Plasmas from Solid Liner Implosions Using Fluid Modeling with Kinetic Closures* ROBERT MASTI, BHUVRANA SRINIVASAN, Virginia Tech JACOB KING, PETER STOLTZ, Tech-X Corporation DAVID HANSEN, ERIC HELD, Utah State University Recent results from experiments and simulations of magnetically driven power liners have explored the role of early-time electrothermal instability in the evolution of the MRT (magneto-Rayleigh-Taylor) instability. Understanding the development of these instabilities can lead to potential stabilization mechanisms; thereby providing a significant role in the success of fusion concepts such as MagLiF (Magnetized Liner Inertial Fusion). For MagLiF the MRT instability is the most detrimental instability toward achieving fusion energy production. Experiments of high-energy density plasmas from wire-array implosions have shown the requirement for more advanced physics modeling than that of ideal magnetohydrodynamics. The overall focus of this project is on using a multi-fluid extended-MHD model with kinetic closures for thermal conductivity, resistivity, and viscosity. The extended-MHD model has been updated to include the SESAME equation-of-state tables and numerical benchmarks with this implementation will be presented. Simulations of MRT growth and evolution for MagLiF-relevant parameters will be presented using this extended-MHD model with the SESAME equation-of-state tables.

*This work is supported by the Department of Energy Office of Science under Grant Number DE-SC0016515.

PP11 7 Kinetic Simulations of Laser Parametric Amplification in Magnetized Plasmas* QING JIA, YUAN SHI, HONG QIN, NATHANIEL FISCH, Princeton University Laser pulse compression using magnetized resonance near the upper-hybrid frequency is promising for achieving higher output intensity in regimes previously thought impossible using unmagnetized plasmas. Using one-dimensional particle-in-cell simulations, we verify that, by partially replacing plasma with an external transverse magnetic field of megagauss scale, the output pulse can be intensified by a factor of a few, due to the increased allowable amplification time despite a decreased growth rate. Further improvement is impeded by the generation of an electromagnetic wakefield, to which the amplified pulse loses more energy than it does in the unmagnetized case. This limitation can however be circumvented by the use of a stronger pump. In contrast to unmagnetized compression, the magnetized amplification remains efficient when the pump intensity is well above the wavebreaking threshold, until a higher phase-mixing threshold is exceeded. This surprising resilience to wavebreaking in magnetized plasma is of great benefit for magnetized compression.
PP11.8 On the Crossover from Classical to Fermi Liquid Behavior in Dense Plasmas* JEROME DALIGAULT, Los Alamos National Laboratory We explore the crossover from classical plasma to quantum Fermi liquid behavior of electrons in dense plasmas. To this end, we analyze the evolution with density and temperature of the momentum lifetime of a test electron introduced in a dense electron gas. This allows us 1) to determine the boundaries of the crossover region in the temperature-density plane and to shed light on the evolution of scattering properties across it, 2) to quantify the role of the fermionic nature of electrons on electronic collisions across the crossover region, and 3) to explain how the concept of Coulomb logarithm emerges at high enough temperature but disappears at low enough temperature.

*Work supported by LDRD Grant No. 20170490ER.

PP11.9 Thermal conductivity study of warm dense matter by differential heating on LCLS and Titan* M. HILL, AWE E. MCKELVEY, S. JIANG, R. SHEPHERD, S. HAU-RIEGE, H. WHITNEY, P. STERNE, S. HAMEL, G. COLLINS, Y. PING, LLNL C. BROWN, E. FLOYD, J. FYRTH, D. HOARTY, AWE R. HUA, M. BAILLY-GRANDVAUX, F. BEG, UCSD B. CHO, M. KIM, J. LEE, GIST H. LEE, E. GALATIER, SLAC A differential heating platform has been developed for thermal conduction study, where a temperature gradient is induced and subsequent heat flow is probed by time-resolved diagnostics. Multiple experiment using this platform have been carried out at LCLS-MEC and Titan laser facilities for warm dense Al, Fe, amorphous carbon and diamond. Two single-shot time-resolved diagnostics are employed, SOP (streaked optical pyrometry) for surface temperature and FDI (Fourier Domain Interferometry) for surface expansion. Both diagnostics provided excellent data to constrain release equation-of-state (EOS) and thermal conductivity. Data sets with varying target thickness and comparison between simulations with different thermal conductivity models are presented.

*This work was performed under DOE contract DE-AC52-07NA27344 with support from DOE OFES Early Career program and LLNL LDRD program.

PP11.10 Proton Beam Driven Isochoric Heating to Warm Dense Matter Conditions on Texas Petawatt® R. ROYCROFT, G.M. DYER, E. MCCARY, X. JIAO, B. BOWERS, A. BERNSTEIN, T. DITMIRE, M. MONTGOMERY, D. WINGET, B.M. HEGELICH, University of Texas Austin Isochoric heating of solids and gases to warm dense matter conditions is relevant to the study of equation of state as well as laboratory astrophysics, specifically heating of hydrogen gas (~10^7-10^19 cm^-3) to 0.5-3eV for the study of white dwarf atmospheres. In a series of experiments on Texas Petawatt, we have built a platform using the petawatt laser focused softly to a large focal spot (60-70um) to generate large numbers of intermediate energy protons via TNSA, ideal for isochoric heating. We have previously used the proton beam to isochorically heat 10um aluminum foils to 20eV. This poster presents results of experiments in which low Z materials such as methane gas, carbon foams, and hydrogen are heated using this platform. We are measuring the surface brightness temperature and heating with a streaked optical pyrometer, and XUV emissions using an XUV spectrometer.

PP11.11 Single pass density diagnostic for expanded warm dense plasmas* THOMAS SCHMIDT, JOSH COLEMAN, Los Alamos National Laboratory SALVADOR PORTILLO, University of New Mexico, ECE Dept. LOS ALAMOS NATIONAL LABS TEAM, UNIVERSITY OF NEW MEXICO, ECE DEPT. TEAM Warm dense plasmas are opaque to visible light. However, the density gradient of the expanded, less dense plasma surrounding the warm dense matter (WDM) can be optically accessed. This paper describes the development and implementation of Moiré deflectometry and Nomarski interferometry techniques for analysis of the expanded WDM produced from an intense electron beam on a thin foil. The 20 MeV beam incident on copper or titanium targets produce plasmas where the densities are < 8 x 10^22 cm^-3. The measurements rely on a probe laser of wavelength 405 nm in which the critical density is ~ 7 x 10^21 cm^-3, meaning a large portion of the plasma is accessible. Preliminary maps of the density gradient obtained by Moiré deflectometry and the density by Nomarski interferometry will be presented. In addition, the characterization, development, and implementation of these techniques are applied to atmospheric plasma sources.

*Supported by NNSA cooperative agreement DE-NA0002008, the DARPA PULSE program (12-63-PULSE-FP014), and the Air Force Office of Scientific Research (FA9550-14-1-0045).

PP11.12 Soft X-ray Spectrometer for Characterization of Electron Beam Driven WDM* NICHOLAS RAMEY, Univ of Michigan - Ann Arbor JOSHUA COLEMAN, JOHN PERRY, Los Alamos National Laboratory A preliminary design study is being performed on a soft X-ray spectrometer to measure K-shell spectra emitted by a warm dense plasma generated by an intense, relativistic electron beam interacting with a thin, low-Z metal foil. A 100-ns-long electron pulse with a beam current of 1.7 kA and energy of 19.8 MeV deposits energy into the thin metal foil heating it to a warm dense plasma. The collisional ionization of the target by the electron beam produces an anisotropic angular distribution of K-shell radiation and a continuum of both scattered electrons and Bremsstrahlung up to the beam energy of 19.8 MeV. A proof-of-principle Bragg-type spectrometer has been built to measure the Ti K-α and K-β lines. The goal of the spectrometer is to measure the temperature and density of this warm dense plasma for the first time with this heating technique.

*This work was supported by the National Nuclear Security Administration of the U.S. Department of Energy under Contract No. DE-AC52-06NA25396.

PP11.13 Extreme ultraviolet capillary discharge lasers SARAH WILSON, ANDREW WEST, GREG TALLENTS, Univ of York An extreme ultraviolet capillary discharge laser has recently been installed at the University of York. The laser produces EUV radiation of wavelength 46.9nm, with pulse durations of approximately 1.2ns and energies of up to 50μJ. A population inversion is produced by a high voltage electrical discharge passing through an argon filled capillary tube. Within the capillary, radial pinching of the argon plasma through Jx B force causes the pressure and temperature of the plasma to increase which causes amplification between 3p - 3s (J=0-1) transitions producing EUV radiation. Laser optimisation,
PP11 14 Prediction of scaling physics laws for proton acceleration with extended parameter space of the NIF ARC* KRISH BHUTWALA, FARHAT BEG, University of California, San Diego DEREK MARISCAL, SCOTT WILKS, TAMMY MA, Lawrence Livermore National Laboratory The Advanced Radiographic Capability (ARC) laser at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory is the world’s most energetic short-pulse laser. It comprises four beamlets, each of substantial energy (∼1.5 kJ), extended short-pulse duration (10-30 ps), and large focal spot (≥50% of energy in 150 μm spot). This allows ARC to achieve proton and light ion acceleration via the Target Normal Sheath Acceleration (TNSA) mechanism, but it is yet unknown how proton beam characteristics scale with ARC-regime laser parameters. As theory has also not yet been validated for laser-generated protons at ARC-regime laser parameters, we attempt to formulate the scaling physics of proton beam characteristics as a function of laser energy, intensity, focal spot size, pulse length, target geometry, etc. through a review of relevant proton acceleration experiments from laser facilities across the world. These predicted scaling laws should then guide target design and future diagnostics for desired proton beam experiments on the NIF ARC.

*This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and funded by the LLNL LDRD program under tracking code 17-ERD-039.

PP11 15 Measurements of plasma mirror reflectivity and focal spot quality for tens of picosecond laser pulses* PIERRE FORESTIER-COLLEONI, UCSD JACKSON WILLIAMS, LLNL GRAEME SCOTT, RAL DERECK. A. MARISCAL, LLNL CHRISTOPHER MCGUFFEY, FARHAT N. BEG, UCSD HUI CHEN, LLNL, DAVID NEELY, RAL TAMMY MA, LLNL The Advanced Radiographic Capability (ARC) laser at the NIF (LLNL) is high-energy (∼4 kJ) with a pulse length of 30ps, and is capable of focusing to an intensity of 10^{18} W/cm^2 with a ∼100 μm focal spot. The ARC laser is at an intensity which can be used to produce proton beams. However, for applications such as radiography and warm dense matter creation, a higher laser intensity may be desired to generate more energetic proton beams. One possibility to increase the intensity is to decrease the focused spot size by employing a smaller f-number optic. But it is difficult to implement such an optic or to bring the final focusing parabola closer to the target within the complicated NIF chamber geometry. A proposal is to use ellipsoidal plasma mirrors (PM) for fast focusing of the ARC laser light, thereby increasing the peak intensity. There is uncertainty, however, in the survivability and reflectivity of PM at such long pulse durations. Here, we show experimental results from the Titan laser to study the reflectivity of flat PM as a function of laser pulse length. A calorimeter was used to measure the PM reflectivity. We also observed degradation of the far and near field energy distribution of the laser after the reflection by the PM for pulse-lengths beyond 10ps.

*Contract DE-AC52-07NA27344. Funded by the LLNL LDRD program: tracking code 17-ERD-039.

PP11 16 Plasma formation and target preheating by prepulse of PW laser light* YASUHIKO SENTOKU, NASUMI IWATA, ILE, Osaka University JAMES KOGA, NICHOLAS DOVER, MAMIKO NISHIUCHI, National Institutes for Quantum and Radiological Science and Technology (QST) An intense short pulse laser with intensity over 10^{21} W/cm^2 has become available, i.e. J-KAREN-P at QST. Although the contrast of the short pulse is improved to be of the order of 10^{-11}, there is an unavoidable prepulse, which has multiple spikes (ps) on top of an exponential profile with intensity greater than 10^{14} W/cm^2 about 50 ps in front of the main pulse. The prepulse preheats the target and also produces tenuous plasmas in front of a target before the main pulse arrives. It is critical to understand such preheating of the target, where the nonlocal heat transport is essential at intensity > 10^{15} W/cm^2, since the target condition might totally change before the interaction with the main pulse. Using a hydro code, FLASH, and a collisional particle-in-cell code, PICLS, we study the preplasma formation and target preheating over tens of picoseconds timescale, and discuss the prepulse effects on the main pulse interaction.

*Work supported by the JSPS KAKENHI under Grant No. JP15K21767.

PP11 17 High order harmonic generation with femtosecond mid-infrared laser* JINPU LIN, JOHN NEES, KARL KRUSHLENICK, Univ of Michigan - Ann Arbor FRANKLIN DOLLAR, TAM NGUYEN, Univ of California - Irvine There has been growing interest in high order harmonic generation (HHG) from laser-solid interactions as a compact source of coherent x-rays. The ponderomotive potential in laser-plasma interactions increases with longer laser wavelength, so there may be significant differences in the physics of harmonic generation and other phenomena when experiments are conducted with mid-infrared lasers. Previous experiments, however, have been done almost exclusively with near-infrared lasers. In this work, we report the results of experiments performed with millijoule, 40 fs, 2 μm laser pulses generated by an optical parametric amplifier (OPA) which are focused onto solid targets such as silicon and glass. The HHG efficiency, polarization dependence, and x-ray emission are studied and compared to measurements with near-infrared lasers.

*Funded by AFOSR MURI.

PP11 18 Enhanced Laser-to-Electron Energy Conversion Efficiency using Micro-Plasma Waveguide (MPW) Targets* DEREK NASIR, Ohio State Univ - Columbus JOSEPH SNYDER, Department of Mathematical and Physical Sciences, Miami University Hamilton LIANG JI, Shanghai Institute of Optics and Fine Mechanics KEVIN GEORGE, CHRISTOPHER WILLIS, GINEVRA COCHRAN, ANTHONY ZINGALE, REBECCA DASKALOVA, DOUG SCHUMACHER, LINN VAN WOERKOM, Ohio State Univ - Columbus We present experiments from the Scarlet laser facility and 3D Particle in Cell (PIC) simulations detailing the improved hot electron spectrum of MPW targets over flat targets. We observe an increase in the electron cutoff energy by a factor of 3 and a 10x enhancement of the total signal of electrons above 5MeV. From PIC simulations, we see strong transverse electric fields extracted electron bunches from the MPW walls with the laser period, which are then accelerated by the usual \textbf{vxB} force. In addition,
quasi-static longitudinal electric fields arise and are observed to increase the acceleration length of electrons along the tube walls. In this way, the micro-engineered structures provide a geometry more conducive to efficient direct laser acceleration and offer a new dimension in target design. We present evidence that by varying the structure’s geometry we can alter the laser plasma interactions with applications in high field science, laser based proton therapy and relativistic nonlinear optics. In particular, the relationship between the MPW tube and laser-electron dephasing length is examined.

*AFOSR #FA9550-14-1-0085; NNSA #DE-NA0003107; DOE #DE-SC0012333.

PP11 19 Modeling Transport of Relativistic Electrons through Warm-Dense Matter Using Collisonal PIC* J MAY, UCLA C MCGUFFEY, T YABUUCHI, UCSD MS WEI, General Atomics F BEG, UCSB WB MORI, UCLA In electron transport experiments performed on the OMEGA EP laser system, a relativistic electron beam was created by focusing a high intensity \( eA/m_c > 1 \) laser onto a gold (Au) foil. Behind the Au foil was a layer of plastic (CH) enabling useful amplification through longer distances. Random inhomogeneities can naturally suppress such major parasitic effects as the transverse filamentation instability and Raman back- and side-scatterings of laser pulses by plasma noise, thus enabling useful amplification through longer distances.

*This work was supported by JSPS KAKENHI Grant Number JP15K21767.

PP11 20 Backward Raman amplification of laser pulses in plasma with random inhomogeneities* VLADIMIR MALKIN, NATHANIEL FISCH, Princeton University Backward Raman amplification of laser pulses in plasmas to nearly relativistic intensities was already observed experimentally, but complete pump depletion by amplified pulse still was not achieved. We argue here that the complete pump depletion may be more readily achieved experimentally in plasmas having noticeable random density inhomogeneities, rather than in highly uniform plasmas which are difficult to produce. Random inhomogeneities can naturally suppress such major parasitic effects as the transverse filamentation instability and Raman back- and side-scatterings of laser pulses by plasma noise, thus enabling useful amplification through longer distances.

*This work was supported by DTRA HDTRA1-11-1-0037, and by the NNSA SSAA Program under Grant No DEMA0002948.

PP11 21 Direct ion heating in overdense plasmas through the Brillouin instability driven by relativistic whistler waves* TAKAYOSHI SANO, MASAYASU HATA, NATSUMI IWATA, ILE, Osaka Univ. KUNIOKI MIMA, GPI YASUHIKO SENTOKU, ILE, Osaka Univ. Strong magnetic fields over kilo-Tesla have been available in the laboratory by the use of ultra-intense lasers. It would be interesting to apply those strong fields to other laser experiments such as the inertial confinement fusion and laboratory astrophysics. The characteristics of laser-plasma interactions could be modified significantly by the presence of such strong magnetic fields. We investigate electromagnetic wave propagation in overdense plasmas along the magnetic field for a right-hand circularly polarized wave by PIC simulations. Since the whistler mode has no cutoff density, it can penetrate into overdense plasmas and interact directly with charged particles there. When the external field strength is near a critical value defined by that the cyclotron frequency is equal to the laser one, it is reported that electrons are accelerated efficiently by the cyclotron resonance. However, if the field strength is far beyond the critical value, the cyclotron resonance is inefficient, while the ions gain a large amount of energy directly from the laser light owning to the Brillouin scattering. As the result, only ions are heated up selectively. We will discuss about the application of this ion heating in dense plasmas.

*This work was supported by the U.S. DOE, Los Alamos National Laboratory Science program, LDRD program, NNSA (DE-NA0002008), and AFOSR (FA9550-14-1-0045). HPC resources provided by TACC, XSEDE, and LANL, Institutional Computing.

PP11 22 Exploring Ultrahigh-Intensity Laser-Plasma Interaction Physics with QED Particle-in-Cell Simulations* S. V. LUEDTKE, Los Alamos National Laboratory, Univ of Texas, Austin L. YIN, Los Alamos National Laboratory L. A. LABUN, Univ of Texas, Austin B. J. ALBRIGHT, D. J. STARK, R. F. BIRD, W. D. NYSTROM, Los Alamos National Laboratory B. M. HEGELICH, Univ of Texas, Austin Next generation high-intensity lasers are reaching intensity regimes where new physics—quantum electrodynamics (QED) corrections to otherwise classical plasma dynamics—becomes important. Modeling laser-plasma interactions in these extreme settings presents a challenge to traditional particle-in-cell (PIC) codes, which either do not have radiation reaction or include only classical radiation reaction. We discuss a semi-classical approach to adding quantum radiation reaction and photon production to the PIC code VPIC. We explore these intensity regimes with VPIC, compare with results from the PIC code PSC, and report on ongoing work to expand the capability of VPIC in these regimes.

*This work was supported by the U.S. DOE, Los Alamos National Laboratory Science program, LDRD program, NNSA (DE-NA0002008), and AFOSR (FA9550-14-1-0045). HPC resources provided by TACC, XSEDE, and LANL, Institutional Computing.

PP11 23 Generation mechanism of power law energy distribution in an expanding thin-foil plasma irradiated by intense lasers* NATSUMI IWATA, YASUHIKO SENTOKU, TAKAYOSHI SANO, Institute of Laser Engineering, Osaka University KUNIOKI MIMA, The Graduate School for the Creation of New Photonics Industries Power law energy spectra consisting of high energy particles have been observed ubiquitously in nature such as cosmic rays in astrophysical plasmas, and are considered to be generated via multiple-scattering processes in electric/magnetic/electromagnetic fields. However, the critical details of the acceleration, diffusion and relaxation processes that lead to the observed superthermal distributions have not understood completely. In intense laser-produced plasmas, the strong laser field in the intensity level exceeding \( 10^{18} \) W/cm² and self-generated fields play a role in stochastic multiple-scattering which dominates the electron acceleration and heating [1, 2]. In this study, by using the particle-in-cell simulation, we found that the high energy tail of the electron energy spectrum becomes power law distribution, so called the ‘kappa distribution’ [3], in the interaction between a thin-foil plasma and a multi-picosecond high intensity laser. We discuss the generation mechanism of the power law tail relating to the multiple-scattering of electrons in the expanding foil plasma in details.
pp11 24 Effects of Soft-Core Potentials and Coulombic Potentials on Bremsstrahlung Radiation during Laser Matter Interaction* RISHI PANDIT, Department of Physics, Southern Illinois University Edwardsville, IL. YASUHIKO SENTOKU, Institute of Laser Engineering, Osaka University, Osaka, Japan. HIROSHI SAWADA, Department of Physics, University of Nevada, Reno, NV. LORA RAMUNNO, Department of Physics, University of Ottawa, Ottawa, Canada. EDWARD ACKAD, Department of Physics, Southern Illinois University Edwardsville, IL. An intense, short laser pulse incident on rare-gas clusters can produce nano-plasmas containing energetic electrons. As these electrons undergo scattering, both from phonons and ions, they emit bremsstrahlung radiation. Here we compare a theory of bremsstrahlung emission appropriate for the interaction of intense lasers with matter using soft-core potentials and coulombic potential. A new scaling for the radiation cross-section and emissivity via bremsstrahlung are derived for soft-core potential which depends on the potential depth, used to avoid coulomb singularity and for coulombic potential and implemented in a particle in cell code (PICLs). The radiation cross-section and emissivity via bremsstrahlung is found to increase rapidly with increase in potential depth up to 100 eV and then becomes mostly saturated for larger depths of a soft-core potential. For both cases, the radiation cross-section and emissivity of Bremsstrahlung increases with increase in laser wavelength. The bremsstrahlung emission may provide a broadband light source for diagnostics.

*This work was supported by Air Force Office of Scientific Research under AFOSR Award No. FA9550-14-1-0247.

PP11 25 Studying Electromagnetic Beam Instabilities in Laser Plasmas for Alfvénic Parallel Shock Formation R. S. DORST, P. V. HEUER, M. S. WEIDL, Univ. of California - Los Angeles, D. B. SCHAEFFER, Princeton University C. G. CONSTANTIN, S. VINCENA, S. TRIPATHI, W. GEKELMAN, Univ. of California - Los Angeles, D. WINSKE, Lawrence Livermore National Laboratory C. NIEMANN, Univ. of California - Los Angeles We present measurements of the collisionless interaction between an exploding laser-produced plasma (LPP) and a large, magnetized ambient plasma. The LPP is created by focusing a high energy laser on a target embedded in the ambient Large Plasma Device (LAPD) plasma at the University of California, Los Angeles. The resulting super-Alfvénic (MA = 5) ablated material moves parallel to the background magnetic field (300 G) through 12m (80 μs) through electromagnetic beam instabilities. The debris is characterized by Langmuir probes and a time-resolved fluorescence monochromator. Waves in the magnetic field produced by the instabilities are diagnosed by an array of 3-axis ‘bot’ magnetic field probes. Measurements are compared to hybrid simulations of both the experiment and of parallel shocks.

PP11 26 Magnetically-Driven Radiative Shock Experiments for Laboratory Astrophysics THOMAS CLAYSON, SERGEY LEBEDEV, FRANCISCO SUZUKI-VIDAL, GUY BURDIKA, JONATHON HALLIDAY, JACK HARE, LEE SUTTLE, ELLIE TUBMAN, Imperial College London We present results from new experiments, aimed at producing radiative shocks, using an ‘inverse liner’ configuration on the MAGPIE pulsed power facility (1.4 MA in 240 ns) at Imperial College London in the UK. In these experiments current passes through a thin walled metal tube and is returned through a central rod on the axis, generating a strong (40 Tesla) toroidal magnetic field. This drives a shock through the tube which launches a cylindrically symmetric, radially expanding radiative shock in to gas surrounding the tube. Unlike previous converging shock experiments [1], where the shock is located within the imploding liner and thus only permits end on probing, this experimental setup is much more open for diagnostic access and allows shocks to propagate further instead of colliding of axis. Multi-frame self-emission imaging, laser interferometry, emission spectrometry and magnetic probes were used to provide a better understanding of the shock dynamics. Results are shown from experiments performed in a variety of gases (Ne, Ar, Kr, Xe 1-50 mbar). In addition, methods for seeding perturbations are discussed which may allow for the study of several shock instabilities such as the Vishniac instability.


PP11 27 Weibel instability mediated collisionless shocks using intense laser-driven plasmas* SASIKUMAR PALANIYAPPAN, Los Alamos Natl Lab FEDERICO FIUZA, SLAC CHENGKUN HUANG, DONALD GAUTIER, Los Alamos Natl Lab WENJUN MA, Peking University JORG SCHREIBER, LMU Germany ABEL RAYMER, North Carolina A&T State University JUAN FERNANDEZ, TOM SHIMADA, RANDALL JOHNSON, Los Alamos Natl Lab The origin of cosmic rays remains a long-standing challenge in astrophysics and continues to fascinate physicists. It is believed that “collisionless shocks” — where the particle Coulomb mean free path is much larger than the shock transition — are a dominant source of energetic cosmic rays. These shocks are ubiquitous in astrophysical environments such as gamma-ray bursts, supernova remnants, pulsar wind nebula and coronal mass ejections from the sun. A particular type of electromagnetic plasma instability known as Weibel instability is believed to be the dominant mechanism behind the formation of these collisionless shocks in the cosmos. The understanding of the microphysics behind collisionless shocks and their particle acceleration is tightly related with nonlinear basic plasma processes and remains a grand challenge. In this poster, we will present results from recent experiments at the LANL Trident laser facility studying collisionless shocks using intense ps laser (80J, 650 fs – peak intensity of ~10^20 W/cm^2) driven near-critical plasmas using carbon nanotube foam targets. A second short pulse laser driven protons from few microns thick gold foil is used to radiograph the main laser-driven plasma.

*Work supported by the LDRD program at LANL.

PP11 28 Multiscale Models for the Two-Stream Instability* ILYA JOSEPH, ANDRIS DIMITS, Lawrence Livermore National Lab JEFFREY BANKS, Rensselaer Polytechnic Institute RICHARD BERGER, Lawrence Livermore National Lab STEPHAN BRUNNER, Ecole Polytechnique Federale de Lausanne THOMAS CHAPMAN, Lawrence Livermore National Lab Interpenetrating streams of plasma found in many important scenarios in nature and in the laboratory can develop kinetic two-stream instabilities that exchange momentum and energy between the streams. A quasilinear model for the electrostatic two-stream instability is under development as a component of a multiscale model that couples fluid simulations to kinetic theory. Parameters of the model will be validated with comparison to full kinetic simulations using LOKI [1] and efficient strategies for numerical solution of the quasilinear model and for coupling to the fluid model will be discussed. Extending the kinetic models into the collisional regime requires an efficient treatment of the collision operator. Useful reductions of the...
collision operator relative to the full multi-species Landau-Fokker-Plank operator are being explored. These are further motivated both by careful consideration of the parameter orderings relevant to two-stream scenarios and by the particular 2D+2V phase space used in the LOKI code.

*Prepared for US DOE by LLNL under Contract DE-AC52-07NA27344 and LDRD project 17- ERD-081.


The universe is permeated by magnetic fields, with strengths ranging from a femtogauss in the voids between the filaments of galaxy clusters to several teragauss in black holes and neutron stars. The standard model for cosmological magnetic fields is the non-linear amplification of seed fields via turbulent dynamo. We have conceived experiments to demonstrate and study the turbulent dynamo mechanism in the laboratory. Here, we describe the design of these experiments through large-scale 3D FLASH simulations on the Mira supercomputer at ANL, and the laser-driven experiments we conducted with the OMEGA laser at LLE. Our results indicate that turbulence is capable of rapidly amplifying seed fields to near equipartition with the turbulent fluid motions.

*This work was supported in part from the ERC (FP7/2007-2013, No. 256973 and 247039), and the U.S. DOE, Contract No. BS591485 to LLNL, FWP 57789 to ANL, Grant No. DE-NA0002724 and DE-SC0016566 to the University of Chicago, and DE-AC02-06CH11357 to ANL.

**PP11 31** NIF Discovery Science Eagle Nebula* JAVE KANE, Lawrence Livermore Natl Laboratory DAVID MARTINEZ, Lawrence Livermore National Laboratory MARC FOUNTAIN, University of Maryland ROBERT HEEGER, Lawrence Livermore National Laboratory ALEXIS CASNER, CEA/DAM/CESTA BRUNO VILLETTE, CEA ROBERO MANDINI, University of Nevada The University of Maryland and ANL and LLNL are investigating the origin and dynamics of the famous Pillars of the Eagle Nebula and similar parsec-scale structures at the boundaries of HI regions in molecular hydrogen clouds. The National Ignition Facility (NIF) Discovery Science program Eagle Nebula has performed NIF shots to study models of pillar formation. The shots feature a new long-duration x-ray source, in which multiple hohlraums mimicking a cluster of stars are driven with UV light in series for 10 to 15 ns each to create a 30 to 60 ns output x-ray pulse. The source generates deeply nonlinear hydrodynamics in the Eagle science package, a structure of dense plastic and foam mock up a molecular cloud containing a dense core. Omega EP and NIF shots have validated the source concept, showing that earlier hohlraums do not compromise later ones by preheat or by ejecting ablated plumes that deflect later beams. The NIF shots generated radiographs of shadowing-model pillars, and also showed evidence that cometary structures can be generated. The velocity and column density profiles of the NIF shadowing and cometary pillars have been compared with observations of the Eagle Pillars made at the millimeter-wave BIMA and CARMA observatories.

*Prepared by LLNL under Contract DE-AC52-07NA27344.

**PP11 32** Experiment to measure oxygen opacity at high density and temperature* PAUL KEITER, HANNA BUTLER, MATT TRANTHAM, Univ of Michigan - Ann Arbor KATIE MUSSACK, JAMES COLGAN, CHRISTOPHES, JOYCE GUZIK, DAVID KILCREASE, TED PERRY, Los Alamos National Laboratory CHRIS ORBAN, Ohio State University JEAN-ERIC DUCRET, MAAELLE LA PENNEC, SYLVIA TURCK-CHIEZE, CEA/Service d’Astrophysique, CE Saclay ROBERT MANCINI, University of Nevada, Reno ROBERT HEEGER, Lawrence Livermore National Laboratory In recent years, there has been a debate over the abundances of heavy elements (Z > 2) in the solar interior. Recent solar atmosphere models [Asplund 2009] find a significantly lower abundance for C, N, and O compared to models used roughly a decade ago. Recent opacity measurements of iron disagree with opacity model predictions [Bailey et al., 2015]. Repeated scrutiny of the experiment and data has not produced a conclusive reason for the discrepancy. New models have been implemented in the ATOMIC opacity code for low-Z elements [Colgan, 2013, Armstrong 2014], however no data currently exists to test the low-Z material models in the regime relevant to the solar convection zone. We present an experimental design using the opacity platform developed at the National Ignition Facility to study the oxygen opacity at densities and temperatures near the solar convection zone conditions.

*This work is funded by the U.S. DOE, through the NNSA-DS and SC-OFES Joint Program in HEDLP, Grant Number DE-NA0002956, and the NLF Program, Grant Number DE-NA0002719, and through the LLE, University of Rochester by the NNSA/OICF under No. DE-NA000244.
PP11 33 Simulation and Preliminary Design of a Cold Stream Experiment on Omega EP∗ SHANE COFFING, ADRIANNA ANGULO, MATT TRANTHAM, Univ of Michigan - Ann Arbor
GUY MALAMUD, Nuclear Research Center - Neveq, Israel CAROLYN KURANZ, R. P. DRAKE, Univ of Michigan - Ann Arbor
Galaxies form within dark matter halos, accreting gas that may clump and eventually form stars. Infalling matter gradually increases the density of the halo, and, if cooling is insufficient, rising pressure forms a shock that slows the infalling gas, reducing star formation. However, galaxies with sufficient cooling become prolific star formers. A recent theory suggests that so called “stream fed galaxies” are able to acquire steady streams of cold gas via galactic “filaments” that penetrate the halo. The cold, dense filament flowing into a hot, less dense environment is potentially Kelvin-Helmholtz unstable. This instability may hinder the ability of the stream to deliver gas deeply enough into the halo. To study this process, we have begun preliminary design of a well-scaled laser experiment on Omega EP. We present here early simulation results and the physics involved.

∗This work is funded by the U.S. Department of Energy, through the NNSA-DS and SC-OFES Joint Program in High-Energy Density Laboratory Plasmas, Grant Number DE-NA0002956, and the National Laser User Facility Program, Grant Number DE-NA0002719, and through the Laboratory for Laser Energetics, University of Rochester by the NNSA/OICF under Cooperative Agreement No. DE-NA0001944.

PP11 34 COMPRESSION AND BURN

PP11 35 Analysis of BigFoot HDC SymCap experiment N161205 on NIF∗ T. R. DITTRICH, K. L. BAKER, C. A. THOMAS, L. F. BERZAK HOPKINS, J. A. HARTE, G. B. ZIMMERMAN, D. T. WOODS, A. L. KRITCHER, D. D. HO, C. R. WEBER, Lawrence Livermore National Laboratory G. KYRALA, Los Alamos National Laboratory. Analysis of NIF implosion experiment N161205 provides insight into both hohlraum and capsule performance. This experiment used an undoped High Density Carbon (HDC) ablator driven by a BigFoot x-ray profile in a Au hohlraum. Observations from this experiment include DT fusion yield, bang time, DSR, Tion and time-resolved x-ray emission images around bang time. These observations are all consistent with an x-ray spectrum having significantly reduced Au m-band emission that is present in a standard hohlraum simulation. Attempts to justify the observations using several other simulation modifications will be presented.

∗This work was performed under the auspices of the Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344.

PP11 36 Enhanced electron/fuel-ion equilibration through impurity ions: Studies applicable to NIF and Omega∗ R.D. PETTASSO, H. SIO, N. KABADI, B. LAHMANN, R. SIMPSON, C. PARKER, J. FRENIE, M. GATU JOHNSON, C.K. LI, F.H. SEGUIN, MIT H. RINDERKNECHT, D. CASEY, P. GRABOWSKI, F. GRAZIANI, LLNL W. TAITANO, A. LE, L. CHACON, N. HOFFMAN, G. KAGAN, A. SIMAKOV, A. ZYLSTRA, LANL M. ROSENBERG, R. BETTI, LLE B. SRINIVASAN, V. Tech R. MANCINI, U of Nev/Reno. In shock-driven exploding-pushers, a platform used extensively to study multi-species and kinetic effects, electrons and fuel ions are far out of equilibrium, as reflected by very different temperatures. However, impurity ions, even in small quantities, can couple effectively to the electrons, because of a $Z^2$ dependence, and in turn, impurity ions can then strongly couple to the fuel ions. Through this mechanism, electrons and fuel ions can equilibrate much faster than they otherwise would. This is a quantitative issue, depending upon the amount and $Z$ of the impurity. For NIF and Omega, we consider the role of this process. Coupled non-linear equations, reflecting the temperatures of the three species, are solved for a range of conditions. Consideration is also given to ablative driven implosions, since impurities can similarly affect the equilibration.

∗This work was supported in part by DOE/NNSA DE-NA0002949 and DE-NA0002726.

PP11 37 Reducing the effects of X-ray pre-heat in double shell NIF capsules by over-coating the high Z shell DOUGLAS WILSON, LANL J.L. MILOVICH, LLNL W.S. DAUGHTON, E.N. LOOMIS, J.P. SAUPPE, E.S. DODD, E.C. MERRITT, D.S. MONTGOMERY, D.B. RENNER, B.M. HAINES, T. CARDENAS, T. DESJARDINS, S. PALANIYAPPAN, S.H. BATHA, LANL Hohlraum generated X-rays will penetrate the ablator of a double shell capsule and be absorbed in the outer surface of the inner capsule. The ablative pressure this generates drives a shock into the central fuel, and a reflected shock that reaches the inner high-Z shell surface before the main shock even enters the fuel. With a beryllium over-coat preheat X-rays deposit just inside the beryllium/high z interface. The beryllium tamps the preheat expansion, eliminating ablation, and dramatically reducing pressure. The slow shock or pressure wave it generates is then overtaken by the main shock, avoiding an early shock in the fuel and increasing capsule yield.

PP11 38 Applying the Braginskii Ion Fluid Model to Reaction Yields and Product Energy Spectra BRIAN APPELBE, JEREMY CHITTENDEN, AIDAN CRILLY, KRIS MCGLINCHHEY, CHRIS WALSH, JON TONG, Imperial College London Collisional plasmas can be described using the Braginskii ion fluid model. This can be used calculate transport fluxes (e.g. ion heat flux and viscosity) as a result of driving thermodynamic forces (temperature gradients and the rate of strain tensor, respectively) by the derivation of a set of transport equations from the kinetic equations. The solutions to these transport equations are perturbations to the Maxwellian distribution function. In this work we investigate how nuclear reaction yields and the energy spectra of reaction products are affected by the driving thermodynamic forces. The transport equations for a plasma with multiple ion species are solved using a set of associated Laguerre polynomials which define the perturbation to the distribution function. The set of polynomials is then used to calculate reaction yields and energy spectra. The model is applied to the plasma conditions found in ICF and MagLIF hotspots. It is shown that the temperature and fluid velocity gradients present in these plasmas can cause significant broadening of the neutron spectra. This broadening can cause the ion temperature inferred from the spectral width to be higher than the burn-averaged ion temperature of the plasma.

PP11 39 NSTX-U

PP11 40 Discharge start-up and ramp-up development for NSTX-U and MAST-U∗ D.J. BATTAGLIA, M.D. BOYER, S.P. GERRHARDT, J.E. MENARD, D. MUELLER, PPPL, G. CUNNINGHAM, A. KIRK, L. KOGAN, G. MCARDELE, L. PANIGONE, A.J. THORNTON, E. REN, CCFE. A collaborative modeling effort is underway to develop robust inductive start-up and
ramp-up scenarios for NSTX-U and MAST-U. These complementary spherical tokamak devices aim to generate the physics basis for achieving steady-state, high-beta and high-confinement plasma discharges with a self-consistent solution for managing the divertor heat flux. High-performance discharges in these devices require sufficient plasma elongation ($\kappa = 2.4 - 2.8$) to maximize the bootstrap and beam-driven current drive, increase MHD stability at high $I_p$ and high $\beta_n$, and realize advanced divertor geometries such as the snowflake and super-X. Achieving the target elongation on NSTX-U is enabled by an L-H transition in the current ramp-up that slows the current diffusion and maintains a low internal inductance ($I_e \leq 0.8$). Modeling focuses on developing scenarios that achieve a suitable field null for breakdown and discharge conditions conducive to an early L-H transition while maintaining vertical and MHD stability, with appropriate margin for variation in experimental conditions. The toroidal currents induced in conducting structures and the specifications of the real-time control and power supply systems are unique constraints for the two devices.

*Work Supported by U.S. DOE Contract No. DE-AC02-09CH11466 and the RCUK Energy Programme [Grant Number EP/P012450/1].

**PP11 41 Analysis of vertical stability limits and vertical displacement event behavior on NSTX-U** MARK BOYER, DEVON BATTAGLIA, STEFAN GERHARDT, JONATHAN MENARD, DENNIS MUELLER, CLAYTON MYERS, Princeton Plasma Physics Laboratory STEVEN SABBAGH, Columbia University DAVID SMITH, University of Wisconsin-Madison The National Spherical Torus Experiment Upgrade (NSTX-U) completed its first run campaign in 2016, including commissioning a larger center-stack and three new tangentially aimed neutral beam sources. NSTX-U operates at increased aspect ratio due to the larger center-stack, making vertical stabilization more challenging. Since ST performance is improved at high elongation, improvements to the vertical control system were made, including use of multiple up-down-symmetric flux loop pairs for real-time estimation, and filtering to remove noise. Similar operating limits to those on NSTX (in terms of elongation and internal inductance) were achieved, now at higher aspect ratio. To better understand the observed limits and project to future operating points, a database of vertical displacement events and vertical oscillations observed during the plasma current ramp-up on NSTX/NSTX-U has been generated. Shots were clustered based on the characteristics of the VDEs/oscillations, and the plasma parameter regimes associated with the classes of behavior were studied. Results provide guidance for scenario development during ramp-up to avoid large oscillations at the time of diverting, and provide the means to assess stability of target scenarios for the next campaign. Results will also guide plans for improvements to the vertical control system.

*Work supported by U.S. D.O.E. Contract No. DE-AC02-09CH11466.

**PP11 42 Advanced Plasma Shape Control to Enable High-Performance Divertor Operation on NSTX-U** PATRICK VAIL, EGEMEN KOLEMEN, Princeton University MARK BOYER, Princeton Plasma Physics Laboratory ANDERS WELANDER, General Atomics This work presents the development of an advanced framework for control of the global plasma shape and its application to a variety of shape control challenges on NSTX-U. Operations in high-performance plasma scenarios will require highly-accurate and robust control of the plasma poloidal shape to accomplish such tasks as obtaining the strong-shaping required for the avoidance of MHD instabilities and mitigating heat flux through regulation of the divertor magnetic geometry. The new control system employs a high-fidelity model of the toroidal current dynamics in NSTX-U poloidal field coils and conducting structures as well as a first-principles driven calculation of the axisymmetric plasma response. The model-based nature of the control system enables real-time optimization of controller parameters in response to time-varying plasma conditions and control objectives. The new control scheme is shown to enable stable and on-demand plasma operations in complicated magnetic geometries such as the snowflake divertor. A recently-developed code that simulates the nonlinear evolution of the plasma equilibrium is used to demonstrate the capabilities of the designed shape controllers. Plans for future real-time implementations on NSTX–U and elsewhere are also presented.

*Supported by the US DOE under DE-AC02-09CH11466.

**PP11 43 Power exhaust scenarios and control for projected high-power NSTX-U operation** JONATHAN MENARD, S.P. GERHARDT, C.E. MYERS, PPPL M.L. REINKE, ORNL A. BROOKS, M. MARDENFELD, PPPL NSTX UPGRADE TEAM An important goal of the NSTX Upgrade (NSTX-U) research program is to characterize energy confinement in the low-aspect-ratio spherical tokamak configuration over a significantly expanded range of plasma current, toroidal field, and heating power, while increasing flattop durations up to 5 seconds. However, the narrowing of the scrape-off layer at higher current combined with an improved understanding of expected halo-current loads has motivated a significant re-design of NSTX-U plasma facing components in the high-heat-flux regions of the divertor. In order to reduce the expected divertor heat flux to acceptable levels, a combination of mitigation techniques will be used: increased divertor poloidal flux expansion, increased divertor radiation, and controlled strike-point sweeping. The machine requirements for these various mitigation techniques are studied here using a newly implemented reduced heat-flux model. Systematic equilibrium scans are used to quantify the required divertor coil currents and to verify vertical stability for a range of plasma shapes. Free-boundary control schemes to constrain the strike-point location and field-line angle-of-incidence will also be discussed.

*Work supported by DOE contract DE-AC02-09CH11466.

**PP11 44 Local compression and global Alfvén eigenmode structure on NSTX and their effect on core energy transport** NA CROCKER, UCLA EV BELOVA, RB WHITE, ED FREDRICKSON, NN GORELENKOV, PPPL K TRITZ, JHU WA PEEBLES, S KUBOTA, UCLA A DIALLO, BP LEBLANC, PPPL A novel method for localized absolute reflectometer measurements of density fluctuations $\delta n$ using a synthetic diagnostic has provided new insight into CAE & GAE amplitude, structure, and associated energy transport in NSTX spherical torus. The new technique is more accurate than previous analysis producing substantially different amplitudes. CAE & GAE activity has been shown to correlate with core anomalous electron thermal transport in high-power beam heated NSTX plasmas [Stutman PRL09] making these measurements of significant interest. High frequency modes (17–33% $f_n$) are identified as GAEs & CAEs in a 6 MW beam heated plasma. The synthetic diagnostic allows direct testing of HYM, a leading CAE & GAE stability code that predicts substantial transport via CAE-KAW coupling [Belova PRL15]. Measured GAE structures show edge peaks, and are broad & flat in the core with $\delta n/\bar{n} \sim 10^{-3}-10^{-4}$. In contrast, CAEs have broad core peaks with $\delta n/\bar{n} \sim 10^{-1}-10^{-2}$. The GAE measurements are used with theory for mode induced stochastization of electron drift orbits [Gorelenkov NF10] to predict the core electron
thermal diffusivity ($\chi_e$), which shows the low amplitudes cannot explain the high $\chi_e$. The theory has been modified to include the CAEs, preliminarily showing negligible increase. Linear HYM simulations show GAE structures similar to those above.

*Support by DOE Grants DE-SC0011810, DE-AC02-09CH11466.

PP11 45 Numerical simulations of GAE stabilization in NSTX-U* ELENA BELOVA, ERIC FREDRICKSON, Princeton Plasma Physics Laboratory NEAL CROCKER, UCLA NSTX-U TEAM Beam-driven Global Alfven Eigenmodes (GAEs) were frequently observed on NSTX and NSTX-U and have been linked with a flattening of the electron temperature profile in the plasma core. New experimental results from NSTX-U have demonstrated that neutral beam injection from the new beam sources with large tangency radii deposit beam ions with large pitch, which can very effectively stabilize all unstable GAEs. Numerical simulations using the HYM code have been performed to study the excitation and stabilization of GAEs in the NSTX-U right before and shortly after the additional off-axis beam injection. HYM simulations reproduce experimental finding, namely it is shown that off-axis neutral beam injection reliably and strongly suppresses all unstable GAEs. Before additional beam injection, the simulations show unstable counter-rotating GAEs with toroidal mode numbers $n=7-12$, and frequencies that match the experimentally observed unstable GAEs. Additional off-axis beam injection has been modeled by adding beam ions with large pitch, and about 1/3 of the total beam ion inventory. The simulations in this case show a complete stabilization of all unstable GAEs ($n=7-12$), even for the cases when the HYM calculated GAE growth rates were relatively large.

*Work supported by U.S. DOE Contract DE’AC02’09CH11466.

PP11 46 Energetic-particle-modified global Alfven Eigenmodes JEFF LESTZ, Princeton University ELENA BELOVA, NIKOLAI GORELENOV, Princeton Plasma Physics Lab Fully self-consistent hybrid MHD/particle simulations reveal strong energetic particle modifications to sub-cyclotron global Alfven eigenmodes (GAEs) in low-aspect ratio, NSTX-like conditions. Key parameters defining the fast ion distribution function – the normalized injection velocity $V_b/V_A$ and central pitch – are varied in order to study their influence on the characteristics of the excited modes. It is found that the frequency of the most unstable mode changes significantly and continuously with beam parameters, depending most substantially on $V_b/V_A$. This unexpected result is present for both co- and counter-propagating GAEs, which are driven by Doppler-shifted cyclotron resonances. Large changes in frequency without clear corresponding changes in mode structure could indicate the existence of a new energetic particle mode, referred to here as an energetic-particle-modified GAE (EP-GAE). Additional simulations conducted for a fixed MHD equilibrium demonstrate that the GAE frequency shift cannot be explained by the equilibrium changes due to energetic particle effects.

PP11 47 Likelihood of Alfvenic instability bifurcation in experiments VINICIUS DUARTE, NIKOLAI GORELENOV, MIRJAM SCHNELLER, ERIC FREDRICKSON, Princeton Plasma Physics Laboratory HERBERT BERK, University of Texas, Austin GUSTAVO CANAL, General Atomics WILLIAM HEIDBRINK, University of California, Irvine STANLEY KAYE, MARIO PODESTA, Princeton Plasma Physics Laboratory MICHAEL VAN ZEELAND, General Atomics WEIXING WANG, Princeton Plasma Physics Laboratory We apply a criterion for the likely nature of fast ion redistribution in tokamaks to be in the convective or diffusive nonlinear regimes. The criterion, which is shown to be rather sensitive to the relative strength of collisional or micro-turbulent scattering and drag processes, ultimately translates into a condition for the applicability of reduced quasilinear modeling for realistic tokamak eigenmodes scenarios. The criterion is tested and validated against different machines, where the chirping mode behavior is shown to be in accord with the model. It has been found that the anomalous fast ion transport is a likely mediator of the bifurcation between the fixed-frequency mode behavior and rapid chirping in tokamaks. In addition, micro-turbulence appears to resolve the disparity with respect to the ubiquitous chirping observation in spherical tokamaks and its rarer occurrence in conventional tokamaks. In NSTX, the tendency for chirping is further studied in terms of the beam beta and the plasma rotation shear. For more accurate quantitative assessment, numerical simulations of the effects of electrostatic ion temperature gradient turbulence on chirping are presently being pursued using the GTS code.

PP11 48 Effect of Sawtooth crashes on fast-ion distribution in NSTX-U* DEYONG LIU, W. W. HEIDBRINK, G. Z. HAO, UC Irvine M. PODESTA, E. F. FREDRICKSON, D. S. DARROW, PPPL During the 2016 experimental campaign of NSTX-Upgrade (NSTX-U), long L-mode and reproducible sawtoothing plasmas have been achieved that were previously not accessible on NSTX. This provides a good opportunity to investigate the conditions of sawtooth appearance and to study their effects on fast ion confinement and re-distribution in spherical tokamaks. The Fast-Ion D-alpha (FIDA) and Solid State Neutral Particle Analyzer (SSNPA) diagnostics on NSTX-U each has two subsystems with one subsystem more sensitive to passing particles and the other one more sensitive to trapped particles. It has been observed on both diagnostics that the passing particles are strongly expelled from the plasma core to the plasma edge during sawtooth crashes while trapped fast ions are weakly affected. The tangential-FIDA (t-FIDA) system which is most sensitive to passing particles saw a signal drop in the region inside the inversion radius (∼125cm), while an increase at the outer region. The neutron rate can drop as much as 13% during sawtooth crashes. This phenomenon is similar to previous observations in DIII-D and ASDEX Upgrade conventional tokamaks. Detailed data analysis and modelling are being performed to quantify the effects of sawtooth crashes on fast-ion redistribution and to compare with the Kadomtsev sawtooth model.

*Work supported by US DOE.

PP11 49 ORBIT modelling of fast particle redistribution induced by sawtooth instability* DOOHYUN KIM, MARIO PODESTA, FRANCESCA POMI, PRINCETON PLASMA PHYSICS LABORATORY TEAM Initial tests on NSTX-U show that introducing energy selectivity for sawtooth (ST) induced fast ion redistribution improves the agreement between experimental and simulated quantities, e.g. neutron rate. Thus, it is expected that a proper description of the fast particle redistribution due to ST can improve the modelling of ST instability and interpretation of experiments using a transport code. In this work, we use ORBIT code [1] to characterise the redistribution of fast particles. In order to simulate a ST crash, a spatial and temporal displacement is implemented as $\xi_x(\rho, t, \theta, \phi) = \sum \xi_{max}(\rho, t) \cos(m\theta + n\phi)$ [2] to produce perturbed magnetic fields from the equilibrium field $B_0 B = \nabla \times (\xi \times B)$, which affect the fast particle distribution. From ORBIT simulations, we find suitable amplitudes of $\xi$ for each ST crash to reproduce the experimental results. The comparison of the simulation and the experimental results will be discussed as
well as the dependence of fast ion redistribution on fast ion phase space variables (i.e. energy, magnetic moment and toroidal angular momentum).

*Work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences under Contract Number DE-AC02-09CH11466.


PP11 50 Destabilization of counter-propagating TAEs by off-axis, co-current Neutral Beam Injection* M. PODESTA', E. FREDRICKSON, M. GORELENKOVA, PPPL Neutral Beam injection (NBI) is a common tool to heat the plasma and drive current non-inductively in fusion devices. Energetic particles (EP) resulting from NBI can drive instabilities that are detrimental for the performance and the predictability of plasma discharges. A broad NBI deposition profile, e.g. by off-axis injection aiming near the plasma mid-radius, is often assumed to limit those undesired effects by reducing the radial gradient of the EP density, thus reducing the “universal” drive for instabilities. However, this work presents new evidence that off-axis NBI can also lead to undesired effects such as the destabilization of Alfvénic instabilities, as observed in NSTX-U plasmas. Experimental observations indicate that counter propagating toroidal AEs are destabilized as the radial EP density profile becomes hollow as a result of off-axis NBI. Time-dependent analysis with the TRANSP code, augmented by a reduced fast ion transport model (known as kick model), indicates that instabilities are driven by a combination of radial and energy gradients in the EP distribution. Understanding the mechanisms for wave-particle interaction, revealed by the phase space resolved analysis, is the basis to identify strategies to mitigate or suppress the observed instabilities.

*Work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences under Contract Number DE-AC02-09CH11466.

PP11 51 Gyrokinetic study of electron transport in NSTX using XGC JUGAL CHOWDHURY, SEUNG-HOE KU, J DOMINSKI, R HAGER, D MIKKELSEN, W GUTTENFELDER, P PORAZIK, CHOONG-SEOCK CHANG, Princeton Plasma Physics Laboratory Electron anomalous transport may play a significant role in the plasma confinement in NSTX. In such a situation it becomes important to identify the origin of the electron heat and particle transport and find ways of reducing it. Among the possible electron modes, the electron temperature gradient mode (ETG) can be important both in the core and edge pedestal plasmas. Here we aim to study the role of ETG on the anomalous loss of electrons in the NSTX tokamak with the gyrokinetic code XGC. XGC is an X-point included full-f gyrokinetic code which can also be run in the delta-f limit. We present a benchmark study of the ETG mode against those from existing flux tube gyrokinetic codes in the limit of simple circular ad hoc model similar to the cyclone base case. Simulations for actual experimental profiles and parameters corresponding to the NSTX will also be reported.

PP11 52 Modeling of blob-hole correlations in GPI edge turbulence data* J.R. MYRA, D.A. RUSSELL, Lodestar Research Corporation F. SCOTTI, Lawrence Livermore National Laboratory S.J. ZWEBEN, Princeton Plasma Physics Laboratory F. MILITELLO, N. WALKDEN, Culham Science Centre AbiTER is a flexible eigenvalue code designed for plasma physics applications. It is used here to gain insight into the spatial dependence of filamentary structures in the scrape-off layer of spherical tokamaks. In particular, observations on MAST reveal the presence of a quiescent x-point region. Observations in NSTX similarly reveal a reduction in divertor fluctuations near the separatrix and a loss of midplane correlation. We will report on the penetration of filamentary structures into the vicinity of the x-point, as well as growth rate trends, for a variety of profiles and toroidal mode numbers. This will determine whether linear properties of these structures can explain experimental observations.

*Work supported by the U.S. Department of Energy Office of Science, Office of Fusion Energy Sciences, under Award Number DE-FG02-02ER54678.

PP11 53 Penetration of filamentary structures in the x-point region of spherical tokamaks* D. A. BAVER, J. R. MYRA, Lodestar Research Corporation F. SCOTTI, Lawrence Livermore National Laboratory S.J. ZWEBEN, Princeton Plasma Physics Laboratory F. MILITELLO, N. WALKDEN, Culham Science Centre AbiTER is a flexible eigenvalue code designed for plasma physics applications. It is used here to gain insight into the spatial dependence of filamentary structures in the scrape-off layer of spherical tokamaks. In particular, observations on MAST reveal the presence of a quiescent x-point region. Observations in NSTX similarly reveal a reduction in divertor fluctuations near the separatrix and a loss of midplane correlation. We will report on the penetration of filamentary structures into the vicinity of the x-point, as well as growth rate trends, for a variety of profiles and toroidal mode numbers. This will determine whether linear properties of these structures can explain experimental observations.

*Work supported by the U.S. Department of Energy Office of Science, Office of Fusion Energy Sciences, under Award Number DE-FG02-02ER54678.

PP11 54 Modelling of Divertor Detachment in MAST Upgrade* DAVID MOULTON, MATTHEW CARR, JAMES HARRISON, ALEX MEAKINS, Culham Centre for Fusion Energy MAST Upgrade will have extensive capabilities to explore the benefits of alternative divertor configurations such as the conventional, Super-X, x divertor, snowflake and variants in a single device with closed divertors. Initial experiments will concentrate on exploring the Super-X and conventional configurations, in terms of power and particle loads to divertor surfaces, access to detachment and its control. Simulations have been carried out with the SOLPS5.0 code validated against MAST experiments. The simulations predict that the Super-X configuration has significant advantages over the conventional, such as lower detachment threshold (2-3x lower in terms of upstream density and 4x higher in terms of PSOL). Synthetic spectroscopy diagnostics from these simulations have been created using the Raysect ray tracing code to produce synthetic filtered camera images, spectra and foil bolometer data. Forward modelling of the current set of divertor diagnostics will be presented, together with a discussion of future diagnostics and analysis to improve estimates of the plasma conditions.

*Work supported by the RCUK Energy Programme [Grant Number EP/P012450/1] and EURATOM.

PP11 55 Radiative divertor optimization for NSTX Upgrade based on open geometry standard divertor experiments in NSTX* V. A. SOUKHANOVSKII, O. IZACARD, F. SCOTTI, LLNL R. MAINGI, R. E. BELL, R. KAITA, S. M. KAYE, B. P.
Recent analyses of NSTX divertor experiments suggest a way to optimize the standard open geometry divertor configuration for partial detachment with deuterium puffing and intrinsic carbon radiation. Results from the NSTX experiments and the divertor transport and radiation model obtained with the multi-fluid code UEDGE are used to show that detachment onset and properties are sensitive to 1) placing the neutral gas source in the vicinity of the strike point, 2) directing the recycling neutrals toward the separatrix by adjusting the poloidal separatrix angle, and 3) entrapping neutrals by plasma plugging via the high poloidal magnetic flux expansion configuration. These findings will be tested in NSTX Upgrade, where H-mode scenarios with 2 MA, 1 T, 10 MW NBI-heated discharges and 5 s flattop are predicted to produce unmitigated peak divertor heat fluxes above 10 MW/m², necessitating the scrape-off layer power sharing between upper and lower divertors and inducing dissipative losses. 

*Supported by the US DOE under Contracts DE-AC52-07NA27344 and DE-AC02-09CH1466.

PP11 56 Plasma-Facing Component and Materials Testing for the NSTX-U* MICHAEL JAWORSKI, A BROOKS, S GERHARDT, D LOESSER, M MARDENFELD, J MENARD, PPPL T GRAY, M REINKE, ORNL The NSTX-U Recovery Project is developing plasma-facing components for use in the divertor of NSTX-U. The extreme conditions of the NSTX-U divertor make it possible to stress even graphite surfaces to the material limits leading to the possibility of component failures. In addition, the complex, mixed-material environment of the NSTX-U due to the use of boron and lithium wall conditioning techniques creates significant uncertainties in the monitoring of the PFCs. A testing program has been developed to inform on the material and design limitations of the NSTX-U high-heat flux components. These tests include high-heat flux testing in electron beam facilities as well as plasma-based testing. The NSTX-U components could experience perpendicular heat fluxes as high as 45 MW/m². Parallel heat fluxes onto leading edges could reach 475 MW/m². The testing program and material survey plan will be presented.

*Work supported by DOE contract DE-AC02-09CH11466 and DE-AC05-00OR22725.

PP11 57 Surface chemistry analysis of boronized TZM and ATJ graphite samples during and after plasma irradiation HANNA SCHAMIS, FELIPE BEOYA, JEAN PAUL ALLAIN, University of Illinois at Urbana-Champaign ROBERT KAITA, Princeton Plasma Physics Laboratory The National Spherical Torus Experiment Upgrade (NSTX-U) plasma facing component diagnostic, the Material Analysis and Particle Probe (MAPP), was installed. MAPP has the capability of conducting XPS studies on materials without exposing them to atmospheric conditions. MAPP was used to conduct XPS studies of ATJ graphite (current first-wall material) and TZM alloy (99% Mo, 0.5% Ti, 0.08% Zr) samples exposed to plasma operations during the 2015-2016 experimental campaign. The data shows evidence of sputtering of the boron layers following plasma operations during H-modes. These promising results in NSTX and related modeling calculations motivated the radiative liquid Li divertor (RLLD) concept and its variant, the active liquid Li divertor concept (ARLLD), taking advantage of the enhanced Li radiation in relatively poorly confined divertor plasmas. It has been suggested that radiation-based liquid lithium (LL) divertor concepts with a modest Li-loop could provide a possible solution for the outstanding fusion reactor technology issues such as divertor heat flux mitigation and real time dust removal, while potentially improving the reactor plasma performance. Laboratory tests are also planned to investigate the Li-T recover efficiency and other relevant research topics of the RLLD.

*This work supported by DoE Contract No. DE-AC02-09CH11466. in collaboration with the NSTX-U team.

PP11 58 Global modeling of wall material migration following boronization in NSTX-U* J.H. NICHOLS, M.A. JAWORSKI, C.H. SKINNER, PPPL F. BEOYA, UIUC F. SCOTTI, V.A. SOUKHANOVSKII, LLNL K. SCHMID, IPP Garching NSTX-U operated in 2016 with graphite plasma facing components, periodically conditioned with boron to improve plasma performance. Following each boronization, spectroscopic diagnostics generally observed a decrease in oxygen influx from the walls, and an in-vacuo material probe (MAPP) observed a corresponding decrease in surface oxygen concentration at the lower divertor. However, oxygen levels tended to return to a pre-boronization state following repeated plasma exposure. This behavior is interpretively modeled using the WallDYN mixed-material migration code, which couples local erosion and deposition processes with plasma impurity transport in a non-iterative, self-consistent manner that maintains overall material balance. A spatially inhomogeneous model of the thin films produced by the boronization process is presented. Plasma backgrounds representative of NSTX-U conditions are reconstructed from a combination of NSTX-U and NSTX datasets. Low-power NSTX-U fiducial discharges, which led to less apparent surface degradation than normal operations, are also modeled with WallDYN. Likely mechanisms driving the observed evolution of surface oxygen are examined, as well as remaining discrepancies between model and experiment and potential improvements to the model.

*Supported by US DOE contract DE-AC02-09CH11466.

PP11 59 Advantages and Challenges of Radiative Liquid Lithium Divertor* MASAYUKI ONO, PPPL, Princeton University Steady-state fusion power plant designs present major divertor technology challenges, including high divertor heat flux both in steady-state and during transients. In addition to these concerns, there are the unresolved technology issues of long term dust accumulation and associated tritium inventory and safety issues. The application of lithium (Li) in NSTX resulted in improved H-mode confinement, H-mode power threshold reduction, and reduction in the divertor peak heat flux while maintaining essentially Li-free core plasma operation even during H-modes. These promising results in NSTX and related modeling calculations motivated the radiative liquid Li divertor (RLLD) concept and its variant, the active liquid Li divertor concept (ARLLD), taking advantage of the enhanced Li radiation in relatively poorly confined divertor plasmas. It has been suggested that radiation-based liquid lithium (LL) divertor concepts with a modest Li-loop could provide a possible solution for the outstanding fusion reactor technology issues such as divertor heat flux mitigation and real time dust removal, while potentially improving the reactor plasma performance. Laboratory tests are also planned to investigate the Li-T recover efficiency and other relevant research topics of the RLLD.

*Supported by US DOE Contract No. DE-AC02-09CH11466.
fast wave (HHFW) power can be lost in the SOL of NSTX. In this presentation, we perform simulations using a 2D full-wave (FW2D) code for HHFW in the SOL of NSTX. A recently developed FW2D code solves the cold plasma wave equations using the finite element method and has been successfully applied to describe low frequency waves in the planetary magnetospheres. Very recently, the FW2D code has been adapted to tokamak geometry to examine radio frequency waves in the SOL of tokamaks. We adopt (1) a rectangular boundary to benchmark with the AORSAs results and (2) a limiter boundary to examine boundary effects on HHFW propagation. As results, we found that (1) FW2D and AORSAs simulations show an excellent agreement in the rectangular boundary; and (2) FW2D results with a realistic limiter boundary are significantly different to results with the rectangular vessel boundary.

PP11 61 Effects of the H species in the HHFW performance in NSTX/NSTX-U plasmas * N. BERTELLI, PPL, E.F. JAEGGER, XCEL R.W. HARVEY, CompX J.C. HOSEA, E.-H. KIM, R.J. PERKINS, G. TAYLOR, E.J. VALEO, PPL. One of the goal of NSTX-U is to operate at full field (B = 1 T). For this magnetic field, the first and second harmonics of hydrogen (H) are located at the high-field side and in the core plasma, respectively. In principle, part of the high-harmonic fast-wave (HHFW) injected power can be absorbed by the H population reducing the electron and/or the fast-ion heating. For this reason, full wave simulations results of NSTX-U scenarios with different H concentrations for wave frequencies of 30 and 60 MHz will be presented and discussed. Plasma scenarios with and without neutral beam injection (NBI) will be considered. Furthermore, the balance between the beam ion and electron power absorption will be analyzed comparing both NSTX and NSTX-U plasmas.

*Work supported by US DOE Contract DE-AC02-09CH11466.

PP11 62 Comparison of neutral density profiles measured using Dα and CIV+ in NSTX-U* R.E. BELL, PPL, F. SCOTTI, LLNL, A. DIALLO, B.P. LEBLANC, M. PODESTA, PPL, S.A. SABBAGHI, Columbus University. Edge neutral density profiles determined from two different measurements are compared on NSTX-U plasmas. Neutral density measurements were not typical on NSTX plasmas. An array of fibers dedicated to the measurement of passive emission of CIV+, used to subtract background emission for charge exchange recombination spectroscopy (CHERS), can be used to infer deuterium neutral density near the plasma edge. This fiber measures CIV+ from the plasma edge. The line emission from CIV+ is dominated by charge exchange with neutral deuterium near the plasma edge. An edge neutral density diagnostic consisting of a camera with a Dα filter was installed on NSTX-U. The line-integrated measurements from both diagnostics are inverted to obtain local emissivity profiles. Neutral density is then inferred using atomic rates from ADAS and profile measurements from Thomson scattering and CHERS. Comparing neutral density profiles from the two diagnostic measurements helps determine the utility of using the more routinely available CIV+ measurements for neutral density profiles. Initial comparisons show good agreement between the two measurements inside the separatrix.

*Supported by US DoE Contracts DE-AC02-09CH11466 and DE-AC52-07NA27344.

PP11 63 3D Field Modifications of Core Neutral Fueling In the EMC3-EIRENE Code* IAN WATERS, Univ of Wisconsin, Madison HEINKE FRERICHS, OLIVER SCHMITZ, University of Wisconsin-Madison JOON-WOOK AHN, Oak Ridge National Laboratory GUSTAVO CANAL, TODD EVANS, General Atomics YUEHE FENG, Max-Planck-Institut für Plasmaphysik STANLEY KAYE, RAJESH MAINGI, Princeton Plasma Physics Laboratory VSEVOLOD SOUKHANOVSKII, Lawrence Livermore National Laboratory The application of 3-D magnetic field perturbations to the edge plasmas of tokamaks has long been seen as a viable way to control damaging Edge Localized Modes (ELMs). These 3-D fields have also been correlated with a density drop in the core plasmas of tokamaks; known as ‘pump-out’. While pump-out is typically explained as the result of enhanced outward transport, degraded fueling of the core may also play a role. By altering the temperature and density of the plasma edge, 3-D fields will impact the distribution function of high energy neutral particles produced through ion-neutral energy exchange processes. Starved of the deeply penetrating neutral source, the core density will decrease. Numerical studies carried out with the EMC3-EIRENE code on National Spherical Tokamak eXperiment-Upgrade (NSTX-U) equilibria show that this change to core fueling by high energy neutrals may be a significant contributor to the overall particle balance in the NSTX-U tokamak: deep core (∝ < 0.5) fueling from neutral ionization sources is decreased by 40-60% with RMPs.

*This work was funded by the US Department of Energy under Grant DE-SC0012315.

PP11 64 CHI Research on NSTX-U* W-S LAY, R RAMAN, T.R JARBOE, B.A NELSON, University of Washington D MUELLER, F EBRAHIMI, M ONO, S.C JARDIN, G TAYLOR, PPL. At present about 20% of the total plasma current required for sustained operation has been generated by transient CHI. The present understanding suggests that it may be possible to generate all of the needed current in a ST / tokamak using transient CHI. In such a scenario, one could transition directly from a CHI produced plasma to a non-inductive sustained plasma, without the difficult intermediate step that involves non-inductive current ramp-up. STs based on this new configuration would take advantage of evolving developments in high-temperature superconductor technology to develop a simpler design ST that relies primarily on CHI for plasma current generation. Motivated by the very good results from NSTX and HIT-II, we are examining the potential application of transient CHI for reactor configurations through these studies. (1) Study of the maximum levels of start-up currents that could be generated on NSTX-U, (2) application of a single biased electrode configuration on QUEST to protect the insulator from neutron damage in a CHI reactor installation, and (3) QUEST-like, but a double biased electrode configuration for PEGASUS and NSTX-U. Results from these on-going studies will be described.

*This work is supported by U.S. DOE Contracts: DE-AC02-09CH11466, DE-FG02-99ER54519 AM08, and DE-SC0006757.

PP11 65 Synthetic capability for the study of poloidal impurity asymmetries in NSTX-U* L. DELGADO-APARICIO, R. E. BELL, M. PODESTA, B. P. LEBLANC, A. DIALLO, PPL, L. MORTON, Oak Ridge Associated Universities H. YAMAZAKI, Y. TAKASE, University of Tokyo M. ONO, PPL. A new capability has been built to compute the two-dimensional mapping of impurity density asymmetries in NSTX-U. This technique relies on flux-surface quantities like electron and ion temperature (T_e,i), and rotation frequency (ω_e), but finds the 2D electron, deuterium and carbon density profiles self-consistently assuming the presence of a poloidal variation due to centrifugal forces. The solution for the electrostatic potential for the measured carbon density and central toroidal rotation using NSTX data will be shown and compared with the values derived using Wesson’s formalism which assumed that the main intrinsic impurity was in the trace limit. The presence of O, Ne,
Ar, Fe, Mo and W are considered at the trace limit with very small changes to quasi-neutrality and $Z_{\text{eff}}$. The few assumptions made considered a zero electron mass, a deuterium plasma, a trace impurity with charge “$Z$” given by coronal equilibrium ($Z = Z(T_e)$) and equilibrated ion temperatures (e.g. $T_D = T_e = T_2$). This capability will help in the understanding of asymmetries before tearing modes onset as well as aid the design of new diagnostics for NSTX-U.

**PP11 66 Design of tangential multi-energy SXR cameras for tokamak plasmas** H. YAMAZAKI, University of Tokyo L. F. DELGADO-APARICIO, N. PABLANT, K. HILL, M. BITTER, PPPL Y. TAKASE, University of Tokyo M. ONO, B. STRATTON, PPPL A new synthetic diagnostic capability has been built to study the response of tangential multi-energy soft x-ray pin-hole cameras for arbitrary plasma densities $(n_p)$, temperature $(T_i)$ and ion concentration $(n_Z)$. For tokamaks and future facilities to operate safely in a high-pressure long-pulse discharge, it is imperative to address key issues associated with impurity sources, core transport and high-Z impurity accumulation. Multi-energy soft x-ray imaging provides a unique opportunity for measuring, simultaneously, a variety of important plasma properties (e.g. $T_e$, $n_Z$ and $\Delta Z_{\text{eff}}$). These systems are designed to sample the continuum- and line-emission from low- to high-Z impurities (e.g. C, O, Al, Si, Ar, Ca, Fe, Ni and Mo) in multiple energy-ranges. These x-ray cameras will be installed in the MST-RFP, as well as NSTX-U and DIII-D tokamaks, measuring the radial structure of the photon emissivity with a radial resolution below 1 cm at a 50 Hz frame rate and a photon-energy resolution of 500 eV. The layout and response expected for the new systems will be shown for different plasma conditions and impurity concentrations. The effect of toroidal rotation driving poloidal asymmetries in the core radiation is also addressed for the case of NSTX-U.

**PP11 67 Upgrade to the MPTS Thomson scattering diagnostic in preparation for NSTX-U restart** BENOIT LEBLANC, AHMED DIALLO, PPPL Upgrades to Multi-Pulse Thomson Scattering (MPTS) diagnostic are in progress. An innovative laser is being added to the existing two 30-Hz Nd:YAG lasers. The new laser also has 30-Hz base operation, but differs notably in its capacity of generating rapid bursts of nominal 50 pulses at either 1 kHz or 10 kHz. This Pulsed-Bursting Laser System (PBLS) is described elsewhere [1]. The current laser delivery optics, which supports two paraxial beam paths, is maintained. One beam path will be occupied by PBLS. The other two laser beams will be actively combined coaxially and will occupy the second beam path. The new laser arrangement will result in a 90-Hz baseline operation, plus the PBLS burst capability. While the existing sample-and-hold electronics is expected to track a 1-kHz sequence, it will not be able to follow a 10-kHz burst. For this purpose, ten radial channels, dedicated to the pedestal region, will be instrumented with 250-MHz digitizers. The NSTX-U longer plasma duration and increased heating power will be conducive to situations with sustained high background light, a condition exacerbated by the absence of viewing dump necessitated by machine geometry. Additional work is slated to study the behavior of the fast signal detection in presence of strong background light.

*This work is supported by US DoE Contract DE-AC02-09CH11466 and ECRF funding.

1 A. Diallo et al., HTPD 2016, Madison, WI.

**PP11 68 The real time multi point Thomson scattering diagnostic at NSTX-U** FLORIAN LAGGNER, EGEMEN KOLEMEN, Princeton University, Princeton, New Jersey 08544 AHMED DIALLO, BENOIT LEBLANC, ROMAN ROZENBLAT, GREG TCHILINGURIAN, Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543 NSTX-U TEAM TEAM This contribution presents the upgrade of the multi point Thomson scattering (MPTS) diagnostic for real time application. As a key diagnostic at NSTX-U, the MPTS diagnostic simultaneously measures the electron density $(n_e)$ and electron temperature $(T_e)$ profiles of a plasma discharge. Therefore, this powerful diagnostic can directly access the electron pressure of the plasma. Currently, only post-discharge evaluation of the data is available, however, since the plasma pressure is one important drive for instabilities, real time measurements of this quantities would be beneficial for plasma control. In a first step, ten MPTS channels were equipped with real time electronics, which improve the data acquisition rate by five orders of magnitude. The commissioning of the system is ongoing and first benchmarks of the real time evaluation routines against the standard, post-discharge evaluation show promising results: The $T_e$ as well as $n_e$ profiles of both types of analyses agree within their uncertainties.

*This work was supported by the US Department of Energy under DE-SC0015878 and DE-SC0015480.

**PP11 69 Overview of High-k Scattering Diagnostics on NSTX and NSTX-U** Y. REN, PPPL E. MAZZUCATO, Retired D. R. SMITH, UW-Madison R. BARCHFIELD, C.W. DOMIER, E.R. SCOTT, N.C. LUMHANN JR., UC-Davis R. KAITA, R. ELLIS, PPPL K.C. LEE, NFRI (Korea) Electron-gyro scale turbulence, e.g. driven by the Electron Temperature Gradient (ETG), has been proposed as a potential candidate for driving anomalous electron thermal transport, a major problem for magnetic confinement fusion. NSTX and NSTX-U provide a unique laboratory for studying electron-scale turbulence and its relation to electron thermal transport due to their low toroidal field, high plasma beta, low aspect ratio and large ExB flow shear. Electron-gyro scale turbulence has been successfully measured in NSTX using a unique high-k, microwave scattering system, providing the first direct evidence of ETG turbulence in STs and detailed studies of parametric dependence of electron-scale turbulence. However, the high-k, microwave scattering system could not capture the predicted ETG spectral peak. Thus a new high-k FIR scattering system is being implemented for NSTX-U. We will present an overview of the scattering systems on NSTX and NSTX-U, including physics designs, capabilities and recent physics results. We will also discuss methods to achieve radially localized scattering measurements.

*The work is supported by DOE.

**PP11 70 BOUNDARY**

**PP11 71 Optimization of time-averaged power flux of RMP footprints in ITER** LUKAS KRIPNER, Institute of Plasma Physics of the CAS, 182 00 Prague, Czech Republic ALBERTO LOARTE, ITER Organization, 13115 St Paul Lez Durance, France PAVEL CAHYNA, JAKUB URBAN, MATEJ PETERKA, Institute of Plasma Physics of the CAS, 182 00 Prague, Czech Republic TODD EVANS, General Atomics, PO Box 85608, San Diego, CA 92186 “5608, USA OLIVER SCHMITZ, University of Wisconsin - Madison, Department of Engineering Physics, 53706 Madison, WI, USA RADOMIR PANEK, Institute of Plasma Physics of the CAS, 182 00 Prague, Czech Republic Plasma-facing components (PFCs) in the ITER tokamak have engineering limits of the incident heat flux ($\sim 10 \text{ MWm}^{-2}$). These limits may be exceeded for example by Edge...
Localized Modes (ELMs) or by Resonant Magnetic Perturbations (RMPs). The time-averaged power flux can be reduced by a toroidal rotation of the ITER ELM coils (IECs) current waveform. However, such a rigid rotation results in large mechanical loads to IECs, which can significantly decrease their lifetime. We evaluate various options to decrease the required variations in the IECs currents while keeping the time-averaged power flux on the ITER divertor below the engineering limit. We use the Bayesian optimization algorithm to seek the optimum configuration. This method works efficiently even for a moderately large dimensionality, in our case up to several tens. For the analysis of a particular waveform we use the tangle distance method [Cahyna et al. Nucl. Fusion 2014], which is, due to its semi-analytical nature, fast enough to evaluate a wide range of options and plasma scenarios.

PP11 72 Fundamental physics behind the divertor heat-flux width in the present tokamaks and ITER* C.S. CHANG, S. KU, R.M. CHURCHILL, R. HAGER, Princeton Plasma Physics Laboratory SCOTT PARKER, Univ. Colorado Boulder JIM MYRA, Lodestar Research Electrostatic gyrokinetic simulation using XGC1 recovers the empirical scaling for the divertor heat-load width $\lambda_q$ in the present tokamaks ($\lambda_q \propto 1/B'^+_{\gamma}$, with $\gamma \sim 1$). $\lambda_q$ is dominated by the neoclassical magnetic drift of ions. However, XGC1 predicts that $\lambda_q$ in ITER is much larger than the value predicted by the empirical scaling. An in-depth study shows that the edge turbulence characteristics in ITER is highly different from that in the present tokamaks. In the present tokamaks, the edge turbulence in an H-mode plasma is “bloppy,” with most of the convective blob motion in the poloidal direction yielding little radial transport. Bloppy electron radial transport is passive, only keeping the quasi-neutrality with ion magnetic drift. However, in ITER, the edge turbulence is found to be ‘streamer-like,’ giving rise to active radial particle and thermal transport. There appears to be a bifurcation of the edge turbulence characteristics from blobs to streamers between JET and ITER, most likely due to the size effect, in the XGC simulation. Fundamental physics behind this turbulence bifurcation will be discussed, in relation to the sheared ExB flow, and the Kelvin-Helmholtz, TEM and ITG turbulence. *Funded by US DOE FES and ASCR. Computing resources provided by ALCC and INCITE programs on Titan.

PP11 73 Drift-kinetic simulations of axisymmetric plasma transport at the edge of a divertor tokamak* M. DORF, M. DORR, D. GHOSH, J. HITTINGER, LLNL W. LEE, UCSD R. COHEN, Retired Eulerian kinetic calculations are presented for the axisymmetric cross-separatrix transport of plasma at the edge of a tokamak. The simulations are performed with a high-order finite-volume code COGENT that solves the full-F drift-kinetic equation for the ion species including the effects of fully-nonlinear Fokker-Plank ion-ion collisions. The ion kinetic response is coupled to two-dimensional self-consistent electrostatic potential variations, which are obtained from the vorticity equation with the isothermal fluid electron model. The paper also presents recent progress toward the full-edge turbulence code. The slab-geometry 3D version has recently become available and is successfully verified in simulations of the collisionless-drift-wave instability. *Work performed for USDOE, at LLNL under contract DE-AC52-07NA27344.

PP11 74 On pressure balance in a low collisionality tokamak scrape-off layer R.M. CHURCHILL, C.S. CHANG, R. HAGER, Princeton Plasma Physics Laboratory Understanding the physics governing the scrape-off layer is necessary in order to reliably predict machine and operation critical quantities, such as the heat flux width at the divertor, plasma-wall interaction, material migration, effect of divertor condition on the pedestal profile, detachment of the divertor plasma, etc. Recent simulation results using the axisymmetric gyrokinetic code XGCa suggest that in a lower ion collisionality near scrape-off layer, where the plasma is highly non-Maxwellian, the fluid form of the momentum equation is not conserved between the low-field side (LFS) midplane and divertor. Taking care to include neutral friction and a Chew-Goldberger-Low (CGL) form of the pressure tensor (i.e. only the dominant diagonal terms) does not resolve the imbalance. Using the full kinetic distribution function in the XGC gyrokinetic code, we explore the effect of off-diagonal pressure tensor terms, to determine their effect in the momentum balance in the scrape-off layer. We also explore other simulations with higher ion collisionality, to begin to study the effect of ion collisionality versus proximity to the separatrix (flux surfaces closer to the separatrix can be more influenced by e.g. X-point loss).

PP11 75 Evolution of pressure drop during detachment in the TCV tokamak O. FEVRIER, C. THEILER, EPFL SPC C. K. TSUI, UCSD K. VERHAEGH, University of York R. MAURIZIO, B. LABIT, H. REIMERDES, B. DUVAL, EPFL SPC J.A. BOEDO, UCSD B. LIPSCHULTZ, University of York TCV TEAM, EURO-FUSION MST1 TEAM To ensure safe power exhaust in future fusion reactors will require, at the least, partially detached divertor operation. To further understand the dynamics of this process, we investigate detachment on TCV in a lower single-null geometry by examining the evolution of the profiles of plasma density, temperature, and pressure at the outboard midplane (“upstream”) and at the outer strikepoint (“target”). A fast reciprocating probe is plunged at different times of reproducible discharges throughout the detachment process. Its measurements are compared with target measurements from probes and infrared thermography. As expected, the roll-over of the ion flux, often used experimentally to identify detachment, coincides with a pressure drop along the field lines. This is compared quantitatively with expectations from an extended two-point model where radiation and momentum losses are evaluated from bolometry and probe data. The roll-over coincides with the onset of “density shoulders” at the outer midplane. These are observed in the upstream density profiles and in bolometric and AXUV measurements, that show a radiation increase at the outer midplane. The application of these findings to detachment in advanced divertor geometries will be discussed.

PP11 76 3D nonlinear numerical simulation of the current-convective instability in detached divertor plasma* ALEXANDER STEPANENKO, Moscow Engineering Physics Institute SERGEI KRASHENINNIKOV, Univ of California - San Diego One of the possible mechanisms responsible for strong radiation fluctuations observed in the recent experiments with detached plasmas at ASDEX Upgrade [Potzel et al., Nuclear Fusion, 2014] can be related to the onset of the current-convective instability (CCI) driven by strong asymmetry of detachment in the inner and outer tokamak divertors [Krasheninnikov and Smolyakov, PoP, 2016]. In this study we present the first results of 3D nonlinear numerical simulations of the CCI in divertor plasma for the conditions relevant to the AUG experiment. The general physical model used to simulate the CCI, qualitative estimates for the instability characteristic growth rate and transverse wavelengths derived for plasma, which is spatially inhomogeneous both across and along the magnetic field lines, are
presented. The simulation results, demonstrating nonlinear dynamics of the CCI, provide the frequency spectra of turbulent divertor plasma fluctuations showing good agreement with the available experimental data.

PP11 77 Detachment studies in the Magnum-PSI linear device
IVO CLASSEN, RENATO PERILLO, WOUTER VIJVERS, RION BARROIS, GIJS AKKEMANN, RODERIK VAN DE LOGT, HENNIE VAN DER MEIDEN, HANS VAN ECK, THOMAS MORGAN, DIFFER - Dutch Institute for Fundamental Energy Research

Divertor detachment experiments on the Magnum-PSI linear device have been performed to investigate the relevant volume and surface processes responsible for detachment in tokamaks. The interaction of the plasma with a neutral background plays a crucial role in achieving a detached plasma regime. Detachment in Magnum-PSI is achieved by raising the \( H_2 \) background pressure by seeding near the target. Increasing the pressure up to 16 Pa showed a significant decrease in plasma pressure, heat flux and ion flux to the target. Radially resolved spectroscopy showed large deviations of the Balmer line ratios from LTE, and will provide detailed information on the volume processes, comparing the experimentally observed line intensities to collisional radiative modelling. To study the plasma chemistry in Nitrogen seeded scenarios, the \( H_2+N_2 \) chemistry has been implemented in the PLASIMO code. This model suggests a modified molecular-activated-recombination (MAR) scheme in which \( N_2H^+ \) and \( NH \) play key roles. The strongly reduced set of primary reaction mechanisms suggested by PLASIMO is being implemented into B2.5-Eunomia. Experiments in Magnum-PSI using a mixed \( H_2+N_2 \) neutral background showed strong \( NH \) radiation from the plasma and significant fractions of \( N_2H \) in the residual gas analyser, qualitatively confirming the chemical processes proposed by PLASIMO.

PP11 78 Time-dependent modeling of dust injection in semi-detached ITER divertor plasma* ROMAN SMIRNOV, SERGEI KRASHENINNIKOV, University of California, San Diego

At present, it is generally understood that dust related issues will play important role in operation of the next step fusion devices, i.e. ITER, and in the development of future fusion reactors. Recent progress in research on dust in magnetic fusion devices has outlined several topics of particular concern: a) degradation of fusion plasma performance; b) impairment of in-vessel diagnostic instruments; and c) safety issues related to dust reactivity and tritium retention. In addition, observed dust events in fusion edge plasmas are highly irregular and require consideration of temporal evolution of both the dust and the fusion plasma. In order to address the dust-related fusion performance issues, we have coupled the dust transport code DUSTT and the edge plasma transport code UEDGE in time-dependent manner, allowing modeling of transient dust-induced phenomena in fusion edge plasmas. Using the coupled codes we simulate burst-like injection of tungsten dust into ITER divertor plasma in semi-detached regime, which is considered as preferable ITER divertor operational mode based on the plasma and heat load control restrictions. Analysis of transport of the dust and the dust-produced impurities, and of dynamics of the ITER divertor and edge plasma in response to the dust injection will be presented.

PP11 79 Analysis of filament statistics in fast camera data on MAST** TOM FARLEY, University of Liverpool FULVIO MILITELLO, NICK WALKDEN, JAMES HARRISON, SCOTT SILBURN, Culham Centre for Fusion Energy JAMES BRADLEY, University of Liverpool

Coherent filamentary structures have been shown to play a dominant role in turbulent cross-field particle transport ([D’Ipolito 2011]. An improved understanding of filaments is vital in order to control scrape off layer (SOL) density profiles and thus control first wall erosion, impurity flushing and coupling of radio frequency heating in future devices. The Elzar code [T. Farley, 2017 in prep.] is applied to MAST data. The code uses information about the magnetic equilibrium to calculate the intensity of light emission along field lines as seen in the camera images, as a function of the field lines’ radial and toroidal locations at the mid-plane. In this way a ‘pseudo-inversion’ of the intensity profiles in the camera images is achieved from which filaments can be identified and measured. In this work, a statistical analysis of the intensity fluctuations along field lines in the camera field of view is performed using techniques similar to those typically applied in standard Langmuir probe analyses. These filament statistics are interpreted in terms of the theoretical ergodic framework presented by F. Militello & J.T. Omotani, 2016, in order to better understand how time averaged filament dynamics produce the more familiar SOL density profiles.

*This work has received funding from the RCUK Energy programme (Grant Number EP/P012450/1), from Euratom (Grant Agreement No. 633053) and from the EUROfusion consortium.

PP11 80 SOLPS simulations of X-divertor in NSTX-U** ZHONG-PING CHEN, MIKE KOTSCHREUTHER, SWADESH MAHAJAN, University of Texas, Austin

The X-divertor (XD) geometry in NSTX-U has demonstrated, in SOLPS simulations, a better performance than the standard divertor (SD) regarding detachment: achieving detachment with a lower upstream density and stabilizing the detachment front near the target. The benefits of such a localized front is that the power exhaust requirement can be satisfied without the radiation front encroaching on the core plasma. It is also found by our simulations that at similar states of detachment the XD outperforms the SD by reducing the heat fluxes to the target and maintaining higher upstream temperatures. These advantages are attributed to the unique geometric characteristics of XD - poloidal flaring near the target. The detailed physical mechanisms behind the better XD performance that is found in the simulations will be examined.

*Work supported by US DOE under DE-FG02-04ER54742 and SC 0012956.

PP11 81 Efficient Coupling of Fluid-Plasma and Monte-Carlo-Neutrals Models for Edge Plasma Transport* A.M. DIMITS, B. I. COHEN, A. FRIEDMAN, I. JOSEPH, L.L. LODESTRO, M.E. RENSINK, T.D. ROGNLIEN, B. SJOGREEN, LLNL D.P. STOTLER, PPPL M.V. UMANSKY, LLNL UEDGE [1] has been valuable for modeling transport in the tokamak edge and scrape-off layer due in part to its efficient fully implicit solution of coupled fluid neutrals and plasma models. We are developing an implicit coupling of the kinetic Monte-Carlo (MC) code DEGAS-2 [2], as the neutrals model component, to the UEDGE plasma component, based on an extension of the Jacobian-free Newton-Krylov (JFNK) method to MC residuals [3]. The coupling components build on

*This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, under Award Number DE-FG02-06ER54852.
the methods and coding already present in UEDGE. For the linear Krylov iterations, a procedure has been developed to “extract” a good preconditioner from that of UEDGE. This preconditioner may also be used to greatly accelerate the convergence rate of a relaxed fixed-point iteration, which may provide a useful “intermediate” algorithm. The JFNK method also requires calculation of Jacobian-vector products, for which any finite-difference procedure is inaccurate when a MC component is present [3]. A semi-analytical procedure that retains the standard MC accuracy and fully kinetic neutrals physics is therefore being developed.

*Prepared for US DOE by LLNL under Contract DE-AC52-07NA27344 and LDRD project 15-ERD-059, by PPP under Contract DE-AC02-09CH11466, and supported in part by the U.S. DOE, OSES.


**PP11 82 A numerical study of neutral-plasma interaction in magnetically confined plasmas**

S. TAHERI, U. SHUMLAK, University of Washington J. R. KING, Tech-X Corporation Interactions between plasma and neutral species can have a large effect on the dynamic behavior of magnetically confined plasma devices, such as the edge region of tokamaks and the plasma formation of Z-pinch. The presence of neutrals can affect the stability of the pinch and change the dynamics of the pinch collapse, and they can lead to deposition of high energy particles on the first wall. However, plasma-neutral interactions can also have beneficial effects such as quenching the disruptions in tokamaks. In this research a reacting plasma-neutral model, which combines a magnetohydrodynamic (MHD) plasma model with a gas dynamic neutral fluid model [1], is used to study the interaction between plasma and neutral gas. Incorporating this model into NIMROD allows the study of electron-impact ionization, radiative recombination, and resonant-charge-exchange in plasma-neutral systems. An accelerated plasma moving through a neutral gas background is modeled in both a parallel plate and a coaxial electrode configuration to explore the effect of neutral gas in pinch-like devices.

*This work is supported by a Grant from US DOE.

Maier and Shumlak, POP 19 (2012).

**PP11 83 GTC Turbulence Simulations near H-mode Pedestal with Resonant Magnetic Perturbations**

LEI SHI, Department of Physics and Astronomy, UCI, Irvine CA 92697 NATHANIEL FERRARO, Princeton Plasma Physics Lab, Princeton, NJ 08543, USA SAM TAIMOURZADEH, Department of Physics and Astronomy, UCI, Irvine CA 92697 JINGYUAN FU, Fusion Simulation Center, Peking University, Beijing, China 100871 ZHIHONG LIN, Department of Physics and Astronomy, UCI, Irvine CA 92697 RAFFI NAZIKIAN, Princeton Plasma Physics Lab, Princeton, NJ 08543, USA Full plasma responses to Resonant Magnetic Perturbations (RMPs) as provided by the resistive MHD code 3D-C1 are implemented into Gyrokinetic Toroidal Code (GTC) to study the effect of magnetic islands and stochastic field regions on microturbulence in realistic DIII-D geometry. Electrostatic turbulence simulations with adiabatic electrons show no significant increase of the saturated ion heat conductivity in the presence of RMP-induced islands. However, electron response to zonal flow in the presence of magnetic islands and stochastic fields can drastically increase zonal flow dielectric constant for long wavelength fluctuations. Zonal flow generation can then be reduced and the microturbulence can be enhanced greatly. Furthermore, because the RMP magnetic island size is comparable to the ion banana width, electron and ion responses to these islands may be fundamentally different, which could drive non-ambipolar particles fluxes leading to changes of the radial electric field shear.

*This work is supported by General Atomics subcontract.

**PP11 84 Linear instabilities near the DIII-D edge simulated in fluid models**

ERIC BASS, CHRISTOPHER HOLLAND, UC San Diego The linear instability spectrum is reported near the DIII-D edge (within the separatrix) for L-mode and H-mode shots using the new eigenvalue solver FluTES (Fluid Toroidal Eigenvalue Solver). FluTES circumvents difficulties with convergence to clean linear eigenmodes (required for diagnosis of nonlinear simulations in codes such as BOUT++) [1] often encountered with fluid initial-value solvers. FluTES is well-verified in analytic cases and against a BOUT++/ELITE benchmark toroidal case. We report results for both a 3-field, one-fluid model (the well-known “elm-ph” model) and a 5-field, two-fluid model. For the peeling-balloonondominated H-mode, the two solutions are qualitatively the same. In the driftwave-dominated L-mode edge, only the two-fluid solution gives robust instabilities which occur primarily at n > 50. FluTES is optimized for this regime (near-flutelike limit, toroidally spectral). Cross-separatrix, coupled fluid and drift instabilities may play a role in explaining the gyrokinetic L-mode edge transport shortfall [2]. Extension of FluTES into the open-field-line region is underway.

*Prepared by UCSD under Contract Number DE-FG02-06ER54871.

1 Dudson et al., Comp. Phys. Comm. 180, 1467 (2009).

**PP11 85 Simulating the DIII-D grassy ELM regime with BOUT++**

B. GUI, T.Y. XIA, ASIPP X.Q. XU, LLNL R. NAZIKIAN, PPPL XI CHEN, R. GROEBNER, GA In order to develop a steady-state regime for the ITER Phase-II mission, a fully non-inductive hybrid regime with the effective ELM control using weak 3D fields is studied on DIII-D. The 2-fluid modules in BOUT++ are used to study the dynamics of ELMS in this regime, especially for grassy ELMS in DIII-D shot #161414. Linear analysis shows that the grassy ELMS in the hybrid regime occur close to the ideal peeling boundary, which is quite different from the conclusion of high-n ballooning modes on JT60U (Oyama, NF2010). However, the inclusion of the measured edge electric field Er, which can alter the peeling-balloonning (PB) instability boundary (J.G. Chen, PoP2017), predicts wide spectrum PB modes, and all the high-n (n>30) modes can be stabilized by ion diamagnetic effects. Therefore, linear instability of grassy ELMS is driven by ideal peeling modes and low-n ballooning modes due to the boundary changing effects of Er. Nonlinear simulations show that the ELM pressure profile crash at the outer mid-plane is enhanced by Er, but the poloidal extent of the crash is limited to the low-field side and the total energy loss is just ~1%. Detailed nonlinear simulation results will be reported in this talk.

*This work was performed under the auspices of the US DOE by LLNL under contract DE-AC52-07NA27344 and DE-FC02-04ER54698 for DIII-D. It was supported by the China NSF 11405215 and 11675217.

**PP11 86 Self-consistent calculation of the radial electric field with ion orbit loss mechanism by using BOUT++**

N.M. LI, DLUT X.Q. XU, LLNL T.M. WLKES, MIT B. GUI, X.T. XIAO, ASIPP J.Z. SUN, D.Z. WANG, DLUT The steady state radial electric field (Er) can be self-consistently calculated by coupling a plasma transport...
model with a quasi-neutrality constraint and the vorticity formulation within the BOUT++ framework. Based on the experimentally measured plasma density and temperature profiles inside the separatrix, the effective particle and heat diffusivities can be interpreted from the set of plasma transport equations. The effective diffusivities are then extended into the scrape off layer (SOL) to calculate the plasma density, temperature and flow profiles across the separatrix into the SOL. With plasma quantities defined in both the pedestal and SOL regions, the electric field can be calculated across the separatrix from the vorticity equations with a sheath boundary condition, and the cross-field drifts are shown to play a significant role by inducing a net flow in both the edge and the SOL region. The sheath boundary condition acts to generate a large, positive Er in the SOL, which is consistent with experimental measurements. Furthermore, the particle, momentum, and energy ion- orbit losses are incorporated into the transport equations and shown to impact intrinsic rotation, and therefore the self-consistent Er calculation.

*Prepared by LLNL under Contract DE-AC52-07NA27344 and the CSC (No. 201606060097).

**PP11 87 Ideal MHD Stability and Characteristics of Edge Localized Modes on CFETR**
ZEYU LI, Peking University VINCENT CHAN, University of Science and Technology of China XUEQIAO XU, Lawrence Livermore National Laboratory XIAOGANG WANG, Harbin Institute of Technology CFETR PHYSICS TEAM
Investigation on the equilibrium operation regime, its ideal magnetohydrodynamics (MHD) stability and edge localized modes (ELM) characteristics is performed for China Fusion Engineering Test Reactor (CFETR). The CFETR operation regime study starts with a baseline scenario derived from multi-code integrated modeling, with key parameters varied to build a systematic database. These parameters, under profile and pedestal constraints, provide the foundation for engineering design. The linear stability relations of low- and intermediate-n peeling-balloonning modes for CFETR baseline scenario are analyzed. Multi-code benchmarking, including GATO, ELITE, BOUT++, and NIMROD, demonstrated good agreement in predicting instabilities. Nonlinear behavior of ELMS for the baseline scenario is simulated using BOUT++. Instabilities are found both at the pedestal top and inside the pedestal region, which lead to a mix of grassy and type-I ELMs. Pedestal structures extending inward beyond the pedestal top are also varied to study the influence on ELM characteristic. Preliminary results on the dependence of the Type-I ELM divertor heat load scaling on machine size and pedestal pressure will also be presented.

*Prepared by LLNL under Contract DE-AC52-07NA27344 and the National Magnetic Confinement Fusion Research Program of China (Grant No. 2014GB110003 and 2014GB107004).

**PP11 88 Simulation of the ELMS triggering by lithium pellet on EAST tokamak using BOUT++**
Y. M. WANG, X. Q. XU, LLNL Z. WANG, LANL Z. SUN, J. S. HU, X. GAO, ASIPP
A new lithium granule injector (LGI) was developed on EAST. Using the LGI, lithium granules can be efficiently injected into EAST tokamak with the granule radius 0.2-1 mm and the granules velocity ∼30-110 m/s. ELM pacing was realized during EAST shot #70123 at time window from 4.4-4.7s, the average velocity of the pellet was ∼75 m/s and the average injection rate is at ∼99Hz. The BOUT++ 6-field electromagnetic turbulence code has been used to simulate the ELM pacing process. A neutral gas sheathing (NGS) model has been implemented during the pellet ablation process. The neutral transport code is used to evaluate the ionized electron and Li ion densities with the charge exchange as a dominant factor in the neutral cloud diffusion process. The snapshot plasma profiles during the pellet ablation and toroidal symmetrization process are used in the 6-field turbulence code to evaluate the impact of the pellets on ELMs. Destabilizing effects of the peeling-balloonning modes are found with lithium pellet injection, which is consistent with the experimental results. A scan of the pellet size, shape and the injection velocity will be conducted, which will benefit the pellet injection design in both the present and future devices.

*Prepared by LLNL under Contract DE-AC52-07NA27344 and this work is supported by the National Natural Science Foundation of China (Grant No. 11505221) and China Scholarship Council (Grant No. 201504910132).

**PP11 89 Simulation comparison of EHO state and broadband MHD phase in near-zero torque QH-mode on DIII-D**
JINGGUO CHEN, PKU XUEQIAO XU, LLNL KEITH BURRELL, XI CHEN, GA
A DIII-D QH-mode discharge (#163518), with NBI toroidal reduced to near zero, exhibits a spontaneous transition from coherent edge-harmonic oscillation (EHO) phase to broadband MHD turbulence state with improved pedestal conditions recently. Simulations are carried out to study the features and the mechanism of both EHO state and broadband MHD phase in QH-mode by using the 6-field two-fluid model in BOUT++ framework. The double null equilibrium and plasma profiles from the DIII-D low-torque QH-mode discharge #163518 at t=2.350ms (EHO state) and t=3.130ms (broadband MHD state) are adopted in the simulations. The linear simulation results demonstrate that the ExB shear flow is the main driving factor of the low-n MHD instabilities and can destabilize the low-n modes which are dominant during this QH-mode discharge. In nonlinear simulation, the intermediate-n (6-12) modes are excited first in the early linear stage and then the low-n modes develop by inverse cascade. The toroidal mode n=1 becomes dominant in the nonlinear saturated phase. The analysis of heat and particle fluxes and frequency spectra in nonlinear simulations is also presented.

*Prepared by LLNL under Contract DE-AC52-07NA27344, Work supported by US DOE under DE-FC02-04ER54698, the CSC (No. 2011606060047), the ITER-China Program (2013GB110000, 2013GB112006), and the NSFC (11261140326, 11375053).

**PP11 90 Impurity migration pattern under RF sheath potential in tokamak and the response of Plasma to RMP**
XIAOTAO XIAO, BIN GUI, TIANYANG XIA, ASIPP XUEQIAO XU, LLNL YOUWEN SUN, ASIPP
The migration pattern of impurities sputtered from RF guarder limiter, is simulated by a test particle module. The electric potential with RF sheath boundary condition on the guard limiter and the thermal sheath boundary condition on the divertor surface are used. The turbulence transport is implemented by random walk model. It is found the RF sheath potential enhances the impurity percentage lost at low filed side middle plane, and decreases impurity percentage drifting into core region. This beneficial effect is stronger when sheath potential is large. When turbulence transport is strong enough, their migration pattern will be dominated by transport, not by sheath potential. The Resonant Magnetic field Perturbation (RMP) is successfully applied in EAST experiment and the suppression and mitigation effect on ELM is obtained. A two field fluid model is used to simulate the plasma response to RMP in EAST geometry. The current sheet on the resonance surface is obtained initially and the resonant component of radial magnetic field is suppressed there. With plasma rotation, the Alven resonance occurs and the current is separated into two current sheets. The simulation result will be integrated with the ELM simulations to study the effects of RMP on ELM.
**PP11 91 Magnetic perturbations at the plasma edge due to Scrape Off Layer currents**
LEONID ZAKHAROV, LiWFusion

While most of fusion community which considers the temperature pedestal region as a mysterious “Edge Transport Barrier”, the author dismisses this notion and its “explanations”. Instead, the temperature of the pedestal represents the boundary condition determined by the ratio of the total heat flux from a plasma component to the particle flux. One of the straightforward results of this understanding is that the level of the pedestal temperature is unshakable by perturbations of transport properties at the edge, what was confirmed unambiguously by RMP experiments on DIII-D in 2005 and in all following experiments. In the other hand, I consider the width of the pedestal determined by destruction of 2-D magnetic configuration at the plasma edge, and the Scrape Off Layer (SOL) currents considered as a primary source of perturbation. The numerical simulations of their effect are presented.

*Partially supported by Tri Alpha Energy, Inc.*

**PP11 92 FLIT: Flowing Liquid metal Torus**
EGEMEN KOLEMEN, Princeton University
RICHAID MAJE SKI, RAJESH MAINGI, PPPL

The design and construction of FLIT, Flowing Liquid Torus, at PPPL is presented. FLIT focuses on a liquid metal divertor system suitable for implementation and testing in present-day fusion systems, such as NSTX-U. It is designed as a proof-of-concept fast-flowing liquid metal divertor that can handle heat flux of 10 MW/m2 without an additional cooling system. The 72 cm wide by 107 cm tall torus system consisting of 12 rectangular coils that give 1 Tesla magnetic field in the center and it can operate for greater than 10 seconds at this field. Initially, 30 gallons Galinstan (Ga-In-Sn) will be recirculated using 6 jxB pumps and flow velocities of up to 10 m/s will be achieved on the fully annular divertor plate. FLIT is designed as a flexible machine that will allow experimental testing of various liquid metal injection techniques, study of flow instabilities, and their control in order to prove the feasibility of liquid metal divertor concept for fusion reactors.

*FLIT: Flowing Liquid metal Torus. This work is supported by the US DOE Contract No. DE-AC02-09CH11466.*

**PP11 93 Effects of externally applied Lorentz force on liquid metal flow**
ADAM FISHER, EGEMEN KOLEMEN, MIKE HVASTA, Princeton University

This work looks at methods of controlling liquid metal flows using externally induced Lorentz forces. Large fusion reactors face an unsolved issue of heat fluxes at the divertor causing reactor damage. Fast-flowing liquid metal divertors can solve the heat flux problem, but to be viable there are various unfavorable flow phenomena that need to be suppressed and controlled. Some of those studied here are hydraulic jumps and surface waves. Externally induced Lorentz forces may be created by injecting electric currents into a liquid metal flow immersed within a magnetic field. Uniform Lorentz forces aligned with gravity work nearly analogously to changing gravity, and as such any flow features driven or affected by gravity may experience changes. As Lorentz force is dependent on current density which can be highly variant as cross-sectional flow depth changes, a non-uniform force field is created that is mostly unique to these types of flows; non-uniform magnetic fields yield similar effects. Lorentz force has been historically used as a driving force in pump applications, but little has been done in the way of flow control. The experiments in this work are galinstan channel flows that investigate the effects that Lorentz force has on hydraulic jump features and surface waves.

**PP11 94 Study of Lithium Vapor Flow In a Detached Divertor using DSMC code**
ERIC EMDEE, JACOB SCHWARTZ, ROBERT GOLDSTON, MICHAEL JAWORSKI, Princeton Plasma Phys Lab

A detached divertor is predicted to be necessary to handle the heat fluxes of a demonstration fusion power plant [1]. The lithium vapor box divertor has poloidal baffles to form distinct chambers and contains dense lithium vapor to cause detachment. These chambers would be differentially pumped via condensation, resulting in flow at Knudsen numbers 0.01-0.5 and densities $10^{19}$-$10^{23}$ m$^{-3}$. This divertor geometry is predicted to handle the estimated heat flux while also localizing the vapor in the divertor [2]. We provide a simulation of the divertor’s lithium vapor flow using the SPARTA Direct Simulation Monte Carlo (DSMC) code [3]. Lithium mass flow, vapor pressures, and temperatures within each chamber are given. Preliminary simulations of a vapor box divertor similarity experiment are within 30% of an ideal-gas choked nozzle flow calculation.

*This work supported by DOE Contract No. DE-AC02-09CH11466.*


**PP11 95 Design and construction of a lithium vapor box divertor similarity experiment**
J. A. SCHWARTZ, Princeton Plasma Physics Laboratory

Future fusion devices will require handling extreme heat fluxes. The lithium vapor box divertor is a concept to manage this heat flux. The divertor plasma impinges on a dense cloud of lithium vapor, leading to volumetric cooling, radiation, and recombination. The vapor is localized by baffles and condensation on the divertor slot walls upstream of the target, limiting the lithium reaching the main chamber. A series of test stand experiments will study vapor confinement and plasma plugging in a simplified baffled-pipe geometry. A first experiment without plasma will validate a DSMC model for evaporation, flow, and condensation of lithium vapor. Three stainless steel cylindrical cans will be heated to 550C, 600C, and 650C respectively inside a vacuum chamber. Lithium flow will be measured by weighing the cans before and after heating and by calorimetry of the latent heat of the vapor. Progress on the experiment will be presented.

*This work supported by DOE Contract No. DE-AC02-09CH11466.*

**PP11 96 DIRECT, INDIRECT AND POLAR-DRIVE**

**PP11 97 3D Laser Imprint Using a Smoother Ray-Traced Power Deposition Method**
ANDREW J. SCHMITT, Plasma Physics Division, Naval Research Laboratory, Washington DC

Imprinting of laser nonuniformities in directly-driven icf targets is a challenging problem to accurately simulate with large radiation-hydro codes. One of the most challenging aspects is the proper construction of the complex and rapidly changing laser interference structure driving the imprint using the reduced laser propagation models (usually ray-tracing) found in these codes. We have upgraded the modelling
capability in our massively-parallel FASTRAD3D code by adding a more realistic EM-wave interference structure. This interference model adds an axial laser speckle to the previous transverse-only laser structure, and can be impressed on our improved smoothed 3D raytrace package. This latter package, which connects rays to form bundles and performs power deposition calculations on the bundles, is intended to decrease ray-trace noise (which can mask or add to imprint) while using fewer rays. We apply this improved model to 3D simulations of recent imprint experiments performed on the Omega-EP laser and the Nike laser that examined the reduction of imprinting due to very thin high-Z target coatings. We report on the conditions in which this new model makes a significant impact on the development of laser imprint.

*Supported by US DoE/NNSA.

**PP11 98 Re-examining the effect of low and intermediate mode number perturbations on Ignition Metrics Scaling Laws** ELAD MALKA, Nuclear Research Center-Negev, Israel DOV SHVARTS, University of Michigan, Nuclear Research Center-Negev, Israel We re-examine the way 2/3D effects on scaling laws for ignition metrics, such as the generalized Lawson Criterion (GLC) and the Ignition Threshold Factor (ITF). These scaling laws were derived for 1D symmetrical case and 2/3D perturbations [Hann et al. PoP 2010; Lindl et al., PoP 2014; Betti et al., PoP 2010]. The main cause for the difference between the 1D and the 2/3D scaling laws in those works, is heat conduction losses from the hot-spot bubbles to the cold shell [Kishony and Shvarts, PoP 2001]. This “dry out” of the bubbles is the dominant mechanism for intermediate mode number perturbations (6 < l < 40) and can be described as an effective 1D implosion. However, for low mode number perturbations (l ≤ 6), heat conduction loss does not fully “dry out” the bubbles and an additional mechanism- residual kinetic energy (RKE) [Kirtcher PoP 2014; Gu et al., PoP 2014] does reduce the hydrodynamic coupling efficiency from the imploding cold shell to the hot spot. These two effects do not have an effective 1D analogue and therefore needs a more complicated model. A consistent extension of the ignition metrics for l ≤ 6, accounting for both energy loss mechanisms, will be presented and compared with previous models and results.

*This work was supported by the LLNL under subcontract B614207.

**PP11 99 Hybrid transport and diffusion modeling using electron transport Monte Carlo SNB in DRACO** JEFFREY CHENHALL, GREGORY MOSES, Univ of Wisconsin, Madison The iSNB (implicit Schurtz Nikolai Busquet [1,2]) multigroup diffusion electron transport method is adapted to an Electron Thermal Transport Monte Carlo (ETTMC) transport method to better model angular and long mean free path non-local effects. Previously, the ETTMC model had been implemented in the 2D DRACO multiphysics code and found to produce consistent results with the iSNB method [3]. Current work is focused on a hybridization of the computationally slower but higher fidelity ETTMC transport method with the computationally faster iSNB diffusion method in order to maximize computational efficiency. Furthermore, effects on the energy distribution of the heat flux divergence are studied. Work to date on the hybrid method will be presented.

*This work was supported by Sandia National Laboratories and the Univ. of Rochester Laboratory for Laser Energetics.

3Chenhall et al., BAPS DPP16 CP10.17 (2015).

**PP11 100 HEAVY ION FUSION**

**PP11 101 Radiation Damage in Si Diodes from Short, Intense Ion Pulses** S. J. DE LEON, Lawrence University, Appleton, WI 54911, USA B. A. LUDEWIGT, A. PERSAUD, P. A. SEIDL, T. SCHENKEL, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA The Neutralized Drift Compression Experiment (NDCX-II) at Berkeley Lab is an induction accelerator studying the effects that concentrated ion beams have on various materials. Charged particle radiation damage was the focus of this research—we have characterized a series of Si diodes using an electrometer and calibrated the diodes response using an 241Am alpha source, both before and after exposing the diodes to 1 MeV He ions in the accelerator. The key part here is that the high intensity pulses from NDCX-II (≥ 10^{18} ions/cm^2 per pulse in < 20 ns) enabled a systematic study of dose-rate effects. An example of a dose-rate effect in Si diodes is increased accumulation of defects due to damage from ions that bombard them in a short pulse. This accumulated damage leads to a reduction in the charge collection efficiency and an increase in leakage current. Testing dose-rate effects in Si diodes and other semiconductors is a crucial step in designing sustainable instruments that can encounter high doses of radiation, such as high intensity accelerators, fusion energy experiments and space applications and results from short pulses can inform models of radiation damage evolution.

*This work was supported by the Office of Science of the US Department of Energy under contract DE-AC0205CH11231.

**PP11 102 Instability growth seeded by ablator material inhomogeneity in indirect drive implosions on the National Ignition Facility** STEVEN HAAN, S.J. ALI, S.H. BAXAMUSA, PM. CELLIERS, D.S. CLARK, A.L. KIRCHTER, A. NIKROO, M. STADERMANN, J. BIENER, R. WALLACE, V. SMALYUK, H. ROBEY, C.R. WEBER, Lawrence Livermore National Lab H. HUANG, H. REYNOLDS, L. CARLSON, N. RICE, General Atomics J.L. KLINE, A.N. SIMAKOV, S.A. YL, Los Alamos National Lab NIF indirect drive ablators (CH, Be, and high density carbon HDC) show hydrodynamic irregularity beyond that expected from surface features. Characterizing these seeds and estimating their growth is important in projecting performance. The resulting modulations can be measured in x-ray backlight implosions on NIF called Hydro Growth Radiography [1], and on Omega with 2D velocimetry [2]. This presentation summarizes the experiments for the three abiators, along with simulations thereof and projections of the significance for NIF. For CH, dominant seeds are photo-induced oxidation, which might be mitigated with alumina coating. For Be, perturbations result from Ar and O contamination. For HDC, perturbations are seeded by shock propagation around melt, depend on shock strength, and may constrain the adiabat of future HDC implosions.

*Work performed under the auspices of the U.S. D.O.E. by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

PP11 103 HYDRODYNAMIC INSTABILITY

PP11 104 Preventing or exploiting turbulence during plasma compression* SETH DAVIDOVITS, NATHANIEL J. FISCH, Princeton University Inertial confinement fusion (ICF) and Z-pinch compressions may be turbulent to varying degrees. The turbulent kinetic energy (TKE) in turbulence undergoing compression can be amplified, if the compression time is fast compared to the dissipation time of the turbulence. By studying the behavior of plasma turbulence under compression, we propose ways of avoiding or exploiting turbulent growth. One possibility for exploiting turbulence during a compression occurs because of a recently discovered “sudden viscous dissipation” mechanism. The TKE, having been amplified during the compression, is suddenly dissipated by viscosity into thermal energy. This is possible in plasmas because of the strong dependence of the viscosity on the temperature, which grows during compression. By intentionally storing energy from the compression partly in TKE, which has different loss mechanisms than the thermal energy, and only converting the TKE into thermal energy late in the compression, energy losses may be reduced. Understanding the behavior of TKE under compression also allows us to predict compression trajectories, in rho-R vs. temperature space, where (bulk) turbulent growth will be suppressed. Contamination of hydrogen plasma with higher Z materials is shown to enhance turbulent growth.

*This work was supported by DOE through Contracts No. DE-AC02-09CH1-1466 and NNSA 67350-9960 (Prime # DOE DE-NA0001836), by DTRA HDTRA1-11-1-0037, and by NSF Contract No. PHY-1506122.

PP11 105 Kelvin-Helmholtz evolution in subsonic cold streams feeding galaxies* ADRIANNA ANGULO, S. COFFING, C. KURANZ, R.P. DRAKE, S. KLEIN, M. TRANTHAM, Univ of Michigan - Ann Arbor G. MALAMUD, Nuclear Research Center The most prolific star formers in cosmological history lie in a regime where dense filament structures carried substantial mass into the galaxy to sustain star formation without producing a shock. However, hydrodynamic instabilities present on the filament surface limit the ability of such structures to deliver dense matter deep enough to sustain star formation. Simulations lack the finite resolution necessary to allow fair treatment of the instabilities present at the stream boundary. Using the Omega EP laser, we simulate this mode of galaxy formation with a cold, dense, filament structure within a hotter, subsonic flow and observe the interface evolution. Machined surface perturbations stimulate the development of the Kelvin-Helmholtz (KH) instability due to the resultant shear between the two media. A spherical crystal imaging system produces high-resolution radiographs of the KH structures along the filament surface. The results from the first experiments of this kind, using a rod with single-mode, long-wavelength modulations, will be discussed.

*This work is funded by the U.S. Department of Energy, through the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, Grant Number DE-NA0002956, and the National Laser User Facility Program, Grant Number DE-NA0002719, and through.

PP11 106 Designing cylindrical implosion experiments on NIF to study deceleration phase of Rayleigh-Taylor N. VAZIRANI, Va. Tech, LANL J. L. KLINE, E. LOOMIS, J. P. SAUPPE, S. PALANIYAPPAN, K. FLIPPO, LANL B. SRINIVASAN, Va. Tech E. MALKA, NCRN A. BOSE, U. of Mich. D. SHVARTS, NCRN, U. of Mich. The Rayleigh-Taylor (RT) hydrodynamic instability occurs when a lower density fluid pushes on a higher density fluid. This occurs in inertial confinement fusion (ICF) implosions at each of the capsule interfaces during the initial acceleration and the deceleration as it stagnates. The RT instabilities mix capsule material into the fusion fuel degrading the Deuterium-Tritium reactivity and ultimately play a key role in limiting target performance. While significant effort has focused on understanding RT at the outer capsule surface, little work has gone into understanding the inner surface RT instability growth during the deceleration phase. Direct measurements of the RT instability are difficult to make at high convergence in a spherical implosion. Here we present the design of a cylindrical implosion system for the National Ignition Facility for studying deceleration phase RT. We will discuss the experimental design, the estimated instability growth, and our outstanding concerns.

PP11 107 Single-Mode Deceleration Stage Rayleigh-Taylor Instability Growth in Cylindrical Implosions* J. P. SAUPPE, S. PALANIYAPPAN, P. A. BRADLEY, S. H. BATHA, E. N. LOOMIS, J. L. KLINE, Los Alamos National Laboratory B. SRINIVASAN, Virginia Tech A. BOSE, University of Michigan E. MALKA, Nuclear Research Center-Negev D. SHVARTS, University of Michigan and Nuclear Research Center-Negev We present design calculations demonstrating the feasibility of measuring single-mode deceleration stage Rayleigh-Taylor instability (RTI) growth at a factor of four convergence. RTI growth rates are modified as a result of convergence [Bell LA-1321, 1951], and cylindrical targets are considered here, as they allow direct diagnostic access along the interface. The 2D computations, performed with the radiation-hydrodynamics code xRAGE [Gittings et al., CSD 2008] utilizing a new laser ray-tracking package, predict growth factors of 6 to 10 for mode 10 and 4 to 6 for mode 4, both of high interest in evaluating inertial confinement fusion capsule degradation mechanisms [Bose et al., this conference]. These results compare favorably to a linear theory [Epstein, PoP 2004] and to a buoyancy-drag model [Srebro et al., LPB 2003], which accounts for the linear and non-linear stages. Synthetic radiographs, produced by combining 2D computations of axial and transverse cross-sections, indicate this growth will be observable, and these will be compared to experimental data obtained at the OMEGA laser facility.


PP11 108 Modeling ICF With RAGE, BHR, And The New Laser Package DYLAN CLICHÉ, Univ of Nevada - Reno LESLIE WELSER-SHERRILL, BRIAN HAINES, Los Alamos National Laboratory ROBERTO MANCINI, Univ of Nevada - Reno Inertial Confinement Fusion (ICF) is one method used to obtain thermonuclear burn through the either direct or indirect ablation of a millimeter-scale capsule with several lasers. Although progress has been made in theory, experiment, and diagnostics, the community has yet to reach ignition. A way of investigating this is through the use of high performance computer simulations of the implosion. RAGE is an advanced 1D, 2D, and 3D radiation adaptive grid Eulerian code used to simulate hydrodynamics of a system. Due to the unstable nature of two unequal densities accelerating into one another, it is important to include a turbulence model. BHR is a turbulence model which uses Reynolds-averaged Navier-Stokes (RANS) equations to model the mixing that occurs between the shell and fusion fuel material. Until recently, it was still difficult to
model direct drive experiments because there was no laser energy deposition model in RAGE. Recently, a new laser energy deposition model has been implemented using the same ray tracing method as the Mazinissin laser package used at the OMEGA laser facility at the Laboratory for Laser Energetics (LLF) in Rochester, New York. Using the new laser package along with BHR for mixing allows us to more accurately simulate ICF implosions and obtain spatially and temporally resolved information (e.g. position, temperature, density, and mix concentrations) to give insight into what is happening inside the implosion.

PP11 109 BASIC PLASMAS

PP11 110 Observation of the effects of stronger magnetic fields on warm, higher energy electrons and ion beams transiting a double layer in a helicon plasma∗ JOHN SCHARER, YUNG-TA SUNG, YAN LI, University of Wisconsin, Madison
Fast, two-temperature electrons (>80 eV, Te=13 eV tail, 4 eV bulk) with substantial tail density fractions are created at low (<=1.7 mtorr) Ar pressure @ 340 G in the antenna region with nozzle mirror ratio of 1.4 on MadHeX @ 900W. These distributions including a fast tail are observed upstream of a double layer. The fast, untrapped tail electrons measured downstream of the double layer have a higher temperature of 13 eV than the trapped, upstream electrons of 4 eV temperature. Upstream plasma potential fluctuations of +−30 percent are observed. An RF-compensated Langmuir probe is used to measure the electron temperatures and densities and OES, mm wave cent are observed. An RF-compensated Langmuir probe is used to measure the electron temperatures and densities and OES, mm wave.

PP11 111 Linear analysis of obliquely propagating longitudinal waves in partially spin polarized degenerated magnetized plasma ZAFAR IQBAL, GHALAM MURTAZA, Department of Physics G C University, Lahore, Pakistan
Linear analysis of obliquely propagating longitudinal waves in partially spin polarized degenerate magnetized plasma Linear analysis of low frequency obliquely propagating electrostatic waves in a partially spin polarized degenerate magnetized plasma is presented. Using Fourier analysis, a general linear dispersion relation is derived for low frequency electrostatic lower hybrid (LH) wave, ion acoustic (IA) wave and ion cyclotron (IC) wave in the presence of electron spin polarization. It is found that the electron spin polarization gives birth to a new spin-dependent wave (spin electron acoustic wave) in the spectrum of these waves. Further, the electron spin polarization also causes drastic shifts in the frequency spectrum of these waves. These effects would have a strong bearing on wave phenomena in degenerate astrophysical fluids.

PP11 112 New Frontier Science Campaign on DIII-D launched in 2017 M KOEPKE, WVU R BUTTERY, GA T CARTER, UCLA

PP11 113 Formation and Evolution of Target Patterns in Cahn-Hilliard Flows: An Extension of the Flux Expulsion Studies in MHD∗ XIAN FAN, Univ of California - San Diego P H DIAMOND COLLABORATION, LUIS CHACON COLLABORATION
Spinodal decomposition is a second order phase transition for a binary liquid mixture to evolve from a miscible phase (e.g., water + alcohol) to two co-existing phases (e.g., water + oil). The Cahn-Hilliard model for spinodal decomposition is analogous to 2D MHD. We study the evolution of the concentration field in a single eddy in the 2D Cahn-Hilliard system to better understand scalar mixing processes in that system. This study extends investigations of the classic studies of flux expulsion in 2D MHD and homogenization of potential vorticity in 2D fluids. Simulation results show that there are three stages in the evolution: (A) formation of a “jelly roll” pattern, for which the concentration field is constant along spirals; (B) a change in isoconcentration contour topology; and (C) formation of a target pattern, for which the isoconcentration contours follow concentric annuli. In the final target pattern stage, the isoconcentration bands align with stream lines. The results indicate that the target pattern is a metastable state. Band merger process continues on a time scale exponentially long relative to the eddy turnover time. The band merger process resembles stick merger in drift-ZF staircases.

PP11 114 Harmonics generation near ion-cyclotron frequency of ECR plasma∗ SATYAJIT CHOWDHURY, Saha Inst of Nucl Phys SUBIR BISWAS, Weizmann Institute of Science NIKhil CHAKRABARTI, RABINDRANATH PAL, Saha Inst of Nucl Phys Wave excitation at different frequency regime is employed in the MaPLe device ECR plasma [1] for varied excitation amplitude. At very low amplitude excitation, mainly fundamental frequency mode of the exciting signal frequency comes into play. With the increase...
in amplitude of applied perturbation, harmonics are generated and dominant over the fundamental frequency mode. There is a fixed critical amplitude of exciter to yield the harmonics and is independent of applied frequency. Observed harmonics and the main frequency mode has propagation characteristics and are discussed here. Exact mode number and propagation nature are also tried to measure in the experiment. Detailed experimental results will be presented.

*Department of Science and Technology of Government of India (Project No. SB/S2/HEP-005/2014).


PP11 115 Ion Acceleration by Double Layers with Multi-Component Ion Species* TIMOTHY GOOD, Gettysburg College, Department of Physics EVAN AGUIRRE, EARL SCIME, West Virginia University, Department of Physics and Astronomy WEST VIRGINIA UNIVERSITY TEAM Current-free double layers (CFDL) models have been proposed to explain observations of magnetic field-aligned ion acceleration in plasmas expanding into divergent magnetic field regions. More recently, experimental studies of the Bohm sheath criterion in multiple ion species plasma reveal an equilibrium of Bohm speeds at the sheath-presheath boundary for a grounded plate in a multi-pole-confined filament discharge [1]. We aim to test this ion velocity effect for CFDL acceleration. We report high resolution ion velocity distribution function (IVDF) measurements using laser induced fluorescence downstream of a CFDL in a helium plasma. Combinations of argon-helium, argon-krypton, and argon-xenon gases are ionized and measurements of argon or xenon IVDFs are investigated to determine whether ion acceleration is enhanced (or diminished) by the presence of lighter (or heavier) ions in the mix. We find that the predominant effect is a reduction of ion acceleration consistent with increased drag arising from increased gas pressure under all conditions, including constant total gas pressure, equal plasma densities of different ions, and very different plasma densities of different ions. These results suggest that the physics responsible for acceleration of multiple ion species in simple sheaths is not responsible for the ion acceleration observed in these expanding plasmas.

*Department of Physics, Gettysburg College.


PP11 116 Gauge-free gyrokinetic theory* JOSHUA BURBY, Courant Institute ALAIN BRIZARD, Saint Michael’s College Test-particle gyrocenter equations of motion play an essential role in the diagnosis of turbulent strongly-magnetized plasmas, and are playing an increasingly-important role in the formulation of kinetic-gyrokinetic hybrid models. Previous gyrocenter models required the knowledge of the perturbed electromagnetic potentials, which are not directly observable quantities (since they are gauge-dependent). A new gauge-free formulation of gyrocenter motion is presented, which enables gyrocenter trajectories to be determined using only measured values of the directly-observable electromagnetic field. Our gauge-free gyrokinetic theory is general enough to allow for gyroradius-scale fluctuations in both the electric and magnetic field. In addition, we provide gauge-free expressions for the charge and current densities produced by a distribution of gyrocenters, which explicitly include guiding-center and gyrocenter polarization and magnetization effects.

*This research was supported by the U.S. DOE Contract Nos. DE-SC0014032 (AB) and DE-AC05-06OR23100 (JB).

PP11 117 Magnetic pumping as a source of particle heating* EMILY LICHKO, JAN EGEDAL, University of Wisconsin - Madison WILLIAM DAUGHTON, Los Alamos National Laboratory JUSTIN KASPER, University of Michigan Magnetic pumping is a means of heating plasmas for both fusion and astrophysical applications. In this study a magnetic pumping model is developed as a possible explanation for the heating and the generation of power-law distribution functions observed in the solar wind plasma. In most previous studies turbulent energy is only dissipated at microscopic kinetic scales. In contrast, magnetic pumping energizes the particles through the largest scale turbulent fluctuations, thus bypassing the energy cascade. Kinetic simulations are applied to verify these analytic predictions. Previous results for the one-dimensional model, as well as initial results for a two-dimensional model which includes the effects of trapped and passing particles are presented. Preliminary results of the presence of this mechanism in the bow shock region, using spacecraft data from the Magnetospheric Multiscale mission, are presented as well.

*This research was conducted with support from National Defense Science and Engineering Graduate (NDSEG) Fellowship, 32 CFR 168, as well as from NSF Award 1404166 and NASA award NNX15AJ73G.

PP11 118 Vlasov simulation of high energy electron tail formation in the presence of Langmuir solitons Y. NISHIMURA, Institute of Space and Plasma Sciences, National Cheng Kung University By an electrostatic Vlasov simulation [1], generation mechanism of high energy electron tails in the presence of Langmuir solitons is studied. The resultant electron distribution function resembles that of the Lorentzian type observed in solar wind plasmas. The particle acceleration is discussed as a transport process toward high energy side due to overlapping of multiple resonant islands in the phase space. After the dumping of specific Fourier modes (by the wave-particle interaction), and thus shrinkage of the resonant islands, the transport across the islands is prohibited. Role of inhomogeneous background density [2] which gives rise to acceleration toward the low density side is discussed employing the kinetic model.


PP11 119 Route to Chaos due to ion sheath oscillations observed in plasma bubble* MARIAMMAL MEGALINGAM, BORNALI SARMA, ARUN SARMA, VIT University Chennai Campus The report is intended to investigate experimentally nonlinear behavior of fluctuations in current carrying unstable plasma and compared with the theory that describes ion dynamics in the sheath and pre-sheath region. Plasma bubbles are created in bulk plasma by negatively biased spherical mesh grid of 80% optical transparency inserted in bulk plasma of the system. Argon plasma is produced in cylindrical chamber of 350 mm in length and 400 mm in diameter by hot cathode filament discharge method. The spherical mesh grid can congregate the particles from the plasma radially in presence or absence of biasing. A virtual anode structure has formed around the bubble when all electrons are reflected. A radially movable Langmuir and emissive probe are used to measure basic parameters. Sheath instability inside the bubble has observed, there appears regime of quasi-periodicity with various frequencies. Scanning has done throughout the bubble to understand fluctuations and its asso-
correlated instabilities. These instabilities are leading to chaos through a region of quasi-period to period doubling at different positions inside the bubble. Experimentally observed ion sheath oscillations are confirmed with some theoretical analysis

*The authors would like to thank Indian Space Research Organisation (ISRO) for their Grant and support.

PP11 120 Inverse Bremsstrahlung momentum absorption and current drive\(^*\) VADIM MUNIROV, NATHANIEL FISCH, Princeton Univ The generation of the plasma current resulting from Bremsstrahlung absorption is considered. It is shown that the electric current is higher than the naive estimates assuming that electrons absorb only the photon momentum and using the Spitzer conductivity would suggest, both because electrons get the recoil momentum from the Coulomb field of ions during the absorption and because electrons absorb power asymmetrically, which leads to the current drive effect.

*Work is supported by DOE Contract No. DE-AC02-09CH1-1466.

PP11 121 Asymmetry Velocity Distribution Function and Its Higher Order Moments in an Inhomogeneous ECR Plasma\(^*\) KENICHIRO TERASAKA, Kyushu University SHINJI YOSHIMURA, National Institute for Fusion Science MITSUTOSHI ARAMAKI, Nihon University MASAYOSHI Y. TANAKA, Kyushu University Laser induced fluorescence spectroscopy (LIF) has been recognized to be a powerful diagnostic tool to directly obtain velocity distribution function. A neutral depletions structure with strong inhomogeneity of density has been observed in an ECR plasma of the HYPER-I device at NIFS. A high-resolution LIF system, which consists of an external cavity diode laser, has been used to measure the LIF spectrum (velocity distribution function) with velocity component parallel and perpendicular to the density gradient. It is found that the distribution function of the radial velocity (parallel to the density gradient) is asymmetry in the inhomogeneous density region. To quantitatively characterize the asymmetry of distribution function, the higher order velocity moments, i.e., skewness (third order moment) and kurtosis (fourth order moment), are evaluated. It is found that the skewness of distribution function is proportional to the inhomogeneity induced flow, and a simple relation between the skewness and the normalized flow velocity, \(u_{\text{flow}}/v_{\text{ce}} = -S/3\), is obtained [1]. The experimental results indicate the skewness has is a fundamental quantity to characterize the flow induced by inhomogeneity of system.

This work was supported by JSPS KAKENHI Grant Number JP17K14425.


PP11 122 A Particle-in-Cell simulation of temporal plasma echo in the presence of Coulomb collisions B.Z. WU, Y. NISHIMURA, C.P. WANG, National Cheng Kang University Particle-in-Cell simulation is developed to study temporal plasma echo of electron plasma wave. By imposing two external pulse electric fields to the plasma (pulse-like in time) [1] the echo signal is observed. Coulomb collisional effect manifests itself as a shift of the echo peak and the damping of the peak amplitude, [2] which can be seen by adding (rather phenomenological) frictional force to the electron equation of motion. A first principle based binary collision model [3] is incorporated into the numerical simulation.


PP11 123 Self-consistent Simulation of Microparticle and Ion Wakefield Configuration\(^*\) DUSTIN SANFORD, BEAU BROOKS, NAOKI ELLIS, LORIN MATTHEWS, TRUELL HYDE, CASPER, Baylor University In a complex plasma, positively charged ions often have a directed flow with respect to the negatively charged dust grains. The resulting interaction between the dust and the flowing plasma creates an ion wakefield downstream from the dust particles, with the resulting positive space region modifying the interaction between the grains and contributing to the observed dynamics and equilibrium structure of the system. Here we present a proof of concept method that uses a molecular dynamics simulation to model the ion wakefield allowing the dynamics of the dust particles to be determined self-consistently. The trajectory of each ion is calculated including the forces from all other ions, which are treated as “Yukawa particles” and shielded from thermal electrons and the forces of the charged dust particles. Both the dust grain charge and the wakefield structure are also self-consistently determined for various particle configurations. The resultant wakefield potentials are then used to provide dynamic simulations of dust particle pairs. These results will be employed to analyze the formation and dynamics of field-aligned chains in CASPER’s PK4 experiment onboard the International Space Station, allowing examination of extended dust chains without the masking force of gravity.

*This work was supported by the National Science Foundation under Grants PHY-1414523 and PHY-1740203.

PP11 124 Characterization of quasi-free-space microwave-driven argon plasmas\(^*\) ADRIAN LOPEZ, University of Michigan REMINGTON REID, Air Force Research Laboratory, Kirtland AFB The Air Force Research Laboratory is interested in studying the interaction of high power electromagnetic waves with plasmas. A multi-kW, 5GHz microwave system is used for generating quasi-free-space microwave-driven argon plasma at pressures ranging from 150 to 200 mTorr. In previous experiments, two general configurations of sustainable quasi-free-space plasma discharges were observed using this system but were never fully characterized. Using a Triple Langmuir Probe (TLP) system, the electron temperature and density of these two observed configurations are measured as they change through time. In addition, a translation stage allows for TLP measurements to be taken in different regions of the generated plasma.

*Research supported by the Air Force Research Laboratory.

PP11 125 Impact of Gas Chemistry on Free-Space Mircrowave Driven Plasmas REMINGTON REID, Air Force Res-Lab-Kirtland ADRIAN LOPEZ, PAUL LEPELL, Leidos The United States Air Force is studying the properties of plasmas sustained using focused microwave beams in free-space. While we have previously demonstrated the possibility to sustain these plasmas indefinitely the plasmas have been found to be unstable across a wide parameter space. The plasma stability has been shown to depend critically on the compositions of the background gas, however to date these results have been poorly quantified. A new precision gas flow system enables us to control the composition of the background gas. We will report on our efforts to quantify the effect of background gas composition on the plasma stability.

PP11 126 Constructing current singularity in a 3D line-tied plasma YAO ZHOU, YI-MIN HUANG, HONG QIN, AMITA BHATTACHARJEE, Princeton University We revisit Parker’s con-
LPI can generate keV to MeV ions, which can undergo fusion reactions due to increasing demand for fast neutrons, there have been many efforts to generate neutrons using Laser Plasma Interactions (LPI). LPI can generate keV to MeV ions, which can undergo fusion reactions. Here, we use a 5-15mJ, 35fs laser operating at 1kHz, to accelerate deuterons from a 20 μm D2O stream. These deuterons collide with cold deuterons in the heavy water stream and the low density D2O vapor yielding 2.45MeV fusion neutrons. From the hydrogen capture peak (2.22MeV) recorded by a HPGe detector, we calculate a flux of 2x10^5 n/s. In addition, the ^73Ge(n, γ) peak on the HPGe detector and nToF analysis confirm the generation of neutrons. Plasma expansion generated by intentional laser pre-pulses boosts the laser absorption efficiency, giving 10 times higher neutron flux compared to ‘clean’ interactions. 2D particle-in-cell simulations show that deuterons are accelerated forward, in the laser propagation direction, and backward in comparable numbers. But, the backward moving deuterons interacting with the low-density gas/plasma are the main contributors to fusion neutrons. Further experiments with background helium should isolate the region of fusion reactions by stopping backward traveling ions.

*Air Force Office of Scientific Research under Award No. FA9550-14-1-0282.

PP11 128 Modeling of flow-dominated MHD instabilities at WIPPAL using NIMROD* K. FLANAGAN, K.J. MCCOLLAM, J. MILHONE, V.V. MIRNOV, M.D. NORNBERG, E.E. PETERSON, R. SILLER, C.B. FOREST, University of Wisconsin-Madison Using the NIMROD (non-ideal MHD with rotation - open discussion) code developed at UW-Madison, we model two different flow scenarios to study the onset of MHD instabilities in flow-dominated plasmas in the Big Red Ball (BRB) and the Plasma Couette Experiment (PCE). Both flows rely on volumetric current drive, where a large current is drawn through the plasma across a weak magnetic field, injecting J × B torque across the whole volume. The first scenario uses a vertical applied magnetic field and a mostly radial injected current to create Couette-like flows which may excite the magnetorotational instability (MRI). In the other scenario, a quadrupolar field is applied to create counter-rotating von Karman-like flow that demonstrates a dynamo-like instability. For both scenarios, the differences between Hall and MHD Ohm’s laws are explored. The implementation of BRB geometry in NIMROD, details of the observed flows, and instability results are shown.

*This work was funded by DoE and NSF.

PP11 129 Equilibrium and stability of flow-dominated Plasmas in the Big Red Ball* ROBERT SILLER, KENNETH FLANAGAN, ETHAN PETERSON, JASON MILHONE, VLADIMIR MIRNOV, CARY FOREST, University of Wisconsin, Madison The equilibrium and linear stability of flow-dominated plasmas are studied numerically using a spectral techniques to model MRI and dynamo experiments in the Big Red Ball device. The equilibrium code solves for steady-state magnetic fields and plasma flows subject to boundary conditions in a spherical domain. It has been benchmarked with NIMROD (non-ideal MHD with rotation - open discussion), Two different flow scenarios are studied. The first scenario creates a differentially rotating toroidal flow that is peaked at the center. This is done to explore the onset of the magnetorotational instability (MRI) in a spherical geometry. The second scenario creates a counter-rotating von Karman-like flow in the presence of a weak magnetic field. This is done to explore the plasma dynamo instability in the limit of a weak applied field. Both scenarios are numerically modeled as axisymmetric flow to create a steady-state equilibrium solution, the stability and normal modes are studied in the lowest toroidal mode number. The details of the observed flow, and the structure of the fastest growing modes will be shown.

*DoE, NSF.

PP11 130 Classical Impurity Transport: New Effects in High-Beta, Anisotropic, and Rotating 1D Systems* IAN OCHS, ELIJAH KOLMES, NATHANIEL FISCH, Princeton University The classical impurity pinch arises from the Braginskii and diamagnetic frictional forces between high-Z impurities and low-Z ions, and leads to the well-known result that peaked temperature profiles can flush impurities that will otherwise accumulate in the plasma core [1]. However, in high-beta systems, or systems with field line curvature, grad-B and curvature drifts will also influence the impurity transport. We analyze the impurity pinch with these drifts added, in the simple context of a screw pinch with constant rotational transformation. We find that high plasma beta tends to help flush impurities, while a large rotational transform tends to cause impurities to accumulate in the plasma core. Extensions to anisotropic temperature distributions and the rotating screw pinch are discussed. The results are relevant for tokamaks at large aspect ratio, magnetized liner fusion, and the newly-proposed wave-driven rotating torus (WDRT) fusion concept [2].

*This work is supported by DOE Grants DE-SC0016072 and DE-FG02-97ER25308.


PP11 131 Investigating the Formation and Sub-Structure of Unmagnetized Collisionless Shocks* DOUGLASS ENDRIZZI, Univ of Wisconsin, Madison J. EGEDAL, C. FOREST, S. GREESS, A. MILLET-AYALA, J. OLSON, A. READY, R. WALEFFE, Univ of Wisconsin-Madison H. GOTA, TriAlphaEnergy Collisionless shocks, where the shock thickness is much smaller than the collisional mean free path, are ubiquitous astrophysical phenomena. In all shocks, the Rankine-Hugoniot jump conditions are satisfied through entropy generation at the interface; the shock propagation angle with respect to the magnetic field affects the mechanism by which this entropy is generated. Two experiments on the Big Red Ball (BRB) at UW-Madison explored the formation mechanisms of...
parallel and perpendicular, un magnetized and magnetized collisional shocks with large ($1 - 3$ m) system sizes. In the first experiment, a 1 m diameter theta-pinch drove a supersonic ($3 < M < 4$) compressive flow perpendicular to the background magnetic field. In the second, a compact toroid (cice TriAlpha) was fired supersonically ($4 < M < 5$) parallel to the background magnetic field. Triple, Langmuir, emissive, and magnetic probes were used to measure electron density, temperature, plasma potential, and fluctuations in magnetic fields. Results showing the transition from above to below $M = 1$, measurements of electron precursors, exploration of subshock structure, evidence of instabilities in the shock formation process, and future work will be presented.

*This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE 1256259.

PP11 132 Dust growth under different plasma conditions in protoplanetary disks∗ CHUCHU XIAO, LORIN MATTHEWS, AUGUSTO CARBALLIDO, TRUELL HYDE, Baylor University Coagulation of dust aggregates plays an important role in the formation of planets and the evolution of protoplanetary disks. As cosmic dust becomes charged in the radiative plasma environment, the trajectories of colliding dust grains can be altered by the electrostatic force acting between them, affecting their coagulation probability. This study compares the dust growth in protoplanetary disks with different turbulence strengths and different plasma conditions, i.e. the ratio of free electrons to free ions. A Monte Carlo approach with a simple kernel based on the radius of the grains is used to choose potential colliding pairs and calculate the elapsed time between collisions. The actual collision outcome is determined using a detailed model of the collision which takes into account the aggregate morphology, trajectory, orientation, and all forces acting on the colliding grains. A statistical analysis of the collision outcomes is used to determine collision probability as well as the physical characteristics of the resulting aggregates for both charged and uncharged grains. Preliminary results show that charged aggregates tend to be more porous than neutral particles, and more highly charged particles experience less restructuring as a result of gentler collisions. In regions with weak turbulence, both the collision rate and the number of bouncing collisions are lower for highly charged grains, and the probability of hit-and-stick collisions leading to aggregate growth is a balance of the collision and bouncing rates.

*This work was supported by the National Science Foundation under Grant PHY-1414523.

PP11 133 Heat capacity of spinning plasma∗ V.I. GEYKO, N.J. FISCH, Princeton University Equilibrium thermodynamics properties, such as heat capacity and adiabatic axial and radial compressibility of a rotating plasma column are studied. These properties depend on rotation speed, charge density, external magnetic field strength and electron-ion mass ratio. Plasma rotation serves as an additional energy storage, hence, yields to increased heat capacity. It also leads to charge separation that changes plasma density distribution due to electrostatic interaction and Lorentz force and therefore modifies thermodynamic properties. The obtained results can provide limits and optimal regimes for radial compression of z-pinch type structures and optimize energy deposition profile.

*This work was supported by NNSA DE-NA0001836 and DE-NA0002948 and by NSF Contract No. PHY-1506122.

PP11 134 The breakdown of the weakly-nonlinear regime for kinetic instabilities DAVID SANZ-OROZCO, University of Tampa HERBERT BERK, Univ of Texas, Austin GE WANG, University of Texas at Austin The evolution of marginally-unstable waves that interact resonantly with populations of energetic particles is governed by a well-known cubic integro-differential equation for the mode amplitude. One of the outcomes predicted by the equation is the so-called “explosive” regime, where the amplitude grows indefinitely, eventually taking the equation outside of its domain of validity. Beyond this point, only full Vlasov simulations will accurately describe the evolution of the mode amplitude. In this work, we study the breakdown of the cubic equation in detail. We find that, while the cubic equation is still valid, the distribution function of the energetic particles locally flattens or “folds” in phase space. This feature is unexpected in view of the assumptions of the theory that are given in. We also derive fifth-order terms in the wave equation, which not only give us a more accurate description of the marginally-unstable modes, but they also allow us to predict the breakdown of the cubic equation. Our findings allow us to better understand the transition between weakly-nonlinear modes and the long-term chirping modes that ultimately emerge.

PP11 135 Viscous heating in $E \times B$ type devices∗ MIKHAIL MLODIK, ELIJAH KOLMES, IAN OCHS, NATHANIEL FISCH, Princeton Plasma Physics Laboratory In a variety of cylindrical plasma devices with axial magnetic fields, a radial electric field gives rise to plasma rotation. This $E \times B$ rotation also heats the plasma through viscous effects. In the recently proposed wave-driven rotating torus (WDRT), this viscous heating is thought to be manageable in creating, in principle, economical fusion power [1]. Here, we explore viscous heating both in the WDRT and, more generally, in devices where the primary dynamics is governed by the $E \times B$ rotation of plasma. In particular, we explore which species are primarily heated, in both cylindrical and toroidal geometry. We discuss the dependence of the heating on a variety of parameters, such as collisionality, speed of rotation, temperature and ion mix.

*DOE Contract No. DE-AC02-09CH11466.


PP11 136 Development of modular scalable pulsed power systems for high power magnetized plasma experiments∗ I.A. BEAN, Virginia Tech T.E. WEBER, Los Alamos National Laboratory C.S. ADAMS, B.R. HENDERSON, Virginia Tech A.J. KLIM, The Ohio State University New pulsed power switches and trigger drivers are being developed in order to explore higher energy regimes in the Magnetic Shock Experiment (MSX) at Los Alamos National Laboratory. To achieve the required plasma velocities, high-power (approx. 100 kV, 100s of kA), high charge transfer (approx. 1 C), low-jitter (few ns) gas switches are needed. A study has been conducted on the effects of various electrode geometries and materials, dielectric media, and triggering strategies; resulting in the design of a low-inductance annular field-distortion switch, optimized for use with dry air at 90 psig, and triggered by a low-jitter, rapid rise-time solid-state Linear Transformer Driver. The switch geometry and electrical characteristics are designed to be compatible with Syllac style capacitors, and are intended to be deployed in modular configurations. The scalable nature of this approach will enable the rapid design and implementation of a wide variety of high-power magnetized plasma experiments.

*This work is supported by the U.S. Department of Energy, National Nuclear Security Administration. Approved for unlimited release, LA-UR-17-2578.

PP11 137 Shock accelerated particles in inertial fusion R BINGHAM, STFC RAL, Didcot, UK E BOELLA, KU Leuven, Belgium R

DPP 2017: Session PP11
TRINES, R BAMFORD, STFC RAL, Didcot, UK RA CAIRNS, University of St Andrews, UK M VRANIC, RA FONSECA, F CRUZ, LO SILVA, IST Lisbon, Portugal S LEBEDEV, Imperial College London, UK A RIGBY, G GREGORI, Oxford University, UK We consider both electrostatic and magnetized shocks in inertial fusion. It is known that strong localized electric fields exist in laser compressed pellets that are associated with shock like structures and these are responsible for DT fuel separation. Here we propose to excite strong shocks in the low density corona to accelerate ions as an alternative to the ion fast ignition schemes where a separate target is used. We also consider shock accelerated particles in magnetized liner inertial fusion where the Z pinch drives a strong shock. We present theory and simulations of both electrostatic and magnetized shock accelerated particles.

PP11 138 Ion Heating and Flows in a High Power Helicon Source* EARL SCIME, West Virginia University RICCARDO AGNELLO, IVO FURNO, ALAN HOWLING, REMY JACQUIER, Gеннадий ПЛУШЧЕВ, EPFL, Swiss Plasma Center (SPC) DEREK THOMPSON, West Virginia University We report experimental measurements of ion temperatures and flows in a high power, linear, magnetized, helicon plasma device, the Resonant Antenna Ion Device (RAID). RAID is equipped with a high power helicon source. Parallel and perpendicular ion temperatures on the order of 0.6 eV are observed for an rf power of 4 kW, suggesting that higher power helicon sources should attain ion temperatures in excess of 1 eV. The unique RAID antenna design produces broad, uniform plasma density and perpendicular ion temperature radial profiles. Measurements of the azimuthal flow indicate rigid body rotation of the plasma column of a few kHz. When configured with an expanding magnetic field, modest parallel ion flows are observed in the expansion region. The ion flows and temperatures are derived from laser induced fluorescence measurements of the Doppler resolved velocity distribution functions of argon ions.

*This work supported by U.S. National Science Foundation Grant No. PHY-1360278.

PP11 139 Studies on ion heating of the GAMMA 10/PDX plasma in a higher density regime toward a future divertor simulating linear device R. IKEZOE, M. ICHIMURA, S. JANG, M. HIRATA, S. SUMIDA, J. ITAGAKI, K. IZUMI, A. TANAKA, Y. KUBOTA, R. SEKINE, M. SAKAMOTO, Y. NAKASHIMA, Univ of Tsukuba Linear plasma devices offer flexible plasma conditions, good control and measurement accessibility, contributing to the necessary physical understanding of boundary plasma and technology development for DEMO. Among many linear devices operating in the world, one missing parameter is ion temperature. On the other hand, end-loss plasmas with ion temperature more than 100 eV are achievable in a standard discharge of GAMMA 10/PDX while the electron density significantly falls below the demand for above studies. Recently ion heating experiments in a higher density regime has been started on GAMMA 10/PDX to bridge a gap between our experiences and the knowledge required for ion heating of a future and operating divertor simulating linear plasmas. We will report on the recent trials, that were performed taking advantage of multi ICRF heating systems on GAMMA 10/PDX; (i) increase of the density of ICRF produced plasma, (ii) experimental investigation on the slow wave excitation in a higher density regime, (iii) development of ion heating methods applicable to a higher density regime.

PP11 140 Optimization of the Magnetic Field Structure for Sustained Plasma Gun Helicity Injection for Magnetic Turbulence Studies at the Bryn Mawr Plasma Laboratory C. A. CARTAGENA-SANCHEZ, D. A. SCHAFFNER, R. SEKINE, M. SAKAMOTO, Y. NAKASHIMA, Univ of Tsukuba The operation of plasmas in the high power helicon device RAID at West Virginia University indicates a potential approach to the continuous and sustained injection of turbulent magnetized plasma. High frequency calibration rather than for sustained spheromak production. The work shown here details the optimization of the magnetic field structure for this sustained helicity injection.

PP11 141 Recent Progress on the magnetic turbulence experiment at the Bryn Mawr Plasma Laboratory D.A. SCHAFFNER, C.A. CARTAGENA-SANCHEZ, H.K. JOHNSON, L.E. FAHIM, C. FIEDLER-KAWARECHI, E. DOUGLAS-MANN, Bryn Mawr College Recent progress is reported on the construction, implementation and testing of the magnetic turbulence experiment at the Bryn Mawr Plasma Laboratory (BMP). The experiment at the BMP consists of an (~ 30μs) long coaxial plasma gun discharge that injects magnetic helicity into a flux-conserving chamber in a process akin to sustained slow-formation of spheromaks. The aim of this source, however, is to supply long pulses of turbulent magnetized plasma for measurement rather than for sustained spheromak production. The work shown here details the optimization of the magnetic field structure for this sustained helicity injection.

PP11 142 Iterative Addition of Kinetic Effects to Cold Plasma RF Wave Solvers* DAVID GREEN, Oak Ridge National Laboratory LEE BERRY, XCEL Engineering RF-SCIDAC COLLABORATION The hot nature of fusion plasmas requires a wave vector dependent conductivity tensor for accurate calculation of wave heating and current drive. Traditional methods for calculating the linear, kinetic full-wave plasma response rely on a spectral method such that the wave vector dependent conductivity fits naturally within the numerical method. These methods have seen much success for application to the well-confined core plasma of tokamaks. However, quantitative prediction of high power RF antenna designs for fusion applications has meant a requirement of resolving the geometric details of the antenna and other plasma facing surfaces for which the Fourier spectral method is ill-suited. An approach to enabling the addition of kinetic effects to the more versatile finite-difference and finite-element cold-plasma full-wave solvers was presented by [1] where an operator-split iterative method was outlined. Here we expand on this approach, examine convergence and present a simplified kinetic current estimator for rapidly updating the right-hand side of the wave equation with kinetic corrections.

*This research used resources of the Oak Ridge Leadership Computing Facility at the Oak Ridge National Laboratory, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.


PP11 143 Analysis of plasma jets produced by a small railgun-based accelerator MAXIMILIAN SCHNEIDER, MICHAEL SHERBURN, JACOB ADAMS, BRIAN HENDERSON, COLIN S. ADAMS, Virginia Tech We report results of an experimental...
effort to characterize temperature, velocity, electron density, and composition of plasma jets generated at the Virginia Tech Center for Space Science and Engineering Research. The linear railgun, which features a 0.5 x 0.32 cm rectangular bore and 10.2 cm long rails, is fed gas from a 700 kPa manifold by a puff valve capable of opening for pulses of several milliseconds. The rails are powered by an LC pulse-forming network (PFN) designed to deliver ~100 kA during a pulse of approximately 10 microsecond duration. A modular accelerator design allows rails and insulators fabricated with different materials and geometries to be swapped out with ease. To characterize the resulting plasma jet, a full suite of diagnostics is utilized including a single-chord Mach Zehnder interferometer, photodiode array, spectrometer, image intensified CCD camera, and Rogowski coil. Initial results obtained while charging the PFN to half its design voltage suggest jet velocities of ~15-25 km/s are obtained consistently. Results from this device will provide groundwork for the design of future jet sources and experiments to study Topics ranging from plasma-material interactions to plasma shocks.

PP11 144 Thin liquid sheet target capabilities for ultra-intense laser acceleration of ions at a kHz repetition rate


The success of laser-accelerated ion experiments depends crucially on a number of factors including how thin the targets can be created. We present experimental results demonstrating extremely thin (under 200 nm) glycol sheet targets that can be used for ultra-intense laser-accelerated ion experiments conducted at the Air Force Research Laboratory at Wright-Patterson Air Force Base. Importantly, these experiments operate at a kHz repetition rate and the recovery time of the liquid targets is fast enough to allow the laser to interact with a refreshed, thin target on every shot. These thin targets can be used to produce energetic electrons, light ions, and neutrons as well as x-rays, we present results from liquid glycol targets which are useful for proton acceleration experiments via the mechanism of Target Normal Sheath Acceleration (TNSA). In future work, we will create thin sheets from deuterated water in order to perform laser-accelerated deuteron experiments.

This research was sponsored by the Quantum and Non-Equilibrium Processes Division of the AFOSR, under the management of Dr. Enrique Parra, and support from the DOD HPCMP Internship Program.

PP11 145 Effect of external forcing on the coupled state of two inductively coupled glow discharge plasma sources

NEERAJ CHAUBEY, SUBROTO MUKHERJEE, ABHIJIT SEN, Inst for Plasma Res

The effect of an external forcing on the in-phase synchronized state of the anode glow oscillations of two inductively coupled glow discharge plasma sources is studied. The parameters of the two plasma sources are initially so adjusted that their anode glow oscillations achieve an in-phase synchronized state with an entrained frequency of 110 kHz. The system is then subjected to an external harmonic forcing from a function generator. It is observed that for a low amplitude forcing (500 mVpp to 800 mVpp) and with a progressive increase in the frequency of the driver from 105 kHz to 112 kHz, the in-phase state changes successively to an anti-phase low frequency state (105 - 108 kHz), to a frequency pulling state (108 - 109 kHz) and finally to an in-phase high frequency state (109 - 112 kHz). When the forcing signal is of a high amplitude (> 800mVpp) the transition from an anti-phase state (105 - 109) kHz to an in-phase state (109 -112) kHz is seen to occur without any intermediate frequency pulling state. These experimental observations are well reproduced in numerical solutions of a theoretical model consisting of two Van der Pol oscillators that are environmentally coupled to each other with one of them driven by an external oscillatory source.

PP11 146 Magnetic helicity balance at Taylor relaxed states sustained by AC helicity injection

MAKOTO HIROTA, Tohoku University PHILIP J. MORRISON, WENDELL HORTON, University of Texas at Austin YUJI HATTORI, Tohoku University

Magnitudes of Taylor relaxed states that are sustained by AC magnetic helicity injection (also known as oscillating field current drive, OFCD) [1,2] are investigated numerically in a cylindrical geometry. Compared with the amplitude of the oscillating magnetic field at the skin layer (which is normalized to 1), the strength of the axial guide field \( B_0 \) is shown to be an important parameter. The relaxation process seems to be active only when \( B_0 < 1 \). Moreover, in the case of weak guide field \( B_0 < 0.2 \), a helically-symmetric relaxed state is self-generated instead of the axisymmetric reversed-field pinch. As a theoretical model, the helicity balance is considered in a similar way to R. G. O’Neill et al. [3], where the helicity injection rate is directly equated with the dissipation rate at the Taylor states. Then, the bifurcation to the helical Taylor state is predicted theoretically and the estimated magnitudes of the relaxed states reasonably agree with numerical results as far as \( B_0 < 1 \).

*This work was supported by JSPS KAKENHI Grant Number 16K05627.


PP11 147 Observations and modeling of magnetized plasma jets and bubbles launched into a transverse B-field

DUSTIN M. FISHER, YUE ZHANG, BEN WALLACE, MARK GILMORE, University of New Mexico WARD B. MANCHESTER IV, BART VAN DER HOLST, University of Michigan BARRETT N. ROGERS, Dartmouth College SCOTT C. HSU, Los Alamos National Laboratory

Hot, dense, plasma structures launched from a coaxial plasma gun on the HelCat dual-source plasma device at the University of New Mexico drag frozen-in magnetic flux into the chamber’s background magnetic field providing a rich set of dynamics to study magnetic turbulence, force-free magnetic spheromaks, shocks, as well as CME-like dynamics possibly relevant to the solar corona. Vector magnetic field data from an eleven-tipped B-dot rake probe and images from an ultra-fast camera will be presented in comparison with ongoing MHD modeling using the 3-D MHD BATS-R-US code developed at the University of Michigan. BATS-R-US employs an adaptive mesh refinement grid (AMR) that enables the capture and resolution of shock structures and current sheets and is uniquely suited for flux-rope expansion modeling. Recent experiments show a possible magnetic Rayleigh-Taylor (MRT) instability that appears asymmetrically at the interface between launched spheromaks (bubbles) and their entraining background magnetic field. Efforts to understand this instability using in situ measurements, new chamber boundary conditions, and ultra-fast camera data will be presented.

*Work supported by the Army Research Office Award No. W911NF1510480.
†Now at the University of Washington.

PP11 148 Measurements of the canonical helicity evolution of a gyrating kinked plasma column

JENS VON DER LINDEN, JASON SEARS, Lawrence Livermore National Laboratory
INTRATOR,1 Los Alamos National Laboratory SETTHIVOINE YOU, University of Tokyo Conversions between kinetic and magnetic energy occur over a wide range of plasma scales as exhibited in astrophysical and solar dynamos, and reconnection in the solar corona and laboratory experiments. Canonical flux tubes present the distinct advantage of reconciling all plasma regimes — e.g. kinetic, two-fluid, and MHD — with the topological concept of helicity: twists, writhes, and linkages. This paper presents the first visualization and analysis of the 3D dynamics of canonical flux tubes and their relative helicity evolution from experimental measurements. Ion and electron canonical flux tubes are visualized from Mach, triple, and B probe measurements at over 10,000 spatial locations of a gyrating kinked plasma column. The flux tubes co-gyrate with the peak density and electron temperature in and out of a measurement volume. The electron and ion canonical flux tubes twist with opposite handedness and the ion flux tube writhes around the electron flux tube. The relative cross helicity between the magnetic and ion flow vorticity flux tubes dominates the relative ion canonical helicity and is anticorrelated with the relative magnetic helicity. The 3D nature of the kink and a reverse eddy current affect the helicity evolution.

†Deceased 3 June 2014.

PP11 149 Statistical study of magnetic field dynamics in a system of merging current filaments MUNI ZHOU, PALLAVI BHAT, NUNO LOUREIRO, Massachusetts Inst of Tech-MIT We investigate magnetic field dynamics in a system of parallel current filaments characterized by a high degree of symmetry. The system evolves through the coalescence and reconnection of the current filaments. This process does not break the symmetry, but does generate increasingly complex patterns with a degree of self-similarity. Analysis of the magnetic and kinetic energy spectra of the system as a function of time shows spectral behavior that is indistinguishable from fully developed turbulence, with the interesting difference that here the spectra show “gaps”, as may be expected of fractal-like patterns. We attempt to characterize pattern complexity by different measures borrowed from general theory of complex systems.

PP11 150 Results from the Mochi.Labjet Experiment ERIC SANDER LAVINE, SETTHIVOINE YOU, University of Washington Magnetized plasma jets are generally modeled as magnetic flux tubes filled with flowing plasma governed by magnetohydrodynamics (MHD). Recent theoretical work has outlined a more fundamental approach based on flux tubes of canonical vorticity, where canonical vorticity is defined as the circulation of a species’ canonical momentum. This approach extends the concept of magnetic flux tube evolution to include the effects of finite particle momentum and enables visualization of the topology of plasma jets in regimes beyond MHD. Under the appropriate conditions this framework suggests how to form and drive stable, collimated plasma jets with very long aspect-ratios. To explore this possibility, a triple electrode planar plasma gun (Mochi.LabJet) has been designed to produce helical shear flows inside a driven magnetized plasma jet. High speed video confirms the experiment can produce long (∼1m), collimated, stable jets with core plasma currents of 60 - 80 kA, skin currents of 100 - 120 kA and axial velocities on the order of 40 – 80 km/s (for hydrogen). Presented here are magnetic and ion flow velocity measurements as well as stability space analysis that suggests the jets are stable to kink instabilities over many Alfvén times.

PP11 151 Temporal evolution of diamagnetic cavity in laser produced plasma NARAYAN BEHERA, Institute for Plasma Research, HBNI, Gandhinagar 382 428, India RAJESH KUMAR SINGH, AJAI KUMAR, Institute for Plasma Research, Gandhinagar 382 428, India Aluminum plasma has been generated by an Nd:YAG laser having pulse energy 150 mJ in an uniform transverse magnetic field varying from 0 to 0.57 T. The dynamical and geometrical behavior of the evolving plasma plume along and across the magnetic field lines have been studied using fast imaging technique. In the fast imaging technique, two internally synchronized ICCD cameras have been mounted in orthogonal directions to the plume propagation direction. At comparatively lower magnetic fields, a well defined cavity-like structure (diamagnetic cavity) has been observed at initial stage of plume propagation in a plane perpendicular to the direction of the magnetic field. After initial expansion, the cavity is tending to stagnation. This behavior is correlated to the plume expansion in diamagnetic limit. With further increase of the delay time the cavity started to collapse and became jet-like structure which again converted to slab-like structure and expanded freely. This feature of the plasma plume is correlated to $E \times B$ drift in non-diamagnetic limit. An elliptical cylinder-like model has been developed to explain the collapse of the diamagnetic cavity.

 SESSION Q12: TURBULENCE/WAVES
Wednesday Afternoon, 25 October 2017; Room: 102ABC at 15:00; Mike Brown, Swarthmore College, presiding

*Invited Papers*

15:00
Q12 1 Magnetorotational Turbulence and Dynamo in a Collisionless Plasma MATTHEW KUNZ, Princeton University

Low-luminosity black-hole accretion flows are collisionless. A kinetic approach is thus necessary to understand the transport of heat and angular momentum, the acceleration of particles, and the growth and structure of the magnetic field in these systems. I present results from the first 6D kinetic simulation of magnetorotational turbulence and dynamo, which was performed using the hybrid-kinetic particle-in-cell code Pegasus. Special attention will be paid to the transport of angular momentum by the anisotropic-pressure stress, as well as to the ion-Larmor-scale kinetic instabilities (firehose, mirror, ion-cyclotron) that regulate it. The latter endows the plasma with an effective viscosity that is biased with respect to the magnetic-field direction and spatially variable. Energy spectra suggest an Alfvén-wave cascade at large scales and a kinetic-Alfvén-wave cascade at small scales, with strong small-scale density fluctuations and weak nonaxisymmetric
density waves. Ions undergo nonthermal particle acceleration, their distribution accurately described by a $\kappa$ distribution. Dedicated nonlinear studies of firehose and mirror instabilities in a shearing plasma will also be presented as a complement to the study of the magnetorotational instability. The profits, perils, and price of using a kinetic approach are discussed.

15:30
**QI2 2 Intermittency, Anisotropy and the onset of reconnection in strong Alfvénic turbulence**

ALFRED MALLET, *University of New Hampshire*

On length scales larger than the ion gyroradius, the turbulence in a plasma with a strong mean magnetic field may be modelled using the equations of reduced magnetohydrodynamics, which describe the evolution of Alfvénic fluctuations propagating up and down the magnetic field. This (strongly nonlinear) turbulence is (i) “critically balanced” - anisotropic with respect to the direction of the local mean magnetic field, (ii) “aligned” - vector fluctuations in the fields in the perpendicular plane point in the same direction to within a small angle, and the structures are highly sheet-like, (iii) highly intermittent - the shape of the probability distributions of many (but not all!) turbulent quantities depends on scale in a non-trivial way. I will discuss the work we have performed connecting these phenomena, and the resulting statistical model for the Alfvénic turbulence we have developed. Finally, I will discuss recent results concerning the onset of reconnection at the small scales of Alfvénic turbulence, and the subsequent disruption of the sheet-like turbulent structures at these scales. This dramatically affects the turbulent cascade at small scales, and may provide a resolution to recent disagreements as to the value of asymptotic spectral index of the turbulence.

*Supported by NSF Grant AGS-1624501.

16:00
**QI2 3 Kinetic Alfvén Wave Turbulence: New Insight from Gyrokinetics and beyond**

DANIEL TOLD, *Max Planck Institute for Plasma Physics, Boltzmannstr. 2, D-85748 Garching, Germany*

One of the most eminent unsolved problems in space physics is the nature of the turbulent energy dissipation at the smallest spatial scales, which is thought to explain the localized plasma heating observed in the solar wind [1]. This work focuses on new results obtained from gyrokinetic simulations of Kinetic Alfvén Wave turbulence, a major ingredient of solar wind turbulence [2]. For conditions similar to the solar wind at 1 AU, previous work [3,4] showed that electron Landau damping can become important even on ion spatial scales and is responsible for about 70% of the turbulent heating, underscoring the importance of retaining electron kinetic physics. In addition, studies of linear wave physics in various kinetic models [5,6] indicate that this dominance of electron damping may be enhanced even more in conditions of plasma beta $< 1$, which is characteristic of the solar wind closer to the sun. Making use of multi-scale nonlinear simulations, we shed light on how such findings carry over to nonlinear simulations for different plasma beta values. We focus in particular on characterizing the kinetic mechanisms that catalyze heating, their dependence on plasma parameters, and their relative importance to each particle species.

*These computations were carried out on Titan at OLCF within a 2016 INCITE Award.


16:30
**QI2 4 First Satellite Measurement of the ULF Wave Growth Rate in the Ion Foreshock**

SETH DORFMAN, *University of California, Los Angeles*

Waves generated by accelerated particles are important throughout our heliosphere. These particles often gain their energy at shocks via Fermi acceleration. At the Earth’s bow shock, this mechanism accelerates ion beams back into the solar wind; the beams can then generate ultra low frequency (ULF) waves via an ion-ion right hand resonant instability. These waves influence the shock structure and particle acceleration, leading to coherent structures in the magnetosheath, and are ideal for non-linear interaction studies relevant to turbulence. We report the first satellite measurement of the ultralow frequency (ULF) wave growth rate in the upstream region of the Earth’s bow shock [1]. This is made possible by employing the two ARTEMIS spacecraft orbiting the moon at $\sim 60$ Earth radii from Earth to characterize crescent-shaped reflected ion beams and relatively monochromatic ULF waves. The event to be presented features spacecraft separation of $\sim 2.5$ Earth radii (0.9 ± 0.1 wavelengths) in the solar wind flow direction along a nearly radial interplanetary magnetic field. By contrast, most prior ULF wave observations use spacecraft with insufficient separation to see wave growth and are so close to Earth (within $\sim 30$ Earth radii) that waves convected from different events interfere. Using ARTEMIS data, the ULF wave growth rate is estimated and found to fall within dispersion solver predictions during the initial growth time. Observed frequencies and wave numbers are within the predicted range. Other ULF wave properties such as the phase speed, obliquity, and polarization are consistent with expectations from resonant beam instability theory and prior satellite
measurements. These results not only advance our understanding of the foreshock, but will also inform future nonlinear studies related to turbulence and dissipation in the heliosphere.

*Supported by NASA, NASA Eddy Postdoctoral Fellowship.


**SESSION RE1: DPP BUSINESS MEETING**
Wednesday Evening, 25 October 2017
Room: 203C at 17:15

**Contributed Papers**

17:15
RE1 1 DPP Business Meeting

**SESSION RE2: DPP RECEPTION AND BANQUET**
Wednesday Evening, 25 October 2017
Room: Crystal Ballroom at 18:30

**Contributed Papers**

18:30
RE2 1 DPP Reception and Banquet
SESSION SR1: JAMES CLERK MAXWELL PRIZE ADDRESS: SCALING LAWS FOR THE DYNAMICAL PLASMA PHENOMENA
Thursday Morning, 26 October 2017; Room: Ballroom C at 8:00; Ellen Zweibel, University of Wisconsin, presiding

Invited Papers

8:00
SR1 1 Maxwell Prize Talk: Scaling Laws for the Dynamical Plasma Phenomena
D. D. RYUTOV, LIVERMORE, CA 94550, USA, Retired

The scaling and similarity technique is a powerful tool for developing and testing reduced models of complex phenomena, including plasma phenomena. The technique has been successfully used in identifying appropriate simplified models of transport in quasistationary plasmas [1,2]. In this talk, the similarity and scaling arguments will be applied to highly dynamical systems, in which temporal evolution of the plasma leads to a significant change of plasma dimensions, shapes, densities, and other parameters with respect to initial state. The scaling and similarity techniques for dynamical plasma systems will be presented as a set of case study problems of techniques from various domains of the plasma physics, beginning with collisionless plasmas, through intermediate collisionalities, to highly collisional plasmas describable by the single-fluid MHD. Basic concepts of the similarity theory will be introduced along the way. Among the results discussed are: self-similarity of Langmuir turbulence driven by a hot electron cloud expanding into a cold background plasma [3]; generation of particle beams in disrupting pinches [4]; interference between collisionless and collisional phenomena in the shock physics [5]; similarity for liner-imploded plasmas [6]; MHD similarities with an emphasis on the effect of small-scale (turbulent) structures on global dynamics [7]. Relations between astrophysical phenomena and scaled laboratory experiments will be discussed.

4S. V. Lebedev, A. Frank, and D. D. Ryutov, to be published.

SESSION TI2: DIRECT DRIVE, FAST IGNITION, AND KINETIC MODELING
Thursday Morning, 26 October 2017; Room: 102ABC at 9:30; John Kline, Los Alamos National Laboratory, presiding

Invited Papers

9:30
TI2 1 The One-Dimensional Cryogenic Implosion Campaign on OMEGA: Modeling, Experiments, and a Statistical Approach to Predict and Understand Direct-Drive Implosions*
R. BETTI, Laboratory for Laser Energetics, U. of Rochester

The 1-D campaign on OMEGA is aimed at validating a novel approach to design cryogenic implosion experiments and provide valuable data to improve the accuracy of 1-D physics models. This new design methodology is being tested first on low-convergence, high-adiabat (\(\alpha \sim 6\) to 7) implosions and will subsequently be applied to implosions with increasing convergence up to the level required for a hydro-equivalent demonstration of ignition. This design procedure assumes that the hydrodynamic codes used in implosion designs lack the necessary physics and that measurements of implosion properties are imperfect. It also assumes that while the measurements may have significant systematic errors, the shot-to-shot variations are small and that cryogenic implosion data are reproducible as observed on OMEGA. One of the goals of the 1-D campaign is to find a mapping of the data to the code results and use the mapping relations to design future implosions. In the 1-D campaign, this predictive methodology was used to design eight implosions using a simple two-shock pulse design, leading to pre-shot predictions of yields within 5% and ion temperatures within 4% of the experimental values. These implosions have also produced the highest neutron yield of \(\sim 10^{14}\) in OMEGA cryogenic implosion experiments with an areal density of \(\sim 100\, \text{mg/cm}^2\). Furthermore, the results from this campaign have been used to test the validity of the 1-D physics models used in the radiation–hydrodynamics codes.

TI2 2 Wavelength Detuning Cross-Beam Energy Transfer Mitigation Scheme for Direct-Drive: Modeling and Evidence from National Ignition Facility Implosions

J.A. MAROZAS, Laboratory for Laser Energetics, U. of Rochester

Cross-beam energy transfer (CBET) has been shown to significantly reduce the laser absorption and implosion speed in direct-drive implosion experiments on OMEGA and the National Ignition Facility (NIF). Mitigating CBET assists in achieving ignition-relevant hot-spot pressures in deuterium–tritium cryogenic OMEGA implosions. In addition, reducing CBET permits lower, more hydrodynamically stable, in-flight aspect ratio ignition designs with smaller nonuniformity growth during the acceleration phase. Detuning the wavelengths of the crossing beams is one of several techniques under investigation at the University of Rochester to mitigate CBET. This talk will describe these techniques with an emphasis on wavelength detuning. Recent experiments designed and predicted using multidimensional hydrodynamic simulations including CBET on the NIF have exploited the wavelength arrangement of the NIF beam geometry to demonstrate CBET mitigation through wavelength detuning in polar-direct-drive (PDD) implosions [1]. Shapes and trajectories inferred from time-resolved x-ray radiography of the imploding shell, scattered-light spectra, and hard x-ray spectra generated by suprathermal electrons all indicate a reduction in CBET. These results and their implications for direct-drive ignition will be presented and discussed. In addition, hydrodynamically scaled ignition-relevant designs for OMEGA implosions exploiting wavelength detuning will be presented. Changes required to the OMEGA laser to permit wavelength detuning will be discussed. Future plans for PDD on the NIF including more-uniform implosions with CBET mitigation will be explored.

∗This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

1 J. A. Marozas et al., submitted to Phys. Rev. Lett.

TI2 3 Demonstration of Efficient Core Heating of Magnetized Fast Ignition in FIREX project

TOMOYUKI JOHZAKI, Hiroshima Univ

Extensive theoretical and experimental research in the FIREX “I project over the past decade revealed that the large angular divergence of the laser generated electron beam is one of the most critical problems inhibiting efficient core heating in electron-driven fast ignition [1]. To solve this problem, beam guiding using externally applied kilo-tesla class magnetic field was proposed, and its feasibility has recently been numerically demonstrated [2]. In 2016, integrated experiments at ILE Osaka University demonstrated core heating efficiencies reaching > 5% and heated core temperatures of 1.7 keV. In these experiments, a kilo-tesla class magnetic field was applied to a cone-attached Cu(II) oleate spherical solid target by using a laser-driven capacitor-coil. The target was then imploded by G-XII laser and heated by the PW-class LFXE laser. The heating efficiency was evaluated by measuring the number of Cu-K-α photons emitted. The heated core temperature was estimated by the X-ray intensity ratio of Cu Li-like and He-like emission lines. To understand the detailed dynamics of the core heating process, we carried out integrated simulations using the FI5 code system. Effects of magnetic fields on the implosion and electron beam transport, detailed core heating dynamics, and the resultant heating efficiency and core temperature will be presented. I will also discuss the prospect for an ignition-scale design of magnetized fast ignition using a solid ball target.

∗This work is partially supported by JSPS KAKENHI Grant Number JP16H02245, JP26400532, JP15K21767, JP26400532, JP16K05638 and is performed with the support and the auspices of the NIFS Collaboration Research program (NIFS12KUGK057, NIFS15KUGK087).


TI2 4 Exploring the dynamics of kinetic/multi-ion effects and ion-electron equilibration rates in ICF plasmas at OMEGA

H. SIO, MIT

During the last few years, an increasing number of experiments have shown that kinetic and multi-ion-fluid effects do impact the performance of an ICF implosion. Observations include: increasing yield degradation as the implosion becomes more kinetic; thermal decoupling between ion species; anomalous yield scaling for different fuel mixtures; ion diffusion; and fuel stratification. The common theme in these experiments is that the results are based on time-integrated nuclear observables that are affected by an accumulation of effects throughout the implosion, which complicate interpretation of the data. A natural extension of these studies is therefore to conduct time-resolved measurements of multiple nuclear-burn histories to explore the dynamics of kinetic/multi-ion effects in the fuel and their impact on the implosion performance. This was accomplished through simultaneous, high-precision measurements of the relative timing of the onset, bang time and duration of DD, D²He, DT and T²He burn from T²He (with trace D) or D²He gas-filled implosions using the new Particle X-ray Temporal Diagnostic (PXTD) on OMEGA. As the different reactions have different temperature sensitivities, T_i(t) was determined from the data. Uniquely to the PXTD, several x-ray emission histories (in different energy bands) were also measured, from which a spatially averaged T_i(t) was also determined. The inferred T_i(t) and T_e(t) data have been
used to experimentally explore ion-electron equilibration rates and the Coulomb Logarithm for various plasma conditions. Finally, the implementation and use of PXTD, which represents a significant advance at OMEGA, have laid the foundation for implementing a $T_e(t)$ measurement in support of the main cryogenic DT programs at OMEGA and the NIF.

∗This work was supported in part by the US DOE, LLE, LLNL, and DOE NNSA SSGF.

11:30
**TI2 5 Understanding Yield Anomalies in ICF Implosions via Fully Kinetic Simulations**
WILLIAM TAITANO, Los Alamos National Laboratory

In the quest towards ICF ignition, plasma kinetic effects are among prime candidates for explaining some significant discrepancies between experimental observations and rad-hydro simulations. To assess their importance, high-fidelity fully kinetic simulations of ICF capsule implosions are needed. Owing to the extremely multi-scale nature of the problem, kinetic codes have to overcome nontrivial numerical and algorithmic challenges, and very few options are currently available. Here, we present resolutions of some long-standing yield discrepancy conundrums using a novel, LANL-developed, 1D-2V Vlasov-Fokker-Planck code iFP. iFP possesses an unprecedented fidelity and features fully implicit time-stepping, exact mass, momentum, and energy conservation, and optimal grid adaptation in phase space, all of which are critically important for ensuring long-time numerical accuracy of the implosion simulations. Specifically, we concentrate on several anomalous yield degradation instances observed in Omega campaigns, with the so-called “Rygg effect” [1], or an anomalous yield scaling with the fuel composition, being a prime example. Understanding the physical mechanisms responsible for such degradations in non-ignition-grade Omega experiments is of great interest, as such experiments are often used for platform and diagnostic development, which are then used in ignition-grade experiments on NIF. In the case of Rygg’s experiments, effects of a kinetic stratification of fuel ions on the yield have been previously proposed as the anomaly explanation, studied with a kinetic code FPION, and found unimportant. We have revisited this issue with iFP and obtained excellent yield-over-clean agreement with the original Rygg results, and several subsequent experiments. This validates iFP and confirms that the kinetic fuel stratification is indeed at the root of the observed yield degradation.

∗This work was sponsored by the Metropolis Postdoctoral Fellowship, LDRD office, Thermonuclear Burn Initiative of ASC, and the LANL Institutional Computing. This work was performed under the NNSA of the USDOE at LANL under contract DE-AC52-06NA25396.

12:00
**TI2 6 Measurements of ion species separation in strong plasma shocks**
HANS RINDERKNECHT, Lawrence Livermore National Laboratory

Shocks are important dynamic phenomena in inertial confinement fusion (ICF) and astrophysical plasmas. While the relationship between upstream and downstream plasmas far from the shock front is fully determined by conservation equations, the structure of shock fronts is determined by dynamic kinetic processes. Kinetic theory and simulations predict that the width of a strong ($M > 2$) collisional plasma shock front is on the order of tens of ion mean-free-paths. The shock front structure plays an important role for overall dynamics when the shock front width approaches plasma scale lengths, as in the spherically converging shock in the DT-vapor in an ICF implosion. However, there has been no experimental data benchmarking shock front structure in the plasma phase. The structure of a shock front in a plasma with multiple ion species has been directly measured for the first time using a combination of Thomson scattering and proton radiography in experiments on the OMEGA laser. Thomson scattering of a 263.25 nm probe beam is used to diagnose electron density, electron and ion temperature, ion species concentration, and flow velocity in strong shocks ($M ∼ 5$) propagating through low-density ($ρ ∼ 0.1$ mg/cc) plasmas composed of H(98%)+Ne(2%). Within the shock front, velocity separation of the ion species is observed for the first time: the light species (H) accelerates to of order the shocked fluid velocity (450 microns/ns) before the heavy species (Ne) begins to move. This velocity-space separation implies that the separation of ion species occurs at the shock front, a predicted feature of shocks in multi-species plasmas but never observed experimentally until now. Comparison of experimental data with PIC, Vlasov-Fokker-Planck, and multi-component hydrodynamic simulations will be presented.

---

**SESSION TI3: STABILITY, SCENARIOS, AND MHD**

Thursday Morning, 26 October 2017; Room: 103ABC at 9:30; Fatima Ebrahimi, Princeton Plasma Physics Laboratory, presiding

**Invited Papers**

**9:30**
**TI3 1 Predict-first experimental analysis using automated and integrated MHD modeling**
BRENDAN C. LYONS, General Atomics, Oak Ridge Associated Universities
The success of ITER and future fusion reactors would benefit significantly from theoretical predictions of stability and performance that have been validated against contemporary tokamaks. We present results of a predict-first analysis of transient-stability experiments using OMFIT [Meneghini, Nucl. Fusion 2015] integrated-modeling workflows. In particular, we look at the effect of shape variation on plasma response to 3D magnetic perturbations in order to predict access to ELM suppression. Beginning from equilibrium reconstructions of past experiments, we use EFIT [Lao, Nucl. Fusion 1985] to modify the shape of equilibrium while other plasma parameters (e.g., beta, pedestal density) are held constant. Additional complexity in the workflows are considered, including using EPED [Snyder, Nucl. Fusion 2011] and NEO [Belli, PPCF 2012] to create pedestals with self-consistent pressure and bootstrap current profiles. We then use the autoC1 script, developed to automate linear M3D-C1 [Jardin, Comput. Sci. Discovery 2012] extended-MHD simulations, to assess the plasma response of each predicted equilibrium as though it is a reconstruction of a future experiment. Results from these workflows are used to guide subsequent experiments on DIII-D and KSTAR, and are then validated against 3D magnetics and ELM-suppression observations from the completed experiments. The validation is then used to develop workflows that would have more accurately predicted the experiment. In doing so, the physics models and ELM-suppression metrics considered are improved with every iteration of prediction and experiment. Lessons learned for best practices in predict-first studies and plans for future areas of application (e.g., disruption avoidance) are discussed.

*Supported by the US DOE under DE-FG02-95ER54309, DE-FC02-06ER54873, DE-FC02-04ER54698, & DE-SC0015499, and South Korea NFRI.

10:00
TI3 2 Understanding the stability of the low torque ITER Baseline Scenario in DIII-D*
FRANCESCA TURCO, Columbia University

Analysis of the evolving current density (J), pedestal and rotation profiles in a database of 200 ITER Baseline Scenario discharges in the DIII-D tokamak sheds light on the cause of the disruptive instability limiting both high and low torque operation of these plasmas. The m=2/n=1 tearing modes, occurring after several pressure-relaxation times, are related to the shape of the current profile in the outer region of the plasma. The q=2 surface is located just inside the current pedestal, near a minimum in J. This well in J deepens at constant betaN and at lower rotation, causing the equilibrium to evolve towards a classically unstable state. Lack of core-edge differential rotation likely biases the marginal point towards instability during the secular trend in J. New results from the 2017 experimental campaign establish the first reproducible, stable operation at T=0 Nm for this scenario. A new ramp-up recipe with delayed heating keeps the discharges stable without the need for ECCD stabilization. The J profile shape in the new shots is consistent with an expansion of the previous “shallow well” stable operational space. Realtime Active MHD Spectroscopy (AMS) has been applied to IBS plasmas for the first time, and the plasma response measurements show that the AMS can help sense the approach to instability during the discharges. The AMS data shows the trend towards instability at low rotation, and MARS-K modelling partially reproduces the experimental trend if collisionality and resistivity are included. The modelling results are sensitive to the edge resistivity, and this can indicate that the AMS is measuring the changes in ideal (kink) stability, to which the tearing stability index delta* is correlated. Together these results constitute a crucial step to acquire physical understanding and sensing capability for the MHD stability in the Q=10 ITER scenario.

*Work supported by US DOE under DE-FC02-04ER54698 and DE-FG02-04ER54761.

10:30
TI3 3 Advanced Tokamak Investigations in Full-Tungsten ASDEX Upgrade
ALEXANDER BOCK, Max-Planck-Institut für Plasmaphysik

The tailoring of the q-profile is the foundation of Advanced Tokamak (AT) scenarios. It depends on low collisionality in q<sup>+</sup> which permits efficient external current drive and high amounts of intrinsic bootstrap current. At constant pressure, lowering n<sub>e</sub> leads to a strong decrease of in plot $\nu_{\text{B}} \sim \nu_{\text{E}}^{-2n_{\text{e}}}$ After the conversion of ASDEX Upgrade to fully W-coated plasma facing components, radiative collapses of H-modes with little gas puffing due to central W accumulation could only be avoided partially with central ECRH. Also, operation at high β with low n<sub>e</sub> presented a challenge for the divertor. Together, these issues prevented meaningful AT investigations. To overcome this, several major feats have been accomplished: Access to lower n<sub>e</sub> was achieved through a better understanding of the changes to recycling and pumping, and optionally the density pump-out phenomenon due to RMPs. ECRH capacities were substantially expanded for both heating and current drive, and a solid W divertor capable of withstanding the power loads was installed. A major overhaul improved the reliability of the current profile diagnostics. This contribution will detail the efforts needed to re-access AT scenarios and report on the development of candidate steady state scenarios for ITER/DEMO. Starting from the ‘hybrid scenario,’ a non-inductive scenario (q<sub>95</sub> = 5.3, β<sub>n</sub> = 2.7, f<sub>ex</sub> > 40%) was developed. It can be sustained for many t<sub>ex</sub>, limited only by technical boundaries, and is also independent of the ramp-up scenario. The β-limit is set by ideal modes that convert into NTMs. The T<sub>e</sub>-profiles are steeper than predicted by TGLF, but nonlinear electromagnetic gyro-kinetic analyses with GENE including fast particle effects matched the experimental heat fluxes. We will also report on scenarios at higher q<sub>95</sub>, similar to the EAST/DIII-D steady state scenario. The extrapolation of these scenarios to ITER/DEMO will be discussed.
11:00
TI3 4 Non-Inductively Driven Tokamak Plasmas at Near-Unity Toroidal Beta in the Pegasus Toroidal Experiment∗
JOSHUA REUSCH, University of Wisconsin-Madison

A major goal of the spherical tokamak research program is accessing a state of low internal inductance $l_i$, high elongation $\kappa$, high toroidal and normalized beta ($\beta_t$ and $\beta_N$), and low collisionality without solenoidal current drive. A new local helicity injection (LHI) system in the lower divertor region of the ultra-low aspect ratio Pegasus ST provides non-solenoidally driven plasmas that exhibit most of these characteristics. LHI utilizes compact, edge-localized current sources ($A_{(0)} \sim 4$ cm$^2$, $I_{(0)} \sim 8$ kA, $V_{(0)} \sim 1.5$ kV) for plasma startup and sustainment, and can sustain more than 200 kA of plasma current. Plasma growth via LHI is enhanced by a transition from a regime of high kink-like MHD activity to one of reduced MHD activity at higher frequencies and presumably shorter wavelengths. The strong edge current drive provided by LHI results in a hollow current density profile with low $l_i$. The low aspect ratio ($R_0/a \sim 1.2$) of Pegasus allows ready access to high $\kappa$ and MHD stable operation at very high normalized plasma currents ($I_\nu = I_\rho/aB_T > 15$). Thomson scattering measurements indicate $T_e \sim 100$ eV and $n_e \sim 1 \times 10^19$ m$^{-3}$. The impurity $T_i$ evolution is correlated in time with high frequency magnetic fluctuations, implying substantial reconnection ion heating is driven by the applied helicity injection. Doppler spectroscopy indicates $T_i \gg T_e$ and that the anomalous ion heating scales consistently with two fluid reconnection theory. Taken together, these features provide access to very high $\beta_t$ plasmas. Equilibrium analyses indicate $\beta_t \sim 100\%$ and $\beta_N \sim 6.5$ is achieved. At increasingly low $B_T$, the discharge disrupts at the no-wall ideal stability limit. In these high $\beta_t$ discharges, a minimum $|B|$ well forms over $\sim$50% of the plasma volume. This unique magnetic configuration may be of interest for testing predictions of stabilizing drift wave turbulence and/or improving energetic particle confinement.

∗This work supported by US DOE Grants DE-FG02-96ER54375 and DE-SC0006928.

11:30
TI3 5 Exploring nuclear reactions relevant to Stellar and Big-Bang Nucleosynthesis using High-Energy-Density plasmas at OMEGA and the NIF∗
M. GATU JOHNSON, MIT

Thermonuclear reaction rates and nuclear processes have been explored traditionally by means of accelerator experiments, which are difficult to execute at conditions relevant to Stellar Nucleosynthesis (SN) and Big Bang Nucleosynthesis (BBN). High-Energy-Density (HED) plasmas closely mimic astrophysical environments and are an excellent complement to accelerator experiments in exploring SN and BBN-relevant nuclear reactions. To date, our work using HED plasmas at OMEGA and NIF has focused on the complementary $^3$He+$^3$He, $^3$He+$^4$He, T+$^3$He and T+$^4$He reactions. First studies of the T+$^3$He reaction indicated the significance of the $^3$He ground-state resonance in the T+$^3$He neutron spectrum. Subsequent T+$^4$He experiments showed that the strength of this resonance varies with center-of-mass (c-m) energy in the range of 16-50 keV, a variation that is not fundamentally understood. Studies of the $^3$He+$^4$He and T+$^3$He reactions have also been conducted at OMEGA at c-m energies of 165 keV and 80 keV, respectively, and the results revealed three things. First, a large cross section for the T+$^3$He→$^4$He+$\gamma$ branch can be ruled out as an explanation for the anomalously high abundance of $^6$Li in primordial material. Second, the results contrasted to theoretical modeling indicate that the mirror-symmetry assumption is not enough to capture the differences between T+$^3$He and $^3$He+$^4$He reactions. Third, the elliptical spectrum assumed in the analysis of $^3$He+$^4$He data obtained in accelerator experiments is incorrect. Preliminary data from recent experiments at the NIF exploring the $^3$He+$^3$He reaction at c-m energies of $\sim$60 keV and $\sim$100 keV also indicate that the underlying physics changes with c-m energy. In this talk, we describe these findings and future directions for exploring light-ion reactions at OMEGA and the NIF.

∗The work was supported in part by the US DOE, LLE, and LLNL.

12:00
TI3 6 Dynamics of Plasma Jets and Bubbles Launched into a Transverse Background Magnetic Field∗
YUE ZHANG, Univ. of New Mexico

A coaxial magnetized plasma gun has been utilized to launch both plasma jets (open B-field) and plasma bubbles (closed B-field) into a transverse background magnetic field in the HelCat (Helicon-Cathode) linear device at the University of New Mexico [1]. These situations may have bearing on fusion plasmas (e.g. plasma injection for tokamak fueling, ELM pacing, or disruption mitigation) and astrophysical settings (e.g. astrophysical jet stability, coronal mass ejections, etc.). The magnetic Reynolds number of the gun plasma is $Rm = \rho_V \nu_j / B_0^2/2\mu_0$, the background magnetic pressure, so that the jet or bubble can easily penetrate the background B-field, $B_0$. When the gun axial B-field is weak compared to the gun azimuthal field, a current-driven jet is formed with a global helical magnetic configuration. Applying the transverse background magnetic field, it is observed that the $n = 1$ kink mode is stabilized, while magnetic probe measurements show contrarily that the safety factor $q(a)$ drops below unity. At the same time, a sheared axial jet velocity is measured. We conclude that the tension force arising from increasing curvature of the background magnetic field induces the measured sheared flow gradient above the theoretical kink-stabilization threshold [2], resulting in the emergent kink stabilization of the injected plasma jet. In the case of injected bubbles, spheromak-like plasma formation is verified. However, when the spheromak plasma propagates into the transverse background magnetic field, the typical self-closed global symmetry magnetic configuration does not
4.6 GHz LHW) on LHCD showed that the higher LH frequency is preferred favorable for current drive at high density. The improvement in LHCD at higher frequency is mainly ascribed to a reduction in the Parametric Instability (PI) and to a lesser extent, Collisional Absorption (CA) in the edge region. Finally, new recent experiments shows that the higher frequency LH improves penetration of the coupled RF power into the plasma core, also leading to a better effect on plasma characteristics more efficient core heating. The detailed results will be given.

TO4 3 Particle and Power Exhaust in EAST LIANG WANG, FANG DING, YAOWEI YU, KAIFU GAN, YUNFENG LIANG, GUOSHENG XU, BINGJIA XIAO, YOUWEN SUN, GUANGNAN LUO, XIANZU GONG, JIANGANG LI, BAOXIN WANG, ASIPP, China RAJESH MAINGI, PPPL, US HOUYANG GUO, ANDREA GAROFALO, GA, US EAST TEAM A total power injection up to 0.3GW has been achieved in EAST long pulse USN operation with ITER-like water-cooling W-monoblock divertor, which has steady-state power exhaust capability of 10 MWm⁻². The peak temperature of W target saturated at t = 12 s to the value T≈500°C and a heat flux ≈3MWm⁻² was maintained. Great efforts to reduce heat flux and accommodate particle exhaust simultaneously have been made towards long pulse of 10⁻² s scale. By exploiting the observation of Pfirsch–Schlüter flow direction in the SOL, the Bt direction with Bₓ∇B away from the W divertor (more particles favor outer target in USN) was adopted along with optimizing the strike point location near the pumping slot, to facilitate particle and impurity exhaust with the top cryopump. By tailoring the 3D divertor footprint through edge magnetic topology change, the heat load was dispersed widely and thus peak heat flux and W sputtering was well controlled. Active feedback control of total radiative power with neon seeding was achieved within f_rad =17-35%, exhibiting further potential for heat flux reduction with divertor and edge radiation. Other heat flux handling techniques, including quasi snowflake configuration, will also be presented.

TO4 4 Integrated Plasma Control for Alternative Plasma Shape on EAST BINGJIA XIAO,∗ Chinese Academy of Sciences To support long pulse plasma operation in high performance, a set of plasma control algorithms such as PEFIT real-time equilibrium reconstruction, radiation feedback, Beta and loop voltage feedback and quasi-snowflake shape control have been implemented on EAST Plasma Control system (PCS) which was adapted from DIII-D PCs. PEFIT is a parallelized version of EFIT by using GPU with highest computation acceleration ratio up to 100 with respect to EFIT. It demonstrated high performance both in DIII-D data analysis and in the real-time shape control on EAST plasma either in normal or quasi-snowflake shape. Loop voltage has been successfully controlled by Low Hybrid Wave (LHW) while the plasma

TO4 2 RF heating and current drive with dominant electron Heating in Long Pulse Discharges on EAST XINJUN ZHANG, YANPING ZHAO, FUKUN LIU, JIAFANG SHAN, XIANZU GONG, BOJIAN DING, MAO WANG, HAN-DONG XU, CHENGMING QIN, XIAOJIE WANG, MIAOHUI LI, JINPING QIAN, BAOXIN WANG, LIQUN HU, YUNTAO SONG, JIANGANG LI, Institute of Plasma Physics, Chinese Academy of Sciences The efficient heating and current drive (H&CD) with dominant electron heating capability using Radio Frequency (RF) Continuous Wave (CW) actuators (LHW, ICRF, ECRH) has been successfully demonstrated with ITER-like low torque conditions in recent EAST fully non-inductive long-pulse H-mode discharges. The plasma was sustained by ~70% RF H&CD together with ~30% bootstrap current function. A high electron temperature plasma (core Te>4.0keV) was obtained, resulting in lower reduced loop voltage, through the investigation possibly due to the synergistic effect between ECRH and LHCD. In separate experiments, the characteristic effect of LH wave frequency (a comparison of 2.45 GHz and
current is maintained by poloidal field coil set. Beta control has been also demonstrated by using LHW and it will be extended to other heating sources because the PCS interface is ready. Radiation feedback control has been achieved by Neon seeding by Super-Sonic Molecular Beam Injection (SMBI). For the plasma operation in quasi-snowflake, we have reached 20 s ELMs free high confinement non-inductive discharges with beta_p ∼ 2, H98 ∼ 1.1 and plasma current ∼ 250 kA.

*EAST orals.

10:18
TO4 5 Multimode Plasma Response in the EAST Tokamak*

A multimodal plasma response to n = 2 RMPs was found in EAST tokamak low β_n plasmas. The signature of the multimodal response is the difference in the radial (B_r) and poloidal (B_p) magnetic field dependencies on the applied phasing (poloidal structure). A difference in the 3D coil phasing that maximizes these two responses is observed only in response to n = 2 fields, while the n=1 B_r and B_p have the same phasing dependence. Neither the maximum B_r nor B_p agrees with the best phasing for ELM mitigation in experiments. GPEC modeling accurately reproduces the experimental measurements only when multiple eigenmodes of the plasma response are included. The measured plasma response is not dominated by resonant current drive from the external field, with non-resonant contributions playing a large role. These results on EAST demonstrate a new type of multimode response based on the variation of the polarization of the plasma response to the 3D field. The results clearly demonstrate the danger of associating any one sensor array with desired physics consequence of 3D fields and the need for 3D modeling to predict optimal 3D field configurations in multi-modal plasmas.

*Supported by the U.S. DOE under DE-AC02-09CH11466.

10:30
TO4 6 Vertical Position and Current Profile Measurements by Faraday-effect Polarimetry On EAST tokamak*

A primary goal for ITER and prospective fusion power reactors is to achieve controlled long-pulse/steady-state burning plasmas. For elongated divertor plasmas, both the vertical position and current profile have to be precisely controlled to optimize performance and prevent disruptions. An eleven-channel laser-based POlarimeter-INterferometer (POINT) system has been developed for measuring the internal magnetic field in the EAST tokamak and can be used to obtain the plasma current profile and vertical position. Current profiles are determined from equilibrium reconstruction including internal magnetic field measurements as internal constraints. Horizontally-viewing chords at/near the mid-plane allow us to determine plasma vertical position non-inductively with subcentimeter spatial resolution and time response up to 1 s. The polarimeter-based position measurement, which does not require equilibrium reconstruction, is benchmarked against conventional flux loop measurements and can be exploited for feedback control.

*Work supported by US DOE through Grants No. DE-FG02-01ER54615 and No. DC-SC0010469.

10:42

A reproducible, fully non-inductive H-mode regime devoid of large ELMs has been achieved by continuous Li injection in EAST into the upper ‘ITER-like’ tungsten divertor, extending previous results on the graphite divertor [1]. These discharges did not suffer from density or impurity accumulation, and maintained constant core radiated power. The new results extend the energy confinement multiplier H98(y,2) ∼ 1.2, as compared to H98(y,2) ∼ 0.75 previously on the graphite divertor. The observed ELM elimination is correlated with a decrease in particle recycling, as expected from the strong Li coating before the experiment, and real-time Li aerosol injection. In addition, core W concentration was reduced during the Li injection. ELM elimination is likely related to the reduced recycling and density /temperature profile changes. A low-n electromagnetic coherent mode (MCM) at ∼ 40kHz became stronger in amplitude and also more coherent. The MCM shows strong magnetic fluctuations as measured by fast Mirnov coils, but weak density fluctuations. As compared to the graphite divertor, Li injection into the tungsten divertor eliminated ELMs at twice the previous auxiliary heating power, and reduced pedestal collisionality.


10:54

Recent experiments at the EAST tokamak have shown a strong reduction in divertor recycling when lithium is injected into the plasma, with tungsten used as the wall material in the active divertor. These extend previous studies using carbon as the wall material onto which lithium is applied, and test the ability to use lithium aerosol injection for active wall conditioning during long-pulse plasmas. Reduced recycling, as evidenced by D? emission, is observed during the lithium injection, qualitatively like that observed in other experiments using pre-discharge lithium deposition. The magnitude of the reduction increases with the lithium injection rate, with up to a factor of ∼ 2 observed. The recycling reduction is most pronounced in the active divertor, consistent with the aerosol being transport by the plasma preferentially to the strongly plasma-wetted regions. In addition, ion flux is affected more weakly, decreasing by less than 20% under lithium injection. Modeling with the SOLPS plasma/neutrals transport code indicates a relative reduction in the divertor recycling coefficient of ∼ 20% (e.g., R = 0.99 to 0.8) with lithium injection. These results show the potential for lithium injection to provide real-time control of recycling and particle removal via surface pumping.

*US scientists supported by U.S. DOE Contracts DE-AC05-000R22725, DE-AC02-09CH11466, DE-FC02-04ER54698, and ASIPP scientists by Contract Nos. 2017YFA0402500, 11625524, 11075185, 11021565, 2013GB114004.

11:06
TO4 9 ELM Suppression and performance improvement with a flowing liquid lithium limiter in EAST G.Z. ZUO, J.S. HU, ASIPP R. MAINGI, PPPL Z. SUN, W. XU, J.G. LI, ASIPP A. DIALLO, R. LUNSFORD, PPPL T. OSBORNE, GA K. TRITZ,
Improvements in plasma performance were observed using a second-generation flowing liquid lithium limiter (FLiLi) in EAST. Compared to the H mode discharges without FLiLi, ELM frequency and amplitude were both lower with FLiLi. Also, ELM frequency and amplitude gradually decreased discharge-by-discharge with FLiLi, similar to the gradual ELM mitigation by real-time Li aerosol injection in successive discharges. Moreover, transient ELM-free H-modes with a strong increase of $W_{MHD}$ and $H_{98}$ were observed for the first time with FLiLi. During the ELM-free phases, MHD activity interpreted from high frequency Mirmov probes differed from activity in the ELMy phases. In addition to the typical low-frequency $\sim 50$ kHz edge coherent MHD mode (ECM), a second mode $\sim 220–240$ kHz also was observed in the ELM-free phase. By computing the Li efflux from the FLiLi limiter surface, it was found that the Li efflux from sputtering during discharges and evaporation between discharges was comparable to the typical mass delivery rates used for Li powder injection rate during plasma operation in EAST. Therefore, gradual accumulation of Li in EAST via real-time Li efflux from the FLiLi surface produces similar effects to aerosol injection, i.e. reduced recycling, enhanced fluctuations, and ELM mitigation.

11:18

TO4 10 Tungsten control in long pulse H-mode discharges on EAST† L ZHANG, J HUANG, ASIPP S MORIZA, NIFS X GONG, Z XU, X YANG, Z SUN, Z WU, L HU, X ZHANG, ASIPP EAST TEAM Tungsten impurity is well controlled in EAST H-mode discharges applying on-axis RF heating and Li wall conditioning, which provide great benefit to achieve the reproductive long pulse H-mode discharges (pulse length $\sim 60$s) with low level of tungsten concentration ($C_w$, e.g. $3.0 \times 10^{-6} - 1.5 \times 10^{-5}$). It was found that the tungsten accumulation can be suppressed by increasing ELM frequency after superimposing 4.6GHz LHW on the NBI phase [L. Zhang et al., NME 2017]. On-axis ECRH with power of 0.35MW is also very effective to control tungsten in core plasma. After injection of ECRH, Cw decreases up to 40% and the peaked profile of tungsten in the core plasma becomes hollow, suggesting a weakened neoclassical tungsten transport in the core region. The real-time Li aerosol injection has also been applied to enhance the particle recycling control on EAST. It is found that with Li aerosol injection, stable profiles of tungsten are sustained both in the plasma core and at the edge, while the concentrations are halved compared to the normal H-mode discharge, suggesting a reduced tungsten source. The mechanism of effective tungsten control will be further discussed in this work.

†This is supported by NNSF of China (Grant Nos. 11575244, 11575249) and the NMCFERP of China (Grant Nos. 2014GB124006, 2015GB110005).

11:30

TO4 11 Prompt triggering of edge localized modes through lithium granule injection on EAST ROBERT LUNSFORD, PPPL Z SUN, J.S. HU, W. XIU, G.Z. ZOU, X.Z. GONG, B.N. WAN, J.G. LI, M. HUANG, ASIPP R MAINGI, A DIALLIO, PPPL K TRITZ, JJHU AND THE EAST TEAM We report successful triggering of edge localized mode (ELMs) in EAST with Lithium (Li) micropellets, and the observed dependence of ELM triggering efficiency on granule size. ELM control is essential for successful ITER operation throughout the entire campaign, relying on magnetic perturbations for ELM suppression and ELM frequency enhancement via pellet injection. To separate the task of fueling from ELM pacing, we initiate the prompt generation of ELMs via impurity granule injection. Lithium granules ranging in size from 200 - 1000 microms are mechanically injected into upper-single null EAST long pulse H-mode discharges. The injections are monitored for their effect on high Z impurity accumulation and to assess the pressure perturbation required for reliable ELM triggering. We have determined that granules of diameter larger than 600 microns (corresponding to $5.2 \times 10^{17}$ Li atoms) are successful at triggering ELMs more than 90% of the time. The triggering efficiency drops precipitously to less than 40% as the granule size is reduced to 400 microns ($1.5 \times 10^{17}$ Li atoms), indicating a triggering threshold has been crossed. Using this information an optimal impurity granule size which will regularly trigger a prompt ELM in these EAST discharges is determined. Coupling these results with alternate discharge scenarios on EAST and similar experiments performed on DIII-D provides the possibility of extrapolation to future devices.

11:42

TO4 12 Investigation of the harmonic coherent modes in the EAST pedestal region CHU ZHOU, ADI LIU, JINLIN XIE, TAO LAN, WANDONG LIU, GE ZHUANG, WEIXIN DING, WENZHE MAO, University of Science and Technology of China GUIDING WANG, University of California, Los Angeles LIANG WANG, YONG LIU, Institute of Plasma Physics, Chinese Academy of Sciences X. ZOU, CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France JIANQIANG HU, MINGYUAN WANG, JIN ZHANG, XI FENG, JIAJU LI, ZHAOYANG LIU, University of Science and Technology of China A coherent mode structure, with up to 7 harmonics of a fundamental frequency of $12–15$ kHz, has been observed in pedestal region during EAST H-mode phase driven by lower hybrid current drive (LHCD). Although such harmonic coherent mode (HCM) has a few similar features as the edge harmonic oscillation (EHO) in the DIII-D QH-mode, some differences between these two modes can still be discerned. The HCM peaks in the steep gradient region of pedestal (near the pedestal top), and has the toroidal mode numbers ranging from $n = 1$ to 7. The edge radial electric field well during the H-mode phase with HCM is much deeper than that without ELM. Moreover, the appearance of HCM is always accompanied by the suddenly decreased Dalphal signals, and the amplitude of fundamental branch is usually smaller than that of higher-order ones, which could be roughly explained by the free energy redistribution among all the harmonic branches through the amplitude correlation method. Bi-spectral analysis indicates that strong coupling between HCM and high frequency turbulence exists at the HCM peaking location, implying the important role of turbulence in HCM saturation process.

11:54

TO4 13 New Small-ELM H-mode Regimes for Steady-state High-performance Operations in EAST G.S. XIU, Q.Q. YANG, Y.F. WANG, N. YAN, G.H. HU, X. LIN, ASIPP, China X.Q. XIU, LLNL, USA A.M. GAROFALO, GA, USA R. MAINGI, PPPL, USA EAST TEAM A stationary high-confinement ($H_{98y2}\sim 1.1$) fully non-inductive H-mode regime characterized by high-frequency ($2\text{kHz}$) small ELMs (divertor peak heat flux $\sim 2\text{MW/m}^2$) at relatively low pedestal collisionality ($\nu^*e_{\text{nucl}}\sim 1$) and optimized high internal inductance ($l_i\sim 1.1$) plasma has been recently achieved with high heating power (source power $\sim 9\text{MW}$) in EAST. This regime was obtained at high triangularity $\delta$ (0.55), high q95 (6) and high $\beta_{p0}$ (1.6), close to the parameter space of the grassy ELM regime in JFT-60U. The relatively low plasma current, high q95, $\beta_{p0}$ and therefore high bootstrap current fraction (>30%) make it a suitable regime to achieve steady-state operation with low disruptivity, good reproducibility and robustness. The access to this regime is insensitive to the change of toroidal torque or plasma density in the explored parameter range. Benefiting from the optimized high $l_i$ and high...
\[ \beta_p, \text{ good core energy confinement has been achieved even at low} \]
\[ \text{core toroidal rotation (} \nu_c \text{ down to 10 km/s). Good density control} \]
\[ \text{has been achieved at a line-averaged density up to 76\% Greenwald.} \]
\[ \text{Impurity concentration and core radiation were maintained at an} \]
\[ \text{acceptably low level, suggesting that sufficient particle exhaust can} \]
\[ \text{be driven by the high-frequency small ELMs.} \]

12:06

**TO4 14 Diagnostic and Hardware Upgrades for the US-PRC PMI Collaboration on EAST**

*KEVIN TRITZ, Johns Hopkins University R. MAINGI, Princeton Plasma Physics Laboratory D. ANDRUCZYK, University of Illinois - Champaign J. CANIK, Oak Ridge National Laboratory Z. WANG, Los Alamos National Laboratory B. WIRTH, S. ZINKLE, University of Tennessee - Knoxville K. WOLLER, Massachusetts Institute of Technology J.S. HU, G.N. LIO, X.Z. GONG, ASIPP EAST TEAM*

Several collaborative diagnostic and hardware upgrades are planned to improve understanding and control of Plasma-Material Interactions on EAST, as part of the US-PRC PMI collaboration. Dual-band thermography adapters, designed by UT-K and ORNL, are being designed for existing IR cameras to improve the accuracy of the divertor heat flux measurements by reducing sensitivity to surface emissivity. These measurements should improve power accounting for EAST discharges, which can show a large gap between input power and divertor exhaust power. MIT is preparing tungsten tiles with fluorine depth markers to measure net erosion of PFC tiles. JHU plans to improve the electronics of the Multi-Energy Soft X-ray diagnostic as well as expand the present edge system to a full core-edge measurement; this will enhance the assessment of the effect of Li injection on tungsten accumulation and transport. In addition to PPPL-developed upgrades to the lithium granule and pellet delivery systems, LANL is assessing core-shell micropellets for pellet ablation analysis. Finally, UIUC and PPL are developing flowing liquid lithium limiters, both with and without LiMIT tile features, for deployment on EAST.

*This work was supported by DoE award DE-SC0016553.

12:18

**TO4 15 Edge simulations in ELMy H-mode discharges of EAST tokamak**

*T.Y. XIA, Y.Q. HUANG, ASIPP X.Q. XU, LLNL Y.B. WU, DHIU L.W. WANG, Z. ZHENG, J.B. LIU, Q. ZANG, Y.Y. LI, D. ZHAO, ASIPP*

Simulations of ELM crash followed by a coherent mode, leading to transient divertor heat flux on EAST are achieved by the six-field two-fluid model in BOUT++. Three EAST ELMy H-mode discharges with different pedestal structure, geometry and plasma current Ip are studied. The ELM-driven crash of the profiles in pedestal is reproduced, and the footprints of ELM filaments on targets are comparable with the measurements from divertor probes. A coherent mode is also found in the edge region in all the simulations after the ELM crash. The frequency and poloidal wave number are in the range of the edge coherent mode (ECM) on EAST. The magnetic fluctuations of the mode are smaller than the electric field fluctuations. The detailed comparisons between simulated mode structures with measurements will be reported. Statistical analysis on the simulated turbulent fluctuations shows that both the turbulent and blobby electron anomalous transport can pump the pedestal energy out into SOL, and then flow to divertors. The similar trend of the heat flux width with Ip is obtained in the simulations. The effects of the SOL current driven by LHW on ELMs will be discussed in this paper.
Ca/Yb plasma equilibration rates in a dual-species ultracold neutral plasma* TUCKER SPRENKLE, ADAM DODSON, QUIN MCKNIGHT, SCOTT BERGESON, Brigham Young University We study energy relaxation in a strongly-coupled neutral plasma of calcium and ytterbium ions at temperatures near 1 K. The ion temperature is determined by disorder-induced heating, and denser plasmas have higher temperatures. The electron temperature is determined by the wavelength of the ionizing laser, and is typically 20 to 200 K. We control the plasma stoichiometry and overall plasma density in order to vary the temperatures of the two ion species. We control the electron temperature to adjust the electron screening length and the plasma expansion rate. We will present measurements of energy relaxation rates in this mixed-species plasma.

Supported by National Science Foundation Grant No. PHY-1500376.

Directly calculating electrical conductivities of dense hydrogen from molecular dynamics QIAN MA, DONGDONG KANG, JIAYU DAI, National University of Defense Technology The transport properties are important in warm and hot dense matter in which the Coulomb interaction is dominated in the scattering process. Density functional theory (DFT) is considered as an effective method to investigate the transport properties, but the dynamical collisions between particles are missed. Here we use an electron force field (eFF) method based molecular dynamics (MD) to include the electronic quantum effects to investigate the transport properties of warm dense hydrogen. The eFF method can be regarded as the development of wave packets molecular dynamics and it has been successfully used to describe the thermodynamics of hydrogen, Auger process in diamondoids, the equation of states for dense lithium. The most important point of eFF method is assuming that each electron is considered as a Gaussian wave packet controlled by position and size while ions are still charged points. The electrical conductivity is calculated via the correlation of electrical current. The results show that electronic quantum effects are important for the transport properties in warm dense hydrogen such as diffusion coefficient and electrical conductivity, which are much smaller than the results from DFT calculations.

Strongly coupled plasmas from compressed gases with controllable coupling* GAUTHAM DHARUMAN, CMSE, Michigan State University (MSU) LIAM G. STANTON, Lawrence Livermore National Laboratory MICHAEL S. MURILLO, CMSE, MSU We propose a method for creating strongly coupled plasmas (SCPs) with controllable coupling and relatively low density. Strong coupling in plasmas created from neutral gases is hindered by the process of disorder induced heating (DIH), as shown in ultracold neutral plasmas (UCNPs) [1]. Mitigating DIH requires the neutral system to be pre-correlated [2]. Using molecular dynamics simulations we examine the formation of SCPs from cool gases that are pre-correlated using high gas pressures. By changing the initial pressure over orders of magnitude, we examine the variations in continuum lowering, ionization state, Coulomb coupling, degeneracy, Coulomb collisional processes, and species partial pressures. We are able to vary and control the effective Coulomb coupling over a wide range and much higher than the measured values in UCNPs [2]. This method has significant advantages over experiments in dense plasmas because of the lower energy-density environments that are produced. Further, the method has the advantage of varying the properties listed above by varying the electron and ion temperatures independently.

Supported by NSF Grant No. PHY-1453736, AFSOR Award No. FA9550-16-1-0221, and used XSEDE computational resources.

Strongly coupled plasmas from compressed gases with controllable coupling EVA KOSTADINOVA, CONSTANZE LIAW, LORIN MATTHEWS, KYLE BUSSE, TRUELL HYDE, CASPER - Baylor University We present a numerical study of Anderson localization in a 2D complex plasma crystal. In the classical regime, Anderson localization is the absence of diffusion of certain wave frequencies due to scattering from lattice defects. The appropriate condition for localization is (known as the modified Ioffe-Regel criterion), where is the wavevector and is the mean free path. As, the wave cannot perform even a single oscillation between successive interactions with defects, which eliminates the propagation. Here we examine transport of in-plane lattice waves through a 2D dusty plasma crystal, which is used as a graphene analogue. The lattice disorder is controlled in two ways: i) through variation of particle size (and thus particle density and interparticle separation) and ii) through variation of the radial confinement force. This allows us to compare the transport properties of the crystal in the weak and strong interaction regimes, which provides valuable information on the effects of strong interactions in the crystal.

NSF & NASA funding is gratefully acknowledged.

Mode spectra measurement of particle-particle interaction and upstream potential around dust particles in a plasma sheath KE QIAO, ZHIYUE DING, JIE KONG, LORIN MATTHEWS, TRUELL HYDE, CASPER - Baylor University The interaction potential between dust particles is a fundamental topic in complex plasmas. It is of particular interest for particles in the plasma sheath due to modification of the potential around a dust particle by the ion flow. In this research, we introduce a non-intrusive mode spectra method to study the interaction between a vertically aligned dust particle pair confined in a glass box in a GEC reference cell. The interaction strength between the two particles is measured simultaneously in both the vertical and horizontal directions. The results show an interaction with strong nonreciprocity in both directions and gives a quantitative value for the horizontal
attraction on the bottom particle. The method also finds an upstream potential with effective screening length in the vertical direction \(\lambda_v\) greater than \(\lambda_h\) in the horizontal direction. This is in agreement with previous predictions [2] and has to our knowledge, never before been observed experimentally.

*Funding from NASA and the NSF is gratefully acknowledged.


11:06

TO5 9 Dust particle pair correlation functions and the non-linear effect of interaction potentials* JIE KONG, KE QIAO, LORIN MATTHEWS, TRUELL HYDE, CASPER - Baylor University Dust temperature is a measure of the energy of the stochastic motion of a dust particle, which is a result of the combination of Brownian motion and fluctuations in between the dust charge and the confining electric field. This presentation will provide results of our recent investigation into the relationship between the dust particle temperature as derived using two different analysis techniques, the mean square displacement and the distribution of displacements obtained from the random motion of the dust particle. Experimental results indicate that the harmonic confinement potential acting on the dust particle can be obtained by combining the two methods, allowing the non-linear effect of the confining force to be investigated.

*Funding from NASA and the NSF is gratefully acknowledged.

11:18

TO5 10 Nonlinear response of vertical particle chains to driven oscillations* ZHIYUE DING, KE QIAO, JIE KONG, LORIN MATTHEWS, TRUELL HYDE, CASPER - Baylor University Vertical chain structures of two or more particles were formed inside a glass box placed on the lower electrode of a modified GEC reference cell. Vertical oscillations of the particles were driven by a sinusoidal potential applied to the lower electrode, and the particle response was studied for various driving parameters. While the particle response generally increases linearly with the driving amplitude, a range of driving amplitudes was found where the particle response is inversely proportional to the driving amplitude. The specific range of parameters depends on the experiment parameters. This work explores the possibility that this behavior is due to two regions within the plasma sheath and the different characteristics of the electric field in each region.

*Funding from NASA and the NSF is gratefully acknowledged.

11:30

TO5 11 The relationship between dust particle structures and confinement* MUDI CHEN, JIE KONG, KE QIAO, JORGE CARMONA-REYES, LORIN MATTHEWS, TRUELL HYDE, CASPER - Baylor University The structure of dust particle systems immersed in plasma is determined by both the particle-particle interaction and the external confinement. Here we present recent experimental results obtained from exploring the relationship between the external confinement and the symmetry of the structures formed by the dust particles. Various structures such as vertical chains, zigzag and helical structures, and horizontal layers have previously been formed experimentally [1] using varying confinement methods (e.g., a circular cutout placed on the lower electrode and a 1/20 or 1_glass box placed on the lower electrode). In the case at hand, after forming a specific structure single dust particles were used as probes to map the local confinement allowing determination of the ratio between the horizontal and vertical confinement.

*Funding from NASA and the NSF is gratefully acknowledged.


11:42

TO5 12 Steady equilibrium co-rotating dust vortices in complex plasma MODHUCHANDRA SINGH LAISHRAM, DEVENDRA SHARMA, KAV P.K., Inst. for Plasma Research Dust clouds suspended in a plasma represent the simplest model for various living/active systems of nature which are inherently complex and thermodynamic non-equilibrium. Dynamics of such dust clouds confined in an axis symmetric cylindrical setup and in dynamic equilibrium with the background plasma is analyzed using hydrodynamics formulation for wide range of Reynolds numbers (Re). It revealed that any non-conservative forces associated with a species in a complex flow causes vortex flow of another slowly moving species in the system. Also in the nonlinear regimes (high Re), the dust flow structure mainly depend on the Re and aspect ratio \((L_h/L_v)\) of the confined domain. For \((L_h/L_v \geq 1)\), the flow structure is characterized by symmetric and elongated circulation at linear regime (low Re), and is turned into new antisymmetric pattern in nonlinear regime (high Re). Further increase in Re produce a spontaneous structural change through a critical parameter Re* by the nonlinear phenomena called structural bifurcation. Then the flow structure spontaneously turn into a system of identical structure co-rotating vertices of almost uniform core region and surrounded by shear layers.


11:54

TO5 13 Interparticle / Interchain Forces in Field-Aligned Chains within a Complex Plasma* TRUELL HYDE, LORIN MATTHEWS, CASPER - Baylor University PETER HARTMANN, CASPER - Baylor University and Wigner Research Centre for Physics, Budapest, Hungary OLEG PETROV, CASPER - Baylor University and Joint Institute for High Temperatures, Russian Academy of Sciences VLADIMIR NOSENKO, CASPER - Baylor University and Institute of Materials Physics in Space, German Aerospace Center (DLR) MARLENE ROSENBERG, University of California at San Diego JIE KONG, KE QIAO, CASPER - Baylor University Since predicted in 1934, various Wigner structures have been observed experimentally. To date, most have assembled under the presence of external system confinement, making the fundamental physics behind these correlation driven effects difficult to determine. Complex plasmas have proven a versatile analog for the study of such systems, particularly where global behavior is determined by the combined effect of the particles' low temperature/kinetic energy, interparticle interaction, global/local confinement and streaming ion flow. Of these the ion wakefield force, although of fundamental importance, is generally weaker than the others leaving its effects partially masked by gravity for terrestrial experiments. In this talk, a recently funded NASA/NSF project proposing examination of field-aligned chains formed in PK-4 microgravity experiments, where the ion flow and resulting interparticle potential can be controlled by tuning an alternating DC bias, will be discussed.
TO5 14 Molecular Dynamics Simulations of Magnetized Dusty Plasmas

C. A. ROMERO-TALAMAS, E. M. BATES, W. J. BIRMINGHAM, W. F. RIVERA, University of Maryland, Baltimore County R. P. SMITH, Capitol Technology University M. LACARRA, University of Maryland, College Park

Molecular Dynamics (MD) simulations of dusty plasma particles under various B and E x B configurations, where E and B are electric and magnetic fields, are presented. The numerical algorithm solves Poisson’s equation dynamically throughout the simulation to account for time-changing conditions such as inter-particle distance and time-dependent functions of ion temperature, and E and B fields. Simulations are run in 2D and 3D, and the results are being used to explore dust crystallization, quenching, and heating under intense B fields and high E x B drift velocities. The MD code is used to explore scenarios for E x B experiments planned with dust immersed in argon plasmas resulting from a combination of RF and DC glow discharges with the B-field produced by a Bitter-type electromagnet under development called ALPHA (Adjustable Long Pulse High-Field Apparatus) capable of sustaining fields up to 10 T from seconds to minutes. Particle tracking and stereoscopic reconstruction algorithms are used on experimental data are also being tested with MD simulated particle position and velocity for ensembles that range from tens to hundreds of particles. The hardware and diagnostic setup planned for the experiments are also presented.

TO5 15 Effect of Stochastic Charge Fluctuations on Dust Dynamics

LORIN MATTHEWS, CASPER, Baylor University BABAK SHOTORBAN, The University of Alabama in Huntsville TRUELL HYDE, CASPER, Baylor University

The charging of particles in a plasma environment occurs through the collection of electrons and ions on the particle surface. Depending on the particle size and the plasma density, the standard deviation of the number of collected elementary charges, which fluctuates due to the randomness in times of collisions with electrons or ions, may be a significant fraction of the equilibrium charge. We use a discrete stochastic charging model to simulate the variations in charge across the dust surface as well as in time. The resultant asymmetric particle potentials, even for spherical grains, has a significant impact on the particle coagulation rate as well as the structure of the resulting aggregates. We compare the effects on particle collisions and growth in typical laboratory and astrophysical plasma environments.

TO6 2 Spectroscopic studies of nitrogen processing plasmas in an RF ICP discharge

MICHAEL BRADLEY, University of Saskatchewan

Nitrogen plasmas have many applications in materials processing. They can be used harden tool steel samples as well as assist in the growth of many important semiconductor nitride films. The detailed composition of nitrogen plasmas in RF ICP (Inductively Coupled Plasma) discharges is therefore a topic of great importance in applied plasma physics. Here we report on studies of a nitrogen RF ICP discharge using Optical Emission (OES) Spectroscopy combined with Langmuir probe characterization of the discharge. We study the discharge at two different locations in the plasma chamber, one closer to and one further from the inductive coil and gas injection ring. The implications of these discharge properties for nitrogen plasma material processing applications are further explored using nitrogen plasma ion implantation into a variety of metallic and semiconductor targets.

TO6 3 Measurement of low temperature plasma properties using non-invasive impedance measurements

ERIC GILLMAN, BILL AMATUCCI, ERIK TEJERO, DAVID BLACKWELL, US Naval Research Laboratory

A plasma discharge can be modeled electrically as a combination of capacitors, resistors, and inductors. The plasma, much like an RLC circuit, will have resonances at particular frequencies. The location in frequency space of these resonances provides information about the plasma parameters. These resonances can be detected using impedance measurements, where the AC impedance of the plasma is measured by sweeping the frequency of an AC voltage applied to a sensor and determining the magnitude and phase of the measured current. In this work, an electrode used to sustain a glow discharge is also used as an impedance probe. The novelty of this method is that insertion of a physical probe, which can introduce perturbation and/or contamination, is not necessary. This non-invasive impedance probe method is used to measure the plasma discharge density in various regimes of plasma operation. Experimental results are compared to the basic circuit model results. The potential applications of this diagnostic method and regimes over which this measurement method is valid will be discussed.

TO6 4 Influence of Neutral Pressure on Instability Enhanced Friction and Ion Velocities at the Sheath Edge of Two-Ion-
Species Plasmas∗ PATRICK ADRIAN, Massachusetts Institute of Technology SCOTT BAALRUD, University of Iowa TREvor LAFLUER, laboratoire de physique des Plasmas, CNRS, Sorbonne Universities, UPMC Univ Paris 06, Univ Paris-Sud, Ecole Polytechnique The speed at which ions enter the sheath is a critical parameter to model in low temperature plasmas. For two ion species plasmas, the Stability-Enhanced Friction (IEF) theory [1] predicts the ions’ sheath-edge flow speeds based upon the presence of ion-ion two stream instabilities in the presheath which cause an enhanced friction between the ions merging their velocities up-until the sheath-edge. Here we will report two contributions advancing the IEF theory. First, we have directly calculated the ion-ion friction force in the presheath due to the two stream instability from new Particle-in-Cell Monte-Carlo Collision (PIC-MCC) simulations. This result directly links the merging of the ion velocities with the enhanced wave-particle scattering due to the ion-ion two stream instability. Our second result was that the two stream instability persisted up to 10’s of mTorr as we varied the neutral pressure in the simulations. Adding an ion-neutral collision operator into the IEF theory resulted in accurate predictions for the ion sheath-edge speeds over a range of neutral pressures. This result could impact plasma-based manufacturing designs which can operate in the 10’s of mTorr as we varied the neutral pressure in the simulations. Adding an ion-neutral collision operator into the IEF theory resulted in accurate predictions for the ion sheath-edge speeds over a range of neutral pressures. This result could impact plasma-based manufacturing designs which can operate in the 10’s of mTorr as we varied the neutral pressure in the simulations.

TO6 6 Characterizing Hypervelocity Impact Plasma Through Experiments and Simulations SIGRid CLOSE, NICOLAS LEE, Stanford University ALex Fletcher, Massachusetts Institute of Technology ANDREW NUTTALL, MONICA HEw, PAUL TARANTINO, Stanford University Hypervelocity micro particles, including meteoroids and space debris with masses <1 ng, routinely impact spacecraft and create dense plasma that expands at the isothermal sound speed. This plasma, with a charge separation commensurate with different species mobilities, can produce a strong electromagnetic pulse (EMP) with a broad frequency spectrum. Subsequent plasma oscillations resulting from instabilities can also emit significant power and may be responsible for many reported satellite anomalies. We present theory and recent results from ground-based impact tests aimed at characterizing hypervelocity impact plasma. We also show results from particle-in-cell (PIC) and computational fluid dynamics (CFD) simulations that allow us to extend to regimes not currently possible with ground-based technology. We show that significant impact-produced radio frequency (RF) emissions occurred in frequencies ranging from VHF through L-band and that these emissions were highly correlated with fast (>20 km/s) impacts that produced a fully ionized plasma.

TO6 7 Latest results and developments from the Hybrid Illinois Device for Research and Applications RABEL RIZKALLAH, DANIEL ANDRUCZYK, ZACHARY JON JECkELL, ANDrew JOHN SHone, DANIEL SCOTT JOHNSon, JEAN PAUL al-LAIN, DAVIDe CURREli, DAVID N Ruzic, Univ of Illinois Urbana THE HIDRA TEAM The Hybrid Illinois Device for Research and Applications (HIDRA) is a five-period, L = 2, m = 5, toroidal fusion device operated at the University of Illinois at Urbana-Champaign (UIUC). It has a major radius R0 = 0.72 m and minor radius a = 0.19 m. Initial heating is achieved with 2.45 GHz electron cyclotron resonance heating (ECRH) at an on-axis magnetic field of B0 = 0.087 T which can go as high as B0 = 0.5 T. HIDRA will mainly be used as a classical stellarator, but can also run as a tokamak. This allows for both steady-state and transient regime operation. Experiments on HIDRA will primarily tackle the issue of plasma-material interactions (PMI) in fusion, and focus on developing innovative plasma facing component (PFC) technologies. Currently, research on flowing liquid lithium PFCs meant to be tested inside the machine in real-time operation, is being carried on. The first experiments run on HIDRA started in early 2016 in the low field region. Now, HIDRA is also capable of running in the high field zone, allowing for more interesting experiments and meaningful outcomes. Here, we present some of the initial results coming from the machine.

TO6 8 Analysis of high-speed rotating flow inside gas centrifuge casing DR. SAHADEV PRADHAN, Chemical Technology Division, Bhabha Atomic Research Centre, Mumbai - 400085 The generalized analytical model for the radial boundary layer inside the gas centrifuge casing in which the inner cylinder is rotating at a constant angular velocity Ω_i while the outer one is stationary, is formulated for studying the secondary gas flow field due to wall thermal forcing, inflow/outflow of light gas along the boundaries, as well as due to the combination of the above two external forcing. The analytical model includes the sixth order differential equation for the radial boundary layer at the cylindrical curved surface in terms of master potential (χ), which is derived from the equations of motion in an axisymmetric (r−z) plane. The linearization approximation is used, where the equations of motion are truncated at linear order in the velocity and pressure disturbances to the base flow, which is a solid-body rotation. Additional approximations in the analytical model include constant temperature in the base state (isothermal compressible Couette flow), high aspect ratio (length is large compared to the annular gap), high Reynolds number, but
there is no limitation on the Mach number. The discrete eigenvalues and eigenfunctions of the linear operators (sixth-order in the radial direction for the generalized analytical equation) are obtained. The solutions for the secondary flow is determined in terms of these eigenvalues and eigenfunctions. These solutions are compared with direct simulation Monte Carlo (DSMC) simulations and found excellent agreement (with a difference of less than 15%) between the predictions of the analytical model and the DSMC simulations, provided the boundary conditions in the analytical model are accurately specified.

11:06 TO6 9 A model of early formation of uranium molecular oxides in laser-ablated plasmas* MIKHAIL FINKO, DAVIDE CURRELI, Univ. of Illinois Urbana-Champaign MAGDI AZER, Illinois Applied Research Institute DAVID WEISZ, JONATHAN CROWHURST, TIMOTHY ROSE, BATIKAN KOROGLU, HARRY RADOUSKY, JOSEPH ZAUG, MIKE ARMSTRONG, Lawrence Livermore National Laboratory An important problem within the field of nuclear forensics is fractionation: the formation of post-detonation nuclear debris whose composition does not reflect that of the source weapon. We are investigating uranium fractionation in rapidly cooling plasma using a combined experimental and modeling approach. In particular, we use laser ablation of uranium metal samples to produce a low-temperature plasma with physical conditions similar to a condensing nuclear fireball. Here we present a first plasma-chemistry model of uranium molecular species formation during the early stage of laser ablated plasma evolution in atmospheric oxygen. The system is simulated using a global kinetic model with rate coefficients calculated according to literature data and the application of reaction rate theory. The model allows for a detailed analysis of the evolution of key uranium molecular species and represents the first step in producing a uranium fireball model that is kinetically validated against spatially and temporally resolved spectroscopy measurements.

*This project was sponsored by the DoD, Defense Threat Reduction Agency, Grant HDR1A-16-1-0020. This work was performed in part under the auspices of the U.S. DoE by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

11:18 TO6 10 Developing the Polynomial Expressions for Fields in the ITER Tokomak STEPHEN SHARMA, University of California, Berkeley and University of Southern California The two most important problems to be solved in the development of working nuclear fusion power plants are: sustained partial ignition and turbulence. These two phenomena are the subject of research and investigation through the development of analytic functions and computational models. Ansatz development through Gaussian wave-function approximations, dielectric quark models, field solutions using new elliptic functions, and better descriptions of the polynomials of the superconducting current loops are the critical theoretical developments that need to be improved. Euler-Lagrange equations of motion in addition to geodesic formulations generate the particle model which should correspond to the Dirac dispersive scattering coefficients and the fluid plasma model. Feynman-Hellman formalism and Heaviside step functional forms are introduced to the fusion equations to produce simple expressions for the kinetic energy and loop currents. Conclusively, a polynomial description of the current loops, the Biot-Savart field, and the Lagrangian must be uncovered before there can be an adequate computational and iterative model of the thermonuclear plasma.

11:30 TO6 11 Particle-In-Cell Simulations of a Thermionic Converter STEPHEN CLARK, None Simulations of thermionic converters are presented where cesium is used as a work function reducing agent in a nano-fabricated triode configuration. The cathode and anode are spaced on the order of 100 μm, and the grid structure has features on the micron scale near the anode. The hot side is operated near 1600 K, the cold side near 600 K, and the converter has the potential to convert heat to DC electrical current upwards of 20% efficiency. Affordable and robust thermionic converters have the potential to displace century old mechanical engines and turbines as a primary means of electrical power generation in the near future. High efficiency converters that operate at a small scale could be used to generate power locally and alleviate the need for large scale power transmission systems. Electron and negative cesium ion back emission from the anode are considered, as well as device longevity and fabrication feasibility.

11:42 TO6 12 A CASPER STEM Oriented Educational Intervention based on Microgravity using a 1.5 sec Drop Tower* JORGE CARMONA, LI WANG, RACHEL MOORE, CASPER - Baylor University JUDY YORK, Region 12 Service Center TODD BUCHS, MARIE CLYATT, Baylor University RENE LAUFFER, LORIN MATTHEWS, TRUELL HYDE, CASPER - Baylor University The CASPER educational research group strives to contribute to the effort of increasing students’ interest in and preparation for STEM careers by cultivating partnerships between educators, industry, and state educational institutions while applying the latest innovations and available tools to curriculum development. To this end, CASPER has brought together a group of educational researchers and curriculum designers to produce the CASPER Microgravity Investigators educational intervention, which is coordinated to the 21st Century Learning framework. Material for this educational intervention is based on a newly constructed 1.5 s drop tower at Baylor University and operated by the Center. In this presentation we present the details of the intervention as well as the physics and STEM material which are incorporated into microgravity experiments.

*Funding from the NSF is gratefully acknowledged.
higher densities than ZaP, with up to 1 keV temperatures [5]. Based on the successful results of ZaP and ZaP-HD, the Fusion Z-pinchof Experiment (FuZE) project is experimentally and computationally studying the plasma performance toward fusion conditions, with the target of a smaller radius, $a = 1$ mm, and higher density, $n \approx 2 \times 10^{24}$ m$^{-3}$. Initial FuZE experimental results show several hundred eV ion temperatures, with pinch currents of 100–200 kA and a few mm radius. 2D kinetic calculations show stabilization of instabilities at moderate sheared flows, and 3D kinetic calculations are in progress.

*This work is supported by an award from US ARPA-E.

1Shumlak PRL 1995.
4Shumlak NF 2009.

9:42
TO7 2 A Reactor Development Scenario for the FuZE Sheared-Flow Stabilized Z-pinchof HARRY S. MCLEAN, D.P HIGGINSON, A. SCHMIDT, K.K. TUMMEL, Lawrence Livermore National Laboratory U. SHUMLAK, B.A. NELSON, E.L. CLAVEAU, E.G. FORBES, R.P. GOLINGO, A.D. STEFANOV, TR WEBER, Y. ZHANG, University of Washington We present a conceptual design, scaling calculations, and development path for a pulsed fusion reactor based on a flow-stabilized Z-pinchof. Experiments performed on the ZaP [1] and ZaP-HD [2] devices have largely demonstrated the basic physics of sheared-flow stabilization at pinch currents up to 100 kA. Initial experiments on the FuZE device [3], a high-power upgrade of ZaP, have achieved ~20 usec of stability at pinch current 100-200 kA and pinch diameter ~few mm for a pinch length of 50 cm. Scaling calculations based on a quasi-steady-state power balance show that extending stable duration to ~100 usec at a pinch current of ~1.5 MA and pinch length of 50 cm, results in a reactor plant Q~5. Future performance milestones are proposed for pinch currents of: 300 kA, where Te and Ti are calculated to exceed 1-2 keV; 700 kA, where DT fusion power would be expected to exceed pinch input power; and 1 MA, where fusion energy per pulse exceeds input energy per pulse.

*This work funded by USDOE ARPA-E and performed under the auspices of Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-734770.

3B. A. Nelson et al., this meeting.

9:54
TO7 3 Characterizing an octant of a spherically imploding plasma liner as an MIF driver* S. C. HSU, S. J. LANGENDORF, J. P. DUNN, LANL K. C. YATES, M. GILMORE, UNM F. D. WITHERSPOON, S. BROCKINGTON, A. CASE, E. CRUZ, HyperV Technologies Y. C. F. THIO, HyperJet Fusion AND THE PLX-α TEAM Spherically imploding plasma liners formed by merging supersonic plasma jets are a proposed compression driver for magneto-inertial fusion (MIF). The Plasma Liner Experiment-ALPHA (PLX-α) aims to demonstrate the formation of sub-fusion-scale plasma liners (~ 150-kJ kinetic energy) via dozens of merging supersonic plasma jets (with initial ion density ~ 10$^{16}$ cm$^{-3}$, velocity ~ 50 km/s, mass ~ 1 mg, and use of various gas species). In this talk, we summarize experimental findings on the formation of an octant of spherically imploding plasma liners by merging up to six plasma jets. Experimental data from gated fast-framing-cameras, survey and high-resolution visible spectrometers, and a multi-chord interferometer have been analyzed to assess (i) ion heating (and associated liner-Mach-number degradation) due to collisional shock formation between merging jets, and (ii) liner uniformity upon jet merging. These data are being used to benchmark code calculations, which will set requirements on the allowable shock heating and nonuniformity for scaled-up plasma liners to be an effective MIF compression driver. We also describe plans to field a 4τ imploding plasma liner experiment.

*Supported by ARPA-E and Strong Atomics, LLC.

10:06
TO7 4 The PLX-α Plasma Guns: Progress and Plans* F.D. WITHERSPOON, S. BROCKINGTON, A. CASE, E. CRUZ, M. LUNA, HyperV Technologies Corp. Y.C. FRANCIS THIO, HyperJet Fusion Corporation AND THE LANL PLX-α TEAM The ALPHA coaxial plasma guns are being developed to support a 60-gun scaling study of spherically imploding plasma liners as a standoff driver for plasma-jet-driven magneto-inertial fusion (PJMIF) [1]. Seven complete guns have been delivered to LANL with 6 guns currently undergoing simultaneous test firings on PLX. The guns are designed to operate over a range of parameters: 0.5-5.0 mg of Ar, Ne, N2, Kr, and Xe; 20-60 km/s; ~ 2 × 10$^{16}$ cm$^{-3}$ muzzle density; and up to 7.5 kJ stored energy per gun. Each coaxial gun incorporates a fast dense gas injection and triggering system, a compact low-weight pfn with integral sparkgap switching, and a contoured coaxial gap to suppress the blow-by instability [2]. Optimizing parameter scans performed at HyperV have achieved: ~4 mg at >50 km/s and length of ~10 cm. Peak axial density 30 cm from the muzzle is ~ 2 × 10$^{16}$ cm$^{-3}$. We will provide an overview of the experimental results, along with plans for further improvements in reliability, maintainability, fabricability, and plasma jet performance, with the latter focused on further improvements in the fast gas valve and the igniters.

*Supported by ARPA-E ALPHA Program under contract DE-AR0000566 and Strong Atomics, LLC.


10:18
TO7 5 Numerical Modeling of Plasma-Liner Formation and Implosion for PLX-α* JASON CASSIBRY, University of Alabama in Huntsville ROMAN SAMULYAK, Stony Brook University KEVIN SCHILLO, University of Alabama in Huntsville WEN SHIIL, Stony Brook University PETER STOLTZ, KRIS BECKWITH, Tech-X Corporation SAMUEL LANGENDORF, SCOTT HSU, Los Alamos National Laboratory PLX-α TEAM Numerical simulations of spherically imploding plasma liners formed by merging hypersonic plasma jets have been performed using the FronTier and smooth particle hydrodynamics (SPH) codes in support of the PLX-α project. The physics includes radiation, Braginskii thermal conductivity and ion viscosity, and tabular EOS (LTE and non-LTE). Solid-angle-averaged and standard deviation of liner ram pressure and Mach number reveal variations in these properties during formation and implosion. Spherical-harmonic mode-number analysis of spherical slices of ram pressure at various radii and times provide a quantitative means to assess the evolution of liner non-uniformity. Simulations of 6 and 7 jets support near-term experiments, and synthetic spectra and line-integrated densities are compared with experimental data.

*Supported by the ARPA-E ALPHA program.
10:30
TO7 6 Magnetothermodynamics: Measuring the equations of state in a relaxed MHD plasma for magneto-inertial fusion* MANJIT KAUR, L. J. BARBANO, E. M. SUEN-LEWIS, J. E. SCHROCK, A. D. LIGHT, Swarthmore College D. A. SCHAFFNER, Bryn Mawr College M. R. BROWN, Swarthmore College The estimation of the equations of state (isothermal or adiabatic) for any set-up is necessary to envisage its behavior as the theoretical models and numerical simulations rely on them. In this talk, we will present compression experiments in which we generate parcels of magnetized, relaxed plasma (called Taylor states [1]) and compress them in a closed volume. We call these experiments magnetothermodynamics. The compressed plasma parameters are measured in a compression volume and a PV diagram is produced which shows ion heating during plasma compression. The magnetohydrodynamic and the double adiabatic (i.e., Chew, Goldberger and Low) equations of state are tested under several experimental conditions. The results from these experiments show that the parallel component of double adiabatic equation of state fit our data best. The compression of this magnetized, relaxed plasma is being investigated as an eventual target for magneto-inertial fusion reactors.

*Work supported by DOE OFES and ARPA-E ALPHA programs.

10:42
TO7 7 Acceleration of Taylor plumes on SSX for magneto-inertial fusion* M. R. BROWN, M. KAUR, J. E. SCHROCK, E. M. SUEN-LEWIS, L. J. BARBANO, S. NAMBIAR, Swarthmore College D. A. SCHAFFNER, Bryn Mawr College We have added two pinch coils to the glass extension of the SSX plasma wind tunnel device in order to accelerate Taylor plumes to over 100 km/s. We have characterized velocity (40 km/s), density (0.4 x 10^16 cm^-3), proton temperature (20 eV), and magnetic field (0.2 T) of relaxed, unaccelerated helical Taylor states [1]. Our goal is to accelerate the Taylor states to over 100 km/s and compress to small volumes by stagnation. Compression by a factor of ten to increase both density and temperature will put the Taylor state in a suitable parameter regime as a magnetoinertial fusion target. One prototype pinch coil operates at 1.75 J (1.3 μF, 40 kV) and the other operates at 2 kJ (3 μF, 40 kV). Both have quarter-cycle rise times of less than 1 μs. Results from both prototype units will be presented.

*Work supported by DOE ARPA-E ALPHA program.

10:54
TO7 8 Instability control in a Staged Z-pinch, using an axial-magnetic field and target plasma* HAFIZ U. RAHMAN, Magneto-Inertial Fusion Technologies, Inc. F. BEG, Univ. CA, San Diego F. CONTI, UCSD A. COVINGTON, Univ. Nevada, Reno T. DARLING, E. DUTRA, UNR J. NARKIS, UCSD P. NEY, MIFTI M. ROSS, UCSD E. RUSKOV, MIFTI J. VALENZUELA, UCSD F. WESSEL, MIFTI Experiments on Zebra at UNR, and COBRA at Cornell, show evidence of a uniform pinch by the inclusion of low-Z target plasma (H, or D) inside a hollow gas shell of high-Z (Ar, or Kr) liner plasma. Adding an axial magnetic field of 1 - 2 kG improves the pinch stability. Numerical simulation is conducted using the 2-1/2 D radiation-MHD code MACH2. During implosion, magnetosonic-type shock waves propagate radially inward at different speeds in the liner and target plasmas, producing a shock front at the liner - target interface and a conduction channel ahead of the liner that preheats the target. This secondary conduction channel remains stable throughout the compression, even as the outer surface of the liner becomes Rayleigh-Taylor (RT) unstable. An axial magnetic field reduces the growth of the RT instability and enhances the secondary conduction channel. And in some cases reverses the effects of the RT instability, resulting in a uniform pinch. Simulations reveal that Bz field "piles-up" at the liner-target interface, instead of compressing uniformly over the entire volume. This scenario confines the target plasma in a magnetic well resulting in a high-β, stable plasma.

*Supported by the Advanced Research Projects Agency - Energy, under Grant Number DE-AR0000569.

11:06
TO7 9 Staged Z-pinch Experiments on Cobra and Zebra* FRANK J. WESSEL, Magneto-Inertial Fusion Technologies, Inc. A. ANDERSON, University of Nevada, Reno J. T. BANASEK, T. BYVANK, Cornell University F. CONTI, University of California, San Diego T. W. DARLING, E. DUTRA, University of Nevada, Reno V. GLEBOV, University of Rochester J. GREENLY, D. A. HAMMER, W. M. POTTER, S. V. ROCCO, Cornell University M. P. ROSS, University of California, San Diego E. RUSKOV, Magneto-Inertial Fusion Technologies, Inc. J. VALENZUELA, F. BEG, University of California, San Diego A. COVINGTON, University of Nevada, Reno J. NARKIS, University of California, San Diego H. U. RAHMAN, Magneto-Inertial Fusion Technologies, Inc. A Staged Z-pinch (SZP), configured as a pre-magnetized, high-Z (Ar, or Kr) annular liner imploding onto a low-Z (H, or D) target, was tested on the Cornell University, Cobra Facility and the University of Nevada, Reno, Zebra Facility; each characterized similarly by a nominal 1-MA current and 100-ns risetime while possessing different diagnostic packages. XUV-fast imaging reveals that the SZP implosion dynamics is similar on both machines and that it is more stable with an axial (Bz) magnetic field, a target, or both, than without. On Zebra, where neutron production is possible, re-producible thermonuclear (DD) yields were recorded at levels in excess of 10^9/shot. Flux compression in the SZP is also expected to produce magnetic field intensities of the order of kilo-Tesla. Thus, the DD reaction produced tritons should also yield secondary DT neutrons. Indeed, secondaries are measured above the noise threshold at levels approaching 10^9/shot.

*Supported by the Advanced Research Projects Agency - Energy, under Grant Number DE-AR0000569.

11:18
TO7 10 Issues with Strong Compression of Plasma Target by Stabilized Imploiding Liner* PETER TURCHI, SHERRY FRESE, MICHAEL FRESE, NumerEx Strong compression (10:1 in radius) of an FRC by imploiding liquid metal liners, stabilized against Rayleigh-Taylor modes, using different scalings for loss based on Bohm vs 100X classical diffusion rates, predict useful compressions with implosion times half the initial energy lifetime [1]. The elongation (length-to-diameter ratio) near peak compression needed to satisfy empirical stability criterion and also retain alpha-particles is about ten. The present paper extends these considerations to issues of the initial FRC, including stability conditions (S'/E) and allowable angular speeds. Furthermore, efficient recovery of the implosion energy and alpha-particle work, in order to reduce the necessary nuclear gain for an economical power reactor, is seen as an important element of the stabilized liner implosion concept for fusion. We describe recent progress in design and construction of the high energy-density prototype of a Stabilized Liner Compressor (SLC) leading to repetitive laboratory experiments to develop the plasma target.
11:30
TO7 11 Experimental investigation of adiabatic compression and heating using collision of an MHD-driven jet with a gas target cloud for magnetized target fusion BYONGHOON SEO, Caltech HUI LI, LANL PAUL BELLAN, Caltech We are studying magnetized target fusion using an experimental method where an imploding liner compressing a plasma is simulated by a high-speed MHD-driven plasma jet colliding with a gas target cloud. This has the advantage of being non-destructive so orders of magnitude more shots are possible. Since the actual density and temperature are much more modest than fusion-relevant values, the goal is to determine the scaling of the increase in density and temperature when an actual experimental plasma is adiabatically compressed. Two new-developed diagnostics are operating and providing data. The first new diagnostic is a fiber-coupled interferometer which measures line-integrated electron density not only as a function of time, but also as a function of position along the jet. The second new diagnostic is laser Thomson scattering which measures electron density and temperature at the location where the jet collides with the cloud. These diagnostics show that when the jet collides with a target cloud the jet slows down substantially and both the electron density and temperature increase. The experimental measurements are being compared with 3D MHD and hybrid kinetic numerical simulations that model the actual experimental geometry.

11:42
TO7 12 Cost Modeling and Design of Field-Reversed Configuration Fusion Power Plants DAVID KIRTLEY, JOHN SLOUGH, Helion Energy HELION TEAM The Inductively Driven Liner (IDL) fusion concept uses the magnetically driven implosion of thin (0.5–1 mm) Aluminum hoops to magnetically compress a merged Field-Reversed Configuration (FRC) plasma to fusion conditions. Both the driver and the target have been studied experimentally and theoretically by researchers at Helion Energy, MSNW, and the University of Washington, demonstrating compression fields greater than 100 T and suitable fusion targets. In the presented study, a national power plant facility using this approach will be described. In addition, a full cost study based on the LLNL Z-IFE and HYLIFE-II studies, the ARIES Tokamak concept, and RAND power plant studies will be described. Finally, the expected capital costs, development requirements, and LCOE for 50 and 500 MW power plants will be given. This analysis includes core FRC plant scaling, metallic liner recycling, radiation shielding, operations, and facilities capital requirements.

11:54
TO7 13 MEMS-based, RF-driven, compact accelerators∗ A. PERSAUD, P. A. SEIDL, Q. JI, I. BREINYN, W. L. WALDRON, T. SCHENKEL, Berkeley Lab, 1 Cyclotron Road, Berkeley, CA 94720 K. B. VINAY AKUMAR, D. NI, A. LAL, ECE, Cornell University, 120 Phillips Hall, Ithaca, NY 14853 Shrinking existing accelerators in size can reduce their cost by orders of magnitude. Furthermore, by using radio frequency (RF) technology and accelerating ions in several stages, the applied voltages can be kept low paving the way to new ion beam applications. We make use of the concept of a Multiple Electrostatic Quadrupole Array Linear Accelerator (MEQALAC) and have previously shown the implementation of its basic components using printed circuit boards, thereby reducing the size of earlier MEQALACs by an order of magnitude. We now demonstrate the combined integration of these components to form a basic accelerator structure, including an initial beam-matching section. In this presentation, we will discuss the results from the integrated multi-beam ion accelerator and also ion acceleration using RF voltages generated on-board. Furthermore, we will show results from Micro-Electro-Mechanical Systems (MEMS) fabricated focusing wafers, which can shrink the dimension of the system to the sub-mm regime and lead to cheaper fabrication. Based on these proof-of-concept results we outline a scaling path to high beam power for applications in plasma heating in magnetized target fusion and in neutral beam injectors for future Tokamaks.

∗This work was supported by the Office of Science of the US Department of Energy through the ARPA-e ALPHA program under contracts DE-AC02-05CH11231.
SHAPIRO, RICHARD J. TEMKIN, Massachusetts Inst of Tech-
MIT The challenge in manufacturing traveling wave tubes (TWTs) at high frequencies is that the sizes of the structures scale with, and are much smaller than, the wavelength. We have designed and are building a 250 GHz TWT that uses an oversized structure to overcome fabrication and power handling issues that result from the small dimensions. Using a photonic band-gap (PBG) structure, we succeeded to design the TWT with a beam tunnel diameter of 0.72 mm. The circuit consists of metal plates with the beam tunnel drilled down their center. Twelve posts are protruding on one side of each plate in a triangular array and corresponding sockets are drilled on the other side. The posts of each plate are inserted into the sockets of an adjacent plate, forming a PBG lattice. The vacuum spacing between adjacent plates forms the “PBG cavity”. The full structure is a series of PBG coupled cavities, with microwave power coupling through the beam tunnel. The PBG lattice provides confinement of microwave power in each of the cavities and can be tuned to give the right amount of diffraction per cavity so that no seer is needed to suppress oscillations in the operating mode. CST PIC simulations predict over 38 dB gain with 67 W peak power, using a 30 kV, 310 mA electron beam, 0.6 mm in diameter.

*Research supported by the AFOSR Program on Plasma and Electro-Energetic Physics and by the NIH National Institute of Biomedical Imaging and Bioengineering.

9:54

TO8 3 Harmonic Frequency-Locking In The Multi-Frequency Recirculating Planar Magnetron* DREW PACKARD, GEOFFREY GREENING, NICHOLAS JORDAN, STEVEN EXELBY, PATRICK WONG, Y.Y. LAU, RONALD GILGENBACH, Univ of Michigan - Ann Arbor BRAD HOFF, Air Force Research Lab Sources that generate high power electromagnetic radiation at multiple microwave frequencies are relevant for technologies such as counter electronics. At The University of Michigan, the Multi-Frequency Recirculating Planar Magnetron (MFRPM) [1,2] has been experimentally demonstrated to produce simultaneous oscillations at 1 GHz and 2 GHz, generating up to 32 MW and 13 MW, respectively. The MFRPM is driven by MELBA-C at -300 kV, 1-10 kA, 0.3-1.0 μs with a 0.11-0.3T magnetic field. A novel harmonic frequency-locked state was observed between the 1 GHz and 2 GHz oscillators. Simulations are being conducted to design new experiments to investigate the physics of this locking behavior.

*Supported by the Office of Naval Research under Grant Numbers N00014-13-1-0566 and N00014-16-1-2353, a DEPS Fellowship to GG, ATK for MAGIC, and L-3 Communications Electron Devices Division.


10:06

TO8 4 Design, Simulation and Experiments on the Recirculating Cross-Field Planar Amplifier* STEVEN EXELBY, GEOFFREY GREENING, NICHOLAS JORDAN, DREW PACKARD, YUE YING LAU, RONALD GILGENBACH, Univ of Michigan - Ann Arbor DAVID SIMON, BRAD HOFF, Air Force Research Laboratory The Recirculating Planar Crossed-Field Amplifier (RPCFA) is the focus of simulation and experimental work. This amplifier, inspired by the Recirculating Planar Magnetron [1], is driven by the Michigan Electron Long Beam Accelerator (MELBA), configured to deliver a ∼300 kV, 1-10 kA, 0.3-1.0 μs pulse. For these parameters, a slow wave structure (SWS), cathode, and housing were designed by using the finite element frequency domain code Ansys HFSS, and verified using the PIC code, MAGIC [2]. Simulations of this device demonstrated amplification of 1.3 MW, 3 GHz signal to approximately 29 MW (13.5 dB) with nearly 53% electronic efficiency. Simulations have also shown the device is zero-drive stable, operates under a range of voltages, with bandwidth of ~10%, on par with existing CFAs. The RPCFA SWS has been fabricated using 3D printing, while the rest of the device has been developed using traditional machining. Experimental RPCFA cold tube characteristics matched those from simulation. Experiments on MELBA have demonstrated zero-drive stability and amplifier experiments are underway.

*Supported by the Office of Science of the US DOE under contracts DE-AC02-05CH11231, DE-AC52-07NA27344 and DE-AC02-09CH11466 and by the China Scholarship Council.

10:30

TO8 5 Probing of high density plasmas using the multi-beam, high power TiSa laser system ARCTURUS OSWALD WILLI, ESIN AKTAN, STEPHANIE BRAUCKMANN, BASTIAN AU-RAND, MIKELA CERCHEZ, RAJENDRA PRASAD, ANNA MARIE SCHROER, Institute for laser and plasma physics, Heinrich Heine University Duesseldorf, D40225, Germany The understanding of relativistic laser plasma interaction at ultra-high intensities has advanced considerably during the last decade with the availability of multi-beam, high power TiSa laser systems. These laser systems allow pump-probe experiments to be carried out. The ARCTURUS laser at the University of Duesseldorf is ideally suited for various kinds of pump-probe experiments as it consists of two identical, high power beams with energies of 53 in 30 fs and a third beam for optical probing with energy of 30 mJ in a 30fs pulse. All three beams are synchronised and have flexible time delays with respect to each other. Several different processes were studied where
one of the beams was used as an interaction beam and the second one was incident on a thin solid gold foil to generate a proton beam. For example, thin foil targets were irradiated either with a linear or circular polarized pulse and probed with protons at different times. The expansion of foils for the two cases was clearly different consistent with numerical simulations. In addition, the interaction of gas targets was probed with protons and separately with an optical probe. With both diagnostics the formation of a channel was observed. In the presentation various two beam measurements will be discussed.

10:42
TO8 7 Picosecond Thermal Dynamics in an Underdense Plasma Measured with Thomson Scattering∗ D. HABERBERGER, J. KATZ, S. BUcht, A. DAVIES, J. BROMAGE, J.D. ZUEGEL, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester R. TRINES, Rutherford Appleton Laboratory R. BINGHAM, University of Strathclyde J. SADLER, P.A. NORREYS, University of Oxford Field-ionized underdense plasmas have many promising applications within the laser-plasma interaction field: nuclear fusion, particle accelerators, x-ray sources, and laser-plasma amplification. Having complete knowledge of the plasma dynamics is essential to establishing optimal parameters for a given application. Here picosecond-resolved Thomson scattering measurements have been used to determine the electron thermal dynamics of an underdense (∼10¹⁷/cm³) H₂ plasma irradiated by a 60-ps, 1053-nm laser pulse with an intensity of 2 × 10¹⁴ W/cm². The picosecond-resolved spectra were obtained with a novel pulse-front tilt compensated streaked optical spectrometer. The electron temperature was observed to rise from an initial 5 eV to a density-dependent plateau in 23 ps. Simulation results indicate that inverse bremsstrahlung heating, radiative cooling, and radial conduction cooling all play an important role in modeling the thermal dynamics.

∗This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

10:54
TO8 8 Nanostructure array plasmas generated by femtosecond pulses at highly relativistic intensities∗ R.C. HOLLINGER, Y. WONG, S. WONG, A. ROCKWOOD, J. GLASBY, V. SHLYAPTESEV, J.J. ROCCA, Colorado State University M.G. CAPELUTO, Universidad de Buenos Aires V. KAYMAK, A. PUHKOV, Heinrich-Heine-Universitat Dusseldorf The irradiation of high aspect ratio ordered nanostructure arrays with ultra-high contrast femtosecond laser pulses of relativistic intensity provides a unique combination of nearly complete optical absorption and drastically enhanced light penetration into near-solid density targets. This allows the material to be volumetrically heated deep into the ultra-high energy density regime [1]. In previous experiments we have shown that irradiation of Ni and Au nanostructures with femtosecond pulses focused to an intensity of 5x10¹⁹ W/cm² generate multi-KeV near solid density plasmas in which atoms are ionized to the Ni^+26 and Au^+52 charge states [2]. Here we present the first results of the irradiation of nanostructure arrays with highly relativistic pulses of intensities up to 5x10²¹W/cm². Silver and Rhodium nanowire arrays were irradiated with frequency-doubled pulses of 30 fs duration from a petawatt-class Ti:Sa laser. Time integrated x-ray spectra show the presence of He-like and Li-like emission. Results of experiments conducted with a variety of different nanowires diameters with a range of interwire spacings will be presented and compared to the result of 3D particle-in-cell-simulations.

∗This work was supported by the Fusion Energy Program, Office of Science of the U.S Department of Energy.

2Purvis et al., Nat. Photonics 7, 769 (2013).

11:06
TO8 9 Back-reflection mitigation solutions for 10 PW high-power laser experiments PETRU GHENUCHE, MIHAICL OCTAVIAN CERNAIANU, DANIEL URSESCU, Extreme Light Infrastructure “Nuclear Physics (ELI-NP), INFN-HH, ROMANIA YOSHIAKI HAYASHI, HIDEAKI HABARA, Graduate School of Engineering, Osaka University, Osaka, Japan FLORIN NEGOITA, RODANO BUCHEL, R. PEREIRA, Universidad de Buenos Aires R. BINGHAM, Rutherford Appleton Laboratory D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester R. TRINES, Rutherford Appleton Laboratory R. BINGHAM, University of Strathclyde J. SADLER, P.A. NORREYS, University of Oxford Field-ionized underdense plasmas have many promising applications within the laser-plasma interaction field: nuclear fusion, particle accelerators, x-ray sources, and laser-plasma amplification. Having complete knowledge of the plasma dynamics is essential to establishing optimal parameters for a given application. Here picosecond-resolved Thomson scattering measurements have been used to determine the electron thermal dynamics of an underdense (∼10¹⁷/cm³) H₂ plasma irradiated by a 60-ps, 1053-nm laser pulse with an intensity of 2 × 10¹⁴ W/cm². The picosecond-resolved spectra were obtained with a novel pulse-front tilt compensated streaked optical spectrometer. The electron temperature was observed to rise from an initial 5 eV to a density-dependent plateau in 23 ps. Simulation results indicate that inverse bremsstrahlung heating, radiative cooling, and radial conduction cooling all play an important role in modeling the thermal dynamics.

∗This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

11:18
TO8 10 Flying Focus: Spatiotemporal Control of the Laser Beam Intensity∗ D.H. FROULA, D. TURNBULL, T.J. KESSLER, D. HABERBERGER, S.-W. BAHK, I.A. BEGISHEV, R. BONI, S. BUcht, A. DAVIES, J. KATZ, A.B. SEFKOW, J.L. SHAW, Laboratory for Laser Energetics, U. of Rochester A “flying focus” is presented: this advanced focusing scheme provides unprecedented spatiotemporal control over the laser focal volume. A chromatic focusing system combined with chirped laser pulses enabled the speed of a small-diameter laser focus to propagate over nearly 100× its Rayleigh length. Furthermore, the flying focus decouples the speed at which the peak intensity propagates from the group velocity of the laser pulse, allowing the laser focus to co- or counter-propagate along its axis at any velocity. Experiments have demonstrated a nearly constant intensity over 4.5 mm while the velocity of the focus ranged from subluminal (0.01c) to superluminal (15c). These properties could provide the opportunity to overcome current fundamental limitations in laser-plasma amplifiers, laser-wakefield accelerators, photon accelerators, ion accelerators, and high-order frequency conversion.

∗This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

11:30
TO8 11 Tunable Intense High-Order Vortex Generation∗ XI-AOMEI ZHANG, BAIFEI SHEN, State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechan-
ics, Chinese Academy of Sciences} In 2015 [1], we found the scheme to generate intense high-order optical vortices that carry OAM in the extreme ultraviolet region based on relativistic harmonics from the surface of a solid target. The topological charge of the harmonics scales with its order. These results have been confirmed in recent experiments [2]. In the two incident beams case [3], we produced relativistic intense harmonics with expected frequency and optical vortex. When two counter-propagating LG laser pulses impinge on a solid thin foil and interact with each other, the contribution of each input pulse in producing harmonics can be distinguished with the help of angular momentum conservation of photons, which is almost impossible for harmonic generation without optical vortex. The generation of tunable, intense vortex harmonics with different photon topological charge is predicted based on the theoretical analysis and 3D PIC simulations.

×This work was supported by the National Natural Science Foundation of China (Grant Nos. 11374319, 11674339).


11:42
TO8 12 Plasma-based amplification of laser beams with higher-order polarization modes ROAUL M TRINES, STFC RAL, Didcot, UK J VIEIRA, RA FONSECA, JT MENDONCA, LO SILVA, IST Lisbon, Portugal EP ALVES, SLAC R BINGHAM, STFC RAL, Didcot, UK Parametric amplification of laser pulses in plasma has been used to amplify both simple Gaussian pulses as well as higher-order Laguerre-Gaussian modes. However, the amplified beams always had a simple mode of polarisation, only linear or circular. Here we present a novel scheme to amplify seed laser pulses with complex modes of polarisation, so-called Poincaré beams, using default Gaussian pump laser beams with simple linear or circular polarisation. As particular examples, we will discuss the amplification of seed laser pulses with radial or azimuthal polarisation, as well as a pulse with polarisation shaped like a Mobius strip.

11:54
TO8 13 PW-class laser-driven super acceleration systems in underdense plasmas MASAHIRO YANO, ALEXEI ZHIDKOV, RYOSUKE KODAMA, Osaka Univ Probing laser driven super-acceleration systems can be important tool to understand physics related to vacuum, space time, and particle acceleration. We show acceleration systems can be important tool to understand physics

12:06
TO8 14 Laser electron collider within a micro-channel LIANG JI, Shanghai Institute of Optics and Fine Mechanics We propose a laser-electron collider based on a laser-driven micro-channel-plate target. In this unique geometry, electrons accelerated within the channel can collide head-on with the laser reflected from a foil attached onto the rear target surface. The simple scheme allows for efficient generation of gamma-photons and most importantly, the observing of radiation-reaction effect for the first time. It resolves the aligning and time synchronization challenges for laser-electron colliding scenarios involving two light/electron beams. We predict that a single 5PW laser is sufficient to make radiation-reaction effect measurable. A principle-of-proof experiment was conducted at a currently available 200TW laser system. The superior acceleration of electrons with the novel micro-channel structure was confirmed, showing enhanced electron cut-off energies and slope temperatures compared to ordinary flat interfaces. The results set forth the basis for radiation-reaction measurement from laser-electron colliding in upcoming multi-petawatt laser systems.

12:18
TO8 15 High-energy vacuum birefringence and dichroism in an ultrastong laser field SEBASTIAN MEUREN,* SERGEY BRAGIN, CHRISTOPH H. KEITEL, ANTONINO DI PIAZZA, Max Planck Institute for Nuclear Physics, Heidelberg, Germany The interaction between real photons in vacuum is a long-standing prediction of quantum electrodynamics, which has never been observed experimentally. Upcoming 10 PW laser systems like the Extreme Light Infrastructure (ELI) will provide laser pulses with unprecedented intensities [1]. If combined with highly energetic gamma photons – obtainable via Compton backscattering from laser-wakefield accelerated electron beams – the QED critical field becomes accessible. In [2] we have derived how a generally polarized probe photon beam is influenced by both vacuum birefringence and dichroism in a strong linearly polarized plane-wave laser field. We put forward an experimental scheme to measure these effects in the nontrivial high-energy regime, where the QED critical field is reached and the Euler-Heisenberg approximation, valid for low-frequency electromagnetic fields, breaks down. Our results suggest the feasibility of verifying/rejecting the QED prediction for vacuum birefringence/dichroism at the 3σ confidence level on the time scale of a few days at several upcoming laser facilities.

*Now at Princeton University, Princeton, NJ.

1Di Piazza et al., Rev. Mod. Phys. 84, 1177 (2012).

SESSION TM9: MINI-CONFERENCE ON BRIDGING THE DIVIDE BETWEEN SPACE AND LABORATORY PLASMA PHYSICS I
Thursday Morning, 26 October 2017
Room: 202DE at 9:30
Kris Klein, University of Michigan, presiding

Contributed Papers

9:30
TMP 1 Wave-particle correlation measurements on the Parker Solar Probe mission STUART BALE, University of California, Berkeley PSP/FIELDS TEAM, PSP/SWAP TEAM The Parker Solar Probe (PSP) mission will launch in July 2018 and eventually
orbit with perihelion at 9.8 solar radii, deep into the solar corona. The FIELDS and SWEAP instruments on PSP will measure in situ electric and magnetic fields and thermal plasmas, respectively. A hardware interface between the FIELDS and SWEAP instruments will allow FIELDS to measure directly individual particle counts from the SWEAP electrostatic analyzer instruments. The FIELDS Time Domain Sampler (TDS) has a channel dedicated to particle counts and sampled simultaneously with electric and/or magnetic field measurements. In this talk, I’ll describe the instrument design and show some laboratory test data, and discuss the science that we hope address with the PSP wave-particle correlation measurements.

9:50
TM9 2 The Basic Plasma Science Facility: a platform for studying plasma processes relevant to space and astrophysical settings* T.A. CARTER, UCLA The Basic Plasma Science Facility at UCLA is a national user facility for studies of fundamental processes in magnetized plasmas. The centerpiece is the Large Plasma Device, a 20 m, magnetized linear plasma device. Two hot cathode plasma sources are available. A Barium Oxide coated cathode produces plasmas with \( n \sim 10^{23} \text{cm}^{-3}, T_e \sim 5 \text{ eV}, T_i \lesssim 1 \text{eV} \) with magnetic field from 400G-2kG. This low-\( \beta \) plasma has been used to study fundamental processes, including: dispersion and damping of kinetic and inertial Alfven waves, flux ropes and magnetic reconnection, three-wave interactions and parametric instabilities of Alfven waves, turbulence and transport, and interactions of energetic ions and electrons with plasma waves. A new Lanthanum Hexaboride (LaB\(_6\)) cathode is now available which produces significantly higher densities and temperatures: \( n \lesssim 5 \times 10^{19} \text{cm}^{-3}, T_e \sim 12 \text{eV}, T_i \sim 6 \text{eV} \). This higher pressure plasma source enabled the observation of laser-driven collisionless magnetized shocks and, with lowered magnetic field, provides magnetized plasmas with \( \beta \) approaching or possibly exceeding unity. This opens up opportunities for investigating processes relevant to the solar wind and astrophysical plasmas.

*BaPSF is jointly supported by US DOE and NSF.

10:10
TM9 3 Plasmoid-Mediated Reconnection and Turbulence in Laboratory and Space Plasmas AMITAVA BHATTACHARJEE, PPPL. Among recent new developments, the so-called plasmoid instability of thin current sheets has challenged classical nonlinear reconnection models. Within the framework of the resistive MHD model, this instability alters qualitatively the predictions of the classical Sweet-Parker model, leading to a new nonlinear regime of fast reconnection in which the reconnection rate itself becomes independent of the Lundquist number. This regime has also been seen in Hall MHD as well as fully kinetic simulations. Plasmoids, which can grow by coalescence to large sizes, provide a powerful mechanism for coupling between large (global) and small (kinetic) scales as well as an efficient accelerator of particles to high energies. A new phase diagram of fast reconnection has been proposed, informing the design of experiments (such as the FLARE experiment at Princeton, and TREX at Madison). In 3D, the instability produces self-generated and strongly anisotropic turbulence in which the reconnection rate for the mean magnetic field remains approximately at the 2D value, but the energy spectrum deviates strongly from standard MHD turbulence phenomenology. Applications of the theory to observations in laboratory (including fusion) and space (both magnetospheric and solar) plasmas will be discussed.

10:30
TM9 4 Probes, Moons, and Kinetic Plasma Wakes*
I H HUTCHINSON, MIT D MALASPINA, University of Colorado C ZHOU, MIT Nonmagnetic objects as varied as probes in tokamaks or moons in space give rise to flowing plasma wakes in which strong distortions of the ion and electron velocity distributions cause electrostatic instabilities. Non-linear phenomena such as electron holes are then produced. Historic probe theory largely ignores the resulting unstable character of the wake, but since we can now simulate computationally the non-linear wake phenomena, a timely challenge is to reassess the influence of these instabilities both on probe measurements and on the wakes themselves. Because the electron instability wavelengths are very short (typically a few Debye-lengths), controlled laboratory experiments face serious challenges in diagnosing them. That is one reason why they have long been neglected as an influence in probe interpretation. Space-craft plasma observations, by contrast, easily obtain sub-Debye-length resolution, but have difficulty with larger-scale reconstruction of the plasma spatial variation. In addition to surveying our developing understanding of wakes in magnetized plasmas, ongoing analysis of Artemis data concerning electron holes observed in the solar-wind lunar wake will be featured.

*Work partially supported by NASA Grant NNX16AG82G.

11:10
TM9 6 Using field-particle correlations to study auroral electron acceleration in the LAPD* J. W. R. SCHROEDER, G. G. HOWES, F. SKIFF, C. A. KLETZING, University of Iowa T. A. CARTER, S. VINCENA, S. DORFMAN, UCLA Resonant non-linear Alfven wave-particle interactions are believed to contribute to the acceleration of auroral electrons. Experiments in the Large Plasma Device (LAPD) at UCLA have been performed with the goal of providing the first direct measurement of this nonlinear process. Recent progress includes a measurement of linear fluctuations of the electron distribution function associated with the production of inertial Alfven waves in the LAPD. These linear measurements have been analyzed using the field-particle correlation technique to study the nonlinear transfer of energy between the Alfven wave electric fields and the electron distribution function. Results of this analysis indicate collisions alter the resonant signature of the field-
particle correlation, and implications for resonant Alfvénic electron acceleration in the LAPD are considered.

*This work was supported by NSF, DOE, and NASA.

11:30

**TM9 7 Magnetic flux rope model for solar coronal loops**

*M. Asgari-Targhi, S.I. Bogatuh, and J. Kim, J. Fusion Energy**

A MHD model for simple loops [1] parametrizes loop steady states in terms of the MHD gravity parameter $G = ga/v_A^2$, relative to the plasma beta $\beta$ and inverse aspect ratio $\epsilon = a/R$, ($g$ is the acceleration due to gravity and $v_A$ the shear Alfvén velocity). At the maximum $G/\beta \sim \epsilon^2$, the plasma density varies strongly between the top and the bottom ends of the loop. Comparison to observed thin loops in solar active regions show that the predicted steady states fit the range of observed heights and that height increases with $G$ up to the critical limit. The model also describes features of the thicker loops that give rise to solar flares and coronal mass ejections and provides insight into a number of open questions in solar physics.

11:50

**TM9 8 Comparison of fluid, astrophysical, and laboratory turbulence using a permutation entropy and statistical complexity technique**

*D. Schaffner, Bryn Mawr College**

Understanding turbulent processes as having a more random/stochastic mechanism or a more chaotic/deterministic mechanism is important for characterizing and comparing different turbulent systems. A statistical time-series analysis technique that quantifies the permutation entropy and statistical complexity of a signal can be used to distinguish noisy fluctuations from those arising from underlying chaotic behavior. This technique is applied to three turbulent datasets: velocity fluctuations from a fluid wind tunnel, magnetic and velocity fluctuations from a satellite observation of the solar wind, and magnetic and velocity fluctuations from a turbulent laboratory plasma. The work aims to develop a more global understanding of turbulent behavior that spans both fluid and plasma regimes. Results show that fluid and astrophysical turbulence exhibit more stochastic like behavior while laboratory plasmas retain higher complexity features. The behavior of complexity and permutation entropy as a function of scale is also examined and such scans are useful for extracting important spatial and temporal scales in the system.

12:10

**TM9 9 Laboratory development and testing of spacecraft diagnostics**


The Naval Research Laboratory’s Space Chamber experiment is a large-scale laboratory device dedicated to the creation of large-volume plasmas with parameters scaled to realistic space plasmas. Such devices make valuable contributions to the investigation of space plasma phenomena under controlled, reproducible conditions, allowing for the validation of theoretical models being applied to space data. However, in addition to investigations such as plasma wave and instability studies, such devices can also make valuable contributions to the development and testing of space plasma diagnostics. One example is the plasma impedance probe developed at NRL. Originally developed as a laboratory diagnostic, the sensor has now been flown on a sounding rocket, is included on a CubeSat experiment, and will be included on the DoD Space Test Program’s STP-H6 experiment on the International Space Station. In this talk, we will describe how the laboratory simulation of space plasmas made this development path possible.

*Work sponsored by the US Naval Research Laboratory Base Program.

---

**TP11 1 DIAGNOSTICS AND SOURCES**

### TP11 2 Runaway Electrons Modeling and Nanoparticle Plasma Jet Penetration into Tokamak Plasma*

*S. A. Galkin, I. N. Bogatuh, Far-Tech Inc.**

A novel idea to probe runaway electrons (REs) [1] by superfast injection of high velocity nanoparticle plasma jet (NPPJ) from a plasma accelerator [2,3] needs to be sustained by both RE dynamics modeling and simulation of NPPJ penetration through increasing tokamak magnetic field. We present our recent progress in both areas. RE simulation is based on the model [4], including Dreicer and “avalanche” mechanisms of RE generation, with emphasis on high Zeff effects. The high-density hyper-velocity C60 and BN NPPJ penetration through transversal B-field is conducted with the Hybrid Electro-Magnetic code (HEM-2D) [5] in cylindrical coordinates, with 1/R field dependence for both DIII-D and ITER tokamaks.

*Work is supported in part by US DOE SBIR Grant.


---

**TP11 3 Nanoparticle Plasma Jet as Fast Probe for Runaway Electrons in Tokamak Disruptions**

*I. N. Bogatuh, S. A. Galkin, Far-Tech Inc.**

Successful probing of runaway electrons (REs) requires fast (1 - 2 ms) high-speed injection of enough mass able to penetrate through tokamak toroidal B-field (2 - 5 T) over ∼1 - 2 m distance with large assimilation fraction in core plasma. A nanoparticle plasma jet (NPPJ) from a plasma gun is a unique combination of milliseconds trigger-to-delivery response and mass-velocity of ∼100 mg at several km/s for deep direct injec-
tion into current channel of rapidly (~1 ms) cooling post-TQ core plasma. After $C_{60}$ NPPJ test bed demonstration we started to work on ITER-compatible boron nitride (BN) NPPJ. Once injected into plasma, BN NP undergoes ablative sublimation, thermally decomposes into B and N, and releases abundant B and N high-charge ions along plasma-traversing path and into the core. We present basic characteristics of our BN NPPJ concept and first results from B and N ions on $Z_{eff} > 1$ effect on REs dynamics by using a self-consistent model for RE current density. Simulation results of BN\textsuperscript{0++} NPPJ penetration through tokamak B-field to RE beam location performed with Hybrid Electro-Magnetic code (HEM-2D) are also presented.

*Work supported by U.S. DOE SBIR Grant.

TP11 4 Synchrotron emission diagnostic of full-orbit kinetic simulations of runaway electrons in tokamaks plasmas\textsuperscript{*} LEOPOLDO CARBAJAL GOMEZ, DIEGO DEL-CASTILLO-NEGRETE, Oak Ridge National Lab Developing avoidance or mitigation strategies of runaway electrons (RE) for the safe operation of ITER is imperative. Synchrotron radiation (SR) of RE is routinely used in current tokamak experiments to diagnose RE. We present the results of a newly developed camera diagnostic of SR for full-orbit kinetic simulations of RE in DIII-D-like plasmas that simultaneously includes: full-orbit effects, information of the spectral and angular distribution of SR of each electron, and basic geometric optics of a camera. We observe a strong dependence of the SR measured by the camera on the pitch angle distribution of RE, namely we find that crescent shapes of the SR on the camera pictures relate to RE distributions with sharp angle cuts, while ellipse shapes relate to distributions of RE with larger pitch angles. A weak dependence of the SR measured by the camera with the RE energy, value of the $q$-profile at the edge, and the chosen range of wavelengths is found. Furthermore, we observe that oversimplifying the angular distribution of the SR changes the synchrotron spectra and overestimates its amplitude.

*Research sponsored by the LDRD Program of ORNL, managed by UT-Battelle, LLC, for the U. S. DoE.

TP11 5 Reflectometry diagnostics on TCV PEDRO MOLINA CABRERA, STEFANO CODA, LAURIE PORTE, NICOLA OFFEEDU, Swiss Plasma Centre - Swiss Federal Institute of Technology TCV TEAM\textsuperscript{*} Both profile reflectometer and Doppler back-scattering (DBS) diagnostics are being developed for the TCV Tokamak using a steerable quasi-optical launcher and universal polarizers. First results will be presented. A pulse reflectometer is being developed to complement Thomson Scattering measurements of electron density, greatly increasing temporal resolution and also effectively enabling fluctuation measurements. Pulse reflectometry consists of sending short pulses of varying frequency and measuring the roundtrip group-delay with precise chronometers. A fast arbitrary waveform generator is used as a pulse source feedingfrequency multipliers that bring the pulses to V-band. A DBS diagnostic is currently operational in TCV. DBS may be used to infer the perpendicular velocity and wave number spectrum of electron density fluctuations in the 3-15 cm\textsuperscript{-1} wave-number range. Off-the-shelf transceiver modules, originally used for VNA measurements, are being used in a Doppler radar configuration.

*See author list of S. Coda et al., 2017 Nucl. Fusion 102011.

TP11 6 Synthetic Microwave Imaging Reflectometry diagnostic using 3D FDTD Simulations\textsuperscript{*} SCOTT KRUGER, THOMAS JENKINS, DAVID SMITHE, JACOB KING, Tech-X Corporation NIMROD TEAM TEAM Microwave Imaging Reflectometry (MIR) has become a standard diagnostic [1] for understanding tokamak edge perturbations, including the edge harmonic oscillations in QH mode operation [2]. These long-wavelength perturbations are larger than the normal turbulent fluctuation levels and thus normal analysis of synthetic signals become more difficult. To investigate, we construct a synthetic MIR diagnostic for exploring density fluctuation amplitudes in the tokamak plasma edge by using the three-dimensional, full-wave FDTD code Vorpahl. The source microwave beam for the diagnostic is generated and reflected at the cutoff surface that is distorted by 2D density fluctuations in the edge plasma. Synthetic imaging optics at the detector can be used to understand the fluctuation and background density profiles. We apply the diagnostic to understand the fluctuations in edge plasma density during QH-mode activity in the DIII-D tokamak, as modeled by the NIMROD code [3].

*This work was funded under DOE Grant Number DE-FC02-08ER45972.


TP11 7 Neural network based real-time reconstruction of KSTAR magnetic equilibria with Bayesian-based preprocessing SEMIN JOUNG, SEHYUN KWAK, Y.-C. GHIM, Department of nuclear and quantum engineering, KAIST, Daejeon, Korea Obtaining plasma shapes during tokamak discharges requires real-time estimation of magnetic configuration using Grad-Shafranov solver such as EFIT. Since off-line EFIT is computationally intensive and the real-time reconstructions do not agree with the results of off-line EFIT within our desired accuracy, we use a neural network to generate an off-line-quality equilibrium in real time. To train the neural network (two hidden layers with 30 and 20 nodes for each layer), we create database consisting of the magnetic signals and off-line EFIT results from KSTAR as inputs and targets, respectively. To compensate drifts in the magnetic signals originated from electronic circuits, we develop a Bayesian-based two-step real-time correction method. Additionally, we infer missing inputs, i.e. when some of inputs to the network are not usable, using Gaussian process coupled with Bayesian model. The likelihood of this model is determined based on the Maxwell’s equations. We find that our network can withstand at least up to 20% of input errors. Note that this real-time reconstruction scheme is not yet implemented for KSTAR operation.

TP11 8 Calibration of high-dynamic-range, finite-resolution x-ray pulse-height spectrometers for extracting electron energy distribution data from the PFRC-2 device C SWANSON, P JAN-DOVITZ, S. A. COHEN, Princeton Plasma Physics Laboratory Knowledge of the full x-ray energy distribution function (XEDF) emitted from a plasma over a large dynamic range of energies can yield valuable insights about the electron energy distribution function (EEDF) of that plasma and the dynamic processes that create them. X-ray pulse height detectors such as Amptek's X-123 Fast SDD with Silicon Nitride window can detect x-rays in the range
of 200eV to 100s of keV. However, extracting EEDF from this measurement requires precise knowledge of the detector’s response function. This response function, including the energy scale calibration, the window transmission function, and the resolution function, can be measured directly. We describe measurements of this function from x-rays from a mono-energetic electron beam in a purpose-built gas-target x-ray tube. Large-Z effects such as line radiation, nuclear charge screening, and polarizatinal Bremstrahlung are discussed [1].

*Work supported by USDOE SBIR Grant DE-SC0013801.

TP11 11 Development of the low-field side reflectometer for ITER* CHRISTOPHER MUSCATELLO, JAMES ANDERSON, ANTHONY GATTUSO, General Atomics EDWARD DOYLE, WILLIAM PEEBLES, RAYMOND SERAYDARIAN, GUIDING WANG, ULA GERRIT KRAMER, ALI ZOLFAGHARI, PPPL GENERAL ATOMICS TEAM, UNIVERSITY OF CALIFORNIA LOS ANGELES TEAM, PRINCETON PLASMA PHYSICS LABORATORY TEAM The Low-Field Side Reflectometer (LFSR) for ITER will provide real-time edge density profiles every 10 ms for feedback control and every 24 μs for physics evaluation. The spatial resolution will be better than 5 mm over 30 – 165 GHz, probing the scrape-off layer to the top of the pedestal in H-mode plasmas. An antenna configuration has been selected for measurements covering anticipated plasma elevations. Laboratory validation of diagnostic performance is underway using a LFSR transmission line (TL) mockup. The 40-meter TL includes circular corrugated waveguide, length calibration feature, Gaussian telescope, vacuum windows, containment membranes, and expansion joint. Transceiver modules coupled to the input of the TL provide frequency-modulated (FM) data for evaluation of performance as a monostatic reflectometer. Results from the mockup tests are presented and show that, with some further optimization, the LFSR will meet or exceed the measurement requirements for ITER. An update of the LFSR instrumentation design status is also presented with preliminary test results.

*Work supported by PPPL under subcontract S013252-A.

TP11 12 Progress in Development of the ITER Plasma Control System Simulation Platform* MICHAEL WALKER, DAVID HUMPHREYS, BRIAN SAMMULI, General Atomics GIUSEPPE AMBROSINO, GIAMARIA DE TOMMASI, University of Naples Federico II MASSIMILIANO MAITTEI, Second University of Naples GERHARD RAUHP, WOLFGANG TRETTERER, Max Planck Institute for Plasma Physics AXEL WINTER, ITER Organization We report on progress made and expected uses of the Plasma Control System Simulation Platform (PCSSP), the primary test environment for development of the ITER Plasma Control System (PCS). PCSSP will be used for verification and validation of the ITER PCS Design for First Plasma, to be completed in 2020. We discuss the objectives of PCSSP, its overall structure, selected features, application to existing devices, and expected evolution over the lifetime of the ITER PCS. We describe an archiving solution for simulation results, methods for incorporating physics models of the plasma and physical plant (tokamak, actuator, and diagnostic systems) into PCSSP, and defining characteristics of models suitable for a plasma control development environment such as PCSSP. Applications of PCSSP simulation models including resistive plasma equilibrium evolution are demonstrated.

*PCSSP development supported by ITER Organization under ITER/CTS/6000000037. Resistive evolution code developed under General Atomics’ Internal funding. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

TP11 13 Detailed Performance Assessment for the ITER ECE Diagnostic* W. ROWAN, M. AUSTIN, S. HOUHMANDYAR, P. PHILLIPS, IFS, Univ. of Texas, Austin J. BENO, A. BRYANT, A. OUROUA, D. WEEKS, CEM, Univ. of Texas, Austin A. HUB-
BARD, MIT PSFC G. TAYLOR, PPPL. One of the primary diagnostics for electron temperature ($T_e$) measurement on ITER is based on the detection of electron cyclotron emission (ECE). Here we describe the predicted performance of the newly completed ECE diagnostic design by quantitatively following the emission from the plasma to the instruments and including the calibration method to assess accuracy. Operation of the diagnostic at 5.3 T is the main interest here but critical features of the emission spectra for 2.65 T and 1.8 T will be described. ECE will be collected by two very similar optical systems: one a radial view, the other an oblique view. Both measurements are used for $T_e$ while the oblique view also allows detection of non-thermal distortion in the electron distribution. An in-vacuum calibration source is included in the front end of each view to calibrate out the effect of any degradation of in-vessel optics. Following collection, the emission is split into orthogonal polarizations and transmitted to the detection instruments via waveguides filled with dry nitrogen, a choice that simplifies construction and analysis. Near the instruments, a switchyard is used to select which polarization and view is detected by each instrument. The design for the radiometer used for 5.3 T will be described in detail.

*Supported by PPPL/US-DA via subcontract S013464-H to UT Austin.

**TP11 14** 3D-localized, high-resolution, non-perturbing, vectorizable magnetic field diagnostic using two-photon Doppler-free laser-induced fluorescence YOUNG DAE YOON, PAUL M. BEL-LAN, Caltech A detailed description of a new plasma magnetic field diagnostic using Doppler-free two-photon laser-induced fluorescence is presented. The diagnostic is based on a method previously developed in the context of rubidium vapor experiments. Two counter-propagating diode laser beams at ~394 nm are directed into an argon plasma to excite Ar-I ions from the metastable level $3s^2 3p^4 4p \, ^1D_{5/2} \rightarrow 3s^2 3p^4 4p \, ^3D_{5/2} \rightarrow 3s^2 3p^5 s \, ^2P_{3/2}$. The levels involve two similar (394.43 nm and 393.31 nm) transition wavelengths, so the two counter-propagating beams effectively cancel out the Doppler effect. The excited ions then decay to the $3s^2 3p^4 4p \, ^2D_{5/2}$ level, emitting a 410.38 nm line which is to be detected by a photomultiplier tube. The Zeeman splitting – normally unobservable because of the large Doppler broadening – of the resultant fluorescence is then to be analyzed, yielding the magnetic field of the particular location. This method is expected to provide 3D localized, non-perturbing vector measurements of the magnetic field. The resolution of the diagnostic is only limited by the cross-section of the laser beam, which can easily be as small as hundreds of microns wide. An experimental implementation is currently in progress.

**TP11 15** OMEGA Supersonic Gas-Jet Target Characterization* A. HANSEN, D. HABERBERGER, J.L. SHAW, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester A supersonic gas-jet target system has been characterized using a Mach–Zehnder interferometer, allowing for the study of the gas dynamics during the opening and closing of the valve. Gas-jet targets provide uniform plasmas with flexibility in size and density while also offering excellent diagnostic access to the plasma. The gas jet is the first component in the development of a new laser–plasma interaction platform to be implemented on the OMEGA Laser System. The platform will use a tunable UV laser from OMEGA EP, known as the tunable OMEGA port 9 beam, to facilitate the study of cross-beam energy transfer and the associated mitigation strategies.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

**TP11 16** Recent progress of the Laser-driven Ion-beam Trace Probe* XIAOYI YANG, CHIJJIE XIAO, YIHANG CHEN, TIAN-CHAO XU, Peking University YI YU, University of Science and Technology of China MIN XU, Southwestern Institute of Physics LONG WANG, Chinese Academy of Sciences CHEN LIN, Peking University XIAOGANG WANG, Harbin Institute of Technology The Laser-driven Ion-beam Trace Probe (LITP) is a new method to diagnose the poloidal magnetic field and radial electric field in tokamaks [1, 2]. Recently significant progresses have been made as follows. 1) The experimental system has been set up on the PKU Plasma Test (PPT) linear device and begun to validate the principle of LITP, including the ion source, the ion detector and the poloidal magnetic field cable. Preliminary experimental results matched the theoretical prediction well. 2) The reconstruction principle has been improved including the nonlinear effect [3, 3] Tomography methods have been applied in the reconstruction codes. Now the laser-driven ion-beam accelerator has been setup on the PPT device, and further test of LITP will start soon. After that a prototype of LITP system will be designed and setup on the HL-2A tokamak device.

*This work was supported by the CHINA MOST under 2012YQ030142, ITER-CHINA program 2015GB120001 and National Natural Science Foundation of China under 11575014 and 11375053.

3Yang et al. JINST submitted.

**TP11 17** Development of a Wolter Optic X-ray Imager on Z* JEFFREY R FEIN, DAVID J. AMPLEFORD, Sandia Natl Labs JULIA K. VOGEL, BERNIE KOZIOZIEMSKI, CHRISTOPHER C. WALTON, Lawrence Livermore Natl Lab MING WU, Sandia Natl Labs JAY AYERS, Lawrence Livermore Natl Lab CHRIS J. BALL, CHRIS J. BOURDON, ANDREW MAUER, Sandia Natl Labs MIKE PIVOVAROFF, Lawrence Livermore Natl Lab BRIAN RAMSEY, NASA Marshall Space Flight Center SUZANNE ROYMAINE, Harvard-Smithsonian Center for Astrophysics A Wolter optic x-ray imager is being developed for the Z Machine to study the dynamics of warm x-ray sources with energies above 10 keV. The optic is adapted from observational astronomy and uses multilayer-coated, hyperbolic and parabolic x-ray mirrors to form a 2D image with predicted 100-μm resolution over a 5x5-mm field of view. The imager is expected to have several advantages over a simple pinhole camera. In particular, it can form quasi mono-energetic images due to the inherent band-pass nature of the x-ray mirrors from Bragg diffraction. As well, its larger collection solid angle can lead to an overall increase in efficiency for the x-rays in the desirable energy band. We present the design of the imaging system, which is initially optimized to view Mo K-alpha x-rays (17.5 keV). In addition, we will present preliminary measurements of the point-spread function as well as the spectral sensitivity of the instrument.

*Sandia National Laboratories is a multimission laboratory managed and operated by NTESS, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. DOE’s NNSA under contract DE-NA-0003525.
surements in laser ablation Z-pinch experiments* ERIC DUTRA, RADU PRESURA, Nevada National Security Site, Livermore Operation, Livermore, Ca 94550 WILLIAM ANGERMEIER, ROBERTO MANCINI, AARON COVINGTON, Department of Physics, University of Nevada, Reno, NV 89557 In plasma pinch experiments, measurements of current distributions and losses across the anode-cathode (A-K) gap are needed to ensure uniform and repeatable implosions. Traditional B-dots measure current a considerable distance away from the plasma source and provide little detailed information on the current distribution across the plasma sheath near the pinch. In the experiments presented here, visible spectroscopic techniques were used to measure magnetically induced Zeeman splitting. Ionic plasma species were chosen such that the Zeeman splitting of different fine structure doublets splits non-uniformly with increasing magnetic field strength in the plasma. This differential splitting enables measurements of non-directional B-field strengths in the plasma across a wide range of conditions. More specifically, the optical emission of Al III, C IV, and O VI doublets, $^2P_{3/2}$ to $^2S_{1/2}$ and $^2P_{1/2}$ to $^2S_{1/2}$ transitions were measured and used to determine the Zeeman broadening. We have applied this technique to diagnose time- and space-resolved B-field strengths in laser ablation Z-pinch experiments (LAZE). Experiments were conducted at the Nevada Terawatt Facility (NTF) using the TW-class laser, which turns the target material (silicon, copper, etc.) into a stream of charged particles creating a smooth and uniform layer onto the substrate. Plasma vapor deposition homogenizes the surface morphology of the sample, reducing the surface area and developing a surface layer which should decrease the outgassing rate and make it impermeable to gasses and unreactive to chemisorption. The outgassing data is compared for each sample before and after post-processing.

**TP11 21 Diagnostic for Measuring the Ion Density Ratio in a Plasma with Two Ion Species** JEFFREY ROBERTSON, STEVE VINCENA, TROY CARTER, PATRICK PRIBYL, Univ of California - Los Angeles Understanding of turbulence and transport in multi-ion species plasmas is important for establishing predictive capability for burning tokamak plasmas with comparable densities of D and T. In order to effectively analyze plasmas with multiple ion species, a new diagnostic is needed in order to measure the density profiles of the individual ion species. In plasmas with two ion species, an ion-ion hybrid resonance frequency exists, from which one can estimate the ratio of the two ion densities [1]. Previous work has been able to successfully measure this resonant frequency on a global scale via observing cutoff for shear Alfvén waves [2]. However, in order to make spatially-resolved measurements a new diagnostic is needed. A new antenna diagnostic was developed to measure the ion-ion hybrid resonance frequency locally in the Large Plasma Device. Initial results using mixes of Helium and Neon will be presented. Additionally, theoretical work was done in order to expand the regime of plasma parameters in which this diagnostic may be applied.


**TP11 22 Direct measurement of the concentration of metastable ions produced from neutral gas particles using laser-induced fluorescence** FENG CHU, FRED SKIFF, JORGE BERMUEN, SEAN MATTINGLY, RYAN HOOD, University of Iowa Extensive information can be obtained on wave-particle interactions and wave fields by direct measurement of perturbed ion distribution functions using laser-induced fluorescence (LIF). For practical purposes, LIF is frequently performed on metastables that are produced from neutral gas particles and existing ions in other electronic states. We numerically simulate the ion velocity distribution measurement and wave-detection process using a Lagrangian model for the LIF signal. The results show that under circumstances where the metastable ion population is coming directly from the ionization of neutrals (as opposed to the excitation of ground-state ions), the velocity distribution will only faithfully represent processes which act on the ion dynamics in a time shorter than the metastable lifetime. Therefore, it is important to know the ratio of metastable population coming from neutrals to that from existing ions to correct the LIF measurements of plasma ion temperature and electrostatic waves. In this paper, we experimentally investigate the ratio of these two populations by externally launching an ion acoustic wave and comparing the wave amplitudes that are measured with LIF and a Langmuir probe using a lock-in amplifier.

**TP11 23 Towards Direct DC Conductivity of Warm Dense Matter Measured by Single-Shot THz Spectroscopy** BENJAMIN OFORI-OKAI, SLAC - Natl Accelerator Lab BRANDON RUSSELL, University of Alberta ZHIJIANG CHEN, SLAC - Natl Accelerator Lab YING TSUI, University of Alberta SIEGFRIED GLEN-
ZER, SLAC - Natl Accelerator Lab  Single-shot terahertz time-domain spectroscopy (THz-TDS) is a promising tool for characterizing properties of materials undergoing irreversible changes (e.g. the complex refractive index or conductivity). The drawback to this is the low signal-to-noise ratio. Maximizing this is important for studies of irreversible processes with small signals or modulation. We present a method for balancing shot-to-shot fluctuations based on: (a) simultaneous detection of single-shot traces, and (b) the use of correlation functions. The method is compared against the state of the art polarization-gated balancing scheme. We use our technique to determine the conductivity of a gold thin film using a transmission configuration. Finally, we present preliminary results on laser heated gold films.

*This work is supported by DOE FES under FWP 100182.

TP11 24 Experimental Results from a Laser-Triggered, Gas-Insulated, Spark-Gap Switch J. F. CAMACHO, Leidio E. L. RUDEN, M. T. DOMONKOS, Air Force Research Laboratory. We are performing experiments on a laser-triggered spark-gap switch with the goal of studying the transition from photoionization to current conduction. The discharge of current through the switch is triggered by a focused 532-nm wavelength beam from a Q-switched Nd:YAG laser with a pulse duration of about 10 ns. The trigger pulse is delivered along the longitudinal axis of the switch, and the focal spot can be placed anywhere along the axis of the 5-mm, gas-insulated gap between the switch electrodes. The switch test bed is designed to support a variety of working gases (e.g., Ar, N₂) over a range of pressures. Electrical and optical diagnostics are used to measure switch performance as a function of parameters such as charge voltage, trigger pulse energy, insulating gas pressure, and gas species. A Mach-Zehnder imaging interferometer system operating at 532 nm is being used to obtain interferograms of the discharge plasma in the switch. We are also developing a 1064-nm interferometry diagnostic in an attempt to measure plasma free electron and neutral gas density profiles simultaneously within the switch gap. Results from our most recent experiments will be presented.

TP11 25 Maximum entropy reconstruction of poloidal magnetic field and radial electric field profiles in tokamaks* YI-HANG CHEN, CHUIJIE XIAO, XIAOYI YANG, Peking University TIANBO WANG, Southwestern Institute of Physics TIANCHAO XU, Peking University YI YU, University of Science and Technology of China MIN XU, Southwestern Institute of Physics LONG WANG, Chinese Academy of Science CHEN LIN, Peking University XIAOGANG WANG, Harbin Institute of Technology. The Laser-driven Ion beam trace probe (LITP) [1, 2] is a new diagnostic method for measuring poloidal magnetic field (Bₚ) and radial electric field (Eᵣ) in tokamaks. LITP injects a laser-driven ion beam into the tokamak, and Bₚ and Eᵣ profiles can be reconstructed using tomography methods. A reconstruction code has been developed to validate the LITP theory, and both 2D reconstruction of Bₚ and simultaneous reconstruction of Bₚ and Eᵣ have been attained [2]. To reconstruct from experimental data with noise, Maximum Entropy and Gaussian-Bayesian tomography methods were applied and improved according to the characteristics of the LITP problem. With these improved methods, a reconstruction error level below 15% has been attained with a data noise level of 10%. These methods will be further tested and applied in the following LITP experiments.

*Supported by the ITER-CHINA program 2015GB120001, CHINA MOST under 2012YQ030142 and National Natural Science Foundation Abstract of China under 11575014 and 11375053.


TP11 26 Absolute calibration of Phase Contrast Imaging on HL-2A tokamak* YI YU, SHAOBO GONG, University of Science and Technology of China MIN XU, Southwestern Institute of Physics YIFAN WU, BODA YUAN, MINYOU YE, University of Science and Technology of China XURU DUAN, Southwestern Institute of Physics HL-2A TEAM TEAM Phase contrast imaging (PCI) has recently been developed on HL-2A tokamak. In this paper we present the calibration of this diagnostic. This system is to diagnose chord integral density fluctuations by measuring the phase shift of a CO₂ laser beam with a wavelength of 10.6 μm when the laser beam passes through plasma. Sound waves are used to calibrate PCI diagnostic. The signal series in different PCI channels show a pronounced modulation of incident laser beam by the sound wave. Frequency-wavenumber spectrum is achieved. Calibrations by sound waves with different frequencies exhibit a maximal wavenumber response of 12 cm⁻¹. The conversion relationship between the chord integral plasma density fluctuation and the signal intensity is 2.3·10⁻¹³ m⁻²W⁻¹, indicating a high sensitivity.

*Supported by the National Magnetic Confinement Fusion Energy Research Project (Grant No.2015GB120002, 2013GB107001).

TP11 27 Fast Plasma Potential Measurements Using an Emissive Probe AMANDA READY, MICHAEL CLARK, DOUGLASS ENDRIZZL, CARY FOREST, ETHAN PETERSON, Univ of Wisconsin, Madison A heated emissive probe was developed for making direct plasma potential (Vₑ) measurements in rapidly fluctuating plasmas. Previous experiments on the Big Red Ball (BRB) were hindered by sudden potential drops, making Langmuir measurements of the plasma potential difficult. DC heating of a tungsten filament to emission allowed for fast (4 MHz) floating potential measurements that closely matched Vₑ. Two BRB experiments currently use the emissive probe. The investigation of unmagnetized, collisionless shocks used plasma potential measurements to study the sub-structure of strong plasma shocks. A separate investigation of emulated magnetospheres in laboratory plasmas used the plasma potential to map the equilibria and instabilities in the electric field of such structures. Results showing electric field measurements and comparison with cold Langmuir measurements will be presented. Future plans for probe modifications and applications to other experiments on the BRB will also be shown.

TP11 28 Progress in joining, reuse, and customization of WR284 waveguide in the laboratory* MIKE CLARK, KEN FLANAGAN, JASON MILHONE, PAUL NONN, CARY FOREST, University of Wisconsin - Madison A system of five 20 kW magnetrons is being installed for the Big Red Ball (BRB) to produce and heat the plasma with 2.45GHz RF energy. An existing system of two 6 kW magnetrons of the same frequency is actively used for the same purpose on Plasma Couette Experiment Upgrade (PCX-U). In each experiment, the RF is transmitted to the vessel via WR284 waveguide. Waveguide occasionally needs to be disassembled, modified and rebuilt for different reasons such as physics interests, ongoing problems (arcing), or efficient utilization of laboratory space. Reuse of disassembled waveguide parts is desirable for cost savings. Methods of assembly, disassembly, and modification of waveguide will be discussed. Also, frequently used designs of chokes, windows, and limiters will be shown. Materials used include copper, brass, and even aluminum. The vacuum vessel of PCX-U is a 1 meter diameter, 1 meter tall cylinder comprised of 1/8" thick stainless steel. PCX-U has one removable end. The vacuum vessel of the BRB is a 3 meter diameter, sphere comprised of two hemispheres of 1-1/2" thick cast...
A356 aluminum. Rings comprised of hundreds of SmCo magnets in each vessel create a cusp field to contain the plasma and provide a resonance surface for the RF.

*Supported by NSF and DoE.

TP11 29 INTENSE BEAMS, ION ACCELERATION, AND LASER-SOLID INTERACTIONS

TP11 30 Plasma Wakefield Excitation in a Cold Magnetized Plasma for Particle Acceleration* MITHUN KARMAKAR, NIKHIL CHAKRABARTI, Saha Institute of Nuclear Physics SUDIP SENGUPTA, Institute for Plasma Research A numerical study has been done to find a travelling wave solution for a highly relativistic electron beam driven cold magnetized plasma. The presence of magnetic field has an effect to reduce the transformer ratio (the ratio of energy gain to the drive beam energy) from its unmagnetized value. The effects of beam shape and the non-relativistic ion motion on the nonlinear structures of different dynamical variables are also discussed. The results owe its significance in the laboratory context of particle acceleration or in the study of generation of ultrahigh accelerating charged particle by strong plasma wave in astrophysical situations.

*Department of Atomic Energy of India and Homi Bhabha National Institute.

TP11 31 Fluid Simulation of relativistic electron beam driven wakefield in the blowout regime* RATAN KUMAR BERA, AMITA DAS, SUDIP SENGUPTA, Inst for Plasma Res Two-dimensional Fluid simulations are employed to study the Wakefield driven by an electron beam in a plasma medium. The 1-D results [1] are recovered when the transverse extent of the beam is chosen to be much longer than its longitudinal extent. Furthermore, it is shown that the blowout structure matches closely with the PIC observations, before the phase mixing. A close comparison of the fluid observations with the analytical modeling made by Lu et al. [2] to PIC observations, have been provided. It is thus interesting to note that a simplified fluid simulation adequately represents the form of the wake potential obtained by sophisticated PIC studies. We also address issues related to particle acceleration in such a potential structure by studying the evolution of injected test particles. A maximum energy gain of ~ 2.8 GeV by the electrons from the back of the driver beam of energy ~ 28.5 GeV in a 10 cm long plasma is shown to be achieved. This is in conformity with the experimental result of Ref. [3]. We observe that maximum energy gain can get doubled to ~ 5.7 GeV when the bunch of test particles was placed near the axial edge of the first blowout structure.

*Inst. for Plasma Research.


TP11 32 Influence of proton bunch and plasma parameters on the AWAKE experiment MARIANA MOREIRA, JORGE VIEIRA, Inst Superior Tecnico (IST) PATRIC MUGGLI, Max-Planck Institute for Physics The Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) at CERN will test the concept underlying plasma wakefield acceleration using long proton beams that undergo the self-modulation instability. The effectiveness of the experiment hinges on the successful and predictable development of this instability, which fragments the initial proton bunch into smaller beamlets with lengths of the order of the plasma wavelength. Since the initial parameters of the experiment inevitably vary from event to event, this work will aim to understand the correlation between these variations and the resulting wakefield. Using both theoretical models and numerical particle-in-cell simulations, the influence of variations in initial bunch charge, bunch dimensions, bunch energy and plasma density profile on the excited accelerating gradients and on the final energies reached by the witness particles will be investigated. In addition, further options in the experiment setup will be explored with the aim of optimizing the results.

TP11 33 Enhancement of the Transformer Ratio in a Plasma Wakefield Accelerator Using an Additional Long Laser Pulse* XI ZHANG, VLADIMIR KHUDIK, The University of Texas at Austin and Cornell University TIANHONG WANG, GENNADY SHVETS, Cornell University Direct laser acceleration (DLA) in both the plasma bubble accelerating regime and the plasma bubble decelerating regime has been recently proposed [1,2,3]. Here we introduce the DLA into the beam-driven plasma wakefield acceleration (PWFA), and report the increase of the transformer ratio through DLA. Instead of interacting with the witness beam directly, the long laser pulse interacts with the driving electron beam and accelerates it through the mechanism of DLA in the plasma bubble decelerating regime. The energy of the driving electron beam is maintained for much longer time compared with the standard PWFA. Therefore, the witness beam gains much more energy without losing its beam quality. Due to the long pump depletion length of the laser pulse, the above PWFA scheme is extended from the single stage to the multi-stage and verified through self-consistent 2D PIC simulations.

*This work is supported by the US DOE Grant DE-SC0007889 and the AFSOR Grant FA9550-14-1-0045.


TP11 34 Cherenkov wakefield excitation by relativistic electron beams in plasma channels TIANHONG WANG, Cornell University VLADIMIR KHUDIK, University of Texas at Austin GENNADY SHVETS, Cornell University We report on our theoretical Investigations of Cherenkov radiation excited by relativistic electron bunches propagating in plasma channels and in polaritonic channels [1]. Two surface plasmons (SPs) modes of the radiation are analyzed: the longitudinal (accelerating) and the transverse (deflecting) ones. Both form Cherenkov cones that are different in the magnitude of the cone angle and the central frequency. We show that the Cherenkov field profile change dramatically depending on the driver velocity and the channel size, and the longitudinal mode forms a reversed Cherenkov radiation cone due to the negative group velocity for sufficiently small air gaps. In addition, we find that when the channel surface is corrugated, a strong deflecting wake is excited by a relativistic electron bunch. A trailing electron bunch experiencing this wake is forced to undergo betatron oscillations and thus to emit radiation. Numerical simulation showed that intense x-ray radiation can be generated.


TP11 35 Cherenkov-cyclotron instability in a metamaterial loaded waveguide for high power generation* XUEYING LU,
MICHAEL SHAFTAIL, RICHARD TEMKIN, Massachusetts Inst of Tech-MIT This work presents the analytical theory for an S-band high power microwave experiment at MIT utilizing a metamaterial (MTM) structure. A 490 kV, 84 A electron beam travels through a rectangular waveguide loaded with two MTM plates in a DC magnetic field $B_0$. The excited waveguide mode is deflecting with a transverse $E$ field on beam axis. Microsecond long megawatt level microwave pulses were generated under a low $B_0$ in the Cherenkov-cyclotron type of interaction. A linear theory has been developed to explain the high power generation due to the Cherenkov-cyclotron instability. The simplified model is a planar waveguide filled with a double negative dispersive medium, and in the mode being studied, the longitudinal $E$ field has an antisymmetric pattern in the direction perpendicular to the MTM plates. We have proved that the Cherenkov-cyclotron instability can happen with a zero initial transverse beam velocity when $B_0$ is below a threshold. Also this instability is a unique feature of the left-handed MTM, since it requires a propagating mode below the cut-off frequency. The minimum beam current to start the instability is calculated, and the scaling law different from that of the traditional backward wave oscillators operated by longitudinal bunching will be discussed.

*This research was supported by the Air Force Office of Scientific Research within the Multidisciplinary University Research Initiative under Grant No. FA9550-12-1-0489 through the University of New Mexico.

TP11 36 Experimental Testing of a Metamaterial Slow Wave Structure for High-Power Microwave Generation* K. SHIPMAN, S. PRASAD, D. ANDREEV, D.M. FISHER, D.B. REASS, E. SCHAINOGLU, M. GILMORE, University of New Mexico A high-power L band source has been developed using a metamaterial (MTM) to produce a double negative slow wave structure (SWS) for interaction with an electron beam. The beam is generated by a 700 kV, 6 kA short pulse (10 ns) accelerator. The design of the SWS consists of a cylindrical waveguide, loaded with alternating split-rings that are arrayed axially down the waveguide. The beam is guided down the center of the rings, where electrons interact with the MTM-SWS producing radiation. Power is extracted axially via a circular waveguide, and radiated by a horn antenna. Microwaves are characterized by an external detector placed in a waveguide. Mode characterization is performed using a neon bulb array. The bulbs are lit by the electric field, resulting in an excitation pattern that resembles the field pattern. This is imaged using an SLR camera. The MTM structure has electrically small features so breakdown is minimally affected by these random variations. We next ignore these random variations, but include finite reflections at the two surfaces and tunneling through the surface under external fields.

*This work was supported by the Air Force Office of Scientific Research, MURI Grant FA9550-12-1-0489.

TP11 37 Absolute Instability near Band Edges in a Traveling Wave Tube* FOIVOS ANTOULAKIS, Y.Y. LAU, PATRICK WONG, ABHIJIT JASSEM, University of Michigan We examine the beam mode and its interaction with the circuit mode near the lower and upper band edges in a traveling wave tube. We find that an absolute instability may arise, according to the Briggs-Bers criterion, if the beam current is sufficiently high, even if the beam mode intersects with the circuit mode at a point in the $(w, k)=$ (frequency, wavenumber) plane with a positive group velocity. This finding differs from the previous works [1, 2] for the lower band edge, and points to the vulnerability to absolute instabilities at both the upper and lower band edges of a TWT. When the threshold current is exceeded, the Green’s function, at a fixed position, exponentially in time at $t^{+1/3}$ initially, but as $(w_i^{+})$ at later time, where $w_i$ is the imaginary part of $w$ in the unstable pole-root region.

*Work supported by AFOSR Awards Nos. FA9550-14-1-0309, FA9550-15-1-0097, DARPA contract HR0011-16-C-0080 with Leidos, Inc., and L-3 Communications.


TP11 38 An Exact Hot-Tube Solution For Thin Tape Helix Traveling-Wave Tube* PATRICK WONG, Y.Y. LAU, RONALD GILGENBACH, University of Michigan We propose to employ Diamond Field-Emitter-Arrays (DFEA) that includes carriers’ transport to the emitter surface and tunneling through the surface under external fields.
The model accounts for the electronic structure size quantization affecting the transport and tunneling process within the sharp diamond tips. We compare this first principle model with other field emission models, such as the Child-Langmuir and Murphy-Good models. By further including effects of carrier photoexcitation, we perform simulations of the DFEAs’ photoemission quantum yield and the emitted electron beam. Details of the theoretical model and validation against preliminary experimental data will be presented.

*Work supported by LDRD program at LANL.

TP11 41 Research of the Electron Cyclotron Emission with Vortex Property excited by high power high frequency Gyrotron

YUKI GOTO, Nagoya Univ; SHIN KUBO, National Institute for Fusion Science, Nagoya Univ; TOHRU TSUJIMURA, HIDENORI TAKUBO, National Institute for Fusion Science Recently, it has been shown that the radiation from a single electron in cyclotron motion has vortex property. Although the cyclotron emission exists universally in nature, the vortex property has not been featured because this property is normally cancelled out due to the randomness in gyro-phase of electrons and the development of detection of the vortex property has not been well motivated. In this research, we are developing a method to generate the vortex radiation from electrons in cyclotron motion with controlled gyro-phase. Electron that rotates around the uniform static magnetic field is accelerated by right-hand circular polarized (RHCP) radiation resonantly when the cyclotron frequency coincides with the applied RHCP radiation frequency. A large number of electrons can be coherently accelerated in gyro-phase by a RHCP high power radiation so that these electrons can radiate coherent emission with vortex feature. We will show that vortex radiation created by purely rotating electrons for the first time.

TP11 42 DD fusion neutron production at UW-Madison using IEC devices

AARON FANCHER, MATT MICHALAK, GERALD KULCINSKI, JOHN SATANTUARIS, RICHARD BONOVO, University of Wisconsin-Madison An inertial electrostatic confinement (IEC) device using spherical, gridded electrodes at high voltage accelerates deuterium ions, allowing for neutrons to be produced within the device from DD fusion reactions. The effects of the device cathode voltage (30-170 kV), current (30-100 mA), and pressure (0.15-1.25 mTorr) on the neutron production rate have been measured. New high voltage capabilities have resulted in the achievement of a steady state neutron production rate of 3.3x10^9 n/s at 175 kV, 100 mA, and 1.0 mTorr of deuterium. Applications of IEC devices include the production of DD neutrons to detect chemical reactions at 175 kV, 100 mA, and 1.0 mTorr of deuterium. Details of the theoretical model and validation against preliminary experimental data will be presented.

TP11 43 Linear Inertial-Electrostatic Fusion Neutron Sources and Highly Enriched Uranium Detection

JOHN SATANTUARIS, GERALD KULCINSKI, MARCOS NAVARRO, AARON FANCHER, RICHARD BONOVO, GILBERT EMMERT, UW-Madison A newly initiated research project investigates methods for detecting shielded highly enriched uranium (HEU) and other special nuclear materials by combining multi-dimensional neutron sources, forward/adjoint calculations modeling neutron and gamma transport, and sparse data analysis of detector signals. An overview of the project will be presented, and progress will be described in: (1) developing optimized, adaptive-geometry, inertial-electrostatic confinement (IEC) neutron source configurations with neutron pulse distributed in space and/or phased in time, and (2) applying sparse data algorithms, such as principal component analysis (PCA) to enhance detection fidelity.


TP11 44 A Compact Self-Driven Liquid Lithium Loop for Industrial Neutron Generation

STEVEN STEMMLEY, MATT SZOTT, KISHOR KALATHIPARAMBIL, CHISING AHN, Univ of Illinois - Urbana BRIAN JURCZYK, Starfire Industries DAVID RUIZIC, Univ of Illinois - Urbana A compact, closed liquid lithium loop has been developed at the University of Illinois to test and utilize the Li-7(d,n) reaction. The liquid metal loop is housed in a stainless steel trench module with embedded heating and cooling. The system was designed to handle large heat and particle fluxes for use in neutron generators as well as fusion devices, solely operating via thermo-electric MHD. The objectives of this project are two-fold, 1) produce a high energy, MeV-level, neutron source and 2) provide a self-healing, low Z, low recycling plasma facing component. The flowing volume will keep a fresh, clean, lithium surface allowing Li-7(d,n) reactions to occur as well as deuterium adsorption in the fluid, increasing the overall neutron output. Expected yields of this system are 10^8 n/s for 13.5 MeV neutrons and 10^6 n/s for 2.45 MeV neutrons. Previous work has shown that using a tapered trench design prevents dry out and allows for an increase in velocity of the fluid at the particle strike point. For heat fluxes on the order of 10^5 MW/m^2, COMSOL models have shown that high enough velocities (70 cm/s) are attainable to prevent significant lithium evaporation. Future work will be aimed at addressing wetting issues of lithium in the trenches, experimentally determine the velocities required to prevent dry out, and determine the neutron output of the system. The preliminary results and discussion will be presented.

*DOE SBIR project DE-SC0013861.

TP11 45 Ion acceleration and neutron production from intense laser interactions with underdense plasmas using OMEGA EP

KARL KRUSHEL Nick, P. KORDELL, A. MAKSIMCHUK, A. HUSSEIN, A.G.R. THOMAS, L. WILLINGALE, Univ of Michigan - Ann Arbor C. ZULICK, US Naval Research Laboratory P. M. NILSON, C. STOECKL, R. S. CRAXTON, Laboratory for Laser Energetics The interaction of the OMEGA EP short pulse laser beam (up to 1.4 kJ at 10 psec) with underdense preformed plasmas was investigated. Using deuterated plastic targets significant neutron emission was measured using a Time-of-Flight neutron spectrometer. The spectrum of radially accelerated ions was also measured using a Thomson parabola ion spectrometer and was found to be complex, containing many narrow energy spread features. The experimental results are compared with numerical simulations.

*This work was supported by the DOE through Grant Number DE-NA0002723.

TP11 46 Ion acceleration driven by a relativistic electron beam under a strong magnetic field

TOSHIHIRO TAGUCHI, Setsunan University THOMAS ANTONSEN, University of Maryland KU NIOKIMIMA, Graduate School for the Creation of New Photonics Industries We have been investigating about an electron beam propagation under a strong magnetic field and found a very interesting phenomena. It is a generation of a large amplitude whistler wave, which is amplified by a nonlinear coupling of obliquely propagating circularly polarized waves [1]. Since the previous work did not include ion motions, such a giant whistler wave mainly affects on
beam electrons and they stagnate due to a large ponderomotive force of the electromagnetic wave. In order to investigate the influence of the strong wave on background ions, we have developed a new PIC code which has an open (upstream and downstream) boundaries. By using the new code, we have been studying the kinetic behavior of ions in a circumstance generating a large whistler wave. As a result, it is found that the electrostatic field induced by the stagnated beam electrons not only creates a density dip in the background electrons but also accelerates background ions. We will discuss the relation between the ion acceleration and a formation of a collisionless shock wave.

*This work was supported by a Grant-in-Aid for Scientific Research (B), 15H03758.


**TP11 47 Simulations of laser-driven ion acceleration from a thin CH target** JEAEHONG PARK, STEPAN BULANOV, QING JI, SVEN STEINKE, FRANZISKA TRESTREFF, JEAN-LUC VAY, THOMAS SCHENKEL, ERIC ESAREY, WIM LEMANS, Lawrence Berkeley National Laboratory HENRI VINCENTI, LIDYL, CEA, CNRS, Universite Paris-Saclay 2D and 3D computer simulations of laser driven ion acceleration from a thin CH foil using code WARP were performed. As the foil thickness varies from a few nm to μm, the simulations confirm that the acceleration mechanism transitions from the RPA (radiation pressure acceleration) to the TNSA (target normal sheath acceleration). In the TNSA regime, with the CH target thickness of 1μm and a pre-plasma ahead of the target, the simulations show the production of the collimated proton beam with the maximum energy of about 10 MeV. This agrees with the experimental results obtained at the BELLA laser facility (1 < 5 × 18W/cm², λ = 800nm). Furthermore, the maximum proton energy dependence on different setups of the initialization, i.e., different angles of the laser incidence from the target normal axis, different gradient scales and distributions of the pre-plasma, was explored.

*This work was supported by LDRD funding from LBNL, provided by the U.S. DOE under Contract No. DE-AC02-05CH11231, and used resources of the NERSC, a DOE office of Science User Facility supported by the U.S. DOE under Contract No. DE-AC02-05CH11231.

**TP11 48 Laser- driven protons and electrons leave X-ray fluorescence signatures in Cu foam** J KIM, C MCGUFFEY, Univ of California - San Diego C KRAULAND, General Atomics F BEG, Univ of California - San Diego M WEI, General Atomic Y UEMATSU, Y YOSHIDA, S NOMA, D NII, S NAKAGUCHI, H HABARA, K TANAKA, A MORACE, Osaka University Y ARIKAWA, S LEE, H SHIRAGA, Institute of Laser Engineering P GRABOWSKI, Lawrence Livermore National Laboratory Rapid energy delivery and local deposition make intense ion beams appealing for fundamental studies and their heating applications including creation of warm dense matter (WDM) samples in a controllable laboratory setting. The LFEX laser with ~kilojoule energy and 1.5 ps pulse duration was used to direct an intense proton and electron beam into a copper foam sample. While they deposit energy, protons and electrons traveling in the Cu foam induce Cu K-alpha emissions, which are imaged to visualize the beam transport and spatial energy deposition throughout the foam. Simulations using a hybrid particle-in-cell (PIC) code clearly show that electrons stop rapidly while protons travel to a deeper depth in the foam. The modeled K-alpha generation spatial profile along the foam presents good agreement with experimental measurement. Detailed experimental results including proton spectrum for different target conditions and simulations explaining beam transport and energy deposition will be presented.

*This work was supported by the U.S. AFOSR under Contract FA9550-14-1-0346 and the Japanese NIFS Project No. #NIFS13KUGK069.

**TP11 49 Investigation of self-induced transparency in laser-solid interaction** BHOOSHAN PARADKAR, UM-DAE Centre for Excellence in Basic Sciences, University of Mumbai SERGEI KRASHENINNIKOV, FARHAT BEG, University of California, San Diego Interaction of an intense laser beam with a thin (<laser wavelength) target in the radiation pressure acceleration (RPA) regime can lead to efficient acceleration of ions. In this regime, the electrons are strongly heated when the target becomes transparent to the incident laser. Therefore, understanding the role of this self-induced transparency (SIT) is crucial for controlling the quality of the accelerated ion beam. In this work, we present detailed numerical investigation of SIT using the 1-D and 2-D Particle-In-Cell simulations. In particular, threshold target thickness below which SIT is effective will be reported for the wide range of laser parameters such as intensity (normalize vector potential ∼10-30), pulse duration (10 – 100 fs) and polarization (linear/circular). The mechanism of SIT in both 1-D and 2-D simulations will be presented.

*The work has been partially supported by the University of California Office of the President Lab Fee Grant Number LFR-17-449059.

1University of California, San Diego.

**TP11 50 Using Microstructured Targets to Determine Energy Distribution and Number of Hot Electrons in Laser Ion Acceleration Experiments** FRANKI AYMOND, TAO WANG, ALEX AREFIEV, TODD DITMIERE, University of Texas at Austin Laser ion acceleration via microstructured targets is an emerging field of much interest. 2D pic simulations (EPOCH) using grating like microstructured targets show not only the enhancement of hot electron temperature and number but also that by adjusting target geometry we are able to selectively control hot electron temperature and number. This allows one to pre-select ion energies and number in laser ion acceleration experiments, which is a crucial next step in feasibility of laser ion acceleration applications (including hadron cancer therapy, neutron beam generation and warm dense matter studies). In addition to simulated results, preliminary experimental data from the University of Texas’s Ghost laser (10¹⁵ W/cm²) will also be presented.

**TP11 51 Stochastic heating in laser interaction with ultra-thin foils** JOANA LUIS MARTINS, EVANGELOS SIMINOS, TUNDE FULOP, Department of Physics, Chalmers University of Technology, 41296 Gothenburg, Sweden Stochastic heating of electrons in multiple counter-propagating electromagnetic waves has been investigated theoretically and numerically in numerous works since the 80s (e.g. Ref. [1]). Stochastic heating has been invoked as a possible mechanism responsible for electron heating in scenarios such as laser interaction with thin foils for ion acceleration and electron heating in beat-wave injection. However, a clear experimental verification of this heating process has not been done, to our knowledge. In this work, we examine electron heating during the interaction of multiple laser pulses with ultra-thin foils (a few atomic layers wide) through numerical particle-in-cell and particle-particle simulations. Such targets could prevent the development of instabilities/processes which could hinder the interpretation of observations. We include realistic temporally and spatially finite laser
pulses and targets and explore in detail possible setups for an experimental observation of stochastic heating, analyzing signatures in the electron energy spectra, angular distribution, and radiation emission.

Mendonça and Doveil, JPP 28, 485 (1982).

TP11 52 Extreme laser-driven magnetic fields: from generation to possible detection

TP11 55 The scattering of electromagnetic waves from turbulent plasmas

A. K. RAM, MIT-PFSC K. HIZANIDIS, NTUA, Greece

In fusion devices, radio frequency (RF) electromagnetic waves encounter turbulent plasmas along their path from the excitation structures to the core of the plasma. In order to optimize heating and current drive by the RF waves, it is necessary to understand the effect of the density turbulence on the propagation characteristics of the waves. A common approach towards quantifying the effects of turbulence is the Kirchhoff technique. Here the wave fields and their normal derivatives are evaluated at a surface separating two different densities using physical optics. The fields at any point on this surface are approximated to be the same as the fields on a tangent plane at that point. Using the Kirchhoff technique, we show that turbulence can lead to changes in the propagation vector and polarization of the waves, side-scattering, and coupling between different plasma waves. This affects the spatial uniformity of power flow into the plasma. Full wave analytical calculations and numerical simulations confirm these physical results. The theory applies to all RF waves, irrespective of their frequency, and allows for arbitrary plasma density variations.

*Supported by DoE Grant DE-FG02-91ER54109 and in part by the Hellenic National Programme on Controlled Thermocuclear Fusion associated with the EUROfusion Consortium.

TP11 56 Propagation of radio frequency waves through density fluctuations

S. I. VALVIS, P. PAPAGIANNIS, A. PAPADOPOULOS, K. HIZANIDIS, E. GLYTSIS, F. BAIRAKTARIS, NTUA, Greece

A. ZISIS, I. TIGELIS, A. K. RAM, MIT-PFSC

On their way to the core of a tokamak plasma, radio frequency (RF) waves, excited in the vacuum region, have to propagate through a variety of density fluctuations in the edge region. These fluctuations include coherent structures, like blobs that can be field aligned or not, as well as turbulent and filamentary structures. We have been studying the effect of fluctuations on RF propagation using both theoretical (analytical) and computational models. The theoretical results are being compared with those obtained by two different numerical codes “a Finite Difference Frequency Domain code and the commercial COMSOL package. For plasmas with arbitrary distribution of coherent and turbulent fluctuations, we have formulated an effective dielectric permittivity of the edge plasma. This permittivity tensor is then used in numerical simulations to study the effect of multi-scale turbulence on RF waves. We not only consider plane waves but also Gaussian beams in the electron cyclotron and lower hybrid range of frequencies. The analytical theory and results from simulations on the propagation of RF waves will be presented.

*Supported in part by the Hellenic National Programme on Controlled Thermocuclear Fusion associated with the EUROfusion Consortium and by DoE Grant DE-FG02-91ER54109.

TP11 57 Quasilinear diffusion operator for wave-particle interactions in inhomogeneous magnetic fields

P. J. CATTO, J. LEE, A. K. RAM, MIT-PFSC

The Kennel-Engelmann quasilinear diffusion operator for wave-particle interactions is for plasmas in a uniform magnetic field. The operator is not suitable for fusion devices with inhomogeneous magnetic fields. Using drift kinetic and
high frequency gyrokinetic equations for the particle distribution function, we have derived a quasilinear operator which includes magnetic drifts. The operator applies to RF waves in any frequency range and is particularly relevant for minority ion heating. In order to obtain a physically meaningful operator, the first order correction to the particle’s magnetic moment has to be retained. Consequently, the gyrokinetic change of variables has to be retained to a higher order than usual. We then determine the perturbed distribution function from the gyrokinetic equation using a novel technique that solves the kinetic equation explicitly for certain parts of the function. The final form of the diffusion operator is compact and completely expressed in terms of the drift kinetic variables. It is not transit averaged and retains the full poloidal angle variation without any Fourier decomposition. The quasilinear diffusion operator reduces to the Kennel-Engelmann operator for uniform magnetic fields.

*Supported by DoE Grant DE-FG02-91ER54109.

TP11 58 A similarity relation of the coupled equations for RF waves in a tokamak* JUNGPYO LEE, MIT Plasma Science and Fusion Center DAVID SMITHE, Tech-X ERWIN JAEGER, LEE BERRY, XCEL Engineering R. W. HARVEY, CompX PAUL BONOLI, MIT Plasma Science and Fusion Center The propagation and damping of RF waves in plasmas are modeled kinetically by solving the coupled equations between Maxwell’s equation and Fokker-Planck equation. When the plasmas are magnetized, the wave dielectric tensor strongly depends on the background magnetic field, which can be calculated using Grad-Shafranov equation in a toroidally symmetric geometry. We found a similarity in the solutions of the coupled equations above, which keep the several dimensionless parameters constant. By changing plasma density and pressure, machine geometry (major radius), and RF wave frequency and power according to the similarity rule, there exists a set of solutions that show the consistent change in the background magnetic fields in the Grad-Shafranov equation, the electric and magnetic fields in the Maxwell’s equation, and the distribution function of the Fokker-Planck equation. By investigating the numerical errors of the solutions from the expected results by the similarity rule, we verify the coupled numerical code for the RF waves in a tokamak (e.g. TORIC or AORSA/CQL3D/ECOM).

*Supported by US DoE Contract No. DE-FC02-01ER54648 under a Scientific Discovery through Advanced Computing Initiative.

TP11 59 Toroidal Ampere-Faraday Equations Solved Simultaneously with CQL3D Fokker-Planck Time-Evolution† R.W. (BOB) HARVEY, YU.V. (YURI) PETROV, CompX C.B. FORREST, Univ. of Wisconsin-Madison R.J. LA HAYE, General Atomics A self-consistent, time-dependent toroidal electric field calculation is a key feature of a complete 3D Fokker-Planck kinetic distribution radial transport code for (r,t,theta,ph,phi). We discuss benchmarking and first applications of an implementation of the Ampere-Faraday equation for the self-consistent toroidal electric field, as applied to (1) resistive turn on of applied electron cyclotron current in the DIII-D tokamak giving initial back current adjacent to the direct CD region and having possible NTM stabilization implications, and (2) runaway electron production in tokamaks due to rapid reduction of the plasma temperature as occurs in pellet injection, massive gas injection, or a plasma disruption. Our previous results assuming a constant current density (Lenz’ Law) model [1] showed that prompt “hot-tail runaways” dominated “knock-on” and Dreicer “drizzle” runaways; we perform full-radius modeling and examine modifications due to the more complete Ampere-Faraday solution. Presently, the implementation relies on a fixed shape eqdsk, and this limitation will be addressed in future work.

†Supported by DOE Grant DE-SC0017843.

TP11 60 A Finite-Orbit-Width Fokker-Planck solver for modeling of RF Current Drive in ITER* YU.V. PETROV, R.W. HARVEY, CompX The bounce-average (BA) finite-difference Fokker-Planck (FP) code CQL3D [1,2] now includes the essential physics to describe the RF heating of Finite-Orbit-Width (FOW) ions in tokamaks. The FP equation is reformulated in terms of constants-of-motion coordinates, which we select to be particle speed, pitch angle, and major radius on the equatorial plane thus obtaining the distribution function directly at this location. A recent development is the capability to obtain solution simultaneously for FOW ions and Zero-Orbit-Width (ZOW) electrons. As a practical application, the code is used for simulation of alpha-particle heating by high-harmonic waves in ITER scenarios. Coupling of high harmonic or helicon fast waves power to electrons is a promising current drive (CD) scenario for high beta plasmas. However, the efficiency of current drive can be diminished by parasitic channeling of RF power into fast ions such as alphas or NBI-produced deuterons, through finite Larmor-radius effects. Based on simulations, we formulate conditions where the fast ions absorb less than 10% of RF power.

*Supported by USDOE Grants ER54649, ER54744, and SC0006614.

TP11 61 Simulations of Low Power DIII-D Helicon Antenna Coupling* DAVID SMITHE, THOMAS JENKINS, Tech-X Corporation We present an overview and initial progress for a new project to model coupling of the DIII-D Helicon Antenna. We lay the necessary computational groundwork for the modeling of both low-power and high power helicon antenna operation, by constructing numerical representations for both the antenna hardware and the DIII-D plasma. CAD files containing the detailed geometry of the low power antenna hardware are imported into the VSIm software’s FDTD plasma model [1]. The plasma can be represented numerically by importing EQDSK or EFIT files. In addition, approximate analytic forms for the ensuing profiles and fields are constructed to facilitate parameter scans in the various regimes of anticipated antenna operation. To verify the accuracy of the numerical plasma and antenna representations, we will run baseline simulations of low-power antenna operation, and verify that the predictions for loading, linear coupling, and mode partitioning (i.e. into helicon and slow modes) are consistent with the measurements from the low power helicon antenna experimental campaign [2], as well as with other independent models. Progress on these baseline simulations will be presented, and any inconsistencies and issues that arise during this project will be identified.

*Supported by DOE Grant DE-SC0017843.

TP11 62 Waveguide to Core: A New Approach to RF Modelling* JOHN WRIGHT, SYUNICHI SHIRAISHA, M. P. F. SCIDAC TEAM A new technique for the calculation of RF waves in toroidal geometry enables the simultaneous incorporation
of antenna geometry, plasma facing components (PFCs), the scrape off-layer (SOL) and core propagation [Shiraia, NF 2017]. Calculations with this technique naturally capture wave propagation in the SOL and its interactions with non-conforming PFCs permitting self-consistent calculation of core absorption and edge power loss. The main motivating insight is that the core plasma region having closed flux surfaces requires a hot plasma dielectric while the open field line region in the scrape-off layer needs only a cold plasma dielectric. Spectral approaches work well for the former and finite elements work well for the latter. The validity of this process follows directly from the superposition principle of Maxwell’s equations making this technique exact. The method is independent of the codes or representations used and works for any frequency regime. Applications to minority heating in Alcator C-Mod and ITER and high harmonic heating in NSTX-U will be presented in single pass and multi-pass regimes.

*Support from DoE Grant Number DE-FG02-91-ER54109 (theory and computer resources) and DE-FC02-01ER54648 (RF SciDAC).

1Please place together with other RF-SciDAC team posters.

TP11 63 Progress on the development of FullWave, a Hot and Cold Plasma Parallel Full Wave Code* J. ANDREW SPENCER, VLADIMIR SVIDZINSKI, LIANGJI ZHAO, JIN-SOO KIM, FAR-TECH, Inc. FullWave is being developed at FAR-TECH, Inc. to simulate RF waves in hot inhomogeneous magnetized plasmas without making small orbit approximations [1]. FullWave is based on a meshless formulation in configuration space on non-uniform clouds of computational points (CCP) adapted to better resolve plasma resonances, antenna structures and complex boundaries. The linear frequency domain wave equation is formulated using two approaches: for cold plasmas the local cold plasma dielectric tensor is used (solving resonances by particle collisions), while for hot plasmas the conductivity kernel is calculated. The details of FullWave and some preliminary results will be presented, including: 1) a monitor function based on analytic solutions of the cold-plasma dispersion relation; 2) an adaptive CCP based on the monitor function; 3) construction of the finite differences for approximation of derivatives on adaptive CCP; 4) results of 2-D full wave simulations in the cold plasma model in tokamak geometry using the formulated approach for ECRH, ICRH and Lower Hybrid range of frequencies.

*Work is supported by the U.S. DOE SBIR program.

TP11 64 Initial Simulations of RF Waves in Hot Plasmas Using the FullWave Code* LIANGJI ZHAO, VLADIMIR SVIDZINSKI, ANDREW SPENCER, JIN-SOO KIM, FAR-TECH, Inc. FullWave is a simulation tool that models RF fields in hot inhomogeneous magnetized plasmas. The wave equations with linearized hot plasma dielectric response are solved in configuration space on adaptive cloud of computational points. The nonlocal hot plasma dielectric response is formulated by calculating the plasma conductivity kernel based on the solution of the linearized Vlasov equation in inhomogeneous magnetic field. In an rf field, the hot plasma dielectric response is limited to the distance of a few particles’ Larmor radii, near the magnetic field line passing through the test point. The localization of the hot plasma dielectric response results in a sparse matrix of the problem thus significantly reduces the size of the problem and makes the simulations faster. We will present the initial results of modeling of rf waves using the Fullwave code, including calculation of nonlocal conductivity kernel in 2D Tokamak geometry; the interpolation of conductivity kernel from test points to adaptive cloud of computational points; and the results of self-consistent simulations of 2D rf fields using calculated hot plasma conductivity kernel in a tokamak plasma with reduced parameters.

*Work supported by the US DOE “SBIR program.

TP11 65 Development of FullWave: Hot Plasma RF Simulation Tool* VLADIMIR SVIDZINSKI, JIN-SOO KIM, J. ANDREW SPENCER, LIANGJI ZHAO, SERGEI GALKIN, FAR-TECH, Inc. Full wave simulation tool, modeling RF fields in hot inhomogeneous magnetized plasma, is being developed. The wave equations with linearized hot plasma dielectric response are solved in configuration space on adaptive cloud of computational points. The nonlocal hot plasma dielectric response is formulated in configuration space without limiting approximations by calculating the plasma conductivity kernel based on the solution of the linearized Vlasov equation in inhomogeneous magnetic field. This approach allows for better resolution of plasma resonances, antenna structures and complex boundaries. The formulation of FullWave and preliminary results will be presented: construction of the finite differences for approximation of derivatives on adaptive cloud of computational points; model and results of nonlocal conductivity kernel calculation in tokamak geometry; results of 2-D full wave simulations in the cold plasma model in tokamak geometry using the formulated approach; results of self-consistent calculations of hot plasma dielectric response and RF fields in 1-D mirror magnetic field; preliminary results of self-consistent simulations of 2-D RF fields in tokamak using the calculated hot plasma conductivity kernel; development of iterative solver for wave equations.

*Work is supported by the U.S. DOE SBIR program.

TP11 66 Overview of FAR-TECH’s magnetic fusion energy research* JIN-SOO KIM, I. N. BOGATU, S. A. GALKIN, J. ANDREW SPENCER, V.A. SVIDZINSKI, L. ZHAO, FAR-TECH, Inc. FAR-TECH, Inc. has been working on magnetic fusion energy research over two decades. During the years, we have developed unique approaches to help understanding the physics, and resolving issues in magnetic fusion energy. The specific areas of work have been in modeling RF waves in plasmas, MHD modeling and mode-identification, and nano-particle plasma jet and its application to disruption mitigation. Our research highlights in recent years will be presented with examples, specifically, developments of FullWave [1,2,3] (Full Wave RF code), PMARS [4] (Parallelized MARS code), and HEM [5] (Hybrid ElectroMagnetic code). In addition, nano-particle plasma-jet [6] (NPPJ) and its application for disruption mitigation will be presented.

*Work is supported by the U.S. DOE SBIR program.

TP11 67 ORNL diagnostic and modeling development for LAPD ICRF experiments* R.C. ISLER, J.B.O. CAUGHMAN, C. LAU, E.H. MARTIN, ORNL R.J. PERKINS, PPPL B. VAN COMPERNOLLE, S. VINCENA, S.K.P. TRIPATHI, W. GEKELMAN, UCLA PPL, UCLA, and ORNL scientists have recently collaborated on a three week ICRF campaign at the upgraded LAPD device to study near field-plasma interactions associated with a single strap antenna driven at 2.38 MHz with 100 kW of RF power. This poster high-
lights ORNL involvement through implementation of the following diagnostics: an optical emission probe to measure neutral density, a retarding field energy analyzer to measure fast ions, phase locked imaging to measure line integrated RF-driven optical emission fluctuations, and an RF compensated triple Langmuir probe to measure density and temperature. To interpret the results of the experimental campaign a 3D cold plasma finite element model with realistic antenna and vacuum vessel geometry was developed in COMSOL. A summary of these results will be discussed. Highlights include a proof of principle localized and spatially resolved measurement of the neutral density, a strong increase in RF-driven optical emission fluctuations directly in front of the RF antenna strap, a shift in fast ion energies near the plasma edge, and qualitative agreement between the COMSOL cold plasma model with the various diagnostics.

*Work performed at the Basic Plasma Science Facility, supported jointly by the National Science Foundation and the Department of Energy.

**TP11 68 RF Rectification on LAPD and NSTX: the relationship between rectified currents and potentials**

R. J. KRAMER, J. K. PERKINS, P. P. PLL, T. CARTER, UCLA J. B. CAUGHMAN, ORNL B. V. VAN COMPERNOLLE, W. GEKELMAN, UCLA J. C. HOSEA, A. M. JAWORSKI, G. J. KRAMER, P. P. PLL, L. A. E. H. MARTIN, ORNL P. PRIBYL, S. K. P. TRIPATHI, S. VINCENA, UCLA RF rectification is a sheath phenomenon important in the fusion community for impurity injection, hot spot formation on plasma-facing components, modifications of the scrape-off layer, and as a far-field sink of wave power. The latter is of particular concern for the National Spherical Torus eXperiment (NSTX), where a substantial fraction of the fast-wave power is lost to the divertor along scrape-off layer field lines. To assess the relationship between rectified currents and rectified voltages, detailed experiments have been performed on the Large Plasma Device (LAPD). An electron current is measured flowing out of the antenna and into the limiters, consistent with RF rectification with a higher RF potential at the antenna. The scaling of this current with RF power will be presented. The limiters are also floated to inhibit this DC current; the impact of this change on plasma-potential and wave-field measurements will be shown. Comparison to data from divertor probes in NSTX will be made. These experiments on a flexible mid-sized experiment will provide insight and guidance into the effects of ICRF on the edge plasma in larger fusion experiments.

**TP11 69 Fast wave experiments in LAPD: RF sheaths, convective cells and density modifications**

T. A. CARTER, B. V. VAN COMPERNOLLE, M. MARTIN, W. GEKELMAN, P. PRIBYL, UCLA D. V. EESTER, K. CROMBE, Royal Military Academy, Belgium R. PERKINS, P. P. PLL, L. A. E. H. MARTIN, J. CAUGHMAN, ORNL S. K. P. TRIPATHI, S. VINCENA, UCLA An overview is presented of recent work on ICRF physics at the Large Plasma Device (LAPD) at UCLA. The LAPD has typical plasma parameters $n_e \sim 10^{12} - 10^{13} \text{cm}^{-3}$, $T_e \sim 1 - 10 \text{eV}$ and $B \sim 1000 \text{G}$. It is starting. The array of insulated-gate bipolar transistor works to inhibit the input power for protecting the klystron. Current ramp-up efficiency of 0.5 A/W has been obtained with focused beam of the second harmonic X-mode. A quasi-optical polarizer unit has been newly installed to avoid arcing events. For steady-state tokamak operation, 8.56 GHz klystron with power of 200 kW is used as the CW-RF source. The high voltage power supply (54 kV/13 A) for the klystron has been built recently, and initial bench test of the CW-ECH system is starting. The array of insulated-gate bipolar transistor works to quickly cut off the input power for protecting the klystron.

This work is supported by JSPS KAKENHI (15H04231), NIFS Collaboration Research program (NIFS13KUTR085, NIFS17KUTR128), and through MEXT funding for young scientists associated with active promotion of national university reforms.

**TP11 70 Excitation of slow waves in front of an ICRF antenna in a basic plasma experiment**

KUNAL SONI, Ghent University, Belgium BART VAN COMPERNOLLE, University of California, Los Angeles KRISTEL CROMBE, Ghent University, Belgium DIRK VAN EESTER, Royal Military Academy, Belgium Recent results of ICRF experiments at the Large Plasma Device (LAPD) indicate parasitic coupling to the slow wave by the fast wave antenna. Plasma parameters in LAPD are similar to the scrape-off layer of current fusion devices. The machine has a 17 m long, 60 cm diameter magnetized plasma column with typical plasma parameters $n_e \sim 10^{12} - 10^{13} \text{cm}^{-3}$, $T_e \sim 1 - 10 \text{eV}$ and $B_0 \sim 1000 \text{G}$. It was found that coupling to the slow mode occurs when the plasma density in front of the antenna is low enough such that the lower hybrid resonance is present in the plasma. The radial density profile is tailored to allow for fast mode propagation in the high density core and slow mode propagation in the low density edge region. Measurements of the wave fields clearly show two distinct modes, one long wavelength $\lambda \sim 1$ fast wave mode in the core and a short wavelength backward propagating mode in the edge. Perpendicular wave numbers compare favorably to the predicted values. The experiment was done for varying frequencies, $\omega/\Omega_i = 25$, 6 and 1.5. Future experiments will investigate the dependence on antenna tilt angle with respect to the magnetic field, with and without Faraday screen.

This work is performed at the Basic Plasma Science Facility, sponsored jointly by DOE and NSF.
TP11 72 Testing update on gyrotrons for electron cyclotron heating applications KEVIN FELCH, MONICA BLANK, PHILIPP BORCHARD, STEPHEN CAUFFMAN, Communications and Power Industries GYROTRON ENGINEERING TEAM

Tests were recently performed on CPI gyrotrons at frequencies of 117.5 GHz and 140 GHz. At 117.5 GHz, output power levels of 1.67 MW were obtained under short-pulse conditions and long-pulse tests with pulse durations of 1-10 s have been performed with power levels up to 700 kW. The 117.5 GHz gyrotron was shipped to General Atomics where further long-pulse testing to higher power levels will be carried out with the goal of demonstrating power levels up to 1.5 MW for 5-second pulses. At 140 GHz, a CPI gyrotron was recently tested up to 810 kW output power for 30-minute pulses at W7-X in Greifswald, Germany. Design details and the latest test results for the two gyrotrons are presented.

TP11 73 Repetitively Pulsed High Power RF Solid-State System∗ CHRIS BOWMAN, TIMOTHY ZIEMBA, KENNETH E. MILLER, JAMES PRAGER, MORGAN QUINLEY, Eagle Harbor Technologies, Inc. Eagle Harbor Technologies, Inc. (EHT) is developing a low-cost, fully solid-state architecture for the generation of RF frequencies and power levels necessary for plasma heating and diagnostic systems at validation platform experiments within the fusion science community. In Year 1 of this program, EHT has developed a solid-state RF system that combines an inductive adder, nonlinear transmission line (NLTL), and antenna into a single system that can be deployed at fusion science experiments. EHT has designed and optimized a lumped-element NLTL that will be suitable RF generation near the lower-hybrid frequency at the Helicity Injected Torus at the High Beta Tokamak (HBT) located at Columbia University. In Year 2, EHT will test this system at the Helicity Injected Torus at the University of Washington and HBT at Columbia. EHT will present results from Year 1 testing and optimization of the NLTL-based RF system.

∗With support of DOE SBIR.

TP11 74 High Voltage, Solid-State Switch for Fusion Science Applications∗ TIMOTHY ZIEMBA, JAMES PRAGER, KENNETH E. MILLER, ILIA SLOBODOV, Eagle Harbor Technologies, Inc. Eagle Harbor Technologies, Inc. is developing a series stack of solid-state switches to produce a single high voltage switch that can be operated at over 35 kV. During the Phase I program, EHT developed two high voltage switch modules: one with isolated power gate drive and a second with inductively coupled gate drive. These switches were tested at 15 kV and up to 300 A at switching frequencies up to 500 kHz for 10 ms bursts. Robust switching was demonstrated for both IGBTs and SiC MOSFETs. During the Phase II program, EHT will develop a higher voltage switch (>35 kV) that will be suitable for high pulsed and average power applications. EHT will work with LTX to utilize these switches to design, build, and test a pulsed magnetron driver that will be delivered to LTX before the completion of the program. EHT will present data from the Phase I program as well as preliminary results from the start of the Phase II program.

∗With support of DOE SBIR.

TP11 75 Phase I Development of Neutral Beam Injector Solid-State Power System∗ JAMES PRAGER, TIMOTHY ZIEMBA, KENNETH E. MILLER, ILIA SLOBODOV, SETH ANDERSON, Eagle Harbor Technologies, Inc. Neutral beam injection (NBI) is an important tool for plasma heating, current drive and a diagnostic at fusion science experiments around the United States, including tokamaks, validation platform experiments, and privately funded fusion concepts. Currently, there are no vendors in the United States for NBI power systems. Eagle Harbor Technologies (EHT), Inc. is developing a new power system for NBI that takes advantage of the latest developments in solid-state switching. EHT has developed a resonant converter that can be scaled to the power levels required for NBI at small-scale validation platform experiments like the Lithium Tokamak Experiment. This power system can be used to modulate the NBI voltages over the course of a plasma shot, which can lead to improved control over the plasma. EHT will present initial modeling used to design this system as well as experimental data showing operation at 15 kV and 40 A for 10 ms into a test load.

∗With support of DOE SBIR.

TP11 76 JET DT Scenario Extrapolation and Optimization with METIS JAKUB URBAN, FABIEN JAULMES, Institute of Plasma Physics of the CAS, Prague, Czech Republic JEAN-FRANCOIS ARTAUD, CEA, IRFM, F-13108 Saint Paul Lez Durance, France Prospective JET (Joint European Torus) DT operation scenarios are modelled by the fast integrated code METIS. METIS combines scaling laws, e.g. for global and pedestal energy or density peaking, with simplified transport and source models, while retaining fundamental nonlinear couplings, in particular in the fusion power. We have tuned METIS parameters to match JET-ILW high performance experiments, including baseline and hybrid. Based on recent observations, we assume a weaker input power scaling than IPB98 and a ∼10% confinement improvement due to the higher ion mass. The rapidity of METIS is utilized to scan the performance of JET DT scenarios with respect to fundamental parameters, such as plasma current, magnetic field, density or heating power. Simplified, easily parameterized waveforms are used to study the effect the ramp-up speed or heating timing. Finally, an efficient Bayesian optimizer is employed to seek the most performant scenarios in terms of the fusion power or gain.

TP11 77 TRANSPORT

TP11 78 Gyrokinetic Simulations of JET Carbon and ITER-Like Wall Pedestals∗ DAVID HATCH, MIKE KOTSCHE-REUTHER, SWADESH MAHAJAN, XING LIU, AUSTIN BLACKMON, IFS, UT-Austin CARINE GIROUD, JON HILLESHEIM, COSTANZA MAGGI, SAMULI SAARELMA, CCFE, Culham Science Centre, Abingdon OX14 3DB UK JET CONTRIBUTORS TEAM∗ Gyrokinetic simulations using the GENE code are presented, which target a fundamental understanding of JET pedestal transport and, in particular, its modification after installation of an ITER-like wall (ILW). A representative pre-ILW (carbon wall) discharge is analyzed as a base case. In this discharge, magnetic diagnostics observe washboard modes, which preferentially affect the temperature pedestal and have frequencies (accounting for Doppler shift) consistent with microtearing modes and inconsistent with kinetic ballooning modes. A similar ILW discharge is examined, which recovers a similar value of H98, albeit at reduced pedestal temperature. This discharge is distinguished by a much higher value of eta, which produces strong ITG and ETG driven instabilities in gyrokinetic simulations. Experimental observations provide several targets for comparisons with simulation data, in-
including the toroidal mode number and frequency of magnetic fluctuations, heat fluxes, and inter-ELM profile evolution. Strategies for optimizing pedestal performance will also be discussed.

"This work was supported by U.S. DOE Contract No. DE-FG02-04ER54742 and by EUROfusion under Grant No. 633053.

TP11 79 Gyrokinetic analysis of pedestal transport* MIKE KOTSCHENREUTHER, X LIU, DR HATCH, LJ ZHENG, S MAHAJAN, Univ of Texas, Austin A DIALLO, PPPL RJ GROEBNER, GA AE HUBBARD, JW HUGHES, MIT CF MAGGI, S SAARELMA, JET CONTRIBUTORS.† CCFE Surprisingly, basic considerations can determine which modes are responsible for pedestal energy transport (e.g., KBM, ETG, ITG, MTM etc.). Gyrokinetic simulations of experiments, and analysis of the Gyrokinetic-Maxwell equations, find that each mode type produces characteristic ratios of transport in the various channels: density, heat and impurities. This, together with the relative size of the driving sources of each channel, can strongly constrain or determine the dominant modes causing energy transport. MHD-like modes are not the dominant agent of energy transport - when the density source is weak as is often expected. Drift modes must fill this role. Detailed examination of experimental observations, including frequency and transport channel behavior, with simulations, demonstrates these points. Also see related posters by X. Liu, D.R. Hatch, and A. Blackmon.

*Work supported by US DOE under DE-FC02-04ER54698, DE-FG02-04ER54742 and DE-FC02-99ER54512 and by Eurofusion under Grant No. 633053.

TP11 80 Pedestal turbulence simulations using GENE* XING LIU, M. KOTSCHENREUTHER, D. R. HATCH, L. J. ZHENG, S. MAHAJAN, Univ of Texas, Austin A DIALLO, PPPL R. J. GROEBNER, GA A. E. HUBBARD, J. W. HUGHES, MIT C. F. MAGGI, S. SAARELMA, JET CONTRIBUTORS.† CCFE We match frequencies, power balance, and other transport characteristics of several pedestals-two DIII-D ELMy H-modes and a C-Mod I-mode, and attempt this for a C-Mod ELMy H-mode. Observed quasi-coherent fluctuations (QCFs) on the DIII-D shots are identified as MTMs. The MTMs match frequencies, power balance, and other transport characteristics including the toroidal mode number and frequency of magnetic fluctuations. Work supported by US DOE under DE-FC02-04ER54698, DE-FG02-04ER54742 and DE-FC02-99ER54512 and by Eurofusion under Grant No. 633053.

TP11 81 Streamer formation and transport for parameters characteristic of H-mode pedestals* AUSTIN BLACKMON, D. R. HATCH, M. KOTSCHENREUTHER, S. MAHAJAN, R. D. HAZELTINE, Univ of Texas, Austin We investigate, through gyrokinetic simulations, the formation of streamers as a consequence of electron temperature gradient driven, electron scale instabilities. We also study the interaction of velocity shear with streamers for parameters typical of H-mode pedestals, exploring both the higher as well as lower temperature gradient regions. Without ExB shear, the streamers form at the pedestal top causing large heat fluxes; the modes, however, did not saturate. When ExB shear was turned on, the streamers dissipated, and heat flux was lowered, though still of significant magnitude. In the middle of the pedestal, with high temperature gradient, heat flux was insignificant. There was no evidence of streamers in this region, leading to a conclusion that streamers have a strong influence on heat flux.

*Work supported by US DOE under DE-FG02-04ER54742.

TP11 82 Estimation of Kubo number and correlation length of fluctuating magnetic fields and pressure in BOUT + edge pedestal collapse simulation JAEOOK KIM, W. J LEE, Department of Nuclear and Quantum Engineering, KAIST, Daejeon, Republic of Korea HOGUN JHANG, H.H. KAANG, National Fusion Research Institute, Daejeon, Republic of Korea Y.-C. GHIM, Department of Nuclear and Quantum Engineering, KAIST, Daejeon, Republic of Korea Stochastic magnetic fields are thought to be one of the possible mechanisms for anomalous transport of density, momentum and heat across the magnetic field lines. Kubo number and Chirikov parameter are quantifications of the stochasticity, and previous studies show that perpendicular transport strongly depends on the magnetic Kubo number (MKN) [1]. If MKN is smaller than one, diffusion process will follow Rechester-Rosenbluth model [2]; whereas if it is larger than one, percolation theory [3] dominates the diffusion process. Thus, estimation of Kubo number plays an important role to understand diffusion process caused by stochastic magnetic fields. However, spatially localized experimental measurement of fluctuating magnetic fields in a tokamak is difficult, and we attempt to estimate MKNs using BOUT++ simulation data with pedestal collapse. In addition, we calculate correlation length of fluctuating pressures and Chirikov parameters to investigate variation correlation lengths in the simulation. We, then, discuss how one may experimentally estimate MKNs.


TP11 83 Particle and heat flux measurements from XGC1 simulations: Spatial patterns and SOL width implications* IOANNIS KERAMIDAS CHARIDAKOS, University of Colorado at Boulder JAMES MYRA, Lodestar Research Corporation SCOTT PARKER, University of Colorado at Boulder SEUNG-HOE KU, JUGAL CHOWDHURY, MICHAEL CHURCHILL, ROBERT HAGER, CHOONG-SEOCK CHANG, Princeton Plasma Physics Laboratory Strong turbulence near the separatrix is believed to produce filamentary structures (blobs), whose detachment from the bulk can account for the intermittent nature of edge turbulence and impact the heat flux width. The SOL width is a parameter of paramount importance in modern tokamaks as it controls the amount of power deposited at the divertor plates, directly affecting thus the viability of fusion. Here, we analyze the results of simulations performed with the full-f, gyrokinetic code XGC1 which includes both turbulence and neoclassical effects in realistic divertor geometry. More specifically, we calculate the integrated particle and heat fluxes across the separatrix and present their spatial pattern. The flux is impacted by neoclassical effects and ExB turbulent-blobby motion. We iso-
late the ExB turbulent flux and estimate its contribution to the SOL width. Furthermore, we offer an interpretation of the observed patterns, tying them to the sheared perpendicular and parallel flows.

*We acknowledge computing resources on Titan at OLCF through the 2015 INCITE and the 2016 ALCC awards. Work supported by DOE Grant DE-FG02-97ER54392.

**TP11 84 Synthetic Gas Puff Imaging Diagnostic for the XGC1 Turbulence Code** D.P. STOTLER, S.H. KU, S.J. ZWEBEN, R.M. CHURCHILL, C.S. CHANG, PPL J.L. TERRY, MIT The full-f edge gyrokinetic code XGC1 has been used recently to study problems of significant interest, such as the divertor heat flux width [1] and the L-H transition [2]. Moreover, XGC1 simulations of the heat flux width in ITER have different edge turbulence characteristics that lead to widths large relative to those based on empirical scalings. To be confident that this and other XGC1 predictions are accurate will require more detailed validation tests of the code against experimental data. One invaluable source of such data is the gas puff imaging (GPI) technique, which measures edge plasma turbulence. We have developed a synthetic GPI diagnostic for XGC1 based on the DEGAS 2 neutral transport code, allowing a direct comparison of simulated and observed turbulence characteristics, such as fluctuation amplitude, auto-correlation time, and correlation lengths. The DEGAS 2 simulations are 3-D and have sub-microsecond time resolution; both Alcator C-Mod fast camera and APD images are produced. We will describe the synthetic diagnostic and present an initial comparison of its results with the corresponding GPI data from two C-Mod discharges.

*This work supported by US DOE contracts DE-AC02-09CH11466 and DE-FC02-99ER54512.


**TP11 85 Reduced model (SOLT) simulations of neutral-plasma interaction** DAVID RUSSELL, JAMES MYRA, Lodestar Res Corp The 2D scrape-off-layer turbulence (SOLT) code has been enhanced by the addition of kinetic-neutral physics. Plasma-neutral interactions include charge exchange (CX) and ionization (IZ). Under the assumption that the CX and IZ collision rates are independent of the ion-neutrall relative velocity, a 1D (radial: x) Boltzmann equation has been derived [1] for the evolution of the (v, v) averaged neutral distribution function (G), and that evolution has been added to SOLT. The CX and IZ rates are determined by the poloidal (y) averaged plasma density and temperatures, and G = G(x,v,x,t). Results from 1D simulations that use diffusion as a proxy for turbulent transport are presented to illustrate the capability, including the approach to a steady state driven by sustained neutral injection in the far-SOL and source-driven heating in the core. Neutral density and energy profiles are obtained for the resulting self-consistent equilibrium plasma profiles. The effect of neutral drag on poloidal ExB mean flow and shearing rate is illustrated. Progress on 2D turbulence (blob) simulations is reported.

*Work supported by the U.S. Department of Energy Office of Science, Office of Fusion Energy Sciences, under Award Number DE-FG02-97ER54392.


**TP11 86 Advances in continuum kinetic and gyrokinetic simulations of turbulence on open-field line geometries** AM-MAR HAKIM, Princeton Plasma Physics Laboratory ERIC SHI, Princeton University JAMES JUNO, University of Maryland TESS BERNARD, University of Texas GREG HAMMETT, Princeton Plasma Physics Laboratory For weakly collisional (or collisionless) plasmas, kinetic effects are required to capture the physics of micro-turbulence. We have implemented solvers for kinetic and gyrokinetic equations in the computational plasma physics framework, Gkeyll. We use a version of discontinuous Galerkin scheme that conserves energy exactly. Plasma sheaths are modeled with novel boundary conditions. Positivity of distribution functions is maintained via a reconstruction method, allowing robust simulations that continue to conserve energy even with positivity limits. We have performed a large number of benchmarks, verifying the accuracy and robustness of our code. We demonstrate the application of our algorithm to two classes of problems (a) Vlasov-Maxwell simulations of turbulence in a magnetized plasma, applicable to space plasmas; (b) Gyrokinetic simulations of turbulence in open-field-line geometries, applicable to laboratory plasmas.

*Supported by the Max-Planck/Princeton Center for Plasma Physics, the SciDAC Center for the Study of Plasma Microturbulence, and DOE Contract DE-AC02-09CH11466.

**TP11 87 Continuum Gyrokinetic Simulations of Turbulence in a Helical Model SOL with NSTX-type parameters** G.W. HAMMETT, Princeton Plasma Physics Laboratory E.L. HAKIM, Princeton Plasma Physics Laboratory T. STOLTZFUS-DUECK, Princeton University We have developed the Gkeyll code to carry out 3D2V full-F gyrokinetic simulations of electrostatic plasma turbulence in open-field-line geometries, using special versions of discontinuous-Galerkin algorithms to help with the computational challenges of the edge region. (Higher-order algorithms can also be helpful for exascale computing as they reduce the ratio of communications to computations.) Our first simulations with straight field lines were done for LAPD-type cases [1]. Here we extend this to a helical model of an SOL plasma and show results for NSTX-type parameters. These simulations include the basic elements of a scrape-off layer: bad-curvature/interchange drive of instabilities, narrow sources to model plasma leaking from the core, and parallel losses with model sheath boundary conditions (our model allows currents to flow in and out of the wall). The formation of blobs is observed. By reducing the strength of the poloidal magnetic field, the heat flux at the divertor plate is observed to broaden.

*Supported by the Max-Planck/Princeton Center for Plasma Physics, the SciDAC Center for the Study of Plasma Microturbulence, and DOE Contract DE-AC02-09CH11466.


**TP11 88 Gyrokinetic continuum simulations of turbulence in the Texas Helimak** T.N. BERNARD, Univ of Texas, Austin E.L. SHI, Princeton University G.W. HAMMETT, A. HAKIM, Princeton Plasma Physics Laboratory E.L. TAYLOR, Univ of Texas, Austin We have used the Gkeyll code to perform 3x-2v full-f gyrokinetic continuum simulations of electrostatic plasma turbulence in the Texas Helimak. The Helimak is an open field-line experiment with magnetic curvature and shear. It is useful for validating numerical codes due to its extensive diagnostics and simple, helical geometry, which is similar to the scrape-off layer region of tokamaks. Interchange and drift-wave modes are the main turbulence mechanisms in the device, and potential biasing is applied to study the effect of velocity shear on turbulence reduction. With Gkeyll, we varied field-line pitch angle and simulated biased and unbiased cases to study different turbulent regimes and turbulence reduction.
These are the first kinetic simulations of the Helimak and resulting plasma profiles agree fairly well with experimental data. This research demonstrates Gkeyll’s progress towards 5D simulations of the SOL region of fusion devices.

*Supported by the U.S. DOE SCGSR program under contract DE-SC0014664, the Max-Planck/Princeton Center for Plasma Physics, the SciDAC Center for the Study of Plasma Microturbulence, and DOE contract DE-AC02-09CH11466.

**TP11 89 Diagnosing entropy production and dissipation in fully kinetic plasmas** JAMES JUNO, JASON TENBARGE, University of Maryland College Park AMMAR HAKIM, Princeton Plasma Physics Lab WILLIAM DORLAND, University of Maryland College Park PETR CAGAS, Virginia Tech University. Many plasma systems, from the core of a tokamak to the outer heliosphere, are weakly collisional and thus most accurately described by kinetic theory. The typical approach to solving the kinetic equation has been the particle-in-cell algorithm, which, while a powerful tool, introduces counting noise into the particle distribution function. The counting noise is particularly problematic when attempting to study grand challenge problems such as entropy production from phenomena like shocks and turbulence. In this poster, we present studies of entropy production and dissipation processes present in simple turbulence and shock calculations using the continuum Vlasov-Maxwell solver in the Gkeyll framework. Particular emphasis is placed on a novel diagnostic, the field-particle correlation, which is especially solver in the Gkeyll framework. Particular emphasis is placed on a linear and shock calculations using the continuum Vlasov-Maxwell noise is particularly problematic when attempting to study grand counting noise into the particle distribution function. The counting noise is particularly problematic when attempting to study grand challenge problems such as entropy production from phenomena like shocks and turbulence. In this poster, we present studies of entropy production and dissipation processes present in simple turbulence and shock calculations using the continuum Vlasov-Maxwell solver in the Gkeyll framework. Particular emphasis is placed on a novel diagnostic, the field-particle correlation, which is especially efficient at separating the secular energy transfer into its constituent components, for example, cyclotron damping, Landau damping, or transit-time damping, when applied to a noise-free distribution function.

*National Science Foundation SHINE award No. AGS-1622306 and the UMD DOE Grant DE-FG02-93ER54197.

**TP11 90 Thermal and Particle Transport in Strong Interchange-Type Turbulence** KENNETH GENTLE, WILLIAM ROWAN, University of Texas at Austin MARK KOEPKE, SAM NOGAMI, West Virginia University. The Helimak is an approximation to the infinite cylindrical slab with a size large compared with turbulence transverse scale lengths, but with open field lines of finite length. A pressure gradient in unfavorable magnetic curvature is unstable to interchange-type modes, leading to large amplitude non-linear fluctuations similar to those in a tokamak SOL. A novel magneto-viscous-baffle probe cluster permits full characterization of the turbulence, including particle and thermal radial transport rates across the plasma profile. Transport rates vary with plasma parameters, but they can be most strongly modified by the application of bias to alter the transverse (poloidal, orthogonal to B and R) flow patterns. The transport effects are mediated by two, often independent, mechanisms. First, the bias changes the amplitudes of the fluctuating fields responsible for the transport. Second, the bias changes the coherence between the fields (seen in either time or frequency domains), leading to changed net transport.

*Work supported by the Department of Energy OFES DE-FG02-04ER54766.

**TP11 91 Baffled-probe compact-cluster measurement of microturbulence and electron temperature fluctuation in the Texas Helimak** SH NOGAMI, ME KOEPKE, VI DEMIDOVI, West Virginia Univ KW GENTLE, CB WILLIAMS, Univ of Texas at Austin. In magnetized-orbit plasma, a baffled-probe compact cluster [1] acquires simultaneous real-time separate measurements of pure space potential, electric field, density, and electron temperature. Time-series analysis yields cross-correlated frequency and phase of the plasma parameter fluctuations and inference of electrostatic particle flux [2]. Radial ac and dc profiles of space potential, electric field, density, and electron temperature were measured in the Texas Helimak [3] in an attempt to quantify field and flow structure associated with specific states of microturbulence. Each state, characterized by magnetic field line connection length and applied radial electric field, is identified by signatures in the plasma parameters measured by a baffled-probe compact cluster.

*Work supported by DE-FG02-04ER54766. WVU gratefully acknowledges support from the Big 12 Faculty Fellowship and the DOE FES GPS program.

1Koepke et al., Contrib. Plasma Phys. 46, 359 (2006);

**TP11 92 Global 3D Braginskii-based edge simulation of an L-H transition** BEN ZHU, MANAURA FRANCISQUES, BARRETT ROGERS, Dartmouth Coll. We present a milli-seconds long pre L-H transition simulation with the global edge turbulence code GDB. This study was carried out in a simple shifted circular flux surfaces magnetic configuration with IWL, Alcator C-Mod parameters. The simulation domain is toroidally and poloidally global and spans 3cm of the closed-flux region and 2cm of the scrape-off layer (−3 cm < r − a < 2 cm). The plasma is heated in the core region (r − a < −3cm) and sourced near the separatrix (r ≈ a). Several interesting features are exhibited in this simulation that concur with experiments, including enhanced E × B shear flow, suppressed turbulence, inward particle pinch and formation of pedestal via plasma heating. Detailed results and further analysis will be presented in the meeting.

*This work was supported by DOE-SC-0010508. This research used resources of the National Energy Research Scientific Computing Center.

**TP11 93 Investigation of energetic particle induced geodesic acoustic mode** MIRJAM SCHNELLER, Princeton Plasma Physics Laboratory GUOYONG FU, Zhejiang University IL-IJIA CHAVDAROVSKI, Max Planck Institute for Plasma Physics WEIXING WANG, Princeton Plasma Physics Laboratory PHILIPP LAUBER, ZHIXIN LU, Max Planck Institute for Plasma Physics Energetic particles are ubiquitous in present and future tokamaks due to heating systems and fusion reactions. Anisotropy in the distribution function of the energetic particle population is able to excite oscillations from the continuous spectrum of geodesic acoustic modes (GAMs), which cannot be driven by plasma pressure gradients due to their toroidally and nearly poloidally symmetric structures. These oscillations are known as energetic particle-induced geodesic acoustic modes (EGAMs) [G.Y. Fu ’08] and have been observed in recent experiments [R. Nazikian’08]. EGAMs are particularly attractive in the framework of turbulence regulation, since they lead to an oscillatory radial electric shear which can potentially saturate the turbulence. For the presented work, the nonlinear gyrokinetic, electrostatic, particle-in-cell code GTS [W.X. Wang ’06] has been extended to include an energetic particle population following either bump-on-tail Maxwellian or slowing-down [Stix’76] distribution function. With this new tool, we study growth rate, frequency and mode structure of the EGAM in an ASDEX Upgrade-like scenario. A detailed understanding of EGAM excitation reveals essential for future studies of EGAM interaction with micro-turbulence.
TP11 94 Numerical simulation of 3D magnetic field and turbulence interaction in tokamak plasma using XGC1 JAE-MIN KWON, National Fusion Research Institute S. KU, C.S. CHANG, Princeton Plasma Physics Laboratory M.J. CHOI, National Fusion Research Institute R. HAGER, Princeton Plasma Physics Laboratory Understanding the physics of 3D magnetic field and turbulence interaction is critical for present and future tokamak experiments. In this work, we report our recent progress in numerical simulation of 3D magnetic field effects on plasma flow and turbulence using XGC1. Employing the full-f gyrokinetic simulation capabilities of XGC1 in realistic tokamak geometry, we perform extended classical simulations including kinetic electrons for a tokamak plasma with assumed 3D magnetic field perturbations. From the simulations, non-axisymmetric kinetic equilibria with self-consistent 3D flows are obtained. Affected by the applied 3D fields, the plasma develops so called the vortex mode, which is mesoscopic convective flow driven by the 3D fields. Detailed analysis of the convective flow structure is presented. Then, using the numerically obtained non-axisymmetric kinetic equilibria, we study the impacts of the 3D fields on micro-instabilities. Both the neoclassical equilibrium flow and mesoscopic vortex mode are important in this study, and it is presented how these flows and combined ExB shearing affect the micro-instabilities, especially their spatial distributions. We also discuss the implication of the modified micro-instabilities on turbulence and transport near the resonant region with applied 3D magnetic fields.

TP11 95 Reduced models for electron and ion heat diffusivities by gyro-kinetic simulation with kinetic electrons in helical TP11 94 Reduced models for electron and ion heat diffusivity interaction in tokamak plasma using XGC1. Non-axisymmetric kinetic equilibria with self-consistent 3D flows are obtained. Affected by the applied 3D fields, the plasma develops so called the vortex mode, which is mesoscopic convective flow driven by the 3D fields. Detailed analysis of the convective flow structure is presented. Then, using the numerically obtained non-axisymmetric kinetic equilibria, we study the impacts of the 3D fields on micro-instabilities. Both the neoclassical equilibrium flow and mesoscopic vortex mode are important in this study, and it is presented how these flows and combined ExB shearing affect the micro-instabilities, especially their spatial distributions. We also discuss the implication of the modified micro-instabilities on turbulence and transport near the resonant region with applied 3D magnetic fields.

TP11 96 Verification of fluid type electromagnetic modes with a gyrokinetic-fluid hybrid model in the XGC code* ROBERT HAGER, PPPL J. LANG, Intel Corporation P. FORAZIK, C.S. CHANG, S. KU, J. DOMINSKI, PPPL Y. CHEN, S. E. PARKER, U. Colorado M. F. ADAMS, LBL. As an alternative option to kinetic electrons, the gyrokinetic total-f particle-in-cell (PIC) code XGC1 has been extended to the MHD/fluid type electromagnetic regime by combining gyrokinetic PIC ions with massless drift-fluid electrons analogous to Chen and Parker [1]. This work complements - as a more economical alternative - the fully kinetic electromagnetic formulation that is also being developed for XGC1 [2]. Two representative long wavelength modes, shear Alfvén waves and resistive tearing modes are verified in cylindrical and toroidal magnetic field geometries. In addition, results for intermediate wavelength drift-Alfvén waves such as ion temperature gradient driven modes, peeling modes, and kinetic ballooning modes are also presented. We plan to apply XGC1 to study the stability of resistive tearing modes in NSTX. These studies are the groundwork for the extension of the current delta-f hybrid model to the total-f method required to study fluid type electromagnetic modes in the tokamak edge plasma and develop a better understanding of the onset of edge localized modes.

*Computing time from NERSC.

1Chen and Parker, Phys. Plasmas 8, 441 (2001).

TP11 97 Electromagnetic gyrokinetic simulation in GTS CHEN-HAO MA, WEIXING WANG, EDWARD STARTSEV, W. W. LEE, STEPHANE ETHIER, Princeton Plasma Physics Laboratory We report the recent development in the electromagnetic simulations for general toroidal geometry based on the particle-in-cell gyrokinetic code GTS. Because of the cancellation problem, the EM gyrokinetic simulation has numerical difficulties in the MHD limit where \( k^2 p_c \rightarrow 0 \) and/or \( \beta > m_e/m_i \). Recently several approaches has been developed to circumvent this problem: (1) \( p_t \) formulation with analytical skin term iteratively approximated by simulation particles (Yang Chen), (2) A modified \( p_t \) formulation with \( \int dE_1 \) used in place of \( A_1 \) (Mishichenko); (3) A conservative scheme where the electron density perturbation for the Poisson equation is calculated from an electron continuity equation (Bao); (4) double-split-weight scheme with two weights, one for Poisson equation and one for time derivative of Ampere’s law, each with different splits designed to reduce large terms from Vlasov equation (Startsev). These algorithms are being implemented into GTS framework for general toroidal geometry. The performance of these different algorithms will be compared for various EM modes.

TP11 98 Electromagnetic Stabilization of ITG Turbulence* G.G. WHELAN, M.J. PUESCHEL, P.W. TERRY, University of Wisconsin-Madison Finite plasma \( \beta \) strongly reduces transport due to ion-temperature-gradient-driven turbulence, far beyond the stabilization quasilinear mixing length models predict. Gyrokinetic simulations reveal that more efficient nonlinear mode coupling, as measured by triplet correlation lifetime, is the dominant mechanism behind nonlinearly-enhanced stabilization. Electromagnetic effects increase triplet correlation lifetime which causes the instability to saturate at lower amplitudes. We will discuss contribution factors to the triplet correlation lifetime. When modified to include the effects of triplet correlation lifetime, quasilinear predictions reproduce nonlinear heat fluxes through a range of temperature gradients and \( \beta \) values. A second, weaker contributor is enhanced stable mode excitation which reduces energy production relative to the unstable eigenmode. This is only responsible for 10-20% of the enhanced stabilization.

*supported by US DOE #DE-FG02-89ER53291.

TP11 99 A Derivation of Critical Balance from Two-Point Evolution in Gyrokinetic Turbulence* P.W. TERRY, University of Wisconsin-Madison The critical balance of parallel and perpendicular correlation times has been postulated for anisotropic tur-
bulence ranging from weak-guide-field MHD to strong-guide-field gyrokinetics. While observed in simulations, an analytical derivation establishing the mechanisms responsible for critical balance has not been given. From a calculation of the temporal evolution of two-point phase-space correlation for turbulence in a reduced gyrokinetic model with a Lenard-Bernstein collision operator critical balance is demonstrated. Using a phase-space conserving closure, differential equations for the temporal evolution of relative separation are derived and solved. When the collision rate is smaller than the turbulent decorrelation rate, critical balance holds as observed in simulation [1]. When the collision rate becomes comparable to the turbulent decorrelation rate, the perpendicular decorrelation rate lags for large eddies. Critical balance is maintained in a collisional regime where collisions set the decorrelation rate, but the relationship between perpendicular and parallel scales is modified by the collision rate through the eddy-damping propagator of the turbulent diffusivity.

*Supported by USDOE Grant DE-FG02-89ER53291.


TP11 100 Non-inductive current generation in fusion plasmas with turbulence∗ WEIXING WANG, S. ETHIER, E. STARTSEV, J. CHEN, Princeton Plasma Phys Lab T. S. HAHM, M. G. YOO, Seoul National University, Korea It is found that plasma turbulence may strongly influence non-inductive current generation. This may have radical impact on various aspects of tokamak physics. Our simulation study employs a global gyrokinetic model coupling self-consistent neoclassical and turbulent dynamics with focus on electron current. Distinct phases in electron current generation are illustrated in the initial value simulation. In the early phase before turbulence develops, the electron bootstrap current is established in a time scale of a few electron collision times, which closely agrees with the neoclassical prediction. The second phase follows when turbulence begins to saturate, during which turbulent fluctuations are found to strongly affect electron current. The profile structure, amplitude and phase space structure of electron current density are all significantly modified relative to the neoclassical bootstrap current by the presence of turbulence. Both electron parallel acceleration and parallel residual stress drive are shown to play important roles in turbulence-induced current generation. The current density profile is modified in a way that correlates with the fluctuation intensity gradient through its effect on k⊥/symmetry breaking in fluctuation spectrum. Turbulence is shown to deduct (enhance) plasma self-generated current in low (high) collisionality regime, and the reduction of total electron current relative to the neoclassical bootstrap current increases as collisionality decreases. The implication of this result to the fully non-inductive current operation in steady state burning plasma regime should be investigated. Finally, significant non-inductive current is found in flat pressure region, which is a nonlocal effect and results from turbulence spreading induced current diffusion.

*Work supported by U.S. DOE Contract DE-AC02-09-CH11466.

TP11 101 Hermite-Laguerre Spectral Velocity Formulation of Gyrokinetics NOAH MANDELL, Princeton University BILL DORLAND, MATT LANDREMAN, University of Maryland - College Park First-principles simulations of tokamak turbulence have proven to be of great value in recent decades. We develop a spectral velocity formulation of the turbulence equations that smoothly interpolates between the highly efficient but lower resolution 3D gyrofluid representation and the conventional but more expensive 5D gyrokinetic representation. Our formulation is a straightforward projection of the nonlinear gyrokinetic equation onto a Hermite basis in parallel velocity and a Laguerre basis in perpendicular velocity. This results in a system that describes the evolution of an arbitrary number of gyrofluid-like velocity moments of the kinetic distribution. We address issues related to collisions, closures, and free energy. The final model is appropriate for the study of instabilities, turbulence, and transport in a wide range of geometries, including tokamaks and stellarators. We provide numerical results from a new code that solves the 5D gyrokinetic equation in our Hermite-Laguerre spectral velocity basis.

TP11 102 Gyrokinetic Dynamic Fidelity Refinement WILLIAM DORLAND, Univ of Maryland-College Park NOAH MANDELL, Princeton University MATT LANDREMAN, MICHAEL MARTIN, MICHAEL NASTAC, JOEY TAYLOR, Univ of Maryland-College Park Gyrokinetic Dynamic Fidelity Refinement is described and demonstrated. The basic problems are familiar from AMR techniques, but there are differences. Our proposed method is pseudo-spectral in all five dimensions (x, y, z, v∥, μB). Mesh refinement occurs by changing the number of Fourier, Hermite, or Laguerre basis functions, according to a dynamic target refinement metric. Low amplitude turbulence (near marginal stability) requires relatively high resolution in Hermite-Laguerre space, but modest resolution in k-space. High amplitude turbulence (away from marginal stability) requires relatively low resolution in Hermite-Laguerre space, but higher resolution in k. Stochastic echoes limit the v-space resolution requirements at high amplitude. Nonlinear phase-mixing ultimately limits the required k∥ resolution, as it provides a physical hyperviscosity mechanism. Depending on the quality of the closures available at low v-space resolution, GKDFR should be the optimal algorithm for evaluating small ρ∗, electromagnetic, gyrokinetic turbulence within the TRINITY multiscale transport framework.

TP11 103 Particle transport in a wave spectrum with a thermal distribution of Larmor radii∗ JULIO MARTINELL, NIKOLAY KRYUKOV, ICN-UNAM DIEGO DEL CASTILLO-NEGRETE, ORNL Test particle E × B transport is studied due to an infinite spectrum of drift waves in two dimensions using a Hamiltonian approach, which can be reduced to a 2D mapping. Finite Larmor radius (FLR) effects are included taking a gyroaverage. When the wave amplitude is increased there is a gradual transition to chaos but the chaos level is reduced when FLR grows, implying that fast particles are better confined. The fraction of confined particles is found to be reduced as the wave amplitude increases. The statistical properties of transport are studied finding that, in the absence of a background flow, it is diffusive with a Gaussian PDF, when all particles have the same FLR. In contrast, for a thermal FLR distribution, the PDF is non-Gaussian but the transport remains diffusive. A theoretical explanation of this is given showing that a superposition of Gaussians produces a PDF with long tails. When a background flow is introduced that varies monotonically with radius, the transport becomes strongly super-diffusive due to the appearance of long Levy flights which dominate the particles. The PDF develops long tails as the flow strength is increased. The particle variance scales as σ ∼ t for chaotic regime but reduces to ballistic (∼ t 2) for low chaos.

*Work funded by PAPIIT-UNAM project IN109115.

TP11 104 Control of ITBs in Magnetically Confined Burning Plasmas SR PANTA, DE NEWMAN, Univ of Alaska- Fairbanks
Both GYRO [1] and CGYRO [2] codes will be compared against is then compared against predictions from nonlinear gyrokinetic etry expected in ITER H-mode plasmas. A subset of these results magnetic shear, and collisionality for nominal conditions and geom-
modes as a function of parameters such as safety factor, investigating the scaling of linear critical gradients of ITG, TEM,
units, such that the plasma should lie close to the critical gradients next step experiments such as ITER and DEMO. Core transport in conditions is essential for confident prediction and optimization of
allow enhanced confinement in one channel but not another which is seen in the I-mode. We propose differential cross-phase modification as a possible mechanism for different transport in different channels. Simple dynamical models have been able to capture a remarkable amount of the dynamics of the core and edge transport barriers found in many devices. By including in this rich though simple dynamic transport model a simple model for cross phase effects, due to multiple instabilities, between the transported fields such as density and temperature, we can investigate whether the dynamics of more continuous transitions such as the I-mode can be captured and understood. This is backed up by multi-scale simulations on full gyro-kinetic codes. If correct this could have broad implications for transport in many systems. If this mechanism is valid, what can the model tell us about control knobs for these promising regimes?

TP11 106 Towards a better understanding of critical gradients and near-marginal turbulence in burning plasma conditions C. HOLLAND, University of California, San Diego J. CANDY, General Atomics N.T. HOWARD, Massachusetts Institute of Technology Developing accurate predictive transport models of burning plasma conditions is essential for confident prediction and optimization of next step experiments such as ITER and DEMO. Core transport in these plasmas is expected to be very small in gyroBohm-normalized units, such that the plasma should lie close to the critical gradients for onset of microturbulence instabilities. We present recent results investigating the scaling of linear critical gradients of ITG, TEM, and ETG modes as a function of parameters such as safety factor, magnetic shear, and collisionality for nominal conditions and geometry expected in ITER H-mode plasmas. A subset of these results is then compared against predictions from nonlinear gyrokinetic simulations, to quantify differences between linear and nonlinear thresholds. As part of this study, linear and nonlinear results from both GYRO [1] and CGYRO [2] codes will be compared against each other, as well as to predictions from the quasilinear TGLF [3] model. Challenges arising from near-marginal turbulence dynamics are addressed.

*This work was supported by the US Department of Energy under US DE-SC0006957.


TP11 107 Revising the L-mode Edge Transport Shortfall with More Accurate Gyrokinetic Simulations R. E. WALTZ, J. CANDY, General Atomics R.V. BRAVENEC, Fourth State Research
While GYRO simulations of core (0<r/a<0.7) DIII-D L-mode shots are in good agreement with experiment, simulated low-k transport and turbulent intensity was more than 5-fold lower in the near edge (r/a =0.8) of DIIIID-shot 128913 [1]. Gyrokinetic codes in good core agreement, differ on the short-fall [7-fold (GYRO, GEM) and 2-fold (GENE, G32)] [2]. Here we focus on the far edge (r/a=0.9) DIII-D-shot 101391 previously reported to have a 10-fold shortfall with GYRO [3]. Using the new CGYRO code [4] with a (k-space) spectral grid, the 10-fold shortfall has vanished. CGYRO is in good agreement with experiment and the spectral GENE code. Repetition of the 2012 GYRO runs [3] at much higher radial space grid resolution and more accurate radial gyro-average and derivatives appear to make up for most of this far edge shortfall.

*Supported by the US DOE under DE-FG02-95ER54309.

3 R. E. Waltz, BAPS 57, 105 (2012), DPPD13.2.

TP11 108 2-D Hybrid Model to Study Flow Curvature Effect on Low Frequency Plasma Turbulence S SEN, National Institute of Aerospace, & William & Mary, VA; Bowie State University, MD D LIN, W SCALES, Virginia Tech, VA M GOLDSTEIN, NASA-GSFC, & University of Maryland Baltimore County, MD In this study of flow curvature effects, a two-dimensional hybrid model is used to simulate the Kelvin-Helmholtz instability (KHI). The hybrid model treats the ions as particles, and electrons as massless fluid. Pressure and resistivity are assumed as isotropic. A classical configuration for the study of KHI is investigated, i.e. transverse shear flow to uniform background magnetic field. This is thought as the most unstable situation in magnetohydrodynamic (MHD) theory. There are 50 super particles per cell in the current simulations, which number could be increased to as much as 200 in the future. The boundary is periodic along the flow direction and reflective in the perpendicular direction. The code was originally developed by the Los Alamos National Laboratory and has been successfully applied to the study of Kelvin-Helmholtz instability on the Earth’s magnetopause. In this study, the code has been running on the Advanced Research Computing (ARC) platforms of Virginia Tech. Four distinct shear profiles are simulated to investigate the effects of flow curvature on the growth of the KHI instability: uniform flow, linear shear without curvature, quadratic profile with positive curvature, and quadratic profile with negative curvature.

**TP11 109 Cross-verification of the GENE and XGC codes in preparation for their coupling**

FRANK JENKO, GABRIELE MERLO, University of California Los Angeles
AMITAVA BHAT-TACHARJEE, CS CHANG, JULIEN DOMINSKI, SEUNGHOE KU, Princeton Plasma Physics Laboratory, Princeton University
SCOTT PARKER, University of Colorado, Boulder
EMMANUEL LANTI, Swiss Plasma Center, Lausanne CH

A high-fidelity Whole Device Model (WDM) of a magnetically confined plasma is a crucial tool for planning and optimizing the design of future fusion reactors, including ITER. Aiming at building such a tool, in the framework of the Exascale Computing Project (ECP) the two existing gyrokinetic codes GENE (Eulerian delta-f) and XGC (PIC full-f) will be coupled, thus enabling to carry out first principle kinetic WDM simulations. In preparation for this ultimate goal, a benchmark between the two codes is carried out looking at ITG modes in the adiabatic electron limit. This verification exercise is also joined by the global Lagrangian PIC code ORB5. Linear and nonlinear comparisons have been carried out, neglecting for simplicity collisions and sources. A very good agreement is recovered on frequency, growth rate and mode structure of linear modes. A similarly excellent agreement is also observed comparing the evolution of the heat flux and of the background temperature profile during nonlinear simulations.

---

**TP11 110 XGC developments for a more efficient XGC-GENE code coupling**

JULIEN DOMINSKI, ROBERT HAGER, SEUNGHOE KU, CS CHANG, Princeton Plasma Phys Lab

In the Exascale Computing Program, the High-Fidelity Whole Device Modeling project initially aims at delivering a tightly-coupled simulation of plasma neoclassical and turbulence dynamics from the core to the edge of the tokamak. To permit such simulations, the gyrokinetic codes GENE [1] and XGC [2] will be coupled together. Numerical efforts are made to improve the numerical schemes agreement in the coupling region. One of the difficulties of coupling those codes together is the incompatibility of their grids. GENE is a continuum grid-based code and XGC is a Particle-In-Cell code using unstructured triangular mesh. A field-aligned filter is thus implemented in XGC. Even if XGC originally had an approximately field-following mesh, this field-aligned filter permits to have a perturbation discretization closer to the one solved in the field-aligned code GENE. Additionally, new XGC gyro-averaging matrices are implemented on a velocity grid adapted to the plasma properties, thus ensuring same accuracy from the core to the edge regions.

---

**SESSION UT2: TUTORIAL: INTEGRATED TOKAMAK MODELING: WHEN PHYSICS INFORMS ENGINEERING AND RESEARCH PLANNING**

Thursday Afternoon, 26 October 2017; Room: 102ABC at 14:00; Orso Meneghini, General Atomics, presiding

---

**Invited Papers**

14:00

**UT2 1 Integrated tokamak modeling: when physics informs engineering and research planning**

FRANCESCA POLI, Princeton Plasma Physics Laboratory

Simulations that integrate virtually all the relevant engineering and physics aspects of a real tokamak experiment are a powerful tool for experimental interpretation, model validation and planning for both present and future devices. This tutorial will guide through the building blocks of an “integrated” tokamak simulation, such as magnetic flux diffusion, thermal, momentum and particle transport, external heating and current drive sources, wall particle sources and sinks. Emphasis is given to the connection and interplay between external actuators and plasma response, between the slow time scales of the current diffusion and the fast time scales of transport, and how reduced and high-fidelity models can contribute to simulate a whole device [1]. To illustrate the potential and limitations of integrated tokamak modeling for discharge prediction, a helium plasma scenario for the ITER pre-nuclear phase is taken as an example. This scenario presents challenges because it requires core-edge integration and advanced models for interaction between waves and fast-ions, which are subject to a limited experimental database for validation and guidance. Starting from a scenario obtained by re-scaling parameters from the demonstration inductive “ITER baseline”, it is shown how self-consistent simulations that encompass both core and edge plasma regions, as well as high-fidelity heating and current drive source models are needed to set constraints on the density, magnetic field and heating scheme. This tutorial aims at demonstrating how integrated modeling, when used with adequate level of criticism, can not only support design of operational scenarios, but also help to assess the limitations and gaps in the available models, thus indicating where improved modeling tools are required and how present experiments can help their validation and inform research planning.

*Work supported by the US DOE under the Exascale Computing Project (17-SC-20-SC).

**Invited Papers**

**14:00**  
**UI3 1 Cavity-cooled electron plasmas**  
**ERIC HUNTER, Univ of California - Berkeley**

Cooling non-neutral plasmas to cryogenic temperature is a long standing challenge. With standard Penning-Malmberg trap geometry these temperatures can be difficult to achieve for lepton plasmas even in strong (> 1 T) magnetic fields. By incorporating a high-Q microwave cavity into the plasma confinement region [1], we observed significantly enhanced cooling rates when the cyclotron frequency, controlled by scanning the axial magnetic field, is near a cavity resonance [2]. With improved cavity design and control over the axial magnetic field gradient, we now obtain resonant cooling for plasmas containing millions of electrons, which approach equilibrium with trap walls at 10 K, remarkably, at fields lower than 0.2 T. The dependence of the cooling rate and final temperature has been investigated over a wide range of system parameters, including plasma length (\(\sim 1\) mm to \(\sim 10\) cm), number of electrons (> \(10^7\) to \(10^8\)), field gradient, and microwave cavity realizations.

\[\text{\cite{1}}\]
\[\text{\cite{2}}\]

---

**14:30**  
**UI3 2 Progress toward magnetic confinement of a positron-electron plasma: nearly 100% positron injection efficiency into a dipole trap**  
**MATTHEW STONEKING, Lawerence University, Appleton, WI**

The hydrogen atom provides the simplest system and in some cases the most precise one for comparing theory and experiment in atomic physics. The field of plasma physics lacks an experimental counterpart, but there are efforts underway to produce a magnetically confined positron-electron plasma that promises to represent the simplest plasma system. The mass symmetry of positron-electron plasma makes it particularly tractable from a theoretical standpoint and many theory papers have been published predicting modified wave and stability properties in these systems. Our approach [1] is to utilize techniques from the non-neutral plasma community to trap and accumulate electrons and positrons prior to mixing in a magnetic trap with good confinement properties. Ultimately we aim to use a levitated superconducting dipole configuration fueled by positrons from a reactor-based positron source and buffer-gas trap. To date we have conducted experiments to characterize and optimize the positron beam [2] and test strategies for injecting positrons into the field of a supported permanent magnet by use of ExB drifts and tailored static and dynamic potentials applied to boundary electrodes and to the magnet itself. Nearly 100% injection efficiency has been achieved under certain conditions and some fraction of the injected positrons are confined for as long as 400 ms. These results are promising for the next step in the project which is to use an inductively energized high Tc superconducting coil to produce the dipole field, initially in a supported configuration, but ultimately levitated using feedback stabilization.

\[\text{\cite{1}}\]
\[\text{\cite{2}}\]

---

**15:00**  
**UI3 3 First Test of Long-Range Collisional Drag via Plasma Wave Damping**  
**MATTHEW AFFOLTER, University of California, San Diego**

In magnetized plasmas, the rate of particle collisions is enhanced over classical predictions when the cyclotron radius \(r_c\) is less than the Debye length \(\lambda_D\). Classical theories describe local velocity scattering collisions with impact parameters \(\rho < r_c\). However, when \(r_c < \lambda_D\), long-range collisions exchange energy and momentum over the range \(r_c < \rho < \lambda_D\) with negligible parallel-perpendicular velocity scattering. Previous experiments and theory have shown that these long-range collisions enhance cross-field diffusion, heat transport, and viscosity by orders of magnitude over classical predictions [1].

Here, we present the first experimental confirmation of a new theory [2], which predicts enhanced parallel velocity slowing due to these long-range collisions. These experiments measure the damping of Trivelpiece-Gould waves in a multispecies pure ion plasma. The damping is dominated by interspecies collisional drag when Landau damping is weak. In this “drag
helicity analysis shows that the magnetic energy is converted and propagated mainly in the form of the Poynting flux, while simulated reconnection rate was found to agree with a previous analytical calculation having the same geometry. Energy motion provides an interpretation for other phenomena as well, such as spiked central electron current filaments. The mechanism. The entire process has positive feedback with no restoring mechanism and therefore is an instability. The magnetic reconnection, which is a conversion of magnetic field into particle velocity, to occur without any dissipation a way that one term becomes smaller while the other becomes larger while preserving constant Q

stretching the flux tube, decreasing its cross-section to maintain a fixed volume and so increasing the magnitude of tube towards the X-point. This flux tube segment is convected downwards with the central electron current, effectively

temperature of 10 K in a 6 T trap is enhanced by a factor of 30.

PMMA (C5H8O2), we find again diamond formation at pressures above

A mechanism for whistler wave generation and propagation is also described, with comparisons to recent spacecraft observations.

Carbon-hydrogen demixing and subsequent diamond precipitation has been predicted to strongly participate in shaping the internal structure and evolution of icy giant planets like Neptune and Uranus [1]. The very same dense plasma chemistry is also a potential concern for CH plastic ablator materials in inertial confinement fusion (ICF) experiments where similar conditions are present during the first compression stage of the imploding capsule. Here, carbon-hydrogen demixing may enhance the hydrodynamic instabilities occurring in the following compression stages. First experiments applying dynamic compression and ultrafast in situ X-ray diffraction at SLAC’s Linac Coherent Light Source demonstrated diamond formation from polystyrene (CH) at 150 GPa and 5000 K. Very recent experiments have now investigated the influence of oxygen, which is highly abundant in icy giant planets on the phase separation process. Compressing PET (C9H10O4) and PMMA (C5H8O2), we find again diamond formation at pressures above ~150 GPa and temperatures of several thousand kelvins, showing no strong effect due to the presence of oxygen. Thus, diamond precipitation deep inside icy giant planets seems very likely. Moreover, small-angle X-ray scattering (SAXS) was added to the platform, which determines an upper limit for the diamond particle size, while the width of the diffraction features provides a lower limit. We find that diamond particles of several nanometers in size are formed on a nanosecond timescale. Finally, spectrally resolved X-ray scattering is used to scale amorphous diffraction signals and allows for determining the amount of carbon-hydrogen demixing inside the compressed samples even if no crystalline diamond is formed. This whole set of diagnostics provides unprecedented insights into the nanosecond kinetics of dense plasma chemistry.

Dense plasma chemistry of hydrocarbons at conditions relevant to planetary interiors and inertial confinement fusion
DOMINIK KRAUS, Helmholtz-Zentrum Dresden-Rossendorf

Carbon-hydrogen demixing and subsequent diamond precipitation has been predicted to strongly participate in shaping the internal structure and evolution of icy giant planets like Neptune and Uranus [1]. The very same dense plasma chemistry is also a potential concern for CH plastic ablator materials in inertial confinement fusion (ICF) experiments where similar conditions are present during the first compression stage of the imploding capsule. Here, carbon-hydrogen demixing may enhance the hydrodynamic instabilities occurring in the following compression stages. First experiments applying dynamic compression and ultrafast in situ X-ray diffraction at SLAC’s Linac Coherent Light Source demonstrated diamond formation from polystyrene (CH) at 150 GPa and 5000 K. Very recent experiments have now investigated the influence of oxygen, which is highly abundant in icy giant planets on the phase separation process. Compressing PET (C9H10O4) and PMMA (C5H8O2), we find again diamond formation at pressures above ~150 GPa and temperatures of several thousand kelvins, showing no strong effect due to the presence of oxygen. Thus, diamond precipitation deep inside icy giant planets seems very likely. Moreover, small-angle X-ray scattering (SAXS) was added to the platform, which determines an upper limit for the diamond particle size, while the width of the diffraction features provides a lower limit. We find that diamond particles of several nanometers in size are formed on a nanosecond timescale. Finally, spectrally resolved X-ray scattering is used to scale amorphous diffraction signals and allows for determining the amount of carbon-hydrogen demixing inside the compressed samples even if no crystalline diamond is formed. This whole set of diagnostics provides unprecedented insights into the nanosecond kinetics of dense plasma chemistry.

A generalized, intuitive two-fluid picture of 2D collisionless reconnection and its relation to whistler waves
YOUNG DAE YOON, Caltech

A generalized, intuitive two-fluid picture of 2D non-driven collisionless magnetic reconnection is described using results from a full-3D numerical simulation. The relevant two-fluid equations simplify to the condition that the flux associated with canonical circulation Q = m_e \nabla \times u_e + q_e B is perfectly frozen into the electron fluid. Q is the curl of the canonical momentum. Since \nabla \cdot Q = 0, the Q flux tubes are incompressible and so have a fixed volume. Because they are perfectly frozen into the electron fluid, the Q flux tubes cannot reconnect. Following the behavior of these Q flux tubes provides an intuitive insight into 2D collisionless reconnection of B. In the reconnection geometry, a small perturbation to the central electron current sheet effectively brings a localized segment of a Q flux tube towards the X-point. This flux tube segment is convected downwards with the central electron current, effectively stretching the flux tube, decreasing its cross-section to maintain a fixed volume and so increasing the magnitude of Q. Also, because Q is the sum of the electron vorticity and the magnetic field, the two terms may change in such a way that one term becomes smaller while the other becomes larger while preserving constant Q flux. This allows magnetic reconnection, which is a conversion of magnetic field into particle velocity, to occur without any dissipation mechanism. The entire process has positive feedback with no restoring mechanism and therefore is an instability. The Q motion provides an interpretation for other phenomena as well, such as spiked central electron current filaments. The simulated reconnection rate was found to agree with a previous analytical calculation having the same geometry. Energy analysis shows that the magnetic energy is converted and propagated mainly in the form of the Poynting flux, while helicity analysis shows that the canonical helicity \int P \cdot Q dV as a whole must be considered when analyzing reconnection. A mechanism for whistler wave generation and propagation is also described, with comparisons to recent spacecraft observations.


A generalized, intuitive two-fluid picture of 2D non-driven collisionless magnetic reconnection is described using results from a full-3D numerical simulation. The relevant two-fluid equations simplify to the condition that the flux associated with canonical circulation Q = m_e \nabla \times u_e + q_e B is perfectly frozen into the electron fluid. Q is the curl of the canonical momentum. Since \nabla \cdot Q = 0, the Q flux tubes are incompressible and so have a fixed volume. Because they are perfectly frozen into the electron fluid, the Q flux tubes cannot reconnect. Following the behavior of these Q flux tubes provides an intuitive insight into 2D collisionless reconnection of B. In the reconnection geometry, a small perturbation to the central electron current sheet effectively brings a localized segment of a Q flux tube towards the X-point. This flux tube segment is convected downwards with the central electron current, effectively stretching the flux tube, decreasing its cross-section to maintain a fixed volume and so increasing the magnitude of Q. Also, because Q is the sum of the electron vorticity and the magnetic field, the two terms may change in such a way that one term becomes smaller while the other becomes larger while preserving constant Q flux. This allows magnetic reconnection, which is a conversion of magnetic field into particle velocity, to occur without any dissipation mechanism. The entire process has positive feedback with no restoring mechanism and therefore is an instability. The Q motion provides an interpretation for other phenomena as well, such as spiked central electron current filaments. The simulated reconnection rate was found to agree with a previous analytical calculation having the same geometry. Energy analysis shows that the magnetic energy is converted and propagated mainly in the form of the Poynting flux, while helicity analysis shows that the canonical helicity \int P \cdot Q dV as a whole must be considered when analyzing reconnection. A mechanism for whistler wave generation and propagation is also described, with comparisons to recent spacecraft observations.


The plasmoid instability has had a transformative effect in our understanding of magnetic reconnection in a multitude of systems. By preventing the formation of highly elongated reconnection layers, it has proven to be crucial in enabling the rapid energy conversion rates that are characteristic of many plasma phenomena. In the well-known Sweet-Parker current sheets, the growth of the plasmoid instability occurs at a rate that is proportional to the Lundquist number (S) raised to a positive exponent. For this reason, in large-S systems, Sweet-Parker current sheets cannot be attained as current layers are linearly unstable and undergo disruption before the Sweet-Parker state is attained. Here, we present a quantitative theory of the plasmoid instability in time-evolving current sheets based on a principle of least time [1]. We obtain analytical expressions for the growth rate, number of plasmoids, plasmoid width, current sheet aspect ratio and onset time for fast reconnection. They are shown to depend on the Lundquist number, the magnetic Prandtl number, the noise of the system, the characteristic rate of current sheet evolution, as well as the thinning process [1,2]. We validate the obtained analytical scaling relations by comparing them against the full numerical solutions of the principle of least time. Furthermore, we show that the plasmoid instability exhibits a quiescence period followed by a rapid growth over a short timescale [1,2,3].

1 This work is supported by NSF, Grant Nos. AGS-1338944 and AGS-1460169, and by DOE, Grant No. DE-AC02-09CH-11466.
3 Y.-M. Huang, L. Comisso, and A. Bhattacharjee, arXiv:1707.01863.
of plasma devices and future fusion reactors such as ITER. Fractal TRIDYN (F-TRIDYN) is an upgraded version of the Monte Carlo, BCA program TRIDYN developed for this purpose that includes an explicit fractal model of surface roughness and extended input and output options for file-based code coupling. Code coupling with both plasma and material codes has been achieved and allows for multi-scale, whole-device modeling of plasma experiments. These code coupling results will be presented. F-TRIDYN has been further upgraded with an alternative, statistical model of surface roughness. The statistical model is significantly faster than and compares favorably to the fractal model. Additionally, the statistical model compares well to alternative computational surface roughness models and experiments. Theoretical links between the fractal and statistical models are made, and further connections to experimental measurements of surface roughness are explored.

"This work was supported by the PSI-SciDAC Project funded by the U.S. Department of Energy through contract DOE-SC00088658.

14:36
UO4 4 Calculations of Helium Bubble Evolution in the PISCES Experiments with Cluster Dynamics SOPHIE BLONDEL, TIMOTHY YOUNKIN, BRIAN WIRTH, University of Tennessee ANE LASA, DAVID GREEN, JOHN CANIK, Oak Ridge National Laboratory JON DROBNY, DAVID CURRELLI, University of Illinois at Urbana "Champaign Plasma surface interactions in fusion tokamak reactors involve an inherently multiscale, highly non-equilibrium set of phenomena, for which current models are inadequate to predict the divertor response to and feedback on the plasma. In this presentation, we describe the latest code developments of Xolotl, a spatially-dependent reaction diffusion cluster dynamics code to simulate the divertor surface response to fusion-relevant plasma exposure. Xolotl is part of a code-coupling effort to model both plasma and material simultaneously; the first benchmark for this effort is the series of PISCES linear device experiments. We will discuss the processes leading to surface morphology changes, which further affect erosion, as well as how Xolotl has been updated in order to communicate with other codes. Furthermore, we will show results of the sub-surface evolution of helium bubbles in tungsten as well as the material surface displacement under these conditions.

14:48
UO4 5 Modeling of Fuzz Formation on Helium-Ion-Irradiated Tungsten Surfaces DWAIAPAYAN DASGUPTA, University of Tennessee, Knoxville DIMITRIOS MAROUDAS, University of Massachusetts, Amherst BRIAN WIRTH, University of Tennessee, Knoxville Experiments have shown that helium (He) from plasma devices is responsible for the formation of a nanostructure with a fuzz-like morphology on the plasma-facing tungsten (W) surface after a few hours of plasma exposure, which can potentially impact fusion reactor performance. We report an atomistically-informed, continuous-domain model capable of describing the surface morphological evolution of He-ion-irradiated W and predicting the initial stage of fuzz formation on W surfaces. Based on this model, a systematic protocol of self-consistent dynamical simulations of the irradiated tungsten surface morphological evolution is conducted to compare the simulation results with experimental studies in the literature. Upon model validation, the simulations are used to identify the critical range of conditions for nanotendril formation on the surface, a precursor to fuzz-like surface growth. We examine a broad range of surface temperature, He ion energy, and He flux values relevant to experimental conditions and present the results of a sensitivity analysis of the key model parameters, such as He concentration and He nanobubble size. Further development of the model, driven by comparisons of its predictions with experimental observations also will be discussed.

15:00
UO4 6 Simulating tokamak PFC performance using simultaneous dual beam particle loading with pulsed heat loading* GREGORY SINCLAIR, SEAN GONDERMAN, JITENDRA TRIPATHI, TAYLER RAY, AHMED HASSANEIN, Purdue University The performance of plasma facing components (PFCs) in a fusion device is expected to change due to high flux particle loading during operation. Tungsten (W) is a promising PFC candidate material, due to its high melting point, high thermal conductivity, and low tritium retention. However, ion irradiation of D and He have each shown to diminish the thermal strength of W. This work investigates the synergistic effect between ion species, using dual beam irradiation, on the thermal response of W during ELM-like pulsed heat loading. Experiments studied three different loading conditions: laser, laser + He+, and laser + He+ + D+. 100 eV He+ and D+ exposures used a flux of 3.0-3.5 x 10^20 m^-2 s^-1. ELM-like loading was applied using a pulsed Nd:YAG laser at an energy density of 0.38-1.51 MJ m^-2 (3600 1 ms pulses at 1 Hz). SEM imaging revealed that laser + He+ loading at 0.76 MJ m^-2 caused surface melting, inhibiting fuzz formation. Increasing the laser fluence decreased grain size and increased surface pore density. Thermally-enhanced migration of trapped gases appear to reflect resultant molten morphology.
"This work was supported by the National Science Foundation PIRE project.

15:12
UO4 7 Tungsten oxide thin film exposed to low energy D and He plasma: evidence for a thermal enhancement of the erosion yield HUSSEIN HIJAZI, C MARTIN, P ROUBIN, Y ADDAB, C CABIE, PARDANAUD, Aix Marseille University BANNISTER, F MEYER, ORNL Nanocrystalline tungsten oxide thin films (25 nm – 250 nm thickness) produced by thermal oxidation of a tungsten substrate were exposed to low energy D and He plasma. Low energy D plasma exposure (11 eV/D+) of these films have resulted in the formation of a tungsten bronze (D_xWO_3) clearly observed by Raman microscopy [1]. D plasma bombardment (4 x 10^21 m^-2) has also induced a color change of the oxide layer which is similar to the well-known electro-chromic effect and has been named “thermal-chromic effect”. To unravel physical and chemical origins of the modifications observed under exposure, similar tungsten oxide films were also exposed to low energy helium plasma (20 eV/He+). Due to the low fluence (4 x 10^21 m^-2) and low ion energy (20 eV), at room temperature, He exposure has induced only very few morphological and structural modifications. On the contrary, at 673 K, significant erosion is observed, which gives evidence for an unexpected thermal enhancement of the erosion yield [2]. We present here new results concerning He beam exposures at low fluence (4 x 10^21 m^-2) varying the He+ energy from 20 eV to 320 eV to measure the tungsten oxide sputtering threshold energy. Detailed analyses before/after exposure to describe the D and He interaction with the oxide layer, its erosion and structural modification at the atomic and micrometer scale will be presented.

15:24
UO4 8 3D measurements and simulations of ion and neutral velocity distribution functions in a magnetized plasma boundary* DEREK S. THOMPSON, West Virginia University, Department of Physics, Astronomy, and Geosciences The performance of plasma-facing components (PFCs) in a fusion device is expected to change due to high flux particle loading during operation. Tungsten (W) is a promising PFC candidate material, due to its high melting point, high thermal conductivity, and low tritium retention. However, ion irradiation of D and He have each shown to diminish the thermal strength of W. This work investigates the synergistic effect between ion species, using dual beam irradiation, on the thermal response of W during ELM-like pulsed heat loading. Experiments studied three different loading conditions: laser, laser + He+, and laser + He+ + D+. 100 eV He+ and D+ exposures used a flux of 3.0-3.5 x 10^20 m^-2 s^-1. ELM-like loading was applied using a pulsed Nd:YAG laser at an energy density of 0.38-1.51 MJ m^-2 (3600 1 ms pulses at 1 Hz). SEM imaging revealed that laser + He+ loading at 0.76 MJ m^-2 caused surface melting, inhibiting fuzz formation. Increasing the laser fluence decreased grain size and increased surface pore density. Thermally-enhanced migration of trapped gases appear to reflect resultant molten morphology.
"This work was supported by the National Science Foundation PIRE project.

15:12
UO4 7 Tungsten oxide thin film exposed to low energy D and He plasma: evidence for a thermal enhancement of the erosion yield HUSSEIN HIJAZI, C MARTIN, P ROUBIN, Y ADDAB, C CABIE, PARDANAUD, Aix Marseille University BANNISTER, F MEYER, ORNL Nanocrystalline tungsten oxide thin films (25 nm – 250 nm thickness) produced by thermal oxidation of a tungsten substrate were exposed to low energy D and He plasma. Low energy D plasma exposure (11 eV/D+) of these films have resulted in the formation of a tungsten bronze (D_xWO_3) clearly observed by Raman microscopy [1]. D plasma bombardment (4 x 10^21 m^-2) has also induced a color change of the oxide layer which is similar to the well-known electro-chromic effect and has been named “thermal-chromic effect”. To unravel physical and chemical origins of the modifications observed under exposure, similar tungsten oxide films were also exposed to low energy helium plasma (20 eV/He+). Due to the low fluence (4 x 10^21 m^-2) and low ion energy (20 eV), at room temperature, He exposure has induced only very few morphological and structural modifications. On the contrary, at 673 K, significant erosion is observed, which gives evidence for an unexpected thermal enhancement of the erosion yield [2]. We present here new results concerning He beam exposures at low fluence (4 x 10^21 m^-2) varying the He+ energy from 20 eV to 320 eV to measure the tungsten oxide sputtering threshold energy. Detailed analyses before/after exposure to describe the D and He interaction with the oxide layer, its erosion and structural modification at the atomic and micrometer scale will be presented.

15:24
UO4 8 3D measurements and simulations of ion and neutral velocity distribution functions in a magnetized plasma boundary* DEREK S. THOMPSON, West Virginia University, Department of Physics, Astronomy, and Geosciences
of Physics and Astronomy SHANE KENILEY, DAVIDE CURRELI, University of Illinois Urbana-Champaign, Department of Nuclear, Plasma, and Radiological Engineering MIGUEL F. HENRIQUEZ, DAVID D. CARON, ANDREW J. JEMIOLO, JACOB W. MCLAUGHLIN, MIKAL T. DUFOR, LUKE A. NEAL, EARL E. SCIME, West Virginia University, Department of Physics and Astronomy M. UMAIR SIDDIQUI, Phase Four, Inc. We present progress toward the first paired 3D laser induced fluorescence measurements of ion and neutral velocity distribution functions (INVDIFs) in a magnetized plasma boundary. These measurements are performed in the presheath region of an absorbing boundary immersed in a background magnetic field that is obliquely incident to the boundary surface ($\psi = 74^\circ$). Parallel and perpendicular flow measurements demonstrate that cross-field ion flows occur and that ions within several gyro-radii of the surface are accelerated in the $E \times B$ direction. We present electrostatic probe measurements of electron temperature, plasma density, and electric potential in the same region. Ion, neutral and electron measurements are compared to Boltzmann simulations, allowing direct comparison between measured and theoretical distribution functions in the boundary region.

“NSF PHYS 1360278.

15:36

UO4 9 Validation of Boltzmann-Poisson Continuum Code with LIF measurements of Plasma Sheath in an Oblique Magnetic Field∗ SHANE KENILEY, DAVIDE CURRELI, University of Illinois at Urbana-Champaign, Department of Nuclear, Plasma, and Radiological Engineering DEREK S. THOMPSON, MIGUEL F. HENRIQUEZ, DAVID D. CARON, ANDREW J. JEMIOLO, JACOB W. MCLAUGHLIN, MIKAL T. DUFOR, LUKE A. NEAL, EARL E. SCIME, West Virginia University, Department of Physics M. UMAIR SIDDIQUI, Phase Four, Inc. Here we present the first fully three-dimensional validation of a 1D3V Boltzmann-Poisson continuum solver against 3D LIF measurements of ion and neutral velocity distribution functions taken in a magnetized plasma sheath. The multi-species full-f plasma model is solved with finite volumes in the phase-space and computes the velocity distribution functions of plasma species, facilitating a direct comparison to LIF data in the magnetic presheath. LIF measurements were taken near an absorbing boundary with a magnetic field obliquely incident to the surface. The plasma model incorporates ionization and charge exchange through a BGK collision operator, with reaction rates computed directly through convolution with the distribution functions. Results clearly display the 3D structure of the magnetized sheath, including acceleration along the ExB direction.

∗Work supported by Scientific Discovery through Advanced Computing (SciDAC) Project on Plasma-Surface Interactions under DE-SC00-08875.

1LIF measurement work was supported by U.S. National Science Foundation Grant No. PHY-1360278.

15:48

UO4 10 Alternative power exhaust studies in an advanced upper divertor in ASDEX Upgrade supported by SOLPS and EMC3-EIRENE simulations TILMANN LUNT, OU PAN, ALBRECHT HERRMANN, DAVID COSTER, MIKE DUNNE, YUEH-FENG, ARNE KALLENBACH, MARCO WISCHMEIER, HARTMUT ZOHM, Max Planck Institute for Plasma Physics ASDEX Upgrade Team In order to study alternative divertor configurations, currently discussed as a possible solution for the power exhaust problem in a fusion reactor, the installation of a pair of in-vessel poloidal field coils in the upper divertor of ASDEX Up-grade was recently decided. Besides the conventional single- and double null configurations, a series of new configurations ranging from an X-divertor, to a low- (LFS SF−) and finally a high field side snowflake minus will be possible with these coils in a machine with a high P/R ratio. The arrangement of these coils was based on the pioneering work of TCV as well as simulations with EMC3-EIRENE, which can rather easily handle topologies with two X-points and which identified a series of heat flux mitigation effects. Due to the lack of drifts and volumetric recombination in the code, however, a clear prediction on the detachment degree and threshold is missing as well as a realistic description of the in-out divertor asymmetries. This limit has now been overcome by creating an adequate computational grid for a LFS SF− configuration for SOLPS. In this contribution we will present the worldwide first simulation on this grid as well as the upgrade plans and discuss the potential different heat flux mitigation mechanisms.

16:00

UO4 11 The role of pumping on particle removal and divertor plasma conditions∗ CHAOFEONG SANG, Dalian University of Technology PETER C. STANGEBY, University of Toronto HOUYANG GUO, VINCENT CHAN, General Atomics LIANG WANG, GUOSHENG XU, Institute of Plasma Physics, Chinese Academy of Sciences DALIAN UNIVERSITY OF TECHNOLOGY TEAM, BPMIC GENERAL ATOMICS COLLABORATION, EAST COLLABORATION The effect of pumping location in a closed detached divertor configuration is examined with SOLPS modeling. A closed divertor can increase neutral pressure and enhance radiative dissipation, thus it is proposed for advanced tokamak operation in order to achieve detachment at as low an upstream plasma density as possible. However, the necessity to pump the closed divertor results in reduction of the high density of neutrals. By changing the recycling rate at the pump, it is confirmed that the pump location has a great impact on the effective pumping speed, which influences the divertor plasma significantly. Higher pumping speed reduces the neutral density and increases Te as well as the heat flux to the target. For a given particle removal rate, however, the plasma conditions are insensitive to the pump location within the divertor. High D2 gas puffing with high pumping could help to achieve detachment only when the upstream density is increased by puffing, in contrast, a deeper divertor can be easily reached in a low pumping and low puffing case.

∗Supported by National Key R&D Program of China 2017YFA0402500, US DOE under DE-FG02-04ER54698.

16:12

UO4 12 Physics of neutral gas jet interaction with magnetized plasmas∗ ZHANHUI WANG, Southwestern Institute of Physics XUEQIAO XU, Lawrence Livermore National Laboratory PATRICK DIAMOND, University of California at San Diego MIN XU, XURU DUAN, DELIANG YU, YULIN ZHOU, YONGFU SHI, LIN NIE, RUI KE, WULV ZHONG, ZHONGBING SHI, AIPING SUN, JIQUAN LI, LIANGHUA YAO, Southwestern Institute of Physics It is critical to understand the physics and transport dynamics during the plasma fuelling process. Plasma and neutral interactions involve the transfer of charge, momentum, and energy in ion-neutral and electron-neutral collisions. Thus, a seven field fluid model of neutral gas jet injection (NGJI) is obtained, which couples plasma density, heat, and momentum transport equations together with neutrals density and momentum transport equations of both molecules and atoms. Transport dynamics of plasma and neutrals are simulated for a complete range of discharge times, including steady state before NGJI, transport during NGJI, and relaxation after NGJI. With the trans-neut module of BOUT++ code,
the simulations of mean profile variations and fueling depths during fueling have been benchmarked well with other codes and also validated with HL-2A experiment results. Both fast component (FC) and slow component (SC) of NGJI are simulated and validated with the HL-2A experimental measurements. The plasma blocking effect on the FC penetration is also simulated and validated well with the experiment.

∗This work is supported by the National Natural Science Foundation of China under Grant No. 11575055.

16:24
UO4 13 Impact of the impurity seeding for divertor protection on the performance of fusion reactors MATTHIA SICCINIO, EMILIANO FABLE, CLEMENTE ANGIONI, Max Planck Institut für Plasmaphysik SAMULI SAARELMA, Culham Centre for Fusion Energy ANDREA SCARABOSIO, HARTMUT ZOHM, Max Planck Institut für Plasmaphysik A 0D divertor and scrape-off layer (SOL) model has been coupled to the 1.5D core transport code ASTRA. The resulting numerical tool has been employed for various parameter scans in order to identify the most convenient choices for the operation of electricity producing fusion devices with seeded impurities for the divertor protection. In particular, the repercussions of such radiative species on the main plasma through the fuel dilution have been taken into account. The main result we found is that, when the limits on the maximum tolerable divertor heat flux are enforced, the curves at constant electrical power output are closed on themselves in the R-BT plane, i.e. no improvement would descend from a further increase of R or BT once the maximum has been reached. This occurrence appears as an intrinsic physical limit for all devices where a radiative SOL is needed to deal with the power exhaust. Furthermore, the relative importance of the different power loss channels (e.g. hydrogen radiation, charge exchange, perpendicular transport and impurity radiation), through which the power entering the SOL is dissipated before reaching the target plate, is investigated with our model.

16:36
UO4 14 Design of fishtail divertor for heat load control during long-pulse operation on EAST tokamak XIAO DONG ZHANG, YI YUN HUANG, DA DAO YAO, BIN JIA XIAO, JIE FENG WU, JIN PING QIAN, HUI DONG ZHANG, YANG ZHANG, Institute of Plasma Physics, Chinese Academy of Sciences EAST TEAM A new divertor concept, FishTail Divertor (FTD), is proposed and designed on EAST tokamak. The basic idea is to design and install an active coil near the strike point under the low divertor target. Applying the AC-current in this coil, the strike point along the radial and poloidal direction can be moved like a swing of fishtail by the additional alternating magnetic field. As a result, the wetted area of the heat flux is spread out, and thereby the averaged heat load is reduced. The heat flux on the divertor target has been simulated by using ANSYS combined with EFIT. It shows that the heat load on the carbon surface of the divertor can be reduced by a factor of 2/3 by applying this fishtail swing. Based on the simulations and preliminary engineering design, it is found that FTD has following advantages compare with other divertor concepts, such as the Snowflake divertor, X-divertor, Super-X divertor, and X-point target divertor: (1) Uniform distribution of the heat flux on the divertor plate; (2) Reliable control of heat load on the divertor plate; (3) Little effect on the plasma shape and X-point location; (4) Feasibility from the engineering and technology point of view.

16:48
UO4 15 Single Null Negative Triangularity Tokamak for Power Handling MITSURU KIKUCHI, National Institutes for Quantum and Radiological Science and Technology(QST) S. MEDVEDEV, KIAM T. TAKIZUKA, Osaka University O. SAUTER, A. MERLE, S. CODA, SPC, EPFL D. CHEN, INEST J.X. LI, SWIP Power and particle control in fusion reactor is challenge and we proposed the negative triangularity tokamak (NTT) to eliminate ELM by operating L-mode edge with improved core confinement [1-3]. The SN configuration has more flexibility in shaping by adopting rectangular-shaped TF coils. The limiting normalized beta is 3.56 with wall stabilization and 3.14 without wall [3]. The vertical stability is assured under a reasonable control system. The wetted area on the divertor plates becomes wider in proportion to the larger major radius at the divertor strike points due to the NT configuration. In addition to the major-radius effect, the (Flux Tune Expansion (FTE)) [4] is adopted to further reduce the heat load on the divertor plate by factor of ~2.6 with a coil current 3 MA. L-mode edge also allows further increase in wetted area. The fusion power of 3 GW is deliverable only at normalized beta 2.1. Therefore this reactor may be operable stably against the serious MHD activities. The CD power for SS operation is ~175 MW at Q = 17. AC operation is also possible option. A required HH factor is relatively modest H = 1.12.

1M. Kikuchi et al., 1st Int. e-Conf. Energies 2014, e002.
3S. Medvedev, M. Kikuchi et al., 26th IAEA-FEC, ICC/P3-47 (2016).
x-ray light source on large-scale international laser facilities, and also opens up the prospect of using them for applications.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under the contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC.

14:12
UO5 2 Simulation of a brilliant betatron gamma-ray source from a two-stage wakefield accelerator
X. DAVOINE, J. FERRI, CEA DAM DIF, 91297 Arpajon, France I. ANDRIYASHI, Synchrotron SOLEIL, 91192 Gif-sur-Yvette, France S. CORDE, A. DOPP, A. DOCHE, C. THAURY, K. TA PHUOC, B. MAHIEU, V. MALKA, A. LIFSCHITZ, LOA, 91762 Palaiseau, France
Thanks to the recent progress in laser-driven plasma acceleration of electrons, the ultra-short, compact and spatially coherent X-ray betatron sources generated in a wakefield accelerator have been successfully applied to high-resolution imaging or ultra-fast probing of matter evolution in the last few years. Here, based on three-dimensional particle-in-cell simulations, we propose an original hybrid scheme in which an electron beam produced in a first stage of laser-driven wakefield, interacts in a second stage with aghiger plasma density to generate a beam-driven wakefield and undergo strong betatron oscillation. This second stage acts as an efficient plasma radiator: we show that this scheme greatly improves the energy efficiency of the source, with about 1% of the laser energy transferred to the radiation, and that the gamma-ray photon energy exceeds the MeV range when using a 15 J laser pulse. This new scheme opens the way to a wide range of applications requiring high-brilliance MeV photon source, such as photo-nuclear reaction study, radiography of dense objects, probing in nuclear physics or electron-positron pair production.

*This work has been supported by Laserlab-Europe (EU-H2020 654148) and GENCI (access to TGCC/Curie under the Grants No. 2016-056129 and 2016-057594).

14:24
UO5 3 Plasma channel undulator excited by high-order laser modes
JINGWEI WANG, Helmholtz Institute Jena CARL SCHROEDER, Lawrence Berkeley National Laboratory MATT ZEPPF, SERGEY RYKOVANOV, Helmholtz Institute Jena
The possibility of utilizing plasma undulators and plasma accelerators to produce compact and economical ultraviolet and X-ray radiation sources has attracted considerable interest for a few decades. This interest has been driven by the great potential to decrease the threshold for accessing such sources, which are now mainly provided by a very few dedicated large-scale synchrotron or free-electron laser (FEL) facilities. However, the typically broad radiation bandwidth of such plasma devices limits the source brightness and makes it difficult for the FEL instability to develop. Here, using multi-dimensional electromagnetic particle-in-cell simulations, we demonstrate that a plasma undulator generated by the beating of a mixture of high-order laser modes propagating inside a plasma channel, leads to a few percent radiation bandwidth. The strength of the undulator can reach unity, the period can be less than a millimeter, and the total number of undulator periods can be significantly increased by a phase locking technique based on the longitudinal density modulation. According to analytical estimates and simulations, in the fully beam loaded regime, the electron current in the undulator can reach 0.3 kA, making such an undulator a potential candidate towards a table-top FEL.

14:36
UO5 4 Intense single attosecond pulse generation through coherent synchrotron emission from laser interaction with capacitor-nanofoil target
R. XU, B. QIAO, Y. X. ZHANG, H. Y. LU, Peking University H. ZHANG, Institute of Applied Physics and Computational Mathematics B. DROMEY, Queen’s University Belfast R. F. LI, Peking University C. T ZHOU, S. P. ZHU, Institute of Applied Physics and Computational Mathematics M. ZEPPF, Queen’s University Belfast X. T. HE, Peking University
In the relativistic laser-plasma interaction process, coherent synchrotron emission (CSE) has been identified as one of the most efficient mechanisms to produce attosecond pulse. However, the electron nanobunch, which is the key character of CSE, is highly sensitive to the interaction condition and is hard to be formed. Here we show that through irradiating on a capacitor-nanofoil target, which is composed of two separated nanofoils, this difficulty can be overcome. Both one-dimensional and two-dimensional particle-in-cell simulations reveal that the strong electrostatic field developed between two foils is responsible for the formation and the acceleration of the ultradense electron nanobunch. This nanobunch reaches both high density and energy in only half laser cycle and smears out in others, resulting in a single attosecond pulse with intensity up to $10^{21} \text{W/cm}^2$ and duration of 8as when the intensity of the driving laser of $7.7 \times 10^{21} \text{W/cm}^2$.

14:48
UO5 5 X-Ray generation by the laser-plasma interaction in the regime of relativistic electronic spring
ARKADY GONOSKOV, THOMAS BLACKBURN, Chalmers University of Technology, SE-41296 Gothenburg, Sweden MANUEL BLANCO, M. T. FLORES-ARIA, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain BENJAMIN WETTERVIK, MATIAS MARKLUND, Chalmers University of Technology, SE-41296 Gothenburg, Sweden
Inducing and controlling relativistic motion of surface electrons in overdense plasmas with high-intensity lasers is a promising way to produce X-rays with unique properties, including high brightness, ultra-short duration and tunable polarization. Although the well-studied relativistic oscillating mirror (ROM) regime provides robust generation of high harmonics, the amplitude of the outgoing light in this regime is always equal to that of the incident radiation because the conversion takes place continuously without energy accumulation. This restriction can be overcome by increasing the laser intensity and/or decreasing the plasma density such that $n/a < 10$. In this case the plasma acts as a spring, first accumulating up to 60% of the energy of one laser cycle, then re-emitting it in the form of a burst of high harmonics. Under optimal conditions this burst can be both 100 times shorter in duration and 100 times higher in intensity. The theory of relativistic electronic spring (RES) [1] describes a wide variety of interaction scenarios in this regime and provides insight into the underlying physics. The talk will concern the prospects of creating and controlling XUV bursts of exceptional brightness in the RES regime.


15:00
UO5 6 Narrowband Compton Scattering Yield Enhancement
SERGEY RYKOVANOV, Helmholtz Institute Jena DANIEL SEIPT, Lancaster University, United Kingdom VASILY KARHIN, Helmholtz Institute Jena Compton Scattering (CS) of laser light off high-energy electrons is a well-established source of X- and gamma-rays for applications in medicine, biology, nuclear and material sciences. Main advantage of CS photon sources is the possibility to generate narrow spectra as opposed to a broad continuum obtained when utilizing Bremsstrahlung. However, due to the low cross-
section of the linear process, the total photon yield is quite low. The most straightforward way to increase the number of photon-electron beam scattering events is to increase the laser pulse intensity at the interaction point by harder focusing. This leads to an unfortunate consequence. Increase in the laser pulse normalized amplitude $a_0$, leads to additional ponderomotive spectrum broadening of the scattered radiation. The ponderomotive broadening is caused by the $\mathbf{v} \times \mathbf{B}$ force, which slows the electron down near the peak of the laser pulse where the intensity is high, and can be neglected near the wings of the pulse, where the intensity is low. We show that laser pulse chirping, both nonlinear (laser pulse frequency “following” the envelope of the pulse) and linear, leads to compensation of the ponderomotive broadening and considerably enhances the yield of the nonlinear Compton sources.

*Work supported by the Helmholtz Association via Helmholtz Young Investigators Grant (VH-NG-1037).

15:12
UO5 7 Electron Beam Diagnosis Using K-edge Absorption of Laser-Compton Photons∗ YOONWOO HWANG, Univ of California - Irvine DAVID GIBSON, ROARK MARSH, Lawrence Livermore National Laboratory CHRISTOPHER BARTY, TOSHIKI TAJIMA, Univ of California - Irvine The mean energy, energy spread and divergence of the electron beam can be deduced from laser-Compton scattered X-rays filtered by a material whose K-edge is near the energy of the X-rays. This technique, combined with a spot size measurement of the beam, can be used to measure the emittance of electron bunches, and can be especially useful in LWFA experiments where conventional methods are unavailable. The effects of the electron beam parameters on X-ray absorption images are discussed, along with experimental demonstrations of the technique using the Compact Laser-Compton X-ray Source at LLNL.

*This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

15:24
UO5 8 Laser-driven ultrafast multi-MeV gamma-ray beam generation JIANCAI XU, BAIFEI SHEN, TONGJUN XU, SHUN LI, YONG YU, JINFENG LI, XIAOMING LIU, CHENG WANG, XINLIANG WANG, XIAOYAN LIANG, YUXIN LENG, RUXIN LI, ZHIZHAN XU, State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences Ultrafast multi-MeV high-flux gamma-ray beam has been experimentally produced via bremsstrahlung radiation of laser-accelerated energetic electrons through millimeter-thick copper targets. By optimizing the electron bunches to the charge of 10 nC in a clustering argon gas target, the obtained gamma-ray beam significantly increases to $10^{10}$ photons per shot. The gamma-ray beam spectrum has been measured using a differential detecting filter and has a broad spectrum up to 15 MeV, which is approximately consistent with the Geant4 simulation. The generated high-flux high-energy gamma-ray beams are promising sources for photoneutral reaction, non-destructive inspection and clinical applications.

1 surtout
UO5 9 Compact gain saturated plasma based X-ray lasers down to 6.9 nm∗ JORGE ROCCA, Y. WANG, S. WANG, A. ROCKWOOD, M. BERRILL, V. SHLYAPTSEV, Colorado State University

Plasma based soft x-ray amplifiers allow many experiments requiring bright, high energy soft x-ray laser pulses to be conducted in compact facilities. We have extended the wavelength of compact gain saturated x-ray lasers to 6.89 nm in a Ni-like Gd plasma generated by a Ti:Sa laser. Gain saturated laser operation was also obtained at 7.36 nm in Ni-like Sm. Isoelectronic scaling and optimization of laser pre-pulse duration allowed us to also observe strong lasing at 6.6 nm and 6.1 nm in Ni-like Tb, and amplification at 6.4 nm and 5.89 nm in Ni-like Dy. The results were obtained by transient laser heating of solid targets with traveling wave excitation at progressively increased gracing incidence angles. We show that the optimum pump angle of incidence for collisional Ni-like lasers increases linearly with atomic number from $Z=42$ to $Z=66$, reaching 43 degrees for Ni-like Dy, in good agreement with hydrodynamic/atomic physics simulations. These results will enable single-shot nano-scale imaging and other application of sub-7 nm lasers to be performed at compact facilities.

*Work supported by Grant DE-FG02-4ER15592 of the Department of Energy, Office of Science, and by the National Science Foundation Grant ECCS 1509925.

15:48
UO5 10 Plasma instability control toward high fluence, high energy x-ray continuum source PATRICK POOLE, ROBERT KIRKWOOD, SCOTT WILKS, BRENT BLUE, Lawrence Livermore National Laboratory X-ray source development at Omega and NIF seeks to produce powerful radiation with high conversion efficiency for material effects studies in extreme fluence environments. While current K-shell emission sources can achieve tens of kJ on NIF up to 22 keV, the conversion efficiency drops rapidly for higher Z K-alpha energies. Pulsed power devices are efficient generators of MeV bremsstrahlung x-rays but are unable to produce lower energy photons in isolation, and so a capability gap exists for high fluence x-rays in the 30 – 100 keV range. A continuum source under development utilizes instabilities like Stimulated Raman Scattering (SRS) to generate plasma waves that accelerate electrons into high-Z converter walls. Optimizing instabilities using existing knowledge on their elimination will allow sufficiently hot and high yield electron distributions to create a superior bremsstrahlung x-ray source. An Omega experiment has been performed to investigate the optimization of SRS and high energy x-rays using Au hohlraums with parylene inner lining and foam fills, producing $\sim10^{18}$ greater x-ray yield at 50 keV than conventional direct drive experiments on the facility. Experiment and simulation details on this campaign will be presented.

*This work was performed under the auspices of the US DoE by LLNL under Contract No. DE-AC52-07NA27344.

16:00
UO5 11 Focusing and up-shift of laser light by relativistic flying mirrors in the high power and large wavelength difference regime∗ JAMES KOGA, SERGEI V. BULANOV, TIMUR ZH. ESIRKEPOV, MASAKI KANDO, National Institutes for Quantum and Radiological Science and Technology Frequency up-shift and compression of electromagnetic waves by relativistic flying mirrors (RFM) have been demonstrated theoretically, numerically and experimentally (see review [1]). RFM are generated with ultra-high power laser pulses (driver pulses) propagating in plasma from breaking plasma waves. Lasers counter-propagating to the breaking plasma waves (source pulses) are reflected, up-shifted and compressed. Here, we investigate the focusing and reflectivity where source pulses with varying intensity have a much longer wavelength...
than the driver pulse and where both pulses are the same intensity using 2D particle-in-cell simulations. We show that the source pulse can significantly modify the RFM at high intensity and show the generation of harmonics when both pulses are the same intensity.

*This work was supported by JSPS KAKENHI Grant Number JP16K05639.


16:12
UO5 12 Recent progress in simulation and theory towards using nonlinear plasma wakefields to drive a compact X-FEL*

XINLU XU, Univ of California - Los Angeles WEI LU, Tsinghua University, Beijing CHAN JOSHI, WARREN MORI, Univ of California - Los Angeles Plasma-based wakefield accelerators can generate and accelerate electrons with 10 100 GV/m acceleration gradient. Compared with conventional radio frequency based accelerators, plasma accelerators can much shrink the size and reduce the cost of X-ray Free-electron-lasers which require high quality and high energy. However there are many challenges needed to be overcome before plasma wakefields can generate electron beams with the required beam quality (brightnesses and low energy spreads) inside the plasma and before these beams can be transported from the plasma to the undulator without beam quality degradation. In this talk, we will present our recent progress from PIC simulations and theory on this topic, including concepts for producing beams with unprecedented normalized brightnesses using density down ramp injection in the nonlinear blowout regime, matching the beam out of the plasma using longitudinally tailored plasma profiles, and start-to-end simulations of such plasma wakefield accelerators driven X-FELs.

*Work supported by NSF and DOE.

16:24
UO5 13 Ultrahigh 6D-brightness electron beams for the light sources of the next generation FAHIM HABIB, GRACE G. MANAHAN, PAUL SCHERKL, THOMAS HEINEMANN, Z.M. SHENG, University of Strathclyde, The Cockcroft Institute D.L. BRUHWILER, RadioSoft LLC J.R. CARY, University of Colorado Boulder, Tech-X Corporation J.B. ROSENZWEIG, UCLA BERNARD HIDDING, University of Strathclyde, The Cockcroft Institute The plasma photocathode mechanism (aka Trojan Horse) enables a path towards electron beams with nm-level normalized emittance and kA range peak currents, hence ultrahigh 5D-brightness. This ultrahigh 5D-brightness beams hold great prospects to realize laboratory scale free-electron-lasers. However, the GV/m accelerating gradient in plasma accelerators leads to substantial energy chirp and spread. The large energy spread is a major showstopper towards key application such as the free-electron-laser. Here we present a novel method for energy chirp compensation which takes advantage of tailored beam loading due to a second “escort” bunch released via plasma photocathode. The escort bunch reverses the accelerating field locally at the trapping position of the ultrahigh 5D-brightness beam. This induces a counter-clockwise rotation within the longitudinal phase space and allows to compensate the chirp completely. Analytical scaling predicts energy spread values below 0.01 percentage level. Ultrahigh 5D-brightness combined with minimized energy spread opens a path towards witness beams with unprecedented ultrahigh 6D-brightness [1].


14:00
UO6 1 The Multipole Plasma Trap—PIC Modeling Results*

NATHANIEL HICKS, AMANDA BOWMAN, KATARINA GODDEN, University of Alaska Anchorage A radio-frequency (RF) multipole structure is studied via particle-in-cell computer modeling, to assess the response of quasi-neutral plasma to the imposed RF fields. Several regimes, such as pair plasma, antimatter plasma, and conventional (ion-electron) plasma are considered. In the case of equal charge-to-mass ratio of plasma species, the effects of the multipole field are symmetric between positive and negative particles. In the case of a charge-to-mass disparity, the multipole RF parameters (frequency, voltage, structure size) may be chosen such that the light species (e.g. electrons) is strongly confined, while the heavy species (e.g. positive ions) does not respond to the RF field. In this case, the trapped negative space charge creates a potential well that then traps the positive species. 2D and 3D particle-in-cell simulations of this concept are presented, to assess plasma response and trapping dependences on multipole order, consequences of the formation of an RF plasma sheath, and the effects of an axial magnetic field. The scalings of trapped plasma parameters are explored in each of the mentioned regimes, to guide the design of prospective experiments investigating each.

*Supported by U.S. NSF/DOE Partnership in Basic Plasma Science and Engineering Grant PHY-1619615.

14:12
UO6 2 One-dimension modeling on the parallel-plate ion extraction process based on a non-electron-equilibrium fluid model HE-PING LI, JIAN CHEN, HENG GUO, DONG-JUN JIANG, MING-SHENG ZHOU, Tsinghua University DEPARTMENT OF ENGINEERING PHYSICS TEAM Ion extraction from a plasma under an externally applied electric field involve multi-particle and multi-field interactions, and has wide applications in the fields of materials processing, etching, chemical analysis, etc. In order to develop the high-efficiency ion extraction methods, it is indispensable to establish a feasible model to understand the non-equilibrium transportation processes of the charged particles and the evolutions of the space charge sheath during the extraction process. Most of the previous studies on the ion extraction process are mainly based on the electron-equilibrium fluid model, which assumed that the electrons are in the thermodynamic equilibrium state. However, it may lead to some confusions with neglecting the electron movement during the sheath formation process. In this study, a non-electron-equilibrium model is established to describe the transportation of the charged particles in a parallel-plate ion extraction process. The numerical results show that the formation of the Child-Langmuir sheath is mainly caused by the charge separation. And thus, the sheath shielding effect will be significantly weakened if the charge separation is suppressed during the extraction process of the charged particles.

14:24
UO6 3 Microwave Assisted Helicon Plasmas*

JOHN MCKEE, DAVID CARON, ANDREW JEMIOLO, EARL SCIME, West Virginia Univ The use of two (or more) rf sources at different frequencies is a common technique in the plasma processing industry
to control ion energy characteristics separately from plasma generation. A similar approach is presented here with the focus on modifying the electron population in argon and helium plasmas. The plasma is generated by a helicon source at a frequency $f_0 = 13.56$ MHz. Microwaves of frequency $f_1 = 2.45$ GHz are then injected into the helicon source chamber perpendicular to the background magnetic field. The microwaves damp on the electrons via X-mode Electron Cyclotron Heating (ECH) at the upper hybrid resonance, providing additional energy input into the electrons. The effects of this secondary-source heating on electron density, temperature, and energy distribution function are examined and compared to helicon-only single source plasmas as well as numeric models suggesting that the heating is not evenly distributed. Optical Emission Spectroscopy (OES) is used to examine the impact of the energetic tail of the electron distribution on ion and neutral species via collisional excitation. Large enhancements of neutral spectral lines are observed in both Ar and He. While small enhancement of ion lines is seen in Ar, ion lines not normally present in He are observed during microwave injection.

*U.S. National Science Foundation Grant No. PHY-1360278.

14:36
UO6 4 Hollow laser plasma self-confined microjet generation* VALERYI SIZYUK, AHMED HASSANEIN, Purdue University, West Lafayette, IN CENTER FOR MATERIALS UNDER EXTREME ENVIRONMENT TEAM Hollow laser beam produced plasma (LPP) devices are being used for the generation of the self-confined cumulative microjet. Most important place by this LPP device construction is achieving of an annular distribution of the laser beam intensity by spot. An integrated model is being developed to detailed simulation of the plasma generation and evolution inside the laser beam channel. The model describes in two temperature approximation hydrodynamic processes in plasma, laser absorption processes, heat conduction, and radiation energy transport. The total variation diminishing scheme in the Lax-Friedrich formulation for the description of plasma hydrodynamic is used. Laser absorption and radiation transport models on the base of Monte Carlo method are being developed. Heat conduction part on the implicit scheme with sparse matrixes using is realized. The developed models are being integrated into HEIGHTS-LPP computer simulation package. The integrated modeling of the hollow beam laser plasma generation showed the self-confinement and acceleration of the plasma microjet inside the laser channel. It was found dependence of the microjet parameters including radiation emission on the hole and beam radiuses ratio.

*This work is supported by the National Science Foundation, PIRE project.

14:48
UO6 5 EUV laser produced and induced plasmas for nanolithography* TATYANA SIZYUK, AHMED HASSANEIN, Purdue University EUV produced plasma sources are being extensively studied for the development of new technology for computer chips production. Challenging tasks include optimization of EUV source efficiency, producing powerful source in 2 percentage bandwidth around 13.5 nm for high volume manufacture (HVM), and increasing the lifetime of collecting optics. Mass-limited targets, such as small droplet, allow to reduce contamination of chamber environment and mirror surface damage. However, reducing droplet size limits EUV power output. Our analysis showed the requirement for the target parameters and chamber conditions to achieve 500 W EUV output for HVM. The HEIGHTS package was used for the simulations of laser produced plasma evolution starting from laser interaction with solid target, development and expansion of vapor/plasma plume with accurate optical data calculation, especially in narrow EUV region. Detailed 3D modeling of mix environment including evolution and interplay of plasma produced by lasers from Sn target and plasma produced by in-band and out-of-band EUV radiation in ambient gas, used for the collecting optics protection and cleaning, allowed predicting conditions in entire LPP system. Effect of these conditions on EUV photon absorption and collection was analyzed.

*This work is supported by the National Science Foundation, PIRE project.

15:00
UO6 6 Characterization and Comparison of Aluminum, Silicon, and Carbon Laser Ablation Plumes* JEREMY IRATCABAL, KYLE SWANSON, AARON COVINGTON, Nevada Terawatt Facility and Physics Department, University of Nevada, Reno Laser ablation of solid targets produces plasma plumes with rapidly evolving temperature and density gradients. A systematic study of the temperature and density of aluminum, silicon, and carbon plasma plumes produced with a 2 TW/cm² laser using spectroscopic, interferometric, fast imaging, and charge diagnostics will be presented. Carbon, aluminum, and silicon plumes are of interest because they are closely grouped on the periodic table but have very different material characteristics. Temporally and spatially resolved data was collected to characterize the evolution of the plasma in the plume. To probe the plasmas produced from these materials, optical spectroscopy was employed to identify and measure the temperature of the coexisting neutral and ionized atomic and molecular species. A Mach-Zehnder interferometer was employed to measure electron density. ICCD imaging and shadowgraphy were used to image the plume dynamics. A comparison of plasma evolution for each element will also be presented and will provide data to benchmark plasma codes.

*This work was supported by the University of Nevada, Reno, the U.S. DOE/NNSA Cooperative Agreement No. DE-NA0002075, and National Security Technologies, LLC under Contract No. DE-AC52-06NA25946/Subcontract No. 165819.

15:12
UO6 7 Laser Induced Ablation of Metals at Different Ambient Conditions: Experiments and Simulation* AHMED ELSIED, PAYSON DIEFFENBACH, PRASOON DIWAKAR, TATYANA SIZYUK, AHMED HASSANEIN, Purdue University CENTER OF MATERIALS UNDER EXTREME CONDITIONS, SCHOOL OF NUCLEAR ENGINEERING, PURDUE UNIVERSITY TEAM Laser erosion of metals under different ambient conditions and laser fluences, has been studied using 1064 nm, 6 ns Nd:YAG laser on 1 mm thick W and Al. Experiments were designed to study the effect of various parameters (material properties, laser fluence, ambient gas, ambient pressure) on metal ablation. Using two different ambient gases (air and argon), the metals were ablated over wide range of incident laser fluence to study the effect of ambient gas on metal ablation. To quantify the ablation process, the crater profile was measured using White Light Profilometer which provided information regarding the amount of mass ablation crater shape, and melt formation. These measurements were used for comparing the ablation processes for various conditions. The study is supported by analytical models and computer simulation which shows strong agreement with the experimental data. The ablation yield
has very consistent dependence on incident laser fluence. At low laser fluence, with respect to ablation threshold, this dependence is logarithmic while, at high laser fluence the ablation yield is linear function of incident laser fluence. Ambient pressure was found to be significant in ablation processes. Detailed mechanisms of these effects will be presented.

*This work was supported by the National Science Foundation PIRE project [Grant Number 1243490-OISE].

15:24
UO6 8 The effect of density scale length on hot electron generation in relativistic laser interaction with under dense plasma SEYED ABOLEFAZL GHASEMI, MASoud PISHDAST, JAMAL ALDIN YAZDANPANAH, Plasma and Fusion Research School, NSTRI, Tehran, Iran. The effect of plasma density scale length on hot electron generation have been investigated in relativistic regime for under dense plasma using 1D PIC simulation. In our simulation, three different density scale lengths, step density, gentle ramp and steep ramp density for two short and long pulse lengths with temporal pulse duration $\tau_L = 60 \, \text{fs}$ and $\tau_L = 300 \, \text{fs}$, respectively have been used. It is found that laser pulse length and density scale length have considerable effects on the energetic electron generation. The results of simulation indicate that for the step density scale length, with respect to the short laser pulse, electrons are accelerated to higher energy level than the case with the long pulse and other scale lengths. Furthermore, time evaluation analysis of the energy distribution function shows that with the time increment of the pulse propagation, plasma electrons can reach energies about two times higher than the energy level of the long pulse case.

15:36
UO6 9 Kinetic effects during the interaction between high density microplasma and electromagnetic wave* DMYTRO LEVKO, LAXMINARAYAN RAJA, The University of Texas at Austin. The interaction between a high-density microplasma and high-power electromagnetic wave is studied by one-dimensional Particle-in-Cell Monte Carlo collisions model coupled with the Maxwell’s equations. We find the value of the amplitude of the wave field above which a fully ionized plasma is generated on the picosecond time scale. This fully ionized plasma is obtained only in the skin layer while the ionization degree of the plasma bulk is $\sim 20\%$. The simulation results show that such non-homogeneous distribution of plasma and gas density influences significantly the heating of plasma electrons and time evolution of the electron energy probability function.

"Air Force Office of Scientific Research (AFOSR) through a Multi-University Research Initiative (MURI) Grant titled “Plasma-Based Reconfigurable Photonic Crystals and Metamaterials” with Dr. Mi- tät Birkan as the program manager.

15:48
UO6 10 Laser Induced Fluorescence (LIF) Measurements of Neutral (ArI) and singly-ionized (ArII) Argon in a LargeScale Helicon Plasma* R. F. KELLY, D. M. FISHER, M. W. HATCH, M. GILMORE, R. H. DWYER, K. MEANey, Univ. of New Mex- ico Y. ZHANG, University of Washington T. R. DESJARDINS, Los Alamos National Laboratory In order to investigate the role of neutral dynamics in helicon discharges in the HelCat (Helicon-Cathode) plasma device at U. New Mexico, a Laser Induced Fluorescence (LIF) system has been developed. The LIF system is based on a $>250 \, \text{mW}$, tunable diode laser with a tuning range between 680 and 700nm. For neutral Argon, the laser pumps the metastable $^{3}P_{3/2}\text{4s}$ level to the $^{2}P_{1/2}\text{4p}$ level using 696. 7352 nm light. The fluorescence radiation from decay to the $^{2}P_{1/2}\text{4s}$ level at 772, 6333 nm is observed. For singly ionized Argon, the laser pumps the $3s^{2}3p^{2}(^{1}P)_{3d}$ level to the $3s^{2}3p^{2}(^{1}P)_{4p}$ level using 686.3162nm light. The fluorescence radiation from the decay to the $3s^{2}3p^{2}(^{1}P)_{4s}$ level is observed. The system design, and velocity measurements in the axial, azimuthal and radial directions for ArI, and in the axial direction for ArII will be presented.

*This work was supported by the DOE/OES Grant DE-SC0008829 and DOE/NNSA contract DE-FC52-06NA27616.  
†Currently at NSTec, LLC.

16:00
UO6 11 A Plasma Edge Electron Density Diagnostic Based on a Doppler-free Measurement of Stark Broadening* ABDUL-LAH ZAFAR, North Carolina State University ELIJAH MARTIN, Oak Ridge National Laboratory STEVE SHANNON, North Carolina State University Passive spectroscopic measurements of Stark broadening have been reliably used to determine electron density for decades. A low-density limit of 1e19 m$^{-3}$ exists using these passive techniques due to Doppler and instrument broadening. At Oak Ridge National Laboratory, a novel diagnostic approach for measuring electron density using Stark broadening is currently under development and is capable of extending the low-density limit to 1e16 m$^{-3}$. The diagnostic is based on measuring the spectral line profile of a Balmer series transition using Doppler-free saturation spectroscopy, a laser-based absorption technique. The spectrum is then fit to a quantum mechanical model using the Explicit Zeeman Stark Spectral Simulator (EZSSS) code to extract the electron density. The increased sensitivity to the electron density is realized because Doppler-free saturation spectroscopy (DFSS) can greatly reduce the Doppler broadening and essentially eliminate the instrument broadening. DFSS has been successfully employed to measure spectral data in a magnetized (500-800 G), low temperature (5 eV), low density (1e17-1e18 m$^{-3}$), He/H2 and He/CH4 plasma in the mTorr pressure range. Experimentally measured pi and sigma H-alpha spectra, fit using the EZSSS code, will be presented. A quantitative model to accurately predict crossover peaks and dips will also be given.

*Supported by U.S. National Science Foundation Award 1500423.

16:12
UO6 12 Magnetic Field Measurements In Magnetized Plasmas Using Zeeman Broadening Diagnostics* SHOWERA HAQUE, MATTHEW WALLACE, University of Nevada, Reno RADU PRESURA,† Voss Scientific, LLC PAUL NEILL, University of Nevada, Reno. The Zeeman effect has been used to measure the magnetic field in high energy density plasmas. This method is limited when plasma conditions are such that the line broadening due to the high plasma density and temperature surpasses the Zeeman splitting. We have measured magnetic fields in magnetized laser plasmas under conditions where the Zeeman splitting was not spec- trally resolved. The magnetic field strength was determined from the difference in widths of two doublet components, using an idea proposed by Tessarin et al. (2011). Time-gated spectra with one-dimensional space-resolution were obtained at the Nevada Terawatt Facility for laser plasmas created by 20 J, 1 ns Leopard laser pulses, and expanding in the azimuthal magnetic field produced by the 0.6 MA Zebra pulsed power generator. We explore the response of the Al III 4s $^2S_{3/2} - 4p^2P_{1/2,3/2}$ doublet components to the external magnetic field spatially along the plasma. Radial magnetic field and electron density profiles were measured within the plasma plume.

*This work was supported by the DOE/OES Grant DE-SC0008829 and DOE/NNSA contract DE-FC52-06NA27616.
16:24
UO6 13 X-Ray Radiography of Laser-Driven Shocks for Inertial Confinement Fusion* A. KAR, P.B. RADHA, D.H. EDGELL, S.X. HU, T.R. BOEHLY, V.N. GONCHAROV, S.P. REGAN, A. SHVY-DKY, Laboratory for Laser Energetics, U. of Rochester Side-on x-ray radiography of shock waves transiting through the planar plastic ablator and cryogenic fuel layer will be used to study shock timing, shock coalescence, shock breakout, and hydrodynamic mixing at the ablator–fuel interface. The injection of ablator material into the fuel can potentially compromise implosion target performance. The difference in refractive indices of the ablator and the fuel can be exploited to image shocks transiting the interface. An experiment to probe the ablator–fuel interface and a postprocessor to the hydrodynamic code DRACO that uses refraction enhanced imaging to view shocks are presented. The advantages of this technique to view shocks are explored and additional applications such as viewing the spatial location of multiple shocks, or the evolution of nonuniformity on shock fronts are discussed.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

SESSION UO7: COMPRESSION AND BURN II
Thursday Afternoon, 26 October 2017
Room: 203AB at 14:00
Jason Bates, Naval Research Laboratory, presiding

Contributed Papers

14:00
UO7 1 Simulation and Analysis of Time-Resolved Narrowband Radiographs of Cryogenic Implosions on OMEGA* R. EPSTEIN, C. STOECKL, V.N. GONCHAROV, P.W. MCKENTY, S.P. REGAN, Laboratory for Laser Energetics, U. of Rochester Spherical polymer shells containing cryogenic DT ice layers have been imploded on the OMEGA Laser System and radiographed with Al backlighter targets ($h\nu = 1.865$ keV) driven with 20-ps IR pulses from the OMEGA EP Laser System. The shadows of the converging DT ice shells have been obtained using a time-resolved (40-ps) narrowband crystal imaging system and improved backlight intensity. Measured x-ray radiographs are compared with their 1-D LILAC and Spect3D simulations. Moments of the imploded radial mass distributions are inferred from radiograph analysis based on Abel inversion. The sensitivity of the radiograph shadows to trace contamination by fuel–shell mix tests the hydrodynamic stability of the implosions indicated by their shell adiabats and in-flight aspect ratios.

*This work was supported by the U.S. Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

14:12
UO7 2 Low-Mode Variations of the Cold-Fuel Distribution in Cryogenic DT Implosions on OMEGA* C.J. FORREST, K.S. ANDERSON, V.YU. GLEBOV, V.N. GONCHAROV, O.M. MANNION, P.B. RADHA, S.P. REGAN, T.C. SANGSTER, C. STOECKL, Laboratory for Laser Energetics, U. of Rochester The neutron energy spectrum generated from cryogenic DT direct-drive implosions in inertial confinement fusion experiments is used to interpret the cold-fuel distribution at peak compression. At the Omega Laser Facility, measurements are used to extract the neutron spectrum utilizing a high-dynamic-range neutron time-of-flight spectrometer. The shape of the energy spectrum is fully determined by the neutron elastic scattering cross section for spherically symmetric target configurations. Significant differences from the expected shape have been measured for some recent implosions, which indicate a deviation from a spherically symmetric fuel assembly. Neutron scattering in the DT cold-fuel assembly has been modeled in radiation–hydrodynamic codes. The experimental data show reasonable agreement with the model when the mass distribution of the compressed DT shell has low-mode perturbations.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

14:24
UO7 3 Three-Dimensional Modeling of Low-Mode Asymmetries in OMEGA Cryogenic Implosions* K.S. ANDERSON, Laboratory for Laser Energetics, Univ. of Rochester P.W. MCKENTY, Laboratory for Laser Energetics, U. of Rochester T.J.B. COLLINS, Laboratory for Laser Energetics, Univ. of Rochester C.J. FORREST, Laboratory for Laser Energetics, U. of Rochester J.A. MAROZAS, Laboratory for Laser Energetics, U. of Rochester F.J. MARSHALL, P.B. RADHA, A.B. SEFKOW, Laboratory for Laser Energetics, Univ. of Rochester M.M. MARINAK, LLNL In direct-drive inertial confinement fusion implosions, long-wavelength asymmetries resulting from target offset, laser power imbalance, beam mispointing, etc. can be highly detrimental to target performance. Characterizing the effects of these asymmetry sources requires 3-D simulations performed in full-sphere geometry to accurately capture the evolution of shell perturbations and hot-spot flow. This paper will present 3-D HYDRA [1] simulations characterizing the impact of these perturbation sources on yield and shell modulation. Various simulated observables are generated, and trends are analyzed and compared with experimental data.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Numbers DE-NA0001944 and performed under the auspices of the LLNL under Contract No. DE-AC52-07NA27344.

14:36
UO7 4 Soft X-Ray Narrowband Radiography of Direct-Drive Cryogenic DT Implosions on OMEGA* C. STOECKL, R. EPSTEIN, V.N. GONCHAROV, D.W. JACOBS-PERKINS, R.K. JUNQUIST, C. MILEHAM, S.P. REGAN, T.C. SANGSTER, W. THEOBALD, Laboratory for Laser Energetics, U. of Rochester Backlit images of cryogenic direct-drive implosions on OMEGA were recorded with a narrowband x-ray imager using an aspherically bent quartz crystal for the Si He $^\alpha$ line at $\sim 1.865$ keV. These implosions are driven on a low adiabat (shell pressure/Fermi degenerate pressure), making them susceptible to Rayleigh–Taylor instabilities. The radiographic images can be used to study the performance of different shell materials like polystyrene and glow-discharge polymer with respect to small-scale mix from laser imprint, and long-wavelength variations of the compressed shell caused by target imperfections and laser illumination nonuniformities. The status of the radiography setup including work to improve the brightness of the backlighter, the alignment accuracy, and the spatial resolution of the imager will be presented.

transport in such capsule implosions. is irrelevant. Measurements showed that in fact the thin-CD capsule was driven somewhat harder than the thick-CD capsule and (b) only an ion-diffusion model indicate that the thick-CD capsule would be μ0.15

LANL KNAUER, V. YU. GLEBOV, C. FORREST, W. GRIMBLE, F. MARSHALL, T. MICHEL, C. STOECKL, LLE B.M. HAINES, A.B. ZYLSTRA, LANL Ion temperatures (T_{ion}) in Inertial Confinement Fusion (ICF) experiments have traditionally been inferred from the broadening of primary neutron spectra. Directional motion (flow) of the fuel at burn, expected to arise due to asymmetries imposed by e.g. engineering features or drive non-uniformity, also impacts broadening and may lead to artificially inflated “T_{ion}” values. Flow due to low-mode asymmetries is expected to give rise to line-of-sight variations in measured T_{ion}, as observed in OMEGA cryogenic DT implosions but not in similar experiments at the NIF. In this presentation, we report on OMEGA experiments with intentional drive asymmetry designed for testing the ability to accurately predict and measure line-of-sight differences in apparent T_{ion} due to low-mode asymmetry-seeded flows. The measurements are contrasted to CHIMERA, RAGE and ASTER simulations, providing insight into implosion dynamics and the relative importance of laser drive non-uniformity, stalk and offset as sources of asymmetry. The results highlight the complexity of hot-spot dynamics, which is a problem that must be mastered to achieve ICF ignition.

*This work was supported in part by the U.S. DOE, NLUF and LLE.

15:00
UO7 6 Testing the relative importance of ion diffusive transport and turbulent mixing with separated-reactant capsules*
NELSON HOFFMAN, ALEX ZYLSTRA, Los Alamos National Laboratory Two recent capsule implosion shots at OMEGA, employing separated reactants (tritium gas surrounded by a layer of deuterated CD plastic) [A. B. Zylstra et al., in preparation], afforded a simple test for distinguishing the importance of ion diffusive transport vs. turbulent mixing in the implosions. One capsule had a CD layer that was twice as thick as the other capsule: 0.3 μm vs 0.15 μm. Simulations using a turbulent-mix model together with an ion-diffusion model indicate that the thick-CD capsule would be expected to give higher DT yield than the thin-CD capsule, owing to the larger quantity of D available to mix with T. By contrast, simulations using the ion-diffusion model alone indicate that the thin-CD capsule would give the higher DT yield, owing to the fact that (a) it was driven somewhat harder than the thick-CD capsule and (b) only an extremely thin layer on the inside of the CD contributes significantly to the DT yield for either capsule, so the thickness difference is irrelevant. Measurements showed that in fact the thin-CD capsule gave higher DT yield, supporting the importance of ion diffusive transport in such capsule implosions.

*Research supported by US DOE under contract DE-AC52-06NA25596.

15:12
UO7 7 Investigating the impact of species charge and mass on the manifestation of multi-ion and kinetic effects*
N. V. KABADI, R. SIMPSON, H. SIO, M. GATU JOHNSON, J. FRENIE, B. LAHMANN, C. PARKER, R. D. PETRASSO, MIT C. FORREST, V. YU GLEBOV, C. STOECKL, S. REGAN, LLE H. G. RINDERKNECHT, LLNL G. KAGAN, LANL Inertial confinement fusion implosions are almost exclusively modeled as hydrodynamic in nature, with a single average-ion fluid and fluid electrons. However, in the shock convergence phase of virtually all inertial fusion implosions, the mean-free path for ion-ion collisions becomes sufficiently long that both the shock front itself and the resulting central plasma are inadequately described by hydrodynamic modeling. In this regime individual ion species behave separately. Understanding how these multi-ion effects manifest themselves in both the kinetic and hydrodynamic regimes is of fundamental importance. In this presentation, first results from an investigation into the effects of individual species’ mass and charge on multi-ion effects in kinetic and hydro-like regimes will be discussed.

*The work was supported by DOE, NLUF, LLNL and LLE.

15:24
UO7 8 Submicron-Scale Control of the Three-Dimensional Modes 1, 2, and 3 of Targets Imploded in the Direct-Drive Configuration on OMEGA*
D.T. MICHEL, I.V. IGIEMENSHICHEV, A.K. DAVIS, D.H. EDGELL, D.H. FROULA, V.N. GONCHAROV, D.W. JACOBS-PERKINS, S.P. REGAN, A. SHVYDKY, E.M. CAMPBELL, Laboratory for Laser Energetics, U. of Rochester Reducing low-mode nonuniformities has been identified as a critical step to demonstrate conditions for laser-direct-drive targets that are hydrodynamically equivalent to ignition when scaled to the megajoule energies at the National Ignition Facility. The 3-D shape of the imploding target was tomographically recorded using four lines-of-sight x-ray measurements of the ablation front. The projected ablation-front contours during the implosion phase were measured with framing cameras using the x-ray self-emission shadowgraphy technique. The projected ablation-front motions were obtained by comparing the positions of the contours on the framing cameras with the corresponding contour positions measured on a nonimploding solid CH ball shot. The amplitudes of the modes were determined within ±0.15% by decomposition into spherical harmonics of the contours oriented perpendicular to the lines-of-sight and shifted by the measured motions. The variations of the amplitudes in modes 1, 2, and 3 between shots were shown to change linearly (within ±0.25%) with the variations of the mode amplitudes of the laser beam energy balance making it possible to compensate the residual target modes (that remain when the laser is balanced) within 1%.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

15:36
UO7 9 Impacts of Implosion Asymmetry And Hot Spot Shape On Ignition Capsules*
BAOLIAN CHENG, THOMAS J.T. KWAN, YI-MING WANG, S. AUSTIN YI, STEVE BATHA, Los Alamos National Laboratory Implosion symmetry plays a critical role in achieving high areal density and internal energy at stagnation during hot spot formation in ICF capsules. Asymmetry causes hot spot irregularity and stagnation de-synchronization that results in lower temperatures and areal densities of the hot fuel. These degradations significantly affect the alpha heating process in the DT fuel as well as on the thermonuclear performance of the capsules. In this work, we explore the physical factors determining the shape of the hot spot late in the implosion and the effects of shape on Î±–particle transport. We extend our ignition theory [1-4] to include the hot spot shape and quantify the effects of the implosion asymmetry on both the ignition criterion and capsule performance. We validate our theory with the NIF existing experimental data. Our theory shows that the ignition criterion becomes more restrictive with the deformation effect.
of the hot spot. Through comparison with the NIF data, we demonstrate that the shape effects on the capsules’ performance become more explicit as the self-heating and yield of the capsules increases. The degradation of the thermonuclear burn by the hot spot shape for high yield shots to date can be as high as 20%. Our theory is in good agreement with the NIF data.

*This work was performed under the auspices of the U.S. Department of Energy by the Los Alamos National Laboratory under Contract No. W-7405-ENG-36.

15:48


The measured neutron spectrum produced by a fusion experiment plays a key role in inferring observable quantities. One important observable is the areal density of an implosion, which is inferred by measuring the scattering of neutrons. This project seeks to use particle-transport simulations to model the effects of hot-spot geometry on backscattering and down-scattering neutron spectra along different lines of sight. Implosions similar to those conducted at the Laboratory of Laser Energetics are modeled by neutron transport through a DT plasma and a DT ice shell using the particle transport codes MCNP and IRIS. Effects of hot-spot geometry are obtained by “detecting” scattered neutrons along different lines of sight. This process is repeated for various hot-spot geometries representing known shape distortions between the hot spot and the shell.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

16:00

UO7 11 Neutron peak velocity measurements at the National Ignition Facility (NIF) using novel quartz detectors* GARY GRIM, MARK ECKART, EDWARD HARTOUNI, ROBERT HATARIK, ALASTAIR MOORE, JABEN ROOT, DANIEL SAYRE, DAVID SCHLOSSBERG, CORY WALTZ, Lawrence Livermore National Laboratory

In mid-2017 the NIF implemented quartz based neutron time-of-flight (nToF) detectors which have a faster and narrower impulse response function (IRF) relative to traditional scintillator detectors. In this presentation we report on comparisons between fusion neutron first moments as measured by quartz and scintillator based detectors using DT layered implosions at the NIF. We report on the change in precision presaged by the quartz converter and quantify the change in both in shot, line-of-site velocity variability.

16:12

UO7 12 Determining hot spot motion using a multi line-of-sight nToF analysis* ROBERT HATARIK, RYAN NORA, BRIAN SPEARS, MARK ECKART, EDWARD HARTOUNI, GARY GRIM, ALASTAIR MOORE, DAVID SCHLOSSBERG, Lawrence Livermore National Laboratory

An important diagnostic value of a shot at the National Ignition Facility (NIF) is the resultant center-of-mass motion of the imploing capsule as it contributes to the efficiency of converting LASER energy into plasma temperature. In the past the projection of this velocity onto a line-of-sight (LOS) for a given detector was determined by using a temperature model to determine the mean energy of the emitted neutrons. With the addition of a fourth neutron time-of-flight LOS at the NIF, it is possible to determine a hot spot vector and mean velocity of the emitted neutron distribution. This entails analyzing all four LOS simultaneously and has the advantage of not relying on a temperature model. Results from recent NIF shots comparing this method with the traditional method will be presented.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

16:24

UO7 13 Implosion anisotropy of neutron kinetic energy distributions as measured with the neutron time-of-flight diagnostics at the National Ignition Facility* EDWARD HARTOUNI, MARK ECKART, JOHN FIELD, GARY GRIM, ROBERT HATARIK, ALASTAIR MOORE, DAVID MUNRO, DANIEL SAYER, DAVID SCHLOSSBERG, Lawrence Livermore Natl Lab

Neutron kinetic energy distributions from fusion reactions are characterized predominantly by the excess energy, Q, of the fusion reaction and the variance of kinetic energy which is related to the thermal temperature of the plasma as shown by e.g. Brysk [1]. High statistics, high quality neutron time-of-flight spectra obtained at the National Ignition Facility provide a means of measuring small changes to the neutron kinetic energy due to the spatial and temporal distribution of plasma temperature, density and velocity. The modifications to the neutron kinetic energy distribution as described by Munro [2] include plasma velocity terms with spatial orientation, suggesting that the neutron kinetic energy distributions could be anisotropic when viewed by multiple lines-of-sight. These anisotropies provide a diagnostic of burn averaged plasma velocity distributions. We present the results of measurements made for a variety of DT implosions and discuss their possible physical interpretations.

16:36


During inertial confinement fusion, higher-order moments of neutron time-of-flight (nToF) spectra can provide essential information for optimizing implosions. The nToF diagnostic suite at the National Ignition Facility (NIF) was recently upgraded to include novel, quartz Cherenkov detectors. These detectors exploit the rapid Cherenkov radiation process, in contrast with conventional scintillator decay times, to provide high temporal-precision measurements that support higher-order moment analyses. Preliminary measurements have been made on the NIF during several implosions and initial results are presented here. Measured line-of-sight asymmetries, for example in ion temperatures, will be discussed. Finally, advanced detector optimization is shown to advance accessible physics, with possibilities for energy discrimination, gamma source identification, and further reduction in quartz response times.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344.
16:48
UO7 15 Measurements of Ion Stopping around the Bragg Peak and its dependence on electron temperature and density in High-Energy-Density Plasmas (HEDP)∗ J. Frenje, C.K. Li, F. Seguin, M. Gat Johnson, H. Sio, R. Petrasso, MIT T. Nagayama, S. L. R. Manici, UNR R. Hernandez, ULP GC P. Grabowski, H. G. Rinderknecht, LLNL V. Y. Glebov, LLE Ion stopping around the Bragg peak and its dependence on plasma conditions were recently measured for the first time in HEDP [1]. The data support most stopping-power models for ion velocities \( v_i \) larger than the average velocity of the thermal electrons \( v_{\text{th}} \), but there are some differences at \( v_i \sim v_{\text{th}} \), which could not be fully explored. This work described here makes significant advances over the first experimental effort by quantitatively assessing the characteristics of ion stopping around the Bragg peak and its dependence on electron temperature and density in HEDP. This effort represents the first sensitive test of plasma-stopping-power models around the Bragg peak, which is an important first step in our efforts to obtain a fundamental understanding of DT-alpha stopping. This work is supported by DOE, NLUF, LLNL and LLE.

∗The work was supported by DOE, NLUF, LLNL and LLE.


14:12
UO8 2 Shock Propagation through Macro-Pore Engineered Foams YonGho Kim, J. M. Smidt, T. J. Murphy, M. R. Douglas, T. Cardenas, D. W. Schmid, C. Hamilton, Los Alamos National Laboratory Shock propagation through macro-pore engineered foams has been studied to examine (1) if the pore size affects shock speed and (2) if spherical geometry of the void may induce turbulence. In the first experiment, three types of macro-pore engineered foams (< 1.0, 5.0, and 90 um in diameter) were used in shock tube experiments driven by the Omega laser. X-ray radiographic data indicates that shock speed through macro-pore engineered foams depends strongly on foam density, less on pore size. In the second experiment, a single foam-filled “void” in a diameter of 250 um was shocked by two opposing planar shocks, which were separated by 6.4 ns. While the first shock compressed a spherical foam-void without much turbulence, the second shock seems to increase a turbulent motion.

14:24
UO8 3 Argon-Doped Capsule Implosion Experiments on the Shenguang-II Laser Facility† Zhimin Hu, Jiamin Yang, Jiyan Zhang, Wenyong Miao, Jiarin Chen, Guhanong Yang, Shaoen Jiang, Yongkun Ding, Baohan Zhang, Laser Fusion Research Center, China Academy of Engineering Physics Argon is often doped in the hydrogen isotope capsule as the tracer for diagnosing the status of the hot spot in inertial confinement fusion implosion experiments. Implosion performance could be affected by the doped argon. For instance, it could bring about the concentration of the heavier argon ions in the center of hot spot, thus degrading the implosion performance. Moreover, implosion mix could be investigated by doping heavier elements in hydrogen isotope capsule, and the atomic-mix effects have been investigated in the pioneering studies. In this talk, we present the performance of argon-doped implosion experiments, in which D-D reaction was used for the substitute of D-T fuel. The experiments were conducted on the Shenguang-II laser facility. The doping-fraction of argon was set as 1%, 2% and 10% (atomic fraction). The temperature and density of electrons are determined by the K-shell emission spectra of the highly-ionized argon. The size of hot spot was recorded by a time-resolving x-ray monochromatic imaging system. The neutron yield were detected by both BF3 and scintillator detectors. A strong correlation between argon x-ray line intensity and neutron yields have been found in the experiments, and the convergence ratios deduced from the hot-spot imaging agree well with numerical simulation for the difference doping fraction which brings about the change of the equations of states and radiative opacity.

†NSFC Grant under Contract No. 11675158.
are able to explore a variety of phenomena, including hydrogen jetting, kinetic effects (non-Maxwellian and anisotropic distributions), plasma physics (size, persistence and role of electric fields) and transport (relative sizes of Fickean diffusion, electrodiffusion and barodiffusion). As compared with the recent molecular dynamics work the kinetic model greatly extends the accessible physical domains we are able to model.

2Stanton et al., submitted to Phys. Rev. X.

14:48
UO8 5 Drive development for an ~10 Mbar Rayleigh-Taylor strength experiment on the National Ignition Facility*
SHON PRISBREY, HYE-SOOK PARK, CHANNING HUNTINGTON, JAMES MCNANEY, RAYM SMITH, CHRISTOPHER WEHRENBERG, DAMIAN SWIFT, CYNTHIA PANAS, DAWN LORD, ATHANASIOS ARSENILIS, Lawrence Livermore National Laboratory Strength can be inferred by the amount a Rayleigh-Taylor surface deviates from classical growth when subjected to acceleration. If the acceleration is great enough, even materials highly resistant to deformation will flow. We use the National Ignition Facility (NIF) to create an acceleration profile that will cause sample metals, such as Mo or Cu, to reach peak pressures of ~10 Mbar without inducing shock melt. To create such a profile we shock release a stepped density reservoir across a large gap with the stagnation of the reservoir on the far side of the gap resulting in the desired pressure drive history. Low density steps (foams) are a necessary part of this design and have been used in the last several years on the Omega and NIF facilities. We will present computational and experimental progress that has been made on the ~10 Mbar drive designs— including recent drive shots carried out at the NIF.

*This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344. LLNL-ABS-734781.

15:00
UO8 6 Modeling and simulations of radiative blast wave driven Rayleigh-Taylor instability experiments* ASSAF SHIMONY, Nuclear Research Center-Negev, Ben Gurion University of the Negev, Israel CHANNING M. HUNTINGTON, Lawrence Livermore National Laboratory MATTHEW TRANTHAM, University of Michigan GUY MALAMUD, Nuclear Research Center-Negev, University of Michigan YONATAN ELBAZ, Nuclear Research Center-Negev CAROLYN C. KURANZ, R. PAUL DRAKE, University of Michigan DOV SHVARTS, Nuclear Research Center-Negev, University of Michigan Recent experiments at the National Ignition Facility measured the growth of Rayleigh-Taylor RT instabilities driven by radiative blast waves, relevant to astrophysics and other HEDP systems. We constructed a new Buoyancy-Drag (BD) model, which accounts for the ablation effect on both bubble and spike. This ablation effect is accounted for by using the potential flow model [Oron et al PoP 1998], adding another term to the classical BD formalism: $\beta Du/a$, where $\beta$ the Takabe constant, $D$ the drag term, $u$ the ablation velocity and $a$ the instability growth velocity. The model results are compared with the results of experiments and simulations using the CRASH code, with nominal radiation or reduced foam opacity (by a factor of 1000). The ablation constant of the model, $\beta_{Du}/a$, for the bubble and for the spike fronts, are calibrated using the results of the radiative shock experiments.

*This work is funded by the Lawrence Livermore National Laboratory under subcontract B614207, and was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

15:12
UO8 7 Experiments of the highly non-linear Rayleigh-Taylor instability regime and dependence on Atwood Number* L. ELGIN, T. HANDY, University of Michigan G. MALAMUD, University of Michigan; Nuclear Research Center “NEGEV, Israel C.M. HUNTINGTON, Lawrence Livermore National Laboratory M.R. TRANTHAM, S.R. KLEIN, C.C. KURANZ, R.P. DRAKE, University of Michigan D. SHVARTS, University of Michigan; Nuclear Research Center “NEGEV, Israel Potential flow models predict that a Rayleigh-Taylor unstable system will reach a terminal velocity (and constant Froude number) at low Atwood numbers. Numerical simulations predict a re-acceleration phase of Rayleigh-Taylor Instability (RTI) and higher Froude number at late times. To observe this effect, we are conducting a series of experiments at OMEGA 60 to measure single-mode RTI growth at low and high Atwood numbers and late times. X-ray radiographs spanning 40+ ns capture the evolution of these systems. Experimental design challenges and initial results are discussed here.

*This work is funded by the Lawrence Livermore National Laboratory under subcontract B614207, and was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

15:24
UO8 8 Coupled Hydrodynamic Instability Growth on Oblique Interfaces with a Reflected Rarefaction* A.M. RASMUS, Los Alamos National Laboratory/University of Michigan K.A. FLIPPO, C.A. DI STEFANO, F.W. DOSS, Los Alamos National Laboratory J.D. HAGER, Lockheed-Martin E.C. MERRITT, T. CARDENAS, D.W. SCHMIDT, J.L. KLINE, Los Alamos National Laboratory C.C. KURANZ, University of Michigan Hydrodynamic instabilities play an important role in the evolution of inertial confinement fusion and astrophysical phenomena. Three of the Omega-EP long pulse beams (10 ns square pulse, ~14 kJ total energy, 1.1 mm spot size) drive a supported shock across a heavy-to-light, oblique, interface. Single- and double-mode initial conditions seeded coupled Richtmyer-Meshkov (RM), Rayleigh-Taylor (RT), and Kelvin-Helmholtz (KH) growth. At early times, growth is dominated by RM and KH, whereas at late times a rarefaction from laser turn-off reaches the interface, leading to decompression and RT growth. The addition of a thirty degree tilt does not alter mix width to within experimental error bars, even while significantly altering spike and bubble morphology. The results of single and double-mode experiments along with simulations using the multi-physics hydrocode RAGE will be presented.

*This work performed under the auspices of the U.S. Department of Energy by LANL under contract DE-AC52-06NA25396. This work is funded by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, Grant Number DE-NA0002956. This material is partially supported by DOE Office of Science Graduate Student Research (SCGSR) program.

15:36
UO8 9 High-Energy-Density Shear Flow and Instability Experiments* F. W. DOSS, K. A. FLIPPO, E. C. MERRITT, C. A. DI STEFANO, B. G. DEVOLDER, S. KURJEN, J. L. KLINE, Los Alamos National Laboratory High-energy-density shear experiments have been performed by LANL at the OMEGA Laser Facility and National Ignition Facility (NIF). The experiments have been simulated using the LANL radiation-hydrocode RAGE and have been used to assess turbulence models ability to function in the high-energy-density, inertial-fusion-relevant regime. Beginning with the basic configuration of two counter-oriented shock-driven
flows of \( \geq 100 \text{ km/s} \), which initiate a strong shear instability across an initially solid-density, 20 \( \mu \text{m} \) thick Al plate, variations of the experiment to details of the initial conditions have been performed. These variations have included increasing the fluid densities (by modifying the plate material from Al to Ti and Cu), imposing sinusoidal seed perturbations on the plate, and directly modifying the plate’s intrinsic surface roughness. Radiography of the unseeded layer has revealed the presence of emergent Kelvin-Helmholtz structures which may be analyzed to infer fluid-mechanical properties including turbulent energy density.

“This work is conducted by the US DOE by LANL under contract DE-0AC52-06NA25396. This abstract is LA-UR-16-24930.

15:48
UO8 10 Modeling of laser-driven hydrodynamics experiments CARLOS DI STEFANO, FORREST DOSS, ALEX RASMUS, KIRK FLIPPO, TIFFANY DESJARDINS, ELIZABETH MERRITT, JOHN KLINE, Los Alamos National Laboratory JON HAGER, Lockheed-Martin PAUL BRADLEY, Los Alamos National Laboratory Correct interpretation of hydrodynamics experiments driven by a laser-produced shock depends strongly on an understanding of the time-dependent effect of the irradiation conditions on the flow. In this talk, we discuss the modeling of such experiments using the RAGE radiation-hydrodynamics code. The focus is an instability experiment consisting of a period of relatively steady shock conditions in which the Richtmyer-Meshkov process dominates, followed by a period of decaying flow conditions, in which the dominant growth process changes to Rayleigh-Taylor instability. The use of a laser model is essential for capturing the transition.

*a also University of Michigan.

16:00
UO8 11 Results from a thin layer Richtmyer-Meshkov experiment at OMEGA TIFFANY DESJARDINS, CARLOS DI STEFANO, ELIZABETH MERRITT, JOHN KLINE, Los Alamos National Laboratory The Richtmyer-Meshkov (RM) instability can degrade heating of the fuel in inertial confinement fusion (ICF) capsules where a multi-layer spherical capsule is ablative driven. The RM hydrodynamic instability occurs when an impulsive force (or shock) impinges and amplifies imperfections at an interface with disparate densities. Any defects on the ablator or between layers in an ICF capsule will grow due to the RM instability and may lead to further degrading hydrodynamic instabilities. The linear instability can be driven into a non-linear regime and even become turbulent if it is subject to more shocks. The \( M_{shock} \) campaign is studying this evolution in a planar multi-interface, multi-shock geometry analogous to an ICF implosion. The campaign uses a beryllium shock tube with low density CH foams and a thin high density CH layer to study the layer’s growth rate and the amount of mix expected based on the interface initial conditions. A smooth, coherent mode and broadband mode on the CH layer provide a broad comparison of mix conditions for simulations. Results from experiments at the OMEGA facility in a simple shock and re-shock configuration and comparisons with the BHR Reynold’s stress model are presented.

16:12
UO8 12 Laser-driven Mach waves for gigabar-range shock experiments* DAMIAN SWIFT, AMY LAZICKI, FEDERICA COPPARI, Lawrence Livermore National Laboratory ALISON SAUNDERS, University of California, Berkeley JOSEPH NILSEN, Lawrence Livermore National Laboratory Mach reflection offers possibilities for generating planar, supported shocks at higher pressures than are practical even with laser ablation. We have studied the formation of Mach waves by algebraic solution and hydrocode simulation for drive pressures at much than reported previously, and for realistic equations of state. We predict that Mach reflection continues to occur as the drive pressure increases, and the pressure enhancement increases monotonically with drive pressure even though the “enhancement spike” characteristic of low-pressure Mach waves disappears. The growth angle also increases monotonically with pressure, so a higher drive pressure seems always to be an advantage. However, there are conditions where the Mach wave is perturbed by reflections. We have performed trial experiments at the Omega facility, using a laser-heated halfraum to induce a Mach wave in a polystyrene cone. Pulse length and energy limitations meant that the drive was not maintained long enough to fully support the shock, but the results indicated a Mach wave of 25-30 TPa from a drive pressure of 5-6 TPa, consistent with simulations. A similar configuration should be tested at the NIF, and a Z-pinch driven configuration may be possible.

*a This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

16:24
UO8 13 Using NIF to Test Theories of High-Pressure, High-Rate Plastic Flow in Metals* ROBERT E RUDD, A. ARSENLIS, R. M. CAVALLO, C. M. HUNTINGTON, J. M. MCNANEY, H. S. PARK, P. POWELL, S. T. PRISBREY, B. A. REMINGTON, D. SWIFT, C. E. WEHRENBERG, L. YANG, Lawrence Livermore National Lab Precisely controlled plasmas are playing key roles both as pump and probe in experiments to understand the strength of solid metals at high energy density (HED) conditions. In concert with theoretical advances, these experiments have enabled a predictive capability to model material strength at Mbar pressures and high strain rates [1]. Here we describe multiscale strength models developed for tantalum starting with atomic bonding and extending up through the mobility of individual dislocations, the evolution of dislocation networks and so on until the ultimate material response at the scale of an experiment [2]. Experiments at the National Ignition Facility (NIF) probe strength in metals ramp compressed to 1-8 Mbar [3]. The model is able to predict 1 Mbar experiments without adjustable parameters [3]. The combination of experiment and theory has shown that solid metals can behave significantly differently at HED conditions [3]. We also describe recent studies of lead compressed to 3-5 Mbar.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27237.


16:36
UO8 14 Numerical analysis of Melting Phenomenon on plates driving by large pulse current GANGHUA WANG, MINGXIAN KAN, Institute of Fluid Physics, CAEP COMPUTATIONAL PHYSICS TEAM Characteristic properties of materials under high pressure, such as isentropic compression lines, are very important, which can be investigated through pulsed intense magnetic field and magnetic force generated by large-current facilities. However, due to the strong Ohmic heating caused by the intense current flowing...
through the loads, the load material undergoes a series of phase transitions including melting, vaporization and even ionization into plasmas. Therefore, estimation and prediction of the ablation condition of the loading surface play an extremely important role in load design and fulfillment of physical goals of large facilities. In this work, the melting of an aluminum plate under a 30 MA loading current is investigated using the MDSC2 code, which is based on Burgess’ resistivity model and Lindeman’s melting criteria. For aluminum plates of different thicknesses, temporal variation of the ablation layer as well as typical physical quantities (i.e. density, temperature, pressure, etc.) during the late time at the interface between the ablation and non-ablation regions are obtained.

16:48
UO8 15 The point explosion with radiation transport ZHIWEI LIN, LIU ZHANG, LONGYU KUANG, SHAOEN JIANG, Research Center of Laser Fusion, China Academy of Engineering Physics, Mianyang 621900, China Some amount of energy is released instantaneously at the origin to generate simultaneously a spherical radiative heat wave and a spherical shock wave in the point explosion with radiation transport, which is a complicated problem due to the competition between these two waves. The point explosion problem possesses self-similar solutions when only hydrodynamic motion or only heat conduction is considered, which are Sedov solution and Barenblatt solution respectively. The point explosion problem wherein both physical mechanisms of hydrodynamic motion and heat conduction are included has been studied by P. Reinicke [1] and A.I. Shestakov [2]. In this talk we numerically investigate the point explosion problem wherein both physical mechanisms of hydrodynamic motion and radiation transport are taken into account. The radiation transport equation in one dimensional spherical geometry has to be solved for this problem since the ambient medium is optically thin with respect to the initially extremely high temperature at the origin. The numerical results reveal a high compression of medium and a bi-peak structure of density, which are further theoretically analyzed at the end.


14:20
UM9 2 Energy Transformation between Forms in the Big Red Ball∗ CARY FOREST, MIKE CLARK, JAN EGEDAL, DOUG ENDRIZZI, KEN FLANAGAN, SAM GREESE, JASON MILHONE, JOE OLSON, ETHAN E. PETERSON, JOHN WALLACE, ROGER WALEFFE, ELLEN ZWEIBEL, University of Wisconsin, Madison Astrophysical and Space plasmas are often characterized by quasi-stationary magnetized plasmas which are both pressure dominated ($\beta \ll 1$) and flow dominated ($\beta > 1$), and yet still behave as ideal plasmas with fluid and magnetic Reynolds numbers being large so that magnetic fields are frozen into the flowing, often turbulent plasma. Such natural plasmas are almost always converting energy of one form into another. For example, dynamos convert plasma flow energy into magnetic fields; magnetic reconnection controls how magnetic energy is released into plasma flow and heat. The Big Red Ball is a device at the core of flexible new user facility (the Wisconsin Plasma Physics Laboratory—WiPPL) designed to study a range of astrophysically relevant plasma processes in this unique regime. This talk will describe the unique capabilities of BRB, along with several experiments, in both operating and planning stages, that illustrate its possibilities, including self-exciting dynamos, collisionless magnetic reconnection, plasma accretion via the magneto-rotational instability (MRI), jet stability, stellar winds and shocks.

∗This work was supported by the DoE and the NSF.

14:40
UM9 3 Unraveling the physics of magnetic reconnection: the interaction of laboratory and space observations with models JAMES DRAKE, University of Maryland Reconnection leads to impulsive conversion of magnetic energy into high-speed flows, plasma heating and the production of energetic particles. A major challenge has been to account for the enormous range of spatial scales in systems undergoing reconnection. Progress on the topic has been facilitated by the observations in space and the laboratory with models bridging the divide. Understanding the mechanisms for fast reconnection is a historical example. However, in this talk I will focus on reconnection in asymmetric systems — those with large ambient gradients in the pressure or density. The interest in the topic has been driven by efforts to understand when and where reconnection takes place in the laboratory (tokamaks) and in space (planetary magnetospheres and the solar wind). Ideas on reconnection suppression due to diamagnetic drifts have produced a unified picture of the conditions required for reconnection onset over a wide range of environments. Observations from the MMS mission have provided an extraordinary window into reconnection at the Earth’s magnetopause, including the mechanisms for magnetic energy dissipation and the role of turbulence. Finally, the prospects for establishing the mechanisms for energetic particle production will be addressed.
Collisionless shocks are one of the most fundamental nonlinear phenomena that involve intense plasma heating and acceleration in space and astrophysical systems. Despite decades of efforts, the key physics underlying electron and ion heating remains unsolved. The continuous 3D high accuracy high cadence data from the Magnetospheric Multiscale (MMS) mission have revealed a drastically different picture on electron and ion heating in our preliminary examination of a number of bow shock crossings. In particular, the MMS measurements of 3D plasma distribution functions that are orders of magnitude higher cadence than ever indicate an intimate relation between the key thermalization phase of ions, the anisotropic temperature increase of electrons, and intense wave fluctuations. Open questions will be posted for computational studies and laboratory experiments on collisionless shocks.

*Work is supported in part by NASA.

15:20
UM9 5 FLARE: A New User Facility for Laboratory Studies of Multiple-Scale Physics of Magnetic Reconnection and Related Phenomena in Heliophysics and Astrophysics H. JI, A. BHATTACHARJEE, A. GOODMAN, S. PRAGER, Princeton U. W. DAUGHTON, LAIL R. CUTLER, W. FOX, F. HOFFMANN, M. KALISH, T. KOZUB, J. JARA-ALMONTE, C. MYERS, Y. REN, P. SLOBODA, M. YAMADA, J. YOO, PPPL S.D. BALE, UC-Berkeley T. CARTER, S. DORFMAN, UCLA J. DRAKE, U. Maryland J. EDGÉDAL, J. SARFF, J. WALLACE, U. Wisconsin The FLARE device (Facility for Laboratory Reconnection Experiments; flare.pppl.gov) is a new laboratory experiment under construction at Princeton with first plasmas expected in the fall of 2017, based on the design of Magnetic Reconnection Experiment (MRX; mrx.pppl.gov) with much extended parameter ranges. Its main objective is to provide an experimental platform for the studies of magnetic reconnection and related phenomena in the multiple X-line regimes directly relevant to space, solar, astrophysical and fusion plasmas. The main diagnostics is an extensive set of magnetic probe arrays, simultaneously covering multiple scales from local electron scales (~2 mm), to intermediate ion scales (~10 cm), and global MHD scales (~1 m). Specific example space physics topics which can be studied on FLARE will be discussed.

15:40
UM9 6 Resonant drag instabilities in fluids and plasmas JONATHAN SQUIRE, Caltech Many plasma instabilities, for instance two-stream instabilities or the magnetorotational instability, arise due to a resonance between two or more oscillation frequencies of the system. In this talk, I will introduce a general method for understanding, and calculating the properties of, such resonant instabilities. Application to dust-laden fluids and plasmas has uncovered a variety of new instabilities that occur when dust moves with a relative speed that matches the phase velocity of a fluid wave. These have interesting astrophysical applications for systems ranging from galactic winds to protoplanetary accretion disks. I will also discuss applications to other systems, for instance plasmas with a population of streaming cosmic rays, or resonant instabilities in collisionless plasmas.

16:00
UM9 7 New insights into kinetic plasma turbulence via model comparisons FRANK JENKO, Univ of California - Los Angeles DANIEL GROSELJ, Max Planck Institute for Plasma Physics SILVIO CERRI, University of Pisa ALEJANDRO BANON NAVARRO, Max Planck Institute for Plasma Physics CHRISTOPHER WILLMOTT, MIT DANIEL TOLD, Max Planck Institute for Plasma Physics NUNO LOUREIRO, MIT FRANCESCO CalIFANO, University of Pisa The nature of plasma turbulence at kinetic scales has received a lot of attention recently, also driven by the availability of new observational data and unprecedented computational capabilities. Here, we carry out the first such investigation via a systematic comparison between different kinetic models of a turbulent collisionless plasma. The models considered include a fully-kinetic description, two widely used reduced models (gyrokinetic and hybrid-kinetic with fluid electrons), and a novel reduced gyrokinetic approach. This is a significant step towards addressing the “turbulent dissipation challenge” which has been called for in recent years. Based on our results, we can clarify several open questions regarding the character of turbulence in the solar wind.

16:20
UM9 8 Bayesian Techniques for Plasma Theory to Bridge the Gap Between Space and Lab Plasmas* CHRIS CRABTREE, GU-RUDAS GANGULI, ERIK TEJERO, US NRL We will show how Bayesian techniques provide a general data analysis methodology that is better suited to investigate phenomena that require a nonlinear theory for an explanation. We will provide short examples of how Bayesian techniques have been successfully used in the radiation belts to provide precise nonlinear spectral estimates of whistler mode chorus and how these techniques have been verified in laboratory plasmas. We will demonstrate how Bayesian techniques allow for the direct competition of different physical theories with data acting as the necessary arbitrator.

*This work is supported by the Naval Research Laboratory base program and by the National Aeronautics and Space Administration under Grant No. NNH15AZ90I.

16:40
UM9 9 Understanding Turbulence using Active and Passive Multipoint Measurements in Laboratory Magnetospheres* M.E. MAULE, M.C. ABLER, T.M. QIAN, A. SAPERSTEIN, J.R. YAN, Columbia University In a laboratory magnetosphere, plasma is confined by a strong dipole magnet, and interchange and entropy mode turbulence [1] can be studied and controlled in near steady-state conditions [2]. Turbulence is dominated by long wavelength modes exhibiting chaotic dynamics, intermittency, and an inverse spectral cascade. Here, we summarize recent results: (i) high-resolution measurement of the frequency-wavenumber power spectrum using Capon’s “maximum likelihood method” [3], and (ii) direct measurement of the nonlinear coupling of interchange/entropy modes in a turbulent plasma through driven current injection at multiple locations and frequencies [4]. These observations well-characterize plasma turbulence over a broad band of wavelengths and frequencies. Finally, we also discuss the application of these techniques to space-based experiments and observations aimed to reveal the nature of heliospheric and magnetospheric plasma turbulence.

*Supported by NSF-DOE Partnership in Plasma Science Grant DFG02-00ER54585.

3Qian et al., Undergraduate Poster Session: This meeting.
4Abler et al., Poster Category 1.8; This meeting.
UP11 1 Non-neutral, Antimatter and Strongly Coupled Plasmas

UP11 2 First Experiments with $e^-/H^-$ Plasmas: Enhanced Mode Damping and Transport* A.A. Kabantsev, K.A. Thompson, C.F. Driscoll, University of California San Diego
Negative Hydrogen ions are produced and confined in a room-temperature plasma electron, causing enhanced mode damping and particle transport effects. We accumulate an $H^-$ charge fraction $n_{H^-}/n_e \sim 20\%$ in about 200 seconds, as externally excited $H_2$ molecules undergo dissociative electron attachment in the plasma. The accumulated $H^-$ fraction causes a novel algebraic damping of diocotron mode amplitude $A(r)$, and the damping is coincident with an enhanced outward drift $v_0$ of the $H^-$ ions. That is, $dA/dr = -\alpha n_H$, with $\alpha \propto n_{H^-} v_0$. We observe that heating the $e^-/H^-$ plasma terminates the enhanced damping and enhanced centrifugal separation, both of which resume when plasma re-cools by cyclotron radiation at $B = 1.2T$. Other interesting observations include: (1) enhanced $e^-$ cooling from collisions with $H^-$ cooled by neutrals; (2) enhanced damping of plasma waves due to $e^-/H^-$ collisional drag; (3) strong exponential damping of diocotron modes in a “floppy” nearly-pure $H^-$ plasma, created by rapid axial ejection of the electrons. Additional novel drift modes and instabilities are predicted theoretically in such a plasma [1].

*Supported by NSF/DOE Partnership Grants PHY-1414570 and DE-SC0008693.


UP11 3 Novel Kinetic Trapped-Particle Mechanism for Modulational Instability in Nonlinear Plasma Waves* D.H.E. Dubin, Dept. of Physics, U. C. S. D. Modulational instabilities, in which a longer-wavelength wave grows on a shorter-wavelength nonlinear wave-train, are endemic in plasmas. This poster discusses a new instability mechanism caused by a small fraction $f$ of particles trapped in the potential wells of the wave-train. This mechanism describes a recently-observed modulational/parametric decay instability in Trivelpiece-Gould waves 2, and could also be active in a broad range of nearly-collisionless nonlinear plasma waves. In the instability, adjacent peaks of the wave-train approach one-another (and therefore recede from the next peaks). This adiabatically heats particles trapped between the approaching peaks, and cools trapped particles between receding peaks. This heating and cooling would normally produce a pressure restoring force that stabilizes the motion of the peaks. However, some trapped particles are heated enough to become untrapped, and these particles are then retrapped and cooled between receding peaks. The net effect of this detraping and retrapping is to change the sign of the pressure force, producing a trapped particle pressure that amplifies the modulations with a growth rate scaling as $\sqrt{f}$. Expressions for the instability growth rate will be presented and compared with experiments and simulations. See adjacent poster.

*Supported by the NSF/DOE Partnership and DOE Grant DE-SC0008693.

UP11 4 Long-Range Collisions: Overview and Open Questions* C. Fred Driscoll, UCSD Wide-ranging theory and experiments at UCSD have broadly characterized the enhanced transport of particles, momentum, and energy from “long-range” collisions. These are drift-kinetic collisions with impact parameters in the range $r_a < \rho < r_d$, distinguished from “classical” velocity-scattering collisions with $\rho < r_a$. These long-range interactions are dominant in non-neutral plasmas, and can enhance the electron channel heat transport and particle transport in neutral plasmas. Some observed characteristics are: (a) Cross-field thermal diffusivity is independent of magnetic field, and is observed up to $10^9$ times classical in electron plasma at $B = 12\mathrm{kG}$. (b) Cross-field particle diffusion and viscosity are strongly enhanced, but reduced by plasma drift-flow shear, with $B$-scalings dependent on the shear and on the axial plasma length. Viscosity up to $10^9$ times classical is observed in short electron plasmas. (c) Individual particle slowing rates are substantially enhanced at low temperatures, exhibiting the novel effects of “velocity caging” and multiple simultaneous collisions. Recent experiments observe 10x enhanced collisional plasma wave damping in cold ion plasmas [1]. (d) Open questions remain concerning the transition from the 3D drift-kinetic regime to the 2D drift-only regime, especially with regard to the subtleties of shear viscosity.

*Supported by NSF/DOE Partnership Grants PHY-1414570 and DE-SC0002451, and by DE-SC0008693.


UP11 5 Finite-Length Diocotron Modes in a Non-neutral Plasma Column* Daniel Walsh, Daniel Dubin, Univ. of California - San Diego Diocotron modes are 2D distortions of a non-neutral plasma column that propagate azimuthally via $E \times B$ drifts. While the infinite-length theory of diocotron modes is well-understood for arbitrary azimuthal mode number $\ell$, the finite-length mode frequency is less developed (with some exceptions [1,2]), and is naturally of relevance to experiments. In this poster, we present an approach to address finite length effects, such as temperature dependence of the mode frequency. We use a bounce-averaged solution to the Vlasov Equation, in which the Vlasov Equation is solved using action-angle variables of the unperturbed Hamiltonian. We write the distribution function as a Fourier series in the bounce-angle variable $\psi$, keeping only the bounce-averaged term. We demonstrate a numerical solution to this equation for a realistic plasma with a finite Debye Length, compare to the existing $\ell = 1$ theory, and discuss possible extensions of the existing theory to $\ell \neq 1$.

*Supported by NSF/DOE Partnership Grants PHY-1414570 and DESC0002451.


UP11 6 Measurement of Correlation-Enhanced Collision Rates in the Mildly Correlated Regime ($\Gamma \sim 1$)* F. Anderegg, D.H.E. Dubin, M. Affolter, C.F. Driscoll, UCSD We have recently measured correlation-enhanced perpendicular-to-parallel collision rates $v_{\perp/\|}$ in cryogenic, strongly magnetized ion plasmas
in the mildly correlated regime. The enhancement of $v_{\perp1}$ is directly analogous [1] to the correlation-enhancement of fusion collisions in hot dense stellar plasma, as first analyzed by Salpeter [2]. The enhancement occurs because plasma screening reduces the repulsive Coulomb potential between charges, allowing closer collisions for a given relative energy. The correlations are parameterized by $\Gamma = e^2/\alpha T$ which is the ratio of the nearest neighbor potential energy to the ion thermal energy. Our prior measurements [3] over the range $0 \leq \Gamma < 15$ observed enhancement up to $10^7 x$, in broad agreement with Salpeter “equilibrium screening” theory. However recent “dynamical screening” theories [4] predict negligible enhancement for $\Gamma \sim 1$. In our magnesium ion plasmas, we obtain $\Gamma \sim 1$ at densities $n = 2 \times 10^9$ cm$^{-3}$ and temperatures $T \approx 5 \times 10^7$ eV. Recent improvements in our cooling and diagnostic lasers provide better long-term stability in $T_e$, enabling more accurate measurements of the enhancements. Our new results rule out the dynamical screening theories.

UP11 7 The Influence of Trapped Particles on the Parametric Decay Instability of Near-Acoustic Waves* M. AFFOLTER, F. ANDEREGG, D.H.E DUBIN, C.F. DRISCOLL, C. University of California, San Diego We present quantitative measurements of a decay instability to lower frequencies of near-acoustic waves. These experiments are conducted on pure ion plasmas confined in a cylindrical Penning-Malmberg trap. The axisymmetric, standing plasma waves have near-acoustic dispersion, discretized by the axial wave number $k_z = m_z/(\pi/L_p)$. The nonlinear coupling rates are measured between large amplitude $m_z = 2$ (pump) waves and small amplitude $m_z = 1$ (daughter) waves, which have a small frequency detuning $\Delta \omega = 2\Omega - \omega_2$. Classical 3-wave parametric coupling rates are proportional to pump wave amplitude as $\Gamma \propto (\partial n_z/\partial n_0)$, with oscillatory energy exchange for $\Gamma < \Delta \omega/2$ and decay instability for $\Gamma > \Delta \omega/2$. Experiments on cold plasmas agree quantitatively with oscillator energy exchange, and agree within a factor-of-two for decay instability rates. However, nascent theory suggest that this latter agreement is merely fortuitous, and that the instability mechanism is trapped particles. Experiments at higher temperatures show that trapped particles reduce the instability threshold below classical 3-wave theory predictions.

UP11 9 Dynamics and stability of electron plasma vortices under external strain* N. C. HURST, J. R. DANIELSON, D. H. E. DUBIN, C. M. SURKO, University of California - San Diego The behavior of an initially axisymmetric 2D ideal vortex under an externally imposed strain flow is studied experimentally [1]. The experiments are carried out using pure electron plasmas confined in a Penning-Malmberg trap; here, the dynamics of the plasma density transverse to the field are directly analogous to the dynamics of vorticity in a 2D ideal fluid. An external strain flow is applied using boundary conditions in a way that is consistent with 2D fluid dynamics. Primarily, elliptical distortions of the vortex core are studied, including dynamical orbits, equilibria, and stability properties. In the case of a quasi-flat vorticity profile, the results are in good agreement with a simple theory of a piecewise elliptical vorticity distribution [2]. For smooth vorticity profiles, deviations from this theory are discussed. Results for time-dependent strain and tests of adiabatic behavior will also be discussed. These experiments may be relevant to many types of quasi-2D fluid behavior, including the dynamics of geophysical fluids, other types of strongly magnetized plasma, and various astrophysical scenarios.

*Supported by NSF Grant PHY-1414570 and DOE Grants DE-SC0002451 and DE-SC0016532.

UP11 10 Electron Plasma Heating due to Collisonal Separatrix Crossings* K.A. THOMPSON, A.A. KABANTSEV, C.F. DRISCOLL, UCSD We observe heating of a pure electron plasma as it undergoes forced sloshing through an electrostatic squeeze potential. Our preliminary measurements show that separatrix induced heating is much larger than bulk viscous heating in the low collisionality regime and the scaling of the heating rate is consistent with theoretical predictions. The cylindrical plasma column is confined in a Penning-Malmberg trap where a $\theta$-symmetric squeeze is applied to the axial midplane of the column. This squeeze creates a velocity separatrix that divides the phase space into regions of trapped and passing particles. Oscillating the confinement end potentials of the trap forces the plasma a distance, $\delta L$, through the squeeze potential. During the compression and expansion of the trapped particle orbits there is collisional separatrix heating, which is caused by particle diffusion across the separatrix, as well as bulk viscous heating. The heating rate is measured via changes in frequency of the $m_0 = 1$ Diodorson mode. We use sloshing frequencies, $\nu_{sl}$, that are greater than the collision rate, $\nu_c$, and smaller than the axial bounce frequency in order to minimize bulk viscous heating. For the low collisionality regime, the heating rate due to collisional separatrix crossings is predicted to scale as $dT/dt \propto T(\delta L/L)^2 (\nu_{sl} \nu_c)^{1/2}$ which is in agree-
ment with our results as well as results from recent experiments in pure ion plasmas (F. Anderegg et al., BAPS.2016.DPPP.P10.114)

*Supported by NSF/DOE Partnership Grants PHY-1414570 and DE-SC0002451.

UP11 11 Discoveries and developments in support of electron/positron pair plasmas E. V. STENSON, J. HORN-STANJA, H. SAITOH, S. NISSL, U. HERGENHAHN, T. SUNN PEDERSEN, MPI for Plasma Physics M. R. STONEKING, Lawrence U. M. SINGER, M. DICKMANN, S. VOHBURGER, C. HUGEN-SCHMIDT, TUM L. SCHWEKHARD, U. of Greifswald J. R. DANIELSON, C. M. SURKO, UCS D Novel techniques being developed by the APEX/PAX (A Positron Electron eXperiment/Positron Accumulation Experiment) project are presented. These are crucial steps in enabling the creation and confinement of an electron-positron pair plasma in the magnetic field of a levitated dipole. A high flux ($10^8/s$) of low-energy positrons (< 20 eV) has been produced and characterized at the NEPOMUC positron source at FRM-II in Munich, leading to nearly 100% injection of positrons into a dipole magnetic field. Luminous responses to positrons and electrons have been measured for several phosphors, increasing their utility for both positron beam and plasma diagnostics. Compared to other levitated dipoles, APEX will be much smaller, requiring the solution to a complex optimization problem. Proof-of-principle tests are in progress to verify both the levitation feedback system and cold-head cooling. Finally, several future projects with linear positrontron traps will be discussed. One extends the capabilities of NEPOMUC by efficient generation of pulsed beams; another seeks to accumulate record numbers of positrons.

UP11 12 Positron experiments in a supported dipole trap J. R. DANIELSON, UCS D H. SAITOH, J. HORN-STANJA, E. V. STENSON, U. HERGENHAHN, S. NISSL, T. SUNN PEDERSEN, MPI for Plasma Physics M. R. STONEKING, Lawrence U. M. SINGER, M. DICKMANN, C. HUGEN-SCHMIDT, TUM L. SCHWEKHARD, U. of Greifswald C. M. SURKO, UCS D A new levitated dipole trap is being designed to experimentally study the unique physics of electron-positron pair plasmas. In parallel with the design process, a number of key questions have been investigated in a supported dipole trap. This includes the use of $E \times B$ drift injection, the manipulation of positron spatial distribution in the trap by external electrostatic potentials, and studies of the positron confinement time in a system with asymmetric perturbations. In particular, $E \times B$ drift injection has been shown to be a viable and robust means of injecting positrons from the NEPOMUC (NEutron-induced P0sitr0n source MUnIch) beam line, across the separatrix, and into the confinement region of the dipole. Nearly 100% injection of the beam has been demonstrated for a large region of parameter space. Once in the trap, positrons can be moved deeper into the confinement region by means of either static or oscillating potentials applied strategically to the segmented outer wall of the trap. Finally, once the injection potentials are switched off, experiments have demonstrated a long-lived component of the trapped positrons lasting for hundreds of milliseconds.

UP11 13 Plasma diagnostic development and UHV testing for the ALPHA collaboration at Marquette University T. D. THARP, Marquette University ALPHA COLLABORATION At Marquette, we are developing the next generation of nonneutral plasma diagnostics for the ALPHA experiment at CERN. ALPHA is building a new vertical experiment to test the gravitational interaction of antihydrogen with Earth. This expansion requires significant changes to the design of our plasma diagnostic suites: the next generation of tools must be able to measure plasmas from two directions, and must be capable of operating in a horizontal position. The diagnostic suite includes measurements of plasma density, shape, and temperature. The hardware used includes a MicroChannel Plate (MCP), a Faraday Cup, and an electron gun. In addition, we are building a vacuum chamber to test the viability of 3-d printed components for UHV compatibility, with target pressures of $10^{-10}$ mbar.

UP11 14 Non-Neutral Plasma Innovations for Antihydrogen Production* CELESTE CARRUTH, JOEL FAJANS, University of California-Berkeley ALPHA COLLABORATION In the ALPHA collaboration in 2016, we succeeded in major improvements in the non-neutral plasma manipulations involved in creating antihydrogen. ALPHA uses plasmas of antiprotons, positrons, and electrons in Penning-Malmberg traps at cryogenic temperatures and 1-3T magnetic fields. The first development was SDREVC, a combination of the strong drive regime with EVC which stabilizes particle numbers and densities allowing us to have repeatable and tunable plasma conditions. After establishing SDREVC, we took advantage of our new stability and changed our antihydrogen mixing procedure from autoresonance excitation of antiprotons to “smerge,” where we slowly lower the potential barrier between the antiproton and positron plasmas. Using smerge, we achieved a ten-fold increase in the average trapping rate. With a higher trapping rate, we then proceeded to develop a method to send electron and positron plasmas through trapped antihydrogen atoms in order to trap additional sets of antihydrogen atoms which allowed us to trap dozens of antihydrogens. With these plasma developments that lead to much higher numbers of antihydrogen atoms, we are able to do some measurements more efficiently and additional measurements previously impossible.

*Special thanks to the United States DOE and NSF for funding this research.

UP11 15 Integral Transport Analysis Results for Ions Flowing Through Neutral Gas* GILBERT EMMERT, JOHN SANTAR-IUS, UW-Madison Results of a computational model for the flow of energetic ions and neutrals through a background neutral gas will be presented. The model methods reactions as creating a new source of ions or neutrals if the energy or charge state of the resulting particle is changed. For a given source boundary condition, the creation and annihilation of the various species is formulated as a 1-D Volterra integral equation [1] that can quickly be solved numerically by finite differences. The present work focuses on multiple-pass, 1-D ion flow through neutral gas and a nearly transparent, concentric anode and cathode pair in spherical, cylindrical, or linear geometry. This has been implemented as a computer code for atomic (3He, 3He+, 3He++) and molecular (D, D2, D-, D+ , D2+, D3+) ion and neutral species, and applied to modeling inertial-electrostatic confinement (IEC) devices. The code yields detailed energy spectra of the various ions and energetic neutral species. Calculations for several University of Wisconsin IEC and on implantation devices will be presented.


UP11 16 An investigation into the role of metastable states on excited populations of weakly ionized argon plasmas, with applications for optical diagnostics* NICHOLAS ARNOLD, STUART LOCH, Auburn University CONNOR BALLANCE, Queen’s University Belfast ED THOMAS, Auburn University Low temperature plasmas ($T_e < 10$ eV) are ubiquitous in the medical, industrial, basic, and dusty plasma communities, and offer an opportunity for researchers to gain a better understanding of atomic processes in plasmas. Here, we report on a new atomic dataset for neutral and low charge states of argon, from which rate coefficients and cross-sections for the electron-impact excitation of neutral argon are determined. We benchmark by comparing with electron impact excitation cross-sections available in the literature, with very good agreement. We have used the Atomic Data and Analysis Structure (ADAS) code suite to calculate a level-resolved, generalized collisional-radiative (GCR) model for line emission in low temperature argon plasmas. By combining our theoretical model with experimental electron temperature, density, and spectral measurements from the Auburn Linear eXperiment for Instability Studies (ALEXIS), we have developed diagnostic techniques to measure metastable fraction, electron temperature, and electron density. In the future we hope to refine our methods, and extend our model to plasmas other than ALEXIS.

*Supported by the U.S. Department of Energy. Grant Number: DE-FG02-00ER54476.

UP11 17 Diffusion of Magnetized Binary Ionic Mixtures at Ultracold Plasma Conditions* KEITH R. VIDAL, SCOTT D. BAALRUD, University of Iowa Ultracold plasma experiments offer an accessible means to test transport theories for strongly coupled systems. Application of an external magnetic field might further increase their utility by inhibiting heating mechanisms of ions and electrons and increasing the temperature at which strong coupling effects are observed. We present results focused on developing and validating a transport theory to describe binary ionic mixtures across a wide range of coupling and magnetization strengths relevant to ultracold plasma experiments. The transport theory is an extension of the Effective Potential Theory (EPT), which has been shown to accurately model correlation effects at these conditions, to include magnetization. We focus on diffusion as it can be measured in ultracold plasma experiments. Using EPT within the framework of the Chapman-Enskog expansion, the parallel and perpendicular self and interdiffusion coefficients for binary ionic mixtures with varying mass ratios are calculated and are compared to molecular dynamics simulations. The theory is found to accurately extend Braginskii-like transport to stronger coupling, but to break down when the magnetization strength becomes large enough that the typical gyroradius is smaller than the interaction scale length.

*This material is based upon work supported by the Air Force Office of Scientific Research under Award Number FA9550-16-1-0221.

UP11 18 Effects of Coulomb Coupling on the Stopping Power of Plasmas* DAVID BERNSTEIN, University of Iowa JEROME DALIGAULT, Los Alamos National Laboratory SCOTT D. BAALRUD, University of Iowa Stopping power of charged particles in plasma is important for a detailed understanding of particle and energy transport in plasmas, such as those found in fusion applications. Although stopping power is rather well understood for weakly coupled plasmas, this is less the case for strongly coupled plasmas. In order to shed light on the effects of strong Coulomb coupling, we have conducted detailed molecular dynamics simulations of the stopping power of a One-Component Plasma (OCP) across a wide range of conditions. The OCP allows first-principle computations that are not possible with more complex models, enabling rigorous tests of analytical theories. The molecular dynamics simulations were compared to two analytical theories that attempt to extend traditional weakly-coupled theories into the strong coupling regime. The first is based on the binary approximation, which accounts for strong coupling via an effective scattering cross section derived from the effective potential theory. The second is based on the dielectric function formulation with the inclusion of a local field corrections.

*Work supported by LANL LDRD project 20150520ER and ir Force Office of Scientific Research under Award Number FA9550-16-1-0221.

UP11 19 Transport Regimes Spanning Magnetization-Coupling Phase Space* SCOTT D. BAALRUD, SANAT TIWARI, Univ of Iowa JEROME DALIGAULT, Los Alamos National Laboratory The manner in which transport properties vary over the entire parameter-space of coupling and magnetization strength is explored. Four regimes are identified based on the relative size of the gyroradius compared to other fundamental length scales: the collision mean free path, Debye length, distance of closest approach and inter-particle spacing. Molecular dynamics simulations of self-diffusion and temperature anisotropy relaxation spanning the parameter space are found to agree well with the predicted boundaries. Comparison with existing theories reveals regimes where they succeed, where they fail, and where no theory has yet been developed. The results suggest that magnetic fields may be used to assist ultracold neutral plasma experiments to reach regimes of stronger electron coupling by reducing heating of electrons in the direction perpendicular to the magnetic field. By constraining electron motion along the direction of the magnetic field, the overall electron temperature is reduced nearly by a factor of three. A large temperature anisotropy develops as a result, which can be maintained for a long time in the regime of high electron magnetization.

*Work supported by LDRD project 20150520ER at LANL, AFOSR FA9550-16-1-0221 and US DOE Award DE-SC00161.

UP11 20 Cooling expansion in an inhomogeneous ultracold plasma created by using space shaped laser pulses VIKRAM DHARODI, MICHAEL MURILLO, Michigan State Univ The ultracold neutral plasmas (UCNP) are created by photoionizing the laser cooled atoms. Here, our main goal is to enhance the coupling strength of UCNP and also try to mitigate the disorder induced heating (DIH). For this, we considered an inhomogeneous UCNP which has been created by using the space shaped laser pulses. An adiabatic expansion of this UCNP from higher dense regions to lower dense regions have been studied. A particle based approach has been employed to explore the dynamical evolution of UCNP. The lighter electron density is presumed to follow the Boltzman relation while the heavy ions interact through a Yukawa potential. The spatial average properties (central moments) like density, velocity and temperature have been studied. In the preliminary results, it is observed that as the ions undergo expansion, ion temperature gets lower in higher density regions and vice versa. Several cases of ion flow configuration have been considered for this study.

UP11 21 Dissipative quantum hydrodynamics model of x-ray Thomson scattering in dense plasmas* ABDOURAHMANE DIAW, MICHAEL MURILLO, Michigan State University X-ray Thomson scattering (XRTS) provides detailed diagnostic informa-
tion about dense plasma experiments. The inferences made rely on an accurate model for the form factor, which is typically expressed in terms of a well-known response function. Here, we develop an alternate approach based on quantum hydrodynamics using a viscous form of dynamical density functional theory. This approach is shown to include the equation of state self-consistently, including sum rules, as well as irreversibility arising from collisions. This framework is used to generate a model for the scattering spectrum, and it offers an avenue for measuring hydrodynamic properties, such as transport coefficients, using XRTS.

*This work was supported by the Air Force Office of Scientific Research (Grant No. FA9550-12-1-0344).

UP11 22 Measurement of strong coupling influences on the electron-ion collision rate in an ultracold plasma* JACOB ROBERTS, WEI-TING CHEN, CRAIG WITTE, Colorado State University We have experimentally measured electron oscillation damping rates in ultracold plasmas formed with a minimal (less than 10 μeV) initial kinetic energy. Under our conditions, the oscillation damping rate is predicted to be dominated by electron-ion collisions and so the measuring the damping rate provides a measure of the electron-ion collision rate. Strong coupling effects are expected to be relevant for these conditions, and indeed we observe a damping rate over a factor of 3 larger than the rate obtained assuming weak coupling. We compare our measurements with theoretical predictions derived from other theories that extend processes such as electron-ion temperature equilibration and stopping power to parameters with significant strong coupling. Simple extensions of these theories do not match our measurements, with implications for the applicability of standard collision approximations that are often used.

*Supported by the AFOSR.

UP11 23 WAVES

UP11 24 The ion cyclotron turbulence generated by a low frequency kinetic Alfvén wave, and the related turbulent heating of ions* VOLODYMYR S. MYKHAYLENKO, VOLODYMYR V. MYKHAYLENKO, HAE JUNE LEE, Pusan National University, South Korea The ion cyclotron instability driven by the strong kinetic Alfvén wave is investigated as a possible source of the anisotropic heating of ions in the coronal holes and solar wind. We present a novel model of a plasma with coupled inhomogeneous current and the sheared flow, which follows from the studies of the particles motion in the electric field of the kinetic Alfvén wave of the finite wavelength. The investigation is performed employing the non-modal kinetic theory grounded on the shearing modes approach. The solution of the governing linear integral equation for the perturbed potential displays that the flow velocity shear, which for the corona conditions may be above the growth rate of the ion cyclotron instability in plasma with steady current, changes the exponential growth of the ion cyclotron potential on the power function of time, that impedes the growth of the unstable ion cyclotron wave and reduces the turbulent heating rate of ions across the magnetic field.

UP11 25 Tertiary instability of zonal flows within the Wigner–Moyal formulation of drift turbulence* HONGXUAN ZHU, D. E. RUIZ, Princeton University I. Y. DODIN, Princeton Plasma Physics Laboratory The stability of zonal flows (ZF) is analyzed within the generalized-Hasegawa–Mima model. The necessary and sufficient condition for a ZF instability, which is also known as the tertiary instability, is identified. The qualitative physics behind the tertiary instability is explained using the recently developed Wigner–Moyal formulation [1] and the corresponding wave kinetic equation (WKE) in the geometrical-optics (GO) limit. By analyzing the drift phase space trajectories, we find that the corrections proposed in Ref. [1] to the WKE are critical for capturing the spatial scales characteristic for the tertiary instability. That said, we also find that this instability itself cannot be adequately described within a GO formulation in principle. Using the Wigner–Moyal equations, which capture diffraction, we analytically derive the tertiary-instability growth rate and compare it with numerical simulations.

*The research was sponsored by the U.S. Department of Energy.

UP11 26 Parametric decay of plasma waves near the upper-hybrid resonance* I. Y. DODIN, PPPL, A. V. AREFEYEV, UCSD An intense X wave propagating perpendicularly to dc magnetic field is unstable with respect to a parametric decay into an electron Bernstein wave and a lower-hybrid wave. A modified theory of this effect is proposed that extends to the high-intensity regime, where the instability rate γ ceases to be a linear function of the incident-wave amplitude [1]. An explicit formula for γ is derived and expressed in terms of cold-plasma parameters. Theory predictions are in reasonable agreement with the results of the particle-in-cell simulations reported in Ref. [2].

* The work was supported by the U.S. DOE through Contract No. DE-AC02-09CH11466 and by the U.S. DOE-NNSA Cooperative Agreement No. DE-NA0002008.


UP11 27 Hall-Driven Effects in Electron-Magnetohydrodynamic Z-Pinch–Like Implosions* A. S. RICHARDSON, S. B. SWANEKAMP, J. W. SCHUMER, Naval Research Laboratory D. MOSHER, P. F. OTTINGER, Independent Consultant through Syn tek Technologies, Inc. In previous work [1], it has been shown that density gradients give rise to Hall-driven magnetic field penetration in electron-magnetohydrodynamics (EMHD). Here, we examine the effect of geometry on this Hall-driven penetration. It is found that in z-pinch–like geometries, the implosion velocity of a Hall-driven magnetic pinch depends on its distance from the axis, moving faster as it approaches the axis. We compare analytical and numerical results for the z-pinch geometry to previous results for a rectangular slab geometry. Similar effects are found in both geometries, including electron-inertia driven nonlinearities, a Kelvin-Helmholtz-like instability, and the generation of vortices. The electric field in
the vortices is also examined, to determine how much charge separation occurs. If the electric field becomes large enough, it could accelerate the background ions to very high energies.

"This work was supported by the Naval Research Laboratory Base Program.


UP11 28 Ion-Acoustic Wave-Particle Energy Flow Rates∗ JORGE BERUMEN, FENG CHU, RYAN HOOD, SEAN MATTINGLY, FRED SKIFF, The University of Iowa We present an experimental characterization of the energy flow rates for ion acoustic waves. The experiment is performed in a cylindrical, magnetized, singly-ionized Argon, inductively-coupled gas discharge plasma that is weakly collisional with typical conditions: n~10^10 cm^-3 T_e~9 eV and B~600 KG. A 4 ring antenna with diameter similar to the plasma diameter is used for launching the waves. A survey of the zeroth and first order ion velocity distribution functions (IVDF) is done using Laser-Induced Fluorescence (LIF) as the main diagnostics method. Using these IVDFs along with Vlasov’s equation the different energy rates are measured for different values of ion velocity and separation from the antenna.

"We would like to acknowledge DOE DE-FG02-99ER54543 for their financial support throughout this research.

UP11 29 Interaction of Kelvin-Helmholtz and drift wave instabilities in IMPED P. K. CHATTOPADHYAY, Institute for Plasma Research SAYAK BOSE, Columbia University NEERAJ WAKDE, J. GHOSH, Institute for Plasma Research The unique control features of Inverse Mirror Plasma Experimental Device (IMPED) enables production of magnetized plasmas with variable radial density, potential and electron temperature profiles over a wide range. The radial density and potential profiles are tailored to simultaneously excite Kelvin-Helmholtz and drift wave instability. The instabilities are identified by measuring the wavelength, amplitude of density and potential fluctuations and radial profiles of density and plasma potential. These instabilities are observed to interact nonlinearly with each other leading to the formation of side bands. Bispectral analysis has been used to confirm the nonlinear coupling. The side bands are usually asymmetric in nature. However, the extent of asymmetry, i.e. the ratio of the power of the left to the right side band is controlled experimentally, which occasionally leads to symmetric side bands. The method of excitation and control of these instabilities and the probable mechanism of power distribution in side bands is presented.

UP11 30 Nonlinear saturation of Weibel-type instabilities∗ BHUVANA SRINIVASAN, PETR CAGAS, Virginia Tech AMMAR HAKIM, Princeton Plasma Physics Laboratory Weibel-type instabilities, which grow in plasmas with anisotropic velocity distribution, have been studied for many years and drawn recent interest due to their broad applicability spanning from laboratory laser plasmas to origins of intergalactic magnetic fields in astrophysical plasmas. Magnetic particle trapping has been considered as the main mechanism of the nonlinear saturation of these instabilities. However, novel continuum kinetic and two-fluid five moment simulations show that there are additional effects—the transverse flow introduced by the magnetic field creates a secondary electrostatic two-stream instability which alters the saturation and is responsible for a quasi-periodic behavior in the nonlinear phase.

∗This research was supported by the Air Force Office of Scientific Research under Grant Number FA9550-15-1-0193.

UP11 31 Zonal-flow dynamics from a phase-space perspective∗ D. E. RUIZ, Princeton University J. B. PARKER, Lawrence Livermore National Laboratory E. L. SHI, I. Y. DODIN, Princeton University The wave kinetic equation (WKE) describing drift-wave (DW) turbulence is widely used in the studies of zonal flows (ZFs) emerging from DW turbulence. However, this formulation neglects the exchange of enstrophy between DWs and ZFs and also ignores effects beyond the geometrical-optics (GO) limit. Here we present a new theory that captures both of these effects, while still treating DW quanta ("driftons") as particles in phase space [1]. In this theory, the drifton dynamics is described by an equation of the Wigner–Moyal type, which is analogous to the phase-space formulation of quantum mechanics. The "Hamiltonian" and the "dissipative" parts of the DW–ZF interactions are clearly identified. Moreover, this theory can be interpreted as a phase-space representation of the second-order cumulant expansion (CE2). In the GO limit, this formulation features additional terms missing in the traditional WKE that ensure conservation of the total enstrophy of the system, in addition to the total energy, which is the only conserved invariant in previous theories based on the traditional WKE. Numerical simulations are presented to illustrate the importance of these additional terms.

∗Supported by the U.S. DOE through Contract Nos. DE-AC02-09CH11466 and DE-AC52-07NA27344, by the NNSA SSAA Program through DOE Research Grant No. DE-NA0002948, and by the U.S. DOD NDSEG Fellowship through Contract No. 32-CFR-168a.

UP11 32 Studies of Plasma Instabilities using Unstructured Discontinuous Galerkin Method with the Two-Fluid Plasma Model YANG SONG, BHUVANA SRINIVASAN, Virginia Tech The discontinuous Galerkin (DG) method has the advantage of resolving shocks and sharp gradients that occur in neutral fluids and plasmas. An unstructured DG code has been developed in this work to study plasma instabilities using the two-fluid plasma model. Unstructured meshes are known to produce small and randomized grid errors compared to traditional structured meshes. Computational tests for Rayleigh-Taylor instabilities in radially-converging flows are performed using the MHD model. Choice of grid geometry is not obvious for simulations of instabilities in these circular configurations. Comparisons of the effects for different grids are made. A 2D magnetic nozzle simulation using the two-fluid plasma model is also performed. A vacuum boundary condition technique is applied to accurately solve the Riemann problem on the edge of the plume.

UP11 33 Study of Beta-induced Alfvén Eigenmodes with RMP system in J-TEXT Tokamak LINZI LIU, QIMING HU, ZHUO HUANG, DAOJIN GUO, ZHIPENG CHEN, GE ZHUANG, HuaZhang University of Science & Technology HUAZHONG UNIVERSITY OF SCIENCE & TECHNOLOGY TEAM The feature of Beta-induced Alfvén eigenmodes (BAE) are studied by two sets of external applied resonant magnetic perturbations (RMPs) system with different magnetic field component in J-TEXT Ohmic plasmas. The experimental results show that with moderate amplitude of RMP, a 3/1 magnetic oscillation emerges, which is regarded as BAE and has standing wave structure with its frequency in the gap triggered by kinetic thermal ion effect in the Alfvén continuum.
The strength of BAEs becomes stronger with increasing RMPs coil current. With strong enough RMP, m/n=2/1 field penetration is triggered. The structure of BAE transits from 3/1 surface to 2/1 while frequency increase about 10kHz which agree with the theoretical dispersion relation of BAE.In the meantime, another magnetic oscillation with higher frequency of 70 kHz is driven, which is defined as MiAE that as nonlinear interaction with magnetic island, i.e. frequency is modulated by width of magnetic island mainly. When we change the RMP component to generate a magnetic island on 3/1 surface, MiAE is triggered only. By measuring the width of magnetic island experimentally, we verified the theoretical dispersion relation of MiAE is agree with experimental value for the first time.

UP11 34 Subcritical bifurcation detected in an unstable magnetized plasma column THIERRY PIERRE, CNRS Paris The study of the transition to turbulence is of major importance in nonlinear dynamics research. We studied the bifurcations in a magnetized plasma when the plasma is rotating (1). When the angular velocity of the plasma column is reduced, the azimuthal modes are evolving from m=3 to m=1. This situation has been revisited checking the existence of a hysteresis near each bifurcation points, determining if the bifurcations are of supercritical or subcritical. A subcritical transition displays hysteresis. This situation has already been investigated theoretically for drift wave in magnetized plasmas (2). The experiment is conducted choosing the same parameters as in (1). The control parameter is the potential of the anode that controls the rotation of the plasma. The control parameter is varied near each bifurcation points in two cases: at first increasing the control parameter and then decreasing the control parameter. Starting from a m=2 mode, the negative anode potential is increased until the m=1 mode is established. Then the anode potential is decreased to get a transition toward an m=2 mode. The results indicate that a hysteresis is present, though a rather high dispersion of the critical value is recorded. The results are more conclusive in the case of the transition from m=1 mode to the turbulent state. A theoretical model is under preparation to get a more precise description of the bifurcations.


UP11 35 Axisymmetric Global Alfven Eigenmodes (GAEs) within the ellipticity-induced frequency gap in the Joint European Torus JAMES OLIVER, University of Texas at Austin SERGEI SHARAPOV, Culham Centre for Fusion Energy BORIS BREIZMAN, LINJIN ZHENG, University of Texas at Austin JET TEAM Alfven eigenmodes with toroidal mode number n = 0 (i.e. axisymmetric) have been observed in the ellipticity-induced frequency range in JET. The n = 0 modes are of interest because they may be used to diagnose fast particle energy distributions at the mode location. The modes were identified as Global Alfven Eigenmodes (GAEs), with the ellipticity of the plasma cross-section preventing strong continuum damping of the modes. The MHD codes CSCAS, MISHKA and AEGIS were used to compute the n = 0 Alfven continuum, eigenmode structure and continuum damping. Finite ellipticity splits the Alfven continuum branch into two branches, producing a frequency gap, and splits the single GAE into two modes. One mode has dominant poloidal harmonics m = ±1 with the same polarity and exists below the minimum of the top branch. The frequency of this mode coincides with the experimentally observed frequency. The other mode is found below the lower branch with opposite polarity of the poloidal harmonics, and is not observed experimentally. Analytical theory for the n = 0 continuum and GAE mode structure in an elliptical cylinder agree with the numerical modelling. Mode drive and damping calculations will also be presented.

UP11 36 Development of Extended Ray-tracing method including diffraction, polarization and wave decay effects KOTA YANAGIHARA, Nagoya Univ. SHIN KUBO, National Institute for Fusion Science, Nagoya Univ. ILYA DODIN, Princeton Plasma Physics Laboratory, Princeton Univ. HIROAKI NAKAMURA, National Institute for Fusion Science, Nagoya Univ. TORU TSUJIMURA, National Institute for Fusion Science Geometrical Optics Ray-tracing is a reasonable numerical analytic approach for describing the Electron Cyclotron resonance Wave (ECW) in slowly varying spatially inhomogeneous plasma. It is well known that the result with this conventional method is adequate in most cases. However, in the case of Helical fusion plasma which has complicated magnetic structure, strong magnetic shear with a large scale length of density can cause a mode coupling of waves outside the last closed flux surface, and complicated absorption structure requires a strong focused wave for ECH. Since conventional Ray Equations to describe ECW do not have any terms to describe the diffraction, polarization and wave decay effects, we can not describe accurately a mode coupling of waves, strong focus waves, behavior of waves in inhomogeneous absorption region and so on. For fundamental solution of these problems, we consider the extension of the Ray-tracing method. Specific process is planned as follows. First, calculate the reference ray by conventional method, and define the local ray-base coordinate system along the reference ray. Then, calculate the evolution of the distributions of amplitude and phase on ray-base coordinate step by step. The progress of our extended method will be presented.

UP11 37 Laser and Plasma Parameters for Laser Pulse Amplification by Stimulated Brillouin Backscattering in the Strong Coupling Regime THOMAS GANGOLF, MAR-IUS BLECHER, ILPP, Heinrich-Heine-Universitaet Duesseldorf SIMON BOLANOS, LIVIA LANCIA, JEAN-RAHAEL MARQUES, LULI, Palaiseau MIRELA CERCEHER, RAJENDRA PRASAD, BASTIAN AURAND, ILPP, Heinrich-Heine-Universitaet Duesseldorf PASCAL LOISEAU, CEA, Arpajon JULIEN FUCHS, LULI, Palaiseau OSWALD WILLI, ILPP, Heinrich-Heine-Universitaet Duesseldorf In the ongoing quest for novel techniques to obtain ever higher laser powers, plasma amplification has drawn much attention, benefiting from the fact that a plasma can sustain much higher energy densities than a solid state amplifier. As a plasma process, Stimulated Brillouin Backscattering in the strong coupling regime (sc-SBS) can be used to transfer energy from one laser pulse (pump) to another (seed), by a nonlinear ion oscillation forced by the pump laser. Here, we report on experimental results on amplification by sc-SBS using the ARCTURUS Ti:Sapphire multi-beam laser system at the University of Duesseldorf, Germany. Counter-propagating in a supersonic Hydrogen gas jet target, an ultrashort seed pulse with a pulse duration between 30 and 160 fs and an energy between 1 and 12 mJ was amplified by a high-energy pump pulse (1.7 ps, 700 mJ). For some of the measurements, the gas was pre-ionized with a separate laser pulse (780 fs, 460 mJ). Preliminary analysis shows that the amplification was larger for the longer seed pulses, consistent with theoretical predictions.
UP11 38 Hamiltonian Single Wave Models to Investigate the Nonlinear Self-Consistent Interaction of Whistler Waves and Electrons* CHRIS CRABTREE, GURUDAS GANGULL, ERIK TEJERO, US NRL. We investigate the nonlinear evolution of a self-consistent Hamiltonian model for the interaction of resonant electrons with whistler waves. We find that in the parallel propagating case there are two classes of solutions. The first class has properties similar to previously derived single wave models and involves a perfectly resonant electron beam. We show that test-particle models in the modulated wave-field indicate that the particles are trapped in a first-order island that tracks the location of the majority of particles. We develop a macro-particle model which explains the small frequency and amplitude oscillations. The second class of solutions involves a slightly off-resonant interaction which leads to an amplitude modulation of the wave that resembles the sub-packet structure observed in both chorus and recent laboratory experiments. In the second class, we show that test-particle models demonstrate that instead of being trapped in the primary resonance, particles get trapped in a second-order island chain. The location of the second-order island chain in phase space tracks the location of the majority of electrons. We develop a two macro-particle model which reproduces the amplitude modulation and sub-packet structure of the full model.

*This work is supported by the Naval Research Laboratory base program and by the National Aeronautics and Space Administration under Grant No. NNH15AZ90I.

UP11 39 Investigating parasitic current formation in MITLs through high-order continuum kinetic simulations* G. V. VOGMAN, J. H. HAMMER, W. A. FARMER, LLNL, U. SHULMLAK, University of Washington. The Z pulsed power facility is designed to deliver more than 20 MA of current to a load through magnetically insulated transmission lines (MITLs), which prevent high voltage arcs. Experimental results show that as much as 10% of the current can be lost due to the unintended formation of low-density plasmas in the MITLs. The configuration of the electric and magnetic fields within the MITL, where the plasma is born, creates conditions in which drift and kinetic instabilities can lead to the formation of parasitic currents. To understand the plasma dynamics that lead to current loss, the MITL configuration is investigated using a high-order continuum kinetic Vlasov solver in two spatial and two velocity dimensions. The simulations capture the effects of varying magnetization and yield insights into plasma behavior over the course of current rise and corresponding magnetic field generation. The effects of plasma formation at the cathode versus at the anode are explored in detail.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

UP11 40 Generalized Case “Van Kampen theory for electromagnetic oscillations in a magnetized plasma” F. BAIKARTARIS, K. HIZANIDIS, NTUA, Greece. A. K. RAM, MIT-PSFC. The Case-Van Kampen theory [1,2] is set up to describe electrostatic oscillations in an unmagnetized plasma. Our generalization to electromagnetic oscillations in magnetized plasma is formulated in the relativistic position-momentum phase space of the particles. The relativistic Vlasov equation includes the ambient, homogeneous, magnetic field, and space-time dependent electromagnetic fields that satisfy Maxwell’s equations. The standard linearization technique leads to an equation for the perturbed distribution function in terms of the electromagnetic fields. The eigenvalues and eigenfunctions are obtained from three integrals “ each integral being over two different components of the momentum vector. Results connecting phase velocity, frequency, and wave vector will be presented.

*Supported in part by the Hellenic National Programme on Controlled Thermonuclear Fusion associated with the EUROfusion Consortium, and by DoE Grant DE-FG02-91ER-54109.


UP11 41 Exploring the Alfven-wave acceleration of auroral electrons in the laboratory* J. W. R. SCHROEDER, F. SKIFF, G. G. HOWES, C. A. KLETZING, University of Iowa, T. A. CARTER, S. VINCENA, S. DORFMAN, UCLA. Inertial Alfven waves likely contribute to the acceleration of auroral electrons. However, a definitive test of Alfvenic electron acceleration is lacking. The Large Plasma Device (LAPD) at UCLA provides a controlled environment to study this wave-particle interaction that may be responsible for a significant fraction of auroras. Inertial Alfven waves were produced in the LAPD while simultaneously measuring the suprathermal tails of the electron distribution function using resonant whistler mode wave absorption. During a burst of inertial Alfven waves, the measured portion of the distribution function oscillates at the Alfven wave frequency. The phase space response of the electrons is well-described by a solution to the linearized Boltzmann equation. Experiments have been repeated using electrostatic and inductive Alfven wave antennas. The oscillation of the distribution function is described by a purely Alfvenic model when the Alfven wave is produced by the inductive antenna. However, when the electrostatic antenna is used, measured oscillations of the distribution function are described by a model combining Alfvenic and non-Alfvenic effects. Indications of a nonlinear interaction between electrons and inertial Alfven waves are present in recent data.

*This work was supported by NSF, DOE, and NASA.

UP11 42 Nonlinear plasma wave models in 3D fluid simulations of laser-plasma interaction* THOMAS CHAPMAN, RICHARD BERGER, BILL ARRIGHI, STEVE LANGER, Lawrence Livermore Natl Lab, JEFFREY BANKS, Rensselaer Polytechnic Institute, STEPHAN BRUNNER, EPFL. Simulations of laser-plasma interaction (LPI) in inertial confinement fusion (ICF) conditions require multi-mm spatial scales due to the typical laser beam size and durations of order 100 ps in order for numerical laser reflectivities to converge. To be computationally achievable, these scales necessitate a fluid-like treatment of light and plasma waves with a spatial grid size on the order of the light wave length. Plasma waves experience many nonlinear phenomena not naturally described by a fluid treatment, such as frequency shifts induced by trapping, a nonlinear (typically suppressed) Landau damping, and mode couplings leading to instabilities that can cause the plasma wave to decay rapidly. These processes affect the onset and saturation of stimulated Raman and Brillouin scattering, and are of direct interest to the modeling and prediction of deleterious LPI in ICF. It is not currently computationally feasible to simulate these Debye length-scale phenomena in 3D across experimental scales. Analytically-derived and/or numerically benchmarked models of processes occurring at scales finer than the fluid simulation grid offer a path forward. We demonstrate the impact of a range of kinetic processes on plasma reflectivity via models included in the LPI simulation code pF3D.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
UP11 43 Landau damping of sound waves in kinetic magnetohydrodynamics JESÚS J. RAMOS, Retired The Landau damping of slow sound waves propagating parallel to the magnetic field in a homogeneous, collisionless and quasineutral plasma is investigated using the kinetic magnetohydrodynamics formulation of Ref. [1]. In this approach, the electric field is eliminated from a closed, hybrid fluid-kinetic system that ensures automatically the fulfillment of the quasineutrality condition. Considering the time evolution of a parallel-propagating sound wave spatial Fourier mode, this can be cast as a standard, second-order self-adjoint problem, with a continuum spectrum of real and positive squared frequencies. Therefore, a standard resolution of the identity with a single continuum basis of singular normal modes is guaranteed, which simplifies significantly a Van Kampen-like treatment of the Landau damping. The explicit form of such singular normal modes is obtained and they are used to derive the damped time evolution of the fluid moments of a wave packet of distribution functions in an initial value problem. As mentioned, the electric field is not used in the treatment of this problem, but it is calculated from its solution after it has been obtained.


UP11 44 Towards a better understanding of high-energy electron pitch-angle scattering by electromagnetic ion cyclotron waves* S VINCIENA, W GEKELMAN, P. PRIBYL, S.W, TANG, UCLA K. PAPADOPOULOS, U. Maryland Shear Alfvén waves are a fundamental mode in magnetized plasmas. Propagating near the ion cyclotron frequency, these waves are often termed electromagnetic ion cyclotron (EMIC) waves and can involve multiple ion species. Near the earth, for example, the wave may interact resonantly with oxygen ions at altitudes ranging from 1000 to 2000 km. The waves may either propagate from space towards the earth (possibly involving mode conversion), or be generated by RF transmitters on the ground. These preliminary experiments are motivated by theoretical predictions [1] that such waves can pitch-angle scatter relativistic electrons trapped in the earth’s dipole field. EMIC waves are launched in the Large Plasma Device at UCLA’s Basic Plasma Science Facility in plasmas with single and multiple ion species into magnetic field gradients where ion cyclotron resonance is satisfied. We report here on the frequency and k-spectra in the critical layer and how they compare with theoretical predictions in computing an effective diffusion coefficient for high-energy electrons.

*Funding is provided by the NSF, DoE, and AFOSR.

1B. Eliasson and K. Papadopoulos (in submission).

UP11 45 Laboratory experiments on Alfvén and kink modes in an arched magnetized plasma* SHREEKRISHNA TRIPATI, WALTER GEKELMAN, Univ of California - Los Angeles In a recently upgraded laboratory plasma experiment, dynamics of an arched magnetized plasma has been explored with a particular focus on Alfvén and global kink modes that exist in solar prominences and coronal loops. The arched plasma \( (\beta \approx 10^{-3}) \), Lundquist number \( \approx 10^5 \) \( \text{to} \) \( 10^6 \), plasma radius/ion-gyroradius \( \approx 20 \), B = 1 kGauss at footpoints, Length \( \approx 0.8 \) m was created using a lanthanum hexaboride (LaB6) plasma source. It evolved in an ambient magnetoplasma produced by another LaB6 source. The experiment runs continuously with a 0.5 Hz repetition rate. Plasma parameters are recorded with excellent resolution using movable Langmuir and three-axis magnetic-loop probes. Images of the plasma are recorded using a fast-CCD camera. The kink-mode oscillations were observed as transverse oscillations across the symmetry plane of the arched plasma. The relative magnitudes of parameters of the arched and ambient plasma were varied to simulate varieties of conditions relevant to the sun. We examine the relevance of theoretical models of kink-modes and study the dispersion of Alfvén waves in the presence of an electrical current.

*Work supported by National Science Foundation, USA under Award Number 1619551.


UP11 46 Low frequency waves behavior in presence of strongly emissive cathodes in the VKP experiment VICTOR DESAN- GLES, Univ Lyon, Ens de Lyon, Univ Claude Bernard, CNRS, Laboratoire de Physique, F-69342 Lyon, France ELISA DE GIOR- GIO, Università della Calabria, Arcavacata di Rende, Italy GUIL- LAUME BOUSSELIN, ALEXANDRE POYE, NICOLAS PLI- HON, Univ Lyon, Ens de Lyon, Univ Claude Bernard, CNRS, Labo- ratoire de Physique, F-69342 Lyon, France Low frequency plasma parameters fluctuations are known to be the cause of strong perpendicular transport in hot plasma devices. These instabilities also appear in smaller linear devices where their excitation and mitigation have been studied using different setups such as polarized cold grids, electro-magnetic drive or concentric annular cold electrodes. We study the behavior of these fluctuations in the Von-Kármán Plasma experiment (VKP) and its modification under the injection of electrons from strongly emissive cathodes and the induced shaping of the plasma potential. VKP is a cylindrical, low pressure, high density plasma experiment with an axial confinement field. The rotation profile of the plasma is controlled using hot emissive cathodes biased relatively to the experiment wall or to cold anodes. Current emission from biased cathodes dramatically changes the radial gradients of plasma density and plasma potential, which therefore modifies the plasma rotation. We report on the influence of this controlled rotation and plasma parameters shaping over the dynamics of low frequency fluctuations in the plasma.

UP11 47 Singl/multiple Global Geodesic Acoustic Modes* TIANCHUN ZHOU, Harbin Institute of Technology Both experiments and simulations reveal that there exist single/multiple global geodesic acoustic modes that have constant frequencies over radial extension in the tokamak plasmas. In the framework of ideal MHD, the global structure of the mode emerges as the requirement the momenta associated with the second poloidal harmonics inside the coupling between the magnetic (geodesic) curvature and the leading pressure perturbations be balanced by the Alfvén perturbations, which involve the plasma displacements of higher order: the normal displacement and the second poloidal harmonic component of the geodesic displacement. The analytical and numerical solutions to the eigen-mode equation will be presented for typical q and temperature profiles. This theory is extended to the case where single local GAM splits into multiple branches as a result of plasma rotations. The rotation also induces richer poloidal harmonic structures and it eventually leads to two coupled ODEs of 2nd order. Multiple global GAMs occur naturally as the solutions of this eigen-value problem.

*This work is supported by National Magnetic Fusion Project China under Grant No. 2015GB110004.

UP11 48 The temporal evolution of the resistive pressure-gradient-driven turbulence and anomalous transport in shear flow across the magnetic field HAE JUNE LEE, VLAD- MIR MIKHAILENKO, Pusan National Universty VLADIMIR
MIKHAILENKO, Pusan National University The temporal evolution of the resistive pressure-gradient-driven mode in the sheared flow is investigated by employing the shearing modes approach. It reveals an essential difference in the processes, which occur in the case of the flows with velocity shearing rate less than the growth rate of the instability in the steady plasmas, and in the case of the flows with velocity shear larger than the instability growth rate in steady plasmas. It displays the physical content of the empirical “quench rule” which predicts the suppression of the turbulence in the sheared flows when the velocity shearing rate becomes larger than the maximum growth rate of the possible instability. We found that the distortion of the perturbations by the sheared flow with such velocity shear introduces the time dependencies into the governing equations, which prohibits the application of the eigenmodes formalism and requires the solution of the initial value problem.

UP11 49 Instabilities and transport in ExB plasma discharges∗ A. SMOLYAKOV, O. CHAPURIN, M. JIMENEZ, S. JANHUNEN, O. KOSHKAROV, XU LIANG, V. MORIN, I. ROMADANOVA, University of Saskatchewan D. SYDORENKOV, University of Alberta I. KAGANOVICH, Y. RAITSES, Princeton Plasma Physics Laboratory We present a nonlinear fluid model describing fluctuations and instabilities in partially magnetized plasma discharge supported by the ExB electron current. This model describes several fundamental modes of partially magnetized plasma: ion sound mode, lower-hybrid mode and anti-drift mode due to plasma density gradient. Density and magnetic field gradients and the electron current result in complex coupling of various modes destabilized by the interplay of ExB drift, ion beam velocity, density and magnetic field gradients, collisions and ionization. The nonlinear simulations have been performed to investigate the nonlinear saturation of the instabilities and resulting nonlinear transport. The simulations demonstrate highly intermittent electron current with magnitudes generally consistent with typical experimental parameters. It is shown that while the most unstable are small scale modes, the dominant contribution to the anomalous transport is provided by the large scale modes. The nonlinear energy transfer to large scale modes is demonstrated in nonlinear simulations. Effects of the parallel electron dynamics and sheath boundary conditions is studied. The role of electron cyclotron instabilities detected in PIC simulations is also discussed.

∗This research is supported in part by NSERC Canada and US AFOSR.

UP11 50 Electron beam current decay in the presence of relativistically intense space charge wave ROOPENDRA SINGH RAJAWAT, SUDIP SENGUPTA, Institute For Plasma Research, HBNI, Bhat, Gandhinagar - 382428, India NIKHIL CHAKRABARTI, Saha Institute of Nuclear Physics, HBNI, IAF, Bidhanagar, Kolkata - 700064, India P. K. KAW, Institute For Plasma Research, HBNI, Bhat, Gandhinagar - 382428, India. Evolution of plasma electrons propagating as a beam against a background of cold homogeneous immobile ions, has been investigated analytically in the presence of a relativistically intense space charge wave. It is shown that the electron beam current diminishes with time due to phase mixing effects, when perturbed longitudinally by imposing a relativistically intense wave. The problem has also been simulated using a 1D relativistic particle-in-cell code for various values of flow velocities($v_0/c$) and relativistic intensities ($\gamma_{max}$) of the perturbed wave. It is found that the rate of decay of current decreases with increasing flow velocity for a fixed ($\gamma_{max}$); and for a given initial current the final magnitude of current decreases with increasing relativistic intensity of the perturbed wave.

UP11 51 TOKAMAKS

UP11 52 Slow rotating mode detection using magnetic probes on passive plate in KSTAR HYUNSUN HAN, Y. IN, J.G. BAK, S.H. HAHN, Y.M. JEON, H.S. KIM, National Fusion Research Institute Since 2015 experimental campaign, to detect a low rotating or fixed non-axisymmetric plasma disturbance, 20 magnetic probes (MPs) which can catch the parallel component of magnetic field have been installed on the passive plate with different toroidal/poloidal positions in KSTAR. To identify n(toroidal mode number) = 1 or 2 plasma instability, the Fourier decomposition method is applied and some preliminary results show its effectiveness when the external fields by the in-vessel coils are properly compensated. This identification method has been implemented in the KSTAR plasma control system to avoid the mode locking and the RWM(Resistive Wall Mode) in the future.

UP11 53 Transport and stability analyses supporting disruption prediction in high beta KSTAR plasmas∗ J.H. AHN, S.A. SABBAGH, Y.S. PARK, J.W. BERKERY, J. JIANG, J. RIQUEZES, Columbia U. H.H. LEE, L. TERZOLEO, NFRI S.D. SCOTT, Z. WANG, PPLL A.H. GLASSER, U. Washington KSTAR plasmas have reached high stability parameters in dedicated experiments, with normalized beta ($\beta_p$) exceeding 4.3 at relatively low plasma internal inductance $l_i$ ($\beta_p/l_i>6$) [1]. Transport and stability analyses have begun on these plasmas to best understand a disruption-free path toward the design target of $\beta_p = 5$ while aiming to maximize the non-inductive fraction of these plasmas. Initial analysis using the TRANSP code indicates that the non-inductive current fraction in these plasmas has exceeded 50 percent. The advent of KSTAR kinetic equilibrium reconstructions now allows more accurate computation of the MHD stability of these plasmas. Attention is placed on code validation of mode stability using the PEST-3 and resistive DCON codes. Initial evaluation of these analyses for disruption prediction is made using the disruption event characterization and forecasting (DECAF) code [2]. The present global mode kinetic stability model in DECAF developed for low aspect ratio plasmas is evaluated to determine modifications required for successful disruption prediction of KSTAR plasmas.

∗Work supported by U.S. DoE under contract DE-SC0016614.


The measurements of the open-loop growth rate of VDE $\gamma_c$ and the maximum controllable vertical displacement $\Delta Z_{\text{max}}$ are done by the release-and-catch method. The dynamics of the vertical movement of the plasma is verified by both relevant magnetic reconstructions and non-magnetic diagnostics. The measurements of $\gamma_c$ and $\Delta Z_{\text{max}}$ were done for different plasma currents, $\beta_p$, internal inductances, elongations and different configurations of the vessel conductors that surround the plasma as the first wall. Effects of control design choice and diagnostics noise are discussed, and comparison with the axisymmetric plasma response model is given for partial accounting for the measured control capability.

*This work supported by Ministry of Science, ICT, and Future Planning under KSTAR project.

UP11 55 Automated Identification of MHD Mode Bifurcation and Locking in Tokamaks  

J.D. RIQUEZES, S.A. SABBAGH, Y.S. PARK, Columbia U. R.E. BELL, PPPL A. MORTON, ORAU  

Disruption avoidance is critical in reactor-scale tokamaks such as ITER to maintain steady plasma operation and avoid damage to device components. A key physical event chain that leads to disruptions is the appearance of rotating MHD modes, their slowing by resonant field drag mechanisms, and their locking. An algorithm has been developed that automatically detects bifurcation of the mode toroidal rotation frequency due to loss of torque balance under resonant braking, and mode locking for a set of shots using spectral decomposition. The present research examines data from NSTX, NSTX-U and KSTAR plasmas which differ significantly in aspect ratio (ranging from $A = 1.3 - 3.5$). The research aims to examine and compare the effectiveness of different algorithms for toroidal mode number discrimination, such as phase matching and singular value decomposition approaches, and to examine potential differences related to machine aspect ratio (e.g. mode eigenfunction shape variation). Simple theoretical models will be compared to the dynamics found. Main goals are to detect or potentially forecast the event chain early during a discharge. This would serve as a cue to engage active mode control or a controlled plasma shutdown.

*Supported by US DOE Contracts DE-SC00166164 and DE-AC02-09CH11466.

UP11 56 LH Transition and rotation studies under non-axisymmetric magnetic fields in KSTAR  

WON-HA KO, Y. IN, H.S. HAHN, J.W. JUHN, J. KIM, J.H. LEE, Y.M. JEON, J. SEOL,  

NFRI, Daejeon, Korea P. DIAMOND, CMTFO and CASS, University of California in San Diego, USA K. IDA, NIFS, Toki, Japan S.W. YOON, Y.K. OH, NFRI, Daejeon, Korea H. PRAK, UNIST, Ulsan, Korea A thorough study of LH transition under the influence of non-axisymmetric field (NF) has been conducted in KSTAR. It shows that LH power threshold depends on the resonant NFs and the line-averaged density-LH power threshold curve agrees well with the power law scaling [1] as the resonant NF $\delta B/B_{\text{tor}}$ is applied up to $2.7 \times 10^{-3}$ in KSTAR which has a low intrinsic error field. However, LH power threshold is independent of non-resonant NFs with $n=1$ and $n=2$ which reduced only toroidal rotation by 30% in L-mode. The rotation pedestal during LH transition with both co-and counter-NBI heating appears saturated at a critical level of edge rotation [2] which is dependent of LH power threshold. However, the core rotation increased with the stored energy in the co-NBI with and without NFs while it is saturated in counter-NBI plasma. In co-NBI heated H-mode, the pedestal width of rotation is 5 cm with wide that of ion temperature (2 cm). On the other hand, in counter-NBI heated H-mode, the rotation pedestal width (2 cm) appeared as similar as that of ion temperature. The newly diagnosed results of rotation in KSTAR seemingly pose a variety of physics questions.

$^1$Martin, JOP (2008).  

UP11 57 MHD stability analysis and global mode identification preparing for high beta operation in KSTAR  


H-mode plasma operation in KSTAR has surpassed the computed $n = 1$ ideal no-wall stability limit in discharges exceeding several seconds in duration. The achieved high normalized beta plasmas are presently limited by resistive tearing instabilities rather than global kink/ballooning or RWs. The ideal and resistive stability of these plasmas is examined by using different physics models. The observed $m/n = 2/1$ tearing stability is computed by using the M3D-C$^*$ code, and by the resistive DCON code. The global MHD stability modified by kinetic effects is examined using the MISK code. Results from the analysis explain the stabilization of the plasma above the ideal MHD no-wall limit. Equilibrium reconstructions used include the measured kinetic profiles and MSE data. In preparation for plasma operation at higher beta utilizing the planned second NBI system, three sets of 3D magnetic field sensors have been installed and will be used for RW active feedback control. To accurately determine the dominant $n$-component produced by low frequency unstable RWs, an algorithm has been developed that includes magnetic sensor compensation of the prompt applied field and the field from the induced current on the passive conductors.

*Supported by US DOE Contracts DE-FG02-99ER54524 and DE-SC0016614.

UP11 58 Kinetic equilibrium reconstruction of KSTAR plasmas including internal pitch angle profile measurement  

YANZHENG JIANG, Columbia Univ STEVEN SABBAGH, YOUNGEOK PARK, JAEHEON AHN, Columbia University JINSEOK KO, NFRI  

High fidelity kinetic equilibrium reconstructions are an essential requirement for accurate stability and disruption prediction analyses to support continuous operation of high beta KSTAR tokamak plasmas. The present work significantly expands our past magnetics-only equilibrium reconstruction capability [1]. The present kinetic equilibrium reconstructions include Thomson scattering (TS) data, charge exchange spectroscopy (CES) data, and allowance for fast particle pressure in addition to external magnetic and shaping field current data, and inclusion of vacuum vessel and passive plate currents following a “partial kinetic” approach used successfully in other devices [2]. In addition, up to 25 channels of Motional Stark Effect (MSE) data are used to constrain the local magnetic field pitch angle to produce reliable evaluation of the safety factor profile. The ramifications of the inclusion of the kinetic profiles and MSE data are examined in the context of plasma stability evaluation, and parameters and analysis used for disruption event characterization and forecasting (DECAF).

*Supported by US DOE Grant DE-SC0016614.

UP11 59 Evaluation of MSE Wavelength-Interpolation Background Subtraction on KSTAR* STEVEN SCOTT, PPPL
ROBERT MUMGAARD, MIT/PSEC JINSEOK KO, NFRI A ten-channel polychromator that simultaneously measures the Motional Stark Effect polarized pi and sigma line emission and two neighboring wavelengths near the MSE spectrum, previously used on Alcator C-Mod, has been integrated into the KSTAR MSE diagnostic. This system provides accurate measurements of the partially-polarized MSE background emission even when the background varies rapidly in time and space. Data acquired during the 2017 KSTAR campaign and data-mining of older data will be used to assess four key issues: (1) what error in measured pitch angle is introduced by not compensating the MSE measurement for the presence of partially-polarized background light (the practice now); (2) how much larger will this error grow when KSTAR realizes higher-performance plasmas, particularly higher density; (3) how accurately can the background polychromator system estimate the polarized background light during beam injection; and (4) what is the relative statistical measurement error between the existing NFRI MSE diagnostic versus the background polychromator system? The answers to these questions will inform a decision in late FY17 about whether to proceed with construction of 15 additional background polychromator channels for installation on KSTAR before the start of its FY18 run campaign.

*This work supported by DoE Contract No. DE-AC02-09CH11466.

UP11 60 First results from the US-PRC PMI collaboration on EAST* R. MAINGI, R. LUNSFORD, D. MANSFIELD, A. DIALLO, PPPL J. HU, Z. SUN, G. ZUO, X. GONG, ASIPP K. TRITZ, JHU J. CANIK, ORNL T. OSBORNE, GA EAST TEAM A US-PRC collaboration was formed to understand the plasma-material interface for improved long pulse discharge performance in EAST, with an emphasis on Li conditioning techniques. The US multi-institutional team consists of participants from PPPL, UIUC, UT-K, ORNL, MIT, LANL, and JHU. In Dec. 2016, this team co-led experiments on the use of Li aerosol injection to mitigate ELMs, Li granule injection to pace ELMs, and a flowing liquid Li limiter to serve as a primary plasma-facing component. Li aerosol injection was shown to eliminate ELMs using the upper ITER-like W divertor, extending previous results of ELM suppression in the lower cabon divertor (J.S. Hu, PRL 2015). In addition Li granule injection was shown to trigger and even pace ELMs, although the paced ELM frequency was slower than the natural ELM frequency in this set of experiments; previously paced ELM frequency was comparable to natural ELMs frequency (D.K. Mansfield, NF 2013). Finally a second generation flowing liquid Li limiter was shown to be compatible with ELMy H-mode plasmas, pushed within 1 cm of the separatrix. The surface showed no damage to PMI and improved wetting as compared to the first generation limiter experiments (J.S. Hu, NF 2016 and G.Z. Zuo, NF 2017).

*US scientists supported in part by US DoE contracts DE-AC02-09CH11466, DE-FG02-09ER55012, DE-AC05-00OR22725, and DE-FC02-04ER54698, and ASIPP scientists by Contract No. 1125524, No. 11075185, No. 11021565, and No. 2015GB114004.

UP11 61 Tearing mode control with electron cyclotron resonant heating and current drive on EAST tokamak YANG ZHANG, Institute of Plasma Physics, Chinese Academy of Sciences HUI SHI, SHUAI GU, LI QUN HU, XIAO DONG ZHANG, Institute of Plasma Physics, Chinese Academy of Sciences, Chinese Academy of Sciences

UP11 62 Experimental investigation of LHCD’s effect on plasma rotation on EAST BO LYU, Chinese Academy of Sciences XI-ANGHUI YIN, University of Science and Technology of China ZHONG LI, BOJIAN DING, MINHOU LI, HAQING LIU, Chinese Academy of Sciences JUN CHEN, RUJI HU, University of Science and Technology of China FUDI WANG, QING ZANG, MAO WANG, FUKUN LIU, JIA FU, Chinese Academy of Sciences YUEJIAO SHI, University of Science and Technology of China BAOJIAN WANG, Chinese Academy of Sciences EAST TEAM LHCD’s effect on plasma rotation was reported. It was found that ~20km/s co-current rotation change was driven, which was linearly correlated with changes in li and q0 and evolves over current diffusion time. Hysteresis between rotation and Te was observed, suggesting different transport between heat and momentum transport. Rotation profile shows that the change arises from the region where LHCD was deposited and then transported to the core, confirming the rotation drive was originated at the plasma edge. For NBI heated plasma, counter-rotation change was observed upon the injection of the LHCD and continued to co-rotation change shortly. Further experiments showed that the change of rotation induced by LHCD decreases with plasma current (Ip), plasma density and increase with LHCD power. A comparison between the rotation driven by 4.6GHz LHCD and 2.45GHz LHCD on EAST is also presented, in which higher frequency LHCD could induce more rotation change, due to the better heating and CD efficiency with 4.6GHz LHW.


The global confinement (H98) increases with the internal inductance (1.0<\rho<0.3, the instability of the tearing \rho=0.4 in EAST. After turning off ECRH, the stored energy decreases by ~30% in 2.5 s. Calculations suggest that the lower hybrid electron heating and driven current move from the core to large radii after turning off ECRH. Power balance analysis show that the LH deposition profile shift from just inside the ITB to outside the ITB after ECRH termination appears to be responsible for the marked drop in stored energy. The slow stored energy decrease is believed to be connected to the long plasma current profile relaxation time. Linear gyrokinetic simulations indicate increasing
low-k instability growth rate from small to large radii, which is consistent with the reduced diffusivity within the ITB. The calculations also show that the CTEM dominate within the ITB, ETG modes grow rapidly outside this region, and that ITG modes dominate near the pedestal top.

*Work supported by the NNSF of China #11575248.

UP11 64 Improved H mode with flat central q profile on EAST* HAIQING LIU, YAO YANG, XIANG GAO, LONG ZENG, JIN-PING QIAN, XIANZU GONG, BAONIAN WAN, Institute of Plasma Physics, Chinese Academy of Sciences WEIXING DING, DAVID LYN BROWER, Department of Physics and Astronomy, University of California Los Angeles EAST TEAM High betaP ($\beta_P \sim 1.8$) plasma with good confinement (H98y2~1.1) on EAST tokamak has been reported recently. These ELMy H-mode plasmas with flat central $q$ profile and absence of sawteeth at high betaP ($\beta_P \sim 1.8$) were characterized by a stationary flat central $q$ profile $q_0 = 1.4$ (as constraint). Base on the optimized current profile, better confinement and absence of sawteeth, like other devices. Accurate q profile, key to unity. Implying an improved H-mode with flat central $q$ profile and edge transport barrier (ETB) are both observed with m/n = 1/1 wave and neutral beam injection. The internal transport barrier (ITB) and edge transport barrier (ETB) are both observed with m/n = 1/1 fishbone, which were identified to clamp central $q$ at values close to unity. Implying an improved H-mode with flat central $q$ profile and absence of sawteeth, like other devices. Accurate q profile, key profile for developing scenarios aim at high performance H mode, were derived by Polariometer-Interferometer (POINT) measurement as constraint. Base on the optimized current profile, better confinement (H98y2~1.4) with an electron ITB was obtained also with flat central $q$ profile and absence of sawteeth at high betaP ($\beta_P \sim 2$) regime with $B_t = 2.5 T$, $I_p = 400 kA$. Both high betaN regime and high betaP regime H mode, are characterized by a stationary flat central $q$ profile $q_0 \geq 1$, but typically close to 1, absence of sawteeth, H98y2(y.2) > 1, and simultaneously, with ITB.

*This work is supported by the National Magnetic Confinement Fusion Program of China with Contract No. 2014GB106002 and partly supported by the US D.O.E. contract DESC0010469.

UP11 65 Measurements and simulations of quasi-coherent fluctuations during the inter-ELM phase in EAST N. YAN, ASIPP X.Q. XU, LLNL J. LI, G.S. XU, T.Y. XIA, H. LAN, H. ZHANG, ASIPP Quasi-coherent fluctuations have been commonly observed preceding type-I ELMs in EAST. They typically show up in two frequency domains. The lower frequency band (30-50 kHz) propagates in ion diamagnetic direction. It predominantly peaks on low field side, but not evidently contribute to local transport. The higher frequency band (180-220 kHz) is detected to propagate in the electron diamagnetic direction. Its amplitude exhibits an in-out symmetry. However, it drives strong particle transport into far SOL region on high field side. Study of these inter-ELM fluctuations are important for our understanding of pedestal physics, SOL width and ELM process itself. For this purpose, BOUT++ simulations for inter-ELM fluctuations are conducted based on EAST experiments. The preliminary simulation results suggest that peeling-balloonning and drift-alfven instabilities could be respectively responsible for the lower frequency band and higher frequency band fluctuations observed during the inter-ELM phase in experiments. Comparison of nonlinear simulations with experimental measurements will be presented.

UP11 66 Current Density Profile Control via Model Predictive Control in EAST* HEXIANG WANG, WILLIAM WEHNER, EU-GENIO SCHUSTER, Lehigh University LEHIGH UNIVERSITY PLASMA CONTROL TEAM Extensive studies have shown that the current density profile, which is closely related to poloidal magnetic flux profile, is a key factor to achieving advanced tokamak operating scenarios that are characterized by improved confinement and possible steady-state operation. In this work, a first-principles-driven, control-oriented model of the poloidal magnetic flux profile evolution is used to design a feedback controller via model predictive control (MPC) for EAST. The goal of the feedback controller is to regulate the poloidal magnetic flux profile evolution around a desired trajectory by minimizing the difference between desired and actual profiles. Due to external disturbances, non-modeled dynamics, and perturbation in initial conditions, feedback-only control solutions usually fail in achieving the desired trajectory. Simulation results illustrate the capability of the proposed model predictive controller in tracking the desired profile by optimizing in real time the actuator waveforms.

*Supported by the US DOE under DE-SC0010537.

UP11 67 Magnetic field amplitude and pitch angle measurements using Spectral MSE on EAST* KEN LIAO, WILLIAM ROWAN, IFS, University of Texas at Austin JIA FU, YING-YING LI, BO LYU, ASIPP, Chinese Academy of Science OLEKSANDR MARCHUK, Forschungszentrum Julich YURI RALCHENKO, NIST We have developed the Spectral Motional Stark Effect technique for measuring magnetic field amplitude and pitch angle on EAST. The experiments were conducted using the tangential co-injection heating beam at A port and Beam Emission Spectroscopy array at D port. A spatial calibration of the observation channels was conducted before the campaign. As a first check, the measured magnetic field amplitude was compared to prediction. Since the toroidal field is dominant, we recovered the expected 1/R shape over the spatial range 1.75<r(m)<3.2 with $R_0 = 1.89m$. The objective is the spatially resolved pitch angle which follows from the ratio of the $\pi$ and $\sigma$ polarized Stark components. The excited state populations are far from local thermal equilibrium and a collisional-radiative model that takes into account the effect of the Lorentz field was used to predict the beam populations. The initial comparison is to an EFIT reconstruction. We are investigating sources of errors using a combination of simulations and calibrations arising from hardware non-idealities and approximations in the analysis. We are also investigating improvements in the EAST spectral MSE diagnostic.

*Supported by the U.S. DOE, Office of Fusion Energy Sciences under Award DE-SC0010500, National Magnetic Confinement Fusion Science Program of China under Grant No. 2015GB103003 and National Natural Science Foundation of China (No. 11605242).

UP11 68 Stimulated L-H transition with SMBI in the HL-2A tokamak WULYU ZHONG, Southwestern Institute of Physics, PO Box 432, Chengdu 6100041, China XIAOLAN ZOU, CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France AUSHU LIANG, XURU DUAN, MIN XIU, BEIBIN FENG, CHENGYUAN CHEN, GUO-LIANG XIAO, ZHONGBING SHI, ZHENGCHEN YANG, MIN JIANG, PEIWAN SHI, JIE WEN, XIANMING SONG, DELIANG YU, LINGE ZANG, LONGWEN YAN, JIAQI DONG, XIANTONG DING, YONG LIU, Southwestern Institute of Physics, PO Box 432, Chengdu 610041, China HL-2A TEAM In the HL-2A plasmas, the transition from low confinement mode (L-mode) to high confinement mode (H-mode) externally stimulated by supersonic molecular beam injection (SMBI) has been observed. SMBI, a fuelling tool with higher fuelling efficiency than that of gas puffing, can abruptly increases the electron density and its gradient. Then it helps to build the pedestal with steep gradient. It was found that
more intense SMBI induces large turbulence intensity. Interestingly, the intensity of geodesic acoustic mode (GAM) was enhanced by SMBI, then the turbulence intensity was clamped. When the plasma transited into the H-mode, the GAM disappeared. The enhanced GAM can also transits into another oscillating shear flow, limit cycle oscillation (LCO). The interplay between oscillating flows and turbulence was studied. The result suggests that the oscillating flows can be enhanced or triggered by SMBI and those flows initiate the L-H transition. Further, they play a important role in the continuous increase of the mean shear flow prior to the transition.

UP11 69 The radiation asymmetry in MGI rapid shutdown on J-TEXT tokamak RUIHAI TONG, Huazhong University of Science & Technology ZHONGYONG CHEN, Huazhong University of Science & Technology and Chengdu University DUWEI HUANG, ZHIFENG CHENG, XIAOLONG ZHANG, GE ZHUANG, Huazhong University of Science & Technology J-TEXT TEAM Disruptions, the sudden termination of tokamak fusion plasmas by instabilities, have the potential to cause severe material wall damage to large tokamaks like ITER. The mitigation of disruption damage is an essential part of any fusion reactor system. Massive gas injection (MGI) rapid shutdown is a technique in which large amounts of noble gas are injected into the plasma in order to safely radiate the plasma energy evenly over the entire plasma-facing first wall. However, the radiated energy during the thermal quench (TQ) in massive gas injection (MGI) induced disruptions is found toroidal asymmetric, and the degrees of asymmetry correlate with the gas penetration and MGI induced magnetohydrodynamics (MHD) activities. A toroidal and poloidal array of ultraviolet photodiodes (AXUV) has been developed to investigate the radiation asymmetry on J-TEXT tokamak. Together with the upgraded mirnov probe arrays, the relation between MGI triggered MHD activities with radiation asymmetry is studied.

UP11 70 Formation and dissipation of runaway current by MGI on J-TEXT YUNONG WEI, ZHONGYONG CHEN, DUWEI HUANG, RUIHAI TONG, XIAOLONG ZHANG, Huazhong University of Science & Technology Plasma disruptions are one of the major concern for ITER. A large fraction of runaway current may be formed due to the avalanche generation of runaway electrons (REs) during disruptions and ruin the device structure. Experiments of runaway current formation and dissipation have been done on J-TEXT. Two massive gas injection (MGI) valves are used to form and dissipate the runaway current. Hot tail RE generation caused by the fast thermal quench leads to an abnormal formation of runaway current when the pre-TQ electron density increases in a range of $0.5-2 \times 10^{19}$ m$^{-3}$. $10^{20-22}$ quantities of He, Ne, Ar or Kr impurities are injected by MGI2 to dissipate the runaway current. He injection shows no obvious effect on runaway current dissipation in the experiments and Kr injection shows the best. The kinetic energy of REs and the magnetic energy of RE beam will affect the dissipation efficiency to a certain extent. Runaway current decay rate is found increasing quickly with the increase of the gas injection when the quantity is moderate, and then reaches to a saturation value with large quantity injection. A possible reason to explain the saturation of dissipation effect is the saturation of gas assimilation efficiency.

UP11 71 Effect of pulse resonant magnetic perturbation on magnetic island rotation in the J-TEXT tokamak* LI DA, DING YONGHUA, HU QIMING, HU FEIRAN, YAN MINXIONG, JI XINKE, ZHU LIZHI, HUANG ZHUO, SONG ZEBAO, School of Electrical and Electronics Engineering, Huazhong University of Science and Technology J-TEXT TEAM TEAM The influence of the static resonant magnetic perturbation (RMP) on the magnetic island depends on the phase difference between the island and RMP. According to the numerical simulation, the pulse RMP, which is applied in certain island phase region, could accelerate and suppress island. Feedback control system has been developed on J-TEXT for passing pulse electricity through resonant magnetic perturbation (RMP) coil when the phase difference between the mode and RMP is in the unique range. It is confirmed by experiment that the effects on magnetic island by modulated RMP varies with the difference phase range, which agree with theoretical expectation and simulation result. The pulse RMP could accelerate island until the electromagnetic torque generated by RMP is balanced by viscous torque. However, the mode frequency increases inconspicuous for finite RMP strength and eddy currents.

*This work was partially supported by the National Natural Science Foundation (Nos. 11275079, 11005090, 11005043, and 11105056) and by the National Magnetic Confinement Fusion Science Program (2014GB113003).

UP11 72 Overview of the EUROfusion Medium Size Tokamak scientific program MATTHIAS BERNERT, Max Planck Institute for Plasma Physics, Garching, Germany TOMMASO BOLONZELLA, Consorzio RFX, Padova, Italy STEFANO CODA, SPC-EPFL, Lausanne, Switzerland ANTTI HAKOLA, VTT Technical Research Centre of Finland Ltd., Espoo, Finland HENDRICK MEYER, CCLL, Culham Science Centre, Abingdon, UK THE TCV TEAM, THE MAST-U TEAM, THE ASDEX UPGRADE TEAM, THE EUROFUSION MST1 TEAM* Under the EUROfusion MST1 program, coordinated experiments are conducted at three European medium sized tokamaks (ASDEX Upgrade, TCV and MAST-U). It complements the JET program for preparing a safe and efficient operation for ITER and DEMO. Work under MST1 benefits from cross-machine comparisons but also makes use of the unique capabilities of each device. For the 2017/2018 campaign 25 topic areas were defined targeting three main objectives: 1) Development towards an edge and wall compatible H-mode scenario with small or no ELMs. 2) Investigation of disruptions in order to achieve better predictions and improve avoidance or mitigation schemes. 3) Exploring conventional and alternative divertor configurations for future high P/R scenarios. This contribution will give an overview of the work done under MST1 exemplified by the highlights results for each top objective from the last campaigns, such as evaluation of natural small ELM scenarios, runaway mitigation and control, assessment of detachment in alternative divertor configurations and highly radiative scenarios.

*See author list of “H. Meyer et al. 2017 Nucl. Fusion 57, 102014”.

UP11 73 Development of an I-mode scenario on the TCV tokamak ANTOINE MERLE, PEDRO MOLINA, OLIVIER SAUTER, BASIL DUAL, EPFL, SPC AMANDA HUBBARD, MIT, PSFC TIM HAPPEL, MPG, IPP ELEONORA VIEZZER, Univ. Seville THE TCV TEAM, THE EUROFUSION MST1 TEAM The I-mode is a promising regime of operation which offers high energy confinement, thanks to the formation of an edge temperature pedestal, low particle confinement and nearly stationary conditions, with the absence of ELMs. This regime is usually obtained by operating with unfavourable ion $B_B > 0$ drift, away from the active X-point, and keeping the heating power below the H-mode threshold. This has been achieved on several tokamaks such as Alcator C-Mod,
ASDEX Upgrade and DIII-D. This paper reports on an ongoing effort to develop an I-mode scenario on the TCV tokamak as part of the TCV domestic campaign and the EUROfusion MST1 campaign. On other tokamaks the heating power window for accessing I-mode was found to be typically smaller at smaller magnetic field. With typical operation at $B_T = 1.45$ T and an absolute maximum of $B_T = 1.54$ T, the TCV tokamak will help investigate whether the I-mode regime can be extended to low toroidal magnetic field. The results of this campaign will be discussed, in particular changes in energy confinement or in the pedestal temperature profiles will be closely investigated. The pedestal fluctuation characteristics will also be investigated using standard and Doppler reflectometer fluctuation measurements.

UP11 74 Upgrade of JET AE Active Diagnostic for Low Frequency Eigenmodes Detection* P. PUGLIA, P. BLANCHARD, D. TESTA, A. FASOLI, EPFL Switzerland V. ASLANYAN, M. PORKOLAB, P. WOSKOV, MIT-PSFC L. RUCHKO, R. GAL-VAO, W. PIRES DE SA, A. DOS REIS, USP Brazil S. SHARAPOV, S. DOWSON, H. SHEIKH, T. BLACKMAN, G. JONES, S. DORLING, CCFE UK J. FIGUEIREDO, C. PEREZ VON THUN, EUROfusion PMU JET COLLABORATION† The upgrade of the Toroidal Alfvén Eigenmode Active Antenna diagnostic at JET was commissioned last year. The new amplifiers have an operational frequency range limited to bands within 10-1000 kHz by a choice of filters. In the last campaigns the AE excitation system was operated on the Alfvénic range of frequencies (f > 80 kHz). For the next campaigns we are proposing operation on the frequency range of 25-50 kHz to excite eigenmodes on the Alfvén-acoustic range (GAMs, BAEs and Alfvén Cascades). The next JET campaigns will involve use of deuterium, tritium and hydrogen, giving a wide range of parameters for the modes to be investigated. Details of the system modifications for operation in this new frequency range and experimental scenarios will be discussed.

*This work has been carried out within the framework of the EUROfusion Consortium No 633053. Support was provided by the US DOE, FAPESP Project 2011/50773-0, by the Swiss NSF, and also the RCUK Energy Programme [Grant Number EP/P012450/1].†See the author list of “X. Litaudon et al. 2017 Nucl. Fusion 102001.

UP11 75 L-H transition studies in JET-ILW ER SOLANO, LNF, CIEMAT, Madrid, Spain E DELABIE, ORNL, Oak Ridge, TN, USA J HILLESHEIM, C MAGGI, CCFE, Abingdon, UK N VIANELLO, Consorzio RFX, Padova, Italy I CARVALHO, IPFN, IST, Univ. Lisboa, Portugal A HUBER, FZJ, Julich, Germany E LERCHE, LPP-ERM/KMS, Brussels, Belgium JET CONTRIBUTORS TEAM Recent experiments at JET have produced new results about the L-H transition. We will present a selection here. We found the power threshold depends on $H/(H+D)$ species concentration in a non-linear manner, with much of the variation taking place at the extremes of the mixture scan. It is unclear why this should be the case, but it may help explain the variability in results of earlier studies that don’t always report an isotope effect, and suggests that small levels of impurities could be important when interpreting isotope experiments. We found that the heating system has an impact on the power threshold in hydrogen and on the location of the density at which the threshold is lowest, ICRF heating being much more effective than NBI heating. This is the first time an effect of the heating system was found on JET. We also observe a stronger isotope effect in the low density branch than in the high density branch of the transition. On a related study, we have characterized axisymmetric magnetic oscillations present in the early H-mode phase, the M-mode, and show that their frequency scaling appears to be related to the poloidal Alfvén frequency in both H and D.

UP11 76 Integrated modeling of temperature and rotation profiles in JET ITER-like wall discharges* T. RAFIQ, Lehigh U., USA A.H. KRITZ, Lehigh U., USA HYUN-TAE KIM, Culham Science Centre, UK E. SCHUSTER, Lehigh U., USA J. WEILAND, Chalmers U., Sweden Simulations of 78 JET ITER-like wall D-D discharges and 2 D-T reference discharges are carried out using the TRANSP predictive integrated modeling code. The time evolved temperature and rotation profiles are computed utilizing the Multi-Mode anomalous transport model [1]. The discharges involve a broad range of conditions including scans over gyroradius, collisionality, and values of $q_95$. The D-T reference discharges are selected in anticipation of the D-T experimental campaign planned at JET in 2019. The simulated temperature and rotation profiles are compared with the corresponding experimental profiles in the radial range from the magnetic axis to the $p = 0.9$ flux surface. The comparison is quantified by calculating the RMS deviations and Offsets. Overall, good agreement is found between the profiles produced in the simulations and the experimental data. It is planned that the simulations obtained using the Multi-Mode model will be compared with the simulations using the TGLF model [2].

*Research supported in part by the US, DoE, Office of Sciences.

UP11 77 Effects of external 3D fields on the core of high-beta hybrid tokamak plasmas PAOLO PIOVESAN, L. MARRELLI, L. PIGATTO, D TERRANOVA, T. BOLZONELLA, Consorzio RFX V IOCHINE, M SERTOLI, C ANGIONI, A BOCK, A GUDE, M MARASCHEK, R MCDERMOTT, W SUTTROP, IPP Garching AF MARTITSCH, SV KASIOLOV, Uni. Graz; YQ LIU, GA ASDEX UPGRADE TEAM, EUROFUSION MST1 TEAM The core of high-beta hybrid tokamoks is sensitive to 3D fields, due to the response of a marginally-stable kink with large $m=1/n=1$ component as the minimum safety factor approaches unity. Helical core displacements of 1-2cm impact various quantities, as found in ASDEX Upgrade by probing the plasma with $n=1$ fields: central electron and ion temperature is reduced, causing confinement degradation; core rotation is braked, leading to performance-limiting 2/1 modes as rotation is roughly halved; outward W transport occurs, a potentially beneficial effect. Due to $n=1$ field amplification, these effects are largest near beta limits and error field correction is applied to minimize them. A modelling effort is ongoing to explain these results. Rotation braking is compared to neoclassical toroidal viscosity predicted by the MHD-kinetic hybrid code MARS-K. The drift-kinetic code NEO-2 is used to evaluate both NTV and the neoclassical W transport in the helical core, represented by a 3D equilibrium from V3FIT-VMEC.

UP11 78 Rehabilitation of the Goal of Ignition, Sober Assessments of the Large Machine Approach to Fusion and the Ignitor Program P. SPILLANTINI, INF, Italy B. COPPI, MIT IGNITOR COLLABORATION Although the value of investigating the physics of plasmas close to or at ignition condition has never been questioned. The “relevance” of efforts with this goal [1] has been too frequently passed under silence by supporters of large scale programs that cannot claim this objective. By now studies of the characteristics of ignited plasmas and of the requirements of power
producing reactors have led to conclude that operating at ignition is necessary for a practically useful fusion reactor. The confinement scaling laws, that were identified originally when the line of high field compact experiments began to be proposed in order in order to investigate igniting plasmas [1], have been rediscovered and confirmed [2]. Both “Damnatio Memoriae” and “Renovatio Memoriae” [2] episodes have occurred in this context as well as in that of the first introduction of high field superconducting magnet technology [3] in fusion research. The record confinement parameters, beginning to approach the ideal ignition conditions, obtained recently by the Alcator C Mod machine have validated the perspectives of success of the Ignitor experiment [3].

1B. Coppi, AIP 1721, 020003 (2017).
2A. E. Costley et al., Nucl. Fus. 56, 066003 (2016).

UP11 79 HBT-EP Program: MHD Dynamics and Active Control through 3D Fields and Currents


The HBT-EP active mode control research program aims to: (i) advance understanding of the effects of 3D shaping on advanced tokamak fusion performance, (ii) resolve important MHD issues associated with disruptions, and (iii) measure and mitigate the effects of 3D scrape-off layer (SOL) currents through active and passive control of the plasma edge and conducting boundary structures. Comparison of kink mode structure and RMP response in circular versus diverted plasmas shows good agreement with DCON modeling. SOL current measurements have been used to study SOL current dynamics and current-sharing with the vacuum vessel wall during kink-mode growth and disruptions. A multi-chord extreme UV/soft X-ray array is being installed to provide detailed internal mode structure information. Internal local electrodes were used to apply local bias voltage at two radial locations to study the effect of rotation profile on MHD mode rotation and stability and radial current flow through the SOL. A GPU-based low latency control system using 96 inputs and 64 outputs to apply magnetic perturbations for active control of kink modes is extended to directly control the SOL currents for kink-mode control. An extensive array of SOL current monitors and edge drive electrodes are being installed for pioneering studies of helical edge current control.

*Supported by U.S. DOE Grant DE-FG02-86ER53222.

UP11 81 Mode control using two electrodes on HBT-EP


Understanding the effects of plasma rotation on magnetohydrodynamic (MHD) modes and tokamak plasma stability is important for performance enhancement of current magnetic confinement experiments and to future fusion devices such as ITER. In order to control plasma rotation, two molybdenum electrodes have been installed on HBT-EP toroidally separated by 144 degrees. This allows independent biasing of the two probes both spatially and temporally. When the bias probes are inserted into the edge of the plasma and a voltage is applied, the probes drive radial currents and produce plasma flow from the torque induced by the currents. If the bias probe voltage is sufficiently positive, the MHD mode rotation transitions into a state with a rapid mode rotation frequency (in excess of 25 kHz) in the direction opposite to mode rotation without bias. The transition into this reversed rotation state occurs when the torque exceeds a threshold, which can depend upon the phase of an applied n = 1 error field [1]. We present recent studies of the two-electrode system on mode rotation, mode stability, and the toroidal symmetry of the radial current through the scrape-off-layer (SOL) during MHD activity and applied magnetic perturbations.

*Supported by U.S. DOE Grant DE-FG02-86ER53222.

UP11 82 Scrape-off-layer currents during MHD activity and disruptions in HBT-EP


We report scrape-off-layer (SOL) current measurements during MHD mode activity and disruptions in the HBT-EP tokamak [1]. Currents are measured via Rogowski coils mounted on tiles in the low-field-side SOL, toroidal jumpers between otherwise-isolated vessel sections, and segmented plasma current Rogowski coils. These currents strongly depend on the plasma’s major radius, mode amplitude, and mode phase. Plasma current asymmetries and SOL currents during disruptions reach 4% of the plasma current. Asymmetric toroidal currents between vessel sections rotate at tens of kHz through most of the current quench, then symmetrize once Ip reaches 30% of its pre-disruptive value. Toroidal jumper currents oscillate between co- and counter-Ip, with co-Ip being dominant on average during disruptions. Increases in local plasma current correlate with counter-Ip current in the nearest toroidal jumper. Measurements are interpreted in the context of two models that produce contrary predictions for the toroidal current polarity during disruptions. Plasma current asymmetries are consistent with both models, and scale with plasma displacement toward the wall. Progress of ongoing SOL current diagnostic upgrades is also presented.

*Supported by U.S. DOE Grant DE-FG02-86ER53222.

UP11 83 Structure and Dynamics of Disruptive Kink Instabilities Measured by Fast Videography and Magnetics in HBT-EP


Measurements of kink instabilities, resonant magnetic perturbations (RMPs), and disruptions in the High Beta Tokamak-Extended Pulse (HBT-EP) are studied using

1J.P. Levesque et al., Nucl. Fusion 57, 086035 (2017).

UP11 80 Scrape-off-layer characterization and current-control of kink modes in HBT-EP

JOHN BROOKS, IAN STEWART, JEFFREY LEVESQUE, MIKE MAUEL, GERALD NAVRATIL, Columbia Univ

Scrape-off layer (SOL) currents and their paths through tokamaks are not well understood, but their control may prove crucial to the success of ITER and future fusion energy devices. We extend Columbia University’s High Beta Tokamak-Extended Pulse (HBT-EP) experiment [1] and active GUP feedback system [2] to study the SOL and control MHD kink instabilities by actively controlling these currents. First, the radial plasma profiles and the edge structure of kink instabilities are measured with two triple probes. Second, we use active feedback control of a radially adjustable biased electrode to change the rotation and magnitude of slowly growing kink instabilities. By changing the phase between the probe’s voltage and the edge instability with active feedback, we study its ability to influence and control plasma MHD structures. This work is in preparation for a planned 2018 multi-electrode SOL control upgrade.

*Supported by U.S. DOE Grant DE-FG02-86ER53222.

toroidal and poloidal arrays of magnetic field sensors [1] and fast videography [2]. The fast camera (Phantom v7.3) is most sensitive to light from the plasma edge and detects the structure of the plasma boundary for all types of MHD activity. Large helical “plumes” and “bubbles” are detected during disruptions (when helical perturbations can exceed 20% of the equilibrium poloidal field) and during kink mode precursors (when the mode amplitude can exceed 5% of the equilibrium field.) We present videos of the distorted plasma boundary and compare high-speed videos with computations of the helical boundary based on magnetic measurements. A variety of disruptions show “plume”+“bubble” structures reach 5 cm (or 30% of the plasma minor radius) from the plasma edge. The distortion and dynamics of the plasma boundary are discussed in relation to on-going investigations of scrape-off layer (SOL) currents during kink instabilities and disruptions.

*Supported by U.S. DOE Grant DE-FG02-86ER53222.

1Levesque et al., Nucl. Fusion 57, 086035 (2017).

UP11 84 Observation and Modeling of External Kink Mode Structure in Shaped HBT-EP Plasmas* P.J. BYRNE, J. BIALEK, M.C. ABLER, J.W. BROOKS, Columbia University C.J. HANSEN, University of Washington J.P. LEVESQUE, M.E. MAUEL, G.A. NAVRATIL, Columbia University The first study of magnetohydrodynamic (MHD) equilibria and external kink modes in shaped plasmas on the High-Beta Tokamak - Extended Pulse (HBT-EP) is described. A poloidal field coil above the vertical midplane on the high-field side modifies the plasma cross section and allows diverted operation. High density magnetic probe arrays observe the structure of kink modes that arise naturally, and those that are excited by externally imposed 3D fields. These observations are compared to calculations of the DCON and VALEN codes, which calculate ideal kink stability and structure, and the influence of 3D eddy fields respectively. In both experiment and calculation, a short-wavelength feature, localized in a narrow poloidal arc near the X-point is discovered. This feature is predicted in external kinks of diverted tokamak plasmas, and is consistent with previous near-edge measurements [1]. The combination of DCON and VALEN provide calculations in good agreement with observations, suggesting generalization of this method to other experiments.

*This work was supported by DOE Grant DE-FG02-86ER53222.


UP11 85 Extreme ultraviolet and Soft X-ray diagnostic upgrade on the HBT-EP tokamak: Progress and Results* S. DESANTO, J.P. LEVESQUE, A. BATTEY, J.W. BROOKS, M.E. MAUEL, G.A. NAVRATIL, Columbia University J.C. HANSEN, University of Washington In order to understand internal MHD mode structure in a tokamak plasma, it is helpful to understand temperature and density fluctuations within that plasma. In the HBT-EP tokamak, the plasma emits bremsstrahlung radiation in the extreme ultraviolet (EUV) and soft x-ray (SXR) regimes, and the emitted power is primarily related to electron density and temperature. This radiation is detected by photodiode arrays located at several different angular positions near the plasma’s edge, each array making several views through a poloidal slice of plasma. From these measurements a 2-d emissivity profile of that slice can be reconstructed with tomographic algorithms. This profile cannot directly tell us whether the emissivity is due to electron density, temperature, line emission, or charge recombination; however, when combined with information from other diagnostics, it can provide strong evidence of the type of internal mode or modes depending on the temporal-spatial context. We present ongoing progress and results on the installation of a new system that will eventually consist of four arrays of 16 views each and a separate two-color, 16-chord tangential system, which will provide an improved understanding of the internal structure of HBT-EP plasmas.

*Supported by U.S. DOE Grant DE-FG02-86ER5322.

UP11 86 SPHERICAL TORUS

UP11 87 Non-Solenoidal Startup via Helicity Injection in the Pegasus ST* M.W. BONGARD, G.M. BODNER, M.G. BURKE, R.J. FONCK, J.L. PACHICOANO, J.M. PERRY, C. PIERREN, N.J. RICHNER, C. RODRIGUEZ SANCHEZ, D.J. SCHLOSSBERG, J.A. REUSCH, J.D. WEBERSKI, University of Wisconsin-Madison Research on the A ~ 1.2 Pegasus ST is developing the physics and technology basis for optimal non-solenoidal tokamak startup. Recent work explores startup via Local Helicity Injection (LHI) using compact, multi-MW current sources placed at the plasma edge in the lower divertor region. This minimizes inductive drive from poloidal fields and dynamic shaping. Plasmas with Ip ≤ 200 kA, Δψpulse ~ 20 ms and B1/2 ≤ 0.15 T are produced to date, sustained by two injectors with Aray = 4 cm², Vray ~ 1.5 kV, and Iray ~ 8 kA, facilitated by improvements to the injectors, limiters, and divertor plates that mitigate deleterious PMI. These plasmas feature anomalous, reconnection-driven ion heating with T1 > Tp > 50 – 100 eV and large-amplitude MHD activity driven by the injectors. Under some conditions, MHD fluctuations abruptly decrease by over an order of magnitude without loss of LHI drive, improving realized Ip, and suggesting short-wavelength modes may relate to the current drive mechanism. The high Ip ≥ 10, ion heating, and low τ, driven by LHI, and the favorable stability of A ~ 1 STs allows access to record βp ~ 100% and high βN ≥ 6.5. Such high-βp plasmas have a minimum |B1| well spanning ~ 50% of the plasma volume. Enhancements to the Pegasus facility are considered to increase B1 towards NSTX-U levels; establish coaxial helicity injection capabilities; and add auxiliary heating and current drive.

*Supported by U.S. DOE Grant DE-FG02-96ER54375.

UP11 88 Enhanced Control for Local Helicity Injection on the Pegasus ST* C. PIERREN, M.W. BONGARD, R.J. FONCK, B.T. LEWICKI, J.M. PERRY, University of Wisconsin-Madison Local helicity injection (LHI) experiments on Pegasus rely upon programmable control of a ~ 250 MVA modular power supply system that drives the electromagnets and helicity injection systems. Precise control of the central solenoid is critical to experimental campaigns that test the LHI Taylor relaxation limit and the coupling efficiency of LHI-produced plasmas to Ohmic current drive. Enhancement and expansion of the present control system is underway using field programmable gate array (FPGA) technology for digital logic and control, coupled to new 10 MHz optical-to-digital transceivers for semiconductor level device communication. The system accepts optical command signals from existing analog feedback controllers, transmits them to multiple devices in parallel H-bridges, and aggregates their status signals for fault detection. Present device-level multiplexing/de-multiplexing and protection logic is extended to include bridge-level protections with the FPGA. An input command filter protects against erroneous and/or spurious noise generated commands that could otherwise cause device failures. Fault regis-
Itation and response times with the FPGA system are 25 ns. Initial system testing indicates an increased immunity to power supply induced noise, enabling plasma operations at higher working capacitor bank voltage. This can increase the applied helicity injection drive voltage, enable longer pulse lengths and improve Ohmic loop voltage control.

*Work supported by US DOE Grant DE-FG02-96ER54375.

UP11 89 \( V_{eff} \) Scaling of \( T_e \) and \( n_e \) Measurements During Local Helicity Injection on the Pegasus Toroidal Experiment* G.M. BODNER, M.W. BONGARD, R.J. FONCK, J.M. PERRY, J.A. REUSCH, C. RODRIGUEZ SANCHEZ, University of Wisconsin-Madison Understanding the electron confinement of local helicity injection (LHI) is critical in order to evaluate its scalability as a startup technique to MA-class devices. Electron confinement in the Pegasus Toroidal Experiment is investigated using multi-point Thomson scattering (TS). The Pegasus TS system utilizes a set of high-throughput transmission gratings and intensified CCDs to measure \( T_e \) and \( n_e \) profiles. Previous TS measurements indicated peaked \( T_e \) profiles ~120 eV in outboard injector discharges characterized by strong inductive drive and low LHI drive. Injectors designed to have dominant non-inductive drive have recently been installed in the divertor region of Pegasus to understand the relationship between effective drive voltage, \( V_{eff} \), and plasma performance. At low \( V_{eff} \) and reduced plasma current, \( I_p \sim 60 \text{ kA} \), TS measurements reveal a flat \( T_e \) profile ~50 eV, with a peaked \( n_e \) profile ~1 \times 10^{19} \text{ m}^{-3}, resulting in a slightly peaked \( p_e \) profile. As current drive is increased, the \( T_e \) profiles become hollow with a core \( T_e \sim 50 \text{ eV} \) and an edge \( T_e \sim 120–150 \text{ eV} \). These hollow profiles appear after the start of the \( I_p \) flattop and are sustained until the discharge terminates. The \( n_e \) profiles drop in magnitude to < 1 \times 10^{19} \text{ m}^{-3} but remain somewhat peaked. Initial results suggest a weak scaling between input power and core \( T_e \). Additional studies are planned to identify the mechanisms behind the anomalous profile features.

*Work supported by US DOE Grant DE-FG02-96ER54375.

UP11 90 Investigating High Frequency Magnetic Activity During Local Helicity Injection on the Pegasus Toroidal Experiment* N.J. RICHNER, M.W. BONGARD, R.J. FONCK, J.J. PACHICANO, J.M. PERRY, J.A. REUSCH, University of Wisconsin-Madison Understanding the current drive mechanism(s) of Local Helicity Injection (LHI) is needed for confident scaling to next-step devices. 3D resistive MHD NIMROD simulations ascribe large-scale reconnection events of helical injector current streams as a current drive mechanism. The events generate \( n = 1B \) fluctuations on outboard Mirnov coils, consistent with experiment. New results suggest additional mechanisms are also active during LHI. Reconnection-driven ion heating is better correlated with high frequency activity than the \( n = 1 \) bursts. Experiments with inboard injectors can exhibit an abrupt (\( \sim 250 \mu \text{s} \)) transition to a reduced MHD state on outboard Mirnovs where the \( n = 1 \) feature vanishes, while still maintaining current growth and/or sustainment. A new insertable magnetics probe was developed to investigate these phenomena. It measures \( T_e X B \), up to 3.5 MHz at 15 points over a 14 cm radial extent (\( \Delta R \sim 1 \text{ cm} \)). Measurements with this probe are consistent with the outboard Mirnovs when positioned far from the plasma boundary. However, measurements near the plasma edge lack the reduction in broadband power (up to 2 MHz) following the transition. The probe shows power is concentrated at higher frequencies during LHI, with mostly flat \( B \) spectra up to ~600–800 kHz (\( \sim f_A \)) at which there is a resonance-like feature; at higher frequencies, the power decreases. These measurements suggest short-wavelength activity may play a significant role in LHI current drive.

*Work supported by US DOE Grant DE-FG02-96ER54375.

UP11 91 Studies of Impurities in the Pegasus Spherical Tokamak* C. RODRIGUEZ SANCHEZ, G.M. BODNER, M.W. BONGARD, M.G. BURKE, R.J. FONCK, J.M. PERRY, J.A. REUSCH, J.D. WEBERSKI, University of Wisconsin-Madison Local Helicity Injection (LHI) is used to initiate ST plasmas without a solenoid. Testing predictive models for the evolution of \( I_p(t) \) during LHI requires measurement of the plasma resistivity to quantify the dissipation of helicity. To that end, three diagnostic systems are coupled with an impurity transport model to quantify plasma contaminants. These are: visible bremsstrahlung (VB) spectroscopy; bolometry; and VUV spectroscopy. A spectral survey has been performed to identify line-free regions for VB measurements in the visible. Initial VB measurements are obtained with a single sightline through the plasma, and will be expanded to an imaging array to provide spatial resolution. A SPRED multichannel VUV spectrometer is being upgraded to provide high-speed (~0.2 ms) spectral surveys for ion species identification, with a high-resolution grating installed for metallic line identification. A 16-channel thinstar bolometer array is planned. Absolutely calibrated VB, bolometer measurements, and qualitative ion species identification from SPRED are used as constraints in an impurity transport code to estimate absolute impurity content. Earlier work using this general approach indicated \( Z_{eff} < 3 \), before the edge current sources were shielded to reduce plasma-interactor interactions.

*Work supported by US DOE Grant DE-FG02-96ER54375.

UP11 92 Microstability Properties of the Local Minimum \(|B|\) Regime in Pegasus* DAVID R. SMITH, M.W. BONGARD, R.J. FONCK, J.A. REUSCH, A.T. RHODES, University of Wisconsin-Madison A local minimum \(|B|\) region, or “magnetic well,” was recently observed in the low-aspect-ratio Pegasus device in high-\( |B| \) scenarios with strong edge current peaking [1]. The VB reversal within the magnetic well alters particle drifts, orbits, fast ion losses, and instability drives. Here, we report on the microstability properties of the magnetic well region with calculations from the GENE gyrokinetic code [2]. In particular, we explore the dependence on magnetic well depth and the role of electromagnetic effects. Preliminary results from local electromagnetic calculations indicate unstable electron modes exist in the magnetic well region. Connections to NSTX-U and MAST-U operational scenarios are also discussed. Finally, probe measurements of electrostatic and magnetic fluctuations in the Pegasus magnetic well region are presented in Ref. 3.

*This material is based upon work supported by the US Department of Energy, Office of Science, Office of Fusion Energy Sciences, under Award Number DE-SC0001288 and DE-FG02-96ER54375.

3. A. T. Rhodes et al., these proceedings.

UP11 93 Initial Measurements of Electrostatic Turbulence in Local Helicity Injection Plasmas* A.T. RHODES, G.M. BODNER, M.W. BONGARD, R.J. FONCK, J.L. PACHICANO, J.M. PERRY, J.A. REUSCH, N.J. RICHNER, University of Wisconsin-Madison Investigation of the edge turbulence during local helicity injection (LHI) in the Pegasus Toroidal Experiment is being pursued using...
THURSDAY AFTERNOON

UP11 94 High Field Side MHD Activity During Local Helicity Injection* J.I. PACHICANO, M.W. BONGARD, R.J. FONCK, J.M. PERRY, J.A. REUSCH, N.J. RICHNER. University of Wisconsin-Madison. MHD is an essential part of understanding the mechanism for local helicity injection (LHI) current drive. The new high field side (HFS) LHI system on the Pegasus ST permits new tests of recent NIMROD simulations. In that model, LHI current streams in the plasma edge undergo large-scale reconnection events, leading to current drive. This produces bursty \( n = 1 \) activity around 30 kHz on low field side (LFS) Mirnov coils, consistent with experiment. The simulations also feature coherent injector streams winding down the center column. Improvements to the core high-resolution poloidal Mirnov array with CatTA Ethernet cabling and differentially driven signal processing eliminated EMI-driven switching noise, enabling detailed spectral analysis. Preliminary results from the recovered HFS poloidal Mirnov coils suggest \( n = 1 \) activity is present at the top of the vessel core, but does not persist down the centerstack. HFS LHI experiments can exhibit an operating regime where the high amplitude MHD is abruptly reduced by more than an order of magnitude on LFS Mirnov coils, leading to higher plasma current and improved particle confinement. This reduction is not observed on the HFS midplane magnets. Instead, they show broadband turbulence-like magnetic features with near consistent amplitude in a frequency range of 90–200 kHz.

*Work supported by US DOE Grant DE-FG02-96ER54375 and DE-FG02-89ER53296.

UP11 95 Progress Towards a New Technique for Measuring Local Electric and Magnetic Field Fluctuations in High Temperature Plasmas* M.G. BURKE, R.J. FONCK, G.R. MCKEE, G.R. WINZ. University of Wisconsin-Madison. Local measurements of electrostatic and magnetic turbulence in fusion grade plasmas is a critical missing component in advancing our understanding of current experiments and validating nonlinear turbulence simulations. A novel diagnostic for measuring local electric and magnetic field fluctuations (\( E \) and \( B \)) is being developed to address this need. It employs high-speed measurements of the spectral linewidth and/or line intensities of the Motional Stark Effect split neutral beam emission. This emission is split into several spectral components, with the amount of splitting being proportional to local magnetic and electric fields at the emission site. High spectral resolution (\( \sim 0.025 \text{ nm} \)), high throughput (\( \sim 0.01 \text{ cm}^2 \text{ str} \)), and high speed (\( f \sim 250 \text{ kHz} \)) are required for the measurement of fast changes in the MSE spectrum. Spatial heterodyne spectroscopy (SHS) techniques coupled to a CMOS detector can meet these demands. A prototype SHS has been deployed to DIII-D for initial testing in the tokamak environment, SNR evaluation, and neutral beam efficacy. In addition, design studies of the SHS interferogram are ongoing to further optimize the measurement technique. One major contributor to loss of fringe contrast is line broadening arising from employing a large collection lens. This broadening can be mitigated by making the lens at the tokamak wall optically conjugate with the interference fringes image field.

*Work supported by US DOE Grant DE-FG02-89ER53296.

UP11 96 Imaging of laboratory magnetospheric plasmas using coherence imaging technique MASAKI NISHIURA, NORIKI TAKAHASHI, ZENSOHO YOSHIDA, KAORI NAKAMURA. The University of Tokyo. YOHEI KAWAZURA, Oxford University. NAOKI KENMOCHI, MASATAKA NAKATSUKA, TETSUYA SUGATA, SHOTARO KATSURA, The University of Tokyo. JOHN HOWARD, Australian National University. The ring trap 1 (RT-1) device creates a laboratory magnetosphere for the studies on plasma physics and advanced nuclear fusion. A levitated superconducting coil produces magnetic dipole fields that realize a high beta plasma confinement that is motivated by self-organized plasmas in planetary magnetospheres. The electron cyclotron resonance heating (ECRH) with 8.2 GHz and 50 kW produces the plasma with hot electrons in a few ten keV range. The electrons contribute to the local electron beta that exceeded 1 in RT-1. For the ion heating, ion cyclotron range of frequencies (ICRF) heating with 2–4 MHz and 10 kW has been performed in RT-1. The radial profile of ion temperature by a spectroscopic measurement indicates the signature of ion heating. In the holistic point of view, a coherence imaging system has been implemented for imaging the entire ion dynamics in the laboratory magnetosphere. The diagnostic system and obtained results will be presented.

UP11 97 Investigations of plasmoid reconnection in the presence of strong guide fields in CHI plasma start-up on HIST MASAYOSHI NAGATA, AKIHIRO FUJITA, YOUHEI IBRAKI, TAKAHIRO MATSUI, YUSUKE KIKUCHI, NAÓYUKI FUKUMOTO, University of Hyogo. TAKASHI KANKI, Japan Coast Guard. Plasmoid magnetic reconnections have been examined in the Coaxial Helicity Injection (CHI) experiments on HIST. Magnetic reconnections are required for the formation of closed flux surfaces in the transient-CHI start-up plasmas. So far, we have observed formation of plasmoids inside an elongated current layer to create the multiple X-points during the CHI process. According to the MHD simulation by F. Ebrahimi and R. Raman, the reconnection rate based on the plasmoid instability is faster than that by Sweet-Parker (S-P) model. To estimate the Lundquist number \( S \) number, we have measured spatial profiles of magnetic field strength, electron density and temperature in the current layer. In this meeting, we will present the effect of the guide (toroidal) magnetic field and mass (H, D and He) on the current layer thickness and reconnection rates of plasmoids. It is found that behavior of plasmoids is synchronized with Ion Doppler temperature, leading to ion heating.

UP11 98 Improved computation of two-fluid flowing equilibrium of spherical torus T. KANKI, Japan Coast Guard Academy. M. NAGATA. University of Hyogo. Two-fluid equilibrium system with small but non-zero two-fluid parameter is identified as a singular perturbation problem. This singularity is eliminated by nearby-fluids ordering that the ion and electron flow surfaces are assumed.
to be close to each other but do not coincide exactly [1]. This elimination of the singularity facilitates to obtain numerical equilibrium solution, but leads to a pseudo singularity when the Alfven Mach number corrected by this ordering approaches unity. For solving this problem, a new equilibrium solver is developed to perform a high-speed, high-accuracy computation without using this ordering. This solver employs a high-speed iterative method, the multi-grid method to reduce an increase in CPU time due to an increase in the mesh numbers. The purpose of this study is to apply this solver to a two-fluid equilibrium for geometry and boundary conditions of the NSTX device and to investigate the convergence properties of the numerical solution and the CPU time. Numerical experiments show that the convergence rate of the residual for the numerical solution is kept at approximately constant with respect to the iteration number of the outer loop and that the average value of the toroidal current density at the symmetry plane converges at the inverse square with respect to the mesh numbers. The multi-grid method is effective for solving the two-fluid flowing equilibrium equations with numerical stability and high accuracy.

UP11 99 Plasma shape reconstruction of merging spherical tokamak based on modified CCS method TOMOHIKO USHIKI, MICHIAKI INOMOTO. Graduate School of Frontier Sciences, The University of Tokyo MASAFUMI ITAGAKI, Hokkaido University STEVEN MCNAMARA, Tokamak Energy Ltd The merging start-up method is the one of the CS-free start-up schemes that has the advantage of high plasma temperature and density because it involves reconnection heating and compression processes. In order to achieve optimal merging operations, the initial two STs should have identical plasma currents and shapes, and then move symmetrically toward the center of the device with appropriate velocity. Furthermore, from the viewpoint of the compression effect, controlling the plasma major radius is also important. To realize the active feedback control of the plasma currents, the positions, and the shapes of the two initial STs and to optimize the plasma parameters described above, accurate estimation of the plasma boundary shape is highly important. In the present work, the Modified-CCS method is demonstrated to reconstruct the plasma boundary shapes as well as the eddy current profiles in the UTST (The University of Tokyo) and ST40 device (Tokamak Energy Ltd). The present research results demonstrate the effectiveness of the M-CCS method in the reconstruction analyses of ST merging.

UP11 100 Power Balance Modeling of Local Helicity Injection for Non-Solonomial ST Startup* J.D. WEBERSKI, J.L. BARR, M.W. BONGARD, R.J. FONCK, J.M. PERRY, J.A. REUSCH, University of Wisconsin-Madison A zero-dimensional power balance model for predicting $I_p(t)$ for Local Helicity Injection (LHI) discharges has been used to interpret experimental results from recent experimental campaigns using high-field-side (HFS) helicity injection. This model quantifies LHI’s effective drive ($V_{eff}$) through helicity balance while enforcing the Taylor relaxation current limit and tracking inductive effects to determine $I_p(t)$. Recent analysis of HFS LHI discharges indicate LHI is the dominant source of drive and provides $V_{eff}$ up to 1.3 V while geometric effects and inductive drive provide < 0.1 V throughout much of the discharge. In contrast to previous analysis of low-field-side (LFS) LHI discharges, which were driven by $V_{eff} = 0.3$ V and 2.0 V from geometric effects and inductive drive. A significant remaining uncertainty in the model is the resistive dissipation of LHI discharges. This requires greater understanding of LHI confinement scaling and impurity content, which are currently under investigation. However, the model and experimental $I_p(t)$ exhibit good agreement for parameters consistent with previous experimental findings. Extrapolation of plasma parameters and shaping from recent experiments allow for the model to project the performance of LHI systems. These projections indicate $I_p \sim 0.3$ MA can be accessed on Pegasus via HFS LHI through changes to injector geometry to provide more $V_{eff}$. This regime can be accessed via a LFS system by increasing the Taylor relaxation current limit early in the discharge.

*Work supported by US DOE Grants DE-FG02-96ER54375 and DE-SC0006928.

UP11 101 The High Field Ultra Low Aspect Ratio Tokamak (HF-ULART) CELSO RIBEIRO, Consultant in Plasma Physics Recently, a medium-size HF-ULART has been proposed [1]. The major objective is to explore the high beta and pressure under the high toroidal field, using present day technology. This might be one of pathway scenarios for a potential ultra-compact pulsed neutron source (UCP-NS) on the spherical tokamak (ST) concept, which may lead to more steady-state NS or even to a fusion reactor, via realistic design scaling. The HF-ULART pulsed mode operation is created by quasi-simultaneous adiabatic compression (AC) in both minor and major radius of a very high beta plasma, possibly with further help of passive-wall stabilization, as envisaged in the RULART concept [2]. This may help the revival of the studies of the AC technique in tokamaks, alongside the less compact and more complex ST-40 device, currently under construction [3]. In addition, by similarities, studies in HF-ULART as a UCP-NS may also help to test the feasibility of the compact NS via the spheromak concept, which also uses the AC technique [4]. Simulations of AC in HF-ULART plasmas will be presented.

UP11 102 The LTX-β Research Program* R. MAJESKI, R.E. BELL, D.P. BOYLE, P.E. HUGHES, R. KAITA, T. KOZUB, E. MERINO, X. ZHANG, P. PPEL, T. M. BIEWER, J.M. CANIK, D.B. ELLIOTT, M.L. REINKE, ORNL J. BIALEK, Columbia U. C. HANSEN, T. JARBOE, U. Washington S. KUBOTA, T. RHODES, UCLA M.A. DORF, T. ROGNIEN, F. SCOTTI, V.A. SOUKHANOFSKI, LLNL B.E. KOEL, Princeton U. D. DONOVAN, A. MAAN, U. Tennessee LTX-β, the upgrade to the Lithium Tokamak Experiment, approximately doubles the toroidal field (to 3.4 kG) and plasma current (to 150 – 175 kA) of LTX. Neutural beam injection at 20 kV, 30 A will be added in February 2018, with systems provided by Tri-Alpha Energy. A 9.3 GHz, 100 kW, short-pulse (5-10 msec) source will be available in summer 2018 for electron Bernstein wave heating. New lithium evaporation sources will allow between-shots recoating of the walls. Upgrades to the diagnostic set are intended to strengthen the research program in the critical areas of equilibrium, core transport, scrape-off layer physics, and plasma-material interactions. The LTX-β research program will combine the capability for gradient-free temperature profiles, to stabilize ion and electron temperature gradient-driven modes, with approaches to stabilization of Vn-driven modes, such as the trapped electron mode (TEM). Candidate stabilization mechanisms for the TEM include sheared flow stabilization, which can be tested on LTX-β. The goal will be to minimize anomalous transport in a low aspect ratio tokamak, which would lead to a very compact, tokamak-based fusion core.

---

2. P. Sieck et al., 18th Int. Spherical Torus Workshop (ISTW) 2015.
UP11 103 Active spectroscopy upgrades and neutral beam injection on LTX-β∗

DREW ELLIOTT, THEODORE BIEWER, JOHN CANIK, MATTHEW REINKE, Oak Ridge National Lab RONALD BELL, DENNIS BOYLE, WALTER GUTTENFELDER, ROBERT KAITA, THOMAS KOZUB, RICHARD MAJESKI, ENRIQUE MERINO, Princeton Plasma Physics Lab The LTX-β upgrade includes the addition of neutral beam injection (NBI) and increased active spectroscopy. Typical plasmas have been and are expected to remain inboard limited, at 14 cm with minor radii of 18-23 cm. The NBI, 35 Amps of 20 keV particles, will enable active diagnosis of ion velocity distribution profiles through charge exchange (CHERS). 18 CHERS views will cover more than a full minor radius, each sampling 2 cm of major radius. The system has both a set of beam directed “active” views and a symmetric set of views pointing away from the beam for stray light subtraction. Along with measuring ion temperatures and impurity transport, the CHERS diagnostic will measure the plasma rotation profiles. The recently described low recycling regime is predicted to allow for high rotational velocities due to the low neutral drag. The planned NBI has been predicted to give on axis velocities near 100 km/s. Flow shear is expected to increase confinement in this regime by suppressing trapped electron mode and other microturbulence enhanced transport. Upgrades to the Thomson scattering system, including an array of polychromators and other microturbulence enhanced transport. The recent upgrade to LTX-β includes installation of a Retarding Field Analyzer (RFEA) has also been developed for the scrape-off layer (SOL) of LTX-β. Measurements of the ion temperature, ion energy distribution, and the local space potential will be performed in the SOL plasma using this RFEA. The lithium coated wall of LTX has been demonstrated to produce a low density, high temperature, and hence low collisionality plasma edge. The recent upgrade to LTX-β includes installation of a neutral beam, which will provide further heating and fueling of the plasma. Core and edge diagnostics will also be expanded. As part of this expansion, a Retarding Field Analyzer (RFEA) has been developed for the scrape-off layer (SOL) of LTX-β. Measurements of the ion temperature, ion energy distribution, and the local space potential will be performed in the SOL plasma using this RFEA. Since a high temperature, low collisional edge is expected for LTX-β, the plasma in the SOL will be mirror-trapped, and could produce an ambipolar potential via differential loss of the electrons and ions, known as the Pastukhov potential in the literature [1]. A simple numerical prediction of the ambipolar potential profile will be presented, along with the design of the RFEA system. Work supported by US DOE contracts DE-AC02-09CH11466 and AC05-00OR22725.

UP11 104 Overview of Upgrades to the Lithium Tokamak Experiment, LTX-β∗

D. BOYLE, R.E. BELL, P.E. HUGHES, R. KAITA, R. MAJESKI, X. ZHANG, PPPL T.M BIEWER, J.M. CANIK, D.B. ELLIOTT, M.L. REINKE, ORNL C. HANSEN, U Washington S. KUBOTA, UCLA F. SCOTTI, V.A. SOUKHANOVSKIL, LLNL D. DONOVAN, A. MAAN, UT Knoxville Exploration of the low-recycling regime at higher plasma performance and with key parameters closer to equilibrium motivated extensive upgrades to the Lithium Tokamak Experiment, now LTX-β. The toroidal field, plasma current, and discharge length will approximately double. The addition of a neutral beam will increase plasma heating by a factor of ~5 and also provide core fueling, enabling constant density in low-recycling conditions without edge fueling. Between-shot lithium evaporation, Li granule injection during discharges, and improved vacuum systems will allow expanded studies into the effects of surface conditions on recycling and performance. The Thomson scattering system will have increased spatial coverage and resolution. New baffles, polychromators, and an intensified camera will also reduce background and increase sensitivity at low density. Planned diagnostic upgrades also include tangential AXUV diode arrays for recycling and radiated power measurements, an additional resistive bolometer array, high- and low-field side Langmuir probes, and enhancements to VUV spectroscopy and fast camera diagnostics. A description and status of these upgrades and diagnostics, with first plasma planned for October 2017 and neutral beam operations in February 2018, will be presented.

UP11 105 Magnetic Diagnostics Suite Upgrade on LTX-β∗

P.E. HUGHES, R. MAJESKI, R. KAITA, T. KOZUB, PPPL C. HANSEN, U. Washington G. SMALLEY, D.P. BOYLE, PPPL LTX-β will be exploring a new regime of flat temperature-profile tokamak plasmas first demonstrated in LTX [D.P. Boyle et al. PRL July 2017]. The incorporation of neutral beam core-fueling and heating in LTX-β is expected to increase plasma beta and drive increased MHD activity. An upgrade of the magnetic diagnostics is underway, including an expansion of the reentrant 3-axis poloidal Mirnov array, as well as the addition of a toroidal array of poloidal Mirnov sensors and a set of 2-axis Mirnov sensors measuring fields from shell eddy currents. The poloidal and toroidal arrays will facilitate the study of MHD mode activity and other non-axisymmetric perturbations, while the new shell eddy sensors and improvements to existing axisymmetric measurements will support enhanced equilibrium reconstructions using the PSI-Tri equilibrium code [C. Hansen et al. PoP Apr. 2017] to better characterize these novel hot-edge discharges.

UP11 106 Characterization of the Scrape-off Layer of Lithium Tokamak xExperiment-β (LTX-β) using a Retarding Field Energy Analyzer∗

XIN ZHANG, Princeton Plasma Laboratory DREW ELLIOTT, Oak Ridge National Laboratory DENNIS BOYLE, RICHARD MAJESKI, Princeton Plasma Laboratory The Lithium Tokamak xExperiment (LTX) is a spherical tokamak device designed to study lithium plasma facing components (PFCs). The lithium coated wall of LTX has been demonstrated to produce a low density, high temperature, and hence low collisionality plasma edge. The recent upgrade to LTX-β includes installation of a neutral beam, which will provide further heating and fueling of the plasma. Core and edge diagnostics will also be expanded. As part of this expansion, a Retarding Field Analyzer (RFEA) has been developed for the scrape-off layer (SOL) of LTX-β. Measurements of the ion temperature, ion energy distribution, and the local space potential will be performed in the SOL plasma using this RFEA. Since a high temperature, low collisional edge is expected for LTX-β, the plasma in the SOL will be mirror-trapped, and could produce an ambipolar potential via differential loss of the electrons and ions, known as the Pastukhov potential in the literature [1]. A simple numerical prediction of the ambipolar potential profile will be presented, along with the design of the RFEA system.

UP11 107 Simulation of the Microwave/Millimeter-Wave Diagnostics on LTX-β for Density Fluctuation Measurements∗

S. KUBOTA, T.L. RHODES, W.A. PEEBLES, UCLA R. MAJESKI, R. KAITA, PPPL Fluctuation measurements and their relation to transport will be of key interest in the LTX-β device, which will have higher $B_T$ and $I_p$, and neutral beam heating. UCLA plans to provide a suite of microwave/millimeter-wave diagnostics to measure internal electron density fluctuations: a 296 GHz single-chord interferometer, an FM-CW (frequency-modulated continuous-wave) reflectometer (13.5—33 GHz), and two tunable fixed-frequency quadrature reflectometer channels (13.5—20.5 and 27—40) GHz. Key to the interpretation of the experimental data will be extensive modeling of the target fluctuations and simulations of the reflectometry/scattering response. To this end a set of simulation tools has been developed to calculate the effects of density fluctuations on the measured signals: 3-D geometrical and physical optics, as well as 1-D and 2-D full-wave codes. The sensitivity of these diagnostics

∗Supported by US DOE contracts DE-AC02-09CH11466 and DE-AC05-00OR22725.

**This work supported by US DOE contracts DE-AC02-09CH11466 and DE-AC05-00OR22725.
to various density profile shapes and turbulence models will be presented. Possible configurations for future microwave diagnostics on LTX-β, such as a Doppler backscattering, will also be explored.

*Supported by U.S. DoE Grants DE-FG02-99ER54527 and DE-AC02-09CH11466.

UP11 108 Investigation of lithium PFC surface characteristics and low recycling at LTX/LTX-Beta* ANURAG MAAN, Univ of Tennessee ROBERT KAITA, PPPL DREW ELLIOTT, ORNL DENNIS BOYLE, RICHARD MAJESKI, PPPL DAVID DONOVAN, Univ of Tennessee LUXHERTA BUZI, BRUCE E KOEL, Princeton University THEODORE M BIEWER, ORNL. Lithium coatings on high-Z PFCs at LTX have led to improved plasma performance. The initial hypothesis was that lithium retains hydrogen by forming lithium hydride and thereby enabling low recycling in LTX. However, recent in-vacuo measurements indicate the presence of lithium oxide in deposited lithium coatings. Improved plasma performance continued to be observed in the presence of lithium oxide. These observations raise questions like what is the nature of the lithium oxide surface, whether the PFC is an amorphous mixture of lithium and lithium oxide or something more ordered like a lithium oxide layer growing on top of lithium, and whether lithium oxide is responsible for any retention of hydrogen from the plasma. To investigate the mechanism by which the LTX PFC might be responsible for low recycling, we discuss the results of deuterium retention measurements using NRA/RBS and sample characterization using high resolution XPS (HR-XPS) in bulk lithium samples. Baseline HR-XPS scans indicate the presence of Lithium Oxide on sputtered lithium samples. Status of related planned experiments at LTX-β will also be discussed.

*This work was supported by the US. D.O.E. contract DE-AC05-00OR22725 and DE-AC02-09CH11466. BEK acknowledges support of this work by the U.S. DOE, Office of Science/FES under Award Number DE-SC0012890.

UP11 109 Effect of 3-D magnetic fields on neutral particle fueling and exhaust in MAST* KURT FLESCH, THIERRY KREMEYER, IAN WATERS, OLIVER SCHMITZ, Univ of Wisconsin, Madison ANDREW KIRK, JAMES HARRISON, Culham Centre for Fusion Energy. The application of resonant magnetic perturbations (RMPs) is used to suppress edge localized modes but causes in many cases a density pump-out. At MAST, this particle pump out was found to be connected to an amplifying MHD plasma response. An analysis is presented on past MAST discharges to understand the effect of these RMPs on the neutral household and on changes in neutral fueling and exhaust during the pump out. A global, 0-D particle balance model [1] was used to study the neutral dynamics and plasma confinement during shots with and without RMP application. Using the De emission measured by filterscopes and a calibrated 1-D CCD camera, as well as S/XB coefficients determined by the edge plasma parameters, globally averaged ion confinement times were calculated. In L-mode, discharges with RMPs that caused an MHD response had a 15-20% decrease in confinement time but an increase in total recycling flux. The application of RMPs in H-mode caused either a decrease or no change in confinement, like those in L-mode, depending on the configuration of the RMPs and plasma response. A spectroscopically assisted Penning gauge is being prepared for the next campaign at MAST-U to extend this particle balance to study impurity exhaust with RMPs.

*This work was supported in part by the U.S. DoE under Grant DE-SC0012315.

UP11 110 MAGNETO-INERTIAL FUSION

UP11 111 2D Kinetic Particle in Cell Simulations of a Flow-Shear Stabilized Z-Pinch* KURT TUMMEL, DREW HIGGINSON, ANTHONY LINK, ANDREA SCHMIDT, HARRY MCLEAN, Lawrence Livermore Natl Lab URI SHUMLAK, BRIAN NELSON, RAY GOLINGO, ELLIOT CLAVEAU, ELEANOR FORBES, TOBIN WEBER, YUE ZHANG, ANTON STEPANOVA University of Washington LLNL TEAM, UW TEAM. The lifetime of Z-pinch plasmas is typically limited by MHD instabilities, e.g. the m = 0 “sausage” and m = 1 “kink” modes. An attractive strategy to suppress these and related instabilities and extend the lifetime of a Z-pinch is to drive sheared axial flows in the plasma, \( \frac{dv}{dr} \neq 0 \). This stabilization was demonstrated in a series of experiments at the UW and these long-lived Z-pinches may offer viable sources of ion beams, neutrons and radiation, or potentially, a fusion reactor. LLNL is running 2D simulations using the particle-in-cell (PIC) code, LSP, to study flow-shear Z-pinch stability and performance. The suppression of the sausage mode by axial flow-shear is seen under the present experimental conditions as well as at reactor scales, with multiple shear-flow profiles. The longevity of these sheared-flows depends on the plasma viscosity, and a preliminary viscosity and shear-flow longevity analysis is also presented. This work represents the first fully-kinetic modeling results for the flow-shear stabilized Z-pinch.

*This work funded by USDOE ARPA-E and performed under the auspices of Lawrence Livermore National Laboratory under Contract DE-AC52-07NA23744. LLNL-ABS-734820.

UP11 112 Overview of the FuZE Fusion Z-Pinch Experiment* U. SHUMLAK, B.A. NELSON, E.L. CLAVEAU, E.G. FORBES, R.P. GOLINGO, A.D. STEPANOVA, T.R. WEBER, Y. ZHANG, University of Washington H.S. MCLEAN, D.P. HIGGINSON, A. SCHMIDT, K.K. TUMMEL, Lawrence Livermore National Lab. Successful results of the sheared flow stabilized (SFS) Z-pinch from ZalP and ZalP-HD have motivated the new FuZE project to scale the plasma performance to fusion conditions. The SFS Z-pinch is immune to the instabilities that plague the conventional Z-pinch yet maintains the same favorable radial scaling. The plasma density and temperature increase rapidly with decreasing plasma radius, which naturally leads to a compact configuration at fusion conditions. The SFS Z-pinch is being investigated as a novel approach to a compact fusion device in a collaborative ARPA-E ALPHA project with the University of Washington and Lawrence Livermore National Laboratory. The project includes an experimental effort coupled with high-fidelity physics modeling using kinetic and fluid simulations. Along with scaling law analysis, computational and experimental results from the FuZE device are presented.

*This work is supported by an award from US ARPA-E.

UP11 113 Producing High-Performance, Stable, Sheared-Flow Z-Pinches in the FuZE project* R. P. GOLINGO, U. SHUMLAK, B.A. NELSON, E.L. CLAVEAU, E.G. FORBES, A.D. STEPANOVA, TR. WEBER, Y. ZHANG, University of Washington H.S. MCLEAN, K.K. TUMMEL, D.P. HIGGINSON, A.E. SCHMIDT, Lawrence Livermore National Laboratory. The project includes an experimental effort coupled with high-fidelity physics modeling using kinetic and fluid simulations. Along with scaling law analysis, computational and experimental results from the FuZE device are presented.

*This work is supported by an award from US ARPA-E.
Lawrence Livermore National Laboratory (LLNL) Collaboration: The Fusion Z-Pinch Experiment (FuZE) has made significant strides towards generating high-performance, stable Z-pinch plasmas with goals of $n_e = 10^{18} \text{ cm}^{-3}$ and $T = 1 \text{ keV}$. The Z-pinch plasmas are stabilized with a sheared axial flow that is driven by a coaxial accelerator. The new FuZE device has been constructed and reproduces the major scientific achievements of the ZaP project at the University of Washington; $n_e = 10^{18} \text{ cm}^{-3}, T = 100 \text{ eV}, r < 1 \text{ cm}$, and $t_{\text{stability}} > 20 \mu\text{s}$. These parameters are measured with an array of magnetic field probes, spectroscopy, and fast framing cameras. The plasma parameters are achieved using a small fraction of the maximum energy storage and gas injection capability of the FuZE device. Higher density, $n_e = 5 \times 10^{17} \text{ cm}^{-3}$, and temperature, $T = 500 \text{ eV}$, Z-pinch plasmas are formed by increasing the pinch current. At the higher voltages and currents, the ionization rates in the accelerator increase. By modifying the neutral gas profile in the accelerator, the plasma flow from the accelerator is maintained, driving the flow shear. Formation and sustainment of the sheared-flow Z-pinch plasma will be discussed. Experimental data demonstrating high performance plasmas in a stable Z-pinch will be shown.

*This work is supported by an award from US ARPA-E.


The FuZE project investigates scaling the sheared flow stabilized (SFS) Z-pinch to fusion conditions. FuZE will generate a 1 mm radius Z-pinch with a 300 kA plasma current. Sheared flow Z-pinches are formed by a coaxial accelerator operating in a deflagration mode. The ionization front can be controlled by the neutral gas injection. Fast-acting valves located inside the inner electrode and at 8 locations on the outer electrode provide spatial and temporal control of the gas distribution. Line-integrated plasma density inside the coaxial accelerator are obtained by an interferometer system. Magnetic field topology is measured by an array of 94 surface-mounted magnetic field probes embedded in the outer copper electrode. Coaxial accelerator current measurements obtained through the magnetic field probes and density are compared with the downstream Z-pinch properties, such as stability, temperature, and density with the goal of understanding the relation between neutral gas injection and Z-pinch plasma parameters and behavior.

*This work is supported by an award from US ARPA-E.

UP11 115 Measurements of the Time Evolution of Ion Temperature Profiles on the FuZE Fusion Z-Pinch Experiment* A.D. Stepakov, U. Shumlak, B.A. Nelson, E.L. Claveau, E.G. Forbes, R.P. Golingo, T.R. Weber, Y. Zhang, University of Washington H.S. Mclean, D.P. Higginson, A.E. Schmidt, K.K. Tummel, Lawrence Livermore National Laboratory The recently constructed sheared flow stabilized (SFS) Z-pinch experiment, the Fusion Z-Pinch Experiment (FuZE), is operational. The experiment is investigating scaling of SFS Z-pinch plasmas towards fusion conditions. Cylindrical plasmas are compressed to small radii ($< 1 \text{ cm}$), and high densities ($> 10^{18} \text{ cm}^{-3}$) as plasma current is increased. Diagnosing the size, density and internal structure of these small radii cylindrical plasmas require a high spatial resolution plasma density diagnostic. Motivated by this, a holographic interferometer with 10 micron spatial resolution has recently been installed on FuZE [1]. A Nd:YAG laser is used with a digital camera to produce holograms from the plasma assembly region. Digital holograms are numerically reconstructed to obtain chord-integrated electron density of compressed plasma, with fine spatial resolution. Assuming cylindrical symmetry in the assembly region, plasma radial density profiles are reconstructed from these chord-integrated electron density data. Both chord-integrated and radial plasma density data from FuZE are presented.

*This work is supported by an award from US ARPA-E.


This work is supported by an award from US ARPA-E.

UP11 117 High resolution digital holographic interferometry on the FuZE Fusion Z-Pinch Experiment* T.R. Weber, U. Shumlak, B.A. Nelson, E.L. Claveau, E.G. Forbes, R.P. Golingo, A.D. Stepakov, Y. Zhang, University of Washington H.S. Mclean, D.P. Higginson, A.E. Schmidt, K.K. Tummel, Lawrence Livermore National Laboratory The recently constructed sheared flow stabilized (SFS) Z-pinch experiment, the Fusion Z-Pinch Experiment (FuZE), is operational. The experiment is investigating scaling of SFS Z-pinch plasmas towards fusion conditions. Cylindrical plasmas are compressed to small radii ($< 1 \text{ cm}$), and high densities ($> 10^{18} \text{ cm}^{-3}$) as plasma current is increased. Diagnosing the size, density and internal structure of these small radii cylindrical plasmas require a high spatial resolution plasma density diagnostic. Motivated by this, a holographic interferometer with 10 micron spatial resolution has recently been installed on FuZE [1]. A Nd:YAG laser is used with a digital camera to produce holograms from the plasma assembly region. Digital holograms are numerically reconstructed to obtain chord-integrated electron density of compressed plasma, with fine spatial resolution. Assuming cylindrical symmetry in the assembly region, plasma radial density profiles are reconstructed from these chord-integrated electron density data. Both chord-integrated and radial plasma density data from FuZE are presented.

*This work is supported by an award from US ARPA-E.

UP11 118 Laser Beat-Wave Magnetization of a Dense Plasma* Kevin Yates, University of New Mexico

MONTGOMERY, JOHN DUNN, SAMUEL LANGENDORF, Los Alamos National Lab BRADLEY POLLOCK, TIMOTHY JOHNSON, Lawrence Livermore National Lab DALE WELCH, CARSTEN THOMA, Voss Scientific We present results from the first of a series of experiments to demonstrate and characterize laser beat-wave magnetization of a dense plasma, motivated by the desire to create high-beta targets with standoff for magneto-inertial fusion. The experiments are being conducted at the Jupiter Laser Facility (JLF) at LLNL. The experiment uses the JLF Janus 1ω (1053 nm) beam and a standalone Nd:YAG (1064 nm) drive to the beat wave, and the Janus 2ω (526.5 nm) beam to ionize/heat a gas-jet target as well as to provide Thomson-scattering (TS) measurements of the target density/temperature and scattered light from the beat wave. Streaked TS data captured electron-plasma-wave and ion-acoustic-wave features utilizing either nitrogen or helium gas jets. Effects of initial gas density as well as laser intensity on target have been measured, with electron densities ranging from 1E18 to 1E19 cm−3 of initial gas density as well as laser intensity on target. Results from a novel long record length LSP simulations were run to aid experimental design and data interpretation.

*LANL LDRD Program.

UP11 119 Experimental characterization of plasma-liner formation via merging supersonic plasma jets* SAMUEL LANGENDORF, SCOTT HSU, JOHN DUNN, Los Alamos National Laboratory KEVIN YATES, MARK GILMORE, University of New Mexico PLX-ALPHA TEAM The Plasma Liner Experiment-ALPHA (PLX-α) is investigating the merging of supersonic plasma jets into a spherically imploding plasma liner as a compression driver for magneto-inertial fusion (MIF). Concurrently, we are also studying the fundamental physics of plasma shocks, from collisional to collisionless regimes, using the same platform. The present work is focused on characterizing the merging of six and/or seven plasma jets, converging in a cone of solid angle 0.47r over a distance of 1.3 meters, as well as studies with fewer jets to isolate and vary shock properties. Data will be presented on plasma jet/liner velocities, electron/ion densities and temperatures, and mean ionization state. Diagnostics include a multi-chord interferometer, visible and high-resolution spectrometers, fast-framing camera, and photodiode arrays. Spectroscopy and interferometry data are compared with synthetic data from 3D front-tracking and smooth-particle-hydrodynamic simulations. Results will provide new understanding of plasma shock structure/dynamics and assessment of plasma liners as an MIF driver.

*Supported by ARPA-E ALPHA, OFES.

UP11 120 Characterization and optimization of the HyperV PLX-α coaxial-gun plasma jet* ANDREW CASE, SAM BROCKINGTON, EDWARD CRUZ, F. DOUGLAS WITHERSPOON, HyperV Technologies HyperV Technologies We present results from characterizing and optimizing performance of the contoured gap coaxial plasma guns under development for the ARPA-E Accelerating Low-Cost Plasma Heating And Assembly (ALPHA) program. Plasma jet diagnostics include fast photodiodes for velocimetry and interferometry for line integrated density. Additionally we present results from spectroscopy, both time resolved high resolution spectroscopy using a novel detector and time integrated survey spectroscopy, for measurements of velocity and temperature as well as impurities. Fast imaging gives plume geometry and time integrated imaging gives overall light emission. Results from a novel long record length camera developed by HyperV will also be presented. Experimental results are compared to the desired target parameters for the plasma jets. The target values for the plasmoid are velocity of 50 km/s, mass of 3.5 mg, and length of 10 cm. The best results so far from the exploration of parameter space for gun operation are: ~4 mg at >50 km/s, with a length of 10 cm. Peak axial density 34 cm downstream from the muzzle is ~2 × 1016 cm−3.

*This work supported by the ARPA-E ALPHA Program under contract DE-AR000566.

UP11 121 Engineering design of the PLX-α coaxial gun* E. CRUZ, S. BROCKINGTON, A. CASE, M. LUNA, F.D. WITHERSPOON, HyperV Technologies Corp. Y.C. FRANCIS THIO, HyperJet Fusion Corporation PLX-α TEAM, LANL We describe the engineering and technical improvements, as well as provide a detailed overview of the design choices, of the latest PLX-α coaxial gun designed for the 60-gun scaling study of spherically imploding plasma liners as a standoff driver for plasma-jet-driven magneto-inertial fusion [1]. Each coaxial gun incorporates a fast, dense gas injection and triggering system, a compact low-weight pfn with integral sparkgap switching, and a contoured gap designed to suppress the blow-by instability [2]. The evolution of the latest Alpha gun is presented with emphasis on its upgraded performance. Changes include a faster more robust gas valve, better-quality ceramic insulator material and enhancements to overall design layout. These changes result in a gun with increased repeatability, reduced potential failure modes, improved fault tolerance and better than expected efficiency. A custom 600-μF, 5-kV pfn and a set of six inline sparkgap switches operated in parallel are mounted directly to the back of the gun, and are designed to reduce inductance, cost, and complexity, maximize efficiency and system reliability, and ensure symmetric current flow.

*This work supported by the ARPA-E ALPHA Program under contract DE-AR000566 and Strong Atomics, LLC.


UP11 122 Simulation Study of Structure and Properties of Plasma Liners for the PLX-α Project* ROMAN SAMULYAK, WEN SHIH, Stony Brook University SCOTT HSU, Los Alamos National Laboratory PLX-ALPHA TEAM Detailed numerical studies of the propagation and merger of high-Mach-number plasma jets and the formation and implosion of plasma liners have been performed using the FronTier code in support of the Plasma Liner Experiment-ALPHA (PLX-α) project. Physics models include radiation, physical diffusion, plasma-EOS models, and an anisotropic diffusion model that mimics deviations from fully collisional hydrodynamics in outer layers of plasma jets. Detailed structure and non-uniformity of plasma liners of due to primary and secondary shock waves have been studies as well as averaged quantities of ram pressure and Mach number. Synthetic data from simulations have been compared with available experimental data from a multi-chord interferometer and survey and high-resolution spectrometers. Numerical studies of the sensitivity of liner properties to experimental errors in the initial masses of jets and the synchronization of plasma gun valves have also been performed.

*Supported by the ARPA-E ALPHA program.

UP11 123 Effects of equation of state, transport, and initial conditions on plasma liner formation and implosion from hypervelocity jets KEVIN SCHILLO, JASON CASSIBRY, Univ of Alabama - Huntsville ROMAN SAMULYAK, Stony Brook University SAMUEL LANGENDORF, SCOTT HSU, Los Alamos National
Laboratory PLX-ALPHA TEAM The PLX-α project is studying plasma liner formation and implosion by merging a spherical array of plasma jets as a standoff driver for magneto-inertial fusion (MIF). A three-dimensional smoothed particle hydrodynamics (SPFMax) code is used to conduct simulations of merging of discrete plasma jets to form a plasma liner and the subsequent implosion of that liner. Peak ram pressure, Mach number, and uniformity of the liner are presented as a function of initial jet properties and assumptions about transport physics. The initial conditions include the number of jets, density, temperature, and implosion velocity. Solid-angle-averaged and standard deviation of liner ram pressure and Mach number reveal variations during liner formation and implosion. Spherical-harmonic mode-number analysis of spherical slices of ram pressure at various radii and times provide a quantitative means to assess the evolution of liner non-uniformity. Comparisons are made with select and equivalent cases of a uniform, imploding liner. Simulations of 6 and 7 jets are provided for select cases to support near-term experiments on PLX-α and will include synthetic spectra and line-integrated densities.

UP11 124 Estimates of Fusion Gain of Plasma Jet Driven Magneto-Inertial Fusion∗ PETER STOLTZ, KRISTIAN BECKETT-WITH, Tech-X Corp. SCOTT HSU, SAMUEL LANGENDORF, Los Alamos National Laboratory A main goal of the PLX-α project is to identify parameters for example, jet velocities and densities that could result in gain > 1 in plasma-jet-driven magneto-inertial fusion [S. C. Hsu et al., IEEE Trans. Plasma Sci. 40, 1287, 2012]. We are employing 2D MHD simulations of a spherically imploding plasma liner compressing a magnetized target using the USim code [K. Beckwith et al., IEEE Trans. Plasma Sci., 4, 2015] to identify those parameters. The simulations include realistic EOS and alpha-deposition models. We look at how different levels of density and velocity perturbations change the gain results, specifically using perturbation levels informed by 3D hydrodynamic simulations. Some of these simulation results come from many-core runs on the Los Alamos high-performance computing resources, and we discuss the performance and scaling of our simulations.

UP11 125 Nuclear Fusion Blast and Electrode Lifetimes in a PJMIF Reactor∗ Y.C. FRANCIS THIO, F.D. WITHERSPOON, A. CASE, S. BROCKINGTON, E. CRUZ, M. LUNA, HyperJet Fusion Corporation S.C. Hsu, LANL We present an analysis and numerical simulation of the nuclear blast from the micro-explosion following the completion of the fusion burn for a baseline design of a PJMIF fusion reactor with a fusion gain of 20. The stagnation pressure from the blast against the chamber wall defines the engineering requirement for the structural design of the first wall and the plasma guns. We also present an analysis of the lifetimes of the electrodes of the plasma guns which are exposed to (1) the high current, and (2) the neutron produced by the fusion reactions. We anticipate that the gun electrodes are made of tungsten alloys as plasma facing components reinforced structurally by appropriate steel alloys. Making reasonable assumptions about the electrode erosion rate (100 ng/C transfer), the electrode lifetime limited by the erosion rate is estimated to be between 19 and 24 million pulses before replacement. Based on known neutron radiation effects on structural materials such as steel alloys and plasma facing component materials such as tungsten alloys, the plasma guns are expected to survive some 22 million shots. At 1 Hz, this is equal to about 6 months of continuous operation before they need to be replaced.

∗Supported by the ARPA-E ALPHA program.

UP11 126 Staged Z-pincher Experiments on the NTF Zebra Facility∗ FABIO CONTI, University of California, San Diego A. ANDERSON, T. W. DARLING, D. DUTRA, University of Nevada, Reno V. GLEBOV, University of Rochester M. P. ROSS, UCSD E. RUSKOV, MIFFI J. C. VALENZUELA, UCSF F. J. WESSEL, MIFFI F. BEG, UCSF A. COVINGTON, UNR J. NARKIS, UCSD H. U. RAHMAN, MIFFI We report results from the latest Staged Z-pinch [1] experiments conducted on the 1 MA, 100 ns Zebra facility at the University of Nevada, Reno. In these experiments, a high-Z annular gas liner (Ar, Kr) with initial radius of 1.2 cm implode onto a deuterium target on axis. Measurements are presented, including data from pinch current, X-ray photodiodes and PCDs signals, visible streak imaging, XUV gated imaging, laser shadowgraphy, neutron time-of-flight and neutron yield detectors, and preliminary data analysis is discussed. The implosion velocity exceeding 300 km/s, and pinch time are consistent with MHD simulations performed with the MACH2 code. The imaging diagnostics indicates that the target column is more stable than the surrounding liner during the implosion. Primary (DD) neutrons of thermonuclear nature were produced with yields higher than $1 \times 10^9$ per shot, reproducibly. In addition, preliminary neutron time-of-flight results indicate that secondary (DT) neutrons can be produced above the detection threshold.

∗Supported by the Advanced Research Projects Agency - Energy, Grant DE-AR0000569.

UP11 127 Staged Z-pincher Experiments at the 1MA Zebra pulsed-power generator: Neutron measurements∗ EMIL RUSKOV, Magneto-Inertial Fusion Technologies, Inc. (MIFFI) T. DARLING, Univ. of Nevada, Reno (UNR) V. GLEBOV, Laboratory for Laser Energetics, Rochester F. J. WESSEL, (MIFFI) A. ANDERSON, (UNR) F. BEG, Univ. of California, San Diego (UCSD) F. CONTI, (UCSD) A. COVINGTON, (UNR) E. DUTRA, National Security Technologies, LLC J. NARKIS, (UCSD) H. RAHMAN, (MIFFI) M. ROSS, J. VALENZUELA, (UCSD) We report on neutron measurements from the latest Staged Z-pincher experiments at the 1MA Zebra pulsed-power generator. In these experiments a hollow shell of argon or krypton gas liner, injected between the 1 cm anode-cathode gap, compresses a deuterium plasma target of varying density. Axial magnetic field $B_z \leq 2 \text{ kGs}$, applied throughout the pinch region, stabilizes the Rayleigh-Taylor instability. The standard silver activation detector, and can be used for accurate calculation of the neutron yield.

∗Supported by the Advanced Research Projects Agency - Energy, under Grant Number DE-AR0000569.

UP11 128 Analysis of staged Z-pincher implosion trajectories from experiments on Zebra∗ MIKE P. ROSS, F. CONTI, University of California, San Diego T. W. DARLING, University of
UP11 129 Staged Z-pinch experiments on the Mega-Ampere current driver COBRA* JULIO VALENZUELA, University of California San Diego JACOB BANASEK, THOMAS BYVANK, FABIO CONTI, JOHN GREENLY, DAVID HAMMER, WILLIAM POTTER, SOPHIA ROCCO, Cornell University MICHAEL ROSS, University of California San Diego FRANK WESSEL, Magneto-Inertial Fusion, Inc JEFF NARKIS, University of California San Diego HAFIZ RAHMAN, EMIL RUSKOV, Magneto Inertial Fusion, Inc FARHAT BEG, University of California San Diego Experiments were conducted on the Cornell’s 1 MA, 100 ns current driver COBRA with the goal of better understanding the Staged Z-pinch physics and validating MHD codes. We used a gas injector composed of an annular (1.2 cm radius) high atomic number (e.g., Ar or Kr) gas-puff and an on-axis plasma gun that delivers the ionized hydrogen target. Liner implosion velocity and stability were studied using laser shadowgraphy and interferometry as well as XUV imaging. From the data, the signature of the MRT instability and zipper effect can be seen, but time integrated X-ray imaging show a stable target plasma. A key component of the experiment was the use of optical Thomson scattering (TS) diagnostics to characterize the liner and target plasmas. By fitting the experimental scattered spectra with synthetic data, electron and ion temperature as well as density can be obtained. Preliminary analysis shows significant scattered line broadening from the plasma on-axis (≈0.5 mm diameter) which can be explained by a low temperature H plasma with Te=Ti=75eV, or by a hot plasma with Ti=3keV, Te=350eV if an Ar-H mixture is present with an Ar fraction higher than 10%.

*Fundied by the Advanced Research Projects Agency - Energy, DE-AR0000569.

UP11 130 Shock formation and Magneto-Rayleigh-Taylor instability mitigation in double-shell Staged Z-pinch implosions* JEFF NARKIS, F. BEG, F. CONTI, University of California, San Diego H. U. RAHMAN, E. RUSKOV, Magneto-Inertial Fusion Technologies, Inc. M. P. ROSS, J. C. VALENZUELA, University of California, San Diego F. J. WESSEL, Magneto-Inertial Fusion Technologies, Inc. Target preheating in a magneto-inertial fusion scheme like the Staged Z-pinch is required to reduce the required convergence ratio for reaching fusion conditions. The current iteration of the Staged Z-pinch uses a single, high-Z gas-puff liner to compress a deuterium (D) target. Prior MHD simulations of similar implosions on a 1 MA driver predicted peak and average implosion velocities of 20 and 10 cm/us, respectively, which resulted in shock temperatures far below the 100 eV required for target preheating [1]. Reduction of liner mass is an effective approach to increasing implosion velocity “ experimental implosion velocities exceeding 30 cm/μs have been reported “ and therefore shock strength, however this also results in increased magneto-Rayleigh-Taylor (MRT) instability growth. Both using a double liner and an axial magnetic field are effective mitigation mechanisms for MRTI growth. However, a double liner provides better MRTI mitigation and a fortuitous increase in shock strength and implosion velocity over a single liner, as demonstrated in simulated Kr / D and Ne / Kr / D implosions.

* Fundied by the Advanced Research Projects Agency - Energy, Grant DE-AR000569.

UP11 131 One-dimensional MHD simulations of MTF systems with compact toroid targets and spherical liners IVAN KHALZOV, RYAN ZINDLER, SANDRA BARSKY, MICHAEL DELAGE, MICHEL LABERGE, General Fusion Inc. One-dimensional (1D) MHD code is developed in General Fusion (GF) for coupled plasma-liner simulations in magnetized target fusion (MTF) systems. The main goal of these simulations is to search for optimal parameters of MTF reactor, in which spherical liquid metal liner compresses compact toroid plasma. The code uses Lagrangian description for both liner and plasma. The liner is represented as a set of spherical shells with fixed masses while plasma is discretized as a set of nested tori with circular cross sections and fixed number of particles between them. All physical fields are 1D functions of either spherical (liner) or small toroidal (plasma) radius. Motion of liner and plasma shells is calculated self-consistently based on applied forces and equations of state. Magnetic field is determined by 1D profiles of poloidal and toroidal fluxes – they are advected with shells and diffuse according to local resistivity, this also accounts for flux leakage into the liner. Different plasma transport models are implemented, this allows for comparison with ongoing GF experiments. Fusion power calculation is included into the code. We performed a series of parameter scans in order to establish the underlying dependencies of the MTF system and find the optimal reactor design point.

UP11 132 Temperature Measurements in Compressed and Uncompressed SPECTOR Plasmas at General Fusion WILLIAM YOUNG, NEIL CARTER, STEPHEN HOWARD, PATRICK CARLE, PETER O’SHEA, General Fusion GENERAL FUSION TEAM Accurate temperature measurements are critical to establishing the behavior of General Fusion’s SPECTOR plasma injector, both before and during compression. As compression tests impose additional constraints on diagnostic access to the plasma, a two-color, filter-based soft x-ray electron temperature diagnostic has been implemented. Ion Doppler spectroscopy measurements also provide impurity ion temperatures on compression tests. The soft x-ray and ion Doppler spectroscopy measurements are being validated against a Thomson scattering system on a uncompressed version of SPECTOR with more diagnostic access. The multipoint Thomson scattering diagnostic also provides up to a six point temperature and
density profile, with the density measurements validated against a far infrared interferometer. Temperatures above 300 eV have been demonstrated to be sustained for over 500 microseconds in uncompressed plasmas. Optimization of soft x-ray filters is ongoing, in order to balance blocking of impurity line radiation with signal strength.

UP11 133 MHD simulation of plasma compression experiments MERITT REYNOLDS, SANDRA BARKSY, PETER DE VIETIEN, General Fusion General Fusion (GF) is working to build a magnetized target fusion (MTF) power plant based on compression of magnetically-confined plasma by liquid metal. GF is testing this compression concept by collapsing solid aluminum liners onto plasmas formed by coaxial helicity injection in a series of experiments called PCS ( Plasma Compression, Small). We simulate the PCS experiments using the finite-volume MHD code VAC. The single-fluid plasma model includes temperature-dependent resistivity and anisotropic heat transport. The time-dependent curvilinear mesh for MHD simulation is derived from LS-DYNA simulations of actual field tests of liner implosion. We will discuss how 3D simulations reproduced instability observed in the PCS13 experiment and correctly predicted stabilization of PCS14 by ramping the shaft current during compression. We will also present a comparison of simulated Mirnov and x-ray diagnostics with experimental measurements indicating that PCS14 compressed well to a linear compression ratio of 2.5:1.

UP11 134 Physics objectives of PI3 spherical tokamak program STEPHEN HOWARD, MICHEL LABERGE, MERITT REYNOLDS, PETER O’SHEA, RUSS IVANOV, WILLIAM YOUNG, PATRICK CARLE, AARON FROESE, KELLY EPP, General Fusion Achieving net energy gain with a Magnetized Target Fusion (MTF) system requires the initial plasma state to satisfy a set of performance goals, such as particle inventory (10^{21} ions), sufficient magnetic flux (0.3 Wb) to confine the plasma without MHD instability, and initial energy confinement time several times longer than the compression time. General Fusion (GF) is now constructing Plasma Injector 3 (PI3) to explore the physics of reactor-scale plasmas. Energy considerations lead us to design around an initial state of R_{vessel} = 1 m. PI3 will use fast coaxial helicity injection via a Marshall gun to create a spherical tokamak plasma, with no additional heating. MTF requires solenoid-free startup with no vertical field coils, and will rely on flux conservation by a metal wall. PI3 is 5x larger than SPECTOR so is expected to yield magnetic lifetime increase of 25x, while peak temperature of PI3 is expected to be similar (400-500 eV) Physics investigations will study MHD activity and the resistive and convective evolution of current, temperature and density profiles. We seek to understand the confinement physics, radiative loss, thermal and particle transport, recycling and edge physics of PI3.

UP11 135 Passive MHD Spectroscopy for Enabling Magnetic Reconstructions on Spherical Tokamak Plasmas at General Fusion Inc PETER O’SHEA, MICHEL LABERGE, ALEX MOSSMAN, MERITT REYNOLDS, General Fusion Magnetic reconstructions on lab based plasma injectors at General Fusion relies heavily on edge magnetic (“Bdot”) probes. On plasma experiments built for field compression (PCS) tests, the number and locations of Bdot probes is limited by mechanical constraints. Additional information about the q profiles near the core in our Spector plasmas is obtained using passive MHD spectroscopy. The coaxial helicity injection (CHI) formation process naturally generates hollow current profiles and reversed shear early in each discharge. Central Ohmic heating naturally peaks the current profiles as our plasmas evolve in time, simultaneously reducing the core safety factor, q(0), and reverse shear. As the central, non-monotonic q-profile crosses rational flux surfaces, we observe transient magnetic reconnection events (MRE’s) due to the double tearing mode. Modal analysis allows us to infer the q surfaces involved in each burst. The parametric dependence of the timing of MRE’s allows us to estimate the continuous time evolution of the core q profile. Combining core MHD spectroscopy with edge magnetic probe measurements greatly enhances our certainty of the overall q profile.

UP11 136 Magnetized Target Fusion At General Fusion: An Overview MICHEL LABERGE, PETER O’SHEA, MIKE DONALDSON, MICHAEL DELAGE, General Fusion GENERAL FUSION TEAM Magnetized Target Fusion (MTF) involves compressing an initial magnetically confined plasma on a timescale faster than the thermal confinement time of the plasma. If near adiabatic compression is achieved, volumetric compression of 350X or more of a 500 eV target plasma would achieve a final plasma temperature exceeding 10 keV. Interesting fusion gains could be achieved provided the compressed plasma has sufficient density and dwell time. General Fusion (GF) is developing a compression system using pneumatic pistons to collapse a cavity formed in liquid metal containing a magnetized plasma target. Low cost driver, straightforward heat extraction, good tritium breeding ratio and excellent neutron protection could lead to a practical power plant. GF (65 employees) has an active plasma R&D program including both full scale and reduced scale plasma experiments and simulation of both. Although pneumatic driven compression of full scale plasmas is the end goal, present compression studies use reduced scale plasmas and chemically accelerated aluminum liners. We will review results from our plasma target development, motivate and review the results of dynamic compression field tests and briefly describe the work to date on the pneumatic driver front.

UP11 137 Magnetic Compression Experiment at General Fusion with Simulation Results∗ CARL DUNLEA, University of Saskatchewan / General Fusion IVAN KHALZOV, General Fusion AKIRA HIROSE, CHIJIN XIAO, University of Saskatchewan GENERAL FUSION TEAM, General Fusion The magnetic compression experiment at GF was a repetitive non-destructive test to study plasma physics applicable to Magnetic Target Fusion compression. A spheromak compact torus (CT) is formed with a co-axial gun into a containment region with an hour-glass shaped inner flux conservor, and an insulating outer wall. External coil currents keep the CT off the outer wall (levitation) and then rapidly compress it inwards. The optimal external coil configuration greatly improved both the levitated CT lifetime and the rate of shots with good compressional flux conservation. As confirmed by spectrometer data, the improved levitation field profile reduced plasma impurity levels by suppressing the interaction between plasma and the insulating outer wall during the formation process. We developed an energy and toroidal flux conserving finite element axisymmetric MHD code to study CT formation and compression. The Braginskii MHD equations with anisotropic heat conduction were implemented. To simulate plasma / insulating wall interaction, we couple the vacuum field solution in the insulating region to the full MHD solution in the remainder of the domain. We see good agreement between simulation and experiment results.

∗Partly funded by NSERC and MITACS Accelerate.
UP11 138 Reconstruction of Axial Energy Deposition in Magnetic Liner Inertial Fusion Based on PECOS Shadowgraph Unfolds Using the AMR Code FLASH∗ MARISSA ADAMS, U. Rochester CHRISTOPHER JENNINGS, STEPHEN SLUTZ, KYLE PETERSON, Sandia National Laboratories PIERRE GOURDAIN, U. Rochester U. ROCHESTER-SANDIA COLLABORATION Magnetic Liner Inertial Fusion (MagLIF) experiments incorporate a laser to preheat a deuterium filled capsule before compression via a magnetically imploding liner. In this work, we focus on the blast wave formed in the fuel during the laser preheat component of MagLIF, where approximately 1kJ of energy is deposited in 3ns into the capsule axially before implosion. To model blast waves directly relevant to experiments such as MagLIF, we inferred deposited energy from shadowgraphy of laser-only experiments performed at the PECOS target chamber using the Z-Beamlet laser. These energy profiles were used to initialize 2-dimensional simulations using the adaptive mesh refinement code FLASH. Gradients or asymmetries in the energy deposition may seed instabilities that alter the fuel’s distribution, or promote mix, as the blast wave interacts with the liner wall. The AMR capabilities of FLASH allow us to study the development and dynamics of these instabilities within the fuel and their effect on the liner before implosion.

∗Sandia Natl Labs is managed by NTES of Sandia, LLC., a subsidiary of Honeywell International, Inc, for the U.S. DOE’s NNSA under contract DE-NA0003525.

UP11 140 Pulsed Laser Gate Experiment for Magnetized Liner Inertial Fusion (MagLIF)∗ S.M. MILLER, Univ of Michigan S.A. SLUTZ, M.R. GOMEZ, Sandia National Labs S.R. KLEIN, P.C. CAMPBELL, J.M. WOOLSTRUM, D.A. YAGER-ELORRIAGA, N.M. JORDAN, Y.Y. LAU, R.M. GILGENBACH, R.D. MCBRIDE, Univ of Michigan Fuel preheating in full scale magnetized liner inertial fusion (MagLIF) currently has low efficiency. This loss is thought to occur from laser-plasma interactions (LPI) at the laser entrance window (LEW). The gaseous fuel is held in a pressurized vessel by the thin mylar LEW that must be removed right before heating. To ensure more laser energy heats the fuel, the LEW could be weakened at an early time [1]. One proposed solution [1] is to use the current from a small pulse generator to break the LEW allowing it to open outward from the fuel. With the LEW removed away from the laser path, LPI losses would be reduced. Wire attached to a 13 kV mini-pulser will be used to remove the LEW from the laser path. We will report on LEW fabrication and the current state of the laser gate project.

∗This research was funded in part by the University of Michigan, a Faculty Development Grant from the NRC, and Sandia National Laboratories under DOE-NNSA contract DE-NA0003525.


UP11 139 Three Dimensional Magneto-Hydrodynamics Simulations of Auto-Magnetizing Imploping Liners for ICF∗ JEFF WOOLSTRUM, Univ of Michigan - Ann Arbor CHRIS JENNINGS, GABRIEL SHIPLEY, THOMAS AWE, STEPHEN SLUTZ, Sandia National Laboratories NICHOLAS JORDAN, YY LAU, Univ of Michigan - Ann Arbor Kyle Peterson, Sandia National Laboratories RYAN MCBRIDE, Univ of Michigan - Ann Arbor AutoMag [1] is a potential next step in the magnetized liner inertial fusion (MagLIF) program. In standard MagLIF, external coils are used to magnetize deuterium gas inside a metal cylindrical liner, which is imploded by the Z-machine at Sandia National Laboratories. In AutoMag, helical slots are cut into the liner and filled with dielectric insulator to form a solenoid, producing an axial magnetic field from the drive current and removing the need for external field coils. Alternatively with external field coils, AutoMag could produce a field-reversed configuration inside the liner. Recent work at Sandia has found that the breakdown of the dielectric material corresponds to the geometry of the liner/dielectric. We explore this finding in 3D resistive-MHD simulations, modeling geometries relevant to both the 20-MA Z facility, and to the 1-MA MAIZE facility at the University of Michigan.

∗Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. DoE’s NNSA under contract DE-NA0003525.


SESSION WE1: TOWN MEETING ON ITER STATUS AND PLANS
Thursday Evening, 26 October 2017
Room: 102ABC at 19:30
Charles M. Greenfield, General Atomics, presiding

Contributed Papers

19:30
WE 1 ITER Status and Plans CHARLES M. GREENFIELD, General Atomics The US Burning Plasma Organization is pleased to welcome Dr. Bernard Bigot, who will give an update on progress in the ITER Project. Dr. Bigot took over as Director General of the ITER Organization in early 2015 following a distinguished career that included serving as Chairman and CEO of the French Alternative Energies and Atomic Energy Commission and as High Commissioner for ITER in France. During his tenure at ITER the project has moved into high gear, with rapid progress evident on the construction site and preparation of a staged schedule and a research plan leading from where we are today through all the way to full DT operation. In an unprecedented international effort, seven partners “China, the European Union, India, Japan, Korea, Russia and the United States” have pooled their financial and scientific resources to build the biggest fusion reactor in history. ITER will open the way to the next step: a demonstration fusion power plant. All DPP attendees are welcome to attend this ITER town meeting.


**Invited Papers**

15:00  
**VI2 1 Experimental Challenges to Stiffness as a Transport Paradigm**  
T.C. LUCE, General Atomics

Transport in plasmas is treated experimentally as a relationship between gradients and fluxes in analogy to the random-walk problem. Gyrokinetic models often predict strong increases in local flux for small increases in local gradient when above a threshold, holding all other parameters fixed. This has been named ‘stiffness’. The radial scalelength is then expected to vary little with source strength as a result of high stiffness. To probe the role of ExB shearing on stiffness in the DIII-D tokamak, two neutral beam injection power scans in H-mode plasmas were specially crafted—one with constant, low torque and one with increasing torque. The ion heat, electron heat, and ion toroidal momentum transport do not show expected signatures of stiffness, while the ion particle transport does. The ion heat transport shows the clearest discrepancy; the normalized heat flux drops with increasing inverse ion temperature scalelength. ExB shearing affects the transport magnitude, but not the scalelength dependence. Linear gyrofluid (TGLF) and nonlinear gyrokinetic (GYRO) predictions show stiff ion heat transport around the experimental profiles. The ion temperature gradient required to match the ion heat flux with increasing auxiliary power is not correctly described by TGLF, even when parameters are varied within the experimental uncertainties. TGLF also underpredicts transport at smaller radii, but overpredicts transport at larger radii. Independent of the theory/experiment comparison, it is not clear that the theoretical definition of stiffness yields any prediction about parameter scans such as the power scans here, because the quantities that must be held fixed to quantify stiffness are varied. A survey of recent literature indicated that profile resilience is routinely attributed to stiffness, but simple model calculations show profile resilience does not imply stiffness. Taken together, these observations challenge the use of local stiffness as a paradigm for explaining global transport behavior.

*Work supported by US DOE under DE-FC02-04ER54698.

15:30  
**VI2 2 Drift waves in the turbulence of reversed field pinch plasmas**  
DEREK THUECKS, Washington College

Turbulence is one of the principal mediators of energy exchange in natural and laboratory plasma settings, for example wave-particle interactions that lead to collisionless heating and acceleration. The turbulent cascade carried by Alfvénic fluctuations is especially important in magnetized plasmas, operating on a wide range of scales larger than the ion gyroradius. The MST laboratory plasma exhibits a robust turbulent cascade driven by tearing instability, which is likely connected to powerful non-collisional ion heating that is also observed. New electric and magnetic field fluctuation measurements in the plasma edge reveal a broadband cascade that is anisotropic relative to the mean $B_0$. Magnetic fluctuations dominate at the tearing scale, as expected, but energy equipartition is not observed at smaller scales. Instead, the kinetic energy, $\frac{1}{2}m_i(n_i(E \times B_0))^2$, begins to dominate at $k_{perp}n_i > 0.2$. Statistical coherency between density, parallel magnetic field, and floating potential fluctuations reveals previously unobserved features at this energy-crossing scale that are consistent with electron-branch drift waves with a phase velocity comparable to the electron drift speed. The edge region contains a strong density gradient, and either drift-Alfvén coupling or unstable modes could be responsible for the excess kinetic energy. The turbulent energy rises and falls in concert with the tearing mode amplitudes, which suggests nonlinear wave coupling powers the cascade, but the coherency at small scales is more persistent than at the tearing-scale during sawtooth relaxation cycles, which suggests possible independent drift wave instability. Gradient regions are a universal feature of plasma interfaces, and similarities may be exploited to better understand turbulent dynamics in other space and laboratory plasmas, e.g., the corona-wind interface.

*Supported by DOE and NSF.

16:00  
**VI2 3 From core to coax: extending core RF modelling to include SOL, Antenna, and PFC**  
SYUN’ICHI SHIRAIWA, PSFC, MIT

A new technique for the calculation of RF waves in toroidal geometry enables the simultaneous incorporation of antenna geometry, plasma facing components (PFCs), the scrape off-layer (SOL), and core propagation [1,2]. Traditionally, core RF wave propagation and antenna coupling has been calculated separately both using rather simplified SOL plasmas. The new approach, instead, allows capturing wave propagation in the SOL and its interactions with non-conforming PFCs permitting self-consistent calculation of core absorption and edge power loss, as well as investigating far and near field impurity generation from RF sheaths and a breakdown issue from antenna electric fields. Our approach combines the field solutions obtained from a core spectral code with a hot plasma dielectric and an edge FEM code using a cold plasma approximation via surface admittance-like matrix. Our approach was verified using the TORIC core ICRF spectral...
code and the commercial COMSOL FEM package [2], and was extended to 3D torus using open-source scalable MFEM library. The simulation result revealed that as the core wave damping gets weaker, the wave absorption in edge could become non-negligible. Three dimensional capabilities with non axisymmetric edge are being applied to study the antenna characteristic difference between the field aligned and toroidally aligned antennas on Alcator C-Mod, as well as the surface wave excitation on NSTX-U.

*Work supported by the U.S. DoE, OFES, using User Facility Alcator C-Mod, DE-FC02-99ER54512 and Contract No. DE-FC02-01ER54648.


16:30
VI2 4 Lower Hybrid Wave Electric Field Vector Measurements Using Non-Perturbative Dynamic Stark Effect Optical Spectroscopy on Alcator C-Mod*
E.H. MARTIN, ORNL

Plasma-wave interactions near the lower hybrid (LH) wave launcher can have a major impact on driven LH current, especially in the high-density regime. To identify the relevant physics responsible for this interaction a correlated effort of experimental measurements and simulations of the LH wave electric field vector, $E_{LH}$, were carried out on Alcator C-Mod using the SELHF (Stark Effect Lower Hybrid Field) diagnostic and COMSOL modeling. For a range of plasma parameters observations show that: 1) The polarization $E_{LH}$ resides primarily in the radial-poloidal plane and becomes increasingly poloidal for locations away and to the top of the LH launcher. 2) Saturation of the radial component of $E_{LH}$ is observed at an LH power density of approximately 12 MW/m². 3) Reflectometry phase fluctuations were found to be correlated with $|E_{LH}|$. These results suggest that the LH resonance cone and power spectrum may be substantially modified near the LH launcher in the high-density regime from the expected radial polarization and square root scaling of the magnitude with LH power. Simulation of the experimental data was carried out through development of a synthetic diagnostic using a full wave cold plasma COMSOL model. Density fluctuations and reflectometry measured density profiles were incorporated. Without density fluctuations, the synthetic $E_{LH}$ signal is dominantly in the radial direction and scales with the square root of LH power, as expected. Increasing density fluctuations in the model can cause the magnitude of $E_{LH}$ to decrease substantially and greatly vary the direction of $E_{LH}$. The observations and results outlined above will be presented in detail and the applicability of density fluctuations as a mechanism behind the behavior of $E_{LH}$ will be discussed.

*Funded by the DOE OFES (DE-AC05-00OR22725 and DE-FC02-99ER54512).
SESSION XR1: REVIEW: THE SCIENCE AND TECHNOLOGY CASE FOR HIGH-FIELD FUSION
Friday Morning, 27 October 2017; Room: Ballroom C at 8:00; Earl Scime, West Virginia University, presiding

Invited Papers

8:00
XR1 1 The Science and Technology Case for High-Field Fusion
D. WHYTE, MIT Plasma Science and Fusion Center

This review will focus on the origin, development and new opportunities of a strategy for fusion energy based on the high-field approach. In this approach confinement devices are designed at the maximum possible value of vacuum magnetic field strength, B. The integrated electrical, mechanical and cooling engineering challenges of high-field on coil (B_{coil}) large-bore electromagnets are examined for both copper and superconductor materials. These engineering challenges are confronted because of the profound science advantages provided by high-B, which are derived and reviewed: high fusion power density, ~B^3, in compact devices, thermonuclear plasmas with significant stability margin, and, in tokamaks, access to higher plasma density. Two distinct high-field strategies emerged in the 1980’s. The first was compact, cryogenically-cooled copper devices (BPX, IGNITOR, FIRE) with B_{coil} > 20 T, while the second was a large-volume, Nb3Sn superconductor device with B_{coil} < 12 T; with the second path exclusively chosen ca. 2000 with the ITER construction decision. The reasoning, advantages and challenges of that decision are discussed. Yet since that decision, a new opportunity has arisen: compact, Rare Earth Barium Copper Oxide (REBCO) superconductor-based devices with B_{coil} > 20 T; a strategy that essentially combines the best components of the two previous strategies. Recent activities examining the technology and science implications of this new strategy are reviewed. On the technology side, REBCO superconductors have now been used to produce B_{coil} > 40 T in small-bore electromagnets, enabled by rapid progress in manufactured REBCO conductor quality, coil modularity and flexible operating temperature range. Specific tokamak designs, over a range of aspect ratios, have been developed to take scientific advantage of these features in various ways, and will be described.

SESSION YI2: SOL AND DIVERTOR
Friday Morning, 27 October 2017; Room: 102ABC at 9:30; John Canik, Oak Ridge National Laboratory, presiding

Invited Papers

9:30
YI2 1 Dynamic ELM and divertor control using resonant toroidal multi-mode magnetic fields in DIII-D and EAST∗
YOUWEN SUN, Institute of plasma physics, Chinese Academy of Sciences

A rotating n = 2 Resonant Magnetic Perturbation (RMP) field combined with a stationary n = 3 RMP field has validated predictions that access to ELM suppression can be improved, while divertor heat and particle flux can also be dynamically controlled in DIII-D. Recent observations in the EAST tokamak indicate that edge magnetic topology changes, due to nonlinear plasma response to magnetic perturbations, play a critical role in accessing ELM suppression. MARS-F code MHD simulations, which include the plasma response to the RMP, indicate the nonlinear transition to ELM suppression is optimized by configuring the RMP coils to drive maximal edge stochasticity. Consequently, mixed toroidal multi-mode RMP fields, which produce more densely packed islands over a range of additional rational surfaces, improve access to ELM suppression, and further spread heat loading on the divertor. Beneficial effects of this multi-harmonic spectrum on ELM suppression have been validated in DIII-D. Here, the threshold current required for ELM suppression with a mixed n spectrum, where part of the n = 3 RMP field is replaced by an n = 2 field, is smaller than the case with pure n = 3 field. An important further benefit of this multi-mode approach is that significant changes of 3D particle flux footprint profiles on the divertor are found in the experiment during the application of a rotating n = 2 RMP field superimposed on a static n = 3 RMP field. This result was predicted by modeling studies of the edge magnetic field structure using the TOP2D code which takes into account plasma response from MARS-F code. These results expand physics understanding and potential effectiveness of the technique for reliably controlling ELMs and divertor power/particle loading distributions in future burning plasma devices such as ITER.

∗Work supported by USDOE under DE-FC02-04ER54698 and NNSF of China under 11475224.

10:00
YI2 2 Imaging Main-Ion and Impurity Velocities for Understanding Impurity Transport in the Tokamak Boundary∗
CAMERON SAMUELL, Lawrence Livermore National Laboratory

Imaging of ion velocities throughout the scrape off layer (SOL) combined with 2D and 3D numerical fluid modeling is establishing the roles of frictional coupling, ion-thermal forces, and parallel pressure gradients in determining impurity and momentum transport on open magnetic field lines. Velocity measurements of C^+_2 impurity ions alongside He^+ main-ion species enabled the first quantitative measurements of the entrainment of impurity velocities with the main ion species
in the divertor and main-chamber SOL. Changing poloidal location of the parallel-B flow stagnation point in H-mode plasmas has been observed as has velocity slowing in both species of up to 10km/s at the mid-plane during detachment. In these cases the direction of the flow relative to the magnetic field direction implies cross-field drift effects are important for determining parallel transport along field lines. UEDGE simulations of these plasmas identify how the ratio of frictional and grad-T, forces balance to determine bulk impurity transport; the degree of entrainment of impurities is expected to vary throughout the SOL, and as a function of power and density. These 2D measurements have been achieved using two coherence imaging spectroscopy systems on DIII-D calibrated with a tunable diode laser to a velocity accuracy better than 1 km/s. In addition, 3D C2 flow perturbations were observed in the vicinity of large coherent n=1 islands produced by external RMP coils. A poloidally alternating pattern of acceleration and deceleration, correlated to island positions, was observed with local velocity changes up to 10km/s and a length scale of 30-40cm. Comparison with EMC3-EIRENE simulations indicate that these perturbations result from temperature-driven parallel pressure gradients.

*Work supported by the US DOE under DE-FC02-04ER54698, DE-AC52-07NA27344 and DE-AC05-00OR22725.

10:30

YI2 3 Universality of intermittent fluctuations in the Alcator C-Mod scrape-off layer

RALPH KUBE,* UIt The Arctic University of Norway

A first-principles understanding of scrape-off layer (SOL) transport is needed in order to anticipate plasma-wall interaction conditions in a reactor-scale device. A stochastic model that describes SOL fluctuations and transport as a super-position of uncorrelated pulses is found to accurately reproduce many of the features seen in the experiments. We report on gas puff imaging (GPI) and mirror Langmuir probe (MLP) measurements on Alcator C-Mod compared to a stochastic model that describes electron density, temperature and electric potential fluctuations as arising from a super-position of uncorrelated pulses attributed to blob-like filaments propagating radially outwards. The statistical properties have been unambiguously established by measurement time series of approximately one second duration under stationary plasma conditions. The GPI fluctuation probability density function is found to change from nearly Gaussian at the separatrix to a strongly skewed and flattened Gamma distribution in the far-SOL. Despite this, the frequency power spectrum is identical for all radial positions in the SOL and for a large range of line-averaged densities. This suggests that both the near- and the far-SOL fluctuations are due to uncorrelated exponential pulses but with much more pulse overlap close to the separatrix. These observations run contrary to the ideas that the shape of the power spectrum arises from the interaction of turbulent eddies or self-similar processes. The fluctuation statistics are shown to be the same in both Ohmic plasmas and high confinement modes. Electron density and temperature fluctuations measured by the MLP system are strongly intermittent with large relative fluctuation levels. The fluctuation-induced radial heat flux has significant contributions from both the convective and conductive components. The model parameters are estimated from the data time series and their variation with the line-averaged density is elucidated.

*In collaboration with Odd Erik Garcia, UIt The Arctic University of Norway.

11:00

YI2 4 Density profiles in the Scrape-Off Layer interpreted through filament dynamics

FULVIO MILITELLO, Culham Centre for Fusion Energy

We developed a new theoretical framework to clarify the relation between radial Scrape-Off Layer density profiles and the fluctuations that generate them. The framework provides an interpretation of the experimental features of the profiles and of the turbulence statistics on the basis of simple properties of the filaments, such as their radial motion and their draining towards the divertor. L-mode and inter-ELM filaments are described as a Poisson process in which each event is independent and modelled with a wave function of amplitude and width statistically distributed according to experimental observations and evolving according to fluid equations. We will rigorously show that radially accelerating filaments, less efficient parallel exhaust and also a statistical distribution of their radial velocity can contribute to induce flatter profiles in the far SOL and therefore enhance plasma-wall interactions. A quite general result of our analysis is the resiliency of this non-exponential nature of the profiles and the increase of the relative fluctuation amplitude towards the wall, as experimentally observed. According to the framework, profile broadening at high fueling rates can be caused by interactions with neutrals (e.g. charge exchange) in the divertor or by a significant radial acceleration of the filaments. The framework assumptions were tested with 3D numerical simulations of seeded SOL filaments based on a two fluid model. In particular, filaments interact through the electrostatic field they generate only when they are in close proximity (separation comparable to their width in the drift plane), thus justifying our independence hypothesis. In addition, we will discuss how isolated filament motion responds to variations in the plasma conditions, and specifically divertor conditions. Finally, using the theoretical framework we will reproduce and interpret experimental results obtained on JET, MAST and HL-2A.
YI2 5 Progress towards modeling tokamak boundary plasma turbulence and understanding its role in setting divertor heat flux widths
BIN CHEN, USTC, China; LLNL

QCMs (quasi-coherent modes) are well characterized in the edge of Alcator C-Mod, when operating in the Enhanced Dα (EDA) H-mode, a promising alternative regime for ELM (edge localized modes) suppressed operation. To improve the understanding of the physics behind the QCMs, three typical C-Mod EDA H-Mode discharges are simulated by BOUT++ using a six-field two-fluid model (based on the Braginskii equations). The simulated characteristics of the frequency versus wave number spectra of the modes is in reasonable agreement with phase contrast imaging data. The key simulation results are: 1) Linear spectrum analysis and the nonlinear phase relationship indicate the dominance of resistive-ballooning modes and drift-Alfvén wave instabilities; 2) QCMs originate inside the separatrix; (3) magnetic flutter causes the mode spreading into the SOL; 4) the boundary electric field E_b changes the turbulent characteristics of the QCMs and controls edge transport and the divertor heat flux width; 5) the magnitude of the divertor heat flux depends on the physics models, such as sources and sinks, sheath boundary conditions, and parallel heat flux limiting coefficient. The BOUT++ simulations have also been performed for inter-ELM periods of DIII-D and EAST discharges, and similar quasi-coherent modes have been found. The parallel electron heat fluxes projected onto the target from these BOUT++ simulations follow the experimental heat flux width scaling, in particular the inverse dependence of the width on the poloidal magnetic field with an outlier. Further turbulence statistics analysis shows that the blobs are generated near the pedestal peak gradient region inside the separatrix and contribute to the transport of the particle and heat in the SOL region. To understand the Goldston heuristic drift-based model, results will also be presented from self-consistent transport simulations with the electric and magnetic drifts in BOUT++ and with the sheath potential included in the SOL.

Work supported by LLNL under Contract DE-AC52-07NA27344. This work was also supported by US DOE Grant DE-FC02-99ER54512, using Alcator C-Mod, a DOE Office of Science User Facility, and under the auspices of the CSC (No. 201506340019).

In collaboration with X.Q. Xu, T.Y. Xia, N.M. Li, Y.M. Wang, M. Porkolab, E. Edlund, B. LaBombard, J. Terry, J.W. Hughes, and M.Y. Ye.

YI2 6 An innovative small angle slot divertor concept for long pulse advanced tokamaks
HOUYANG GUO, General Atomics

A new Small Angle Slot (SAS) divertor is being developed in DIII-D to address the challenge of efficient divertor heat dispersal at the relatively low plasma density required for non-inductive current drive in future advanced tokamaks. SAS features a small incident angle near the plasma strike point on the divertor target plate with a progressively opening slot. SOLPS (B2-Eirene) edge code analysis finds that SAS can achieve strong plasma cooling when the strike point is placed near the small angle target plate in the slot, leading to low electron temperature T_e across the entire divertor target. This is enabled by strong coupling between a gas tight slot and directed neutral recycling by the small angle target to enhance neutral buildup near the target. SOLPS analysis reveals a strong correlation between T_e and D_2 density at the target for various divertor configurations including the flat target, slanted target, and lower single null divertor. The strong correlation suggests that achievement of low T_e may reduce essentially to identifying the divertor baffle geometry that achieves the highest target gas density at a given upstream condition. The SAS divertor concept has recently been tested in DIII-D for a range of plasma configurations and conditions with precise control of slot strike point location. In confirmation of SOLPS predictions, a sharp transition is observed when the strike point is moved to the critical outer corner of SAS. A set of Langmuir probes imbedded in SAS show that the T_e radial profile, which is peaked at the strike point when it is located away from the SAS corner, becomes low across the target when the strike point is located near the corner. With further increase in density, deep-slot detachment occurs with T_e 1 eV, measured by the unique DIII-D divertor Thomson Scattering diagnostic.

Work supported by US DOE under DE-FC02-04ER54698.

SESSION YI3: PLASMA ACCELERATION
Friday Morning, 27 October 2017; Room: 103ABC at 9:30; Bernhard Hidding, University of Strathclyde, presiding

Invited Papers

9:30
YI3 1 Particle acceleration and exotic light emission in structured plasma wakefields
JORGE VIEIRA, GolP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

Twisted Laguerre Gaussian lasers, with orbital angular momentum (OAM), are characterised by twisted wavefronts and doughnut intensity profiles. These lasers provide a transformative set of research directions in a growing range of fields,
particularly at intensities below damage thresholds. Here, we explore how the interaction between ultra-intense twisted light and matter could enhance plasma accelerators and light sources. We support our findings with theory and massively parallel three-dimensional particle-in-cell Osiris simulations [1]. Providing a solution to a long-lasting challenge in plasma acceleration, we show that twisted light can excite a nonlinear doughnut blowout suitable for electron and positron focusing and acceleration [2]. This is a new type of wakefield that contrasts with the nonlinear spherical blowout, characterised by positron defocusing forces. Despite being driven by an OAM laser, doughnut plasma waves contain no OAM. This picture changes dramatically, when the laser driver contain multiple OAM levels characterised by distinct frequencies. The corresponding beating pattern results in a spiralling laser intensity profile, known as a light spring [3], which can excite a twisted plasma wave with OAM. The twisted wakefields accelerate particles both longitudinally and azimuthally. This feature can be exploited towards the generation of relativistic bunches with similar longitudinal and transverse momenta, which changes radiation emission processes. Structured lasers have been produced in the laboratory, using conventional spiral phase plates and plasma based holograms [4]. Here, we demonstrate how to create and amplify ultra-intense OAM lasers in the plasma, through stimulated Raman backscattering [5].

∗Work supported by FCT (Portugal) Grant No. SFRH/IF/01635/2015.


10:00
YI3 2 Single-shot measurements of low emittance beams from laser-plasma accelerators comparing two triggered injection methods∗
JEROEN VAN TILBORG, Lawrence Berkeley National Laboratory

The success of laser plasma accelerator (LPA) based applications, such as a compact x-ray free electron laser (FEL), relies on the ability to produce electron beams with excellent 6D brightness, where brightness is defined as the ratio of charge to the product of the three normalized emittances. As such, parametric studies of the emittance of LPA generated electron beams are essential. Profiting from a stable and tunable LPA setup, combined with a carefully designed single-shot energy-dispersed emittance diagnostic, we present a direct comparison of charge dependent emittance measurements of electron beams generated by two different injection mechanisms: ionization injection and shock-induced density down-ramp injection. Both injection mechanisms have gained in popularity in recent years due to their demonstrated stable LPA performance. For the down-ramp injection configuration, normalized emittances a factor of two lower were recorded: less than 1 micron at spectral charge densities up to 2 pC/MeV. For both injection mechanisms, a contributing correlation of space charge to the emittance was identified. This measurement technique in general, and these results specifically, are critical to the evaluation of LPA injection methods and development of high-quality LPA beam lines worldwide.

∗This work is supported by the U.S. DOE under Contract No. DE-AC02-05CH11231, by the U.S. DOE NNSA, DNN R&D (NA22), by the National Science Foundation under Grant No. PHY-1415596, and by the Gordon and Betty Moore Foundation under Grant ID GBMF4898.

10:30
YI3 3 Frontiers of Beam Diagnostics in Plasma Accelerators: Measuring the Ultra-fast and Ultra-cold
ALESSANDRO CIANCHI, University of Rome Tor Vergata and INFN

Advanced diagnostics are essential tools in the development of plasma-based accelerators. The accurate measurement of the quality of beams at the exit of the plasma channel is crucial to optimize the parameters of the plasma accelerator. 6D electron beam diagnostics will be reviewed with emphasis on emittance measurement, which is particularly complex due to large energy spread and divergence of the emerging beams, and on femtoseconds bunch length measurements.

11:00
YI3 4 Mechanisms for the mitigation of the hose instability in plasma-wakefield accelerators
TIMON MEHRLING, Deutsches Elektronen-Synchrotron DESY

The hose instability is a long standing challenge for plasma wakefield accelerators (PWFAs). It results from a coherent coupling between transverse phase space asymmetries of beam particles and plasma electrons. According to current models, the beam centroid displacement is amplified exponentially during the beam propagation in the plasma, resulting in an unstable acceleration process or beam-breakup. However, particle-in-cell (PIC) simulations indicate that these models overestimate the hosting growth rates, suggesting that PWFAs intrinsically provide saturation mechanisms for the hose instability [1]. In this work we review the theory for the hose instability in order to identify and describe diverse mitigation mechanisms. By means of a self-consistent theoretical model that includes the energy exchange between beam and plasma, we show that the beam energy evolution can significantly mitigate the hose instability. We also discuss other mechanisms which disrupt the coherent coupling between beam and plasma, and thereby lead to a saturation or damping of the beam
centroid oscillations. In addition, we examine how the transverse beam asymmetries, which seed hosing, can be reduced. Hence, the presented work reveals crucial mechanisms allowing for stable beam acceleration over long distances in PWFAs.


11:30
YI3 5 Experimental realization of underdense plasma photocathode wakefield acceleration at FACET
PAUL SCHERKL, Univ of Strathclyde

Novel electron beam sources from compact plasma accelerator concepts currently mature into the driving technology for next generation high-energy physics and light source facilities. Particularly electron beams of ultra-high brightness could pave the way for major advances for both scientific and commercial applications, but their generation remains tremendously challenging. The presentation outlines the experimental demonstration of the world’s first bright electron beam source from spatiotemporally synchronized laser pulses [1] injecting electrons into particle-driven plasma wakefields at FACET. Two distinctive types of operation - laser-triggered density downramp injection (“Plasma Torch”) and underdense plasma photocathode acceleration (“Trojan Horse”) [2] – and their intermediate transitions are characterized and contrasted. Extensive particle-in-cell simulations substantiate the presentation of experimental results. In combination with novel techniques to minimize the beam energy spread [3], the acceleration scheme presented here promises ultra-high beam quality and brightness.

1A. Knetsch, P. Scherkl, T. Heinemann et al., to be submitted.
2A. Deng, O. Karger, P. Scherkl et al., to be submitted.

12:00
YI3 6 First direct observation of runaway electron-driven whistler waves in tokamaks*
DONALD A. SPONG, Oak Ridge National Laboratory

Whistlers are electromagnetic waves that can be driven unstable by energetic electrons and are observed in natural plasmas, such as the ionosphere and Van Allen belts. Recent DIII-D experiments at low density demonstrate the first direct observation of whistlers in tokamaks, with 100-200 MHz waves excited by runaway electrons (REs) in the multi-MeV range. Whistler activity is correlated with RE intensity and the frequencies scale with magnetic field strength and electron density consistent with a whistler dispersion relation. Fluctuations occur in discrete frequency bands, and not a continuum as would be expected from plane wave analysis, suggesting the important role of toroidicity. An MHD model including the bounded/periodic nature of the plasma identifies multiple eigenmode branches. For a toroidal mode number $n = 10$, the predicted frequencies and spacing are similar to observations. The instabilities are stabilized with increasing magnetic field, as expected from the anomalous Doppler resonance. The whistler amplitudes show intermittent time variations. Predator-prey cycles with electron cyclotron emission (ECE) signals are observed, which can be interpreted as wave-induced pitch angle scattering of moderate energy REs. Such nonlinear dynamics are supported by quasi-linear simulations indicating that REs are scattered both by whistlers and high frequency magnetized plasma waves. The whistler wave predominantly scatters the high energy REs, while the magnetized plasma wave scatters the low energy REs, abruptly enhancing the ECE signal. Amplitude variations are also associated with sawtooth activity, indicating that the REs sample the $q = 1$ surface. These features of the RE-driven whistler have connections to ionospheric plasmas and open up new directions for the modeling and active control of tokamak REs.

*Work supported by the US DOE under DE-FC02-04ER54698, DE-AC52-07NA27344, DE-FG02-07ER54917, DE-SC00-16268, and DE-AC05-00OR22725.
Berk-Breizman theory. In addition to the low frequency mode, the high frequency BAE is excited during the nonlinear evolution. For the transient case of beam pressure fraction where the low and high frequency modes are simultaneously excited in the linear phase, only one dominant mode appears in the nonlinear phase with frequency jumps up and down during nonlinear evolution.

"This work is supported by the National Natural Science Foundation of China under Grant Nos. 11605245 and 11505022, and the CASHIPS Director’s Fund under Grant No. YZJJ201510, and the Department of Energy Scientific Discovery through Advanced Computing (SciDAC) under Grant No. DE-AC02-09CH11466.


9:42
YO4 2 Low-Frequency Fishbone Driven by Passing Fast Ions in Tokamak Plasmas∗ FENG WANG, School of Physics, Dalian University of Technology, LIMIN YU, Department of Physics, East China University of Science and Technology G.Y. FU, Institute for Fusion Theory and Simulation and Department of Physics, Zhejiang University After the first report in PDX [1], fishbone instabilities were commonly observed in tokamak plasmas with fast ions induced by NBI and/or RF heating. In PDX, with perpendicular NBI, it was understood that the fishbone instability was driven through the resonance with the trapped energetic ions’ toroidal precessional drift frequency [2]. In PBX, fishbone instability driven by passing fast ions was first reported. In ITER-like plasmas, fast ions are mostly passing particles. Thus it is important to understand fishbone instability driven by passing fast ions. With finite FOW effects of passing fast ions, analytical results showed that there exist two branches of fishbone with low and high frequency [3–5]. For the low frequency fishbone, previously, the mode frequency of the low frequency fishbone was determined by the bulk ion-diamagnetic-drift frequency [3]. In this work, the fishbone dispersion relation is solved self-consistently and the obtained mode is of EPM type where the frequency is determined by fast ion dynamics. In addition to the analytical results, numerical study using HL-2A tokamak parameters is also presented. These results are helpful to understand the low frequency fishbone observed in HL-2A.

"This work is supported by the SciDAC under Grant No. DE-AC02-09CH11466, the NNSF of China under Grant No. 11505022, 11375029.


9:54
YO4 3 A Two Species Bump-On-Tail Model With Relaxation for Energetic Particle Driven Modes∗ V. ASLANYAN, M. PORKOLAB, MIT-PSFC S. E. SHARAPOV, CCFE UK D. A. SPONG, ORNL. Energetic particle driven Alfven Eigenmodes (AEs) observed in present day experiments exhibit various nonlinear behaviours varying from steady state amplitude at a fixed frequency to bursting amplitudes and sweeping frequency. Using the appropriate action-angle variables, the problem of resonant wave-particle interaction becomes effectively one-dimensional. Previously, a simple one-dimensional Bump-On-Tail (BOT) model has proven to be one of the most effective in describing characteristic nonlinear near-threshold wave evolution scenarios. In particular, dynamical friction causes bursting mode evolution, while diffusive relaxation may give steady-state, periodic or chaotic mode evolution. BOT has now been extended to include two populations of fast particles, with one dominated by dynamical friction at the resonance and the other by diffusion; the relative size of the populations determines the temporal evolution of the resulting wave. This suggests an explanation for recent observations on the TJ-II stellarator, where a transition between steady state and bursting occurred as the magnetic configuration varied. The two species model is then applied to burning plasma with drag-dominated alpha particles and diffusion-dominated ICRH accelerated minority ions.

"This work was supported by the US DoE and the RCUK Energy Programme [Grant Number EP/P012450/1].

10:06
YO4 4 Nonlinear Dynamics of Fast-electron Driven Beta-induced Alfven eigenmode JUNYI CHENG, WENLU ZHANG, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China ZHIHONG LIN, Department of Physics and Astronomy, University of California, Irvine, California 92697, USA DING LI, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China The fast-electron driven beta-induced Alfven eigenmode (e-BAE) has been routinely observed in HL-2A tokamak. We study e-BAE for the first time using global gyrokinetic GTC simulations, where the fast electrons are described by the drift kinetic model. Frequency chirping is observed in nonlinear simulations in the absence of sources and sinks, which provides a new nonlinear paradigm beyond the standard “bump-on-tail” model. Analysis of nonlinear wave-particle interactions shows that the frequency chirping is induced by the nonlinear evolution of the coherent structures in the fast electron phase space, where the dynamics of the coherent structure is controlled by the formation and destruction of phase space islands in the canonical variables. Furthermore, we put forward a new theory frame to demonstrate that the evolution of chirping phenomenon is essentially induced by balance and destruction of net shear flow in the toroidal direction combined by the background shear flow and perturbed shear flow, which provides a novel and clear physical image.

10:06
YO4 5 Excitation of Low Frequency Alfven Eigenmodes in Toroidal Plasmas ZHIHONG LIN, University of California, Irvine Low frequency Alfven eigenmodes in toroidal geometry, such as beta-induced Alfven-acoustic eigenmode (BAAE) and beta-induced Alfven eigenmode (BAE), can cause significant loss of energetic particles in fusion plasmas. Our global gyrokinetic toroidal code (GTC) simulations find that unstable BAAE and BAE can be simultaneously excited with similar radial mode width and comparable linear growth rates even though the damping rate of BAAE is much larger than BAE in the absence of energetic particles. This surprising result is attributed to non-perturbative effects of the energetic particles that modify ideal MHD mode polarizations and nonlocal geometry effects that invalidate radially local acoustic dispersion relation. GTC simulations with various tokamak sizes show that dominant mode changes from the BAAE in a larger tokamak to the BAE in a smaller tokamak due to the dependence of wave-particle resonance condition on the tokamak size. In nonlinear GTC simulations, the lower frequency BAAE is nonlinearly driven after BAE saturates in the realistic simulation of a DIII-D experiment where low frequency Alfven eigenmodes are responsible for half of the fast ion loss. In collaborations with Yaqi Liu, Huasen Zhang, Wenlu Zhang.
10:30  
YO4 6 Stimulated Emission of Fast Alfvén Waves within Toroidally Confined Low Beta Fusion Plasmas  
JAMES W S COOK, Univ of California - Irvine  
RICHARD O DENDY, CCFE, Culham Science Centre, Abingdon, Oxfordshire OX14 3DB, United Kingdom  
SANDRA C CHAPMAN, Centre for Fusion, Space and Astrophysics, Department of Physics, Warwick University, Coventry CV4 7AL, United Kingdom  
A fast Alfvén wave of initially low energy is shown to be greatly amplified by a new stimulated emission process [1]. This extracts energy from a population inversion of fusion-born ions, which is observed to arise naturally in the outer mid-plane of large tokamak plasmas. The inward propagation of a fast Alfvén wave through the outboard edge of a tokamak plasma, in the presence of this fast ion population, is modeled using full orbit kinetic particle-in-cell simulations using the nonlinear self-consistent Maxwell-Lorentz equations. Within the constraints of periodic boundary conditions, and initially uniform density and magnetic field, these simulations demonstrate this novel alpha-particle channelling scenario for the first time.  


10:42  
YO4 7 Incorporating pedestals with feedback into sandpile models for fusion plasmas  
CRAIG BOWIE, MATTHEW HOLE, Australian National University  
The pedestal in a H-mode fusion plasma is thought to result from shear flow induced by a radial electric field. The size of the pedestal relates to the Larmor radius of the ions, and in turn to their temperature. This creates a feedback mechanism within the plasma as temperature changes cause changes in pedestal size. We present here modifications of a sandpile model [1] in which we incorporate feedback effects. A key parameter, $L_I$, defines the distance over which the sandpile can interact with itself, analogous to shear flow in the plasma. Decreasing the value of $L_I$ increases the energy in the sandpile. By changing $L_I$ at the edge of the sandpile over a distance related to the energy of the system, we produce a pedestal, and introduce an element of feedback analogous to changes in the shear flow in a fusion plasma. We also show other variants of the model which produce pedestals without introducing feedback. We observe that maximum waiting times between mass loss events (MLEs), and maximum MLE sizes, grow with pedestal size, consistent with the behaviour of ELMs in a fusion plasma, and that this occurs only in the presence of feedback in the model.  


10:54  
YO4 8 Gyrokinetic simulations of DIII-D near-edge L-mode plasmas*  
TOM NEISER, FRANK JENKO, TROY CARTER, LOTTHAR SCHMITZ, GABRIELE MERLO, UCL DANIEL TOLD, ALEJANDRO BANON NAVARRO, MPI of Plasma Physics- Garching GEORGE MCKEE, ZHENG YAN, UW-Madison  
In order to understand the L-H transition, a good understanding of the L-mode edge region is necessary. We perform nonlinear gyrokinetic simulations of a DIII-D L-mode discharge with the GENE code in the near-edge, which we define as $\rho_{tor} \geq 0.8$. At $\rho = 0.9$, ion-scale simulations reproduce experimental heat fluxes within the uncertainty of the experiment. At $\rho = 0.8$, electron-scale simulations reproduce the experimental electron heat flux while ion-scale simulations do not reproduce the respective ion heat flux due to a strong poloidal zonal flow. However, we reproduce both electron and ion heat fluxes by increasing the local ion temperature gradient by 80%. Local fitting to the CER data in the domain $0.7 \leq \rho \leq 0.9$ is compatible with such an increase in ion temperature gradient within the error bars. Ongoing multi-scale simulations are investigating whether radial electron streamers could dampen the poloidal zonal flows at $\rho = 0.8$ and increase the radial ion-scale flux.  

*Supported by U.S. DOE under Contract Numbers DE-FG02-08ER54984, DE-FC02-04ER54698, and DE-AC02-05CH11231.

11:06  
YO4 9 Toroidal Electromagnetic Particle-in-Cell Code with Gyro-kinetic Electron and Fully-kinetic ion*  
JINGBO LIU, UNIV OF SCI & TECH OF CHINA WENLU ZHANG, CHAO DONG, INSTITUTE OF PHYSICS, CAS JINGBO LIN, UNIV OF SCI & TECH OF CHINA  
DING LI, JINTAO CAO, INSTITUTE OF PHYSICS, CHINESE ACADEMIC OF SCIENCES  
An electromagnetic kinetic simulation model has been developed using gyro-kinetic electron and fully-kinetic ion by removing fast gyro motion of electrons using the Lie-transform perturbation theory. An electromagnetic particle-in-cell kinetic code is developed based on this model in general magnetic flux coordinate systems, which is particularly suitable for simulations of toroidally confined plasma. Single particle motion and field solver are successfully verified respectively. Integrated electrostatic benchmark, for example the lower-hybrid wave (LHW) and ion Bernstein wave (IBW), shows a good agreement with theoretical results. Preliminary electromagnetic benchmark of electromagnetic lower hybrid wave is also presented. This code can be a first-principal tool to investigate high frequency nonlinear phenomenon, such as parametric decay instability, during lower-hybrid current drive (LHCD) and ion cyclotron radio frequency heating (ICRF) with complex geometry effect included.  

*Supported by National Special Research Program of China For ITER and National Natural Science Foundation of China.

11:18  
YO4 10 Self-consistent gyrokinetic Vlasov-Maxwell system for nonlinear processes in plasmas  
PENGFEI LIU, Unive of Sci & Tech of China WENLU ZHANG, CHAO DONG, Institute of Physics, CAS JINGBO LIN, Univ of Sci & Tech of China ZHIHONG LIN, University of California, Irvine  
A self-consistent gyrokinetic Vlasov-Maxwell system which is capable of studying phenomena related to ponderomotive force is developed with long wavelength approximation and background Maxwellian distribution in the presence of electromagnetic fluctuations. According to the ordering analysis, the introduction of quadratic Hamiltonian would raise the order of the Vlasov-Maxwell system. Therefore, guiding-center transformation is proceeded up to the order of $\epsilon_r^2$, and gyrocenter transformation is proceeded up to the order of $\epsilon_r^2$. And higher order terms of the first order gyrocenter Hamiltonian $H_1$ and gauge field $S_1$ are brought back. In this way, effects are also presented which are resulted from the inhomogeneities of equilibrium profile but the curvature of equilibrium magnetic field on the moments of distribution.

11:30  
YO4 11 Can the Time-Spectral Method GWRM Advance Fusion Transport Modelling?  
KRISTOFFER LINDVALL, JAN SCHEFFEL, Fusion Plasma Physics, KTH Royal Institute of Technology, Stockholm, Sweden  
Transport phenomena in fusion plasma pose a daunting task for both real-time experiments and numerical modelling. The transport is driven by micro-instabilities caused by a host of unstable modes, for example ion temperature gradient and
trapped electron modes. These modes can be modelled using fluid or gyrokinetic equations. However, the equations are characterised by high degrees of freedom and high temporal and spatial numerical requirements. Thus, a time-spectral method GWRM has been developed in order to efficiently solve these multiple time scale equations. The GWRM assumes a multivariate Chebyshev expansion ansatz in time, space, and parameter domain. Advantages are that time constraining CFL criteria no longer apply and that the solution accurately averages over small time-scale dynamics. For benchmarking, a two-fluid 2D drift wave turbulence model has been solved in order to study toroidal ion temperature gradient growth rates and nonlinear behaviour.

11:42
YO4 12 ExB shear damping of geodesic acoustic mode in tokamak RAMESWAR SINGH, Institute for Plasma Research, Bhat, Gandhinagar - 382 428, Gujarat, India OZGUR D GURCAN, LPP, Ecole Polytechnique, F-91128 Route de Saclay, Palaiseau Cedex, France ExB shearing effect on geodesic acoustic mode (GAM) is investigated both as an initial value problem in the shearing frame and as an eigenvalue problem in the lab frame. The novel effects are that ExB shearing couples the standard GAM perturbations to their complimentary poloidal parities. The resulting GAM acquires an effective inertia increasing in time leading to GAM damping. Eigenmode analysis shows that GAMs are radially localized by ExB shearing with the mode width being inversely proportional and radial wave number directly proportional to the shearing rate for weak shear. The physics of GAM disappearance during LH transition will be discussed.

11:54
YO4 13 Isotope and mixture effects on neoclassical transport in the pedestal ISTVAN PUSZTAL, STEFAN BULLER, JOHN T. OMOTANI, Chalmers University of Technology SARAH L. NEWTON, CCFE, Culham Science Centre The isotope mass scaling of the energy confinement time in tokamak plasmas differs from gyro-Bohm estimates, with implications for the extrapolation from current experiments to D-T reactors. Differences in mass scaling in L-mode and various H-mode regimes suggest that the isotope effect may originate from the pedestal. In the pedestal, sharp gradients render local diffusive estimates invalid, and global effects due to orbit-width scale profile variations have to be taken into account. We calculate neoclassical cross-field fluxes from a radially global drift-kinetic equation using the PERFECT code [1], to study isotope composition effects in density pedestals. The relative reduction to the peak heat flux due to global effects as a function of the density scale length is found to saturate at an isotope-dependent value that is larger for heavier ions. We also consider D-T and H-D mixtures with a focus on isotope separation. The ability to reproduce the mixture results via single-species simulations with artificial “DT” and “HD” species has been considered. These computationally convenient single ion simulations give a good estimate of the total ion heat flux in corresponding mixtures.

*Funding received from the International Career Grant of Vetenskapsradet (VR) (330-2014-6313) with Marie Sklodowska Curie Actions, Cofund, Project INCA 600398, and Framework Grant for Strategic Energy Research of VR (2014-5392).

12:06
YO4 14 Understanding helium transport: experimental and theoretical investigations of low-Z impurity transport at ASDEX Upgrade ATHINA KAPPATOU, CLEMENTE ANGIONI,
RACHEL M. MCDERMOTT, PIERRE MANAS, THOMAS PÜTTERRICH, RALPH DUX, CECILIA BRUHN, Max Planck Institute for Plasma Physics, Garching, Germany ELEONORA VIEZER, University of Seville, Seville, Spain MARCO CAVE- DON, MIKE DUNNE, RAINER FISCHER, GIOVANNI TAR- DINI, Max Planck Institute for Plasma Physics, Garching, Ger- many THE ASDEX UPGRADE TEAM The presence of helium is fundamentally connected to the performance of a fusion reactor. To predict the helium density profile in future fusion devices, understanding of helium transport is indispensable, as are experimentally validated theoretical models of the low-Z impurity turbulent transport. At ASDEX Upgrade, detailed, multi-species investigations of low-Z impurity transport have been undertaken in dedicated experiments, resulting in an extensive database of helium and boron density profiles over a wide range of parameters relevant for turbulent transport (normalised gradients of the electron density, the ion temperature and the toroidal rotation). Detailed comparisons of the experimental density gradients of both impurities with gyrokinetic simulations of the turbulent transport have shown that a qualitative agreement between experiment and theory cannot always be obtained, with strong discrepancies observed in some cases. The role of rotation and fast ions will be discussed as possible explanations for these discrepancies, which indicate a missing element in our understanding of low-Z impurity transport.

Contributed Papers

9:30
YO6 1 Study of transport phenomena in laser-driven, non-equilibrium plasmas in the presence of external magnetic fields* G. ELIJAH KEMP, D.A. MARISCAL, G.J. WILLIAMS, B.E. BLUE, J.D. COLVIN, T.M. FEARS, S.M. KERR, M.J. MAY, J.D. MOODY, D.J. STROZZI, LLNL, H.J. LIEFEVRE, S.R. KLEIN, C.C. KURANZ, Univ. Michigan M.J.-E. MANUEL, General Atomicics D.C. GAUTIER, D.S. MONTGOMERY, LANL. We present experimental and simulation results from a study of thermal transport inhibition in laser-driven, mid-Z, non-equilibrium plasmas in the presence external magnetic fields. The experiments were performed at the Jupiter Laser Facility at LLNL, where x-ray spectroscopy, proton radiography, and Brillouin backscatter data were simultaneously acquired from sub-critical-density, Ti-doped silica aerogel foams driven by a 20J laser at ∼ 5 × 10^13 W/cm^2. External B-field strengths up to ~ 20 T (aligned antiparallel to the laser propagation axis) were provided by a capacitor-bank-driven Helmholtz coil. Pre-shot simulations with HYDRA, a radiation-magnetohydrodynamics code, showed increasing electron plasma temperature with increasing B-field strength – the result of thermal transport inhibition perpendicular to the B-field. The influence of this thermal transport inhibition on the experimental observables as a function of external field strength and target density will be shown and compared with simulations.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344 and funded by LDRD project 17-ERD-027.
9:54
YO6 3 Validation of non-local electron heat conduction model for radiation MHD simulation in magnetized laser plasma∗
HIDEO NAGATOMO, KAZUKI MATSUO, Institute of Laser Engineering, Osaka University PILIPPE NICOLAI, CELIA, University of Bordeaux TAKASHI ASAHINA, SHINSUKE FUJIOKA, Institute of Laser Engineering, Osaka University In laser plasma physics, application of an external magnetic field is an attractive method for various research of high energy density physics including fast ignition. Meanwhile, in the high intense laser plasma the behavior of hot electron cannot be ignored. In the radiation hydrodynamic simulation, a classical electron conduction model, Spitzer-Harm model has been used in general. However the model has its limit, and modification of the model is necessary if it is used beyond the application limit. Modified SNB model [1], which considering the influence of magnetic field is applied to 2-D radiation magnetohydrodynamic code PINOCCO. Some experiments related the non-local model are carried out at GXII, Osaka University. In this presentation, these experimental results are shown briefly. And comparison between simulation results considering the non-local electron heat conduction mode are discussed.

∗This study was supported JSPS KAKENHI Grant No. 17K05728.


10:06
YO6 4 Laser-Plasma Modeling Using PERSEUS Extended-MHD Simulation Code for HED Plasmas∗ NATHANIEL HAMIL, CHARLES SEYLER, Cornell University We discuss the use of the PERSEUS extended-MHD simulation code for high-energy-density (HED) plasmas in modeling the influence of Hall and electron inertial physics on laser-plasma interactions. By formulating the extended-MHD equations as a relaxation system in which the current is semi-implicitly time-advanced using the Generalized Ohm’s Law, PERSEUS enables modeling of extended-MHD phenomena (Hall and electron inertial physics) without the need to resolve the smallest electron time scales, which would otherwise be computationally prohibitive in HED plasma simulations. We first consider a laser-produced plasma plume pinched by an applied magnetic field parallel to the laser axis in axisymmetric cylindrical geometry, forming a conical shock structure and a jet above the flow convergence. The Hall term produces low-density outer plasma, a helical field structure, flow rotation, and field-aligned current, rendering the shock structure dispersive. We then model a laser-foil interaction by explicitly driving the oscillating laser fields, and examine the essential physics governing the interaction.

∗This work is supported by the National Nuclear Security Administration stewardship sciences academic program under Department of Energy cooperative agreements DE-FOA-0001153 and DE-NA0001836.
10:42
YO6 7 X-ray Spectropolarimetry of Z-pinch Plasmas with a Single-Crystal Technique* MATT WALLACE, SHOWERA HAQUE, PAUL NEILL, University of Nevada, Reno NINO PEREIRA, Ecopulse, Inc. RADU PRESURA, National Security Technologies When directed beams of energetic electrons exist in a plasma the resulting x-rays emitted by the plasma can be partially polarized. This makes plasma x-ray polarization spectroscopy, spectropolarimetry, useful for revealing information about the anisotropy of the electron velocity distribution. X-ray spectropolarimetry has indeed been used for this in both space and laboratory plasmas. X-ray radiation measurements are typically performed employing two crystals, both at a 45° Bragg angle. A single-crystal spectropolarimeter can replace two crystal schemes by utilizing two matching sets of internal planes for polarization-splitting. The polarization-splitting planes diffract the incident x-rays into two directions that are perpendicular to each other and the incident beam as well, so the two sets of diffracted x-rays are linearly polarized perpendicular to each other. An X-cut quartz crystal with surface along the [11-20] planes and a paired set of [10-10] planes in polarization splitting enables the spectropolarimetry of extended sources. The design of a single-crystal x-ray spectropolarimeter and experimental results will be presented.

Work was supported by U.S. DOE, NNSA Grant DE-NA0001834 and cooperative agreement DE-FC52-06NA27616.

10:54
YO6 8 Picosecond Time-Resolved Temperature and Density Measurements with K-Shell Spectroscopy* C.R. STILLMAN, P.M. NILSON, S.T. IVANCIC, C. MILEHAM, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester I.E. GOLOVKIN, Prism Computational Sciences The thermal x-ray emission from rapidly heated solid targets containing a buried-aluminum layer was measured to track the evolution of the bulk plasma conditions. The targets were driven by high-contrast 10 laser pulses at focused intensities up to 1 x 10^19 W/cm^2. A streaked x-ray spectrometer recorded the Al Kα and lithium-like satellite lines with 2-ps temporal resolution and moderate resolving power (ΔE / ΔE ≈ 1000). Time-integrated measurements over the same spectral range were used to correct the streaked data for variations in photocathode sensitivity. Linewidths and intensity ratios from the streaked data were interpreted using a collisional radiative atomic kinetics model to provide the average plasma conditions in the buried layer as a function of time. Experimental uncertainties in the measured plasma conditions are quantified within a consistent model-dependent framework. The data demonstrate the production of a 330±56 eV, 0.9±0.3 g/cm^3 plasma that evolves slowly during peak Heα emission.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

11:06
YO6 9 The Talbot-Lau x-ray deflectometer: a refraction-based electron density diagnostic for High Energy Density experiments* MARIA PIA VALDIVIA, DAN STUTMAN, Johns Hopkins CHRISTIAN STOECKL, CHAD MILEHAM, ILDAR BEGISHEV, WOLFGANG THEOBALD, JAKE BROMAGE, SEAN REGAN, Laboratory for Laser Energetics SALLEE KLEIN, University of Michigan MILENKO VESCOVI, GONZALO MUNOZ-CORDOVEZ, VICENTE VALENZUELA-VILLASECA, FRANCISCA VILLANUEVA, FELIPE VELOSO, Pontificia Universidad Catolica de Chile Talbot-Lau x-ray Deflectometry (TXD) has been developed as an electron density diagnostic for High Energy Density (HED) plasmas. The diagnostic delivers refraction, attenuation, elemental composition, and scatter information from a single-shot Moiré image. A Talbot-Lau interferometer was benchmarked using laser-target and X-pinch x-ray backlighters. Grating survival and electron density mapping were demonstrated for: a) 25–29 J, 8–30 ps laser pulses using Cu targets and b) a 4 x 25 μm copper X-pinch driven by a ~400kA/350ns generator. X-ray backlighter quality was assessed in order to optimize areal electron density gradient retrieval and electron density mapping. TXD enabled accurate areal electron density detection with high contrast (>25%) and spatial resolution of ~50 μm in the high-power laser experiments, while a higher spatial resolution <27 μm and lower contrast (<15%) were found in pulsed power experiments, thus demonstrating the potential of TXD as an electron density diagnostic for HED plasmas.

*DEAN002955; FONDECYT N1171412.
and multiple-frame imaging detectors. Preliminary designs utilize a novel CMOS detector designed by Sandia National Lab. Our initial experiments include scoping studies that will focus on photometrics and shielding requirements in the high EMP environment close to the target.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC, LLNL-ABS-734470.

11:42 YO6 12 Measurement of absolute laser energy absorption by nano-structured targets* IAEBUM PARK, R. TOMMASINI, R. LONDON, Lawrence Livermore National Laboratory C. BARGSTEN, R. HOLLINGER, M. G. CAPELUTO, V. N. SHLYAPTEY, J. J. ROCCA, Colorado State University, Fort Collins Nano-structured targets have been reported to allow the realization of extreme plasma conditions using table top lasers [1], and have gained much interest as a platform to investigate the ultra-high energy density plasmas (> 100 MJ/cm³). One reason for these targets to achieve extreme conditions is increased laser energy absorption (LEA) [1]. The absolute LEA by nano-structured targets has been measured for the first time and compared to that by foil targets. The experimental results, including the effects of target parameters on the LEA, will be presented.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC5209NA27344, and funded by LDRD (#15-ERD-054).

11:54 YO6 13 Studies of soft x-ray transmission through grid supported CH layers* J.S. DAVIS, Naval Surface Warfare Center/University of Michigan P.A. KEITER, S.R. KLEIN, University of Michigan Y. FRANK, Soreq Nuclear Research Center R.P. DRAKE, D. SHVARTS, University of Michigan Recent experiments have shown that it may be possible to use laser-heated high-Z foils to drive new radiation transport (RadTran) experiments in gas fill tubes. These tubes must be pressurized above 1 atm and the x-ray source needs to be physically separated from the gas. To achieve this, a grid-supported CH seal is implemented. The grid reduces the total surface area of the gas-seal interaction region lowering the thickness requirements for the CH layer. However, as mesh spacing is reduced, hole closure from wire ablation may reduce the x-ray flux. To optimize the seal design, experiments were performed measuring x-ray transmission through CH layers supported by meshes composed of copper, gold, or stainless steel and using hexagonal or square mesh geometries. The x-ray source was formed by heating a 0.5 µm thick planar gold foil with a 4 ns laser pulse at an intensity of 2 x 10^14 W/cm². Emission data was collected using an x-ray framing camera and a Dante photodiode array. Experiments show that the CH layers can reach effective temperatures of nearly 100 eV but mesh design significantly affects performance, with a nearly 20 eV difference between the best and worst performing seal targets. This talk will discuss our findings and their impact on future RadTran experiments.

*This work is funded by the U.S. DOE, through the NNSA-DS and SC-OFES Joint Program in HED Laboratory Plasmas, Grant Number DE-NA0001840, the National LUPF, Grant Number DE-NA0000850, and through NNSA/OICF under Cooperative Agreement No. DE-FC52-08NA2830.
Inertial Confinement Fusion (ICF) capsules on the National Livermore National Laboratory J. CRIPPEN, N. RICE, General Atomics

Inertial Confinement Fusion (ICF) capsules on the National Ignition Facility (NIF) are filled with thermonuclear fuel through a fill-tube. When the capsule implodes, perturbations caused by the fill-tube allow ablating material to mix into the hot spot and reduce fusion performance. This talk will explore several design options that attempt to reduce this damaging effect. Reducing the diameter of the fill-tube and its entrance hole is the obvious course and has been tested in experiments. Simulations also show sensitivity to the amount of glue holding the fill-tube to the capsule and suggest that careful control of this feature can limit the amount of injected mass.

Finally, an off-axis fill-tube reduces the initial squirt of material into the fuel and may be a way of further optimizing this engineering feature.

Work performed under the auspices of the U.S. D.O.E. by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Mitigate the tent-induced perturbation in ignition capsules by supersonic radiation propagation

ZHENGSHENG DAI, JIANFA GU, WUDIZHENG, Institute of Applied Physics and Computational Mathematics

In the inertial confinement fusion (ICF) scheme, to trap the alpha particle products of the D-T reaction, the capsules need to be imploded and compressed with high symmetry. In the laser indirect drive scheme, the capsules are held at the center of high-Z hohlraums by thin membranes (tents). However, the tents are recognized as one of the most important contributors to hot spot asymmetries, areal density perturbations and reduced performance. To improve the capsule implosion performance, various alternatives such as the micro-scale rods, a larger fill-tube and a low-density foam layer around the capsule have been presented. Our simulations show that the radiation propagates supersonically in the low-density foam layer and starts to ablate the capsule before the perturbations induced by the tents reach the ablating fronts. The tent-induced perturbations are remarkably weakened when they are propagating in the blow-off plasma.

Work performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344.


Direct-Drive DT Cryogenic Implosion Performance with a Fill Tube


The effects of a fill tube on the performance of direct-drive DT cryogenic implosions on the 60-beam, 30-J, 351-nm OMEGA laser are presented. The calculated adiabat, convergence ratio, and in-flight-aspect ratio quantities were ~4, ~17, and ~23, respectively. Changes to the measured neutron yield, areal density, and ion temperature caused by the fill tube were found to be within experimental uncertainties. Gated x-ray images recorded during the acceleration phase at photon energies down to ~1 keV show evidence of the fill tube perturbing the implosion shell and causing a region of enhanced emission from the hot spot, while gated x-ray images of the hot spot in the 4- to 8-keV photon energy range show no effect from the fill tube.

This work is based upon work supported by the Department Of Energy National Nuclear Security Administration under Award Number DE-NA0001944.
10:54
YO7 8 Diffusive tunneling for alleviating Knudsen-layer reactivity reduction under hydrodynamic mix* XIANZHU TANG, CHRIS MCDEVITT, ZEHUA GUO, Los Alamos National Laboratory Hydrodynamic mix will produce small features for intermixed deuterium-tritium fuel and inert pusher materials. The geometrical characteristics of the mix feature have a large impact on Knudsen layer yield reduction. We considered two features. One is planar structure, and the other is fuel cells segmented by inert pusher material which can be represented by a spherical DT bubble enclosed by a pusher shell. The truly 3D fuel feature, the spherical bubble, has the largest degree of yield reduction, due to fast ions being lost in all directions. The planar fuel structure, which can be regarded as 1D features, has modest amount of potential for yield degradation. While the increasing yield reduction with increasing Knudsen number of the fuel region is straightforwardly anticipated, we also show, by a combination of direct simulation and simple model, that once the pusher materials is stretched sufficiently thin by hydrodynamic mix, the fast fuel ions diffusively tunnel through them with minimal energy loss, so the Knudsen layer yield reduction becomes alleviated. This yield recovery can occur in a chunk-mixed plasma, way before the far more stringent, asymptotic limit of an atomically mixed model. Our simulated results compare well to the experimental yield, ion temperature, burn width, and x-ray size data.

11:06
YO7 9 Sensitivity of Gas-Ablator Mix to Shock Merger Depth in 2-Shock Syncaps at the National Ignition Facility T. MA, S. A. MACLAREN, J. D. SALMONSON, D. HO, S. F. KHAN, L. MASSE, J. E. PINO, J. E. RALPH, C. CZAJKA, R. E. TIPTON, Lawrence Livermore National Laboratory G. A. KYRALA, Los Alamos National Laboratory The HED 2-Shock implosion campaign was developed on the National Ignition Facility as a relatively robust and well-behaved nearly one-dimensional, low convergence, symmetric platform by employing a two-shock pulseshape in a low gas-fill hohlraum and a large case-to-capsule (hohlraum-to-capsule size) ratio. Additionally, the relatively thick capsule shell (low aspect ratio of 3.9) combined with the temperature of the foot of the laser pulse (~120 eV) essentially eliminates ablation front instability growth. The result is a platform that is well suited to the study of mixing at the gas-ablator interface without the complications of low mode asymmetries or mix feedback. A layer of CD plastic on the inner surface of the CH shell filled with a mixture of H and T allows for the inference of gas-ablator mix via the measurement of DD and DT neutron yields. By advancing or retracting the time of launch of the second shock, the depth into the capsule at which the two shocks merge can be systematically varied from the shell to the gas. The effect of this, and possible rebound shocks, on inducing mix at the gas-ablator interface is studied. Details and results of these experiments will be described.

11:18
YO7 10 Update on 2-D OMEGA Capsule Implosions* PAUL BRADLEY, Los Alamos Natl Lab We have an upgraded laser energy deposition package in our AMR-Eulerian radiation-hydrodynamic code called RAGE. As part of our validation effort, we ran 2-D simulations for a series of OMEGA direct drive implosion capsules that have shell thickness ranging from 7.2 to 29.3 μm and different gas fills. These simulations include the effect of surface roughness, laser spot non-uniformity, the mounting stalk, and the glue spot. We examined the sensitivity of our simulated results to mesh resolution and mix model. Our simulated results compare well to the experimental yield, ion temperature, burn width, and x-ray size data.

11:30
YO7 11 Effect of Symmetry on Performance of Imploding Capsules using the Big Foot Design* SHAHAB KHAN, DANIEL CASEY, KEVIN BAKER, CLIFF THOMAS, RYAN NORA, BRIAN SPEARS, LAURA BENEDETTI, NOBUHIKO IZUMI, TAMMY MA, SABRINA NAGEL, ARTHUR PAK, Lawrence Livermore Natl Lab NATIONAL IGNITION FACILITY COLLABORATION At the National Ignition Facility, several simultaneous designs are investigated for optimizing Inertial Confinement Fusion (ICF) energy gain of indirectly driven implosion fuel capsules. Relatively high neutron yield has been achieved while exhibiting a non-symmetric central core and/or shell. While developing the “Big Foot” design, several tuning steps were undertaken to minimize the asymmetry of both the central hot core as well as the shell. Surrogate capsules (syn caps) were utilized in the 2-D Radiography platform to assess both the shell and central core symmetry. The results of the tuning experiments are presented. In addition, a comparison of performance and shape metrics demonstrates that improving symmetry of the implosion can yield better performance.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-683471.

11:42
YO7 12 Initial Findings on Hydrodynamic Scaling Extrapolations of National Ignition Facility BigFoot Implosions* R. NORA, J. E. FIELD, J. LUC PETERSON, B. SPEARS, M. KRUSE, K. HUMBIRD, J. GAFFNEY, P. T. SPRINGER, S. BRANDON, S. LANGER, Lawrence Livermore National Laboratory We present an experimentally corroborated hydrodynamic extrapolation of several recent BigFoot implosions on the National Ignition Facility. An estimate on the value and error of the hydrodynamic scale necessary for ignition (for each individual BigFoot implosion) is found by hydrodynamically scaling a distribution of multi-dimensional HYDRA simulations whose outputs correspond to their experimental observables. The 11-parameter database of simulations, which include arbitrary drive asymmetries, dopant fractions, hydrodynamic scaling parameters, and surface perturbations due to surrogate tank and fill-tube engineering features, was computed on the TRINITY supercomputer at Los Alamos National Laboratory. This simple extrapolation is the first step in providing a rigorous calibration of our workflow to provide an accurate estimate of the efficacy of achieving ignition on the National Ignition Facility.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

11:54
YO7 13 Using deep neural networks to augment NIF post-shot analysis* KELLI HUMBIRD, Lawrence Livermore National Laboratory, Texas A&M University LUC PETERSON, Lawrence Livermore National Laboratory RYAN MCCLARREN, Texas A&M University JOHN FIELD, JIM GAFFNEY, MICHAEL KRUSE, RYAN NORA, BRIAN SPEARS, Lawrence Livermore National Laboratory Post-shot analysis of National Ignition Facility (NIF) experiments is the process of determining which simulation inputs yield results consistent with experimental observations. This analysis is typically accomplished by running suites of manually adjusted simulations, or Monte Carlo sampling surrogate models...
since the yield amplification is a function of the fractional alpha energy and yield amplification.

This material is based upon work supported by the Department of Energy Office of Fusion Energy Services under Award Number DE-FC02-04ER54789 and National Nuclear Security Administration under Award Number DE-NA0001944.

SESSION YP11: POSTER SESSION IX:
SUPPLEMENTAL: POST-DEADLINE ABSTRACTS
Friday Morning, 27 October 2017
Exhibit Exhibit Hall D at 9:30

YP11 2 Binary gas mixture in a high speed channel DR. SAHADEV PRADHAN, Chemical Technology Division, Bhabha Atomic Research Centre, Mumbai- 400085

The viscous, compressible flow in a 2D wall-bounded channel, with bottom wall moving in the positive $x$-direction, simulated using the direct simulation Monte Carlo (DSMC) method, has been used as a test bed for examining different aspects of flow phenomenon and separation performance of a binary gas mixture at Mach number $Ma = (U_w/\sqrt{\gamma k T_w/m})$ in the range $0.1 < Ma < 30$, and Knudsen number $Kn = l/(\sqrt{\pi}d^2n_H)$ in the range $0.1 < Kn < 10$. The generalized analytical model is formulated which includes the fifth order differential equation for the boundary layer at the channel wall in terms of master potential ($\chi$), which is derived from the equations of motion in a 2D rectangular ($x - y$) coordinate. The starting point of the analytical model is the Navier-Stokes, mass, momentum and energy conservation equations in the $(x - y)$ coordinate, where $x$ and $y$ are the streamwise and wall-normal directions, respectively. The linearization approximation is used [1], where the equations of motion are truncated at linear order in the velocity and pressure perturbations to the base flow, which is an isothermal compressible Couette flow. Additional assumptions in the analytical model include high aspect ratio ($L \gg H$), constant temperature in the base state (isothermal condition), and low Reynolds number (laminar flow). The analytical solutions are compared with direct simulation Monte Carlo (DSMC) simulations and found good agreement (with a difference of less than 10%), provided the boundary conditions are accurately incorporated in the analytical solution.


YP11 3 DSMC Simulations of High Mach Number Taylor-Couette Flow DR. SAHADEV PRADHAN, Chemical Technology Division, Bhabha Atomic Research Centre, Mumbai- 400085

The main focus of this work is to characterise the Taylor-Couette flow of an ideal gas between two coaxial cylinders at Mach number $Ma = (U_w/\sqrt{\gamma k T_w/m})$ in the range $0.01 < Ma < 1$, and Knudsen number $Kn = l/(\sqrt{\pi}d^2n_H)$ in the range $0.001 < Kn < 1$, using two-dimensional (2D) direct simulation Monte Carlo (DSMC) simulations. Here, $r_1$ and $r_2$ are the radius of inner and outer cylinder respectively, $U_w$ is the circumferential wall velocity of the inner cylinder.
cylinder, \( T_w \) is the isothermal wall temperature, \( n_d \) is the number density of the gas molecules, \( m \) and \( d \) are the molecular mass and diameter, and \( kb \) is the Boltzmann constant. The cylindrical surfaces are specified as being diffusely reflecting with the thermal accommodation coefficient equal to one. In the present analysis of high Mach number compressible Taylor-Couette flow using DSMC method, wall slip in the temperature and the velocities are found to be significant. Slip occurs because the temperature/velocity of the molecules incident on the wall could be very different from that of the wall, even though the temperature/velocity of the reflected molecules is equal to that of the wall. Due to the high surface speed of the inner cylinder, significant heating of the gas is taking place. The gas temperature increases until the heat transfer to the surface equals the work done in moving the surface. The highest temperature is obtained near the moving surface of the inner cylinder at a radius of about (1.26 \( r_1 \)).

YP11 4 Observation of plasma microwave emission during the injection of supersonic plasma flows into magnetic arch* MIKHAIL VIKTOROV, DMITRY MANSFELD, ALEXANDER VODOPYANOV, SERGEY GOLUBEV, The Institute of Applied Physics of the Russian Academy of Sciences Understanding of the energy transfer mechanisms from supersonic plasma flow into the thermal energy of plasma, waves and accelerated particles in the environment of planetary bow shocks and interplanetary shocks have been topical for many decades. Almost all mechanisms of energy dissipation in collisionless shock waves end with microscopic processes involving wave-particle interactions. Excitation of plasma waves in electron cyclotron frequency range plays an important role in the dissipation of bulk flow energy across the Earth bow shock. In the present work, the process of plasma deceleration during the injection of supersonic plasma flow across the magnetic field of an arched configuration is experimentally demonstrated. Pulsed plasma microwave emission in the electron cyclotron frequency range is observed. It is shown that the frequency spectrum of plasma emission is determined by the position of the deceleration region in the magnetic field of the arc and its bandwidth is defined by the magnetic field inhomogeneity in the deceleration region. The observed emission can be related to the cyclotron mechanism of wave generation by non-equilibrium energetic electrons in the dense plasma, especially excitation of electron Bernstein waves.

*The work was supported by RFBR (Project No. 16-32-60056).

YP11 5 On the correspondence between classical geometric phase of gyro-motion and quantum Berry phase* HONGXUAN ZHU, Princeton University HONG QIN, PPPL/USTC We show that the geometric phase of the gyro-motion of a classical charged particle in a uniform time-dependent magnetic field described by Newton’s equation can be derived from a coherent Berry phase for the coherent states of the Schrödinger equation. This correspondence is established by constructing coherent states for a particle using the energy eigenstates on the Landau levels and proving that the coherent states can maintain their status of coherent states during the slow varying of the magnetic field. It is discovered that the orbital Berry phases of the eigenstates interfere coherently to produce an observable effect, which is exactly the geometric phase of the classical gyro-motion. The use of the adiabatic theorem is justified. The conclusion also applies to electrons described by the Dirac equation [1].

*This research was supported by the U.S. Department of Energy (DE-AC02-09CH11466).

YP11 6 Some not such wonderful magnetic fusion facts; and their solution* WALLACE MANHEIMER, Retired from NRL The first not such wonderful fusion fact (NSWFF) is that if ITER is successful, it is nowhere near ready to develop into a DEMO. The design Q=10, along with electricity generating efficiency of 1/3 prevents this. Making it smaller and cheaper, increasing the gain by 3 or 4, and the wall loading by an order of magnitude is not a minor detail, it is not at all clear the success with ITER will lead to a similar, pure fusion DEMO. The second NSWFF is that tokamaks are unlikely to improve to the point where they can be effective fusion reactors because their performance is limited by conservative design rules. The third NSWFF is that developing large fusion devices like ITER takes an enormous amount of time and dollars, there are no second chances. The fourth NSWFF is that it is unlikely that alternative confinement configurations will succeed either, at least in this century; they are simply too far behind. There is only a single solution for fusion to become a sustainable, carbon free power source by midcentury or shortly thereafter. This is to develop ITER (assuming it is successful) into a fusion breeder.

*This work was not supported by any organization, private or public.

YP11 7 Influences of the shielding cylinder on the length of radio-frequency cold atmospheric plasma jets* HE-PING LI, JING LI, XIAO-FEI ZHANG, HENG GUO, JIAN CHEN, Tsinghua University DEPARTMENT OF ENGINEERING PHYSICS TEAM Cold atmospheric plasma jets driven by a radio frequency power supply contain abundant species and complex chemical reactions, which have wide applications in the fields of materials processing and modifications, food engineering, bio-medical science, etc. Our previous experiments have shown that the total length of a radio-frequency cold atmospheric plasma (RF-CAP) jet can exceed 1 meter with the shielding of a quartz tube. However, the shielding mechanisms of the solid cylinder has not been studied systematically. In this study, a two-dimensional, quasi-steady fluid model is used to investigate the influences of the shielding tube on the length of the RF-CAP jets under different conditions. The simulation results show that the total jet length grows monotonously; while simultaneously, the jet length out of the tube shows a non-monotonic variation trend, with the increase of the tube length, which is in good agreement with the experimental observations. The shielding mechanisms of the solid cylinder on the RF-CAP jet is also discussed in detail based on the modeling results.

*This work was supported by the National Natural Science Foundation of China (11475103, 21627812), the National Key Research and Development Program of China (2016YFD0102106) and Tsinghua University Initiative Scientific Program (20161080108).

YP11 8 Sample pre-heating in magnetic ramp compression experiments on the GEPI high pulsed power driver THIERRY D’ALMEIDA, PIERRE-YVES CHANAL, JEAN-LUC ZINSZNER, CEA GAETAN DAULHAC, ITHPP GEPI is a 3 MA, 500 ns, high pulsed power driver operated by the CEA and mainly used for dynamically compressing materials in a quasi-isentropic regime at stress levels up to 100 GPa. Usually, materials are loaded starting from ambient temperature conditions, thus, following a single thermodynamic path near an isentrope. Dynamically loading
samples from non-ambient initial conditions, either in pressure or temperature, can significantly improve our ability to obtain direct measurements over specific thermodynamic paths of interest. For instance, ramp-compressing multiphase metallic materials from various initial temperatures can help constrain their Equation of State. We have recently equipped the GEPI facility with a preheating device capable of pre-heating metallic samples up to 1100 K prior to their loading. We present results from preliminary experiments on copper and iron ramp compressed starting from temperatures ranging from 300 K to 900 K.

YP11 9 Various Forms of Power Radiated via Radiative Damping by Using Higher Order Terms in Super Intense Laser Matter Interaction* RISHI PANDIT, EDWARD ACKAD, Department of Physics, Southern Illinois University Edwardsville, IL, EMANUEL D’HUMIERES, Department of Physics, University of Bordeaux, Bordeaux, France YASUHIKO SENTOKU, Institute of Laser Engineering, Osaka University, Osaka, Japan. We had derived the radiation reaction terms including the higher orders and implemented in PICCLS codes [1]. We also derived the power radiated via radiative damping using higher order terms of radiative damping for the first time in various forms, the angular distribution, the spectral distribution or the combined angular and spectral distributions of radiation. These various forms of power radiated in the interaction of extremely intense laser (> 10^21 W/cm^2) with dense plasma are studied with a help of a collisional particle-in-cell simulation, PICCLS coupled with radiation transport code. It is found that the direction of motion of electron is a strongly preferred direction of emission at high energies. The narrow cone of radiation generated by an energetic electron indicates that only a small part of the trajectory is effective in producing radiation observed in a given direction, which also implies that very high frequencies are emitted. We will discuss the laser intensity and electron energy dependence of the entire spectral and angular distribution of radiation via radiative damping in super intense laser matter interactions.

*This work was supported by Air Force Office of Scientific Research under AFOSR Award No. FA9550-14-1-0247.

YP11 10 Numerical simulation of exploding pusher targets* S. ATZENI, Dip. SBAI, Universita’ di Roma “La Sapienza” M. J. ROSENBERG, LLE, Univ. Rochester M. GATU JOHNSON, R. D. PETRASSO, PSFC, MIT. Exploding pusher targets, i.e. gas-filled large aspect-ratio glass or plastic shells, driven by a strong laser-generated shock, are widely used as pulsed sources of neutrons and fast charged particles. Recent experiments on exploding pushers provided evidence for the transition from a purely fluid behavior to a kinetic one [1]. Indeed, fluid models largely overpredict yield and temperature as the Knudsen number Kn (ratio of ion mean-free path to compressed gas radius) is comparable or larger than one. At Kn = 0.3 - 1, fluid codes reasonably estimate integral quantities as yield and neutron-averaged temperatures, but do not reproduce burn radii, burn profiles and DD/DHe3 yield ratio. This motivated a detailed simulation study of intermediate-Kn exploding pushers. We will show how simulation results depend on models for laser-interaction, electron conductivity (flux-limited local vs nonlocal), viscosity (physical vs artificial), and ion mixing.

*Work partially supported by Sapienza Project C26A15YTM, Sapienza 2016 (n. 257584), and Eurofusion Project AWP17-ENR-IFE-CEA-01.

YP11 11 Self-organized edge density profile with turbulent pinch* BEN ZHU, MANAURA FRANCISQUEZ, BARRETT ROGERS, Dartmouth Coll In many tokamak operations, plasma is only fueled by ionization of neutrals in the periphery which subsequently penetrate inward toward core and form a peaked density profile - a process commonly referred as density pinch. Although the Wawereffect, and drift wave-RTG-TEM-based turbulent transport theory are proposed to explain density pinch in the core region ($r/a < 0.6$), the density pinch on the edge region remains barely explored to date. We present here an edge density pinch study based on the global 3D two-fluid edge turbulence code, GDB. GDB is a flux-driven electromagnetic model self-consistently evolving plasma density, temperature as well as the sheared flow profiles in both closed-flux surfaces and the SOL. In this study, the effective simulation domain is $0.8 < r/a < 1.1$ with a heat source located at $r/a < 0.8$ and a Gaussian particle source located in a relatively small region near the separatrix ($0.96 < r/a < 1.05$). An inward (up-gradient) particle flux in the closed flux region is observed once the particle source is turned on until the system reaches quasi-steady-state with a slightly peaked density profile. The final density profile seems insensitive to particle source profiles but largely depends on the other plasma parameters, e.g., plasma temperature.

*This work was supported by DOE-SC-0010508. This research used resources of the National Energy Research Scientific Computing Center.

YP11 12 Numerical investigation of design and operation parameters on CHI spheromak performance* J.B. O’BRYAN, Univ of Washington C.R. ROMERO-TALAMAS, Univ of Maryland, Baltimore County S. WOODRUFF, Woodruff Scientific, Inc. Nonlinear, numerical computation with the NIMROD code is used to explore magnetic self-organization in spheromaks formed with coaxial helicity injection, particularly with regard to how externally controllable parameters affect the resulting spheromak performance. The overall goal of our study is to inform the design and operational parameters of a future proof-of-principle spheromak experiment. Our calculations start from vacuum magnetic fields and model multiple distinct phases of evolution. Results indicate that modest changes to the design and operation of past experiments, e.g. SSPX [E.B. Hooper et al. PPCF 2012], could have significantly improved the plasma-current injector coupling efficiency and performance, particularly with respect to peak temperature and lifetime. While we frequently characterize performance relative to SSPX, our conclusions extrapolate to fundamentally different experimental designs. We also explore adiabatic magnetic compression of spheromaks, which may allow for a small-scale, high-performance and high-yield pulsed neutron source.

*This work is supported by DAPRA under Grant No. N66001-14-1-4044.

YP11 13 Conservation Laws for Gyrokinetic Equations for Large Perturbations and Flows* ANDRIS DIMITS, LLNL Gyrokinetic theory has proved to be very useful for the understanding of magnetized plasmas, both to simplify analytical treatments and as a basis for efficient numerical simulations. Gyrokinetic theories were previously developed [1-3] in two extended orderings that are applicable to large fluctuations and flows as may arise in the tokamak...
edge and scrapeoff layer. In the present work, we cast the resulting equations in a field-theoretical variational form, and derive, up to second order in the respective orderings, the associated global and local energy and (linear and toroidal) momentum conservation relations that result from Noether’s theorem. The consequences of these for the various possible choices of numerical discretization used in gyrokinetic simulations are considered.

*Prepared for US DOE by LLNL under Contract DE-AC52-07NA27344 and supported by the U.S. DOE, OFES.


YP11 14 Generating uniform, non-equilibrium, mid- to high-Z plasmas for radiative properties studies at the Omega laser facility* G. ELIJAH KEMP, L.C. JARROTT, E.V. MARLEY, R.F. HEETER, D.A. LIEDAHL, C.W. MAUCHE, P.K. PATEL, M.B. SCHNEIDER, K. WIDMANN, M.E. FOORD, LLNL. Recent experiments and theoretical work are focused on improving our non-local thermodynamic equilibrium (NLTE) atomic models, important for understanding intense laser-heated plasma such as those found in inertial confinement fusion (ICF) hohlraums and high-energy-density (HED) experiments. These hot (multi-keV), highly ionized plasmas, require complex NLTE atomic physics modeling to predict the radiation emission and transport. A laser-heated, buried-layer target platform on the Omega laser facility is being developed for the purposes of benchmarking our atomic physics models – plasma density and temperature uniformity of the mid- to high-Z buried-layer are critical to this work. We describe our radiation-hydrodynamic simulations used to understand the spatial and temporal evolution of the density, temperature and x-ray emission. Comparisons with Omega data along with designs to push the platform to more extreme conditions on the National Ignition Facility will be presented.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

YP11 15 An Ionization and Equation of State Model for Dense, Plasma Mixtures* LIAM STANTON, LAWRENCE LIVERMORE NATIONAL LABORATORY ROBERT ARGUS, OLGA DORABIALA, ZANDER KELLEY, BRANDON SRIPTIMONWAN, Institute for Pure and Applied Mathematics CHRISTIAN SCULLARD, FRANK GRAZIANI, LAWRENCE LIVERMORE NATIONAL LABORATORY YAN YAN SHEN, california state university, Northridge MICHAEL MURILLO, Michigan State University Almost all high energy-density physics experiments involve a multitude of species, which introduces nontrivial challenges to the models for both theoretical and practical reasons. To make matters worse, the ion species will be composed of multiple ionization states themselves. The theoretical connection to the single-species properties, such as the transport coefficients or equations of state, is rarely as straightforward as a simple superposition. Additionally, our knowledge of such mixtures must span orders of magnitude in temperature and density, and impurities from higher-Z elements can fundamentally change the physical properties of the plasma as well. Here, we present a new model that can accurately and efficiently predict ionization, thermodynamic and correlational properties of dense plasma mixtures over a wide range parameter. This model is not only applicable to mixtures of an arbitrary number of ionic components, but it resolves properties of individual ionization states as well.

YP11 16 Particle-in-cell simulations of hot electron generation with high intensity IR laser in shock ignition regime* JUN LI, SHUZHANG, CENTER FOR ENERGY RESEARCH, Unlv of california - san diego ELI BORWICK, CHUANG REN, University of rochester FARHAT BEG, Center for Energy Research, Unlv of california - san diego MINGSHENG WEI, General Atomicis Experiments [1] conducted on OMEGA EP laser facility with high-intensity, multi-kJ IR laser (5×10^{19}W/cm^2, 2.5kJ, 100 ps) have shown strongly directional hot electrons with moderate temperature (90 keV), which is favorable for electron assisted shock ignition. We performed 2-dimensional particle-in-cell (PIC) simulations using the OSIRIS code to study the hot electron generation by laser plasma instabilities(LPI) in the experiments. We aimed at investigating the hot electron energy fraction, temperature and angular distribution and the corresponding LPIs contribution. The simulation results show SRS is the dominant LPI. The hot electrons generated by SRSs are directional with a half angle of 23 degree, and the temperature of the hot electrons is 81 keV, which agrees very well with the experiments. More details of the simulation results will be presented in the meeting. The research used resources of the National Energy Research Scientific Computing Center.

*This work was supported by the Air Force Office of Scientific Research under Award Number FA 9550-14-1-0282; by DOE under Grant No. DE-SC0014666, DE-NA0002730.


YP11 17 Particle transport in the vicinity of divertor separatrix* Y. NISHIMURA, J.C. LYU, Institute of Space and Plasma Sciences, national Cheng kung university Guiding center orbit following code in a tokamak edge geometry is developed which connects straight field line coordinate system (away from the separatrix) and Cartesian coordinate system (in the vicinity of the separatrix) smoothly in the equation of motion [1]. In the presence of magnetic stochasticity [2,3] charged particles in the closed magnetic field line region can be transported to the open field line region and then hit the divertor plates within several toroidal transits. Our preliminary studies suggest finite heat load both on the inner and outer divertor plates. Energy spectrum of particles reaching the plates (which differs from that of the bulk plasma) as function of imposed magnetic stochasticity, is analyzed.

*This work is supported by Taiwan MOST 104-2112-M-006-019.

1 Coordinate transformations x = x(ψ, θ), y = y(ψ, θ), ψ = ψ(x, y), θ = θ(x, y) are obtained by solving magnetic field line equation.

YP11 18 Foam-lined hohlraums at the National Ignition Facility* CLIFF THOMAS, Lawrence Livermore Natl Lab Indirect drive inertial confinement fusion (ICF) is made difficult by hohlraum wall motion, laser backscatter, x-ray preheat, high-energy electrons, and specular reflection of the incident laser (i.e. glint). To mitigate, we line the hohlraum with a low-density metal foam, or tamper, whose properties can be readily engineered (opacity, den-
sity, laser absorption, ion-acoustic damping, etc.). We motivate the use of low-density foams for these purposes, discuss their development, and present initial findings. Importantly, we demonstrate that we can fabricate a 200-500 µm thick liner at densities of 10-100 mg/cm³ that could extend the capabilities of existing physics platforms. The goal of this work is to increase energy coupled to the capsule, and maximize the yield available to science missions at the National Ignition Facility.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

YP11 19 Hybrid laser-plasma wakefield acceleration BERNHARD HIDDING, THOMAS HEINEMANN, PAUL SCHERKLI, DANIEL ULLMANN, ANDREW BEATON, University of Strathclyde Laser wakefield accelerators (LWFA) can produce electron bunches with characteristics which suggest they are highly suitable to be used as drivers for electron-beam driven plasma wakefield accelerators (PWFA) [1]. The presentation will report on recent experimental results and conceptual advances which substantiate this idea. It looks as if hybrid LWFA-PWFA systems are highly promising systems to harness specific advantages of PWFA (no dephasing, long acceleration distances, wide potential for ionization injection schemes) realized in these truly compact systems.


3O. Karger et al., to be submitted.

YP11 20 Multigrid treatment of implicit continuum diffusion* MANAURE FRANCISQUEZ, BEN ZHU, BARRETT ROGERS, Dartmouth College Implicit treatment of diffusive terms of various differential orders common in continuum mechanics modeling, such as computational fluid dynamics, is investigated with spectral and multigrid algorithms in non-periodic 2D domains. In doubly periodic time dependent problems these terms can be efficiently and implicitly handled by spectral methods, but in non-periodic systems solved with distributed memory parallel computing and 2D domain decomposition, this efficiency is lost for large numbers of processors. We built and presented here a multigrid algorithm for these types of problems which outperforms a spectral solution that employs the highly optimized FFTW library. This multigrid algorithm is not only suitable for high performance computing but may also be able to efficiently treat implicit diffusion of arbitrary order by introducing auxiliary equations of lower order. We test these solvers for fourth and sixth order diffusion with idealized harmonic test functions as well as a turbulent 2D magnetohydrodynamic simulation. It is also shown that an anisotropic operator without cross-terms can improve model accuracy and speed, and we examine the impact that the various diffusion operators have on the energy, the entrophy, and the qualitative aspect of a simulation.

*This work was supported by DOE-SC-0010508. This research used resources of the National Energy Research Scientific Computing Center (NERSC).

YP11 21 Creating laboratory gamma-ray bursts with 10²¹ W.cm⁻² laser EDISON LIANG, WILLIE LO, Rice University

YP11 22 Status of parallel Python-based implementation of UEDGE* M.V. UMANSKY, A.Y. PANKIN, T.D. ROGNLIEN, A.M. DIMITS, A. FRIEDMAN, I. JOSEPH, LLNL The tokamak edge transport code UEDGE [1] has long used the code-development and run-time framework Basis [2]. However, with the support for Basis expected to terminate in the coming years, and with the advent of the modern numerical language Python, it has become desirable to move UEDGE to Python, to ensure its long-term viability. Our new Python-based UEDGE implementation takes advantage of the portable build system developed for FACETS [3]. The new implementation gives access to Python’s graphical libraries and numerical packages for pre- and post-processing, and support of HDF5 simplifies exchanging data. The older serial version of UEDGE has used for time-stepping the Newton–Krylov solver NKSOL. The renovated implementation uses backward Euler discretization with nonlinear solvers from PETSc [4], which has the promise to significantly improve the UEDGE parallel performance [5]. We will report on assessment of some of the extended UEDGE capabilities emerging in the new implementation, and will discuss the future directions.

*Work performed for U.S. DOE by LLNL under contract DE-AC52-07NA27344.


5McCourt et al., Comp. Science and Discovery 5, 014012 (2012).

YP11 23 POST-DEADLINE

YP11 24 An Extension of the Miller Equilibrium Model into the X-Point Region* M.D. HILL, R.W. KING, W.M. STACEY, Georgia Institute of Technology The Miller equilibrium model [1] has been extended to better model the flux surfaces in the outer region of the plasma and scrape-off layer, including the poloidally non-uniform flux surface expansion that occurs in the X-point region(s) of diverted tokamaks. Equations for elongation and triangularity are modified to include a poloidally varying component and grad-r, which is used in the calculation of the poloidal magnetic field, is rederived. Initial results suggest that strong quantitative agreement with experimental flux surface reconstructions and strong qualitative agreement with poloidal magnetic fields can be obtained using this model. Applications [2] are discussed. A major new application is the automatic generation of the computation mesh in the plasma edge, scrape-off layer, plenum and divertor regions for use in the
GTNEUT [3] neutral particle transport code, enabling this powerful analysis code to be routinely run in experimental analyses.

*Work supported by US DOE under DE-FC02-04ER54698.


YP11 25 Blobs and drift wave dynamics YANZENG ZHANG, SERGEI KRASHENINNIKOV, Univ of California - San Diego PLASMA PHYSICS GROUP TEAM, PLASMA PHYSICS GROUP TEAM The modified Hasegawa-Mima equation retaining all nonlinearities is investigated from the point of view of the formation of blobs. The linear analysis shows that the amplitude of drift wave packet propagating in the direction of decreasing background plasma density increases and eventually saturates due to nonlinear effects. Nonlinear modification of time averaged plasma density profile results in the formation of large amplitude modes locked in x-direction but still propagating in y-direction, which resembles experimentally observed chain of blobs propagating in poloidal direction. Such specific density profiles, causing the locking of drift waves can form naturally at the edge of tokamak due to neutral ionization source. As a result, locked modes can grow in situ due to plasma instabilities, e.g. caused by finite resistivity. Also modulation instability (in poloidal direction) of locked modes can result in a blob like burst of plasma density.

YP11 26 Micro hollow cathode discharge jets utilizing solid fuel DEJAN NIKIC, Boeing Micro hollow cathode discharge devices with a solid fuel layer embedded between the electrodes have demonstrated an enhanced jetting process. Outlined are series of experiments in various pressure and gas conditions as well as vacuum. Examples of use of these devices in series and parallel configurations are presented. Evidence of utilization of solid fuel is obtained through optical spectroscopy and analysis of remaining fuel layer.

YP11 27 Stability and structure of fields of a flow with a hydrodynamic discontinuity DANII ILYIN, Caltech YASUHIDE FUKUMOTO, Kyushu University, Japan WILLIAM GODDARD, Caltech SNEZHANA ABARZHI, The University of Western Australia We consider from a far field the evolution of a hydrodynamic discontinuity separating incompressible ideal fluids of different densities, with mass flow across this interface. By solving the boundary value problem and finding fundamental solutions of linearized dynamics, we directly link interface stability to structure of the flow fields. We find that classic Landau’s system of equations for the Landau-Darrieus instability has a degenerate and singular character. Eliminating this degeneracy leads to appearance of a neutrally stable solution whose vortical field can seed the instability. We further find that the interface is stable if the flux of energy fluctuations produced by the perturbed interface is small compared to the flux of kinetic energy across the planar interface. The interface is unstable otherwise. Landau’s solution is consistent with the latter case.

YP11 28 Maximum initial growth-rate of strong-shock-driven Richtmyer-Meshkov instability* SNEZHANA I. ABARZHI, The University of Western Australia AKLANT K. BHOWMICH, Carnegie Mellon University, USA ZACHARY R. DELL, The Ohio State University, USA ARUN PANDIAN, Carnegie Mellon University, USA MILOS STANIC, FluidDyna GmbH, Germany ROBERT F. STELLINGWERF, Stellingwerf Consulting, USA NORA C. SWISHER, Carnegie Mellon University, USA We focus on classical problem of dependence on the initial conditions of the initial growth-rate of strong shocks driven Richtmyer-Meshkov instability (RMI) by developing a novel empirical model and by employing rigorous theories and Smoothed Particle Hydrodynamics (SPH) simulations to describe the simulations data with statistical confidence in a broad parameter regime. For given values of the shock strength, fluids’ density ratio, and wavelength of the initial perturbation of the fluid interface, we find the maximum value of RMI initial growth-rate, the corresponding amplitude scale of the initial perturbation, and the maximum fraction of interfacial energy. This amplitude scale is independent of the shock strength and density ratio, and is characteristic quantity of RMI dynamics. We discover the exponential decay of the ratio of the initial and linear growth-rates of RMI with the initial perturbation amplitude that excellently agrees with available data.

*National Science Foundation, USA.

YP11 29 Stability and structure of fields of a flow with a hydrodynamic discontinuity DV ILYIN, WA GODDARD III, California Institute of Technology, USA Y FUKUMOTO, Kyushu University, Japan SI ABARZHI, The University of Western Australia, AU We consider from a far field the evolution of a hydrodynamic discontinuity separating incompressible ideal fluids of different densities, with mass flow across this interface. By solving the boundary value problem and finding fundamental solutions of linearized dynamics, we directly link interface stability to structure of the flow fields. We find that classic Landau’s system of equations for the Landau-Darrieus instability has a degenerate and singular character. Eliminating this degeneracy leads to appearance of a neutrally stable solution whose vortical field can seed the instability. We further find that the interface is stable if the flux of energy fluctuations produced by the perturbed interface is small compared to the flux of kinetic energy across the planar interface. The interface is unstable otherwise. Landau’s solution is consistent with the latter case.

YP11 30 Temperature Measurements of High-Z Plasma Exiting the Laser Entrance Hole of Ignition Scale Depleted Uranium Hohlraums NICHOLAS PARRILLA, Case Western Reserve University JOE RALPH, BEN BACHMANN, CLEMENT GoyON, EDUARD DEWALD, Lawrence Livermore National Laboratory The temperature profile from the Laser Entrance Hole to 3.5 mm from the exit point was measured for plasma with high atomic number (high-Z) of Depleted Uranium ignition scale hohlraums. Each hohlraum was filled with 0.6 mg/cc He as part of the high foot CH campaign. Temperature of the flowing plasma is measured by fitting the velocity distribution to a Maxwellian and considering the Planckian spectral distributions with and without a 42 um Ge filter. The two spectra are then compared to determine the temperature of the high-Z plasma.

YP11 31 Experimental evaluation of opacity in the deep solar interior using the concept of “microscopic equivalence” YAIR KURZWEIL, GIORA HAZAK, NRCN, Israel JAMES BAILEY, TAISUKE NAGAYAMA, Sandia National Lab, USA A problem for stellar astrophysics is that existing opacity models have been called into question both by experiments [1] and by solar model comparisons with helioseismology, but an alternative opacity model does not yet exist. Importantly, the experiments measured opacity only
for iron, at 182 eV – 195 eV temperatures ($T_e$) comparable to the value at $\sim0.7$. Experimental validation of opacity models at higher $T_e$ and density ($n_e$) are required to understand the entire Sun. Unfortunately, controlled transmission measurements at the required conditions are extremely difficult to achieve at lab. We propose to help resolve this dilemma using experiments at achieved conditions combined with the “microscopic equivalence” principle. Thus, using this principle, we can use a lower-atomic-number surrogate element to test opacity model physics important for iron at higher $T_e$ and $n_e$ than can be reached in present experiments. Theoretical modeling to evaluate this idea, using the CRSTA[2,3]/PRCRSTA [4] models will be discussed.

$^{1}$J. E. Bailey et al., Nature 517, 56 (2015).

YP11 32 Weibel instability in relativistic electron positron plasma ZAHIDA EHSAN, COMSATS Institute of Information Technology, Lahore 54000, Pakistan. NODAR TSINTSADZE, Faculty of Exact and Natural Sciences and Andronovich Institute of Physics, Javakhishvili Tbilisi University, Tbilisi 0128, Georgia PETER YOON, IPST, University of Maryland, College Park, MD 20742-2431, USA We consider a situation in which the interaction of relativistically intense EM waves with an isotropic electron positron plasma takes place, i.e., we consider short pulse lasers with intensity up to $10^{21}$ W/cm$^2$, in which the photon density is of the order of $10^{9}$ cm$^{-3}$ and the strength of electric field $E = 10^9$ statvolt/cm. Such a situation is possible in astrophysical and laboratory plasmas which are subject to intense laser radiation, thus leading to nonthermal equilibrium field radiations. Such interaction of the superstrong laser radiation with an isotropic pair plasma leads to the generation of low frequency electromagnetic EM waves and in particular a quasistationary magnetic field. When the relativistically circularly polarized transverse EM wave propagates along $z$-axis, it creates a ponderomotive force, which affects the motion of particles along the direction of its propagation. On the other hand, motion of the particles across the direction of propagation is determined by the ponderomotive potential. Moreover dispersion relation for the transverse EM wave using a special distribution function, which has an anisotropic form, is derived and is subsequently investigated for a number of special cases. In general, it is shown that the growth rate of the EM wave strongly depends upon its intensity.

YP11 33 A new mode and Cherenkov instability in pair plasma ZAHIDA EHSAN, COMSATS Institute of Information Technology, Lahore 54000, Pakistan. NODAR TSINTSADZE, Faculty of Exact and Natural Sciences and Andronovich Institute of Physics, Javakhishvili Tbilisi University, Tbilisi 0128, Georgia HASSAN SHAH, GC University Lahore 54000 Lahore RAOU, Trines, Central Laser Facility, STFC Rutherford Appleton Laboratory, Didcot OX11 0QX, United Kingdom Positive and negative ions forming the so-called pair plasma differing in sign of their charge but asymmetric in mass and temperature support a new acoustic-like mode. The condition for the excitation of ion sound wave through electron beam induced Cherenkov instability is also investigated. This beam can generate a perturbation in the pair ion plasmas in the presence of electrons when there is number density, temperature, and mass difference in the two species of ions. Basic emphasis is on the focusing of ion sound waves, and we show how, in the area of localization of wave energy, the density of pair particles increases while electrons are pushed away from that region. Further, this localization of wave is dependent on the shape of the pulse. Considering the example of pancake and bullet shaped pulses, we find that only the former leads to compression of pair ions in the supersonic regime of the focusing region. Here, possible existence of regions where pure pair particles can exist may also be speculated which is not only useful from the academic point of view but also to mimic the situation of plasma (electron positron asymmetric and symmetric) observed

YP11 34 Expressions for Fields in the ITER Tokamak STEPHEN SHARMA, University of California, Berkeley The two most important problems to be solved in the development of working nuclear fusion power plants are: sustained partial ignition and turbulence. These two phenomena are the subject of research and investigation through the development of analytic functions and computational models. Ansatz development through Gaussian wave-function approximations, dielectric quark models, field solutions using new elliptic functions, and better descriptions of the polynomials of the superconducting current loops are the critical theoretical developments that need to be improved. Euler-Lagrange equations of motion in addition to geodesic formulations generate the particle model which should correspond to the Dirac dispersive scattering coefficient calculations and the fluid plasma model. Feynman-Hellman formalism and Heaviside step functional forms are introduced to the fusion equations to produce simple expressions for the kinetic energy and loop currents. Conclusively, a polynomial description of the current loops, the Biot-Savart field, and the Lagrangian must be uncovered before there can be an adequate computational and iterative model of the thermonuclear plasma.

YP11 35 Symmetry and Asymmetry FLORENTIN SMARANDACHE, University of New Mexico In some examples, the Special Theory of Relativity considers a symmetric time dilation of two inertial reference frames. But in other examples, such as in the GPS position system where the satellite clocks are slowed because of the satellite velocity, it considers an asymmetric time dilation of two inertial reference frames. As in the case of the Twin Paradox, the time dilation was simply... abandoned! Again an auto-contradiction.

YP11 36 Unmatter Plasma revisited FLORENTIN SMARANDACHE, University of New Mexico Unmatter Plasma is a novel form of plasma, exclusively made of matter and its antimatter counterpart. The electron-positron beam plasma was generated in the laboratory in the beginning of 2015. This experimental fact shows that unmatter, a new form of matter that is formed by matter and antimatter bind together (mathematically predicted since 2004) really exists. That is the electron-positron plasma experiment of 2015 is the experimentum crucis verifying the mathematically predicted unmatter. Unmatter is formed by combinations of matter and antimatter that bind together, or by long-range mixture of matter and antimatter forming a weakly-coupled phase. Binding and bound state means that the interaction is sufficiently strong to tie together the particles of a system, therefore hindering them from becoming free. For example, a usual liquid is a bound state of molecules, while a gas is an un-bounded where the molecules can move freely in successive collisions.

scheme for the calculations of gyrokinetic MHD and its associated equilibrium is discussed related a recent paper on the subject [1]. The scheme is based on the time-dependent gyrokinetic vorticity equation and parallel Ohm’s law, as well as the associated gyrokinetic Ampere’s law. This set of equations, in terms of the electrostatic potential, \( \phi \), and the vector potential, \( \mathbf{A} \), supports both spatially varying perpendicular and parallel pressure gradients and their associated currents. The MHD equilibrium can be reached when \( \mathbf{\nabla} \cdot (J_1 + J_2) = 0 \) and the associated magnetic islands. Examples in simple cylindrical geometry will be given.

*The present work is partially supported by US DoE Grant DE-AC02-09CH11466.


YP11 38 A new linear plasma device for various edge plasma studies at SWIP* MIN XI, PENGFEI ZHENG, *Southwestern Institute of Physics GEORGE TYNAN, Jacobs School of Engineering, UC San Diego TONG CHE, ZHANHUI WANG, DONG GUO, RAN WEI, *Southwestern Institute of Physics To facilitate the plasma-material interactions (PMI) studies, Southwestern Institute of Physics (SWIP) has constructed a linear plasma device. It is comprised of a source chamber (\( \Phi \) 0.4 m), a target chamber (\( \Phi \) 0.9 m), 15 magnets with different sizes, and power supplies with the total power of a few hundred kilowatts, etc. A maximum magnetic field of 0.3 Tesla along the axial direction can be produced. The current of each of the 15 magnets can be independently controlled. More than 60 ports are available for diagnostics, with the sizes vary from \( \Phi \) 50 mm to \( \Phi \) 150 mm. Rectangular ports of 190 mm \( \times \) 270 mm are also available. 12 ports looking at the sample holder are specially designed for ion beam injection, of which the axes are 25 \( \times \) 25 \( \times \) 90 mm and 20 \( \times \) 20 \( \times \) 90 mm to the chamber axis. The device is equipped with a LaB6 hot cathode plasma source, which is able to generate steady-state H/D/He plasmas with a diameter of \( \sim \Phi \) 100 mm, density of \( \sim 1 \times 10^{19} / \text{m}^3 \), and a particle flux of \( 10^{22} \sim 10^{23} \text{ n/m}^2 \text{s} \). The electron temperature is usually \( \sim \text{a few eV} \). Further, a Helicon RF plasma source is also planned for plasma transport studies.

*Int’l Sci & Tech Cooperation Program of China (No. 2015DFA61760).

YP11 39 Divertor detachment and power dissipation by Neon impurity gas seeding DEZHENG WANG, DAOYUAN LIU, CHAOFEI SANG, *School of Physics, Dalian University of Technology, Dalian 116024, China LIANG WANG, *Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, People’s Republic of China Scrape-Off Layer Plasma Simulation (SOLPS) code package, has been applied to study the mechanism of neon gas seeding induced radiation power dissipation. Impurity seeding is a conventional method to achieve divertor detachment for the tokamak devices with metallic plasma facing materials (PFMs). Neon (Ne) is one of the typical seeding gases. It is known that the impurities can increase the power radiation significantly; however, the role of different charge state at different locations is still unclear. By comparing distributions of the line radiation losses and the density of different charge states of neon, it is found that the power radiation is not only decided by the impurities density, e.g. the radiation loss is dominated by Ne5+, however, Ne8+ has the highest peak density, but also decided by the impurity distributions. The main reason is that power radiation is also a function of electron temperature. In the tokamak, different locations have different \( T_e \), therefore, it can influence the power radiation rates. By doing a large level of power scan, the power radiation by Ne is evaluated, which can help to understand the impurity-induced detachment for the future reactor.

YP11 40 Solving free-plasma-boundary problems with the SIESTA MHD code R. SANCHEZ, H. PERAZA-RODRIGUEZ, J.M. REYNOLDS-BARREDO, V. TRIBALDOS, Univ Carlos III De Madrid, SPAIN J. GEIGER, Max-Planck-Institut fur Plasmaphysik, Greifswald, GERMANY S.P. HIRSHMAN, M. CIANCIOSA, Oak Ridge National Laboratory, Tennessee, USA SIESTA [1] is a recently developed MHD equilibrium code designed to perform fast and accurate calculations of ideal MHD equilibria for 3D magnetic configurations. It is an iterative code that uses the solution obtained by the VMEC code [2] to provide a background coordinate system and an initial guess of the solution. The final solution that SIESTA finds can exhibit magnetic islands and stochastic regions. In its original implementation, SIESTA addressed only fixed-boundary problems. This fixed boundary condition somewhat restricts its possible applications. In this contribution we describe a recent extension of SIESTA [3] that enables it to address free-plasma-boundary situations, opening up the possibility of investigating problems with SIESTA in which the plasma boundary is perturbed either externally or internally. As an illustration, the extended version of SIESTA is applied to a configuration of the W7-X stellarator.


YP11 41 Global Surrogates for the Upshift of the Critical Threshold in the Gradient for ITG Driven Turbulence* CRAIG MICHOSKI, University of Texas at Austin SALOMON JAN-HUNEN, University of Saskatchewan DANIAL FAGHIHI, University of Texas at Austin VARIS CAREY, University of Colorado at Denver ROBERT MOSER, University of Texas at Austin. The suppression of micro-turbulence and ultimately the inhibition of large-scale instabilities observed in tokamak plasmas is partially characterized by the onset of a global stationary state. This stationary attractor corresponds experimentally to a state of “marginal stability” in the plasma. The critical threshold that characterizes the onset in the nonlinear regime is observed both experimentally and numerically to exhibit an upshift relative to the linear theory. That is, the onset in the stationary state is up-shifted from those predicted by the linear theory as a function of the ion temperature gradient \( R_I / L_T \). Because the transition to this state with enhanced transport and therefore reduced confinement times is inaccessible to the linear theory, strategies for developing nonlinear reduced physics models to predict the upshift have been ongoing. As a complement to these effort, the principle aim of this work is to establish low-fidelity surrogate models that can be used to predict instability driven loss of confinement using training data from high-fidelity models.

*DE-SC0008454 and DE-AC02-09CH11466.

YP11 42 Stochastic acceleration of electrons from multiple uncorrelated plasma waves* DAVID GEE, PIERRE MICHEL, Lawrence Livermore National Laboratory, Livermore, California 94551, USA JONATHAN WURTELE, Physics Department, University of California, Berkeley, California 94720 One-dimensional theory puts a strict limit on the maximum energy attainable by an
electron trapped and accelerated by an electron plasma wave (EPW). However, experimental measurements of hot electron distributions accelerated by stimulated Raman scattering (SRS) in ICF experiments typically show a thermal distribution with temperatures of the order of the kinetic energy of the resonant EPW’s (Thot $\sim m_v^2$), where $v_p$ is the phase velocity of the EPW’s driven by SRS) and no clear cutoff at high energies. In this project, we are investigating conditions under which electrons can be stochastically accelerated by multiple uncorrelated EPW’s, such as those generated by incoherent laser speckles in large laser spots like the ones used on NIF ($\sim$-mm-size), and reproduce distributions similar to those observed in experiments.

"This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

†Also at Physics Department, University of California, Berkeley, California 94720.

YP11 43 Surface Modification of Nonwoven fabrics by Atmospheric Brush Plasma LUTFI OKSUZ, Suleyman Demirel University EMRE UYGUN, FERHAT BOZDUMAN, Teknopark, Plazma Tek., Suleyman Demirel University GOZDE YURDABAK KARACA, Department of Chemistry, Faculty of Arts and Sciences, Suleyman Demirel University ORKUN NURI ASAN, Teknopark, Plazma Tek., Suleyman Demirel University AYSEGUL UYGUN OKSUZ, Department of Chemistry, Faculty of Arts and Sciences, Suleyman Demirel University Polypropylene nonwoven fabrics (PPNF) are used in disposable absorbent articles, such as diapers, feminine care products, wipes. PPNF need to be wettable by water or aqueous-based liquid. Plasma surface treatment/modification has turned out to be a well-accepted method since it offers superior surface property enhancement than other chemical methods. The cold plasma brush can most efficiently use the discharge power as well as the plasma gas for material and surface treatment. The very low power consumption of such an atmospheric argon plasma brush provides many unique advantages in practical application. The purpose of this study was to reveal the effectiveness of non-thermal atmospheric plasma brush in surface wettability and modification of two different nonwoven surfaces.

YP11 44 Atmospheric Plasma Blade for Surgical Purposes LUTFI OKSUZ, Suleyman Demirel University GOZDE YURDABAK KARACA, Department of Chemistry, Faculty of Arts and Sciences, Suleyman Demirel University EMIR OZKAPTAN, EMRE UYGUN, Teknopark, Plazma Tek., Suleyman Demirel University AYSEGUL UYGUN OKSUZ, Department of Chemistry, Faculty of Arts and Sciences, Suleyman Demirel University Atmospheric plasma cut is a process at the minimum level due to the ions, radicals and free electrons generated by the active electrode and target tissue. Atmospheric plasma cutting devices provide significant advantages as a non-contact electrocautery system that can operate in isotonic environment. During operations where plasma cutting is applied, bleeding is controlled and the side effects that would create the isotonic environment are eliminated. In this study in vivo and in vitro studies will be carried out by producing and optimizing the atmospheric plasma blade. Once the optimum parameters of the instrument are determined, in vivo studies will be performed and the pathology results will be evaluated.

YP11 45 Electron-impact excitation and recombination of molecular cations in edge fusion plasma: application to H2+ and BeD+ NICOLINA POP,∗ Department of Fundamental of Physics for Engineers, Politehnica University Timisoara, Romania FELIX LACOB, Physics Faculty, West University of Timișoara, Timișoara, Romania ZSOLT MEZEI, Laboratoire Aime Cotton, CNRS, ENS Cachan and Univ. Paris-Sud, Orsay, France OUSMANOU MO-TAPON, Department of Physics, Faculty of Sciences, University of Douala, Cameroon SEBASTIEN NIYONZIMA, Department of Physics, Faculty of Sciences, University of Burundi, Bujumbura, Burundi IOAN SCHNEIDER, Laboratoire Ondes et Milieux Complexes, CNRS, Univ. du Havre, France Dissociative recombination, ro-vibrational excitation and dissociative excitation of molecular cations with electrons are major elementary process in the kinetics and in the energy balance of astrophysically-relevant ionized media (supernovae, interstellar molecular clouds, planetary ionospheres, early Universe), in edge fusion and in many other cold media of technological interest. For the fusion plasma edge, extensive cross sections and rate coefficients have been produced for reactions induced on HD+, H2+ and BeD+ using the Multichannel Quantum Defect Theory (MQDT). Our calculations resulted in good agreement with the CRYRING (Stockholm) and TSR (Heidelberg) magnetic storage ring results, and our approach is permanently improved in order to face the new generation of electrostatic storage rings, as CSR (Heidelberg) and DESIREE (Stockholm).

∗Member of APS Reciprocal Society: European Physics Society.

YP11 46 Analytical formulation for potential energy surfaces in molecular collision dynamics of cold plasma FELIX IACOB, Faculty of Physics, West University of Timișoara, Romania NICOLINA POP, Department of Fundamental of Physics for Engineers, Politehnica University of Timisoara, Romania We consider the characteristic discharge chemistry processes in cold plasma, which are mainly driven by free electrons, but also by ion-molecule reactions. In order to obtain a better description of the collision between two molecules, a form for the molecular interaction potential should be assumed. Determining theoretically the rate coefficients, first one has to focus on electronic calculations of potential energy surfaces (PES), in BO approximation, further used to study the motion of the nuclei (collision dynamics). Currently used are ab-initio models, in this work an analytical expression of potential energy surface is derived and used to describe the molecular dynamics in cold plasmas. A specially attention was given to the exotic cases where the present data fully support a model that assumes potential barriers or bottle necks. Some dissociative recombination cross section where calculated using this new analytical form in the case of electron reacting with HD+. Also the Maxwell-Boltzmann rates have been calculated being of particular interest to the plasma research. The result are compared with literature. Low temperature experiments have shown that there can be significant deviations from such simple models.

YP11 47 Simulations of collisionless counter-propagating plasma flows in support of two-wire implosion experiments* JAMES CAPLINGER, VLADIMIR SOTNIKOV, ANDREW HAMILTON, Air Force Research Laboratory, WPAFB, OH PLASMA PHYSICS SENSORS LABORATORY TEAM One of the simplest configurations leading to colliding plasma flows is created by driving strong currents through a pair of parallel wires. The azimuthal magnetic fields generated around each wire, and the Ohmic current dissipation and heating occurring upon wire evaporation, launches powerful radial outflows of magnetized plasmas. Upon colliding they form a flow pattern suggestive of magnetic field reconnection, and the development of various plasma instabilities. In the current effort, we analyzed collision of two high-temperature precursor light ion plasma flows via PIC (Particle-In-Cell) simulations using LSP. The aim is to demonstrate the appearance of an
electric field parallel to the direction of a plasma flow. This field appears in colliding plasma flows due to the charge separation and is associated with the Buneman instability. It is responsible for the creation of ExB drift of electrons. Next, an interaction between drifting electrons and unmagnetized ions, moving parallel to them, lead to excitation of a modified Buneman instability in the frequency range close to the Lower-Hybrid frequency. Simulation results will allow us to identify the characteristics of nonlinear density fluctuations that appear in the process of such an interaction.

*This work was supported by the Air Force Office of Scientific Research.

YP11 48 Nonlinear Interaction of Naturally and Artificially Excited VLF and ELF Waves in the Ionosphere* VLADIMIR SOTNIKOV, JAMES CAPLINGER, TONY KIM, Air Force Research Laboratory, WPAFB, OH EUVGENY MISHIN, Air Force Research Laboratory, Kirtland AFB, NM We report on analysis of nonlinear parametric coupling between quasi-electrostatic whistler waves (also known as Lower Oblique Resonance (LOR) waves) and Extremely Low Frequency (ELF) fast magnetosonic waves to generate electromagnetic whistler waves. Natural and artificial VLF and ELF sources are analyzed. In the case of naturally excited VLF/ELF waves we show that nonlinear parametric coupling between the LOR and ELF waves suffices to explain the observed electromagnetic whistler waves in the plasmasphere boundary layer. In the case of artificial sources such as a loop antenna a great deal of the source power is radiated not as an electromagnetic whistler wave, but as a quasi-electrostatic LOR mode. Only a small percentage of the power is radiated as the electromagnetic whistler wave. We present new results on parametric interaction of LOR waves with ELF waves to demonstrate the possibility to overcome this difficulty. It will be shown that interaction of LOR waves gives rise to excitation of electromagnetic whistler waves. Additionally, particle-in-cell (PIC) simulations, which demonstrate the excitation and spatial structure of VLF waves excited by conventional and parametric sources will be presented.

*This work was supported by the Air Force Office of Scientific Research.

YP11 49 Investigations of spontaneous arc extinction in Cs-Ba plasma of highly-efficient switching converters ALEK SANDR MUSTAFAEV, Saint Petersburg Mining University, Russia VLADIMIR SOUKHOMLINOV, Saint Petersburg State University, Russia ARTIOM GRABOVSKII, EVGENIA SHTODA, Saint Petersburg Mining University, Russia This talk deals with the investigations of spontaneous arc extinction in the devices with a fine-mesh grid, operating in the collisionless mode, have been carried out. In order to study the mechanism of the arc extinction, the time dependencies of the luminosity of a series of CsI, BaII and Bal lines were obtained. The use of Cs-Ba mixture, where cesium is a plasma-forming component, allowed to obtain emission currents from the cathode up to 100 A/cm2 in Cs-pressure range 10^-3-10^-2 Torr and, thus, easily attain the electric power density of 5 kW/cm2 and the efficiency more than 95%1, 2. It has been established, that the arc extinction in the triode, having the fine-mesh, highly-transparent grid, is due to the high degree of atom ionization and to the escape of atoms from the spacing, while the large duration of the current pulse is determined by atom desorption from the electrodes.

YP11 50 Ultra-compact photoionization analyzers. Ecological monitoring application at hazardous production facilities ALEXANDER MUSTAFAEV,∗ JULIJA RASTVOROVA, FATIMA ARSLANNOVA, Saint-Petersburg Mining University It is generally recognized that careful implementation of ecological monitoring should be provided at hazardous production facilities continuously to protect the surrounding environment as well as health and safety of employees. However, the existing devices may not be able to control the environmental situation uninterrupted due to their technical characteristics or measurement methods. Developed by The Mining University Plasma Research Group ultra-compact photoionization analyzer is proposed as innovative equipment which creates the basis for a new measuring approach. The general operating principle is based on the patented method of stabilization of electric parameters – CES (Collisional Electron Spectroscopy). During the operation at the atmospheric pressure, the vacuum ultraviolet (UVV) photoionization sensor measures the energy of electrons produced by means of ionization with the resonance photons whose wavelength is situated in the UVV. A special software tool was developed to obtain the second-order derivative of the I–U characteristic, taken by the UVV sensor, to construct the characteristic electrons energy spectra. The portable analyzer with a unique set of parameters such as small size (10*10*1 mm), low cost, a wide range of recognizable molecules, great measurement accuracy at the atmospheric pressure can be effectively used both for rapid testing of air pollution load and the study of noxious factors that influence oil and gas industry employees.

∗Dr. Sci., Ph.D, Principal Scientist, Professor.

YP11 51 Hydro-scaling of DT implosions on the National Ignition Facility∗ PRAVESH PATEL, BRIAN SPEARS, DAN CLARK, Lawrence Livermore National Laboratory Recent implosion experiments on the National Ignition Facility (NIF) exceed 50 kJ in fusion yield and exhibit yield amplifications of >2.5-3x due to alpha-particle self-heating of the hot-spot. Two methods to increase the yield are (i) to improve the implosion quality, or stagnation pressure, at fixed target scale (by increasing implosion velocity, reducing 3D effects, etc.), and (ii) to hydrodynamically scale the capsule and absorbed energy. In the latter case the stagnation pressure remains constant, but the yield—in the absence of alpha-heating—increases as Y ~ S^4.5, where the capsule radius is increased by S, and the absorbed energy by S^4. With alpha-heating the increase with scale is considerably stronger. We present projections in the performance of current DT experiments, and the extrapolations to ignition, based on applying hydro-scaling theory and accounting for the effect of alpha-heating.

∗This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

YP11 52 Magnetic nanomotor fabrication by plasma coating method and its biological application LUTFI OKSUZ, Department of Physics, Faculty of Arts and Science, Suleyman Demirel University GOZDE YURDABAK KARACA, Department of Chemistry, Faculty of Arts and Sciences, Suleyman Demirel University EMRE UYGUN, Teknopark, Plasma Tek., Suleyman Demirel University AYSEGUL UYGUN OKSUZ, Department of Chemistry, Faculty of Arts and Sciences, Suleyman Demirel University
Nano/micro scale motors are exciting research area due to a wide range of application area especially offer considerable promise for the diagnosis and treatment of the diseases. In this scope, the preparation and characterization of Gold (Au) Nickel (Ni) nanomotors transport and their applications based on the detection of miRNA-21 will be examined. In addition, magnetic segment Ni which was coated by RF magnetron sputter technique on to the electrochemical synthesized Au nanowire can also be used to focus on the controlled movement and target. We propose a sensitive stable plasma coated magnetic nanomotor-based approach for miRNA-21 detection for simple and cancer diagnosis.

YP11 53 Determination of the profit rate of plasma treated production in the food sector ELIF CEREN GOK, Industrial Engineering, Antalya Science University EMRE UYGUN, Techno Park Plasma Tek Company, Suleyman Demirel University ESIN EREN, Department of Chemistry, Suleyman Demirel University, Faculty of Arts and Science LUTFI OKSUZ, Department of Physics, Faculty of Arts and Science, Suleyman Demirel University AYSEGUL UYGUN OKSUZ, Department of Chemistry, Suleyman Demirel University, Faculty of Arts and Science

Recently, plasma is one of an emerging, green processing technologies used for diverse applications especially food industry [1]. Plasma treatment proposes diverse opportunities in food industry such as surface decontamination, modification of surface properties and improvement in mass transfer with respect for foods and food-related compounds [1]. Sometimes manufacturers use chemical treatment to demolish pathogenic flora, but its capabilities are rather limited. New methods of food sterilization consisting of ionizing radiation, exposure to magnetic fields, high-power ultrasonic treatment are needed expensive equipment or have not yet been developed for industrial use. Plasma could be used for the above mentioned reasons. In this study, the profit rate of plasma treated production in food sector was calculated.

1S. A. Mir, M. A. Shah, and M. M. Mir, Food Bioprocess Technol. 9, 734 (2016).

YP11 54 Sheath and bulk expansion induced by RF bias in atmospheric pressure microwave plasma* JIMO LEE,‡ WOOJIN NAM, JAE KOO LEE, GUNSU YUN, Pohang University of Science and Technology A large axial volume expansion of microwave-driven plasma at atmospheric pressure is achieved by applying a low power radio frequency (RF) bias at an axial location well isolated from the original plasma bulk. The evolution of the plasma plume visualized by high speed ICCD imaging suggest that the free electrons drifting toward the bias electrode cause the prodigious expansion of the sheath, creating a stable plasma stream channel between the microwave and the RF electrodes. For argon plasma in ambient air, enhanced emissions of OH and N$_2$ spectral lines are measured in the extended plume region, supporting the acceleration of electrons and subsequent generation of radical species. The coupling of RF bias with microwave provides an efficient way of enlarging the plasma volume and enhancing the production of radicals.

*Work supported by the National Research Foundation of Korea under BK21+ program and Grant No. 2015R1D1A1A01061556 (Ministry of Education).

YP11 55 Mechanisms generating kappa distributions in plasmas* GEORGIOS LIVADIOTIS, Southwest Research Institute Kappa distributions have become increasingly widespread across plasma physics. Publication records reveal an exponential growth of papers relevant to kappa distributions. However, the vast majority of publications refer to statistical fits and applications of these distributions in plasmas. Up to date, there is no systematic analysis on the origin of kappa distributions, that is, the mechanisms that can generate kappa distributions in plasmas. The general scheme that characterizes these mechanisms is composed of two parts: (1) the generation of local correlations among particles, and (2) the thermalization, that is, the stabilization of the particle system into stationary states described by kappa distributions or combinations thereof. Several mechanisms are known in the literature, each characterized by a specific relationship between the plasma properties. These relationships serve as conditions that need to be fulfilled for the corresponding mechanisms to be applied in the plasma. Using these relationships, we identify three mechanisms that generate kappa distributions in the solar wind plasma: (i) Debye shielding, (ii) magnetic field binding, and (iii) thermal fluctuations, each one prevailing in different scales of the solar wind plasma and magnetic field properties.

*The work was supported in part by the project NNX17AB74G of NASA’s HGI Program.

YP11 56 Imaging and spectroscopy of optical transition radiation from thin foils irradiated by ultraintense laser pulse* LEE-JIN BAE, MINSANG CHO, YELIM JI, GYEONGBO KANG, MINJU KIM, SEONGHYEOK YANG, CHUINHONG YAP, BYOUNG-ICK CHO, Gwangju Inst Sci & Tech CHEONHA JEON, Institute for Basic Science Optical transition radiation (OTR) by relativistic electrons emerging the rear surface of target conveys numerous information on laser-target interaction. Imaging of the radiation shows the spatial distribution of hot electron beams. Spectrum of OTR infers the temporal structure of relativistic electron bunches. In this contribution, we present the OTR images and spectra from foil target with various thickness (100 nm – 10 um) irradiated by intense laser pulses up to $10^{20}$ W/cm$^2$. The significant modulation on OTR shape and spectra are observed from nano-foils at extremely high intensity. Pre-pulses also introduce significant difference in OTR spectra. Detailed data and possible mechanism for such modulations will be presented.

*This work was supported by NRF of Korea (No. NRF-2016R1A2B4009631 and NRF-2016H1A2A1909533) and the Institute for Basic Science.

YP11 57 Liquid Plasma Synthesis of Carbon Coated Iron Oxide Particles AYSEGUL UYGUN, Department of Chemistry, Suleyman Demirel University, Faculty of Arts and Science NOAH HERSHKOWITZ, College of Engineering, University of Wisconsin-Madison ESIN EREN, Department of Chemistry, Suleyman Demirel University, Faculty of Arts and Science EMRE UYGUN, Techno Park Plasma Tek Company, Suleyman Demirel University GAMZE CELIK COGAL, GOZDE YURDABAK KARACA, Department of Chemistry, Suleyman Demirel University, Faculty of Arts and Science SORIN MANOLACHE, College of Engineering, University of Wisconsin-Madison GUNASEKARAN SUNDARAM, OMER SADAK, Biological Systems Engineering, University of Wisconsin-Madison LUTFI OKSUZ, Department of Physics, Faculty of Arts and Science, Suleyman Demirel University Recently, magnetic metal or metal oxide nanoparticles encapsulated in carbon are important in biomedical applications [1]. The relevant reason to study toxicity of the magnetic nanoparticles coated by carbon is that they have great potential to contribute to cancer treatment. In this work, the synthesis of iron oxide nano-particles coated by graphitic carbon shells using pulsed plasma in liquid method. Short duration of
RF plasma discharge, low electrical energy and fast quenching of the surrounding media can let to synthesize various kinds of pure nanoparticles.

*Corresponding author: ayseguluygun@sdu.edu.tr, lutfiok-suz@sdu.edu.tr.

1. S. khabiabi et al., Artificial Cells, Nanomedicine and Biotechnology 45, 6 (2017).

YP11 58 2D High-Resolution Measurement of High Guide-Field Magnetic Reconnection in TS-3U Spherical Tokamak Merging Experiment QINGHONG CAO, MOE AKIMITSU, ASUKA SAWADA, HIROSHI TANABE, YASUSHI ONO, the University of Tokyo The TS-3U experiment performs magnetic reconnection with a strong guide field by merging two spherical tokamak plasmas. To observe the 2D configuration of the current sheet, we developed a high-resolution 2D magnetic probe array with 260 channels, arranged into 13x10 Bz components and 13x10 Br components, with up to 5 mm spatial resolution spread over a 40 cm x 30 cm poloidal area. The current density \( J_z \), the electric field \( E_t \), and the current sheet’s effective resistivity \( \eta_{eff} = \frac{L}{\eta} \) will therefore be followed during the reconnection process. Under a strong guide magnetic field, the sheet resistivity is expected to be almost classical because the sheet thickness is much larger than the ion gyroradius. But resistivity is observed to be anomalous with pileup and plasmoid formation appearing to regulate the reconnection speed. The anomalous increase in resistivity is being studied as a possible cause for the high power heating of fast magnetic reconnection.

YP11 59 Application of nonlocal plasma technology for controlling plasma conductivity CHENGXUN YUAN, Harbin Institute of Technology V. I. DEMIDOV, WVU A. A. KUDRYAVTSEV, I. P. KURYANDSKAYA, Harbin Institute of Technology T. V. RUDAKOVA, SPbGU Z. X. ZHOU, Harbin Institute of Technology A promising approach for better control of the plasma parameters involves the exploitation of peculiarities of plasmas with a nonlocal electron energy distribution. Nonlocal plasma technology (NLP-technology) is based on the effect of energetic electrons in the plasma volume. In this work, an experimental study of influence of the chemo-ionization processes on non-stationary plasma conductivity has been conducted. Due to energetic, supra-thermal, electrons, which appear in the chemo-ionization reactions, the highly non-equilibrium and time dependent nonlocal electron energy distribution function is formed. In such a plasma thermal electrons always have positive conductivity (mobility), while supra-thermal, energetic electrons may have negative conductivity in heavy (argon, krypton and xenon) noble gases dependently on conditions. Experiments demonstrate that this effect may lead to the non-monotonic temporal behavior of plasma conductivity and may potentially create the negative electron mobility.

YP11 60 Semiconductor nanostructures for plasma energetic systems ALEXANDER MUSTAFAEV,* ROSTISLAV SMERDOV, BORIS KLIMENKO, Saint Petersburg Mining University, Saint Petersburg, Russia In this talk we discuss the research results of the three types of ultrasmall electrodes namely the nanoelectrode arrays based on composite nanostructured porous silicon (PS) layers, porous GaP and nanocrystals of ZnO. These semiconductor materials are of great interest to nano- and optoelectronic applications by virtue of their high specific surface area and extensive capability for surface functionalization. The use of semiconductor (GaN) cathodes in photon-enhanced thermionic emission systems has also proved to be effective although only a few (less than 1%) of the incident photons exceed the 3.3 eV GaN band gap. This significant drawback provided us with a solid foundation for our research in the field of nanostructured PS, and composite materials based on it exhibiting nearly optimal parameters in terms of the band gap (1.1 eV). The band gap modification for PS nanostructured layers is possible in the range of less than 1 eV and 3 eV due to the existence of quantum confinement effect and the remarkable possibilities of PS surface alteration thus providing us with a suitable material for both cathode and anode fabrication. The obtained results are applicable for solar concentration and thermionic energy conversion systems.

* Dr. Sci., Ph.D, Principal Scientist, Professor.

YP11 61 Nonlinear excitation of fast magnetosonic waves via quasi-electrostatic whistler wave mixing NATHAN ZECHAR, Riverside Research, Beavercreek, OH VLADIMIR SOTNIKOV, JAMES CAPLINGER, Air Force Research Laboratory, WPAFB, OH ARTHUR CHU, University of Illinois at Urbana-Champaign, Urbana, IL We report on experiments of nonlinear simultaneous generation of low frequency fast magnetosonic waves and electro-magnetic whistler waves using two loop antennas in the afterglow of a cold magnetized helium plasma. The exciting antennas each have a frequency that is below half the electron cyclotron frequency, and the difference between the two is just below the lower hybrid frequency. They both directly excite whistler waves, however their nonlinear interaction excite the low frequency fast magnetosonic waves at the frequency given by their difference. Plasma is generated using a helicon plasma source in a one meter length cylindrical chamber. The spatial and temporal data of the electromagnetic and electrostatic components of the plasma waves are then captured with developed diagnostic techniques. Wave spectra, general structure and time domain frequencies observed will be reported.

YP11 62 Development of high-resolution two-dimensional magnetic field measurement system by use of printed-circuit technology* MOE AKIMITSU, CAO QINGHONG, ASUKA SAWADA, HIRONORI HATANO, HIROSHI TANABE, YASUSHI ONO, Graduate School of Frontier Sciences TS-GROUP TEAM We have developed a new-types of high-resolution magnetic probe array for our new magnetic reconnection experiments: TS-3U (ST, FRC: R=0.2m, 2017-) and TS-4U (ST, FRC: R=0.5m, 2018-), using the advanced printed-circuit technology. They are equipped with all three-components of magnetic pick-up coils whose size is 1-5mm x 3mm. Each coil is composed of two-sided coil pattern with line width of 0.05mm. We can install two or three printed arrays in a single glass (ceramic) tube for two or three component measurements. Based on this new probe technique, we started high-resolution and high-accuracy measurement of the current sheet thickness and studied its plasma parameter dependence. We found that the thickness of current sheet increases inversely with the guide toroidal field. It is probably determined by the ion gyroradius in agreement with the particle simulation by Horiuchi etc. While the reconnection speed is steady under low guide field condition, it is observed to oscillate in the specific range of guide field, suggesting transition from the quasi-steady reconnection to the intermittent reconnection. Cause and mechanism for intermittent reconnection will be discussed using the current sheet dissipation and dynamic balance between plasma inflow and outflow.
Numerically with the MHD and gyrokinetic theory. Radial propagation of the ion temperature mode is supported by the ion (radial) heat flux, while the restoring force is created by the radial current due to the ion diamagnetic velocity. The structure of the global GAM and radial propagation is studied numerically with the MHD and gyrokinetic theory.

*Supported in part by NSERC Canada and Russian Science Foundation 17-12-01470.

YPII 64 Global electrostatic potential structures of merging flux tubes in TS-U torus plasma merging experiment* ASUKA SAWADA, HIRONORI HATANO, MOE AKIMITSU, QINGHONG CAO, KOTARO YAMASAKI, HIROSHI TANABE, YASUSHI ONO, Graduate School of Frontier Sciences, University of Tokyo TS-GROUP TEAM We have been investigating 2D potential profile of global merging tokamaks to solve high-power heating of magnetic reconnection in TS-3 and TS-3U (ST, FRC:R=0.2m, 1985-, 2017-) and TS-4 (ST, FRC:R=0.5m, 2000-), UTST (ST:R=0.45m, 2008-) and MAST (ST:R=0.9m, 2000-) devices. These experiments made clear that the electrostatic potential well is formed not only in the downstream area of magnetic reconnection but also in the whole common (reconnected) flux area of two merging flux tubes: tokamak plasmas. This fact suggests that the ion acceleration/heating occurs in much wider region than the reconnection downstream. We studied how the potential structure depends on key reconnection parameters:guide toroidal field and plasma collisionality. We found the polarity of the guide toroidal field determines those of potential hills and wells, indicating their formation is affected by the Hall effect. The peak value of the electrostatic potential well decreased with gas pressure increasing, suggesting plasma collisionality suppresses the Hall effect. The relationship between the electrostatic potential structure and anomalous ion heating is being studied as a possible cause for the high-power heating of fast magnetic reconnection.

*This work was supported by JSPS KAKENHI Grant Numbers 15H05750, 15K14279 and 17H04863.

YPII 66 Laser-driven ion acceleration at BELLA* JIANHUI BIN, SVEN STEINKE, QING JI, KEI NAKAMURA, Lawrence Berkeley National Laboratory FRANZISKA TREFFERT, Technical University Darmstadt STEPAN BULANOV, Lawrence Berkeley National Laboratory MARKUS ROTH, Technical University Darmstadt CSABA TOTH, CARL SCHROEDER, ERIC ESAREY, THOMAS SCHENKEL, WIM LEEMANS, Lawrence Berkeley National Laboratory BELLA is a high repetition rate PW laser and we used it for high intensity laser plasma acceleration experiments. The BELLA-i program is focused on relativistic laser plasma interaction such as laser driven ion acceleration, aiming at establishing an unique collaborative research facility providing beam time to selected external groups for fundamental physics and advanced applications. Here we present our first parameter study of ion acceleration driven by the BELLA-PW laser with truly high repetition rate. The laser repetition rate of 1Hz allows for scanning the laser pulse duration, relative focus location and target thickness for the first time at laser peak powers of above 1 PW. Furthermore, the long focal length geometry of the experiment (f=65) and hence, large focus size provided ion beams of reduced divergence and unprecedented charge density.

*This work was supported by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

YPII 67 Measurements of Ion and Neutral Fluctuation Changes with Pressure in a Large-Scale Helicon Plasma* R.H. DWYER, D.M. FISHER, R.F. KELLY, M.W. HATCH, M. GILMORE, University of New Mexico Neutral particle dynamics may play an important role both in laboratory plasmas and in the edge of magnetic fusion devices. However, studies of neutral dynamics in these plasmas have been limited to date. Here we report on a basic study of ion and neutral fluctuations as a function of background neutral gas pressure. These experiments have been conducted in helicon discharges in the HelCat (Helicon-Cathode) dual-source plasma device at the University of New Mexico. The goal is to measure changes in ion and neutral density fluctuations with pressure and to gain an improved understanding of plasma-neutral interactions. Langmuir probe, Ar-1 LIF, and high-speed imaging measurements of the fluctuations will be presented.

*Supported by U.S. National Science Foundation Award 1500423 and The University of New Mexico School of Engineering. Also with Hope Christian High School.

YPII 68 Rapid Evolution of Small-Scale Flows in Solar Granulation RILEY HEIMAN, University of Wisconsin - Green Bay We used local correlation tracking to estimate horizontal velocities in an image sequence of convection at the solar photosphere, at high amplitude analysis that is valid beyond reshock is applied to predict the evolution of the mix layer width and to quantify the impact of RT/RM instabilities and convergence and compression effects on the mix layer growth. Finally, it is shown that the mix layer growth is well represented by a just-saturated mode model.

*This research was supported under the ARC Discovery Projects funding scheme (Project No. DP150101059) and used computational resources at the NCI provided through the NCMAS allocation scheme.
spatial and temporal resolution (0.034” pixels and 10-second cadence, respectively) observed in TiO (705.7 nm) with the Goode Solar Telescope. A key goal of our study was to estimate the lifetimes of flows in granules, which have implications for models of coronal heating that rely upon rapid evolution in photospheric forcing of coronal magnetic field evolution. We estimate flow lifetimes by fitting the decorrelation times of flow maps. For LCT apodization windows near 200 km (8 pixels), we find flow lifetimes of about 60 sec. On these scales, we also find flow speeds consistent with previous reports, of order a few km/sec. With the LCT apodization window set to 100 km (4 pixels), we found flows to be faster and shorter-lived. The observed flow evolution is therefore rapid enough to excite turbulent interaction between upward- and downward-propagating Alfvén waves between the photosphere and corona, consistent with the predictions of a coronal heating model proposed by van Ballegooijen et al. (2011).
Author Index
Author Index

Efimenko, Evgeny NM9 5, NM9 6
Efthimion, P. GO7 2, NP11 37
Efthimion, P.C. BP11 121, JP11 61
Egedal, J PP11 112
Egedal, J. GP11 16, JP11 111, NP11 131, UM9 5
Eggert, J. JO8 1, PO5 7
Eggert, J.H. JO8 3, JO8 4, JO8 6, NP11 42, YO6 10
Ehrlich, R. PO7 8
Ehsan, Zahida YP11 32, YP11 33
Eideitis, N. NO4 11
Eidiitis, N. GP11 105
Eidiitis, N.W. GP11 103, GP11 104, GP11 110, NO4 10, PO4 1, UP11 52
Eisert, D. CP11 84
Ekedahl, A. TP11 54
Elbaz, Yonatan UO8 7
Elder, D. NP11 83
Elder, JD. BP11 112, NP11 84
Eldon, D. GP11 94
Eldon, David GP11 93, GP11 117
Elgin, L. UO8 7
Elgin, Laura NP11 63
Elia, Paul PO6 2
Elle, J. GP11 37
Elle, Jennifer GP11 44, NO6 9
Elliot, Drew UP11 104
Elliot, D.B. UP11 100, UP11 102
Elliot, Drew UP11 101, UP11 106
Ellis, Naoki PP11 123
Ellis, R. PP11 69
Ellis, Ron NP11 74
Ellison, C. Leland GP11 145
Elshed, Ahmed UO6 7
Elser, Fred GO7 11
Emami, T. JP11 76, JP11 77
Embréus, Ola JP11 95
Emdee, E.D. PP11 95
Emdee, Eric PP11 94
Emdee, Eric D. JP11 100
Emig, J NP11 41
Emig, J. PO8 6
Emig, J.A. CO5 11
Emig, James CO5 5, JO8 12
Emig, Jim NP11 38
Emmott, Gilbert TP11 43, UP11 15
Endrizzi, D. NP11 174
Endrizzi, Doug UM9 2
Endrizzi, Douglass JP11 6, JP11 152, NP11 175, PP11 131, TP11 27
Eng, Chester D. GP11 29
Engelhorn, Kyle GO7 11
Englesbe, Alexander GP11 44, NO6 9
Enloe, Lon NP11 153, TM9 9
Ennever, P. CO4 11, JP11 99
Ennever, P.C. CO4 10
Ennis, DA NP11 81
Ennis, D.A. CP11 59
Ennis, D.A. CP11 60, CP11 61, CP11 62, CP11 63
Epp, Kelly UP11 132
Epstein, R. CO7 1, GO7 6, NO7 8,
Ernst, D.R. GP11 85, NP11 88
Ernst, Darin R. JP11 91
Ernst, D BO4 7
Eren, Esin YP11 52, YP11 56
Eren, D. GP4 7
Eristov, Tunde JP11 95
Esarey, E. GP11 57
Esarey, Eric BO5 4, BO5 6, BO5 14, GO5 8, GP11 33, GP11 36, PM9 9, TP11 47, YP11 65
Esirkepov, Timur Zh. UO5 11
Esnaoui, Leo NM9 8
Espinosa, Silvia NP11 9
Etcher, S. TP11 100
Etcher, Stephane JP11 142, TP11 97
Evans, Eugene S. NP11 120, NP11 123
Evans, Matthew BP11 16, PO8 3
Evans, T. BO4 6
Evans, T. DE 49
Evans, T. JP11 74, NP11 68
Evans, Todd PP11 63, PP11 71
Everson, Chris NP11 113
Everson, Christopher NP11 111
Everson, C.J. NP11 110
Exelby, Steven TO8 3, TO8 4
Fülöp, Tünde JP11 95
Faber, B.J. CP11 72, CP11 80, CP11 81, GO4 1
Fable, Emiliano UO4 13
Faghihi, Danial YP11 40
Fajans, Joel UP11 14
Falabella, S. CP11 43, CP11 44
Falabella, Steve NO5 5
Falabella, Steven CP11 42
Falcon, Ross CO5 12, YP11 68
Falcone, R. NP11 60
Falcone, Roger JO8 5
Falcone, R.W. JO8 9, NO7 14, PO5 5
Fan, Xiang DI2 2, PP11 113
Fancher, Aaron TP11 42, TP11 43
Farniella, Deano GP11 39, GP11 156
Farley, Tom PP11 79
Farmer, W.A. BO7 8, BP11 136, PO7 9, UP11 38
Farmer, William A. GP11 29
Farrell, M. YO7 7
Farrell, Mike GO7 11
Fasanelli, Fabio YP11 21
Fassina, Alessandro CP11 120
Ferrer, J. UO5 2
Ferrer, Michel BP11 112
Ferron, J. GP11 71, GP11 91
Ferron, John GP11 73
Ferron, J.R. GP11 61, GP11 63, GP11 118
Feugeas, Jean-Luc GO8 2
Fevrier, O. PP11 75
Fiedler-Kawaguchi, C. JP11 33
Fiedler-Kawaguchi, C. PP11 2
Firri, S.J. YO7 3, YO7 5
Finsen, Sayu J. JO8 2
Fiksel, G JO5 12
Fernandez, A. PO5 15
Fernandez, J.C. NP11 40
Fernandez, Juan PP11 27
Fernandez, Juan C. JO5 8
Fernandez-Panella, A. JO8 6, NP11 42
Ferraro, A. NP11 39
Ferraro, N. BO4 4, NP11 91
Ferraro, Nate CP11 112
Ferraro, Nathaniel CP11 113, PP11 83
Ferraro, N.M. CP11 114, GP11 108, JO4 6
Ferrero, A. YP11 2
Ferrero, A. YP11 12
Ferron, Max CP11 2, PO7 9, YO7 12
Figueiredo, J. UP11 72
Fiks, G JO5 12
Fiks, G. GP11 23, NP11 172, PP11 2
Fiks, Gennady CO5 15, NP11 161, NP11 170
Fimognari, P.J. CP11 55, JP11 123
Finkenthal, D. GP11 86
Finkenthal, D.K. PO4 8
Finko, Mikhail TO6 9
Finn, J.M. CP11 109, GO4 10, JP11 151
Finn, John NP11 118
Fiquet, G JO8 10
Galtier, E. IPS 10, JO8 10
Galtier, E. NP11 42, PP11 9
Galvao, R. UP11 72
Gambou, E. NP11 42
Gan, Kaifu TO4 3
Ganesh, R CO6 13
Ganesh, Rajaraman
Gan, Kaifu TO4 3
Gao, Xiang GP11 157,
Gao, X. PP11 88
Gao, Li NP11 7
Gao, L. BP11 121,
Gangoli, Gurudas UM9 8,
Gangolf, Thomas
Garrett, Michael BP11 95,
Garofalo, Andrea GP11 70,
Garfalo, A. BP11 72
Garfalo, A.M. BP11 43,
Garcia-Martin, P. CP11 130
Garcia-Martin, P. CP11 130
Garofalo, A. BO4 9
Garofalo, A. GP11 72
Garofalo, A.M. BP11 43,
Gebra, T. CP11 89
Gede, Cameron BO5 4,
Gede, Cameron G.R. BO5 5
Gede, C.G.R. GP11 57
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Gee, David UP11 51,
Hahn, K.D. BP11 117, PO8 1
Hahn, Kelly BP11 115, BP11 116, PO8 3
Hahn, M. NP11 154
Hahn, Sang-hee UP11 52
Hahn, S.H. NO4 2, NO4 7, NO4 10, NO4 11, UP11 50, UP11 55
Haines, B M UO8 1
Haines, B.M. NO7 7, PP11 37, UO7 5
Haines, Brian GO8 8, JO7 12, PP11 108
Hajjar, Rima NP11 15
Hakel, P. GO7 5
Hakel, Peter GO7 4
Hakim, A BP11 21
Hakim, A. TP11 87, TP11 88
Hakim, Ammar BP11 7, CP11 22, JO6 6, JP11 143, TP11 86, TP11 89, UP11 30
Hakimi, Sahel GP11 39
Hakola, Antti UP11 70
Halfmoon, M.R. CP11 109, GO4 10
Hall, Gareth GO7 3
Hall, G.N. GO7 9
Hall, Taylor CP11 7, CP11 10
Halliday, Jack CP11 35
Halliday, Jonathan BO6 4
Halliday, Jonathanon PP11 26
Halpern, Federico JP11 147, NP11 70
Ham, Eric NP11 122
Hamel, S. PP11 9
Hamilton, Andrew BP11 124, YP11 46
Hamilton, C. UO8 2
Hamilton, C E UO8 1
Hamilton, David JP11 72, NP11 30
Hamlin, Nathanial YO6 4
Hammel, B.A. GP11 122, YO7 3, YO7 5
Hammer, D.A. TO7 9
Hammer, David CP11 32, CP11 33, NO5 3, UP11 127
Hammer, J.H. BO7 1, UP11 38
Hammerberg, James JO7 8
Hammet, Greg TP11 86
Hammett, G.W. TP11 87, TP11 88
Hammig, Mark PP11 127
Han, H.S. NO4 3, UP11 55
Han, Hyunsun UP11 50
Han, Jia NP11 181
Han, Lily CO5 14, NP11 171
Hane, Stephanie PO8 3
Han, Tao CP11 111
Hanada, K. TP11 71
Hanayama, Ryohei NO5 11
Handy, T. UO8 7
Handy, Timothy NP11 63
Hansen, A. TP11 15
Hansen, C. JP11 141, UP11 100, UP11 102, UP11 103
Hansen, C.J. NP11 112, UP11 77, UP11 82, UP11 83
Hansen, David PP11 5, PP11 6
Hansen, S. CO5 8
Hansen, S.B. BP11 117, CO5 3, PO8 1, PO8 4, PO8 5
Hansen, Stephanie BP11 16
Hansen, Stephanie GO8 11, KI2 1, PO5 9
Hansen, Stephanie B. PO5 8
Hanson, J. GP11 68, GP11 113
Hanson, James CP11 127
Hanson, J.D. CP11 59, CP11 62, CP11 63
Hanson, Jeremy GP11 109, GP11 115, GP11 118, PO4 5
Hanson, J.M. GP11 69, GP11 107, GP11 108, GP11 111
Hansusch, Adrian BP11 25
Hanyongquan, Han BP11 2
Hao, G.Z. JO4 7, PP11 48
Hao, Liang BP11 131, CO7 5
Happel, T. JP11 84
Happel, Tim UP11 71
Haque, Showera UO6 12, YO7 6
Harding, D. YO7 7
Harding, D.R. CO8 15
Harding, E. BP11 117, PO8 4
Harding, E.C. PO8 1, PO8 5, PO8 7
Harding, Eric BP11 115, PO8 2, PO8 3
Hardy, M. PO7 8
Hare, J. YO6 2
Hare, Jack BO6 4, CP11 35, NI2 1, PP11 26
Hares, J.D. BP11 118, GO7 12
Harmand, M JO8 10
Harmand, Marion YO6 9
Harrison, James JO4 2, PP11 54, PP11 79, UP11 107
Hart, Grant UP11 8
Harte, J.A. PP11 35
Harte, Judy JO8 14
Hartigan, P. NP11 172
Hartigan, Patrick CO5 15
Hartley, N JO5 10, JO8 10
Hartmann, Peter TO5 13
Hartouri, Edward UO7 11, UO7 12
Hartrun, E. PO8 2, UO7 13
Hartwell, G.J. CP11 59, CP11 60, CP11 61, CP11 62, CP11 63
Hartwig, Z. JP11 80
Harvey, Robert JP11 110, NP11 175
Harvey, R.W. BP11 107, PP11 61, TP11 58, TP11 60
Harvey, R.W. (Boby) TP11 59
Harvey-Thompson, Adam CP11 39, PO8 7
Harvey-Thompson, Andrew CP11 115, PO8 3
Harvey-Thompson, A.J. CP11 38, PO8 4, PO8 5, PO8 6
Hasegawa, M. TP11 71
Haskey, S BO4 7
Haskey, Shaun GP11 76, GP11 78, JP11 31
Haskey, S.R. GP11 114
Hassam, A. CP11 68
Hassanein, Ahmed GO8 13, NO5 13, PO4 7, UO4 6, UO6 4, UO6 5, UO6 7
Hasson, Hannah YP11 21
Hastings, Jerome NP11 125
Hastings, Jerry YO6 9
Hata, Masayasu PP11 21
Hato, Hironori BO6 8, BO6 9, YP11 61, YP11 63
Hatarik, R. NP11 60, YO7 13
Hatarik, Robert UO7 11, UO7 12
Hatch, David TP11 78
Hatch, David R. JP11 91
Hatch, DR TP11 79
Hatch, M.W. JP11 53, NP11 26, UO6 10, YP11 66
Hattori, Yuji PP11 116
Hauck, Cory UO8 4
Hau-Riege, S. PP11 9
Haw, Magnus BO6 13, BP11 13
Hawkins, Steven NO7 6
Hawrelak, James JO8 5
Hawryluk, R.J. JO4 5
Hayakawa, Takehito PM9 6
Hayashi, Takumi BO6 9
Hayashi, Yoshiaki TO8 9
Hayes, Alyssa CP11 25
Hakaz, G. CO5 3
Hakaz, Giora YP11 31
Hazelbabe, R.D. TP11 81
He, Wen NP11 6
He, Xiantu BP11 40, CO7 13
He, Xian-Tu CO7 15
He, X.T. GO5 3, UO5 4
Hecla, J. CO4 6, JP11 82
Heeter, B NP11 41
Heeter, Bob NP11 58
Heeter, R. PO8 6
Heeter, R.F. CO5 6, CO5 11, YP11 14
Heeter, Robert CO5 5, JO8 12, PP11 31, PP11 32
Hegelich, Bjorn GP11 50
Hegelich, B.M. JP5 8, PP11 10, PO11 22
Hegna, C C JP11 100, CP11 106
Hegna, C.C. CP11 69, CP11 72, GO4 1, JP11 133
Heim, Chris CP11 86
Heim, Chris C CP11 101
Heidbrink, W GP11 96
Heidbrink, W. GP11 72, GP11 99
Heidbrink, William BP11 89, PP11 47
Heidbrink, W.W. GP11 86, GP11 97, GP11 101, GP11 102, JO4 7, PP11 48
Heiman, Riley YP11 67
Heimann, Philip NP11 125
Heinemann, Thomas JO5 4, UO5 13, YP11 19
Heimrich, J. BP11 97
Heimrich, Jonathon BP11 101, BP11 103
Held, Per CO4 2
Held, E.D. JP11 133
Held, Eric JP11 132, PP11 5, PP11 6
Held, Eric D. GP11 138, JP11 134
Helm, H. JO8 13
Hell, M.H. GP11 35
Hellingher, Petr NP11 33
Helm, A. JP1 4
Helm, Anton GP11 30, GP11 31
Henchen, R.J. BO7 12
Henderson, B. JO8 3
Henderson, B.J. PO5 7
Henderson, B.R. CP11 47, PP11 136
Heninger, J.M. GP11 137
Henriquez, Miguel F. JP11 49, JP11 75, UO4 8, UO4 9
Henry, Olivier BP11 112
Henson, Alex NP11 124
Hermindal, J.L. GP11 103, GP11 104, PO4 1
Hergenhahn, U. UP11 11, UP11 12
Hering, P. POS 2
Herrmann, M. POS 12
Herrmann, M.R. GO5 15
Hernandez, R. UO7 14
Herrera-Velazquez, J. Julio E. CP11 128
Herrmann, Albrecht UO4 10
Herrmann, H BP11 119
Herrmann, Hans GO7 4
Herrmann, H.W. GO7 12
Hershkovitz, Noah CP11 23, JP11 47, YP11 56
Hess, Mark BP11 114, BP11 115
Hesse, Michael NP11 167
Heuer, P.V. GO6 3, PP11 25
Hew, Monica TO6 6
Hibbard, R. GO7 9
Hibbard, Robin GO7 3
Hicks, Nathaniel JP11 11, JP11 55, JP11 65, UO6 1
Hilding, Bernhard JOS 4, JO6 5, UO5 13, YP11 19
Higgins, D. CO5 2, CP11 43, CP11 44
Higgins, D.P. TO7 2
Higgins, D.P. TO7 1, UP11 110, UP11 111, UP11 113, UP11 115
Higgins, Drew CP11 40, CP11 45, UP11 109
Hitaji, Hussein UO4 7
Hildebrand, L. GP11 147
Hildebrand, Lance JOS 3
Hill, Carrie NP11 121
Hill, David GP11 60, NP11 69
Hill, D.N. NP11 71
Hill, K. JP11 61, PP11 66
Hill, K.W. BP11 121, GO7 2, NP11 37
Hill, M. PP11 9
Hill, M.D. NP11 97, NP11 98, YP11 24
Hillesheim, J UP11 73
Hillesheim, Jon TP11 78
Hilsabeck, T. BP11 122, GO7 12
Hilsabeck, T.J. BP11 118
Himeno, Shunichi BO6 9
Hine, George GP11 48
Hinkel, D. PO7 1
Hinkel, D.E. BO7 8, PO7 2, PO7 8
Hinson, E.T. NP11 66, PO4 10
Hioki, Tatsumi NO5 11
Hirata, M. PP11 139
Hiratsuka, Masanori
NP11 130
Hirose, Akira UP11 135
Hirota, Makoto PP11 146
Hiszch, S.P. CP11 56, YP11 39
Hiszh, Steven BO4 5
Hirvijoki, Eero CP11 102, GP11 106, GP11 130, GP11 136
Hittinger, J. PP11 73
Hittinger, Jeffrey GO8 5, JP11 143, JP11 144
Hizanidis, K. TP11 55, TP11 56, UP11 39
Ho, A. GP11 132
Ho, Andrew GP11 133
Ho, D. JO7 13
Ho, D. NO7 9, PO7 4, YO7 9
Ho, Darwin NO7 6
Ho, D.D. BO7 1, PO7 3, PO7 6, PP11 35
Hoarty, D. PP11 9
Hoeferl, Udo GO4 3
Hoeffel, Udo JOS 4
Hoelzl, Matthias CP11 112, GO4 8, NP11 87
Hoff, Brad TO8 3, TO8 4, TP11 38
Hoffman, H. CO4 6, JP11 82
Hoffman, N. PP11 36
Hoffman, Nelson GO7 4, UO7 6
Hoffman, NM BP11 119
Hoffmann, F. GP11 16, UM9 5
Hohenberger, M. CO7 1, CO7 2, JO7 1, PO7 1, PO7 2
Hohenberger, Matthias PO7 7, YO7 2
Holcomb, C. GP11 72, NP11 105, NP11 106
Holcomb, Chris GP11 70
Holcomb, C.T. BO4 11, GP11 61, GP11 63, GP11 71, NP11 92
Holc, Matthew YO4 7
Holc, Milan GO8 2
Holguin, F. NP11 31
Holland, C. CP11 110, JP11 87, TP11 106
Holland, Christopher PP11 84
Holland, Leo BP11 70
Hollinger, R.C. TO8 8
Hollinger, Reed JO5 7
Hollmann, E.M. BO4 11, GP11 103, PO4 1
Hollmann, Eric BO4 13, GP11 104
Holly, D.J. CP11 57, JP11 116, JP11 120
Holmes, Ian NP11 74
Holmes, Michael NP11 121
Holod, I. CP11 43, CP11 44
Holod, Ibor BP11 57, GP11 88
Hommz, M CP11 58
Hong, Rongjie JP3 3, JP11 98, NP11 8, NP11 15, NP11 32
Hong, Suk Ho NO4 6
Honrubia, Javier NP11 64
Hood, Ryan CP11 24, TP11 22, UP11 28
Hoover, D.E. PO7 4
Hoppe, M. NO7 3
Hoppe, Mathias JP11 95
Hopson, J. JP11 76, JP11 77
Horrates, Konstantinos NP11 160
Hosany, Mihaly NP11 181
Horiata, Hirokata NP11 146
Horichui, Rikoto GP11 3
Horichui, Shunsaku GO6 15
Horn-Stanja, J. UP11 11, UP11 12
Horsfield, C.J. GO7 12
Horton, R TP11 10
Horton, W. GO6 13, NP11 16
Horton, Wendell GO4 12, PP11 146
Horton, William TP11 54
Hosea, J C TP11 68
Hosea, J.C. PP11 61
Hosea, Joel JP11 42, PP11 60
Hosozawa, A. BP11 55
Hossack, Aaron NP11 113
Hossack, A.C. NP11 110
Houshamdyar, S. TP11 13
Houshanmdyar, Saeed JP11 91
Howard, John UP11 94
Howard, N. JP11 90
Howard, NT. CO4 8, JP11 87, TP11 106
Howard, Stephen UP11 130, UP11 132
Howard, E.C. CP11 59, CP11 63
Hower, G PP11 112
Hower, G.G. TM9 6, UP11 40
Hower, Greg NP11 156
Hower, Gregory NP11 30, NP11 155
Hower, Gregory G. MR1 1, NP11 157
Howling, Alan NP11 138
Hoyang, Joshua JP11 22
Hsing, W BO7 7
Hsing, W. PO7 4
Hsing, W.W. PO7 3, PO7 6, YO7 5
Hsu, S.C. PO7 13, TO7 3, UP11 123
Hsu, Scott GO7 4, TO7 5, UP11 116, UP11 117, UP11 120, UP11 121, UP11 122
Hsu, Scott C. CP11 147
Hu, Di PO4 2
Hu, G.H. TO4 13
Hu, Guangyue BP11 111, BP11 131
Hu, J. TO4 7, UP11 58
Hu, Jianqiang TO4 12
Hu, Jiansheng TO4 3
Hu, J.S. PP11 88, TO4 8, TO4 9, TO4 11, TO4 14
Hu, L TO4 10
Hu, Lijun TO4 2
Hu, Li qun UP11 59
Hu, Q. GP11 146, GP11 147
Hu, Qming BP11 12, UP11 33
Hu, Ruiji UP11 60
Hu, Suxing JOS 8, NP11 170
Hu, Su-Xing BP11 135
Hu, S.X. BI2 3, CO8 12, GO7 8, GO8 10, GP11 23, JO3 3, JO8 7, NP11 161, PO5 7, UO6 13, YO7 7
Hu, W. GP11 99
Hu, Wei CO6 12
Hu, Xiwei CP11 132
Hu, Youjun NP11 14
Hu, Zhimin UO5 3
Hua, R. PO5 15, PP11 9
Hua, Rui NP11 58
Huang, Chengkun NP11 40, PP11 27, TP11 40
Huang, Duwei UP11 67, UP11 68
Huang, H. NO7 13, PO7 9, PP11 102
Huang, Haibo GO7 11, NO7 10
Huang, J TO4 10
Huang, Jerry CO4 9, NP11 92
Huang, Juan GP11 70, GP11 100
Huang, M. TO4 8, TO4 11
Huang, Mei-Feng CP11 29
Huang, Tao NP11 141, NP11 142
Huang, Wenlong CP11 107
Huang, Yi Min GP11 11, GP11 148, PP11 126
Huang, Yi Yun UO4 14
Huang, Y.M. GP11 23
Huang, Y.Q. TO4 11, TO4 15
Huang, Yu JO6 2
Huang, Zhouji JO4 15
Huang, Zuo NP11 55
Huang, Yi Min
Huang, Y. M. GP11 23
Huang, Yi-Min
Huang, Yi Min, JP11 85
Huang, Yoonwoo
Huang, Zuo UO5 7
Huang, Z. NP11 55
Huang, Z. YO5 13
Huang, Zhuo UP11 33
Huang, Zhouji JO4 15
Huang, Zhuo YP11 36
Huang, Y. M. GP11 23
Huang, Y. Q. TO4 11, TO4 15
Huang, Y. M. GP11 23
Huang, Yoonwoo
Huang, Yoonwoo, JP11 85, JP11 99, TP11 80
Hubbard, A. CO4 11, JP11 98, TP11 13
Hubbard, AE TP11 79
Hubbard, Amanda CO4 9, JP11 86, UP11 71
Hubbard, Kevin BP11 63
Hubbard, R.F. GP11 35
Huber, A. UP11 73
Hudson, S.R. YP11 36
Huebner, U JO5 10
Huff, M. PO5 7
Huffman, E.J. CO5 11
Huffman, Eric CO5 5
Hugenschmidt, C. UP11 11, UP11 12
Hughes, Jerry CO4 9, GI2 1, JP11 85, JP11 86
Hughes, P.E. UP11 100, UP11 102, UP11 103
Huijsmans, Guido NP11 87, PO4 12
Hulin, S. GP11 54
Hulin, Sebastien NM9 8
Huller, Stefan BO5 10
Hüller, Stefan BP11 129
Humbird, K. YO7 12
Humbird, K.D. BO7 6
Humbird, Kelli YO7 13
Humphreys, D.A. GP11 74, GP11 110, NO4 10, NO4 11, UP11 52
Humphreys, David GP11 73, TP11 12
Hunter, Eric UI3 1
I Jacob, Felix YP11 44, YP11 45
Ibragi, Youhei UP11 95
Ichimura, M. PP11 139
Iida, K. UP11 54
Iida, Katsuhi NO4 9
Iidi, H. TP11 71
Igarashi, Akihiko NP11 145
Iglesias, C.A. CO5 3
Iglesias, Carlos CO5 5
Ignace, Richard BP11 49
Igochino, V CP11 115, UP11 75
Igumenshchev, I. UO7 5
Igumenchev, I.V. CO7 8, CO8 11, UO7 8, YO7 7
Ikekoc, R. PP11 139
Ilderton, Anton JO5 14, NM9 5
Ilgisonis, V. YP11 62
Ilie, Raluca JO6 2
Ilyin, Daniil YP11 27
Ilyin, DV YP11 29
In, Y. NO4 3, NO4 4, NO4 7, UP11 50, UP11 54
In, Y.K. NO4 10, UP11 55
In, Yongkyoon GI2 3, NO4 5, NO4 6, NO4 9
Inchingolo, Giannandrea
BPP11 37
Innocenti, Maria CP11 132
Innocenti, Maria Elena JO6 3
Inomoto, Michiaki UP11 97
Inoue, S. GP11 113
Intrator, Thomas PP11 148
Iqbal, Zafar PP11 111
Iratabal, Jeremy UO6 6
Irby, J. CO4 10, JP11 80
Irby, James CO4 9
Irlam, Kristin
Irby, James CO4 9
Iqbal, Z. YO7 13
Irby, James, CO4 9
Irby, James, CO4 9
Jакобсон, Д. П. PP11 2
Jacobs-Perkins, D. PP11 2
Jacobs-Perkins, D.W. UO7 4, UO7 8
Jacquier, Remy PP11 138
Jaeger, E.F. PP11 61
Jaeger, Erwin TP11 58
Jaeger, Fred NP11 104
Jaervinen, A.E. NP11 71
Jaiswal, Surabhi CP11 11
Jakubowski, M. CP11 52
James, R.W. JP11 76, JP11 77
James, S.D. CP11 110
Jan, Egedal GP11 24
Jansen, K.A.S. NP11 31
Jandovitz, P TP11 8
Jang, Dogeon GP11 43
Jang, S. PP11 139
Jahnunen, S. UP11 48, YP11 62
Jahnunen, Salomon YP11 40
Jansen, O. BO5 2, NM9 7
Jansen, Olivier GP11 49, NM9 8, NM9 9, TP11 52
Jaquez, J. PO7 8, PO7 9
Jaquez, Javier GO7 11
Jailer, Sophie NM9 9
Jara-Almonete, J. CP11 16, UM9 5
Jara-Almonete, Jonathan
GP11 8, GP11 18
Jara-Almonete, Jon JP11 7
Jarboe, T. UP11 100
Jarboe, Thomas BP11 24, NP11 111, NP11 114
Jarboe, Tom NP11 113
Jarboe, T.R. PP11 64
Jarboe, T.R. BP11 23,
NP11 110, NP11 112, PO4 3
Jardin, S.C. UP11 64
Jardin, S.C. CP11 114, NO4 8
Jardin, Stephen CP11 113
Jardin, Stephen C. CP11 112
Jarrot, Charlie JO8 12
Jarrot, C. PO7 9
Jarrot, L.C. CO8 2, PO7 2, YP11 14
Jarrot, Leonard GO7 1
Jarvinski, Aaro NP11 74
Jaspers, R.J.E. NP11 108
Jaspers, Roger NP11 108
Jassem, Abhijit TP11 37,
TP11 39
Jaulmes, Fabien TP11 76
Jaworski, M A TP11 68
Marklund, Mattias
Mariscal, Derek PP11 3, Mariscal, Dereck A. PP11 15
Marinal, Alessandro PP11 67
Mariscal, D.A. BO7 11, Masamune, S. JP11 125
Mar, L. JO7 13, Masse, L. PO7 10, YO7 9
Marais, L.P. NO7 11, NO7 12, Masson-Laborde, Paul-Edouard BO5 10, CO5 8, GP11 121
Marzetta, Mattei, Massimiliano TP11 12, Mattellini, Lorenzo NP11 33
Matteucci, J. GP11 23, NP11 161
Matteucci, Jackson BO6 2, GP11 28
Mattheaus, William NP11 162
Matthews, Lorin PP11 123, PP11 132, TO5 7, TO5 8, TO5 9, TO5 10, TO5 11, TO5 13, TO15 15, TO6 12
Mattingly, Sean J13 6, NP11 158, TP11 22, UP11 28
Mattsson, Thomas J08 2, Mauch, C. YO7 2, Mauch, Christoph J08 12, Mauch, Christopher W. BO7 10
Mauch, C. W. YP11 14
Maucel, Mike UP11 78
Maurer, Andrew TP11 17
Maurer, D. CP11 64
Maurer, D.A. CP11 59, CP11 60, CP11 61, CP11 62, CP11 63
Maurizio, R. PP11 75
Maximov, A.V. CO7 3, CO7 4, YO6 5
May, J. PP11 19
May, J. GP11 147
May, Mark CI3 2
May, Mark J. BP11 115
May, M.J. YO6 1
Mayes, D CO5 10
Mayes, Daniel CO5 13
Mayes, D.C. CO5 9
Mazarakis, Michael CP11 133
Mazzotta, C. NP11 13
Mazzuoco, E. PP11 69
McArdle, G. PP11 40
McBride, E J08 10
McBride, Emma Elizabeth YO6 9
McBride, R.D. NO5 6, NO5 7, NO5 8, NO5 11, UP11 138
McBride, Ryan CP11 36, UP11 137
McBride, E J05 10
McCarthy, B. WP11 108, CO4 3
McCarthy, William JP11 96
McCarville, Thomas GO7 3
McCarville, T.J. GO7 9
McCary, E. J05 8, PP11 10
McCarron, Ryan YO13 7
McClenaghan, J. BO4 3, GP11 61, GP11 71, GP11 72
McClaren, Joseph GP11 70
McClow, Hannah JP11 52
McCollam, K. JP11 104
McConnell, R. JP11 109
McCoy, C.A. J05 7
McCrory, R.L. GO7 14
McGuire, Thomas BP11 116, BP11 117, BP11 124, BP11 125, PP11 128
McGuire, T. BP11 97
McKenna, Fan BP11 115
McKenna, Paul MP5 5
McKenty, F. PO7 13
McKenty, P. WP11 138, CO8 15, JO7 1, JO7 5, UO7 1, UO7 3, YO7 7
McKew, B.B. PO8 9
McKinlay, Michael CP11 8
McKimney, L.J. CP11 81
McKnight, Quinn TO5 3
McLaughlin, Jacob JP11 50
McLaughlin, Jacob W. JP11 75, UO4 8, UO4 9
McLean, Adam BO4 13, NP11 74
McLean, A.G. NP11 66, NP11 71, NP11 72, NP11 78, NP11 84, PO4 10
McLean, Harry UP11 109
McLean, James TO7 2
McLean, HS NP11 41
McLean, H.S. TO7 1, UP11 110, UP11 111, UP11 112, UP11 113, UP11 115
McLean, James JP11 63
McMahon, M. CP11 44, PO5 7
McMahon, Matthew CP11 40
McNabb, Dennis P. J02 8
McNally, P. PP11 2
McNamara, Steven UP11 97
McNanev, James UO8 5
McNanev, J.M. UO8 13
McQuown, Levon BP11 83
McWatters, Bruce BP11 116
Meakins, Alex PP11 54
Meaney, K.D. GO7 12
Meaney, Kevin BP11 119
Meany, K. UO6 10
Medvedev, M. BP11 33
Medvedev, Mikhail GO6 10, NP11 173
Medvedev, Mikhail V. BP11 35
Medvedev, S. UO4 15
Meeran, N BO7 7
Meeran, N. PO7 4, PO7 8
Meeran, Nathan BO7 3, BO7 4, CO8 7, YO7 2
Meeran, N.B. PO7 3, PO7 6, PO7 9
Megalingam, Mariamal PP11 119
Mehrling, Timon YI3 4
Meier, Eric NP11 67, NP11 123
Meinecke, J PP11 30
Meinecke, J. CO5 2
Meinecke, Jena CO6 8
Meitner, S.J. CP11 89
Melzer, Andre TO6 1
Menard, J. JP11 56
Menard, J. JO4 5
Menard, J.E. JO4 6, PO4 3, PP11 40, PP11 55
Menard, Jonathan GP11 118, PP11 41, PP11 43
Menati, Mohmad CP11 9
Mendonna, JT TO8 12
Meneghini, O JP11 89
Meneghini, O. GP11 71, GP11 89, GP11 91, JP11 68, NP11 92
Meneghini, Orso CP11 94, GO4 5, GP11 90, GP11 92, GP11 117, JP11 30
Meng, Cong PB11 19, NP11 20
Meng, G. BP11 92
Meng, X.C. TO4 8
Meng, Xujun JO2 7
Merino, E. UP11 100
Merino, Enrique UP11 101
Merka, Jan NP11 160
Merle, A. UO4 15
Merle, Antoine UP11 71
Merlino, Robert CP11 4, CP11 24
Merlo, Gabriele JO4 15, JP11 144, TP11 109, YO4 8
Merrill, Frank CO8 4
Merritt, E. NO7 15
Merritt, E.C. NO7 1, NO7 3, NO7 4, PP11 37, UO8 8, UO8 9
Merritt, Elizabeth NO7 2, UO8 10, UO8 11
Mettler, Jeremy JO4 13
Metzkes, J JO5 10
Metzkes, J. GO5 12
Meuren, Sebastian PM9 4, TO8 15
Meyer, Ch. GP11 54
Meyer, F. UO4 7
Meyer, Fred W. BP11 75
Meyer, Hendrik UP11 70
Meyer, John TO5 6
Meyer, Thomas NP11 119
Meyer, W.H. NP11 73
Meyer, William NP11 75
Meyeron, Iosif NM9 5
Meyer-ter-Vehn, Juergen GO5 4
Mezei, Zsolt YP11 44
Mezolin, E. NP11 116
Mezolin, E.D. NP11 117
Mezolin, Ephrem JP11 114
Miao, Bo BO5 9, GP11 48
Miao, Wenyong UO8 3
Miars, Grant NP11 178
Micera, Alfredo JO6 3
Michalak, Matt TP11 42
Michel, D.T. CO8 12, GO7 8, JO4 7, UO7 8
Michel, P. YP11 41
Michel, T. PO7 13, UO7 5
Michoski, Craig YP11 40
Miencnikowski, Matthew GP11 142
Migliore, Christina JP11 72
Mikhailenko, Vladimir UP11 47
Mikhailenko, Vladimir S. GP11 153
Mikhailenko, Vladimir V. GP11 153
Mikhailenko, Vladimir UP11 47
Mikhailova, Julia GP11 53
Mikitchuk, D. YP11 68
Mikkelsen, D PP11 51
Milanese, L. BP11 108
Milcher, Howard BO5 9, GP11 48
Milder, A.L. BP11 127
Milder, Avi GP11 50, UO5 1
Mileham, C. NO6 6, YO7 4, YO6 8
Miles, A.R. NP11 182
Miles, J.A. NP11 127
Milhone, J. PP11 128
Milhomme, Jason JP11 35, NP11 174, NP11 175, PP11 129, TP11 28, U9M 2
Milhotello, F. PP11 53
Milhotello, Fulvio PP11 79, YI2 4
Militzer, Burkhard PO5 6
Miller, Gabrielle GP11 154
Miller, K. GP11 147
Miller, Kenneth E. NP11 124, TP11 73, TP11 74, TP11 75
Miller, Kyle BP11 130, PO6 2
Miller, S. JO7 6, NO5 7, NO5 8
Miller, Sean GP11 126, PO6 6
Miller, S.M. GO6 6, UP11 138
Miller, S.T. GP11 132, NP11 137
Miller, Stephanie CP11 36
Millet-Ayala, A. PP11 131
Millet-Ayala, Alexander GP11 10, GP11 12, GP11 22, NP11 165, NP11 166
Millot, M. JO4 8, JO4 6
Milnes, J. GO7 12
Miloshevich, George CO6 9
Milovich, J. GP11 122, YO7 3, YO7 5
Milovich, J.L. PO7 2, PO7 3, PO7 6, PP11 37
Milovich, Jose BO7 4
Mima, Kunioki NO5 12, PP11 21, PP11 23, TP11 46
Min, Byunghoon NP11 10, NP11 11
Minervini, J. JP11 80
Miniatii, F PP11 30
Miniatii, Francesco CO6 8
Minxiong, Yan UP11 69
Mirmov, Vladimir JP11 56, NP11 175, PP11 129
Mirmov, V.V. BP11 107, PP11 128
Mironov, Sergey GP11 56
Mishin, Evgeny GP11 47
Mishra, Rohini NO6 7
Mitchell, Robert BP11 102, BP11 104
Mitra, Vramori
Mitarrai, J. CP11 44
Mitarrai, James CP11 41, NO5 5
Mittelberger, Daniel BO5 8
Miura, Eiisuke NO5 11
Miura, Hideaki GO4 12
Miyashiki, K J08 10
Miyashita, Kohei YO6 9
Miyazawa, Junichi NP11 145
Miyoshi, Takahiro BO6 5
Mizuta, Akira GO6 14
Mlovid, Mikhail PP11 135
Mo, M. PO5 2, PO5 3
Mo, Mianzhen KI2 4, NP11 125
Moeller, C.P. NP11 103
Mohamed, Z.L. UO7 10
Mohoney, J.M. CP11 77
Moir, R.W. BP11 105
Moissard, Clement BO6 2
Molina, Pedro UP11 71
Molina Cabrera, Pedro TP11 5
Mollén, Albert GO4 2
Molodtsova, M. NP11 39
Molvig, K. NO7 5
Molvig, Kim NP11 53, PO7 13
Momo, Barbara CP11 120
Montal, Angana JO5 6
Montag, Peter GP11 9, GP11 25
Montecalvo, N. BP11 97
Montecalvo, Niccolo PB11 100
Monteil, Marie-Christine GP11 121
Montes, Kevin CP11 95
Montes, P. CP11 130
Montgomery, D. NO7 15
Montgomery, David NO7 2, UP11 116
Montgomery, D.S. NO7 1, NO7 3, NO7 4, PP11 37, YO6 1
Montgomery, M. PB11 10
Montgomery, Mike CO5 12
Moody, J BO7 3, NP11 41
Moody, C.D. BO7 8, CO7 2, PO7 8, YO6 1
Moody, John CO8 7, YO7 2
Moore, A. PO7 4
Moore, Alastair BO7 7,
CO8 7, UO7 11, UO7 12, YO7 2
Moore, A.S. BO7 8, PO7 3, PO7 6, UO7 13
Moore, Rachel TO6 12
Morace, A JO5 12, TP11 48
Morales, George CO6 10, NP11 2, NP11 27
Morales, George J. JP11 12
Morales, G.J. NP11 5
Morard, G JO8 10
Mordijck, Saskia BO4 8,
GP11 81, NP11 93
More, R.M. CO5 3
Author Index

Park, JongKyu GP11 118
Park, J-M GP11 61
Park, Jaebum JO5 13
Park, InSun NP11 134
Park, H.K. CO4 14, NO4 1,
Park, G.Y. NO4 3, NO4 4
Park, H.K. CO4 14, NO4 1, NO4 2, NO4 8, NO4 12, NO4 14
Park, H-S PP11 30
Park, H.S. CO8 6, GO6 2,
GP11 23, NP11 182, UO8 13
Park, Hyeon K. NO4 5
Park, Hye-Sook COS2 2,
CO6 8, JO8 2, UO8 5
Park, InSun NP11 134
Park, In-Sun CP11 23, JP11 47
Park, J GO6 2, JO5 12,
NP11 41
Park, Jaebum JO5 13
Park, Jaehong GO5 8,
TP11 47
Park, Jey Ming NP11 76
Park, J.K. CP11 114, NO4 3,
NO4 4
Park, J-M GP11 61
Park, J.M. GP11 68, NP11 105
Park, Jong-Kyu GP11 118
Park, J.K. NO4 1
Park, Youngseok UP11 56
Park, Y.S. CP11 93, NO4 7,
UP11 51, UP11 53, UP11 55
Parke, E. JP11 111, JP11 112
Parke, Eli JP11 118
Parker, C. BP11 120, PP11 36,
UO7 77
Parker, C.E. BP11 113,
BP11 118, BP11 122
Parker, J.B. UP11 31
Parker, Jeffrey D12 1,
JP11 144
Parker, Scott BI3 5, BP11 90,
GP11 142, JP11 145,
NP11 14, PP11 72, TP11 83,
TP11 109
Parker, S.E. TP11 96
Parks, Paul CP11 90, PO4 4
Parks, P.B. CP11 89
Parrilla, Nicholas YP11 30
Parsons, Matthew CP11 91
Pasley, John JO5 6
Patankar, S. BO7 1
Patel, Bhavesh BP11 126
Patel, D. JQ7 4, YO7 14
Patel, Mehul V. BO7 10
Patel, M.V. GP11 122
Patel, P. GQ5 9, NP11 60,
PQ7 5
Patel, P.K. YP11 14
Patel, Prav GO7 1
Patel, Pravesh YQ7 6,
YP11 50
Patel, Sonal YP11 68
Pattissou, Loic BP11 112
Patten, H. PP11 136
Pattton, James BP11 9
Paul, Elizabeth CP11 187
Pavlkeno, Vitaly TP11 40
Pavone, Andrea GO4 3,
GO4 4, JP11 34
Pawley, C.J. NP11 107
Paz-Soldan, C. BP11 113
Paz-Soldan, C. BP11 113
Paz-Soldan, Carlos N13 2,
TO4 5
Pe'er, Asaf GO6 5
Pearly, Jacob JP11 57,
JP11 59
Pearson, A. CP11 44
Pearson, Aric NO5 5
Pedersen, Thomas Sunn
CP11 49
Pedersen, T. Sunn UP11 11,
UP11 12
Peebles, J. PP11 4
Peelies, J.L. PO8 11,
PO8 12
Peelies, WA PP11 44
Peelies, W.A. BO4 10,
UP11 105
Peelies, William TP11 11
Pelka, A JO5 10
Penano, J.R. GP11 35
Peng, Shuitao NP11 6
Peng, Xianshi BP11 111
Peng, Yanli CP11 132
Penn, James NP11 114
Penna, J.M. NP11 110
Peraza-Rodriguez, H.
YP11 39
Pereira, Nino YO6 7
Perez, Joe D. JO6 4
Perez Von Thun, C. UP11 72
Perillo, Renato PP11 17
Perlin, M. GP11 149
Perkins, L. John NO7 6
Perkins, R. JP11 98, TP11 69
Perkins, R.J. TP11 68
Perkins, R.J. PP11 61, TP11 67
Perkins, Rory JP11 42
Perry, J.M. JO4 4, UP11 85,
UP11 86, UP11 87, UP11 88,
UP11 89, UP11 91, UP11 92, UP11 98
Perry, J.O. PO5 4
Perry, John PP11 12
Perry, T. CO8 2
Perry, Ted JO8 11, NO7 10,
PP11 32
Perry, Theodore CO5 5
Perry, T.S. CO5 6, CO5 11,
NO7 11, NO7 12
Persaud, A. PP11 101,
TO7 13, TO8 5
Perseo, V. CP11 61
Peterka, Matej PP11 71
Peterson, Bryan UP11 8
Peterson, E.E. BP11 107,
NP11 174, PP11 128
Peterson, Ethan JP11 56,
NP11 175, PP11 129,
TP11 27
Peterson, Ethan E. UM9 2
Peterson, J.L. BO7 6
Peterson, J. Luc YO7 12
Peterson, K. PO8 4, PO8 6,
PO8 7
Peterson, K.J. PO8 1, PO8 5,
PO8 9
Peterson, Kyle BP11 114,
PO8 3, UP11 136, UP11 137
Peterson, Luc GQ7 10,
YO7 13
Peterson, Robert JO7 12
Peterson, R.R. NO7 7
Petkov, E.E. JO8 13
Petrasco, R PP11 30
Petrasco, R. CO5 2, UO7 5,
UQ7 14
Petrasco, R.D. BO7 9,
BP11 113, BP11 118,
BP11 120, BP11 122,
CO8 2, CO8 12, GO7 5,
PP11 36, UO7 7, YP11 10
Petrasco, Richard CO5 14,
CO6 8, NP11 171
Petre, R.B. YO6 10
Petrie, T NP11 77
Petrie, T.W. BO4 11,
GP11 63, GP11 64, NP11 86
Petrov, George PP11 127
Petrov, Oleg TO5 13
Petrov, Yu V. TP11 60
Petrov, Yu V. (Yuri) TP11 59
Pett, CC JP11 89
Pett, C.C. BO4 2, BO4 4,
GP11 63, GP11 64, GP11 65,
GP11 66, GP11 94, NP11 86
Petty, Craig GP11 93
Peysson, Y. TP11 54
Pfefferle, D. CP11 114,
JP11 136
Pfefferle, David CP11 102,
CP11 113, GP11 136, NP11 131
Pham, Anh-Vu NP11 94
Phan, Tai NP11 163
Philippe, Franck CO8 14,
GP11 121
Phillips, Edward GP11 126,
PO6 6
Phillips, P. TP11 13
Phillips, Perry E. JP11 91
Pickworth, L. CO8 2, YO7 5
Pickworth, L.A. YO7 3
Pickworth, Louisa GI3 3
Picone, Silvia NO5 9
Pieronek, Christopher BO5 12
Pieronek, C.V. BOS 13
Pierre, Thierry UP11 34
Pierren, C. JO4 4, UP11 85,
UP11 86
Pigatto, L UP11 75
Pikuz, Sergei BO6 4,
CP11 32
Pinches, S. GP11 89
Pindzola, MS NP11 81
Ping, Y. BP11 121, NO7 3,
NO7 4, NP11 15, NP11 42,
NP11 60, PO5 15, PP11 9
Ping, Yuan NP11 58
Pino, J. NO7 15
Pino, J.E. YO7 9
Pino, Jesse GO8 12,
GP11 120, JO7 13, JO7 14
Pinsker, R.I. GP11 102,
JP11 17, JP11 68, NP11 103,
NP11 105, NP11 106
Pinsker, Robert NP11 104
Piotrowicz, P. BP11 77
Piotrowicz, P.A. BP11 78
Piovesan, Paolo NP11 169,
UP11 75
Piper, N.A. NP11 100
Author Index

461

Sugata, Tetsuya BP11 11, BP11 19, UP11 94
Sugiyama, Linda CP11 131, TM9 7
Suk, Hyoung GP11 43
Sullivan, R. BP11 97
Sullivan, Regina BP11 99
Sulym, Alex JP11 31
Sumida, S. PP11 139
Sun, Aiping UO4 12
Sun, J.Z. PP11 86
Sun, Peihao NP11 125, YO6 9
Sun, Y. NO4 7
Sun, Youwen PP11 90, TO4 3, TO5 4, Y12 1
Sun, Z. TO4 10, TO4 11
Sun, Z. PP11 88, TO4 7, TO4 8, TO4 9, UP11 58
Sunahara, Atsushi NO5 11, NO5 13
Sundaram, Gunasekaran YP11 56
Sung, C. BO4 2, GP11 66
Sung, Choongki BI3 6, GP11 92
Sung, Yung-Ta PP11 110
Sunn Pedersen, T. CP11 52
Surko, C.M. UP11 9
UP11 11, UP11 12
Suslova, Anastassiya GO8 13
Sutcliffe, G.D. BP11 113, BP11 120, BP11 122
Suter, L.J. BO7 8, PO7 9
Sutherland, Andrew JO5 4
Sutherland, D.A. NP11 110, NP11 112
Suttle, L. YO6 2
Suttle, Lee BO6 4, CP11 35, PP11 26
Suttrop, W CP11 106, CP11 115, UP11 75
Suzuki, Y. CP11 52
Suzuki-Vidal, F. YO6 2
Suzuki-Vidal, Francisco CP11 35, PP11 26
Svensson, Jakob GO4 3, GO4 4, JP11 34, PO6 8
Svidzinski, V.A. TP11 66
Svidzinski, Vladimir TP11 63, TP11 64, TP11 65
Svitlyk, V JO8 10
Syatsky, D. GO7 5
Swadling, G. COS 2
Swanekamp, S.B. UP11 27
Swanekamp, Steve NO5 4
Swanson, C CP11 18
Swanson, Charles NP11 122
Swanson, Kelly BO5 4, BO5 6
Swanson, Kelly K. BO5 5
Swanson, K.J. YO6 5
Swanson, Kyle CO5 13, UO6 6
Swanson, P. JP11 46
Swantusch, Marco GP11 40
Swee, Colin NP11 151
Sweeney, Ryan PO4 2
Swerdlow, Josh JP11 29
Swift, D. JO8 1, NP11 60, PO5 5, UO8 13
Swift, Damian JO8 5, UO8 5, UO8 12
Swift, Damian C. JO8 2
Swift, D.C. JO8 6
Swisher, Nora C. YP11 28
Sydora, Richard CO6 10, GP11 155, NP11 27
Sydora, Rick GP11 21
Sydoreno, D. UP11 48
Szabo, Adam GO6 6
Szott, Matt TP11 44
Szott, Matthew JO4 12, JO4 13
T
Tabak, M. BO7 1, GO5 15
Tabbutt, M. BP11 34
Tabbutt, Megan JP11 35
Tableman, A. BP11 133, GP11 147
Tableman, Adam BO5 3, BP11 15, BP11 130
Taborek, Peter GP11 39
TAE TEAM, The BP11 62
Taguchi, Yoshihiro TP11 46
Taheri, S. PP11 82
Taimourzadeh, Sam GP11 88, PP11 83
Taitano, W. JP11 130, NP11 54, PP11 36
Taitano, William NP11 57, TI2 5
Taitano, W.T. NP11 56
Tajima, T. BP11 42
Tajima, Toshi GP11 58
Tajima, Toshihiko BP11 57
Tajima, Toshihiko BP11 58, BP11 59, BP11 60, BP11 61, BP11 65, GO6 14, GO6 15, GP11 39, GP11 56, UO5 7
Takahashi, Noriki UP11 94
Takase, Y. PP11 65, PP11 66
Takatsu, Mikio NP11 130
Takeuchi, Yasuki NO5 11
Takizuka, T. UO4 15
Takubo, Hidenori TP11 41
Tala, T BO4 7
Tala, Tuomas BO4 8
Tallents, Greg PP11 13
Talmadge, J.N. CP11 75, CP11 76, CP11 78, CP11 79, CP11 80, CP11 81, CP11 82
Tambazidis, A. YO7 7
Tamburini, M. NM9 4
Tan, E. JP11 62, JP11 103
Tanabe, Hiroshi BO6 8, BO6 9, YP11 57, YP11 61, YP11 63
Tanaka, A. PP11 139
Tanaka, F. BP11 55
Tanaka, Fumiyuki NP11 130
Tanaka, K. TP11 48
Tanaka, Kazuo A TO8 9
Tanaka, Masayoshi Y. PP11 121
Tang, K. CP11 54
Tang, S GP11 101
Tang, Shawn Wenjie GP11 5, GP11 21
Tang, S.W. UP11 43
Tang, X. JP11 130
Tang, Xianzhu GO4 9, YO7 8
Tang, Xian-Zhu CP11 98
Tang, Yuejin BP11 12
Tangri, V. CP11 39, NP11 59
Tangri, Varun CP11 38
Ta Phuoc, K. UO5 2
Tarantino, Paul TO6 6
Tardini, Giovanni YO4 14
Tassin, V. BO7 9
Tassin, Veronique CO8 14, GP11 121
Tata, Sheroy JP11 65
Tausig, D. GP11 105
Tausig, Doug NP11 74
Taylor, E.I. NP11 16, TP11 18
Taylor, G. PP11 64
Taylor, G. PP11 61, TP11 13
Taylor, Joey TP11 102
Taylor, N.Z. GP11 65
Taylor, P.L. GP11 86
Taylor, Trevor JP11 132
Taylor, Z. GP11 113
Tchilinguirian, Greg PP11 68
Team, Alcator C-Mod CO4 11
Team, And the Tri Alpha Energy BP11 46
Team, General Fusion UP11 135
Team, HSX CP11 74
Team, PLX-@ UP11 119
Team, TAE BP11 52
Team, the TAE BP11 42
Team, W7-X CP11 61
Tejero, Erik NP11 153, TO6 3, TM9 9, UO9 8, UP11 37
Teklu, A PO4 9
Teklu, Abraham JP11 74
Tema Biwole, Arsene GO4 5, GP11 90
Temkin, Richard TP11 35
Temkin, Richard J. TO8 2
Tenk, R.J. TO8 1
Tenbarge, J. CP11 68
TenBarge, Jason BP11 7, TP11 89
Tepluhkina, Anna JP11 139
Terasaka, Kenichiro PP11 121
Terranova, D CP11 115, UP11 75
Terry, J. JP11 80
Terry, James JP11 86, JP11 93
Terry, Jim CO4 2, CO4 12, JP11 94, JP11 98
Terry, J.L. CO4 3, CO4 4, CO4 13, CP11 54, TP11 84
Terry, Paul JP11 105, JP11 114, JP11 118
Terry, PW TP11 104
Terry, P.W. TP11 105
Tessake, D. UP11 72
Thévenet, Maxence BO5 8
Thakur, Saikat NP11 15
Thatiapamula, Shekar G.
CO6 13
Thauri, C. UO5 2
Theiler, C. JP11 85, PP11 75
Theiler, C.G. JP11 92
Theobald, W. BO5 2, GO7 6, NO5 10, UO7 4
Theobald, Wolfgang JO8 8
Theodersen, Audun CO4 12, JP11 93
Theo, W7-X CP11 61
Thibodeau, Matthew JP11 20
Thio, Y.C.F. TO7 3
Thio, Y.C. Francis TO7 4, UP11 119, UP11 123
Tih, Siva Sashank TO6 5
Thoma, Carsten UP11 116
Thoma, A.G.R. GP11 37, NO6 6, TP11 45
Thomas, Alec PP11 127
Thomas, Alexander PM9 8


Thomas, Alexander G.R. PM9 7
Thomas, C BO7 7
Thomas, C. P.07 1
Thomas, C.A. PO7 7, PP11 35, YO7 3
Thomas, C.E. BP11 84
Thomas, Cliff PO7 12, YO7 2, YO7 11, YP11 18
Thomas, Dan BO4 14, BP11 70, NP11 70, NP11 74, NP11 85
Thomas, DM NP11 77
Thomas, D.M. BO4 11, BO4 12, NP11 78, NP11 79
Thomas, E. NP11 116, NP11 117
Thomas, Ed UP11 16
Thomas, Edward CP11 4, CP11 5, CP11 6, CP11 7, CP11 8, CP11 9, CP11 10, CP11 11, CP11 12, CP11 13
Thomas, Hubertus CP11 14, TO5 6
Thomas, M.A. JP11 120
Thomas, W.R. NP11 137
Thomas, Jr., Edward CP11 14
Thome, K GP11 101
Thome, K.E. BO4 2, BO4 11, GP11 63, GP11 102, JP11 68
Thome, K.H. GP11 66
Thompson, Derek JO6 13, JP11 13, PP11 138
Thompson, Derek S. JP11 49, JP11 75, UO4 8, UO4 9
Thompson, K.A. UP11 2, UP11 10
Thompson, Matthew BP11 43, BP11 53
Thompson, Matthew C. BP11 52
Thompson, M.C. BP11 42, BP11 44
Thompson, Nathaniel CO5 5
Thompson, N.B. CO5 11
Thor, D. GO7 2, GO7 5
Thor, D.B. BP11 121, NO7 13, NO7 14, NP11 37, PO7 9
Thorner, Ben YP11 64
Thornton, A.J. PP11 40
Thuecks, Derek VI2 2
Tian, Li NP11 29
Tigeli, T. TP11 56
Tikhonchuk, Vladimir CO5 1, NM9 8, NM9 9
Tikhonchuk, Vladimir T. GO8 2
Tilborg, Jeroen van BO5 5
Tinguey, R.A. CO4 6, JP11 82
Tinguey, R Alex JP11 95
Tinsley, Jim JO7 5
Tipton, R. NO7 15
Tipton, R E JO7 13
Tipton, R.E. NO7 11, YO7 9
Tipton, Robert GO8 12, GP11 120, JO7 14
Titus, James JP11 114
Titus, J.B. NP11 116, NP11 117
Tiwari, G. JO8 5
Tiwari, Sanat UP11 19
Tiwari, Sanat Kumar TO5 1, TO5 2
Tobias, Ben GP11 98
Tobias, Benjamin NP11 94
Tobin, M. BP11 44
Tochitsky, S. GO5 9
Toda, S TP11 95
Told, Daniel JO4 15, JP11 144, Q12 3, UM9 7, YO4 8
Toleikis, S. PO5 3
Tolman, E. JP11 85
Tolman, E.A. CO4 6, JP11 82
Tolman, Elizabeth BO6 6, CO4 9
Tolson, B.A. NP11 127
Tommasini, R. NO7 15
Toncian, T. GO5 2, NM9 7
Toncian, Toma GP11 49, NO6 8, NM9 8, TP11 52
Tong, Jon PP11 38
Tong, Ruihai UP11 67.
UP11 68
Torres, J.A. BP11 117
Torres, Jose BP11 115
Torrezan, Antonio JP11 32, NP11 102
Toth, Cs. GP11 57
Toth, Csaba GO5 8, YP11 65
Totorica, Samuel BO6 1, CO6 7
Touati, M. GP11 147
Town, R.P. PO7 6
Town, R. Pj. PO7 8
Town, R.P.J. PO7 3
Tran, Jonathan NP11 144
Tranquille-Marques, Yves BP11 112
Trantham, M. PP11 105
Trantham, M.A. JP11 33
Trantham, Matt CO5 7, PP11 32, PP11 33
Trantham, Matthew BP11 28, CO5 15, UO8 6
Trantham, M.R. UO8 7
Tranthan, M.A. NP11 182
Trask, E BP11 47
Trask, Erik BP11 45, BP11 46
Traverso, P.J. CP11 59, CP11 60
Treffert, F. TO8 5
Treffert, Franziska GO5 8, TP11 47, YP11 65
Trefuerer, Wolfgang TP11 12
Trevisan, VL PO4 9
Trevisan, G.L. JP11 74, NP11 68
Tribeidos, V. YP11 39
Trimmolo Mora, Humberto GO4 3
Trines, R PP11 137
Trines, R. TO8 7
Trines, Raoul NO6 11, YP11 33
Trines, Raoul M TO8 12
Tripathi, Jitendra UO4 6
Tripathi, S. GP6 3, PP11 25
Tripathi, Shreekrishna JP11 72, UP11 44
Tripathi, S K P TP11 68
Tripathi, S.K.P. TP11 67, TP11 69
Tritz, K PP11 44, TO4 11
Tritz, K. JO4 6, JO4 7, TO4 7, TO4 8, TO4 9, UP11 58
Tritz, Kevin TO4 14
Tronci, Cesare GP11 139, GP11 140
Truong, Dinh GP11 67
Tsai, Hai-En BO5 4, BO5 5, BS 6
Tsai, H.E. GP11 57
Tsintsadze, Nodar YP11 32, YP11 33
Tsai, C.K. PP11 75
Tsai, Ying TP11 23
Tsai, Y.Y. PO5 2
Tsujimura, T. TI4 41
Tsujimura, Tohru TP11 41
Tsujimura, Toru TP11 111
Tsung, F. BP11 138
Tsung, Frank BO5 3, BP11 130, BP11 134, PO6 2
Tsung, F.S. BP11 133, GP11 146, GP11 147, NP11 40
Tu, Weichao JP11 150
Tubman, Eleanor BO6 4, CP11 35
Tubman, Ellie PP11 26
Tubman, E.R. NO6 6
Tummel, K.K. TO7 1, TO7 2, UP11 110, UP11 111, UP11 113, UP11 115
Tummel, Kurt UP11 109
Turci, Peter TO7 10
Turck-Chieze, Sylvaine PP11 32
Turco, F. BO4 14, GP11 63, GP11 64, GP11 108, NP11 86, PO4 14
Turco, Francesca BO4 5, GP11 109, TP11 2
Turk, J. JP11 76, JP11 77
Turkin, Yuriy GO4 2
Turkington, M NP11 81
Turnbull, A.D. GP11 61, GP11 108
Turnbull, Alan GP11 98
Turnbull, D. CO7 7, NO5 10, TO8 10
Turnbull, David CO6 8
Tuszewski, M. BP11 42
Tuszewski, Michel BP11 43
Tybo, Josh CO8 4
Tyburska-Pueschel, B. GO6 8
Tyan, George CP11 2, JP11 98, NP11 8, NP11 32, YP11 37
Tyan, George R NP11 15
Tyan, George R. JP11 69, NP11 29
Tzeferacos, P PP11 30
Tzeferacos, P. CO5 2, NP11 43
Tzeferacos, Petros CO5 14, CO6 8, JP11 45, JP11 66, NP11 44, NP11 45, NP11 159, NP11 171
Tzoufras, Michail BP11 15

U
Uchizono, Nolan NP11 121
Uematsu, Y TP11 48
Ullmann, Daniel JO5 4, YP11 19
Umansky, M.V. CO4 5, PP11 81, YP11 22
Underwood, Thomas BP11 69, JO6 11
Unterberg, EA NP11 77
Unterberg, E.A. BO4 11, BO4 12, NP11 78, NP11 79, NP11 83, NP11 95, PO4 10
Wang, Hui hui UP11 59
Wang, Huiqian BO4 13, BO4 14, NP11 85
Wang, Jingwei UO5 3
Wang, Kaijie CP11 122
Wang, L. TO4 7, TO4 15
Wang, Li TO6 12
Wang, Liang J06 6, TO4 3, TO4 12, UO4 11, JP11 38
Wang, Long NP11 22, TP11 16, TP11 25
Wang, Lu NP11 4, NP11 6
Wang, M. NO7 15, TO4 1
Wang, Mao TO4 2, UP11 60
Wang, Mingyuan TO4 12
Wang, Nengchao BP11 12
Wang, Qing CO7 13, CO7 14
Wang, S. UO5 9
Wang, Shan NP11 167
Wang, Sheng CP11 117
Wang, Shicong NP11 151
Wang, Shoujun JO5 7
Wang, S. UO5 9
Wang, Tianbo TP11 25
Wang, Xinliang UO5 8
Wang, Xiaojie TO4 2
Wang, Xiaogang BP11 40, GC11 135, NP11 22, NP11 87, TP11 16, TP11 25
Wang, Xueyun NP11 19, NP11 20
Wang, Y. UO5 9, UP11 61
Wang, Yan NP11 94
Wang, Y.F. TO4 13
Wang, Yi-Ming UO7 9
Wang, Y.M. PP11 88
Wang, Yongqiang NP11 125
Wang, Z. GO6 2
Wang, Z. GP11 113, NO4 4, PP11 88, TO4 14, UP11 51, UP11 55
Wang, Zhanhui UO4 12, YP11 37
Wang, Zhebin BP11 111
Wang, Zhirui GP11 118
Ward, Ryan JP11 43, JP11 78
Wark, Justin YO6 9
Warta, Daniel JP11 65
Warwick, J. GP11 37
Watatanabe, T.-H TP11 95
Waters, Ian PP11 63, UP11 107
Watkins, J. NP11 84, NP11 95, PO4 10
Watkins, JG PO4 9
Watkins, J.G. GP11 64, NP11 66, NP11 79, NP11 86
Watkins, Jon BO4 13, NP11 85
Watkins, Jonathan BO4 14
Watson, J. CP11 44
Watt, R.G. NO7 1
Watkins, J. NP11 84, NP11 95, PO4 10
Waters, Ian PP11 63, UP11 107
Weber, T.E. TP11 1, UP11 110, TP11 2
Weber, Christopher R. TO7 2
Weber, Tobin UP11 109
Weber, T.R. TO7 2
Welander, Anders GP11 115, NP11 66, NP11 79, NP11 86
Wexler, Sherril, Leslie PP11 108
Wexler, Sherril, Leslie PP11 108
Weisberg, D.B. GP11 61, GP11 69
Weisz, David TO6 9
Weitzner, Harold CP11 67, JP11 138
Welander, A. GP11 99
Welander, Anders GP11 115, PP11 42
Welch, D. BP11 101
Welch, Dale BP11 102, BP11 104, UP11 116
Welch, Dale R. NP11 123
Welch, D.R. CP11 47, PO5 4
Welser-Sherrill, Leslie PP11 108
Wen, Han BP11 130
Wen, Jie UP11 66
Wendelborn, John JO4 13
Wendt, Amy JP11 5, NP11 151
Wenzel, Uwe TP11 9
Werner, G.R. NP11 139
Werner, Greg NP11 181, PO6 3
Werner, Gregory BO6 10, CO6 6, GP11 151
Wessel, F. TO7 8
Wessel, F.J. UP11 124, UP11 125, UP11 126, UP11 128
Wessel, F. TO7 8
Wessel, F.J. UP11 124, UP11 125, UP11 126, UP11 128
Westerfeld, Blake GP11 9, GP11 24, GP11 25
Wettervik, Benjamin UO5 5
Whelan, G.G.
Whelan, E.N. CP11 59
White, A. NP11 23
White, A.E. CO4 1, CO4 8, CO4 10, JP11 87, JP11 90
White, Anno JO4 8, JP11 94
White, Dan NP11 52
White, RB PP11 44
White, RB. BP11 92
White, Roscoe CP11 70
White, Sonya X11 23
White, Z. UO5 9
Wick, Kevin CP11 115
Widmann, Klaus JO8 12
Wiedenmayer, Matthias JP11 93
Wieh, P. YO6 5
Wild, Robert BO4 5, GI2 2
Wild, R.S. CP11 79
Wild, C. PO7 3, PO7 4
Wild, Carl CO8 4
Wilkes, S GO6 2
Wilkins, Frank CP11 133
Wilkinson, Corey JP11 52
Wilks, S. CO5 2, NP11 42
Wilks, S.C. BO7 9, CO8 5, GO5 15
Wilks, Scott BO5 10, CO8 7, NP11 58, PP11 14, UO5 10
Wilks, T. JP11 84
Wilks, Theresa BO4 9
Wilks, T.M. GP11 69, JP11 85, PP11 86
Willard, Jake JP11 64
Willensdorfer, M CP11 106
Willi, Oswald GP11 40, JP11 9, TO8 6, UP11 36
Williams, A TP11 10
Williams, Bob NP11 74
Williams, CB TP11 91
Williams, Gerald GP11 41
Williams, G.J. BO5 2, NO6 6, YO6 1
Williams, J. BP11 138
Williams, Jackson CO8 8, JO5 13, PP11 3, PP11 15
Williams, Jeremiah CP11 14, CP11 15, JP11 22, JP11 23
Williams, R. NP11 116, NP11 117
Williams, R.E. NP11 115
Williamson, E.N. CP11 59
Willingale, L. BO5 10, NO6 6, TP11 45
Willingale, Louise GO5 10
Willingale, L. BO5 2, NO6 6, TP11 45
Willingale, L. BO5 2, NO6 6, TP11 45
Wills, Christopher BO5 15, GO5 7, GO5 13, PP11 18
Williott, Christopher UM9 7
Wilson, B. CO5 3
Wilson, Brian CO5 5
Wilson, D.C. NO7 1, NO7 3, NO7 4
Wilson, Doug JO7 12, NO7 2
Wilson, Douglas PP11 37
Zinszner, Jean-Luc YP11 8
Zisis, A. TP11 56
Zohm, H CP11 106
Zohm, H. BO4 6
Zohm, Hartmut UO4 10, UO4 13
Zolfaghari, Ali TP11 11
Zonca, A. GP11 146
Zonca, Fulvio CP11 125
Zou, Shiyang PO7 10
Zou, Xiaolan UP11 66
Zou, X.L. TO4 12
Zou, Z.Y. TO4 6
Zuegel, J.D. TO8 7
Zuin, Matteo CP11 120
Zulick, C. TP11 45
Zuo, G. TO4 7, UP11 58
Zuo, G.Z. TO4 8, TO4 9
Zueben, S. JO4 9
Zueben, S.J. PP11 52, PP11 53, TP11 84
Zueben, Stewart JP11 9
Zweibel, E.G. NP11 24
Zweibel, Ellen UM9 2
Zwicker, A. JP11 2
Zwicker, Andrew JP11 3
Zylstra, A. BP11 120, CO5 2, CO8 2, NO7 13, NP11 172, PO7 1, PP11 36
Zylstra, AB BP11 119
Zylstra, A.B. CO8 6, GO7 12, NO7 7, NO7 11, NO7 12, NO7 14, UO7 5
Zylstra, Alex CO6 8, CO8 7, GP3 1, JO7 12, NO7 8, NO7 10, PO7 13, UO7 6
Zywicki, Bailey GP11 90, JP11 30
HILTON

Lobby Level