Monday, October 27, 2014 8:00AM - 9:00AM –
Session AR1 Review: Ignition at NIF: Where We Have Been, and Where We Are Going
Acadia/Bissonet - David Meyerhofer, University of Rochester

8:00AM AR1.00001 Ignition at NIF: Where we have been, and where we are going

ROSEN, Lawrence Livermore National Laboratory — This talk reviews results from the past several years in the pursuit of indirect-drive ignition on the National Ignition Facility (NIF), and summarizes ideas and plans for moving forward. We describe the challenging issues encountered by the low-adiabat (“low foot”), “ignition point design” approach, such as: hydrodynamic instability growth and ensuing mix of the CH ablator into the DT hot spot; very high convergence implosions with resultant imperfect symmetry; possible other issues such as hot electron preheat. The complex interplay among these issues is a key theme. We describe the progress that has been made in the understanding and diagnosis of these issues. We present the results from the high-adiabat (“high foot”) approach, with its property of relative hydrodynamic stability when compared to the low foot approach, its somewhat reduced convergence ratio, and its achievement of entering the alpha heating regime, an important milestone on the road to ignition. Paths forward towards ignition include excursions from the present approaches in pulse shape, hohlraum, and choice of ablator. Further pulse shaping can lower the adiabat of the high foot approach and lead to higher performance if it continues to retain its hydrodynamic stability properties. Conversely, pulse shaping can provide for “adiabat-shaping” for the low foot approach for it to try to attain better stability. A plethora of hohlraum approaches (size, shape, materials, gas fills) can improve the zero-order drive, as well as the low-mode shape of the implosion. Diagnosing, and then correcting, the time dependence of the symmetry is also a key issue. A variety of ablator materials, along with carefully engineering the drive spectrum, can increase implosion velocity. The high-density carbon ablator has shown promising results in this regard. Some combinations of these developments may allow for an operating space that has a relatively short pulse, in a near vacuum hohlraum. That combination has shown, to date, much better coupling efficiency, and a much lower level of laser plasma instabilities (thus, less electron preheat), than the longer pulse, full-gas-fill, high-K hohlraums. Advances in modeling experimental diagnostic techniques developed over the past several years have been enabling technologies in moving towards ignition, and we anticipate further advances as well. We gratefully acknowledge the dedicated efforts of many hundreds of personnel across the globe who have participated in the laser construction, operation, target fabrication, and all aspects of the target physics program, that have taken us this far towards ignition.

1This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Monday, October 27, 2014 9:30AM - 12:30PM –
Session BI1 Edge Pedestal Physics
Acadia - Anne White, Massachusetts Institute of Technology

9:30AM BI1.00001 The effects of impurities and core pressure on pedestal stability in JET and MAST

SAARELMA, CCFE, Culham Science Centre, Abingdon, Oxon OX14 3DB, UK — The H-mode pedestal plays an important role in determining global confinement in tokamaks. In high triangularity H-mode experiments in JET with the ITER-like wall (JET-ILW), plasma purity is improved, but both the pedestal temperature height and global confinement are degraded compared with JET plasmas with a carbon wall (JET-C). The JET-C performance can be partially recovered with nitrogen seeding. The stability calculations show that edge localised impurity concentration can increase the electron pressure pedestal at the point of marginal stability, mainly through ion dilution but also due to changes in the bootstrap current profile, whilst not degrading the total core pressure. The edge stability in low triangularity plasmas is improved less by the edge impurities due to a different shape of the stability boundary, consistent with a weak improvement in pedestal height with impurity seeding. Significantly better confinement and pedestal height has been observed in JET plasmas when the global pressure is increased. The enhanced pedestal height is linked to an improvement in edge stability arising from an increase in the Shafranov-shift. In MAST a 20% increase in the global β at the LH-transition led to a doubling of the electron pressure pedestal height just before the first ELM. The increase in global β results in an increase in the marginally stable pressure gradient. This increases the attainable pedestal height, but also results in increased edge impurity content due to a longer first ELM period, which enhances the electron pressure pedestal height by ion dilution. The JET and MAST experiments and modelling show the importance of impurities and core pressure in determining the pedestal height.

1Work supported by the RCUK Energy Programme and EUROfusion

10:00AM BI1.00002 Edge Instabilities Limiting the Pedestal Evolution

DIALLO, Princeton Plasma Physics Laboratory — Identifying the transport mechanism and instabilities limiting pedestal properties and global confinement are essential to predict and control the performance of ITER and future fusion devices. Measurements of the edge density and magnetic fluctuations on the DIII-D and Alcator C-Mod tokamaks provide direct evidence for the onset of quasi-coherent edge fluctuations limiting the pedestal temperature recovery after an edge-localized-mode (ELM). These instabilities onset at the critical pressure gradient for kinetic ballooning mode (KBM) instabilities, which is consistent with predictions of EPED model. On both C-Mod and DIII-D, the low-k coherent fluctuations are observed having magnetic signatures, localized near the pedestal top. At low current on DIII-D these fluctuations are observed to correlate well with the density gradient recovery (measured with high temporal resolution) suggesting that particle transport is responsible for limiting the pedestal. At higher plasma current, the density gradient recovers on the same time scale as in the low current case. However, the temperature gradient increases until saturation, which suggests a different transport mechanism compared to the low current case. This plasma current dependence is consistent with changes of heat flux from the core needed to replenish the pedestal after an ELM crash. This paper reports detailed measurements of the pedestal recovery dynamics and associated edge fluctuations in two fusion devices, which clearly indicate that quasi-coherent edge fluctuations with magnetic signatures limit the temperature pedestal evolution. These new measurements as well as the recovery time of the pedestal strongly suggest that the pedestal temperature is a potential control knob, if acted on early in the recovery phase, for optimizing the pedestal in future fusion devices.

1Supported by the US DOE under DE-AC02-09CH11466 and DE-FC02-04ER54698.
10:30AM BI1.00003 Poloidal Asymmetries in Edge Transport Barriers. R.M. CHURCHILL, Princeton Plasma Physics Laboratory — Investigations of the poloidal structure within edge transport barriers on Alcator C-Mod using novel impurity measurements are presented, revealing large poloidal variations of parameters within a flux surface in the H-mode pedestal region, and significantly reduced poloidal variation in L-mode or I-mode pedestals. These measurements provide complete sets of impurity density, temperature, flow velocity, and electrostatic potential at both the low- and high-field side midplane, utilizing the Gas Puff-CXRS technique. Uncertainties in magnetic equilibrium reconstructions require assumptions to be made in order to properly align the LFS/HFS profiles. In H-mode plasmas, if profiles are aligned assuming impurity temperature is constant on a flux surface, large potential asymmetries would result (\(\Delta \phi / T_e \approx 0.6\)). If instead total pressure is assumed constant on a flux-surface, then the measured potential asymmetry is significantly reduced, but large in-out asymmetries result in the impurity temperature (>1.7x). This shows that impurity temperature and potential can not both be flux functions in the pedestal region. In both alignment cases, large asymmetries in impurity density (>6x) are present in H-mode plasmas. In I-mode plasmas, which lack an electron density pedestal but do have a temperature pedestal, the poloidal variation of impurity temperature is weaker (\(<\sim 3x\)) and the impurity density nearly symmetric between the LFS and HFS. These measurements indicate that the sharp gradients in the pedestal region, particularly of main ion density, have a significant effect on the poloidal and radial distribution of impurities, which could have important implications for the prediction of impurity contamination in future fusion reactors such as ITER. Estimates of particle and heat transport timescales suggest that the radial and parallel transport timescales are of the same order in the pedestal region of C-Mod, supporting the idea that two-dimensional transport effects need to be retained in impurity modeling of the pedestal region. To this end, initial comparisons to global neoclassical transport codes in the pedestal region will be presented.

1RM Churchill, et al, RSI 84 (9), 093505 (2013)

11:00AM BI1.00004 Impact of inward turbulence spreading on energy loss of edge-localized modes1. CHENHONG MA, Meking University, LLNL — BOUT++ six-fold Landau-fluid simulations show that an ELM crash has two phases: fast initial crash of ion temperature profile on the order of Alfven time scale near the peak gradient region and slow electron inward turbulence spreading from the ELM crash event. Both of them contribute to the ELM energy loss. However, the conducted ELM energy loss dominates over the convected ELM energy loss, which remains almost constant after the initial crash. The total ELM energy loss is mainly determined by the MHD turbulence spreading when the pedestal temperature height is large. The inward front propagation of electron temperature perturbation spreads into the linearly stable zone, while the ion perturbation front has much less spreading. The electron temperature fluctuation peaks on the rational surfaces and the front jumps gradually inwards towards neighboring rational surfaces. The electron wave-particle resonances via Landau closure provide a relatively strong parallel damping effect on the electron temperature perturbation and induce a large cross-phase shift of about \(\pi/2\) angle between ExB velocity and the ion temperature, which yields almost no spreading for ion temperature and density fluctuations. When pedestal temperature height increases, the cross-phase shift of electron decreases and is close to \(\pi/4\) which yields a large turbulence spreading and generates the large electron conducted energy loss. The front propagation stops at the position where the radial turbulent correlation length is shorter than the magnetic surface spacing. The energy burst of an ELM is controlled by the magnetic shear profile, the characteristic front propagating velocity and the turbulence correlation time. The inward turbulence spreading is mainly driven by (1) a series of micro-crashes due to a localized steepening of profile and (2) the magnetic flux. The impact of other kinetic effects, such as full FLR effect and toroidal resonances, will be presented via simulations of a newly developed electro-magnetic Gyro-Landau-Fluid extension.


11:30AM BI1.00005 4D Fokker-Planck calculations of neoclassical effects in tokamak pedestals and stellarators. M.L. LANDREMAN, University of Maryland — In this work, techniques are discussed for efficiently solving time-independent 4D (2 space + 2 velocity) linear drift-kinetic equations with Fokker-Planck collisions, illustrating several applications in stellarators and tokamaks. Conventional calculations of neoclassical flows and fluxes, and hence becomes inadequate in the tokamak pedestal if strong gradients violate the thin-orbit-width ordering, yet accurate calculation of these quantities is important for understanding edge stability and confinement. We have therefore developed a new radially global continuum neoclassical code PERFECT [1] which allows some radial scale lengths to be as small as the poloidal ion gyroradius. Using this tool, we demonstrate the first precise verification of recent analytic theory that accounts for finite orbit width effects in the limit of large aspect ratio [2]. The main ion and impurity flows predicted by the finite-orbit-width theory are significantly different from the previous results, and the poloidal potential is found to be much less sensitive to the orbit width than previously thought. A related new code SFINCS implements these same algorithms but with a toroidal angle in place of the radial coordinate, enabling calculations of regimes of high aspect ratio. For W7-X and LHD scenarios, we use SFINCS to compare the common incompressible-\(E \times B\) drift-motion model with more accurate drift-kinetic equations. For radial electric fields below roughly 1/3 of the resonant value, the different kinetic equations lead to similar predictions for the fluxes and flows, whereas the results can differ significantly for larger electric fields. SFINCS calculations for expected W7-X conditions, the various kinetic models predict similar levels of bootstrap current, improving confidence in past predictions for this quantity that strongly impacts the W7-X divertor.


1Supported by US DOE.

12:00PM BI1.00006 The effects of weakly 3D equilibria on the stability and turbulent transport of tokamak pedestals. THOMAS BIRD, Max-Planck-Institut für Plasmaphysik, Greifswald — It has been widely demonstrated experimentally that externally applied resonant magnetic perturbations (RMPs) can substantially modify the properties of tokamak pedestals. In this work we demonstrate that perturbations of experimentally relevant magnitudes can have an \(O(1)\) effect on the marginal stability boundaries for ideal MHD ballooning modes and the heat flux driven by ITG instabilities. It has recently been established that RMPs can induce 3D flux surface deformations by exciting stable kink modes to finite amplitude, even when strong screening of the resonant field occurs. These deformations are usually only a few percent of the minor radius, but have a potent and generally destabilizing effect on pedestal stability. Local 3D equilibrium theory is employed to show how the deformations modify the normal curvature and local magnetic shear. We will show how helical Pfirsch-Schlüter currents can strongly modulate the local magnetic shear near rational surfaces. The sensitivity of infinite-n ideal MHD ballooning stability to these deformation-induced effects is calculated as a proxy for the onset of KKM turbulence. The effect on ITG turbulence is assessed using a newly developed “full-surface” version of the GENE code that has been designed for 3D configurations. We will show how 3D deformations enhance the ion heat flux driven by ITGs, which may be able to explain recent measurements of the sensitivity of turbulent density fluctuations to RMP fields. A hypothesis for ELM suppression will be presented, based on strong helical local shear modulations causing enhanced transport near the pedestal top. Using MSD-C1 linear response calculations to model experimentally relevant tokamak equilibria, we will quantify the magnitude of the 3D effects as well as their sensitivity to various experimental knobs.
9:30AM B12.00001 Turbulent amplification of magnetic fields in the laboratory1. GIANLUCA GREGORI, University of Oxford — Magnetic fields exist ubiquitously in the Universe, as revealed by either diffuse radio-synchrotron emission, or Faraday rotation observations, with strengths from a few nG to tens of μG. The energy density of these fields is typically comparable to the energy density of the fluid motions of the plasma in which they are embedded, making magnetic fields essential players in the dynamics of the luminous matter in the Universe. At present, the origin and the distribution of the magnetic fields are far from being understood. The standard model for the origin of these intergalactic magnetic fields is through the amplification of seed fields via turbulent processes to the level consistent with current observations. We have conducted a series of laboratory experiments using high power laser facilities to explore the scale invariance of the magneto-hydrodynamics equations. While the scaling is not perfect (e.g., in what concerns dissipation coefficients such as resistivity or viscosity), the similarity is sufficiently close to make such experiments interesting – and the results have been showing up the fundamental physical process at play. Our results indicate the magnetic field is indeed amplified by turbulent mechanisms. We relate our findings with processes occurring in supernova remnants and in cluster of galaxies. These experiments provide an example of magnetic field amplification by turbulence in plasmas, a physical process thought to occur in many astrophysical phenomena. 

[1] G. Gregori et al., Nature 481, 480 (2012);

1The research leading to these results has received funding from the European Research Council under the European Community’s Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement no. 256973.

10:00AM B12.00002 Observation of electromagnetic Weibel instabilities in laser-driven high Mach number counter-streaming plasma flow experiments1. HYE-SOOK PARK, Lawrence Livermore Natl Lab — Astrophysical collisionless shocks are ubiquitous, occurring in supernova remnants, gamma ray bursts, and protostellar jets. They appear when the ion-ion collision mean free path is much larger than the system size. Here we present laboratory experiments using the high-power lasers and investigate the dynamics of high Mach number collisionless shock formation in two interpenetrating plasma streams. It is believed that in the astrophysical environment such shocks are the sites where seed magnetic fields are generated on a cosmologically fast timescale [1] via the Weibel [2] (or filamentation) instability. Particle-in-cell (PIC) numerical simulations have confirmed that the strength and scale of the generated magnetic field [3,4] are consistent with this concept. Our recent proton probe experiments on Omega show filamentary structures of Weibel instabilities, that are from electromagnetic nature and the inferred magnetization level could be as high as ∼1% [5]. These results imply significance of electromagnetic instabilities in the plasma interactions in the ICF and astrophysical conditions. This paper will review the recent experimental results from various laser facilities as well as the simulation results and the theoretical understanding of these observations. The planned NIF experiments will be presented where it will be possible to observe the fully formed shocks.


1This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

10:30AM B12.00003 Astrophysical Weibel instability in counter-streaming laser-produced plasmas. W. FOX, Princeton Plasma Physics Laboratory — Astrophysical shock waves play diverse roles, including energizing cosmic rays in the blast waves of astrophysical explosions, and generating primordial magnetic fields during the formation of galaxies and clusters. These shocks are typically collisionless and require collective electromagnetic fields to couple the upstream and downstream plasmas. The Weibel instability has been proposed to provide the requisite interaction mechanism for shock formation in weakly-magnetized shocks by generating turbulent electric and magnetic fields in the shock front. This work presents the first laboratory identification of this Weibel instability between counterstreaming supersonic plasma flows and confirms its basic features, a significant step towards understanding these shocks. In the experiments, conducted on the OMEGA EP laser facility at the University of Rochester, a pair of plasmas plumes are generated by irradiating of a pair of opposing parallel plastic (CH) targets. The ion-ion interaction between the two plumes is collisionless, so as the plumes interpenetrate, supersonic, counterstreaming ion flow conditions are obtained. Electromagnetic fields formed in the interaction of the two plumes were probed with an ultrastable laser-driven proton beam, and we observed the growth of a highly striated, transverse instability with extended filaments parallel to the flows. The instability is identified as an ion-driven Weibel instability through agreement with analytic theory and fully kinetic particle-in-cell simulations of colliding ablation flows, which include a collision operator. The experimental proton-radiography results are compared with synthetic ray-tracing through 3-D simulations.


11:00AM B12.00004 Turbulence in the Solar Wind from MHD to Kinetic Scales. CHRISTOPHER CHEN, Imperial College London — The solar wind provides one of the best opportunities to investigate plasma turbulence with a range of detailed in situ measurements. In this talk, I will describe some recent work that has been made in understanding this turbulence, both at MHD scales and at small kinetic scales, where recent high resolution measurements have led to a rapid increase in our understanding. In particular, I will discuss measurements of the energy spectrum, anisotropy, intermittency and the interplay between linear and non-linear dynamics in the cascade. I will also compare these results to modern theories of plasma turbulence and discuss the implications for our understanding of how turbulent plasmas are heated.
11:30AM B12.00005 Experimental study of energy conversion in the magnetic reconnection layer\(^1\), MASAKI YAMADA, Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ USA — Magnetic reconnection, in which magnetic field lines break and reconnect to change their topology, occurs throughout the universe: in solar flares, the earth’s magnetosphere, star forming galaxies, and laboratory fusion plasmas \([1]\). The essential feature of reconnection is that it energizes plasma particles by converting magnetic energy to particle energy; this process both accelerates and heats the plasma particles. Despite the recent advances of reconnection research, the exact mechanisms for bulk plasma heating, particle acceleration, and energy flow channels remain unresolved. In this work, the mechanisms responsible for the energization of plasma particles in the magnetic reconnection layer are investigated in the MRX device together with a quantitative evaluation of the conversion of magnetic energy to ions and electrons. A comprehensive analysis of the reconnection layer is made in terms of two-fluid physics based on the measurements of two-dimensional profiles of 1) electric potential, 2) flow vectors of electrons and ions, and 3) the electron temperature, \(T_e\) and the ion temperature, \(T_i\) in the layer. It is experimentally verified that a saddle shaped electrostatic electric potential profile is formed in the reconnection plane. Ions are accelerated across the separatrices by the strong electrostatic field and enter the exhaust region where they become thermalized \([2,3]\). Electron heating is observed to extend beyond the electron diffusion region, and non-classical heating mechanisms associated with high frequency fluctuations is found to play a role. Our quantitative analysis of the energy transport processes and energy inventory concludes that more than 50 % of magnetic energy is converted to plasma particles, of which 2/3 transferred to ions and 1/3 to electrons. The results which demonstrate that conversion of magnetic energy occurs in a significantly larger region than theoretically considered before, are compared with the two-fluid simulations and the recent space measurements \([4]\). Broader implication of the present results will be discussed.

\(^1\)Supported by DOE, NASA and NSF. Collaborators; J. Yoo, J. Jara Almonte, H. Ji, R. Kulsrud, C. Myers

12:00PM B12.00006 3D MHD simulation of Caltech Plasma Jet Experiment and Implications for Astrophysical Jets\(^1\), XIANG ZHAI, Caltech — Magnetic fields are believed to play an essential role in astrophysical jets with observations suggesting the presence of helical magnetic fields. In this talk we present 3D ideal MHD simulations of the Caltech plasma jet experiment using a magnetic tower scenario as the baseline model. Magnetic fields consist of an initially localized dipole-like poloidal component and a toroidal component that is continuously being injected into the domain. This flux injection mimics the poloidal currents driven by the anode-cathode voltage drop in the experiment. The injected toroidal field stretches the poloidal fields to large distances, while forming a collimated jet along with several other key features. Detailed comparisons between 3D MHD simulations and experimental measurements provide a comprehensive description of the interplay among magnetic force, pressure and flow effects. In particular, we delineate both the jet structure and the transition process that converts the injected magnetic energy to other forms. With suitably chosen parameters that are derived from experiments, the jet in the simulation agrees quantitatively with the experimental jet in terms of magnetic/kinetic/inertial energy, poloidal current, jet radius and jet propagation velocity. Specifically, the jet velocity in the simulation is proportional to the poloidal current divided by the square root of the jet density, in agreement with both the experiment and analytical theory. This work provides a new and quantitative method for relating experiments, numerical simulations and astrophysical observation, and demonstrates the possibility of using terrestrial laboratory experiments to study astrophysical jets.

\(^1\)The work has been done under the collaboration between Caltech Bellan group and LANL Li group.

Monday, October 27, 2014 9:30AM - 12:18PM — Session BO3 Plasma Wakes and Dusty Plasmas

9:30AM BO3.00001 Simulation of Unsteady Wakes in Magnetized Plasmas\(^1\), CHRISTIAN BERNT HAAKONSEN, IAN H. HUTCHINSON, CHUTENG ZHOU, MIT PSFC — Wakes occur in plasmas moving past obstacles such as probes or the moon, and can take a variety of forms for different plasma parameters. The present work addresses relative motion perpendicular to a magnetic field, where the plasma Debye length and typical ion gyroradius are smaller than the obstacle. We have discovered such wakes to be unsteady, using Particle-In-Cell simulations, both for subsonic and supersonic relative motion. The underlying drive for the unsteadiness is provided by counterstreaming ions in the wake, and for supersonic motion kinetic electron effects lead to unsteadiness closer to the obstacle than what is seen in simulations with a Boltzmann electron response. It is thus sometimes necessary to resolve the electron time-scale in simulations, requiring parallel simulations using significant computational resources. The subsonic simulations are for a regime applicable to (among other things) Mach probes in the scrape-off layers of tokamaks, where unsteady wake effects could potentially be detected. The supersonic simulations are for instance relevant to the solar wind flowing past the moon, where the present work dramatically improves the resolution and understanding of plasma phenomena in the wake.

\(^1\)C.B. Haakonsen and C. Zhou were supported by NSF/DOE Grant No. DE-SC0010491.

9:42AM BO3.00002 Is the compressibility positive or negative in a strongly-coupled dusty plasma?\(^1\), JOHN GOREE, W. D. SURANGA RUHUNUSIRI, The University of Iowa — In dusty plasmas, dust particles are often strongly coupled with a large Coulomb coupling parameter \(\Gamma\), while the electrons and ions that share the same volume are weakly coupled. In most substances, compressibility \(\beta\) must be positive; otherwise there would be an explosive instability. In a multicomponent plasma, however, one could entertain the idea that \(\beta\) for a single strongly coupled component could be negative, provided that the restoring force from charge separation overwhelms the destabilizing effect. Indeed, the compressibility for a strongly-coupled dust component is assumed to be negative in three theories we identified in the literature for dust acoustic waves. These theories use a multi-fluid model, with an OCP (one component plasma) or Yukawa-OCP approach for the dust fluid. We performed dusty plasma experiments designed to determine the value of the inverse compressibility \(\beta^{-1}\), and in particular its sign. We fit an experimentally measured dispersion relation to theory, with \(\beta^{-1}\) as a free parameter, taking into account the systematic errors in the experiment and model. We find that \(\beta^{-1}\) is either positive, or it has a negligibly small negative value, which is not in agreement with the assumptions of the OCP-based theories.

\(^1\)Supported by NSF and NASA
9:54AM BO3.00003 Dust density measurements in 3D dust clouds by tomography 1, ANDRE MELZER, Institute of Physics, University Greifswald, 17498 Greifswald, Germany — Dusty plasmas usually consist of (micron-sized) dust particles trapped in a gaseous discharge plasma. Volume-filling dust clouds can be generated in the laboratory by thermophoretic levitation of the particles against gravity or under the microgravity conditions of parabolic flights. In these discharges, the dust density is typically so high that together with the high charge on the particles, the dust charge density can compete with the ion and electron (charge) density indicating a regime of charge depletion. Here, we present a technique that allows to measure the spatially resolved 3D dust density in such dusty discharges. For that purpose, the dust cloud is transilluminated by a homogeneous light source and the transmittance is measured under different angles in a tomographic-like manner. This allows to reconstruct the full 3D dust density within the discharge volume and further to deduce the force balance for the dust component.

1Supported by DLR 50 WM 1138.

10:06AM BO3.00004 Measurement of Intertube/Interstring Forces in Vertically Aligned Dust Particle Systems, TRUELL HYDE, JIE KONG, OLEG PETROV, BO ZHANG, LORIN MATTHEWS, CASPER — Baylor University — Particle–particle, cluster–cluster and string–string interactions have long been of interest across a variety of scientific research disciplines. Complex plasmas have proven to be a versatile analog for studying such systems, often providing a mechanism for determining the fundamental physics behind the strong correlation effects observed. In this talk, the interaction between two, two-particle vertically aligned strings, two, three–particle vertically aligned strings and two vertically aligned dust particle clusters is examined experimentally. The energy storage held within the Coulomb field between particles will be discussed using data collected employing a technique using externally assigned potentials on the walls of an Indium Tin Oxide (ITO) box.

10:18AM BO3.00005 Dust as In-Situ Probes for Plasma Magnetic Field Interactions in a Dusty Plasma, MICHAEL DROPPMANN, RENAUF LAUER, GEORG HERDRICH, CASPER — Baylor University / IRS – University of Stuttgart, LORIN MATTHEWS, TRUELL HYDE, CASPER — Baylor University — A series of experiments were conducted inside a GEC rf reference cell to map the forces in three dimensions above a magnet placed in a dusty plasma and employing both horizontal and vertical orientations. Micron sized dust particles were used as in-situ probes to investigate the interaction between the low-temperature plasma produced and a magnetic field close to a non-conductive surface. Dust particles were dropped into the plasma where they obtained a negative charge leading to trajectories, which were strongly influenced by both electric and ion drag forces. By recording the trajectories of the particles, which were illuminated by a vertical laser plane, the forces onto the particles were determined. A strong influence of the magnetic field onto the plasma sheath was observed. Given the electrons are strongly magnetized by the magnet while ions remain comparatively unaffected by the magnet a charge separation takes place, which leads to strong electric fields. As a result the sheath thickness varies significantly within the magnetic field, showing strong horizontal force components. Based on these observations, analogies to the interaction of the lunar plasma with known lunar magnetic anomalies will be drawn to contribute to the explanation of the formation of lunar swirls.

10:30AM BO3.00006 Dust particles as probe in a complex plasma 1, RAZIYEH YOUSEFI, ALLEN DAVIS, JORGE CARMONA-REYES, LORIN MATTHEWS, TRUELL HYDE, CASPER — Baylor University — Understanding the behavior of dust particles in a complex plasma requires a knowledge of the basic properties such as the net electrostatic charge and dipole moment of the dust as well as the local electrostatic fields. In this study, dust aggregates are formed from gold coated monodisperse spherical melamine-formaldehyde monomers in a radio-frequency (rf) argon discharge plasma. The behavior of observed dust aggregates is analyzed both by studying the particle trajectories and by employing computer models examining 3D structures of aggregates and their interactions and rotations as induced by torques arising from their dipole moments. These allow the basic characteristics of the dust aggregates, such as the electrostatic charge and dipole moment, and local electrostatic fields to be determined from the behavior of particles. It is shown that the experimental results agree with predicted values from computer models for aggregates in these environments.

1This work was supported by the National Science foundation under Grant No. 0847127.

10:42AM BO3.00007 The Potential Field within a Biased Indium Tin Oxide Glass Box Located in a Dusty Plasma Environment, JORGE CARMONA-REYES, LORIN MATTHEWS, TRUELL HYDE, CASPER — Baylor University — The number of studies in complex plasmas have increased rapidly due to the field’s ability to act as an analog for research in other areas such as metallic glasses in engineering, coulomb interactions in pure physics, and double helical formation in biophysics. Much of the data collected in such studies occurs inside a glass box placed on the lower powered electrode of a GEC rf reference cell. Recently, several research groups have expanded this technique through use of an Indium Tin Oxide (ITO) glass box for better control of the confining potential. Unfortunately, a proper understanding of the underlying physics producing the confinement inside a glass box is lacking. This work will provide results from a mapping of the potential well inside an ITO box, employing a user positioned reference probe installed in a Zyvex S-100 nanomanipulator. The shape of the potential well, the plasma sheath and the particle interaction inside the ITO box will be discussed.

10:54AM BO3.00008 Small Dust Cluster Probes within a Dusty Plasma, JIE KONG, KE QIAO, LORIN MATTHEWS, TRUELL HYDE, CASPER — Baylor University — Small-number dust particle clusters are often seen in dusty plasmas. Interestingly, such clusters can often be used as in-situ probes providing plasma diagnostics. The number of dust particles, as well as the cluster size and shape, can be easily controlled employing a glass box placed on the powered lower electrode within a GEC rf reference chamber to provide confinement of the dust. Adjusting the rf power alters the plasma conditions creating structural changes within the cluster. This effect can be used to probe the relationship between the rf power and other plasma parameters of interest. This experiment employs the sloshing and breathing modes of small cluster oscillations to examine the relationship between the system’s rf power and the particle screening length inside the glass box as well as determine the particle charge. Experimental results indicate that both the screening length and the dust charge decrease as the rf power inside the box increases.

11:06AM BO3.00009 Mode Coupling and Resonance Instabilities in a Dust Chain, KE QIAO, JIE KONG, LORIN MATTHEWS, TRUELL HYDE, CASPER — Baylor University — Mode couplings and resonance instabilities have recently received tremendous attention in both large plasma crystals [1] and small dust clusters [2, 3]. In this research, normal modes are investigated using both simulation and experiment to examine a horizontal finite chain consisting of 3–50 dust particles in a complex plasma. The resultant mode coupling and resonance instabilities are analyzed and compared with previous research on large crystals and circular dust clusters.

11:18AM BO3.00010 Sheared and unsheared rotation of driven dust clusters, DIETMAR BLOCK, JAN SCHABLINSKI, JAN CARSTENSEN, FRANKO GREINER, ALEXANDER PIEL, University of Kiel, Germany — In dusty (complex) plasmas rotating dust clusters with either rigid body rotation, horizontally sheared rotation, or vertical sheared rotation are observed in axial magnetic fields, rotating electric fields, rotating neutral gas columns, and in laser manipulation experiments. Our experiments and simulations now add a small anisotropy of only a few percent to the confinement potential. Such anisotropies are hardly avoidable in experiments and therefore their role should be carefully studied to avoid misinterpretation of the experimental observations. This contribution reports on systematical investigations of the motion of driven dust clusters in a slightly anisotropic confinement. Special attention is paid to the questions whether an unsheared drive always results in an unsheared cluster rotation and how symmetry and particle arrangement affect the dynamical response of the system.
11:30AM BO3.00011 Selective mode excitation in 2D dust clusters1, JAN SCHABLINSKI, DIETMAR BLOCK, University of Kiel, ANDRE MELZER, University of Greifswald, ALEXANDER PIEL, University of Kiel — The dynamical properties of dust clusters are still a hot topic in recent research activities. In many applications intense lasers are used as a tool for the manipulation of the dynamics of particle systems. For example, specific particle motion patterns like the intershell rotation of small clusters can be driven or the systems can be effectively heated by randomized momentum transfer using multiple lasers. In this contribution we present a method to drive a selection of eigenmodes of the particle system, which are mainly associated with radial particle oscillations, and give a characterization of the driving mechanism. Further, the impact of a localized driving force on the ability to excite either breathing or wave-like modes is discussed.

1DFG grant SFB TRR 24, project A3

11:42AM BO3.00012 Shock Propagation in Dusty Plasmas by MD Simulations, MATTHEU MARCIANTE, MICHAEL MURILLO, Los Alamos National Laboratory — The study of shock propagation has become a common way to obtain statistical information on a medium, as one can relate properties of the undisturbed medium to the shock dynamics through the Rankine-Hugoniot (R-H) relations. However, theoretical investigations of shock dynamics are often done through idealized fluid models, which mainly neglect kinetic properties of the medium constituents. Motivated by recent experimental results [1] we use molecular dynamics simulations to study the propagation of shocks in 2D-dusty plasmas, focusing our attention on the influence of kinetic aspects of the plasma, such as viscosity effects. This study is undertaken on two sides. On one side, the shock wave is generated by an external electric field acting on the dust particles, giving rise to a shock wave as obtained in a laboratory experiment. On another side, we generate a shock wave by the displacement of a two-dimensional piston at constant velocity, allowing to obtain a steady-state shock wave. Experiment-like shock waves propagate in a highly non-steady state, what should ask for a careful application of the R-H relations in the context of non-steady shocks. Steady-state shock waves show an oscillatory pattern attributed to the dominating dispersive effect of the dusty plasma.


11:54AM BO3.00013 Intrinsic Charge Fluctuations of Dust in Plasmas Containing Multiply Charged Ions, BABAK SHOTORBAN, The University of Alabama in Huntsville — A master equation, formulated for states of the charge of a grain in a plasma containing various kinds of singly or multiply charged ions (Shotorban, Phys Plasmas, 2014) is presented. From the master equation, a Fokker-Planck equation is derived through van Kampen’s system-size expansion method. The derived Fokker-Planck equation has a Gaussian solution with a mean and variance governed by two initial-value differential equations involving the ions and electron attachment rates. Also, a Langevin equation, statistically equivalent to the Fokker-Planck equation, and a discrete stochastic method, statistically representing the master equation, are developed to model the grain charge fluctuations in time. Grain charging in a plasma containing electrons, protons, and alpha particles is considered as a test problem. It is shown that the Gaussian solution is in very good agreement with the master equation’s solution obtained numerically for this problem.

12:06PM BO3.00014 ABSTRACT WITHDRAWN —

Monday, October 27, 2014 9:30AM - 12:30PM —
Session BO4 Compression and Burn I Salon E - Debra Callahan, Lawrence Livermore National Laboratory

9:30AM BO4.00001 Measures of Alpha Heating in Inertial Confinement Fusion, R. BETTI, A.R. CHRISTOPHERSON, Fusion Science Center and Laboratory for Laser Energetics, U. of Rochester — Assessing the degree to which fusion alpha particles contribute to the fusion yield is essential to the understanding of the onset of the thermal runaway process of thermonuclear ignition. It is shown that in inertial confinement fusion, the yield enhancement resulting from alpha particle heating (before ignition occurs) depends on the fractional alpha energy or, equivalently, on the generalized Lawson criterion. Both the fractional alpha energy and the generalized Lawson criterion can be inferred from experimental observables. This result can be used to assess the performance of current ignition experiments at 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 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.

9:42AM BO4.00002 Alpha-Heating and a Burning Plasma State1, O.A. HURRICANE, D.A. CALLAHAN, D.T. CASEY, E.L. DEWALD, T.R. DITTRICH, T. DOEPPLER, M.A. BARRIOS GARCIA, S. HAAN, D.E. HINKEL, L.F. BERZAK HOPKINS, O. JONES, A.L. KRITCHER, S. LE PAPE, T. MA, A. MACPHEE, J. MILOVICH, J. MOODY, A. PAK, H.-S. PARK, P.K. PATEL, B.A. REMINGTON, H.F. ROBYE, J. SALMONSON, P.T. SPRINGER, R. TOMMASINI, LLNL — L. R. BENEDETTI, D. BRADLEY, D. FITTINGHOFF, N. IZUMI, S. KHAN, R. TOWN (LLNL) — The study of shock propagation has become a common way to obtain statistical information on a medium, as one can relate properties of the undisturbed medium to the shock dynamics through the Rankine-Hugoniot (R-H) relations. However, theoretical investigations of shock dynamics are often done through idealized fluid models, which mainly neglect kinetic properties of the medium constituents. Motivated by recent experimental results [1] we use molecular dynamics simulations to study the propagation of shocks in 2D-dusty plasmas, focusing our attention on the influence of kinetic aspects of the plasma, such as viscosity effects. This study is undertaken on two sides. On one side, the shock wave is generated by an external electric field acting on the dust particles, giving rise to a shock wave as obtained in a laboratory experiment. On another side, we generate a shock wave by the displacement of a two-dimensional piston at constant velocity, allowing to obtain a steady-state shock wave. Experiment-like shock waves propagate in a highly non-steady state, what should ask for a careful application of the R-H relations in the context of non-steady shocks. Steady-state shock waves show an oscillatory pattern attributed to the dominating dispersive effect of the dusty plasma. Inference of the alpha-heating contribution to the yield is made using a simulation database of DT implosions and the one-to-one correspondence between R-H and experimental observables. This result can be used to assess the performance of current ignition experiments at 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 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.

1Work performed under the auspices of U.S. Dept. of Energy by LLNL under Contract DE-AC52-07NA27344.

9:54AM BO4.00003 Thin Shell, High Velocity, High-Foot ICF Implosions on the National Ignition Facility1, T. MA, O.A. HURRICANE, D.A. CALLAHAN, M.A. BARRIOS, D.T. CASEY, E.L. DEWALD, T.R. DITTRICH, T. DOEPPLER, M.A. BARRIOS GARCIA, S. HAAN, D.E. HINKEL, L.F. BERZAK HOPKINS, S. LE PAPE, A.G. MACPHEE, A. PAK, H.-S. PARK, P.K. PATEL, H.F. ROBYE, B.A. REMINGTON, J.D. SALMONSON, P.T. SPRINGER, R. TOMMASINI, Lawrence Livermore National Laboratory — Experiments have recently been conducted at the National Ignition Facility utilizing ICF capsule ablators that are 175 µm in thickness, 10% thinner than the nominal thickness capsule used throughout the High-Foot and most of the National Ignition Campaigns. These three-shock, high-adiabat, high-foot implosions have demonstrated good performance, with higher velocity and better symmetry control at lower laser powers and energies than their nominal thickness ablator counterparts. Early results have shown good repeatability, with little to no hydrodynamic mix into the DT hot-spot, and > 1/2 the yield coming from α-particle self-heating.

1This work performed under the auspices of U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
10:06AM BO4.00004 High-Performance Layered DT Capsule Implosions in Depleted Uranium Hohlraums on the NIF\textsuperscript{1}, T. I. DOEPPNER, O. A. HURRICANE, D. A. CALLAHAN, D. CASEY, T. MA, H. S. PARK, L. BENEDETTI, E. L. DEWALD, T. R. DITTRICH, T. FITTINGHOFF, S. HAAN, D. HINKEL, L. BERZAK HOPKINS, N. IZUMI, A. KRITCHER, S. LE PAPE, A. PAK, P. PATEL, H. ROBEY, B. REMINGTON, J. SALMISONON, P. SPRINGER, K. WIDMANN, Lawrence Livermore National Laboratory, F. MERRILL, C. WILDE, Los Alamos National Laboratory — We report on the first layered DT capsule implosions in depleted uranium (DU) hohlraums driven with a high-foot pulse shape. High-foot implosions have demonstrated improved resistance to hydrodynamic instabilities. \cite{Hurricane2014}. DU hohlraums provide a higher albedo and thus an increased drive equivalent to 25 TW extra laser power at the peak of the drive compared to Au hohlraums. Additionally, we observe an improved implosion shape closer to round which indicates enhanced drive from the waist. As a result, these first high-foot DU experiments achieved total neutron yields approaching $10^{16}$ neutrons where more than 50\% of the yield was due to additional heating of alpha particles stopping in the DT fuel.

\begin{itemize}
\item This work performed under the auspices of U.S. Department of Energy Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
\end{itemize}

10:18AM BO4.00005 Hot spot conditions in DT implosions on the NIF\textsuperscript{1}, P. K. PATEL, D. A. CALLAHAN, C. CERJAN, D. S. CLARK, T. R. DITTRICH, T. DOEPPNER, M. J. EDWARDS, S. HAAN, D. E. HINKEL, L. F. BERZAK HOPKINS, O. A. HURRICANE, A. L. KRITCHER, J. D. LINDL, T. MA, A. G. MACPHEE, A. E. PAK, H. S. PARK, H. F. ROBEY, J. D. SALMISONON, B. SPEARS, P. T. SPRINGER, N. IZUMI, S. KHAN, Lawrence Livermore National Laboratory — We describe a 1D model that uses experimentally measured data to derive the thermodynamic conditions at stagnation of the hot spot, dense fuel, and ablator, in deuterium-tritium (DT) layered implosions on the National Ignition Facility (NIF). Neutron measurements—spectrally, spatially and temporally resolved—are used to infer the hot spot burn-averaged pressure, density, areal density, ion temperature, volume, and internal energy. X-ray spectral measurements are used to infer electron temperature, radiative energy loss, and the presence of ablator mix in the hot spot. In addition, we can calculate the fraction of alpha-particle energy trapped in the hot spot and, hence, estimate the degree of self-heating. Recent DT layered implosions using the high-foot design \cite{Hurricane2014} have achieved areal densities and temperatures in the hot spot whereby a significant fraction of the internal energy at stagnation can be attributed to alpha-particle self-heating. This work was performed under the auspices of the U.S. Department of Energy Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

10:30AM BO4.00006 Cryogenic THD and DT layer implosions with high density carbon ablators in near-vacuum hohlraums\textsuperscript{1}, N. B. MEEZAN, L. F. BERZAK HOPKINS, S. LE PAPE, S. F. KHAN, A. E. PAK, L. DIVOL, D. D. HO, T. MA, T. DOEPPNER, J. R. RYGG, J. E. FIELD, O. S. JONES, J. L. MILOVICH, B. J. KOZIOZIEMSKI, A. V. HAMZA, A. J. MACKINNON, W. W. HSING, M. J. EDWARDS, Lawrence Livermore National Laboratory — High Density Carbon (HDC or diamond) is a promising ablator material for use in near-vacuum hohlraums, as its high density allows for ignition designs with laser pulse durations < 10 ns. A series of experiments in 2013 on the National Ignition Facility culminated in a DT layered implosion driven by a 6.5 ns, 2-shock laser pulse. This talk describes these experiments and comparisons with the design code HYDRA. Backlit radiography of a THD layered capsule demonstrated an ablator implosion velocity of 385 km/s with a slightly oblate hot spot shape; however, other diagnostics suggested an asymmetric compressed fuel layer. The streak camera-based SPIDER diagnostic showed a double-peaked history of the capsule self-emission. Simulations suggest that this is a signature of a low-temperature hot spot. Changes to the laser pulse-shape and pointing for a subsequent DT implosion resulted in a higher temperature, prolate hot-spot and a thermonuclear yield of $1.8 \times 10^{15}$ neutrons.

\begin{itemize}
\item Prepared by LLNL under Contract DE-AC52-07NA27344.
\end{itemize}

10:42AM BO4.00007 Cryogenic Implosion Performance Using High-Purity Deuterium–Tritium Fuel, T. C. SANGSTER, V. N. GONCHAROV, P. B. RADHA, R. EARLEY, R. EPSTEIN, C. J. FORREST, D. H. FROULA, V. YU. GLEBOV, S. X. HU, I. V. IGUMENSHCHEV, F. J. MARSHALL, P. W. MCKENTY, W. T. SHMAYDA, M. J. SHOUP III, D. T. MICHEL, C. STOECKL, W. SEKA, Laboratory for Laser Energetics, U. of Rochester, J. A. FREJNIE, M. CATU JOHNSON, PSCF, MIT — Demonstrating hydrodynamic equivalence between symmetric implosions on OMEGA and National Ignition Facility ignition designs will require a number of facility enhancements that include dynamic bandwidth reduction, a set of higher-order super-Gaussian phase plates, high-spatial-resolution gated-core imaging, high-bandwidth neutron burnthrough measurements, improved power balance, and contaminant-free deuterium–tritium (DT) fuel. The historic DT fuel supply was contaminated with \~0.6 atm% of $^3$H, leading to significant fractionation of the fuel during the layering process (the triple points of H:D and H:T are significantly colder than DD, DT, and TT). The fractionation leads to a drop in the potential yield because the D and T number densities are lower in the void than they would be with a pure-DT mixture. An isotope separation system has been developed to remove the $^3$H from the DT fuel supply. This talk will discuss the first results with the purified fuel, conclusions from recent implosions to test cross-beam energy transfer mitigation, and the status of the remaining facility enhancements. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

10:54AM BO4.00008 Early time hot electron generation and deposition at the capsule in indirect drive ICF implosions on the National Ignition Facility\textsuperscript{1}, E. L. DEWALD, A. R. PAK, J. S. MILOVICH, B. BACHMANN, Lawrence Livermore National Laboratory, M. H. Hohenberger, Laboratory of Laser Energetics, University of Rochester, F. CERJAN, T. D. CLARK, D. T. DOEPPNER, A. MACKINNON, N. MEZAN, D. CALLAHAN, D. CASEY, T. MA, H. S. PARK, E. R. ROBEY, C. THOMAS, L. D. TROOST, J. S. WIDMANN, Lawrence Livermore National Laboratory — In indirect drive ICF experiments \cite{Edwards2013} on the National Ignition Facility (NIF), hot electrons generated by laser plasma instabilities can preheat the deuterium–tritium (DT) capsule, compromising ignition. While below detection limit, the early time (picket) allowable hot electrons in low adiabat implosions \cite{Hurricane2013} are \~1J in electrons with >170 keV energy compared to 1000 J during the late time peak laser power \cite{Edwards2010}. At the same time, High Foot implosions \cite{Hurricane2014} that demonstrated fuel-ablator mix mitigation and improved yield, have also shown picket hot electrons that can be comparable to allowable threshold. High Foot Re-emit experiments for tuning the picket radiation symmetry also infer the fraction and uniformity of hot electrons reaching the capsule by hard x-ray (50 keV) imaging combined with 40-300 keV spectra \cite{Debbie2010}. Their scalings with laser and plasma conditions are discussed.

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\begin{itemize}
\item This work performed under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344.
\end{itemize}
11:06AM BO4.00009 The measurement of cold fuel abiat from neutron images of ICF experiments at NIF  
FRANK MERRILL, BAOLIAN CHENG, CHRISTOPHER DAWY, NEVZAT GULER, CARL WILDE, PETR VOLEGOV, Los Alamos National Laboratory, DAVID FITTINGHOFF, Lawrence Livermore National Laboratory — Dozens of laser driven inertially confined fusion (ICF) experiments have been performed at NIF over the past several years to investigate the potential for ignition in indirect ablative compression of plastic (CH) capsules containing DT ice layers, initially filled with DT gas. In these experiments, the gas inside of the DT ice layer is compressed and heated by the convergent implosion to temperatures of ~5 keV. This hotspot is surrounded by the colder fuel that was initially in the DT ice layer. Fusion in the hot spot generates 10^{14}-10^{15} 14 MeV neutrons and ~5% of these are scattered in the surrounding cold fuel to energies of 6-12 MeV. Images are formed with 14 MeV neutrons and 6-12 MeV neutron time of flight (ToF) detectors to determine fuel density and cold fuel size shape, respectively. Measurements of DT yield and cold fuel size shape are made for a set of these implosions, which show that the ratio of the hotspot diameter to the cold fuel diameter provides a measure of the abiat on which the cold fuel is compressed. The most recent neutron imaging data, which has been analyzed to extract this information, will be presented to show relative changes of the fuel compression abiat from ICF experiments performed at NIF.

11:18AM BO4.00010 Direct measurement of the effect of early time hot electron preheat on a deuterium-tritium cryogenic ice layer  
JAMES ROSS, HARRY ROBEY, JOHN MOODY, PETER CELLIERS, LAURENT DIVOL, LAURA BERZAK-HOPKINS, SEBASTIEN LE PAPE, Lawrence Livermore National Laboratory, MATTHIAS HOHENBERGER, Laboratory for Laser Energetics, JOE RALPH, OTTO LANDEN, JOHN EDWARDS, Lawrence Livermore National Laboratory — The direct effect of early time supra-thermal electron preheat on a deuterium-tritium (DT) cryogenic ice layer has been measured for the first time in indirect drive inertial confinement fusion experiments on the National Ignition Facility. Controlled changes in the early-time laser power are used to vary the hot electron (E > 170 keV) energy over the range of <1 J to 27 J. At the 27 J energy level the DT ice layer was measured to expand from the initial thickness of 71.5 µm to a thickness of 82.4 µm prior to the breakout of the first laser generated shock using the layered keyhole platform. There was no measurable expansion of the DT ice layer when the hot electron level was 5 J or less. Hot electron levels >5 J increase the entropy of the fuel and can significantly degrade the quality of the implosion. The experimental results are compared to past shot simulations.

11:30AM BO4.00011 A model for degradation of indirectly driven ICF implosions by supra-thermal electron preheat  
H.F. ROBEY, M.D. ROSEN, D.S. CLARK, E.L. DEWALD, S.W. HAAN, A.L. KRITCHER, W. KRUER, J.D. LINDL, M.M. MARINAK, J.D. MOODY, M. PATEL, P.K. PATEL, J.S. ROSS, J.D. SALMONSON, P.T. SPRINGER, C.R. WEBER, Lawrence Livermore National Laboratory, D. SHWARTZ, TN. Negev and Ben Gurion University of the Negev, M. HOHENBERGER, Laboratory for Laser Energetics, B. AFEYAN, Polymath Research Inc., D.S. MONTGOMERY, Los Alamos National Laboratory — In recent years, significant progress has been made in the performance of indirectly driven inertial confinement fusion (ICF) implosions performed on the National Ignition Facility (NIF). Experimental results to date, however, have fallen short of the predicted neutron yield, the expected compression of the deuterium-tritium (DT) fuel layer, and the pressure and density achieved in the central hot spot. A numerical model is presented for the degradation of implosion performance due to preheat of the DT fuel layer by supra-thermal electrons. The model is benchmarked by comparison with focused experiments, which directly measure the expansion of a DT ice layer caused by preheat from a controlled, well-characterized flux of supra-thermal electrons. The same model applied to ignition implosions shows improved agreement with a wide range of experimental observables, and may help to provide an explanation for many of the features observed in ignition implosions on the NIF.

11:42AM BO4.00012 Antipodal neutron time of flight (nToF) detectors more than double their diagnostic value  
JOSEPH KILKENNY, General Atomics, JAMES KNAUER, LLE, JOSEPH CAGGIANO, MARK ECKART, ROBERT HATARIK, DAVID MUNRO, DANIEL SAYRE, LLNL — Moments of the neutron-velocity distribution give unique insights to the quality of an inertial confinement fusion (ICF) implosion. The three, 20m distance nToF detectors on the NIF are being augmented by adding an antipodal detector to each of them. Antipodal pairs of detectors increase the sampling of imploded DT ice but also allow an accurate measurement of the areal density of the odd modes of the compressed ice from the un-scattered yield ratio, and with the two measurements distinguishing center of mass drift velocity from the thermodynamic ion temperature.

11:54AM BO4.00013 Angular Distribution of Ion-Temperature Measurements for Non-Stagnating Inertial Confinement Fusion Implosions  
J.P. KNAUER, Laboratory for Laser Energetics, U. of Rochester, J.A. CAGGIANO, R. HATARIK, D. MUNRO, D.B. SAYRE, B.K. SPEARS, LLNL, M. GATU JOHNSON, J.A. FRENJE, PSFC, MIT — Moments of the neutron-velocity distribution give unique insights to the quality of an inertial confinement fusion (ICF) implosion. The second moment (width) has been used to measure the ion temperature of an ICF core. An analysis is presented that shows how the velocity distribution of an ICF core that does not stagnate changes the measured width with angle. Neutron data from implosions at the National Ignition Facility provide five DT peak width and three DD peak width measurements. These data are used to determine thermal temperatures for DD and DT fusion and the direction and magnitude of a “shear”-like motion in the core. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

12:06PM BO4.00014 ABSTRACT WITHDRAWN

12:18PM BO4.00015 Inference of total DT fusion neutron yield from prompt gamma-ray measurements at the National Ignition Facility  
J.A. CHURCH, Lawrence Livermore Natl Lab, H.W. HERRMANN, Los Alamos Natl Lab, W. STOEFFL, J.A. CAGGIANO, C. CERJAN, D. SAYRE, Lawrence Livermore Natl Lab — Prompt D-T fusion gamma-rays measured at the National Ignition Facility (NIF) with the Gamma-ray Reaction History detector (GRH) have been used recently to infer the total DT fusion neutron yield of inertial confinement fusion (ICF) implosions. The model is benchmarked by comparison with focused experiments, which directly measure the expansion of a DT ice layer caused by preheat from a controlled, well-characterized flux of supra-thermal electrons. The same model applied to ignition implosions shows improved agreement with a wide range of experimental observables, and may help to provide an explanation for many of the features observed in ignition implosions on the NIF.
Towards Spectral Control of Laser-Driven Ion Beams Generated in the Relativistic Transparency Regime.

9:30AM BO5.00001 JUAN C. FERNANDEZ, D.C. GAUTIER, C. HAMILTON, C. HUANG, S. PALANIYAPPAN, Los Alamos National Laboratory — Until recently, experiments on the LANL Trident laser in the relativistic transparency regime have demonstrated efficient, volumetric acceleration of the bulk target ions to high energies by the laser-plasma interaction, but with broad ion-energy distributions. That ion acceleration mechanism (Breakout Afterburner) is intrinsically capable of producing quasi-monoenergetic ion-energy distributions. However, there are processes responsible for energy spread, both during the laser-plasma interaction with present-day experimental conditions, as well as during the subsequent transport of the beam, driven by expansion of the co-moving hot-electron population. Strategies to counter such spread are discussed. Furthermore, our work to understand the recent observation of efficiently-generated, quasi-monoenergetic, \( \approx 150 \text{ MeV} \) Al-ion beams indicates that the dynamics immediately following the laser-plasma interaction can be quite important and beneficial. It has uncovered a new strategy, i.e., using plasma-electron dynamics to increase the ion energy and to decrease its spread. This presentation thus motivates and frames two companion talks on these laser-driven Al-ion beams by Palaniyappan et al. and Huang et al. in this conference.

9:42AM BO5.00002 Magnetic electron trapping generates efficient quasi-monoenergetic ion beam from laser-driven plasmas.

9:54AM BO5.00003 Influence of the strong self-generated magnetic field on ion acceleration during laser-solid target interaction.

10:06AM BO5.00004 Energetic ion beams from ultra thin relativistic transparent targets.

10:18AM BO5.00005 Maximum attainable ion energy in the radiation pressure acceleration regime.

10:30AM BO5.00006 Hole-boring radiation pressure proton acceleration at high intensity in near-critical density targets.
10:42AM BO5.00007 Proton Acceleration from Shock Compressed Gaseous Target∗, MICHAEL HELLE, DANIEL GORDON, DMITRI KAGANOVICH, US Naval Research Laboratory, YU-HSIN CHEN, ANTHONY ZINGALE, RSI, Inc., ANTONIO TING, US Naval Research Laboratory — We will present experimental results of the acceleration of protons from a near critical density target produced by the collision of two strong shockwaves fronts. The target is created by igniting optically driven, counter-propagating hydrodynamic shocks into the flow of a gas jet in vacuum. The colliding shockwaves produce a 50um thick hydrogen gas region with a peak density greater than quarter critical. Preliminary results show proton energies ~ 2 MeV using the 10TW TFL laser system at NRL. 3D PIC simulations of this interaction yield comparable proton energies and show characteristics of Magnetic Vortex Acceleration. This mechanism takes advantage of an inductive accelerating field setup by the strong azimuthal magnetic field produced by electrons accelerating through the back of the target. Further experimental results examining various targets, laser parameters, and ion species will be discussed.

1This work is supported by the DoE, HEL-JTO and NRL Base Program

10:54AM BO5.00008 Experimental Study for the Laser Driven Protons Acceleration with a Circularly Polarized Ultra-short and High-intense Laser Pulse Interaction with Ultra-thin Target∗, DONGHOON KUK, JOEL BLAKENEY, SAMUEL FELDMAN, GILLISS DYER, BJORN HEGELICH, TODD DITMIRE, University of Texas at Austin, CENTER FOR HIGH ENERGY DENSITY SCIENCE TEAM — When a linearly polarized TW laser pulse interacts with a solid target, the hot electrons generated by the J x B heating lead to charge separation and accelerate ions to multi-MeV. However, this non–adiabatically heated hot electrons result thermal distribution of the accelerated ions. To suppress the thermal effects of the hot electrons, circularly polarized laser incident on an ultra-thin target has been suggested in which the oscillating component of the J x B force is removed. In this paper, we present the experimental study of the circularly polarized 1019 W/cm2 irradiance beam interaction with few tens of nanometer thickness of PMMA targets. We observe that the circularly polarized beam generates obviously decreased number of hot electrons compared with the linearly polarized beam and that results the different energy spectrum of the accelerated protons.

11:06AM BO5.00009 Proton energy enhancement in multiple-beam solid foil interaction, MARCO SWANTUSCH, JUERGEN BOEKER, RAJENDRA PRASAD, MIRELA CERCHEZ, MARIE SCHROER, STEPHANIE BRAUCKMANN, SVEN SPICKERMANN, THOMAS WOWRA, TOMA TONCIAN, OSWALD WILLI, Institute for laser and plasma physics, Heinrich Heine University Duesseldorf, Germany — Laser driven ion acceleration from solid foils has been a spectacular field of research for more than a decade. The target normal sheath acceleration has been addressed as main mechanism. Recent research has been focused on increasing the proton energy by using multiple laser beams. Understanding the dynamics of multiple beams interaction is relevant for several multi beams high power laser facilities. The multi-MeV ion acceleration in an electrostatic sheath field is investigated by applying two ultrashort laser pulses onto thin foil targets. We resolve for the first time the fs-dynamics of the acceleration mechanism in the ultrashort pulse regime and by varying the pulse duration and time delay. The experiments were carried out at the ARCTURUS laser system in Düsseldorf. Two ultrashort (30 fs) laser pulses were focused onto a 5 μm thick titanium target to intensities of 1020W/cm². The enhancement of the proton energy was significant for the time delay of around 200 fs, between the two pulses. The maximum proton cut-off energy was obtained for the zero time delay. Consequently, this implies that the addition of multiple beams for energy enhancement is most effective while the beams are synchronized. The Particle-In-Cell simulations are in good agreement with our experimental results.

11:18AM BO5.00010 Increased efficiency of ion acceleration by using femtosecond laser pulses at higher harmonic frequency∗, JAN PSIKAL, ONDREJ KLIMO, FNSPE, Czech Technical University in Prague, Czech Republic, STEFAN WEBER, DANIELE MARGARONE, ELI-Beamlines project, Institute of Physics ASCR, Prague, Czech Republic, JIRI LIMPOUCH, FNSPE, Czech Technical University in Prague, Czech Republic — When ultrashort intense laser pulse at higher harmonic frequency irradiates a thin solid foil, the target may become relativistic in a few tens of femtoseconds. The condition for laser driven ion acceleration is then met. In the case of relativistic target, the ion acceleration results in an enhanced heating of hot electrons as well as increased maximum energies and numbers of accelerated ions. Our particle-in-cell simulations indicate the increase of maximum proton energy and of the number of high-energy protons by a factor of 2 after the interaction of an ultrashort laser pulse of maximum intensity 7 × 1021 W/cm² with a fully ionized plastic foil of realistic density and of optimal thickness about 200 nm when switching from the fundamental frequency to the third harmonics.

1This research has been supported by the Czech Science Foundation (project No. P205/12/P366).

11:30AM BO5.00011 Generation of high-energy monoenergetic heavy ion beams by radiation pressure acceleration of ultra-intense laser pulses∗, B. QIAO, D. WU, C. MCGUFFEY, F.N. BEG, UCSD — Generation of high-energy monoenergetic heavy ion beams by radiation pressure acceleration (RPA) of intense laser pulses is investigated for the first time. Different from previously studied RPA of protons or light ions, the dynamic ionization of high-Z atoms can self-organize and stabilize the heavy ion acceleration. A self-organized, stable RPA scheme specifically for heavy ion beams is proposed, where the laser peak intensity is required to match with the large ionization energy gap when the successive ionization passing the noble gas configurations [such as removing an electron from the helium-like charge state (Z-2)+ to (Z-1)+]. Two-dimensional PIC simulations show that a monoenergetic Al13+ beam with peak energy 1.0GeV and energy spread only 5% can be obtained at intensity 7 × 1019W/cm² through the proposed scheme. Heavier monoenergetic Fe20+ beam at peak energy 17GeV can be obtained by increasing the intensity to 1022W/cm². Heavy ion acceleration with the designed laser conditions of Extreme Light Infrastructure (ELI) is also systematically investigated, where both ionization and radiation-radiation effects need to be taken into account.

1Work supported by the Air Force Office of Scientific Research (AFOSR) Basic Research Initiative.

11:42AM BO5.00012 Laser Acceleration of Protons Using Multi-Ion Plasma Gaseous Targets and Its Medical Implications∗, XI SHAO, TUNG-CHANG LIU, CHUAN-SHENG LIU, University of Maryland, College Park, BENGT ELIASSON, Strathclyde University, WENDELL HILL, University of Maryland, College Park, JYHPYNG WANG, Academia Sinica, SHIH-HUNG CHEN, National Central University — We present an acceleration scheme by applying a combination of laser radiation pressure and shielded Coulomb repulsion in laser acceleration of protons in multi-species gaseous targets. By using a circularly polarized CO2 laser pulse with a wavelength of 10 μm, the critical density is significantly reduced, and a high-pressure gaseous target can be used to achieve an overdense plasma. This gives us a larger degree of freedom in selecting the foil compounds or mixtures, as well as their density and thickness profiles. An 80 MeV quasi-monoenergetic proton beam can be generated using a half-sine shaped laser beam with peak power 70 TW and pulse duration of 150 wave periods. We compared the effects of modifying the thickness and density of the gaseous targets and showed that the compression of the gaseous target affects significantly in the quasi-monoenergetic property of the proton beams. To assess the feasibility of laser-proton cancer therapy with such a proton accelerator, simulations are carried out to model the interaction of protons with water and determine the depth and lateral dose distribution for particle beams produced from PIC simulation. Comparison between the dosage maps of the proton beams produced with different foil densities and thicknesses is also presented.

1This work was supported by US DoE grant DE-SC0008391.
11:54AM BO5.00013 An Ultra-Short Pulsed Neutron Source, ISHAY POMERantz, EDDIE MCCary, ALEXANDER R. MEADOWS, Center for High Energy Density Science, C1510, The University of Texas at Austin, Austin, Texas 78712, USA — We report on a novel compact laser-driven neutron source with unprecedented short pulse duration (<50 ps) and high flux (>10^18 neutrons/cm^2/s), an order of magnitude higher than any existing source. In our experiments, high-energy electron jets are generated from thin (<1 μm) plastic targets irradiated by a petawatt laser. These intense electron beams are used to generate neutrons from a metal converter. Our method opens venues for enhancing neutron radiography contrast, conducting time-resolved neutron-damage studies at their characteristic evolution time-scales and for creating astrophysical conditions of heavy element synthesis in the laboratory.

12:06PM BO5.00014 Characterization of short-pulse laser driven neutron source, KATERINA FALK, Los Alamos National Laboratory, DANIEL JUNG, Queens University of Belfast, NEVZAT GULER, Jefferson Lab, OLIVER DEPPERT, Technische Universität Darmstadt, MATTWY DEVLIN, J.C. FERNANDEZ, D.C. GAUTIER, Los Alamos National Laboratory, M. GESSEL, Sandia National Laboratories, R.C. HAIGHT, Los Alamos National Laboratory, B.M. HEGELIC, University of Texas at Austin, DANIELA HENZLOVA, K.D. IANAKIEV, METODI ILIEV, R.P. JOHNSON, F.E. MERRILL, Los Alamos National Laboratory, G. SCHAUMANN, Technische Universität Darmstadt, K. SCHONEBERG, T. SHIMADA, T.N. TADDEucci, J.L. TYBO, Los Alamos National Laboratory, F. WAGNER, Technische Universität Darmstadt, S.A. WENDER, G.A. WURDEN, ANDREA FAVALLi, Los Alamos National Laboratory, MARKUS ROTH, Technische Universität Darmstadt — We present a full spectral characterization of a novel laser driven neutron source, which employed the Break Out Afterburner ion acceleration mechanism. Neutrons were produced by nuclear reactions of the ions deposited on Be or Cu converters. We observed neutrons at energies up to 150 MeV. The neutron spectra were measured by five neutron time-of-flight detectors at various positions and distances from the source. The nTOF detectors observed that emission of neutrons is a superposition of an isotropic component peaking at 3.5-5 MeV resulting from nuclear reactions in the converter and a directional component at 25-70 MeV, which was a product of break-up reaction of the forward moving deuterons. Energy shifts due to geometrical effects in BOA were also observed.

12:18PM BO5.00015 Selective Deuteron Acceleration and Neutron Production on the Vulcan PW Laser1, A.G. KRyGier, Ecole Polytechnique/Ohio State University, J.T. MORRISON, Air Force Research Laboratory, R.R. FREEMAN, Ohio State University, H. AHMED, J.A. GREEN, A. ALEJO, S. KAR, Queens University, L. VASSURA, Ecole Polytechnique — Fast neutron sources are important for a variety of applications including radiography and the detection of sensitive materials. Here we report on the results of an experiment using the Vulcan PW laser at Rutherford Appleton Laboratory to produce a nearly pure deuterium ion beam via Target Normal Sheath Acceleration. The typical contaminants are suppressed by freezing a μm’s thick layer of heavy water vapor (D2O) onto a cryogenic target during the shot sequence. Neutrons were generated by colliding the accelerated deuterons were into secondary targets made of deuterated plastic in the pitch-catcher arrangement. Absolute yields for deuterium ions and neutrons are reported.

1This work is supported by DOE contract DE-FC02-04ER54789.

Monday, October 27, 2014 9:30AM - 12:06PM — Session BO7 Magnetized Plasmas and Z-Pinch Physics Galerie 6 - Daniel Sinars, Sandia National Laboratories

9:30AM BO7.00001 Pulsed Magnetic Field System for Magnetized Target Experiments at the National Ignition Facility1, M.A. RHODES, J.M. SOLBERG, B.G. LOGAN, L.J. PERKINS, Lawrence Livermore Natl Lab — High-magnitude magnetic fields applied to inertially confined targets may improve fusion yield and enable basic science applications. We discuss the development of a pulsed magnetic field system for NIF with the goal of applying 10-70T to various NIF targets. While the driver may be little more than a spark-gap switched capacitor, the magnetic fields applied to inertially confined targets may improve fusion yield and enable basic science applications. We discuss the development of a pulsed magnetic field system for NIF with the goal of applying 10-70T to various NIF targets. With this work supported by DOE contract DE-AC52-07NA27344.

9:42AM BO7.00002 Magnetized HDC ignition capsules for yield enhancement and implosion magnetohydrodynamics1, G. ZIMMERMAN, D. HO, J. PERKINS, G. LOGAN, S. HAWKINS, M. RHODES, LLNL — Imposing a magnetic field on capsules can turn capsules that fail, because of low 1-D margin, into igniting capsules that give yield in the MegaJoule range. The imposed magnetic field can be amplified by up to O(10^5) as it is being compressed by the imploding shell, e.g. if the initial field is 50T, then the field in the hot spot of the assembled configuration can reach >10^4 T. We are currently designing hardware that can provide a field in the 50T range inside NIF hohlraums.) With this highly compressed field strength, the gyro radius of alpha particles becomes smaller than the hot spot size. Consequently, the heating of the hot spot becomes more efficient. The imposed field can also prevent hot electrons in the hohlraum from reaching the capsule. We choose capsules with high-density carbon (HDC) ablators for this study. HDC capsules have good 1-D performance and also have short pulses (10 ns or less), allowing the use of low gas-filled or near-vacuum hohlraums which provide high coupling efficiency. We describe a 2-D simulation of a 3-shock HDC capsule. We will show detailed magnetohydrodynamic evolution of the implosion. HDC capsules with 2-shock pulses have low margin because of their high adiabat, and it is difficult to achieve ignition in realistic 2-D simulations. The improvement in performance for 2-shock magnetized capsules will be presented.

1This work was supported by LLNL Laboratory Directed Research and Development LDRD 14-ER-028.
9:54AM BO7.00003 Use of External Magnetic Fields in Hohlraum Plasmas to Improve Laser-Coupling

1. D.S. MONTGOMERY, B.J. ALBRIGHT, J.L. KLINE, L. YIN, Los Alamos National Laboratory, P.Y. CHANG, J.R. DAVIES, G. FIKSEL, D.H. FROULA, R. BETTI, Laboratory for Laser Energetics, University of Michigan — Controlling laser plasma instabilities and beam propagation in hohlraum plasmas is important for achieving high-gain inertial fusion using indirect drive. Experiments at the National Ignition Facility (NIF) suggest that coronal electron temperatures in NIF hohlraums may be cooler than initially thought due to efficient thermal conduction from the under dense low-Z plasma to the dense high-Z hohlraum wall [1]. This leads to weaker Landau damping and stronger growth of stimulated Raman scatter, and poorer laser transmission due to absorption in the cooler plasma. Magnetic insulation of the heat conducting electrons can occur when the Hall parameter \( \omega / \tau_e \gg 1 \), where \( \omega = c/eB \) is the electron-cyclotron frequency, and \( \tau_e \) is the electron-ion collision time. For NIF laser-plasma conditions, it is shown that a 10-T external magnetic field may substantially reduce cross-field transport and may increase coronal plasma temperatures, thus increasing linear Landau damping and mitigating SRS. We will present calculations and simulations supporting this concept, and will present initial results from Omega experiments using gas-filled hohlraums with external B-fields up to 10-T.


1 Work performed under the auspices of DOE by LANL under contract DE-AC52-06NA25396.

10:06AM BO7.00004 Study of Strong Magnetic Fields Using Parametric Instability in a Magnetised Plasma

1. V.V. IVANOV, University of Nevada, Reno, A.V. MAXIMOV, University of Rochester, A.A. ANDERSON, B.S. BAUER, K. YATES, University of Nevada, Reno — Generation of strong magnetic fields with a strength of 10-50MG plays a key role in some recent conceptions for controlled fusion. We suggest a laser method for measuring the local magnetic field, \( B > 10MG \), based on the parametric decay of the laser radiation to \( \omega / 2 \) and \( 3\omega / 2 \) harmonics which are generated in the area with the electron density of a quarter of the critical plasma density. Spectral components of parametric harmonics carry a signature of \( \rho/B \), where \( \rho \) is the electron-cyclotron frequency, and \( B \) is the magnetic field. A two-photon decay of laser radiation was studied in a magnetized plasma at the 1MA pulsed power Zebra facility at the University of Nevada, Reno. Dense magnetized plasma with a magnetic field of 1-3MG was created by the 1MA current flowing in the metal rod 0.7-2mm in diameter. Radiation from the narrowband laser with intensity \( > 10^{14} \) W/cm\(^2\) was focused on the surface plasma. Spectrum of the backscattering \( 3\omega/2 \) harmonic included “red” and “blue” shifted components. Large 2-3nm shifts of spectral components was identified with laser heating of plasma. Components with a small 0.1nm spectral shift was of the magnetic field.

1 Work supported by the DOE grant DE-SC0008824 and DOE/NNSA UNR grant DE-FC52-06NA27616.

10:18AM BO7.00005 The Application of Imposed Magnetic Fields to Ignition and Thermonuclear Burn on the National Ignition Facility

1. L. JOHN PERKINS, G. LOGAN, D. HO, G. ZIMMERMAN, D. STROZZI, M. RHODES, R. PLUMMER, S. HAWKINS, Lawrence Livermore Natl Lab — We are studying the impact of highly compressed axial magnetic fields on ignition targets for the National Ignition Facility. Both magnetized room-temperature DT gas targets and CH/diamond cryo-ignition capsules are under study. Initial seed fields of 30-70T that compress to greater than 10000T (100MG) under implosion can reduce hotspot conditions required for ignition and propagating burn [L.J.Perkins et al, Phys. Plasmas, 2013]. The field can also reduce hohlraum laser-plasma interactions by increasing the temperature, and supress the transport of hot electron preheat to the capsule. These combined attributes of compressed B-fields may permit recovery of ignition, or at least significant alpha particle heating, in submarginal capsules that would otherwise fail because of adverse hydrodynamic conditions and, more generally, may permit attainment of ignition in targets redesigned to operate under reduced drive and/or lower convergence ratios. Present engineering studies are also assessing the maximum attainable fields for a NIF hohlraum coil driven by a pulsed power supply located in a NIF Diagnostic Insertion Module (DIM). LLNL is operated by LLNS, LLC, for the U.S.DOE, NNSA under Contract DE-AC52-07NA27344. This work supported by LLNL LDRD 14-ER-028.

10:30AM BO7.00006 Laser-generated magnetic fields in quasi-hohlraum geometries

1. BRADLEY POLLOCK, DAVID TURNBULL, STEVEN ROSS, ANDREW HAZI, JOSEPH RALPH, SEBASTIAN LEPAPE, Lawrence Livermore National Laboratory, DUSTIN FROULA, DAN HABERBERGER, Laboratory for Laser Energetics, JOHN MOODY, Lawrence Livermore National Laboratory — Laser-generated magnetic fields of 10-40 T have been produced with 100-4000 J laser drives at Omega EP and Titan. The fields are generated using the technique described by Daido et.al. [Phys. Rev. Lett. 56, 846 (1986)], which works by directing a laser through a hole in one plate to strike a second plate. Hot electrons generated in the laser-produced plasma on the second plate collect on the first plate allowing a current of 10s of kA to flow and generate a solenoidal magnetic field. The magnetic field is characterized using Faraday rotation, b-dot probes, and proton radiography. Further experiments to study the effect of the magnetic field on hohlraum performance are currently scheduled for Omega. This work was performed under the auspices of the United States Department of Energy by the Lawrence Livermore National Laboratory under contract No. DE-AC52-07NA27344.

10:42AM BO7.00007 Weibel magnetic field amplification and saturation in expanding plasmas

1. KEVIN SCHOEFFLER, NUNO LOUREIRO, LUIS SILVA, RICARDO FONSECA, University of Lisbon, Lisbon, Portugal — Recent laser-solid interaction experiments have been used to generate high energy density plasmas with megagauss magnetic fields. These intense magnetic fields are generated by the Biermann battery mechanism via perpendicular temperature and density gradients, and via temperature anisotropy instabilities such as the Weibel instability. Performing particle-in-cell simulations of similar expanding plasmas, we find that in some laser systems as well as in astrophysical shocks the Weibel instability may play the dominant role [Schoeffler et al. Phys. Rev. Lett. 112, 175001 (2014)]. Particularly in systems where the Biermann Battery is expected to generate only small fields with plasma \( \beta \sim L/d_i \), (with system size large compared to ion inertial length), while the Weibel may reach fields close to \( \beta \sim 1 \). Although the Weibel instability is a popular topic regarding these systems, the mechanism for saturation is not clearly understood. We investigate this saturation, as well as uncover a striking confirmation of gyrokinetic predictions of turbulence (from the Biermann field) with a sub-\( \rho_i \) (electron gyroradius) \( -1/3 \) power law for electric field energy and \( -1/3 \) for magnetic fields [Schechkin et al. Astrophys. J. Suppl. Ser. 182, 310 (2009)].

1 also affiliated with DCTI/ISCTE Lisbon University Institute, 1649-026 Lisbon, Portugal

10:54AM BO7.00008 Interpenetration, stagnation and deflection of supersonic tungsten plasma flows produced by wire-array Z-pinchess

1. GEORGE SWADLING, SERGEY LEBDEV, GUY BURDIK, LEE SUTTLE, SIDDHARTH PATANKAR, ROLAND SMITH, MATTHEW BENNETT, J. BURT HALL, FRANCISCO SUZUKI-VIDAL, Imperial College, JIANQIANG YUAN, Institute of Fluid Physics, ADAM HARLEY-THOMPSON, Sandia National Laboratories, WOICHEH ROZMUS, University of Alberta — We present Thomson Scattering measurements [G F Swadling et al, Phys. Rev. Lett. (Accepted 17 June 2014)] of the interpenetration, stagnation and deflection of supersonic tungsten plasma flows, produced in wire array z-pinch experiments on the MAGPIE (1.4MA, 240ns) pulsed power generator at Imperial College London. These measurements were made at wire array in the evolution of the arrays, prior to the formation of the dense precursor column (120ns), when the collisional scale length between the streams was still significant compared to the scale length of the array. The scattering geometry used in these experiments allowed independent measurements of the radial and axial velocity distributions of the interacting flows; temporally and spatially resolved measurements were made over seven points across the array diameter. Analysis of the Thomson spectra provides evidence of flow interpenetration; the flows decelerate and are heated over an extended distance (1.5mm) before they fully stagnate. A previously unobserved axial deflection of the plasma flow towards the anode as it approaches the array axis provides evidence of the presence of a significant (20 T) toroidal magnetic field embedded within the precursor column at early times.
11:06 AM BO7.00009 ABSTRACT WITHDRAWN

11:18 AM BO7.00010 Effect of axial B-field on shock structure within gas-filled liner z-pinch experiments performed on MAGPIE, GUY BURDIAK, SERGEY LEBEDEV, FRANCISCO SUZUKI-VIDAL, GEORGE SWADDLING, SIMON BLAND, LEE SUTTLE, MATTHEW BENNET, JACK HARE, Imperial College London — Cylindrical liner z-pinches can be used to drive convergent shock waves through gas contained inside with a striking degree of azimuthal symmetry. Here we present data from gas-filled liner experiments that include an azimuthally anisotropic magnetic field. The 4-fold azimuthal symmetry of the magnetic field distribution imprints itself upon the shape of the convergent shocks. This occurs despite a ratio of shock ram pressure to magnetic pressure of order 100. Interferometry and emission imaging data that show the evolution of the shock structure as it converges are presented alongside potential explanations for the dynamics. These experiments provide a potential platform for studying magnetized plasma physics with relevance to magnetized fusion schemes. Experiments were performed on the 1.4 MA, 240 ns rise-time MAGPIE pulsed-power device at Imperial College London.

11:30 AM BO7.00011 High-Z Pusher Experiments on the Cobra Triple Nozzle Gas-Puff Z-Pinch, PHILIP DE GROUCHY, Cornell University, NIANSHENG QI, L-3 Communications, Oakland CA, BRUCE KUSSE, CHARLES SEYLER, LEVON ATOYAN, TOM BYVANK, ADAM CAHILL, JOHN GREENLY, CAD HOYT, Cornell University, SERGEI PIKUZ, TANIA SHELKOVENKO, Lebedev Physical Institute, Moscow, DAVID HAMMER, Cornell University — For inertial confinement fusion application and as efficient hard x-ray sources, the imploiding sheath of a gas-puff z-pinch or thin liner must be accelerated to the highest possible velocity before hydrodynamic instabilities significantly disrupt the implosion symmetry. Much recent work has focused on increasing implosion stability using radially structured mass-density profiles produced by multi-nozzle gas-puff valves. The introduction of a high-Z element such as xenon into the outer gas shells in such experiments can modify radiation output during the implosion phase as well as at stagnation. In these experiments xenon is introduced into the triple-nozzle gas valve fielded on the (IMA, 200ns) COBRA z-pinch machine at Cornell University. The xenon is introduced only in the outer shell, only in the inner shell or in both, to investigate the radiative effects on implosion hydrodynamics and x-ray yield. Results are compared to those obtained during pure argon implosions with the same mass-density profile. Sheath thicknesses and stability are recorded using laser interferometry (532nm) and multi-frame imaging systems. The distribution of flow velocities and of high-Z material across the pinch is investigated using a (SGW, 527nm) Thomson scattering probe.

1Work supported by DOE Grant No. DE-NA0001836.

11:42 AM BO7.00012 High energy axial ion beam generated by deuterium gas-puff Z-pinch at the current level of 3 MA, K. REZAC, D. KLIR, P. KUBES, J. CIKHARDT, B. BATOBOLOTOVA, J. KRAVARIK, FEE CTU in Prague, H. ORCIKOVA, K. TUREK, NPI AS CR, A. SHISHLOV, A. LABETSKY, V. KOKSHENEV, N. RATAKHIN, IHCE in Tomsk, GIT-12 TEAM — The contribution presents results from Z-pinch experiments with a plasma shell on deuterium gas-puff (with deuterium linear mass of about 100 μg/cm) carried out on the GIT-12 generator at IHCE in Tomsk at the current level slightly below 3 MA. The first purpose of experiments was to study the influence of different parameters on the production of neutrons. Neutron yield up to 5 × 10^{12} neurons/shot was measured in the shot with LiF catcher. The second purpose was the examination of high-energy ions generated on the Z-pinch axis using RCF and CR-39. Very interesting results were provided by ion pinhole camera, where the influence of magnetic field on the ion beam could be studied. One of the conclusions is that the ions with energy below 10 MeV were significantly deflected by magnetic field.

1Work supported by MEYS CR research programs No. ME090871, No. LG13029, by GACR grant No. P205/12/0454, grant CRA IAEA No. 17088 and RFBR grant No. 13-08-00479-a.

11:54 AM BO7.00013 Effect of Driver Impedance on Dense Plasma Focus Z-Pinch Neutron Yield and Beam Acceleration, J. SEARS, A. LINK, J. ELLSWORTH, S. FALABELLA, B. RUSNAK, V. TANG, A. SCHMIDT, Lawrence Livermore National Laboratory, D. WELCH, Voss Scientific — We explore the effect of driver characteristics on dense plasma focus (DPF) neutron yield and beam acceleration using particle-in-cell (PIC) simulations of a kJ-scale DPF [1]. Our PIC simulations are fluid for the run-down phase and transition to fully kinetic for the pinch phase. The anode-cathode boundary is driven by a circuit model of the capacitive driver, including system inductance, the load of the railgap switches, the guard resistors, and the coaxial transmission line parameters. Simulations are benchmarked to measurements of a table top kJ DPF experiment with neutron yield measured with He3-based detectors. Simulated neutron yield scales approximately with the fourth power of peak current, I^4. We also probe the accelerating fields by measuring the acceleration of a 4 MeV deuteron beam and by measuring the DPF self-generated beam energy distribution [2], finding gradients higher than 50 MV/m.

[1] A. Schmidt et al., PRL, 109 (2012);

3This 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 (11-ERD-063) at LLNL.

9:30 AM - 9:30 AM

Session BP8 Poster Session I: MHD, Energetic Particles, Predictive Modeling, Plasma Surface Interactions; Diagnostic Measurements & Analysis; Non-Neutral, Anti-Matter & Strongly Coupled Plasmas; Plasma Technology Preservation Hall

BP8.00001 MHD, ENERGETIC PARTICLES, PREDICTIVE MODELING, PLASMA SURFACE INTERACTIONS

BP8.00002 Expansion of a MHD equilibrium About a Magnetic Axis, HAROLD WEITZNER, New York University — Earlier work, Phys. Plasmas, 21,022515 (2014) showed that a formal expansion of a non-symmetric ideal MHD equilibrium in a topological torus was possible to all orders the parameter corresponding to the amplitude of the “helical” field components. Selected field components were not arbitrary, but had to be chosen appropriately. This analysis did not allow the toroidal domain in which the expansion was carried out to include a magnetic axis. The present work examines the nature of non-symmetric equilibria in the neighborhood of a magnetic axis in a topological toroidal domain. An expansion is carried out in the distance from the magnetic axis for two simple cases. In the first the axis is a straight line, and in the second the axis is a space curve. The expansions to all orders are carried out and conditions for the expansions to exist are given. Again for selected cases equilibria appear possible.
BP8.00003 Magnetic flux coordinates for high-beta tokamak equilibria with flow\textsuperscript{1}. ATSUSHI ITO, NORIYOSHI NAKAJIMA, National Institute for Fusion Science — Magnetic flux coordinates are useful for the study of stability of toroidal plasmas. A set of the magnetic flux coordinates are constructed from an analytic solution for the reduced magnetohydrodynamic equilibrium equations for high-beta tokamaks in the presence of toroidal and poloidal flows comparable to the poloidal sound velocity. The set of magnetic flux coordinates are found by solving the algebraic equations for the relation between the cylindrical and magnetic flux coordinates that are obtained by extending those for the static equilibrium. As an application, the pressure profile in the magnetic coordinates is examined. The poloidal profiles of the pressure on each constant radial coordinate show that the pressure maxima are located in the outer midplane for sub-sonic poloidal flow and in the inner midplane for super-sonic poloidal flow. The flux surface average of the pressure does not strongly depend on the poloidal flow velocity, but it is peaked near the magnetic axis for sub-sonic poloidal flow while it is broad for super-sonic poloidal flow, compared with that for the static equilibrium.

\textsuperscript{1}This work was partially supported by JSPS KAKENHI Grant Number 24740375.

BP8.00004 Theory and computation of general force balance in non-axisymmetric tokamak equilibria\textsuperscript{1}. JONG-KYU PARK, NIKOLAS LOGAN, ZHIRUI WANG, KIMIN KIM, PPPL, ALLEN BOOZER, CU, YUEQIANG LIU, CCFE, JONATHAN MENARD, PPPL — Non-axisymmetric equilibria in tokamaks can be effectively described by linearized force balance. In addition to the conventional isotropic pressure force, there are three important components that can strongly contribute to the force balance; rotational, anisotropic tensor pressure, and externally given forces, i. e. \(\nabla p + \rho \mathbf{v} \cdot \nabla \mathbf{v} + \nabla \cdot \Pi \mathbf{j} = j \times \mathbf{B} \), especially in, but not limited to, high \(\beta\) and rotating plasmas. Within the assumption of nested flux surfaces, Maxwell equations and energy minimization lead to the modified-generalized Newcomb equation for radial displacements with simple algebraic relations for perpendicular and parallel displacements, including an inhomogeneous term if any of the forces are not explicitly dependent on displacements. The general perturbed equilibrium code (GPEC) solves this force balance consistent with energy and torque given by external perturbations. Local and global behaviors of solutions will be discussed when \(\nabla \cdot \Pi\) is solved by the semi-analytic code PENT and will be compared with MARS-K. Any first-principle transport code calculating \(\nabla \cdot \Pi\) or \(\mathbf{j}\), e. g. POCA, can also be incorporated without demanding iterations. This work was supported by DOE Contract DE-AC02-09CH11466.

BP8.00005 Improving the quality of the experimental reconstructions as the initial equilibrium state for the NIMROD code\textsuperscript{1}. JACOB KING, SCOTT KRUGER, Tech-X Corp, NIMROD TEAM — High quality equilibria are essential for extended-MHD modeling with the initial-value NIMROD code [Sovinec et al., JCP 195, 355 (2004)]. Typically the spatial resolution requirements for extended-MHD modeling, which must resolve singular-layer physics and highly anisotropic diffusion, are more stringent than the resolution of equilibrium reconstructions from experimental discharges. With the current workflow, reconstructed fields are mapped onto the NIMROD finite-element grid, and the disparity between the coarse resolution reconstruction and the fine resolution FE grid can create artificial small-scale artifacts. Extended-MHD modeling, which contains many high-order differential operators, can be corrupted by the mapping errors. We describe efforts to re-solve the Grad-Shafranov equation with open-flux regions using the NIMEQ solver [Howell and Sovinec, CPC 185, 1415 (2014)] to generate a new equilibrium while using the mapped results for both an initial guess and to specify the boundary conditions. Effects on computations with and without the re-solving for force balance will be described.

\textsuperscript{1}Work funded by US DOE.

BP8.00006 Inclusion of parallel fluid flow in the KITES 3D MHD equilibrium code. DANIEL RABURN, None — The KITES (Kyoto ITerative Equilibrium Solver) code is being developed for the calculation of flowing MHD (magnetohydrodynamic) equilibria in nonaxisymmetric devices. [Daniel Raburn and Atsushi Fukuyama, Plasma and Fusion Research: Regular Articles, 7:240381 (2012).] An update on the code is presented, including preliminary results on the calculation of equilibria with purely parallel flow.

BP8.00007 Effects of density gradient caused by multi-pulsing CHI on two-fluid flowing equilibria of spherical torus plasmas. T. KANKI, Japan Coast Guard Academy, M. NAGATA, University of Hyogo — Two-fluid dynamo relaxation is examined to understand sustainment mechanism of spherical torus (ST) plasmas by multi-pulsing CHI (M-CHI) in the HIST device. The steeper density gradient between the central open flux column (OFC) and closed flux regions by applying the second CHI pulse is observed to cause not only the E\(\times\)B drift but also the ion diamagnetic drift, leading the two-fluid dynamo. The purpose of this study is to investigate the effects of the steep change in the density gradient on the ST equilibria by using the two-fluid equilibrium calculations. The toroidal magnetic field becomes from a diamagnetic to a paramagnetic profile in the closed flux region while it remains a diamagnetic profile in the OFC region. The toroidal ion flow velocity is increased from negative to positive values in the closed flux region. Here, the negative ion flow velocity is the opposite direction to the toroidal current. The poloidal ion flow velocity between the OFC and closed flux regions is increased, because the ion diamagnetic drift velocity is changed in the same direction as the E\(\times\)B drift velocity through the steeper ion pressure gradient. As a result, the strong shear flow and the paramagnetic toroidal field are generated in the closed flux region. Here, the ion flow velocity is the same direction as the poloidal current. The radial electric field shear between the OFC and closed flux regions is enhanced due to the strong dependence on the magnetic force through the interaction of toroidal ion flow velocity and axial magnetic field. The two-fluid effect is significant there due to the ion diamagnetic effect.

BP8.00008 The observation of Synchronous Oscillation prior to Disruption in the HL-2A tokamak. DI HU, Peking University, School of Physics, M.JIANG TEAM, X.C.WANG TEAM, Z.B.SHI TEAM, Y.B.DONG TEAM, X.Q.JI TEAM — An evident class of MHD activities before disruption has been observed during the density limit induced disruptions of the HL-2A tokamak discharge. It is named “SOD,” the Synchronous Oscillations prior to Disruption, which is characterized by the synchronous oscillations between ECE signal, the core SXR signal, Mirnov signal, and H line radiation crossing the divertor region. It is observed in the parameter regime which typically corresponds to radiation-induced disruptions. It is also found that during SODs, most of the plasma current is enclosed within the \(q=2\) surface, making the resistive kink mode unstable. It has been found that the 2/1 mode and its higher order harmonics are dominant during SODs, and it is the decrease of mode frequency and the final mode locking that leads to the disruptions. The electron temperature perturbation structure shows that plasma is dominant by resistive-kink with gradual phase shift in the core plasma region and a single island in the cool, highly resistive boundary layer. There is little indication of the existence of multi-helicities islands prior to the disruption. This suggests that it is the non-linear growth of this 2/1 kink and its higher order harmonics, rather than the overlapping of multiple islands, ultimately triggered disruption.
BP8.00009 Hiro and Evans currents in Vertical Disruption Event¹. LEONID ZAKHAROV, Princeton University, PPPL. XIUJING LI TEAM, SERGEI GALKIN TEAM — The notion of Tokamak Magneto-Hydrodynamics (TMHD), which explicitly reflects the anisotropy of a high temperature tokamak plasma is introduced. The set of TMHD equations is formulated for simulations of macroscopic plasma dynamics and disruptions in tokamaks. Free from the Courant restriction on the time step, this set of equations is appropriate for high performance plasmas and does not require any extension of the MHD plasma model. At the same time, TMHD requires the use of magnetic field aligned numerical grids. The TMHD model was used for creation of theory of the Wall Touching Kink and Vertical Modes (WTKM and WTVM), prediction of Hiro and Evans currents, design of an innovative diagnostics for Hiro current measurements, installed on EAST device. While Hiro currents have explained the toroidal asymmetry in the plasma current measurements in JET disruptions, the Evans currents explain the tile current measurements in tokamaks. The recently developed Vertical Disruption Code (VDE) have demonstrated 5 regimes of VDE and confirmed the generation of both Hiro and Evans currents. The results challenge the 24 years long misinterpretation of the tile currents in tokamaks as “halo” currents, which were a product of misuse of equilibrium reconstruction for VDE.

¹This work is supported by US DoE contract No. DE-AC02-09-CH1146

BP8.00010 Separation of Evans and Hiro currents in VDE of tokamak plasma¹, SERGEI A. GALKIN, V.A. SVIDZINSKI, FAR-TECH Inc., L.E. ZAKHAROV, PPPL — Progress on the Disruption Simulation Code (DSC-3D) development and benchmarking will be presented. The DSC-3D is one-fluid nonlinear time-dependent MHD code, which utilizes fully 3D toroidal geometry for the first wall, pure vacuum and plasma itself, with adaptation to the moving plasma boundary and accurate resolution of the plasma surface current. Suppression of fast magnetoosonic scale by the plasma inertia neglecting will be demonstrated. Due to code adaptive nature, self-consistent plasma surface current modeling during non-linear dynamics of the Vertical Displacement Event (VDE) is accurately provided. Separation of the plasma surface current on Evans and Hiro currents during simulation of fully developed VDE, then the plasma touches in-vessel tiles, will be discussed.

¹Work is supported by the US DOE SBIR grant # DE-SC0004487.

BP8.00011 Simulations of vertical disruptions with VDE code: Hiro and Evans currents¹. XIUJING LI, Academy of Mathematics, CAS, DI HU TEAM, LEONID ZAKHAROV TEAM, GALKIN TEAM — The recently created numerical code VDE for simulations of vertical instability in tokamaks is presented. The numerical scheme uses the Tokamak MHD model, where the plasma inertia is replaced by the friction force, and an adaptive grid numerical scheme. The code reproduces well the surface currents generated at the plasma boundary by the instability. Five regimes of the vertical instability are presented:

1. Vertical instability in a given plasma shaping field without a wall;
2. The same with a wall and magnetic flux $\Delta \Psi^X_{\text{pol}} < \Delta \Psi^\text{wall}_X$ (where $X$ corresponds to the X-point of a separatrix);
3. The same with a wall and magnetic flux $\Delta \Psi^X_{\text{pol}} > \Delta \Psi^\text{wall}_X$;
4. Vertical instability without a wall with a tile surface at the plasma path;
5. The same in the presence of a wall and a tile surface.

The generation of negative Hiro currents along the tile surface, predicted earlier by the theory and measured on EAST in 2012, is well-reproduced by simulations. In addition, the instability generates the force-free Evans currents at the free plasma surface. The new pattern of reconnection of the plasma with the vacuum magnetic field is discovered.

³This work is supported by US DoE contract No. DE-AC02-09-CH11466

BP8.00012 Surface Currents during a Major Disruption¹. P. BOLGERT, Princeton Plasma Physics Laboratory, C.S. NG, University of Alaska Fairbanks, J. BRESLAU, A. BHATTACHARYEE, Princeton Plasma Physics Laboratory — Understanding the surface current on the plasma-vacuum interface during a disruption event is important for predicting the subsequent evolution of the instability and its interaction with the wall, with serious implications for ITER. Even in the linear regime, these surface currents are controversial and poorly understood, with disagreements over both their nature and sign. Previously, most analytical studies have used step-function background plasma profiles, for example, the linearized reduced MHD disruption model of Strauss et al. (PoP 17, 082505 (2010)). In this study we extend that model by replacing step-function profiles with more realistic profiles characterized by a strong but finite gradient along the radial direction. It is found that the resulting “surface current” is localized in the region of strong gradient but can also have an internal structure with peaks of both signs. We benchmark our results using the M3D code, finding quantitative agreement in the structure of the currents as well as the kink mode growth rate. The role of plasma resistivity in these simulations is explained. We also present preliminary M3D results showing the nonlinear evolution of these surface currents.

³This work is supported by DoE Contract DE-AC02-09CH11466

BP8.00013 Wall touching kink mode calculations with the M3D code. J.A. BRESLAU, Princeton Plasma Physics Laboratory — In recent years there have been a number of results published [1-3] concerning the transient vessel currents and forces occurring during a tokamak VDE, as predicted with simulations with the nonlinear MHD code M3D [4]. The nature of the simulations is such that these currents and forces occur at the boundary of the computational domain, making the proper choice of boundary conditions critical to the reliability of the results. The M3D boundary condition includes the prescription that the normal component of the velocity vanish at the wall. It has been argued [5] that this prescription invalidates the calculations because it would seem to rule out the possibility of advection of plasma surface currents into the wall. This claim has been tested by applying M3D to an idealized case - a kink-unstable plasma column - in order to abstract the essential physics from the complications involved in the attempt to model real devices. While comparison of the results is complicated by effects arising from the higher dimensionality and complexity of M3D, we have verified that M3D is capable of reproducing both the correct saturation behavior of the free boundary kink and the “Hiro” currents arising when the kink interacts with a conducting tile surface interior to the ideal wall. [1] H.R. Strauss, R. Paccagnella, and J. Breslau, Phys. Plasmas 17, 082505 (2010). [2] H. Strauss, R. Paccagnella, J. Breslau, L. Sugiyama, and S. Jardin, Nucl. Fus. 53, 073018 (2013). [3] H. Strauss, L. Sugiyama, R. Paccagnella, J. Breslau, and S. Jardin, Nucl. Fus. 54, 043017 (2014). [4] W. Park, et al., Phys. Plasmas 6, 1796 (1999). [5] L.E. Zakharov, Phys. Plasmas 17, 124703 (2010).
BP8.00014 Toroidal current asymmetry and boundary conditions in disruptions\textsuperscript{1}. HENRY STRAUSS, HRS Fusion — It was discovered on JET \cite{1} that disruptions were accompanied by toroidal asymmetry of the plasma current. The toroidal current asymmetry $\Delta I_0$ is proportional to the vertical current moment $\Delta M_{IZ}$, with positive sign for an upward vertical displacement event (VDE) and negative sign for a downward VDE. It was claimed \cite{2} that this could only be explained by Hiro current. It is shown that instead it is essentially a kinematic effect produced by the VDE displacement of a 3D magnetic perturbation. This is verified by M3D simulations. The simulation results do not require penetration of plasma into the boundary, as in the Hiro current model \cite{2}. It is shown that the normal velocity perpendicular to the magnetic field vanishes at the wall, in the small Larmor radius limit of electromagnetic sheath boundary conditions \cite{3}. Plasma is absorbed into the wall only via the parallel velocity, which is small, penetrates only an infinitesimal distance into the wall, and does not affect forces exerted by the plasma on the wall.

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\bibitem{3} H. R. Strauss, Physics of Plasmas 21, 032506 (2014).
\end{thebibliography}

\textsuperscript{1}Supported by USDOE and ITER.

BP8.00015 Plasma surface and wall eddy currents and their connection to Halo currents during disruptions in tokamaks \textsuperscript{1}. VADIM YANOVSKIY, ROBERTO PACCAGNELLA, Consorzio RFX — The behaviour of plasma surface currents and resistive wall eddy currents is analysed analytically within a cylindrical model for pressureless ideal plasma with flat and parabolic equilibrium current profiles. This mimics possible conditions in tokamak plasmas during disruptions between the thermal and the current quench phases. Earlier studies \cite{1, 2} predict that plasma surface currents have to be taken into account for explanation of the Halo currents intensity and distribution. Our results show that this is true only in a very narrow window of edge safety factor $q_0$ and that in a wide region of $q_0$ the wall eddy currents are comparable or much larger than the plasma skin currents. The study reveals ranges of plasma and wall parameters for which the surface currents could play a role in Halo currents dynamics. Some comparison of the results with previous works \cite{1, 2} on this topic is also presented.

\begin{thebibliography}{9}
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\end{thebibliography}

\textsuperscript{1}This effort is supported by U.S. Department of Energy grant DE-FG02-06ER54850.

BP8.00016 Initial Computations of Vertical Displacement Events with NIMROD\textsuperscript{1}. KYLE BUNKERS, C.R. SOVINEC, Univ of Wisconsin, Madison — Disruptions associated with vertical displacement events (VDEs) have potential for causing considerable physical damage to ITER and other tokamak experiments. We report on initial computations of generic axisymmetric VDEs using the NIMROD code \cite{1}. An implicit thin-wall computation has been implemented to couple separate internal and external regions without numerical stability limitations. A simple rectangular cross-section domain generated with the NIMEQ code \cite{2, 3} modified to use a symmetry condition at the midplane is used to test linear and nonlinear axisymmetric VDE computation. As current in simulated external coils for large-$R/a$ cases is varied, there is a clear $n = 0$ stability threshold which lies below the decay-index criterion for the current-loop model of a tokamak to model VDEs \cite{4, 5}. Results with a vacuum region surrounding a resistive wall will also be presented. Initial nonlinear computations show large vertical displacement of an intact simulated tokamak.

\begin{thebibliography}{9}
\bibitem{1} S.E. Kruger et al Plasma Physics of Plasmas, 12, 056113 (2005)
\bibitem{2} R. Paccagnella et al Nucl. Fusion 49 035003 (2009)
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\textsuperscript{1}This is supported by U.S. Department of Energy contract DE-FG02-06ER54850.

BP8.00017 3D MHD Simulations of Tokamak Disruptions \textsuperscript{1}. SIMON WOODRUFF, JAMES STUBER, Woodruff Scientific Inc — Two disruption scenarios are modeled numerically by use of the CORSICA 2D equilibrium and NIMROD 3D MHD codes. The work follows the simulations of pressure-driven modes in DIII-D \cite{1} and VDEs in ITER \cite{2}. The aim of the work is to provide starting points for simulation of tokamak disruption mitigation techniques currently in the DCR phase for ITER. Pressure-driven instability growth rates previously observed in simulations of DIII-D are verified; Halo and Hiro currents produced during vertical displacements are observed in simulations of ITER with implementation of resistive walls in NIMROD. We discuss plans to exercise new code capabilities and validation.

\begin{thebibliography}{9}
\bibitem{1} S.N. Gerasimov et al. Nucl. Fusion 073009 (2014).
\bibitem{2} H. R. Strauss, Physics of Plasmas 21, 032506 (2014).
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BP8.00018 MHD Pedestal Formation in Time-Dependent Simulations\textsuperscript{1}. LUCA GUAZZOTTO, University of Rochester (now Auburn University), RICCARDO BETTI, University of Rochester, STEVE JARDIN, Princeton Plasma Physics Laboratory — Finite toroidal and poloidal flows are routinely observed in the edge plasma region of tokamak experiments. MHD theory predicts that when the poloidal velocity is transonic with respect to the poloidal sound speed ($c_{sp} \equiv c_{s,p}/B$, where $B_p$ is the poloidal field) a transient will develop. After the end of the transient, a steady-state MHD pedestal in plasma density and pressure is left, with the height of the pedestal depending on the poloidal location. The formation of the MHD pedestal was demonstrated with time-dependent simulations with the resistive-MHD code SIM2D. In the present work, we explore the effect of additional physics on the formation of the pedestal. The advanced model implemented in M3DC1 is used to validate and extend SIM2D calculations. Since M3DC1, contrary to SIM2D, was not developed to study transonic transients, this also gives a strong independent verification of the correctness of the MHD pedestal model. Special focus is given to poloidal viscosity, which is already implemented in M3DC1 and is being implemented in SIM2D. Analytic calculations complement and support numerical results.

\begin{thebibliography}{9}
\bibitem{1} S.E. Kruger et al Plasma Physics of Plasmas, 12, 056113 (2005)
\bibitem{2} R. Paccagnella et al Nucl. Fusion 49 035003 (2009)
\end{thebibliography}

\textsuperscript{1}Supported by US Department of Energy Contract No. DE-FG02-93ER54215.

BP8.00019 Nonlinear MHD effects on the structure of ELMs and edge instabilities\textsuperscript{1}. LINDA SUGIYAMA, M.I.T. — Toroidal fusion plasmas with steep edge pressure gradients exhibit many different types of electromagnetic instabilities in the plasma edge, ranging from large Type I ELM crash to saturated inter-ELM modes to small coherent oscillations without ELMs. Experimental observations find coherent spatial structures that typically have moderate toroidal numbers $n = 10$, which are poorly explained by the MHD linear eigenmode spectrum. Nonlinear effects may be important in some cases, within MHD alone strong toroidal and nonlinear mode coupling can produce such mode numbers for larger amplitude modes, when the full MHD model and plasma configuration are used. MHD also easily produces strong low-$n$ harmonics (typically $n = 1$, but also higher) that have been observed in recent experiments. The low-$n$ harmonics tend to be relatively larger in the magnetic field compared to density or temperature; most experiments have analyzed the magnets. Strong $n = 1$ manifests as a band of higher-$n$ field-aligned filaments that wraps once around the outboard plasma edge from top to bottom. Nonlinear effects are analyzed for a number of plasmas from different experiments with differing edge conditions and types of instability to attempt to determine what sets the dominant mode numbers.

\begin{thebibliography}{9}
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\textsuperscript{1}Supported by the U.S. Department of Energy.
The effect of strong radial variation of the diamagnetic frequency on two-fluid stabilization of edge localized MHD instabilities

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Toroidal Simulations of Sawteeth with Diamagnetic Effects

Matthew Beidler, Paul Cassak, West Virginia University, Stephen Jardin, Princeton Plasma Physics Laboratory — The sawtooth crash in tokamaks limits the core temperature, adversely impacts confinement, and seeds disruptions. Adequate knowledge of the physics governing the sawtooth crash and a predictive capability of its ramifications has been elusive, including an understanding of incomplete reconnection, i.e., why sawteeth often cease prematurely before processing all available magnetic flux. There is an indication that diamagnetic suppression could play an important role in this phenomenon. While computational tools to study toroidal plasmas have existed for some time, extended-MHD physics have only recently been integrated. Interestingly, incomplete reconnection has been observed in simulations when diamagnetic effects are present [1]. In the current study, we employ the three-dimensional, extended-MHD code M3D-C1 [2] to study the sawtooth crash in a toroidal geometry. In particular, we describe how magnetic reconnection at the q=1 rational surface evolves when self-consistently increasing diamagnetic effects are present. We also explore how the termination of reconnection may lead to core-relaxing ideal-MHD instabilities.


Investigations on Sawtooth Reconnection in ASDEX Upgrade Tokamak Discharges Using the 3D Non-linear Two-fluid MHD Code M3D-C1

Isabel Krebs, Max-Planck/Princeton Center for Plasma Physics, Stephen C. Jardin, Princeton Plasma Physics Laboratory, Princeton, NJ, USA, Valentin Igochine, Sibylle Guenter, Matthias Hoezl, Max Planck Institute for Plasma Physics, Garching, Germany, ASDEX UPGRADE TEAM — We study sawtooth reconnection in ASDEX Upgrade tokamak [Herrmann et al., Fusion Sci. Technol. 44(3) (2003)] plasmas by means of 3D non-linear two-fluid MHD simulations in toroidal geometry using the high-order finite element code M3D-C1 [S.C. Jardin et al., J. Phys. : Conf. Ser. 125 (2008)]. Parameters and equilibrium of the simulations are based on typical sawtoothing ASDEX Upgrade discharges. The simulation results are compared to features of the experimental observations such as the sawtooth crash time and frequency, the evolution of the safety factor profile and the 3D evolution of the temperature. 2D ECE imaging measurements during sawtooth crashes in ASDEX Upgrade indicate that the heat is transported out of the core through a narrow poloidally localized region [Igochine et al., Phys. Plasmas 17 (2010)]. We investigate if incomplete sawtooth reconnection can be seen in the simulations which is suggested by soft X-ray tomography measurements in ASDEX Upgrade showing that an \( (m=1, n=1) \) perturbation is typically observed to survive the sawtooth crash and approximately maintain its radial position [Igochine et al., Phys. Plasmas 17 (2010)].

Modeling Giant Sawtooth Modes in DIII-D using the NIMROD code

Scott Kruger, Thomas Jenkins, Tech-X Corp, Eric Held, Utah State University, Jacob King, Tech-X Corp, NIMROD TEAM — Ongoing efforts to model giant sawtooth cycles in DIII-D shot 96043 are summarized. In this discharge, an energetic ion population induced by RF heating modifies the sawtooth stability boundary, supplanting the conventional sawtooth cycle with longer-period giant sawtooth oscillations of much larger amplitude. NIMROD has the unique capability of being able to use both continuum kinetic and particle-in-cell numerical schemes to model the RF-induced hot-particle distribution effects on the sawtooth stability. This capability is used to numerically investigate the role played by the form of the energetic particle distribution, including a possible high-energy tail drawn out by the RF, to study the sawtooth threshold and subsequent nonlinear evolution. Equilibrium reconstructions from the experimental data are used to enable these detailed validation studies. Effects of other parameters on the sawtooth behavior (such as the plasma Lundquist number and hot-particle \( \beta \)-fraction) are also considered. Ultimately, we hope to assess the degree to which NIMROD’s extended MHD model correctly simulates the observed linear onset and nonlinear behavior of the giant sawtooth, and to establish its reliability as a predictive modeling tool for these modes.

Self-organized stationary states of inductively driven tokamaks

S.C. Jardin, PPPL, N. Ferraro, GA, I. Krebs, IPP-PPPL, J. Chen, PPPL — We report on a mechanism for preventing the current and temperature profiles from peaking in a stationary state tokamak. For certain parameters, regardless of the initial state, the plasma profiles will evolve into a self-organized state with the safety factor \( q \) slightly above 1 and constant in a central volume. This large shear free region is unstable to intermode changes for any pressure gradient, and the instability drives a strong (1,1) helical flow. This flow has the property that \( \mathbf{V} \times \mathbf{B} \) is the gradient of a potential, so it does not affect the magnetic field evolution. However, the driven flow appears in the temperature evolution equation and dominates over the thermal conductivity in the center of the discharge. The net effect is to keep the central temperature (and resistivity) profiles flat so that the resistive steady state preserves the self organized state with \( q \) slightly above 1 and constant in the central volume. This mechanism was discovered with the M3D-C1 toroidal 3D MHD code, and could possibly explain the mechanism at play in non-sawtoothing discharges with \( q \) just above 1 such as hybrid modes in DIII-D and ASDEX-U and long-lived modes in NSTX and MAST.

This work was initiated by the late Dr. Dalton Schnack. Equilibria were provided by Dr. A. Turnbull of General Atomics.

Study of extended MHD effects on interchange modes in spheromak equilibria

E.C. Howell, C.R. Sovinec, University of Wisconsin-Madison — A study of extended MHD effects on linear interchange modes is performed using the NIMROD code [Sovinec & King JCP 2010]. A linear cylindrical equilibrium model is adapted from [Jardin NF 1982] to allow finite toroidal current at the edge. These equilibria are representative of SSPX discharges where currents are driven on the open field to keep the safety factor above \( \frac{1}{2} \) across the profile [McLean et al POP 2006]. These spheromaks have weak magnetic shear, and interchange stability is an important consideration. The Suydam parameter, \( D \), is scaled to study resistive and ideal interchange modes. The calculated MHD growth rate increases with \( D \). The resistive interchange scaling \( \gamma \sim \eta^{1/3} \) is observed for \( D < \frac{4}{3} \). Calculations using the full extended MHD model are performed for a range of hall parameters \( \Lambda \). This model includes gyro-viscosity, the hall term, equilibrium diamagnetic flows, and the cross-field diamagnetic heat flux. Two fluid effects in the full model are always destabilizing at large \( \Lambda \). However, some cases exhibit a range of \( \Lambda \) where the growth rate for the full model is reduced relative to the MHD growth rate.

Work supported by US DOE.
BP8.00026 Magnetic islands and singular currents at rational surfaces in three-dimensional MHD equilibria, JOAQUIM LOIZU, Max Planck Institut fur Plasmaphysik, STUART HUDSON, AMITAVA BHATTACHARJEE, Princeton Plasma Physics Laboratory, PER HELANDER, Max Planck Institut fur Plasmaphysik, MAX-PLANCK-PRINCETON CENTER FOR PLASMA PHYSICS COLLABORATION — Ideal MHD predicts the existence of singular current densities forming at rational surfaces in non-axisymmetric equilibria. These current singularities consist of a Pfirsch-Schlüter component that arises as a result of finite pressure gradient and a delta-function current that presumably prevents the formation of islands that would otherwise develop in a non-ideal plasma. While analytical formulations have been developed to describe such currents, a numerical proof of their existence has been hampered by the assumption of smooth functions made in conventional MHD equilibrium models such as VMEC. Recently, a theory based on the energy principle was developed that incorporates the possibility of non-smooth solutions to the MHD equilibrium problem and bridges the gap between Taylor’s relaxation theory and ideal MHD. Leveraging a numerical implementation of this multi-region, relaxed MHD model, we provide a numerical proof of the formation of singular currents in non-axisymmetric ideal MHD equilibria. For each numerical result we perform careful convergence studies and analytical benchmarks. Finally, we discuss the implications for the MHD stability of non-axisymmetric, toroidally confined plasmas.

BP8.00027 Perturbed particle orbits and kinetic plasma response in non-axisymmetric tokamaks, KIMIN KIM, J.-K. PARK, PPPL, A.H. BOOZER, Columbia University, N.C. LOGAN, Z.R. WANG, J.E. MENARD, PPPL — Non-axisymmetric magnetic fields interact with the drift trajectories of ions and electrons to create an anisotropic plasma pressure. The force produced by the gradient of this anisotropic pressure produces a torque, the Neoclassical Toroidal Viscosity (NTV), which tends to relax the plasma rotation to a specific offset rotation, and modifies the energy required to perturb the plasma. Complexities, such as resonances of the ExB drift with particle bounce frequencies, finite orbit width, and full collisional effects, require full numerical simulation to determine the NTV and the perturbation energy. The POCA delta-f drift kinetic particle code has been used to: (1) demonstrate the existence of the bounce resonances with the ExB drift and show that they often dominate the magnitude of the NTV, (2) show the NTV of perturbations with different toroidal mode numbers are generally decoupled, and (3) verify a quadratic NTV dependence on the asymmetric magnetic field. Such results imply the pressure anisotropy is linear in the magnetic perturbation and can produce a significant change in the applied non-axisymmetric field. Progress on integrating this pressure anisotropy into a perturbed equilibrium solver to obtain self-consistent solutions is presented.

BP8.00028 Effects of remaining magnetic islands in resonant magnetic perturbations, C.C. CHANG, J.C. LU, Y. NISHIMURA, C.Z. CHENG, Institute of Space and Plasma Sciences, National Cheng Kung University — Effects of remaining magnetic islands in stochastic magnetic field is investigated. A guiding center orbit following code is employed. The island remnants play an important role in characterizing the radial particle and heat transport. By increasing the trapped particle fraction, the transport level is reduced due to the conservation of second adiabatic invariants. Three dimensional particle motion is projected onto one dimensional radial profile to compare with a 1D transport model. Furthermore, particle source is incorporated into the kinetic simulation to retain the global profile as in realistic tokamak discharge. This work is supported by National Science Council of Taiwan, NSC 100-2112-M-006-021, 103-2112-M-006-007, and NCKU Top University Project.

BP8.00029 Model of Tearing Mode Suppression by Resonant Magnetic Perturbations in a Tokamak, WENLONG HUANG, University of Science and Technology of China, PING ZHU, University of Science and Technology of China, University of Wisconsin-Madison — The conventional error field theory has been extended to model the interaction between tearing mode and resonant magnetic perturbation (RMP) in a tokamak approximated by a screw pinch configuration. The model is applied to the analysis and understanding of the mechanism underlying the tearing mode suppression induced by resonant magnetic perturbation as observed in recent tokamak experiments and simulations. Numerical solutions of the model demonstrate that at lower strength, RMPs are able to reduce the tearing mode amplitude. As the RMP strength increases, the tearing mode is locked in phase and its amplitude jumps to a higher level. Model analysis further reveals that both the tearing mode suppression and the mode locking are achieved through the modulation of the tearing mode rotational frequency using RMPs. The model predictions for the parameter regimes of tearing mode suppression and locking have been examined, and comparisons with recent experimental observations and simulations will be discussed.

BP8.00030 Linear and Nonlinear Response of a Rotating Tokamak Plasma to a Resonant Error-Field, RICHARD FITZPATRICK, IFS, University of Texas at Austin — An in-depth investigation of the effect of a resonant error-field on a rotating, quasi-cylindrical, tokamak plasma is performed within the context of resistive-MHD theory. General expressions for the response of the plasma at the rational surface to the error-field are derived in both the linear and nonlinear regimes, and the extents of these regimes mapped out in parameter space. Torque-balance equations are also obtained in both regimes. These equations are used to determine the steady-state plasma rotation at the rational surface in the presence of the error-field. It is found that, provided the intrinsic plasma rotation is sufficiently large, the torque-balance equations possess dynamically stable low-rotation and high-rotation solution branches, separated by a forbidden band of dynamically unstable solutions. Moreover, bifurcations between the two stable solution branches are triggered as the amplitude of the error-field is varied. A low- to high-rotation bifurcation is invariably associated with a significant reduction in the width of the magnetic island chain driven at the rational surface, and vice versa. General expressions for the bifurcation thresholds are derived, and their domains of validity mapped out in parameter space.

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BP8.00031 Convective Radial Energy Flux Due To Resonant Magnetic Perturbations¹, FRANCISCO ALBERTO MARCUS, Institute of Physics at University of S˜ ao Paulo, PETER BEYER, GUILLAUME FUHR, ARNAUD MONNIER, SADRUBBIN BENKADDA, Aix-Marseille Université — With the resonant magnetic perturbations (RMPs) consolidating as an important tool to control the transport barrier relaxation, the mechanism on how their work is still a subject to be clearly understood. In this work we investigate the equilibrium states in the presence of RMPs for a reduced MHD model using 3D electromagnetic fluid numerical code (EMEDGE3D) with a single harmonic RMP (single magnetic island chain) and multiple harmonics RMPs in cylindrical and toroidal geometry. Two different equilibrium states were found in the presence of the RMPs with different characteristics for each of the geometries used. For cylindrical geometry the RMPs, the coupling between the equation for shear Alfven waves involving inertia and bending energy terms and the sound wave equation. The presence of a magnetic

¹French agency CNRS and Brazilian agencies CNPq and FAPESP. Projects Numbers: ANR2010-BLAN-904-01, 560491/2010-7 and 201119296-1.

BP8.00032 The effect of small 3D magnetic perturbations on linear micro-instability properties¹, C.C. HEGNA, University of Wisconsin-Madison — Small externally applied non-axisymmetric magnetic perturbations can significantly alter the edge properties of tokamaks. In this work, we model the effect of the applied 3D fields on the flux surface deformation and show that these can alter key geometric properties of interest to microinstabilities. Shielding physics is assumed to be operable so that flux surface integrity is retained. Local 3D equilibrium theory is employed using a perturbative approach to calculate flux surface deformations consistent with magnetostatic force balance [1]. Prior work has shown applied 3D fields can significantly alter ideal ballooning stability boundaries due to order unity 3D field induced changes to the local shear [2]. The impact of 3D fields on ion temperature gradient and trapped electron mode growth rates are quantified using analytically derived proxy functions.

¹Research supported by U. S. DoE grant no. DE-FG02-86ER553218.

BP8.00033 A Cross-Benchmarking and Validation Initiative for Tokamak 3D Equilibrium Calculations¹, A. REIMAN, Princeton Plasma Phys Lab, A. TURNBULL, T. EVANS, N. FERRARO, General Atomics, E. LAZARUS, Oak Ridge National Laboratory, J. BRESLAU, Princeton Plasma Phys Lab, A. CERFON, New York University, C.S. CHANG, R. HAGER, Princeton Plasma Phys Lab, J. KING, Oak Ridge National Laboratory, M. LANCOTOT, General Atomics, S. LAZERSON, Princeton Plasma Phys Lab, Y. LIU, Culham Science Centre, G. MCFADDEN, National Institute of Standards and Technology, D. MONTICELLO, R. NAZIKIAN, J.K. PARK, Princeton Plasma Phys Lab, C. SOVINEC, University of Wisconsin, Y. SUZUKI, National Institute for Fusion Science, Kyoto, P. ZHU, University of Wisconsin, Madison — We are pursuing a cross-benchmarking and validation initiative for tokamak 3D equilibrium calculations, with 11 codes participating: the linearized tokamak equilibrium codes IPEC and MARS-F, the time-dependent extended MHD codes M3D-C1, M3D, and NIMROD, the gyrokinetic code XGC, as well as the stellarator codes VMEC, NSTAB, PIERS, HINT and SPEC. Dedicated experiments for the purpose of generating data for validation have been done on the DIII-D tokamak. The data will allow us to do validation simultaneously with cross-benchmarking. Initial cross-benchmarking calculations are finding a disagreement between stellarator and tokamak 3D equilibrium codes.

¹Work supported in part by U.S. DOE under contracts DE-AC02-09CH11466, DE-FC02-04ER54698, DE-FC02-95ER54309 and DE-AC05-00OR22725.

BP8.00034 Energetic Ion Effects on Tearing Mode Stability in Tokamak Equilibria, MICHAEL HALFM OON, Univ of Tulsa, DYLAN BRENNAN, Princeton University — The 2/1 tearing mode is found to be damped or stabilized by energetic ions in a slowing down distribution, where the interaction between the ions and the mode is similar to their interaction in ideal MHD, which has been extensively studied. This damping effect is mainly due to trapped particle precession resonance and causes the tearing mode to have a finite real frequency. This study focuses on the pressure-driven, slow growing tearing modes; which are the first modes to be driven unstable as pressure increases. The layer physics modifies the mode interaction, and affects the frequency of the mode. In these simulations, a series of equilibria with fixed safety factor and varying pressure are analyzed using a hybrid-kinetic MHD code in NIMROD. Our equilibrium consists of a D-shaped poloidal cross section, a peaked pressure profile, and safety factor with finite shear to the magnetic axis. Also, a high aspect ratio toroidal model based on Hu & Betti’s work is investigated analytically to gain insight to the physics of mode-particle interactions. We combine our computational and analytic tools in an effort to explain this damping and stabilizing effect.

BP8.00035 Nonlinear simulation of the fishbone instability, MALIK IDOUAKASS, MATTEO FAGANELLO, Aix-Marseille Université, HERBERT BERP, University of Texas, XAVIER GARBET, Commissariat à l’Energie Atomique, SADRUBBIN BENKADDA, Aix-Marseille Université, PIIME TEAM, IFS TEAM, IRMF TEAM — We propose to extend the Obdomb-Breizman precessional fishbone model [1] to account for both the MagnetohydroDynamic (MHD) nonlinearity at the q = 1 surface and the nonlinear response of the energetic particles contained within the q = 1 surface. This electromagnetic mode, whose excitation, damping and frequency chirping are determined by the self-consistent interaction between an energetic trapped particle population and the bulk plasma evolution, can induce effective transport and losses for the energetic particles, being them alpha-particles in next-future fusion devices or heated particles in present Tokamaks. The model is reduced to its simplest form, assuming a reduced MHD description for the bulk plasma and a two-dimensional phase-space evolution (gyro and bounce averaged) for deeply trapped energetic particles. Numerical simulations have been performed in order to characterize the mode chirping and saturation, in particular looking at the interplay between the development of phase-space structures and the system dissipation associated to the MHD non-linearities at the resonance locations.


BP8.00036 Analytical theory of BAE gap modification due to a magnetic island¹, CARSON COOK, CHRIS HEGNA, University of Wisconsin, DONALD SPONG, Oak Ridge National Laboratory — The Beta-induced Alfven Eigenmode (BAE) gap is a break in the frequencies of the shear Alfven continuum. This gap is important because a discrete Alfven eigenmode can exist within the gap frequency range and will not be affected by continuum damping. In order for the BAE gap to appear, finite beta and curvature effects must be present. Under these conditions, there is a coupling between the equation for shear Alfven waves involving inertia and bending energy terms and the sound wave equation. The presence of a magnetic island has been shown to cause an upshift in the BAE gap frequency [1]. In the presence of an island the minimum of the continuum frequencies is located at the resonant rational surface; the island moves the location of the minimum to the island separatrix as a result of the coupling between helical mode numbers. The physical mechanism for this shift will be described employing analytical modeling. The shear Alfven spectrum is obtained globally through analytical methods, inside and outside the separatrix, for the first time. A WKBJ approximation is used in this analysis, and good agreement is found with previous numerical results.

¹Research supported by the U.S. DOE under grants DE-FG02-99ER55456 and DE-SC0006103.
One-dimensional energetic particle quasilinear diffusion for realistic TAE instabilities. VINCIUS DUARTE, Princeton Plasma Physics Laboratory, Princeton University, KATY GHANTOUS, Laboratoire de Physique des Plasmas, Ecole Polytechnique, France, HERBERT BERK, Institute for Fusion Study, University of Texas, Austin, NIKOLAI GORELENKOV, Princeton Plasma Physics Laboratory, Princeton University — Owing to the proximity of the characteristic phase (Alfvén) velocity and typical energetic particle (EP) superthermal velocities, toroidicity-induced Alfvén eigenmodes (TAEs) can be resonantly destabilized endangering the plasma performance. Thus, it is of ultimate importance to understand the deleterious effects on the confinement resulting from fast ion driven instabilities expected in fusion-grade plasmas. We propose to study the interaction of EPs and TAEs using a line broadened quasilinear model, which captures the interaction in both regimes of isolated and overlapping modes. The resonance particles diffuse in the phase space where the problem essentially reduces to one dimension with constant kinetic energy and the diffusion mainly along the canonical toroidal angular momentum. Mode structure and wave-particle resonances are computed by the NOVA code and are used in a quasilinear diffusion code that is being written to study the evolution of the distribution function, under the assumption that they can be considered virtually unalterable during the diffusion. A new scheme for the resonant particle diffusion is being proposed that builds on the 1-D nature of the diffusion from a single mode, which leads to a momentum conserving difference scheme even when there is mode overlap.

Alpha particle redistribution produced by internal kink modes. HUGO FERRARI, Comision Nacional de Energia Atómica, Centro Atómico Bariloche, Bariloche, Argentina and CONICET, Argentina, RICARDO FARENGO, Comision Nacional de Energia Atómica, Centro Atómico Bariloche, Bariloche, Argentina, PABLO GARCIA-MARTINEZ, CONICET, Argentina, MARIE CHRISTINE FIRPO, WAHB ETTOUMI, Laboratoire de Physique des Plasmas, CNRS, Ecole Polytechnique, Palaiseau, France, AGUSTIN LISCHSITZ, Laboratoire d’Optique Appliquée, ENSTA, CNRS, Ecole Polytechnique, Palaiseau, France — The redistribution of alpha particles due to internal kink modes is studied. The exact particle trajectories in the total fields, equilibrium plus perturbation, are calculated. The equilibrium has circular cross section and the plasma parameters are similar to those expected in ITER. The alpha particles are initially distributed according to a slowing down distribution function and have energies between 18 keV and 3.5 M eV. The (1,1), (2,2) and (2,1) modes are included and the effect of changing their amplitude and frequency is studied. When only the (1,1) mode is included the spreading of high energy (E \geq 1 MeV) alpha particles increases slowly with the energy and mode frequency. At lower energies the redistribution is more sensitive to the mode frequency and particle energy. When a (2; 1) mode is added the spreading increases significantly and particles can reach the edge of the plasma. Trapped particles are the most affected and the redistribution parameter can have maxima above 1 MeV, depending on the mode frequency. These results can have important implications for ash removal.

Role of phase locking in nonlinear dynamics of fishbones and EPMs. FULVIO ZONCA, ENEA, C.R. Frascati, LIU CHEN, UCI and IFTS, ZJU, ZHIYONG QIU, IFTS, ZJU — Fishbones [1] and, more generally, Energetic Particle Modes (EPM) [2], are discrete non-normal modes excited out of the shear Alfvén wave (SAW) continuous spectrum. Their frequency is the characteristic one of resonant EPs and maximizes wave-EP power exchange, opposite SAW continuum damping. These properties are maintained during the nonlinear evolution of the system, due to the intrinsic non-perturbative response of EPs to the fluctuating SAW fields and their self-consistent interplay with the perturbed EP source. This dynamic behavior is given by “phase locking” between resonant EPs and SAW fluctuations, as demonstrated in this work; and can be generally described by a Dyson equation for the emission and reabsorption of SAW fluctuations by the EP population [3]. Here, we apply this theoretical framework to nonlinear fishbone and EPM dynamics in fusion plasmas, and discuss their description as complex Nonlinear Schrödinger Equation, for which we provide solutions in simple yet practically relevant limiting cases [3].

Finite-beta effects of non-Maxwellian fast ions in gyrokinetics. GEORGE WILKIE, University of Maryland, IAN ABELO, Princeton University, WILLIAM DORLAND, University of Maryland — The presence of relatively small concentrations of fast ions is known to have a significant effect on the Alfvénic physics of fusion plasmas. These fast ions have large gyroradii and are usually non-Maxwellian, so the low-collisionality ordering of gyrokinetics is an appropriate tool. Here, we use the GS2 gyrokinetics code to study finite-beta nonlinear effects in the presence of non-Maxwellian fast ions.

Predictive models for fast ion profiles relaxation in burning plasmas. NIKOLAI GORELENKOV, PPPL, W.W. HEIDBRINK, UC Irvine, J. LESTZ, M. PODESTA, PPPL, M. VAN ZEELAND, GA, San Diego, R.B. WHITE, PPPL — The performance of the burning plasmas is limited by the confinement of superalfvenic fusion products, alpha particles, which are capable to resonate with the Alfvenic eigenmodes (AEs). Two techniques based on linear AE stability theory are developed to evaluate the AE induced fast ion relaxation. The first is the reduced quasilinear technique or critical gradient model (CGM) where marginally unstable (or critical) gradient of fast ion pressure is due to unstable AEs. It allows the reconstruction of fast ion pressure profile and compute their losses. The second technique is called hybrid that is also based on NOVA-K linear stability computations of TAE (or RSE) mode structures and growth rates. AE amplitudes are computed from the nonlinear theory perturbatively and used in numerical runs. With the help of the guiding center code ORBIT the hybrid model predicts the relaxation of the fast particle profiles. We apply these models for NSTX and DIII-D plasmas with the neutral beam injections in order to validate the models. Both methods are relatively fast ways to predict the fast ion profiles in burning plasmas and can be used for plasma modeling prior to building experimental devices such as ITER.

A hybrid simulation model for runaway electron interaction with the tearing mode. CHANG LIU, DYLAN BRENNAN, Princeton University, ALLEN BOOZER, Columbia University — The runaway electron problem is one of the key issues in disruption studies. It is predicted that in future large tokamaks devices like ITER the runaway beam can be significantly large and energetic, which can cause serious damage to the device. In experiments increasing magnetic turbulence can suppress runaway electrons, which is due to the increase of runaway electron radial transport when the magnetic fields become stochastic. On the other hand, a large amount of runaway current can change the MHD stability, causing MHD instabilities, which can affect the magnetic field structure. It is therefore important to study the interaction of runaway electrons and MHD instabilities self-consistently. We are working towards a hybrid simulation using a drift-kinetic, Monte-Carlo particle code for the runaway electrons and NIMROD for the background plasma. Our simulation will be self-consistent, which means it will include a coupling of the runaway electrons to the MHD equations through the current. The kinetic simulation of the runaway electrons, even uncoupled from the MHD, can be used to analyze existing experiments on runaway electrons. In addition, we present a self-consistent fluid treatment of the runaway current coupled to MHD, which captures much of the essential physics.
BP8.00043 Resistivity and sheared rotation effects on the toroidal external kink mode. A.J. COLE, Columbia University, D.P. BRENNAN, Princeton University, J.M. FINN, Los Alamos National Laboratory — We present PEST-III analysis of the toroidal external kink with plasma resistivity and sheared rotation for a range of equilibrium varying elongation, driven unstable by increasing $\beta$. The results show that the typical ordering for marginally stable $\beta$ values is $\beta_{p,0} < \beta_{p,iw} < \beta_{ip,0} < \beta_{ip,iw} < \beta_{iw,0}$. The $\beta$ -resistive case $\beta_{iw}$ is significantly lower than the other two ideal plasma values. We vary aspects of the tearing layer physics by means of a variational principle with Padé approximants, and compare with a general computational solution for the layers to gain insight. We also include pressure gradient and local velocity shear within the layers. Global rotation shear $\Omega$ is included in the form of a relative rotation of the $q = 3, 4, \cdots$ surfaces and we investigate the resultant effect on the poloidal mode number spectrum. We then present a model for active feedback control, which is the toroidal generalization building on recent results in cylindrical mode control theory [D.P. Brennan and J.M. Finn and submitted to Physics of Plasmas (2014)].

BP8.00044 Verification of the Resistive DCON Code. A.H. GLASSER, University of Washington, Z.R. WANG, J.-K. PARK, Princeton Plasma Physics Laboratory — The ideal MHD axisymmetric toroidal stability code DCON has been extended to treat resistive instabilities, with resonant surfaces at rational safety factor values of $q = m/n$. DCON solves the ideal MHD equations using a singular Galerkin method to obtain matching data for the ideal outer region. Robust convergence is achieved by a careful choice of basis functions: $C^1$ Hermite cubics to resolve nonresonant solutions; a high-order power series in the neighborhood of each singular surface to resolve large and small resonant solutions; distributed with a grid-packing algorithm with high resolution near the singular surfaces and adequate grid to resolve the nonresonant region. The degenerate case for $\beta = 0$ has been derived and coded up for verification, in addition to the nondegenerate case $\beta > 0$. The DELTAR code computes corresponding inner region matching data for the resistive MHD equations of Glasser, Greene, and Johnson. The MATCH code matches the inner and outer region data to obtain global eigenvalues and eigenfunctions. The VACUUM provides data for a vacuum region outside the plasma region. The MARS-F code, which solves the same equations by a straight-through method, is used to verify the accuracy of the DCON solution. Results will be presented.

BP8.00045 Neoclassical Tearing Modes characterization in JET ILW operation. Matteo Baruzzo, RFX, Corso Stati Uniti 4, Padova, Italy, Barry Alper, CCFE, Clemente Angioni, IPP, Garching, Yuriy Baranov, CCFE, Paolo Buratti, Enea, Francis Casson, Tim Hender, CCFE, Paola Mantica, Chiara Marchetto, CNR, Milano, Laura Lauro Taroni, Marco Valisa, RFX, JET-EFDA CONTRIBUTORS TEAM — After several years of operation with the ITER Like Wall a comprehensive evidence on the effect of Neoclassical Tearing Modes on discharge stability and confinement has been collected. NTMs appearance is coincident with a flattening of the electron temperature profile within the island (the effect with the C-wall), but it is sometimes correlated with enhanced core plasma radiation and eventually radiative collapse. A mechanism for W accumulation in presence of magnetic island has been outlined in [1], where the island is responsible of connecting two radial regions characterized by different transport regimes. In this work the statistics of W accumulation measured with bolometry and Soft X-ray will be correlated with the island radial position and island width as measured by fast Electron Cyclotron Emission for different toroidal mode numbers and in different tokamak operational scenarios.

1 JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK
2 See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, US.

BP8.00046 GTC Simulation of Tearing Modes in Fusion Plasmas. Dongjian Liu, College of Physical Science and Technology, Sichuan University, IHOR HOLOD, University of California, Irvine, Wenlu Zhang, Institute of Physics, Chinese Academy of Sciences, Zhihong Lin, University of California, Irvine — In Tokamak discharge, Tearing modes are very important modes which may cause the disruption and sawtooth crash. For the reason, an effective physics model and corresponding simulation code are needed to study these modes. We have modified the fluid-kinetic hybrid electron model used in Gyro-kinetic Toroidal Code (GTC) and developed both resistive and finite mass electron fluid model for tearing mode simulations. Using the model in GTC, we have successfully recovered linear behavior of both the classical resistive tearing mode and the collisionless tearing mode, and verified the capability of GTC to study this mode. The modified GTC may supply a more powerful implement for kinetic-MHD study of Tokamak plasma.

BP8.00047 Studies of NSTX equilibria with beta above the n=1 no-wall limit using new toroidal resistive wall boundary condition in NIMROD. A.L. Becerra, C.C. Hegna, C.R. Sovinec, University of Wisconsin, Madison, S.E. Kruger, J.R. King, Tech-X Corp., S.A. Sabbagh, Columbia University — We make use of the generalized thin resistive wall boundary condition recently implemented in NIMROD to study the linear and nonlinear RWM stability properties of a series of reconstructed NSTX equilibria. The boundary condition operates by matching the magnetic field inside the computational domain with external fields found using the GRIN vacuum-field solver at the wall, and is valid for toroidal geometries with poloidal asymmetry as well as for cylindrical geometries. A time series of NSTX equilibrium reconstructions from a single shot with a range of normalized beta above and below the no-wall limit is used to benchmark this boundary condition by comparing the beta computed for RWM onset with the stability limit predicted by DCON. Scans with varying wall parameters are also performed to demonstrate the approximately linear relationship between growth rate and wall resistivity, and to determine the wall parameters that are the best match to the NSTX device. The stability of these equilibria for n=1 is also tested, with both linear and non-linear runs.

1 Research supported by U. S. DoE under grant no. DE-FG02-86ER53218.

BP8.00048 Magnetic Field Line Stickiness in Tokamaks. Caroline G.L. Martins, University of Texas at Austin, Department of Physics, Institute for Fusion Studies, Austin - TX 78712, USA, Marisa Roberto, Departamento de Fisica, Instituto Tecnologico de Aeronautica, Sao Jose dos Campos, SP, 12228-900, Brazil, Eber L. Caldas, Universidade de Sao Paulo, Instituto de Fisica, Sao Paulo, SP, 05315-970, Brazil, Philip J. Morrison, University of Texas at Austin, Department of Physics, Institute for Fusion Studies, Austin - TX 78712, USA — We analyze a Hamiltonian model with five wire loops that delineate magnetic surfaces of tokamaks with poloidal divertors. Non-axisymmetric magnetic perturbations are added by external coils, similar to the correction coils that have been installed or designed in present tokamaks. We obtain the footprints and deposition patterns on the divertor plates, and, additionally, we show that while chaotic lines escape to the divertor plates, some of them are trapped, for many toroidal turns, in complex structures around magnetic islands, giving rise to evidence of stickiness characteristic of chaotic Hamiltonian systems [Caroline G. L. Martins et al. IEEE Transactions on Plasma Science (accepted), 2014]. In order to identify sticky structures, we perform a finite time rotation number calculation [J. D. Szezech Jr. et al. Phys. Lett. A, 377, 452, 2013]. Finally, we introduce a random collisional term to the field line mapping to investigate the effect of particle collisions on stickiness. The results indicate that the reported trapping may affect the transport in present tokamaks [Caroline G. L. Martins et al. Physics of Plasmas (Submitted), 2014].
BP8.00049 Hamiltonian and Action Principle Formalisms for Gyroviscous models, MANASVI LINGAM, PHILIP J. MORRISON, Institute for Fusion Studies, The University of Texas at Austin — A general procedure for constructing action principles for continuum models via the generalized Hamilton's principle of mechanics is described. In [1], this procedure is employed to construct a class of actions, which includes several hydrodynamics and magnetohydrodynamics(MHD) models. The conditions under which the conservation of energy, linear and angular momentum hold are presented. The generalized formalism is used to develop a simple model with intrinsic angular momentum. In [2], the action principle for a specific 2D gyroviscous MHD model is developed, which is identical to a reduced version of Braginskii's fluid equations. The procedure explains the origin of the gyro, used in deriving previous gyrofluid models. A systematic reduction procedure yields the Hamiltonian model of this type through the noncanonical Poisson bracket. The construction procedure yields classes of Casimir invariants, which are then used to derive variational principles for equilibria with flow and gyroviscosity. It is shown that the model can be modified to obtain other reduced models in the literature.


BP8.00050 Extended MHD simulations of Rayleigh-Taylor instability with real frequency in a 2D slab, RYOSUKE GOTO, The Graduate University for Advanced Studies (SOKENDAI), HIDEAKI MIURA, ATSUSHI ITO, MASHAKI SATO, National Institute for Fusion Science, TOMOHARU HATORI, The Graduate University for Advanced Studies (SOKENDAI) — Small scale effects such as the Finite Larmor Radius (FLR) effect and the Hall term can change the linear and non-linear growth of the high wave number unstable modes of the pressure driven instability considerably. Here we consider a simple Rayleigh-Taylor (R-T) instability in a 2D slab, and study the effect of the Hall term and the FLR effect to the R-T instability by means of numerical simulations of the Braginskii-type extended MHD equations [1]. As we have reported earlier, the linear growth rates of the high wave number modes are highly reduced when the Hall term and the FLR effect are added simultaneously [2]. However, there appears little real frequency in the previous work. Since the diamagnetic drift associated with the real frequency is considered to affect the growth of the linear and nonlinear evolutions, we provide a new equilibrium in which appearance of the real frequency is expected and carry out numerical simulations. Influences of the real frequency on the growth rates as well as on the nonlinear mixing width for some combinations of the Hall and the FLR parameters are going to be presented.


BP8.00051 Building Action Principles for Extended MHD Models, JOANNIS KERAMIDAS CHARIDAKOS, MANASVI LINGAM, PHILIP MORRISON, RYAN WHITE, Institute for Fusion Studies and Department of Physics, The University of Texas at Austin, ALEXANDER WURM, Department of Physical and Biological Sciences, Western New England University — The general, non-dissipative, two-fluid model in plasma physics is Hamiltonian, but this property is sometimes lost in the process of deriving simplified two-fluid or one-fluid models from the two-fluid equations of motion. One way to ensure that the reduced models are Hamiltonian is to derive them from an action. We start with the general two-fluid action functional for an electron and an ion fluid interacting with an electromagnetic field, expressed in Lagrangian variables. We perform a change of variables and make various approximations (eg. quasineutrality and ordering of the fields) and small parameter expansions directly in the action. The resulting equations of motion are then mapped to the Eulerian fluid variables using a novel nonlocal Lagrange-Euler map. The correct Eulerian equations are obtained after we impose locality. Using this method and the proper approximations and expansions, we recover Lust’s general two-fluid model, extended MHD, Hall MHD, and Electron MHD from a unified framework. The variational formulation allows us to use Noether’s theorem to derive conserved quantities for each symmetry of the action. References: I.Keramidas Charidakos, M.Lingam, P.J.Morrison, R.White, A. Wurm “Action Principles for Extended MHD Models” (to be submitted)


BP8.00052 Simulation and analytic analysis of radiation driven islands at the density limit, D.P. BRENNAN, C. LIU, Princeton University, D.A. GÁTES, L. DELGADO-APARICIO, R. WHITE, Princeton Plasma Physics Laboratory — The effect of radiative cooling on the onset and evolution of magnetic islands is investigated with nonlinear resistive MHD simulations and reduced theoretical analysis. The configuration is a cylindrical tokamak with a m/n = 2/1 island and includes three dimensional resistivity and anisotropic heat conduction in the simulations. The radiative cooling is implemented as a temperature perturbation inside the island, which modifies the island structure and drives the island more unstable. Analytic reduction of the saturated island size and structure supports the simulation results. The results offer intuitive understanding of experimental observations of radiation driven magnetic islands, which may explain density limit disruptions.

BP8.00053 Tri-dimensional Ribbon Burning Modes in Igniting Plasmas*, B. COPPI, MIT — The fusion burn conditions of magnetically confined plasmas are investigated usually by one- dimensional or 1+1/2 D codes, when referring to toroidal configurations. This means that the fusion burning process is being described as an axisymmetric and a poloidally symmetric process in a toroidal configuration. On the other hand when the presence of magnetic shear in the considered confinement configuration and the effects of anisotropic thermal conductivities, relative to the confining magnetic field, are taken into account a new kind of thermonuclear instability can be found in plasmas close to ignition conditions [1]. Deuterium-tritium plasmas are considered in particular. The relevant mode involving the growth of electron temperature perturbations is tri-dimensional and radially localized around a given rational magnetic surface. Clearly, the onset, evolution and this kind of “ribbon” modes have to be considered in order to envision and predict how a condition of global ignition [1] can be reached. *Sponsored in part by the U.S. DOE.


BP8.00054 Numerical Analysis of Drift Resistive Inertial Ballooning Modes, A.H. KRITZ, V. TANGRI, T. RAFIQ, Lehigh University, A.Y. PANKIN, Tech-X Corp. — Three numerical techniques employing differentiation matrices are used to investigate the linear analysis of drift resistive inertial ballooning modes (DRIBM). The techniques applied avoid numerical stability issues associated with the frequently used shooting method. Hermite and Sinc spectral methods and a finite difference method are applied to compute the DRIBM eigenvalues and eigenvectors. It is shown that the spectral methods converge more rapidly than the finite difference method. In the DRIBM, model incorporated in the Multi-Mode transport model, the strong ballooning approximation is used [T. Rafiq et. al., Phys. Plasmas 20, 032506 (2013)], whereas, in the numerical analysis of these modes presented here, a strong ballooning limit approximation is not used. It is shown that for conditions appropriate for the edge region of a DIII-D plasma (where contributions to transport associated with DRIBM are significant), the Multi-mode DRIBM component (utilizing a strong ballooning limit) and the numerical analysis that does not involve a strong ballooning approximation yield similar growth rates for the most unstable mode. This result follows from the fact that in the tokamak edge region the ballooning modes are strongly localized. The techniques utilized in this paper for calculating eigenvalues are quite general and are relevant to investigate other modes that can be analyzed using the ballooning mode formalism.

1Supported by US DoE Grant DE-FG02-92ER54141.
BP8.00056 Parallel electron heat flow along a spatially varying magnetic field. JOUNG-YOUNG JI, ERIC HELD, Utah State University — We solve a system of general moment equations to obtain the parallel electron heat flow in an inhomogeneous magnetic field. Magnetic field gradient terms are kept and treated using both finite difference and Fourier series methods. Convergence in the heat flow is demonstrated as the number of moments is increased in regimes of high to moderate collisionality. Properties of the moment equations in the collisionless limit are also discussed. The heat flow shows local enhancement and reduction due to magnetic variations when compared to the integral parallel heat flow closure.

BP8.00057 A self-consistent model of an isothermal tokamak. STEVEN MCNAMARA, MATTHEW LILLEY, Imperial College London — Continued progress in liquid lithium coating technologies have made the development of a beam driven tokamak with minimal edge recycling a feasible possibility. Such devices are characterised by improved confinement [1] due to their inherent stability and the suppression of thermal conduction. Particle and energy confinement become intrinsically linked and the plasma thermal energy content is governed by the injected beam. A self-consistent model of a purely beam fuelled isothermal tokamak is presented, including calculations of the density profile [2], bulk species temperature ratios and the fusion output. Stability considerations constrain the operating parameters and regions of stable operation are identified and their suitability to potential reactor applications discussed.

BP8.00058 PSI-Center Validation Studies. B. A. NELSON, C. AKCAY, A. H. GLASSER, C. J. HANSEN, T. R. JARBOE, G. J. MARKLIN, R. D. MILROY, K. D. MORGAN, P. C. NORGARD, U. SHULMAK, D. A. SUTHERLAND, B. S. VICTOR, University of Washington, C. R. SOVINEC, J. B. O'BRYAN, University of Wisconsin-Madison, E. D. HELD, J.-Y. JI, Utah State University, V. S. LUKIN, Naval Research Laboratory — The Plasma Science and Innovation Center (PSI-Center - http://www.psicenter.org) supports collaborating validation platform experiments with 3D extended MHD simulations using the NIMROD, HiFi, and PSI-TET codes. Collaborators include the Bellan Plasma Group (Caltech), CTH (Auburn U), HBT-EP (Columbia), HIT-SI (U Wash - UW), LTIX (PPPL), MAST ( Culham), Pegasus (U Wisc-Madison), SSX (Swarthmore College), TCSU (UW), and ZAP/ZAP-HD (UW). The PSI-Center is exploring application of validation metrics between experimental data and simulations results. Biothermal decomposition (BOD) is used to compare experiments with simulations. BOD separates data sets into spatial and temporal structures, giving greater weight to dominant structures. Several BOD metrics are being formulated with the goal of quantitative validation. Results from these simulation and validation studies, as well as an overview of the PSI-Center status will be presented.

BP8.00059 Evolving magnetic equilibria in anomalous turbulent transport simulations. JUNGPYO LEE, ANTOINE CERFON, NYU CIMS, EDMUND HIGHCOCK, MICHAEL BARNES, Oxford University, Rudolf Peierls Centre for Theoretical Physics, UK — The evolution of poloidal and toroidal magnetic fluxes in a tokamak are determined by Faraday’s law in which electric field needs to be consistent with 1-D radial transport of density, temperature, and toroidal angular momentum. Consistency is required because the transport of the thermodynamic variables depends on the 2-D magnetic equilibrium that changes depending on the radial pressure profile. For neo-classical transport, consistency is achieved through a proper treatment of the parallel electric field and Ohm’s law [Hinton and Hazeltext, (1976), Hirshman and Jard (1979)]. Recently, consistency for the anomalous turbulent transport has been studied analytically using a Lagrangian formulation of gyrokinetics [Sugama et. al. (2014)]. In this poster, we propose a simple numerical model to evolve both the magnetic equilibrium and the radial profile of density, temperature, and toroidal angular frequency due to turbulent transport with fixed q profile (safety factor) profile. The constraint of fixed q profile makes the evolution self-consistent only if the transport time scale is much smaller than the resistive current diffusion time scale. In this model, we use the transport code TRINITI coupled with the local gyrokinetic code GS2. The numerical model of the Grad-Shafranov code ECOM.

BP8.00060 Predictive Modeling of Tokamak Density, Temperature and Toroidal Rotation Profiles1. T. RAFIQ, A.H. KRITZ, Lehigh University, A.Y. PANKIN, Tech-X Corp, X. YUAN, PPPL — The predictive TRANSPort and integrated modeling code, PTRANSP, is used to compute electron density, temperature, toroidal velocity and radial electric field profiles. The Multi-Mode anomalous transport model, MMM7.1, or the Trapped Gyro-Landau Fluid model, TGLF, is used along with the new numerical transport solver, PT-SOLVER, in carrying out the simulations. An option to evolve the electron density profiles has been recently introduced to PT-SOLVER. The effects associated with this new option on the plasma profiles in the predictive PTRANSP simulations that advance the coupled density, energy, and momentum equations are presented. The self-consistent evolution of the equilibrium is computed using a Lagrangian formulation of gyrokinetics [Sugama et. al. (2014)]. In this poster, we propose a simple numerical model to evolve both the magnetic equilibrium and the radial profile of density, temperature, and toroidal angular frequency due to turbulent transport with fixed q profile (safety factor) profile. The constraint of fixed q profile makes the evolution self-consistent only if the transport time scale is much smaller than the resistive current diffusion time scale. In this model, we use the transport code TRINITI coupled with the local gyrokinetic code GS2 and the q-solver version of the Grad-Shafranov code ECOM.

BP8.00061 An improved bootstrap current formula for edge pedestal plasma. ROBERT HAGER, C.-S. CHANG, PPPL — An improved version of a bootstrap current formula based on the results of the neoclassical guiding-center particle-in-cell code XGC0 [Koh et al., Phys. Plasmas 19, 072505 (2012)] is presented. The original formula improved the accuracy of the predicted bootstrap current in the edge pedestal, where the ion orbit width can be comparable to the pressure gradient scale length, the passing particle region is narrow, and the ions experience orbit loss. We improved two aspects of this formula. We corrected the asymptotic behavior of the bootstrap current coefficients at higher collisionality from what was inherited from the Sauter formula [O. Sauter et al., Phys. Plasmas 6, 2834 (1999)]. We also improved the jumpy aspect ratio dependence of the transition between an enhanced (NSTX) and reduced (DIII-D) bootstrap current regime found by Koh et al. In addition, we elucidate the physical origins of the improvement and of the difference from a local analysis that includes the importance of finite ion orbit excursion effects on the electron current in the edge pedestal.

BP8.00062 The Material Plasma Exposure eXperiment (MPEX)1. J. RAPP, T.M. BIEWER, T.S. BIGELOW, J. CANIK, J.B.O. CAUGHMAN, R.C. DUCKWORTH, R.H. GOULDING, D.L. HILLIS, J.D. LORE, A. LUMSDAINE, W.D. MCGINNIS, S.J. MEITNER, L.W. OWEN, G.C. SHAW, Oak Ridge National Laboratory, Oak Ridge, TN, USA, G.-N. LUIO, Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, China — Next generation plasma generators have to be able to access the plasma conditions expected on the divertor targets in ITER and future devices. The Material Plasma Exposure eXperiment (MPEX) will address this regime with electron temperatures of 1 – 10 eV and electron densities of 10\(^{21}\). The resulting heat fluxes are about 10 MW/m\(^2\). MPEX is designed to deliver those plasma conditions with a novel Radio Frequency plasma source able to produce high density plasmas and heat electron and ions separately with Electron Bernstein Wave (EBW) heating and Ion Cyclotron Resonance Heating (ICRH). Preliminary modeling has been used for pre-design studies of MPEX. MPEX will be capable to expose neutron irradiated samples. In this concept targets will be irradiated in ORNL’s High Flux Isotope Reactor (HFIR) or possibly at the Spallation Neutron Source (SNS) and then subsequently (after a sufficient long cool-down period) exposed to fusion reactor relevant plasmas in MPEX. The current state of the pre-design of MPEX including the concept of handling irradiated samples will be presented.

1 ORNL is managed by UT-Battelle, LLC, for the U.S. DOE under contract DE-AC-05-000227257
BP8.00063 Initial Operation of the Proto-MPEX High Intensity Plasma Source, J.B.O. CAUGHMAN, R.H. GOULDING, T.M. BIEWER, T.S. BIGELOW, S.J. DIEH, P.V. PESAVENTO, J. RAPP, H.B. RAY, G.C. SHAW, Oak Ridge National Laboratory, ORNL, Laboratory Directed Research and Development (LDRD) funding enabled the initial installation of laser based, Thomson Scattering (TS), Rayleigh Scattering (RS), and Laser Induced Breakdown Spectroscopy (LIBS) diagnostics on the prototype Material-Plasma Exposure eXperiment (proto-MPEX). TS measures the electron temperature and density while RS measures the neutral density. LIBS is performed by focusing laser radiation onto a target surface, ablating the surface, forming a plasma plume, and analyzing the plume to determine the surface matter composition. The design elements and preliminary measurements for the TS, RS, and LIBS will be discussed, along with considerations for further optimization.

Research sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U. S. Department of Energy

BP8.00064 Preliminary results of Laser-based diagnostics for proto-MPEX, G. SHAW, University of Tennessee, T.M. BIEWER, Oak Ridge National Laboratory, G.N. LUO, Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, China — The Prototype Materials Plasma Experiment (Proto-MPEX) is a linear high-intensity rf plasma source that combines a high-density helicon plasma generator with electron and ion heating. It is being used to study the physics of heating over-dense plasmas, as well as exploring source interactions with a downstream target. High density plasmas have been produced in He (\(>3\times10^{13}/m^3\)) and D (\(>1.5\times10^{13}/m^3\)), and operation in magnetic field strengths up to 1T has been demonstrated. Details of the experimental results will be presented, as well as future plans for studying plasma surface interactions and rf antenna plasma interactions.

BP8.00065 Determining the Spatial Coherence of Modes in a Linear Plasma Using Filterscopes, H. RAY, T.M. BIEWER, D. FEHLING, E.A. UNTERBERG, Oak Ridge National Lab, G.N. LUO, Chinese Academy of Sciences — The Prototype Materials Plasma Experiment (Proto-MPEX) is a linear plasma device dedicated to the understanding of plasma material interaction (PMI) physics. A photo multiplier tube (PMT) based diagnostic system called a filterscope examines the visible light emission from Proto-MPEX in the radial (r) and axial (z) directions. Each of the filterscope’s twelve PMTs has a calibrated D filter for plasma edge and target region analysis. Fiber optics located at various r- and z-positions along Proto-MPEX will transmit the brightness of the plasma as a function of time to the filterscope. Analysis of the data will include performing a Fast Fourier Transform (FFT) to determine the dominant modes in the spectral emission and characterizes these modes in relation to the facilities operating parameters. Pairs of measurements are also analyzed to determine the spatial coherence of the signals, which include phase shifts and relative differences, in order to determine mode localization.

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

BP8.00066 Digital Holography for Plasma Facing Component (PFC) Erosion Measurement, C.E. (TOMMY) THOMAS JR., Third Dimension Technologies LLC, T.M. BIEWER, L.R. BAYLOR, S.K. COMBS, S.J. MEITNER, D.L. HILLIS, ORNL, E.M. GRANSTEDT, Tri-Alpha Energy, R. MAJESKI, R. KAITA, PPPPL — One of the more serious engineering problems facing magnetic fusion energy reactors is the plasma/first-wall or plasma/divertor interface. Hot particles striking these PFC’s could easily force replacement in less than a year. In-situ quantitative real-time erosion diagnostics to help understand the erosion process are not currently available. Single wavelength Digital Holography (DH) has been developed to a considerable level of sophistication and dual-wavelength (synthetic wavelength) DH has the potential to be a reliable vibration-resistant erosion diagnostic. Ambiguity free measurements at kHz rates of up to 1 cm of erosion with ~1 micron resolution into the PFC and diffraction limited resolution transverse to the PFC are possible. Development of DH as an in-situ real-time PFC erosion diagnostic will be discussed and example data from single-wavelength DH will be presented.

Partial Support from USDOE Contract DE-AC02-08CH11466 and USDOE Grant DE-FG02-07ER84724 is gratefully acknowledged.

BP8.00067 Monte Carlo TRIM simulations, with evolving target and surface morphology, in support of plasma simulations and devices, KYLE LINQUIST, CPMI, Department of Nuclear, Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign, Urbana 61801, DAVIDE CURRELLI, Department of Nuclear, Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign, Urbana 61801, KISHOR KALATHIPARAMBIL, DAVID RUZIC, CPMI, Department of Nuclear, Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign, Urbana 61801 — Simulations using fractal and dynamic versions of the BCA code TRIM (Fractal TRIDYN) are reported. The sputtering yields from the simulations are being used to support experiments and simulations of plasma devices. The use of linear plasma scenarios can provide an intermediate point of understanding before attempting full tokamak systems. Specifically, we are targeting experiments, like those at PISCES-B, of light, low energy ions (H/D/T/He) incident on beryllium targets. The sputtering yield of Be by D and He has been shown at PISCES-B to be about 6 and 13 times smaller, respectively, than traditional TRIM results would predict. We show what combinations of surface roughness, target composition, and incident ion composition can produce the observed sputtering yields. The current model for sputtering in the SOLPS code uses the Bohdansky formula. The surface roughness feature of Fractal TRIDYN can be used to improve upon this. Shown are database results and the rough surface fitting parameters that are being used to implement an improved curve fit for the Bohdansky model.
BP8.00068 Effects of hydrogen surface processes on hydrogen retention in plasma facing components


This work is performed under the auspices of USDOE Grant No. DE-FG02-04ER54739 and the PSI Science Center Grant DE-SC0001999 at UCSD.

BP8.00069 Development of an analytical hydrogen isotope exchange model in fusion relevant plasma facing components

RUSSELL DOERNER, GEORGE TYNAN, University of California San Diego — A simple model for H isotope retention depth profiles in W is developed, which can easily be extended to other plasma facing components (PFCs). This retention model is subsequently used to model how the depth profile changes after H isotope exchange. We calculate how trapping defects in W trap D (or H) inventory as W is being exposed to plasma. The model characterizes each trapping site by a trapping rate and a release rate, where the only free parameters are the distribution of these trapping sites in the material. The filled trap concentrations for each trap type are modeled as a diffusion process because post-mortem D depth profiles indicate that traps are filled well beyond the ion implantation zone (3-4 nm with 100 eV ions). Using this retention model, an isotope exchange rate is formulated. The retention model and isotope exchange rate are compared to low temperature (100 °C) isotope exchange experiments in W with good agreement. Experimental retention profiles were measured using the D(TdHe)α nuclear reaction after plasma treatment. We additionally discuss how a uniform damage profile up to 1 micron in W induced by Cu ions using incident energies of 0.5, 2, and 5 MeV affect retention in W and the retention model.

BP8.00070 Temperature effects in accumulation of deuterium and helium at the grain boundaries of a nano-grained tungsten

IGOR KAGANOVIĆ, Princeton Plasma Physics Laboratory, PREDRAG KRSTIC, Stony Brook University, EDWARD STARTSEV, Princeton Plasma Physics Laboratory — It has been known that defects in tungsten, in particular at the grain boundaries, are preferable sites for deuterium and helium retention. For the case of the nano-grained boundaries, we study by classical molecular dynamics the cumulative retention of deuterium and helium at impact energies below 100 eV as functions of tungsten temperature at models of the dislocation boundaries. We obtain a strong preference of the retention of the impact particles at the boundaries at high temperature of 1000K.

Support of PPPL LDRD grant acknowledged.

BP8.00071 Retention property of deuterium for fuel recovery in divertor by using hydrogen storage material

SAORI MERA, AKIRA TONEGAWA, YOSHIMITO MASUMURA, Tokai Univ, KOKOSUKE SATO, Chubu Electric Power Co. Inc., KAZUTAKA KAWAMURA, Tokai Univ — Magnetic confinement fusion reactor by using Deuterium and Tritium of hydrogen isotope as fuels is suggested as one of the future energy source. Most fuels don’t react and are exhausted out of fusion reactor. Especially, Tritium is radioisotope and rarely exists in nature, so fuels recovery is necessary. This poster presentation will explain about research new fuel recovery method by using hydrogen storage materials in divertor simulator TPD-Sheet IV. Samples are tungsten coated with titanium; tungsten of various thickness and titanium films deposited by ion plating on tungsten substrates. The sample surface temperature is measured by radiation thermometer. Retention property of deuterium after deuterium plasma irradiation was examined with thermal desorption spectroscopy (TDS). As a result, the TDS measurement shows that deuterium is retained in titanium. Therefore, Titanium as a hydrogen storage material expects to be possible to use separating and recovering fuel particles in divertor.

BP8.00072 Molecular dynamics simulations of growth and coalescence of helium nano-bubbles in tungsten

ROMAN SMIRNOV, SERGEI KRASHENINNIKOV, JEROME GUTERL, UCSD — It was experimentally observed that filamentary nano-structures, called fuzz, can grow on tungsten surfaces irradiated with plasma containing helium. Although the mechanism of the fuzz growth is not clearly understood, experiments show that formation of helium nano-bubbles in tungsten always precedes fuzz creation. In this work we investigate mechanisms of growth and coalescence of helium bubbles using molecular dynamics code LAMMPS. We demonstrate that the growth process is governed by crystal symmetries and properties of generated dislocations forming helium nano-bubbles of non-spherical geometry. This produces complex stress field in the tungsten lattice around the bubble with distinct compression and tension regions. We show that helium transport in the stressed lattice in bubble vicinity can be dominated by drift from the compression to tension regions. Helium transport coefficients in tungsten are also obtained. Modeling of two closely positioned helium nano-bubbles demonstrates that their coalescence proceeds preferentially by lateral growth. The implications of the obtained results on fuzz formation mechanism are discussed.

BP8.00073 Effect of Li coatings on coarse-grained W exposed to high flux He plasmas at high temperatures

ANTON NEFF, JEAN PAUL ALLAIN, University of Illinois, THOMAS MORGAN, FOM-DIFFER (Dutch Institute for Fundamental Energy Research) — Tungsten is appealing as a plasma facing component (PFC) because of its high sputter threshold, high melting temperature, and good thermal conductivity. However, when exposed to He ions at low energy and high flux, like those in a tokamak divertor, the surface microstructure changes detrimentally, creating bubbles, holes, and fuzz. Recent studies show that adding impurities (C and Be) to the He plasma can inhibit the growth of fuzz. Additionally, lithium as a PFC coating in multiple tokamaks has improved plasma performance. We investigated the effect that a thin ~500 nm Li coating had on the formation of these surface defects in W. Samples were exposed in the linear plasma device Magnum PSI, at fluxes of ~1024 m^-2s^-1 and T_surf >700°C. After irradiation, the surface of the samples were characterized with scanning electron microscopy (SEM). These results will be presented along with XPS and SIMS results investigating the survivability of the Li coating under these conditions.

This work is supported by US DOE Contracts: DE-SC0010717 and DE-SC0010719.
BP8.00074 Disruption Studies and Simulations in Ignitor*, G. RAMOGIDA, ENEA, F. VILLONE, Univ. Cassino - CREATE, G. RUBINACCI, Univ. Napoli - CREATE, B. COPPI, MIT — The prediction of plasma disruption features and evaluation of the associated EM loads played an important role in the development of Ignitor [1]. The kind and number of expected plasma disruptions drove the development of the plasma scenarios and the design of in-vessel components, as these events produced by far the largest EM loads the components must withstand. A strong integration of physics and engineering expertise was required to estimate the range of expected variation, based on the experimental data from existing machines, of the main parameters of the disruptions: thermal and current quench times, evolution of the plasma current, li, safety factor limits, halo current fraction and width, and radiated heat fraction. The MAXFEA axisymmetric 2D MHD code was used to evaluate the effects on the induced currents and EM loads caused by variation of the disruption parameters. Further, the detailed evolution of the plasma was simulated using the CarMa0NL code, which is able to self-consistently couple a nonlinear axisymmetric plasma evolution with volumetric 3D conductors. This allows the evaluation of the effects of the non-axisymmetric components of the machine such as the plasma chamber ports. *US DOE partly sponsored.


BP8.00075 DIAGNOSTIC MEASUREMENTS & ANALYSIS —

BP8.00076 Two Photon Absorption Laser Induced Fluorescence of Helium Ions in a Microwave Assisted Helicon Source†, EARL SCIAME, West Virginia University — The spectroscopic measurement of helium ion velocity distribution functions in a low temperature plasma is problematic for a number of reasons. First and foremost is the difficulty in accessing the UV and soft x-ray transitions to the ground state. Conventional laser induced fluorescence on ions in plasmas is routinely performed in argon, neon, xenon, and barium. Two-photon absorption laser induced fluorescence (TALIF) on neutrals has been demonstrated in hydrogen, nitrogen, and oxygen plasmas. We have successfully performed LIF on helium atoms and have had some hints of success with laser absorption spectroscopy on excited states of helium ions, the n = 2 to n = 6 transition in the infrared (1012 nm). Here we report a new approach using TALIF to access the n = 2 to n = 6 transition of singly ionized helium. The fluorescence path at 656 nm completes the three-level sequence. To obtain the electron temperatures necessary to create a sufficient population of metastable helium ions trapped in the 25 state, we have increased the electron temperature of a helicon plasma with 1.2 kW of microwaves at 2.45 GHz. Here we report emission spectroscopy measurements that confirm the increase in excited state population densities and preliminary TALIF measurements on helium ions.

†This work is funded by the US Department of Energy through grant DE-SC0004736.

BP8.00077 Improving Resolution of Confocal Laser Induced Fluorescence in Argon Helicon Plasma, MARK SODERHOLM, ROBERT VANDERVORT, EARL SCIAME, JOHN MCKEE, DUSTIN MCCARREN, West Virginia Univ — Laser Induced Fluorescence (LIF) provides measurements of flow speed, temperature and when absolutely calibrated, density of ions or neutrals in a plasma. Traditionally, laser induced fluorescence requires two ports on a plasma device. One port is used for laser injection and the other is used for fluorescence emission collection. Traditional LIF is tedious and time consuming to align. These difficulties motivate the development of an optical configuration that requires a single port and remains fully aligned at all times; confocal LIF. Our confocal optical design employs a single two inch diameter lens to both inject the laser light and collect the stimulated emission from an argon plasma. A dichroic mirror is used to separate the injected laser light from the collected emission. The measurement location is scanned radially by manually adjusting the final focusing lens position. In the initial version of the confocal optical system, measurements were poorly resolved radially because they were integrated over a fairly large path length (~ 4 cm) centered at the focal point. Here we present collected data from a modified configuration that significantly improves the special resolution of confocal measurements. The confocal measurements are compared to traditional, two-port, LIF measurements over the same radial range.

BP8.00078 Continuous Wave Cavity Ring-Down Spectroscopy and Laser Induced Fluorescence Measurements of Argon Ion Velocity Distribution Functions in a Helicon Plasma, DUSTIN MCCARREN, ROBERT VANDERVORT, MARK SODERHOLM, EARL SCIAME, West Virginia University — LIF is an established and powerful technique, but suffers from the requirement that the initial state of the LIF sequence have a substantial density. This usually limits LIF to ions and atoms with large metastable state densities for the given plasma conditions. Cavity ring down spectroscopy (CRDS) is a proven, ultra-sensitive, cavity enhanced absorption spectroscopy technique and when combined with a continuous wavelength (CW) diode laser that has a sufficiently narrow line width, the Doppler broadened absorption line, i.e., the target specie velocity distribution function (VDFs), is measured. CW-CRDS is designed for measurements of ion and atom states inaccessible to conventional techniques such as LIF. However, being a line integrated technique, CW-CRDS lacks the spatial resolution of LIF. We present a comparison of CW-CRDS and spatially resolved LIF measurements of the VDFs in an argon plasma using the 668.614 nm (in vacuum) line of Ar II.

BP8.00079 Direct Measurements of the Spatial and Velocity Dependence of the Ion Density Fluctuation Spectrum of a Laboratory Plasma with Two Independent LIF Schemes, SEAN MATTINGLY, JORGE BERUMEN, FENG CHU, RYAN HOOD, FRED SKIFF, University of Iowa Department of Physics and Astronomy — By using two independently tunable lasers, each with its own collection optics and Ar II LIF transition scheme, we are able to investigate plasma ion density fluctuations as a function of not only spatial scales but also as a function of ion velocities as sampled on different points of a single Doppler - broadened spectral emission line. We do this by measuring the two point correlation C(x,v,x′,v′,t) = ⟨f(x,v,t) f(x′,v′,t−τ)⟩. With the current system, the two carries determine x and x′, while the velocities selected by each laser determine v and v′. Using the two lasers to make two point correlations in phase space demonstrates effects that are not fully understood. In this experiment, we explore the striking difference in correlations when, in the past, the particle orbits overlap in space versus when they do not overlap. This is performed on a small cylindrical laboratory plasma with n ~ 10^9 cm^{-3}, T_e ~ 5eV, T_i ~ 0.06 eV, and a 1kG axial magnetic field. LIF is performed on ions at two locations aligned with the magnetic field line with a viewing volume comparable to the size of the Larmor radius. Results and interpretations from these experiments are presented and discussed.

DOE Grant DE-FG02-99ER54543

BP8.00080 Electron and ion currents to a planar probe oriented at an arbitrary angle to the magnetic field in a cesium Q machine plasma, MICHAEL J. MCKINLAY, SEAN M. HARDING, ROBERT L. MERLINO, University of Iowa — Current collection to a planar Langmuir probe in a magnetized Q machine plasma was investigated. The Q machine was operated in the single-ended mode with cesium ions having densities in the range of 10^{13} to 10^{17} m^{-3}, electron and ion temperatures, T_e,T_i~0.2 eV, and magnetic fields from 0.06 T to 0.8 T. The probe was a disk of 9.5 mm diameter, and the side facing away from the plasma source was insulated. The effect of varying the angle between the magnetic field and the probe’s surface normal vector on the ion and electron saturation currents and the floating potential was the focus of this study. The effect of varying the probe normal-magnetic field angle on the excitation and quenching of current-driven electrostatic ion cyclotron waves was also observed.

Supported by DOE and NSF
Design and Operation of a Two-Color Interferometer to Measure Plasma and Neutral Gas Densities in a Laser-Triggered Spark Gap Switch.

BP8.00081 J.F. CAMACHO, Numerex, LLC, E.L. RUDEN, M.T. DOMONKOS, A. SCHMITT-SODY, Directed Energy Directorate, Air Force Research Lab, A. LUCERO, Boeing — A Mach-Zehnder imaging interferometer, operating with 1064-nm and 532-nm wavelength beams from a short-pulse laser and a frequency-doubled branch, respectively, has been designed and built to simultaneously measure plasma free electron and neutral gas densities within a laser-triggered spark gap switch with a 5-mm gap. The switch will be triggered by focusing a separate 532-nm or 1064-nm laser pulse along the gap's axis to trigger low-jitter breakdown. Illuminating the gap transversely to this axis, the diagnostic will generate interferograms for each wavelength which will then be numerically converted to phase-shift maps. These will be used to calculate independent line-integrated free electron and neutral density profiles by exploiting their different frequency dispersion curves. The density profiles themselves, then, will be calculated by Abel inversion. Details of the interferometer's design will be presented along with density data obtained using a variety of fill gases at various pressures. Other switch parameters will be varied as well in order to characterize more fully the performance of the switch.

Development of a dual v and B diagnostic for fast reconnection.

BP8.00082 DOUGLASS ENDRIZZI, JAN EGEDAL, JOSEPH OLSON, CARY FOREST, JOHN WALLACE, UW Madison — The Terrestrial reconnection experiment (TREX) under construction at the Wisconsin Plasma Astrophysics Facility will study magnetic reconnection in a low-β, collisionless plasma. A probe to simultaneously measure the velocity and magnetic fields during a fast reconnection event is being constructed. An array of 3D B probes and 2D Mach probes will measure at a ~2 cm spatial resolution and MHz frequencies. Using a digitally controlled drive, the probe will be able to sweep the full radial length (1.5 m) of the experiment and through an angle of ~1 radian, providing significant coverage of the anticipated event region. Measurements and results from the probe will be presented.

Comparison of imaging and probe measurements in a linear plasma column.

BP8.00083 A.D. LIGHT, Earlham College, S.C. THAKUR, C. BRANDT, University of California, San Diego, Y. SECHREST, University of Colorado Boulder, G.R. TYNAN, T. MUNSAT, University of California, San Diego — The advent of fast imaging diagnostics, which provide two-dimensional measurements on relevant plasma time scales, has proven invaluable for interpreting plasma dynamics in laboratory devices. Despite its success, imaging remains a qualitative aid for many studies, because intensity often cannot be mapped onto a single physical variable for use in a theoretical model. This study explores the relationship between visible-light and electrostatic probe measurements in the Controlled Shear Decoration Experiment (CSDX). CSDX is a well-characterized linear machine producing dense plasmas relevant to the tokamak edge (Te ~ 3 eV, ne ~ 10¹³/cc). Visible light from ArI and ArII line emission is collected at high frame rates using a fast digital camera. Floating potential and ion-saturation current are measured by an array of electrostatic probe tips. We construct a detailed comparison between imaging and probe measurements of fluctuations, including temporal, spatial, and spectral properties. In addition, we combine probe and imaging techniques to identify modes in a multi-instability regime.

EUV and visible light imaging of magnetic reconnection associated with Rayleigh-Taylor instability in MHD driven jets.

BP8.00084 KIL-BYOUNG CHAI, PAUL BELLAN, California Institute of Technology — A high-speed EUV movie camera has been developed for imaging magnetic reconnection in the Caltech MHD-driven jet experiment. In order to achieve high temporal resolution, a high-speed visible camera (up to 2x10⁶ fps) is utilized with a fast-decaying YAG:Ce scintillator crystal that converts EUV radiation into visible light. A custom-designed, broadband Si/Mo multilayer mirror having central wavelength at 36 nm is used to form an image on the scintillator crystal. The jet 3D structure is imaged in visible light by a two-branch fiber bundle which simultaneously captures end and side view images. The fiber bundle is coupled to the high-speed visible light movie camera. Comparison of EUV and visible light movies shows that the EUV images are similar to visible light images at early times. However, the EUV images differ from the visible light images when a Rayleigh-Taylor instability occurs. A small segment near the apex of the kinked jet becomes extremely bright in EUV but dark in visible light. Future plans include further investigation of this bright spot, plasma evolution and upgrade of optical sensitivity by better optical coupling to the scintillator crystal.

Upgrade Plans for the C-Mod FIR Polarimeter.

BP8.00085 R. WATTERSON, MITemps, D. GARNIER, Columbia University, J. IRBY, MIT-PSFC, D.L. BROWER, UCLA, P. XI, Wells Fargo, W.F. BERGERSON, MIT-Lincoln Labs, W.X. DING, UCLA, W. GUTTENFELDER, PPPL, E.S. MARMAR, MIT-PSFC — The 3-chord FIR polarimeter presently deployed on C-Mod is capable of responding to both fast changes in the plasma equilibrium and high frequency fluctuations. It operates under ITER-like plasma conditions and magnetic fields, and uses an optical layout similar to that proposed for ITER. The details of this system and some results from the C-Mod 2012 campaign will be presented, along with the design of the upgrade that is now being implemented. The new system will provide horizontal chords near the mid-plane and low loss etalon windows to improve both the signal level and our ability to study magnetic fluctuations. The laser table has been relocated from the C-Mod cell to a shielded and climate controlled location, and improvements have been made to its acoustic isolation. New collimation optics, and a beam-line needed to convey the FIR beams into the tokamak port have been designed. Improvements to the detector electronics will also be discussed, as will initial testing of the laser system and reference detectors during C-Mod operation.

Faraday-Effect Polarimeter-Interferometer System for current density measurement on EAST.

BP8.00086 HAIQING LIU, YINXIAN JIE, Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), WEIXING DING, DAVID LYN BROWER, Department of Physics and Astronomy, University of California Los Angeles, ZHIYONG ZOU, WEIMING LI, JINPING QIAN, YAO YANG, LONG ZENG, Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), TING LAN, GONGSHUN LI, University of Science and Technology of China, LIQUN HU, BAONIAN WAN, Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP) — A multichannel far-infrared laser-based POLarimeter-INTERferometer (POINT) system utilizing the three-wave technique is under development for current density and electron density profile measurements in the EAST tokamak. Novel molybdenum retro-reflectors are mounted in the inside wall for the double-pass optical arrangement. A Digital Phase Detector with 250 kHz bandwidth, which will provide real-time Faraday rotation angle and density phase shift output, have been developed for use on the POINT system. System time response (~ 1 microsecond) and phase resolution (<0.1°) allows resolution of fast equilibrium changes associated with MHD events. Initial calibration indicates the electron line-integrated density resolution is less than 5 × 10¹⁵m⁻² (~2°), and the Faraday rotation angle rms phase noise is <0.1°. Initial results of POINT system will be presented.
BP8.00087 Plasma spectroscopy using optical vortex laser1. SHINJI YOSHIMURA, National Institute for Fusion Science, MITSUTOSHI ARAMAKI, Nihon University, KENICHIRO TERASAKA, Kyushu University, YASUNORI TODA, Hokkaido University, UWE CZARNET-ZKI, Ruhr University Bochum, YUTAKA SHIKANO, Institute for Molecular Science — Laser spectroscopy is a useful tool for noninvasive plasma diagnostics; it can provide many important quantities in a plasma such as temperature, density, and flow velocity of ions and neutrals from the spectrum obtained by scanning the frequency of narrow bandwidth laser. Obtainable information is, however, limited in principle to the direction parallel to the laser path. The aim of this study is to introduce a Laguerre-Gaussian beam, which is called as optical vortex, in place of a widely used Hermite-Gaussian beam. One of the remarkable properties of the Laguerre-Gaussian beam is that it carries an angular momentum in contrast to the Hermite-Gaussian beam. It follows that particles in the laser beam feel the Doppler effect even in the transverse direction of the laser path. Therefore it is expected that the limitation imposed by the laser path can be overcome by using an optical vortex laser. The concept of optical vortex spectroscopy, the development of the laser system, and some preliminary results of a proof-of-principle experiment will be presented.  

1This work is performed with the support and under the auspices of NINS young scientists collaboration program for cross-disciplinary study, NIFS collaboration research program (NIFS13KOAP026), and JSPS KAKENHI grant number 25287152.

BP8.00088 Measurements of the ion temperature and ion energy distribution in a linear pulsed plasma-material interaction test stand1. MICHAEL CHRISTENSEN, SOONWOOK JUNG, CASEY BRYNIARSKI, KISHOR KALATHIPARAMBIL, DANIEL ANDRUCZYK, DAVID RZIC, Univ of Illinois - Urbana — Critical components in understanding interactions between the highly transient plasma and target materials in the ThermoElectric-driven Liquid-metal plasma-facing Structures (TELS) device are the ion temperature and subsequent energy distribution, since the ions are nearly as energetic as the electrons under such extreme conditions. An electrostatic energy analyzer has been proposed and modified to extract this information under different pulse conditions in an effort to gain insight about plasma transport to the target region. The electrostatic analyzer was chosen as the most practical method for evaluating ion information in TELS, since it is suitable for measuring temperatures on the order of 10 to 100 eV. Accounting for high displacement current, recent results indicate ion temperatures on the order of 19.95 ± 1.39 eV when applying a guiding magnetic field to improve transport, which are in good agreement with theoretical and experimental predictions subject to specific pulse conditions. The development and modification of the electrostatic analyzer are discussed in conjunction with recent modifications to the TELS device, including the addition of compact toroid magnetic fields used to generate a reversed field configuration.

1This project was supported under the US DOE project DOE-DE SC0008587.

BP8.00089 Investigation of X-Ray Thomson Scattering Using A Statistical Approach1. LAURA JOHNSON, Cornell University — We present a statistical method of computing x-ray Thomson scattering signals. This model uses average atom wave functions for both bound and continuum electrons, which are computed in a spherically symmetric, self-consistent potential. The wave functions are used to obtain electron distributions for a statistical approach to computing the scattering signals. We compare the differences between using distorted-wave continuum electrons and free-electrons in both the statistical approach and the impulse approximation. The results are compared to various experiments including experimental data taken at Cornell’s Laboratory of Plasma Studies.

1Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

BP8.00090 Simulation of Laser Induced Fluorescence (LIF) Signals in a Plasma1, F. CHU, F. SKIFF, Univ of Iowa — Velocity-space diffusion and electric mean fields play important roles in the transport phenomena in the turbulent plasma. One way to explore how they determine transport is through the optical test-particle diagnostics, which is based on using ionic electronic states as a means of tagging particles. It requires a means of changing and measuring the state densities by optical pumping and LIF. In order to interpret the LIF signals, which provide the information on particle orbits, we introduce a transfer function that specifies the probability of finding a particle at position x and velocity v at time t, given that the particle was at position x' and velocity v' at time t'. We model the signal at first without the presence of waves in the plasma, studying only the roles that optical pumping and velocity-space diffusion play in the resulting LIF signals. Then we consider how mean-field waves affect the distributions of metastable states. Finally we combine the two factors to construct the complete theory. We note that even “ordinary” LIF using a single laser and detection system can benefit from the test-particle approach under conditions where there is significant optical pumping or where the metastable lifetime is not long compared to a wave period.

1US DOE DE-FG02-99ER54543

BP8.00091 NON-NEUTRAL, ANTI-MATTER & STRONGLY COUPLED PLASMAS —

BP8.00092 Nonlinear Interactions of Trivelpiece-Gould Waves1. ARASH ASHOURVAN, DANIEL H.E. DUBIN, UCSD — We study nonlinear Trivelpiece-Gould waves in a cold, finite length plasma model. Analytical expressions for the forms and frequencies of both traveling and standing cnoidal waves are obtained, and parametric resonances between waves are studied and compared to numerical solutions of the 1D fluid equations. For waves with $k_{\perp} < k_\perp$, where $k_{\perp}$ and $k_\perp$ are the axial and perpendicular wave numbers respectively, 3-wave resonance conditions can be satisfied. Using perturbation theory we obtain a reduced system of evolution equations for slowly varying mode amplitudes in a 3 wave interaction. We use them to study the parametric resonance between a dominant $m = 2$ mode and a small amplitude $m = 1$ mode, including the effect of higher harmonics. We obtain an instability threshold amplitude $A_{1h}^3$ for mode $m = 2$. For $A_2 > A_{2h}^3$ mode $m = 1$ becomes unstable and grows exponentially, whereas for $A_2 < A_{2h}^3$, mode $m = 1$ exhibits beat wave oscillations. We find that if enough harmonics are kept in the theory, $A_{2h}^3$ converges to a value independent of the number of harmonics. On the other hand, for a short plasma with $k_\perp > k_{\perp}$, 3-wave resonances cannot occur but conditions allow 4-wave resonances, especially in the short wave-length scales ($k_{\perp} > k_{\perp}$). In our simulations we observe mode instabilities that have signatures of this 4-wave interaction.

1Supported by NSF/DOE Partnership grants PHY-0003877 and DE-SC0002451.
BP8.00093 Non-resonant Particle Heating due to Collisional Separatrix Crossings

M. AFFOLTER, D.H.E. DUBIN, C.F. DRISCOLL, UCSD — We observe weak plasma heating when a pure ion column is “sloshed” back and forth across a partial trapping region, and coherent laser diagnostics characterize the resulting particle distributions. Here, an externally applied theta-symmetric “squeeze” potential creates a velocity separatrix between trapped and passing particles, and weak collisions at rate $\nu_\perp$ cause separatrix crossings. The trapped particles are repeatedly compressed and expanded (by $\delta L$) whereas the passing particles counter-stream and Debye shield the resultant potential variations. The LIF diagnostics then clearly determine the separatrix energy $E_{\text{sep}}(r)$, since the trapped and passing particle distributions are in-phase and out-of-phase with the plasma rotation. The measured $E_{\text{sep}}(r)$ is in agreement with that calculated from a $(r, \omega)$ Boltzmann-Poisson equilibrium solution. Theory predicts heating from separatrix crossings scaling as $\nu_\perp^{3/2}E_{\text{sep}}(\delta L/L)^2$, distinct from bulk viscosity heating scaling as $\nu_\perp^4$. Experimental scalings with density and temperature will allow direct comparison to theory.

1Supported by NSF/DOE Partnership grants PHY-0903877 and DE-SC0002451.

BP8.00094 Non-linear Coupling and Decay Instability of Plasma Waves

M. AFFOLTER, F. ANDEREGG, C.F. DRISCOLL, UCSD, F. VALENTINI, Univ. of Calabria — We measure the non-linear coupling of plasma waves for both the “standard” Langmuir waves with $v_{\text{phase}} \gg v_{\text{bar}}$, and for the unusual “EAW” (KEEN) waves with $v_{\text{phase}} \sim v_{\text{bar}}$. These are $\theta$-symmetric standing modes on pure ion and (separately) pure electron plasma columns, with discrete Landau numbers $k_\perp = n_z(\pi/L_p)$. The non-linear coupling rates are measured between large amplitude $m_z = 2$ waves and small amplitude $m_z = 1$ waves, which have a small detuning $\Delta \omega = 2\omega_1 - \omega_2$. For Langmuir waves at small excitation amplitudes, this detuning causes the $m_z = 1$ mode amplitude to “bounce” at rate $\Delta \omega$, with amplitude excursions $\Delta \omega \propto n_{12}/n_1$ consistent with cold fluid theory and Vlasov simulations. At larger excitation amplitudes, theory and simulations predict phase-locked exponential growth of the $m_z = 1$ mode. Experimentally we find the effects of detuning to be more pervasive than simple theory would suggest. Typically at these large amplitudes we observe strong amplitude bouncing, with a yet unexplained slower average growth. In contrast, EAW waves exhibit phase-locked exponential growth or no growth at all, apparently due to “frequency fungibility” of the EAW waves. Measurements on higher temperature Langmuir waves with $v_{\text{phase}} \sim 4v_{\text{bar}}$ are being conducted to investigate the effects of wave-particle kinetics on the non-linear coupling rates.

1Supported by DOE/HEDL grant DE-SC0008693.

BP8.00095 Nonlinear Spatial Landau Damping of Plasma Waves Beating at Plasma Angular Velocity

A.A. KABANTSEV, C.F. DRISCOLL, UCSD — Experiments on pure electron plasma characterize the nonlinear beat between two counter-propagating plasma waves, and the spatial Landau damping of the beat wave at the wave/rotation critical radius. The two plasma waves are ($m_\perp = 1, k_\perp = 1, \omega = \omega_1 \pm \omega_2$), giving the beat wave with ($m_\perp = 2, \omega_1 \pm \omega_2$). The beat wave is resonant with the plasma rotation $\Omega(r)$ at radius $r_\star$, where $\Omega(r_\star) = \omega_z$. The net effect of this resonance is an energy exchange through wave-particle interaction between the two primary plasma waves and the background plasma rotation. Initial excitation of only one of the waves leads first to its fast sharing of energy with the other wave, and then followed by a slower combined decay of both waves. In contrast, initial excitation of both waves to (approximately) the same amplitude leads to three alternative scenarios: 1) both plasma waves may show the slow and synchronous decay evolution; 2) one of the waves may decay faster, with temporarily arrested decay of the other; 3) it may switch back and forth (seemingly randomly) between the first two types of evolution. Interestingly, wave/particle energy flow can be reversed when the plasma density profile is made to have a positive density gradient at $r_\star$. In this case, spontaneous excitation (instability) of both $\omega = \omega_1 \pm \omega_2$ plasma waves is observed.

1Supported by NSF/DoE Partnership grants PHY-0903877 and DE-SC000245, and DOE/HEDL grant DE-SC0008693.

BP8.00096 A Novel Damping Mechanism for Diocotron Modes

C.H. YUNG CHIM, THOMAS M. O’NEIL, UCSD — Recent experiments with pure electron plasma in a Malmberg-Penning trap have observed the algebraic damping of $m = 1$ and $m = 2$ diocotron modes. Transport due to small field asymmetries produces a low density halo of electrons moving radially outward from the plasma core, and the mode damping begins when the halo reaches the resonant radius, where $f = m f_{\text{ex}}(r)$. The damping rate is proportional to the flux of halo particles through the resonant layer. The damping is related to, but distinct from spatial Landau damping, in which a large wave-particle resonance produces exponential damping. This poster explains with analytic theory and simulations the new algebraic damping due to both mobility and diffusive fluxes. The damping is due to transfer of canonical angular momentum from the mode to halo particles, as they are swept around the “cat’s eye” orbits of resonant wave-particle interaction. Another picture is that the electrons in the resonant layer form a dipole ($m = 1$) or quadrupole ($m = 2$) density distribution, and the electric field for this distribution produces $E \times B$ drifts that symmetrizes the core and damps the mode.

1Supported by NSF/DoE Partnership grants PHY-0903877 and DE-SC0002451.


BP8.00097 Enhanced Collisional Rates in Correlated Plasmas

C.F. DRISCOLL, F. ANDEREGG, D.H.E. DUBIN, T.M. O’NEIL, UCSD — Experiments on cryogenic pure ion plasmas corroborate the Salpeter collisional enhancement factor $\Gamma = e^{\Delta E/AT}$ large. This factor enhances the perp-to-parallel collision rate in the magnetized plasmas described earlier and also enhances the nuclear reaction rates in dense stellar interiors. The enhancement is caused by plasma screening of the repulsive Coulomb potential, enabling closer collisions for a given particle energy. The Salpeter theory assumes thermal equilibrium screening, whereas various dynamical theories suggest other factors. Prior experiments corroborate the predicted $g \sim \exp(\Gamma)$ enhancement as enhancements as large as $g \sim 10^4$. Current theory is considering the effects of parallel collisions in multi-species ion plasmas, and cyclotron modes and energy exchange. Current experiments with improved laser cooling and plasma stability will provide more accurate tests of equilibrium theory in the sensitive regime of $\Gamma \lesssim 1$, and may also approach the (classical) pyrocnuclear regime.

1Supported by DOE/HEDL grant DE-SC0008693.


4F. Anderegg et al., PRL 102, 185001 (2009)
BP8.00098 Parallel Slowing from Long-Range Collisions in a Magnetized Plasma

Daniel H.E. Dubin, U. C. San Diego — This poster presents a new theory of the collisional drag rate \( \nu \) parallel to the magnetic field in a plasma for which \( r_c < \lambda_D \), where \( r_c \) is the thermal cyclotron radius and \( \lambda_D \) is the Debye length. In such a plasma, long-range collisions with impact parameters \( \rho > r_c \) make a dominant contribution to the drag. Such collisions are described by guiding centers moving in one dimension (1D) along the magnetic field. These 1D long-range collisions are not included in the classical collision rates. We show that such collisions separate into two classes: Boltzmann collisions where colliding particles can be treated as an isolated pair, and Fokker-Planck (FP) collisions where many weak interactions are occurring simultaneously. These collision classes are separated by a new fundamental length scale \( \lambda \) where \( \lambda \approx (\nu_c/\nu)(r_c/r_c)^{-2} \), and Boltzmann collisions dominate for \( \rho > \lambda \) or \( \rho < \lambda \) respectively. Furthermore, the drag due to Boltzmann collisions is enhanced by “collisional caging”: colliding charges are influenced by surrounding charges to diffuse in relative velocity, reversing their 1D motion and colliding several times while remaining correlated.

1Supported by NSF/DOE Partnership grants PHY-0903877 and DE-SC0002451.
2D. Dubin, Phys. Plasmas 21, 052108 (2014)

BP8.00099 Numerical solution for linear cyclotron and diocotron modes in a nonneutral plasma column

Daniel Walsh, Daniel H.E. Dubin, UCSD — This poster presents numerical methods for solution of the linearized Vlasov-Poisson (LVP) equation applied to a cylindrical single-species plasma in a uniform magnetic field. The code is used to study z-independent cyclotron and diocotron modes of these plasmas, including kinetic effects. We transform to polar coordinates in both position and velocity space and Fourier expand in both polar angles (i.e. the cyclotron gyro angle and \( \theta \)). In one approach, we then discretize in the remaining variables \( r \) and \( v \) (where \( v \) is the magnitude of the perpendicular velocity). However, using centered differences the method is unstable to unphysical eigenmodes with rapid variation on the scale of the grid. We remedy this problem by averaging particular terms in the discretized LVP operator over neighboring gridpoints. We also present a stable Galerkin method that expands the \( r \) and \( v \) dependence in basis functions. We compare the numerical results from both methods to exact analytic results for various modes.

1Supported by NSF/DOE Partnership grants PHY-0903877 and DE-SC0002451.

BP8.00100 Experimental Investigation of Rotational, Pumping, Magnetic Pumping and Toroidal Asymmetry Modes in a Toroidal Electron Plasma

A.R. Doares, K. Wang, A.S. Patterson, M.R. Stoneking, Dept. of Physics, Lawrence University, Appleton, WI 54911 — Electron plasma is confined with a purely toroidal magnetic field in the Lawrence Non-Neutral Torus II \((R_0 = 18 \text{ cm}, a \sim 2 \text{ cm})\), for times \((\sim 1 \text{ s})\) that are much longer than any of the dynamical timescales of the system. The experiment can be operated as a variable-length partial torus or a full torus trap. The damping rate for the \( m = 1 \) diocotron mode in a partial torus trap is found to depend on the equilibrium position (major radius) and on magnetic field (150 G – 550 G). We report on efforts to explain these results in terms of rotational and magnetic pumping effects using 3D (Poison-Boltzmann) equilibria calculations. Novel full torus asymmetry modes are examined with multiple separatrices and a new charge tomography is developed to infer charge density from image charge measurements on the conducting boundary.

1This work is supported by National Science Foundation Award No. 1205450.

BP8.00101 Phase space dynamics of Landau damping with a truncated Maxwellian distribution

Grant Hart, Emma Hoggan, Ross Spencer, Brigham Young University — We have built a Particle-In-Cell (PIC) simulation that models a damped wave in a nonneutral plasma. In this simulation we can cut off the distribution function at an arbitrary velocity. As the cut-off velocity is passed through the resonant velocity, the change in plasma behavior demonstrates the effect of that group of plasma particles on the damping of the wave. Certain particles change from damping to anti-damping as they change their phase relative to the wave in the resonant region. The frequency of the wave changes by about 2% as the cut-off velocity passes through the resonance, much larger than expected from the change in the charge in the plasma. We are developing different ways of analyzing the data from this simulation to illuminate the different effects that occur.

BP8.00102 Effect of a central “squeeze” potential on asymmetry-induced transport

D.L. Eggleston, Occidental College — We report on initial experiments measuring the radial particle flux produced when a “squeeze” voltage \( V_{sq} \approx \pm 1 \text{ V} \) is applied to the center ring of the cylindrical Malmberg-Penning trap at the same time as the voltages producing our usual asymmetry potential \( V (r) \cos (k_z r) \cos (\omega t - \theta) \). Two results are of interest: 1) When a negative DC squeeze voltage is applied to \( S_3 \), the flux produced by the asymmetry is reduced by a factor of \( \left( V_{sq}/V_{0} \right)^2 \) where \( V_0 \approx 1.2 \text{ V} \). Evidently, particles need to be able to transit the entire machine to produce transport. This is consistent with our transport model but the scale factor \( V_{sq} \) is much larger than expected. 2) When symmetric \( \pm \text{voltage} \) are applied to the two azimuthally-divided halves of \( S_3 \), DC or low-frequency voltages increase the radial flux while high-frequency voltages decrease it. In similar experiments, others have attributed such transport changes to induced chaotic particle orbits, but we note that the squeeze voltage itself produces transport and the resulting modification of the plasma may also be a factor in changing the observed flux. We have not yet found a way to distinguish between these two effects.

1Supported by U.S. Department of Energy grant DE-FG02-06ER54882.

BP8.00103 Recent Results on the Study of Transverse Beam Dynamics Using the Laser-Induced-Fluorescence Diagnostic on the Paul Trap Simulator Experiment (PTSX)

Hua Wang, Erik Gilson, Ronald Davidson, Philip Ephthimiou, Richard Majeski, Princeton Plasma Phys Lab — The Paul Trap Simulator Experiment (PTSX) is a compact Paul trap that simulates the nonlinear transverse dynamics of an intense charged particle beam propagating through an equivalent kilometers-long magnetic alternating-gradient (AG) focusing system. The recently developed laser-induced-fluorescence (LIF) diagnostic allowed us to measure the time dependent, transverse phase space profiles of the charge bunch and better understand critical issues in charged particle beam dynamics including emittance growth, and halo particle formation. The LIF diagnostic system includes an excimer laser, a dye laser, a CCD camera system and a stable high-density barium ion source. The measurements of the radial density profiles of the barium ion source using the LIF diagnostic are calibrated and compared to measurements using a charge collector. The design of the new barium ion source and the LIF diagnostic system will be discussed. The initial results of the radial density profiles measured by the LIF diagnostic will be presented.

1This research is supported by the U.S. Department of Energy.
BP8.00104 New Mechanism for Single-Component Plasma Loss from Asymmetric Potentials

N.C. HURST, J.R. DANIELSON, C.J. BAKER, C.M. SURKO, University of California, San Diego — The manipulation of single-component plasmas in a Penning-Malmberg trap often requires the use of applied asymmetric potentials. While it has long been known that these asymmetries can cause plasma expansion, it is shown here that direct particle loss may also occur; and this is deleterious for many applications, especially antimatter storage. The plasma self-potential and the applied potential superpose to form a separatrix, and this can result in the $E \times B$ drift of plasma particles out of the trap. A simple model is presented which captures the observed behavior. The analogy of this effect to the stripping of a 2D vortex by a shear flow will be discussed.

This work was supported by the U.S. DTRA.

BP8.00105 Hawking radiation and classical tunneling

EUGENE TRACY, DMITRIY ZHIGUNOV, William & Mary — “Hawking radiation” is most familiar as a quantum field phenomenon in curved space-times that contain an event horizon. Unruh pointed out that acoustic waves in classical fluids with nonuniform background flows can exhibit analogous behavior. [1] The “event horizon” in that case consists of the set of spatial points where the flow speed and sound speed are equal. A WKB analysis [2] of the acoustic wave equation reveals that tunneling occurs at the “event horizon,” but it is not of the standard type. We have recast the Unruh model into a self-adjoint form using a formulation of linearized MHD due to Brizard [3]. A self-adjoint formulation of the linearized wave equation allows the use of variational methods. These provide a systematic means to derive conservation laws and, after discretization, symplectic integration schemes.


BP8.00106 Electron plasma behavior during autoresonant diocotron excitation

C.J. BAKER, J.R. DANIELSON, N.C. HURST, C.M. SURKO, University of California, San Diego — A novel multicell Penning-Malmberg trap is currently being studied as a way to trap and store up to $10^{12}$ positrons using kV confinement potentials. A test structure has been constructed to conduct preliminary experiments. It consists of a large diameter “master” cell and four smaller diameter “storage” cells, three of which are off-axis. To load the multicell trap, plasma in the master cell is moved off-axis to radial displacements $\Delta > r_p$, where $r_p$ is the plasma radius, before being transferred axially into off-axis storage cells. Details of the radial transfer process, which relies upon the autoresonant excitation of the diocotron mode will be discussed, as well as the plasma behavior during the axial transfer process.

This work was supported by the U.S. DTRA.

BP8.00107 Operation of a Multicell Trap

J.R. DANIELSON, N.C. HURST, C.J. BAKER, C.M. SURKO, University of California, San Diego — The multicell Penning-Malmberg trap has been proposed as a way to obtain high-capacity and/or portable antimatter traps. A new multicell test-structure is investigated, which has several off-axis cells as well as the capability of studying plasmas with kV space charge potentials. Experiments using test electron plasmas have demonstrated the injection of over 50% of the plasma into an off-axis trap, and the confinement of plasmas with $2 \times 10^9$ particles in an off-axis cell for hours using rotating electric fields. Other results to be discussed include the limits of the injection process, stacking plasmas in the off-axis cells, and comparing asymmetry-induced transport in off-axis and on-axis cells. Near-term goals include increasing off-axis injection efficiency, as well as the trapped particle number to $> 10^{10}$ in a single cell. These studies will test further the basic physics of the multicell concept and help refine the design a 21-cell trap for $10^{12}$ positrons.

This work was supported by the U.S. DTRA.

BP8.00108 Progress toward positron-electron pair plasma experiments

J. STANJA, U. HERGENHAHN, H. NIEMANN, N. PASCHKOWSKI, T. SUNN PEDERSEN, H. SAITO, E.V. STENSON, Max Planck Institute for Plasma Physics, CH. HUGENSCHMIDT, Technische Universität München, G.H. MARX, L. SCHWEIKHARD, Ernst Moritz Arndt University of Greifswald, J.R. DANIELSON, C.M. SURKO, University of California, San Diego — Matter-antimatter pair plasmas have been of great theoretical and astrophysical interest for a long time. A Positron-Electron Experiment (APEX) aims for the creation and study of such a plasma in the laboratory. It will be operated at the NEPOMUC facility which provides a cold beam handling for separation into multiple beams in order to reduce the energy spread of the positron beam; injection and trapping of electrons in a prototype dipole field device with a permanent magnet; and design plans for the next generation of confinement device.

on behalf of the APEX/PAX team and collaborators
BP8.00109 Progress toward positon accumulation for use in pair plasmas, E. V. STENSON, U. HERGENHAHN, H. NIEMANN, N. PASCHKOWSKI, T. SUNN PEDERSEN, H. SAITOHI, J. STANJA, Max Planck Institute for Plasma Physics, G. H. MARX, L. SCHWEIKHARD, Ernst Moritz Arndt University of Greifswald, C. HUGENSCHMIDT, Technische Universität München, J. R. DANIELSON, C. M. SURKO, University of California, San Diego — A Positron-Electron Experiment (APEX) is being developed to create and investigate magnetically confined matter-antimatter pair plasmas in the laboratory. These plasmas, whose oppositely charged species have precisely equal mass, have long been a topic of theoretical and astrophysical interest. The accompanying Positron Accumulation Experiment (PAX) comprises a series of non-neutral plasma traps. PAX will provide a bridge between the parameters of the NEPOMUC (Neutrino-Induced Positron Source Munich) beam, from which APEX will receive its positrons, and the parameters needed to achieve at least 10 Debye lengths within APEX’s flux surfaces. Presented here is an overview of work from the PAX team. Topics include the following: diagnostics for non-neutral plasmas, including a comparison of phosphor luminescence in response to electrons versus positrons, as well as work on a nonperturbative potential probe; progress to date on injection into and trapping within various sub-components of the experiment (buffer gas trap, accumulator, and high-field trap); and a discussion of design considerations for the next-generation, multi-cell trap to be built for the high-field magnet.

1on behalf of the APEX/PAX team and collaborators

BP8.00110 Low-Frequency Rotating Wall Compression of Electron-Antiproton Plasmas, ANDREY ZHMOGINOV, JOEL FAJANS, JONATHAN WURTLE, University of California, Berkeley, ANDREA GUTIERREZ, MAKOTO FUJIIWARA, University of British Columbia, THOMAS O’NEIL, University of California, San Diego — Recent advances in antihydrogen production and trapping would be impossible without the means for compressing and mixing individual particle species [1]. Rotating wall technique based on applying harmonically-changing potentials to segmented electrodes of an electrostatic plasma trap is one of the methods widely used for compressing non-neutral plasmas. The frequency of the rotating wall perturbation used for compressing electrons in a laboratory is typically on the order of several MHz. However, it has recently been observed in ALPHA (CERN) that an efficient compression of two-component electron-antiproton plasmas may occur at much lower frequencies. We show that the mechanism of such compression can be attributed to single particle resonances in contrast to excitation of collective plasma modes [2]. A model of resonant plasma compression based on kinetic theory is presented and shown to agree with experimental results in a strongly-collisonal regime. Plasma evolution in the opposite weakly-collisonal regime is also discussed. The most complicated intermediate case is analyzed using a 2D n-body code.


BP8.00111 Techniques to improve plasma properties for antihydrogen production in ALPHA, T. THARP, J. FAJANS, University of California, Berkeley, H. BOSTOCK, N. MADSEN, Swansea University, W. BERTSCHE, University Of Manchester And The Cockcroft Institute, T. FRIESEN, Aarhus University, ALPHA COLLABORATION — Spectroscopic studies of antihydrogen in ALPHA depend on the reliable production of antihydrogen atoms in quantities large enough to achieve the necessary statistics for precision studies. The efficient production of anti-hydrogen requires the simultaneous trapping of antiproton and positron populations with high densities and very low temperatures. Presently, we report on two recent developments in the ALPHA-2 apparatus: (1) Initial experiments have been performed to identify multiple regimes of plasma compression using electrostatic rotating wall boundary conditions, and (2) a system of cryogenic flaps is being developed to actively close off various sources of radiative heating in order to achieve colder plasma temperatures.

BP8.00112 Improvement to the Effective Potential Transport Theory Based on Enskog’s Theory of Dense Gases, SCOTT D. BAALRUD, University of Iowa, JEROME DALIGAULT, Los Alamos National Laboratory — We recently proposed a method for extending traditional plasma transport theories to strong coupling using a binary collision model in which many-body correlation effects were included through an effective interaction potential [1]. By comparing with molecular dynamics simulations, this was shown to be quite successful at extending the binary collision approach well into the strongly coupled regime. However, one persistent feature was an approximately 30% overestimation of the collision rate in the range 1 < \( \Gamma^- \), where \( \Gamma^- \) is the coupling parameter. Here we show that this can be corrected by applying the same scattering cross section to Enskog’s kinetic equation for dense gases, rather than Boltzmann’s equation for dilute gases. The salient new physics is an exclusion radius for the probability distribution of initial scattering positions that arises due to the strong Coulomb repulsion at close distances; i.e., by accounting for the finite size of particles. Although Enskog’s equation was developed exclusively for hard spheres, we propose a connection between the Percus-Yevick equation for hard spheres and the hypernetted chain equation to find the appropriate exclusion radius for Coulomb systems.


3Work supported by The University of Iowa and US DOE.

BP8.00113 Diffusive Transport Properties Across Coupling Regimes, G. DHARUMAN, MSU, M. S. MURILLO, LANL, J. VERBONCOEUR, A. CHRISTLIEB, MSU — Transport properties are poorly known across coupling regimes, therefore understanding them is of importance for theoretical and practical reasons. A useful tool is an ultracold plasma system because of the experimental capability to tune the system to achieve Coulomb coupling \( \Gamma^- \) ranging from 0.1 to 1 to 10 with the screening parameter \( \kappa \) ranging from 0 to 4 to 8, spanning the regions of the phase diagram from weak to moderate to strongly coupled and screened systems. Strong coupling is possible if Disorder Induced Heating is mitigated which requires a correlated initial ion state [1]. Of particular interest is Rydberg blockaded gas of ultracold atoms where the local blockade effect results in correlations. Predictions of Rydberg blockaded gas of ultracold atoms have been reported [2]. In this work we examine the diffusive transport properties of ultracold plasma system using molecular dynamics simulations for experimentally realizable values of \( \Gamma^- \) and \( \kappa \) as discussed above.


BP8.00114 Semiclassical Ponderomotive Lagrangian for the Dirac Electron, D. E. RUIZ, I. Y. DODIN, Princeton University — The ponderomotive effect caused by a high-frequency electromagnetic field on a classical particle can be calculated conveniently, within a first-principle variational approach, as the force experienced by the particle’s quantum wave function in the semiclassical approximation. The previous calculations have been restricted to nonrelativistic scalar particles in weak fields [1]. Here we extend those results to relativistic vector particles in arbitrarily strong fields. In particular, we derive the ponderomotive Lagrangian for the Dirac electron in a relativistically-intense laser wave propagating in vacuum. Classical waves in plasma can be described in a similar manner; hence our calculation also generalizes the recent “ponderomotive” theory of wave-wave adiabatic coupling [2] to fully electromagnetic interactions.


This work was supported by the DOE NNSA through contract number DE274-FG52-08NA28553.

BP8.00115 PLASMA TECHNOLOGY —
BP8.00116 Issues and Solutions for Implementation of a Nanoparticle Plasma Jet Diagnostic on DIII-D

J. R. THOMPSON, J. N. BOGATU, FAR-TECH, Inc. — For ITER, runaway electron (RE) beams are considered a critical problem. Moreover, RE beam dynamics involves processes not yet fully understood or precisely diagnosed. FAR-TECH has proposed using a C60/C plasma jet as a novel diagnostic probe for RE beam-plasma interaction on DIII-D. The existing FAR-TECH prototype plasma jet system is expected to deliver up to ~75 mg C60, at ~4 km/s, and within ~1 ms of triggering, resulting in a free and bound electron density ~2.4x10^21 m^-3, about 60 times larger than the typical DIII-D pre-disruption operation value. Implementation of a 100 kJ pulsed power plasma jet system is non-trivial, with electromagnetic interference (EMI) and safety being two major issues. Microsecond timescale, high current drivers generate significant EMI from which other DIII D systems need to be shielded. Safety issues associated with high voltage and potential capacitor failure must also be addressed. We will present the status of our investigation into the principle solutions for the critical issues involved in the implementation of FAR-TECH’s prototype C60/C plasma jet system on DIII-D.

1Work supported by US DOE grant DE-SC0011864

BP8.00117 Demountable, High field High-Temperature Superconductor TF coils for flexible steady-state fusion experiments

PHILLIP MICHAEL, LESLIE BROMBERG, RUI VIEIRA, JOSEPH MINERVINI, CHRISTOPHER GALEA, SARAH HENSLEY, DENNIS WHYTE, MIT — The excellent properties of HTS materials (e.g., YBCO) at high fields and elevated temperatures (>20 K), offer operational advantages for fusion machines, but results in challenges. For fusion devices, the ability to disassemble the TF coil is very attractive as it provides direct access to maintain the vacuum vessel, first wall and other components in a timely manner. High current conductors, made from multiple thin tapes, are not available but are being developed. Quench protection is a serious issue with HTS magnets, and novel means are needed to detect normal zones and to quickly discharge the magnet. Potential cables designs, demountable magnets and solutions to quench and protection issues for an HTS TF magnet for the Vulcan device (long term PMI studies) will be described. We also describe means for making continuous, persistent loops with HTS tapes. These loops offer an alternative to expensive monoliths for field control for complex geometries, such as stellarator-like fields.

1Partially supported by US DOE DE-FC02-93ER45186

BP8.00118 High Field Magnet Developments for the Future of High Field Compact Experiments

G. GRASSO, Columbus, Italy; B. COPPI, MIT — The adoption of “All Superconducting Hybrid” (ASH) magnets for the design of new high field confinement machines with relatively long plasma current pulses has been considered. These consist of MgB2, superconducting coils, in the outer portion of the magnet, that operate at about 10 K like those adopted for the Ignitor1 vertical field coils, but can produce up to 10T as in the case of the hybrid magnet with a copper core under construction at Grenoble. In the case of the envisioned ASH magnets the inner core will be made of high temperature superconductors capable of operating at very high fields. The inclusion of advanced solutions [1] such as that concerning the coupled toroidal magnet and central solenoid system for new advanced machines is envisioned. *Supported in part by the US DOE.


BP8.00119 Surface morphology changes to tungsten under exposure to He ions from an electron cyclotron resonance plasma source

DAVID DONOVAN, University of Tennessee-Knoxville, DEAN BUCHENAUER, JOSH WHALEY, RAYMOND FRIDDLE, Sandra National Laboratory, GRAHAM WRIGHT, Massachusetts Institute of Technology — Exposure of tungsten to low energy (<100 eV) helium plasmas at temperatures between 900-1900 K in both laboratory experiments [1] and tokamaks [2] has been shown to cause severe nanoscale modification of the near surface resulting the growth of tungsten tendrils. In this work we will present experimental and computational studies to understand the interactions of helium ions and electrons with tungsten surfaces. Theoretical models will be presented to understand the formation and growth of tungsten tendrils and the results will be compared to experimental observations.


1Work supported by US DOE Contract DE-AC04-94AL85000 and the PSI Science Center.

BP8.00120 Velocity Measurements of Thermoelectric Driven Flowing Liquid Lithium

MATTHEW SZOTT, WENYU XU, PETER FIFILIS, IAN HAEHNLEIN, AVEEK KAPAT, KISHOR KALATHIPARAMBI, DAVID N. RUZIC, CPMI, Department of Nuclear, Plasma, and Radiological Engineering, University of Illinois at Urbana-Champaign, Urbana 61801 — Liquid lithium has garnered additional attention as a PFC due to its several advantages over solid PFCs, including reduced erosion and thermal fatigue, increased heat transfer, higher device lifetime, and enhanced plasma performance due to the establishment of low recycling regimes at the wall. The Lithium Metal Infused Trenches concept (LiMIT) has demonstrated thermoelectric magnetohydrodynamic flow of liquid lithium through horizontal open-faced metal trenches with measured velocities varying from 3.7+/- 0.5 cm/s in the 1.76 T field of HT-7 to 22+/- 3 cm/s in the SLiDE facility at UIUC at 0.059 T. To demonstrate the versatility of the concept, a new LiMIT design using narrower trenches shows steady state, thermoelectric-driven flow at an arbitrary angle from horizontal. Velocity characteristics are measured and discussed. Based on this LiMIT concept, a new limiter design has been developed to be tested on the mid-plane of the EAST plasma. Preliminary modelling suggests lithium flow of 6 cm/s in this device. Additionally, recent testing at the Magnum-PSI facility has given encouraging results, and velocity measurements in relation to magnetic field strength and plasma flux are also presented.

BP8.00121 ABSTRACT WITHDRAWN

BP8.00122 Silicon Carbide (SiC) MOSFET-based Full-Bridge for Fusion Science Applications

TIMOTHY ZIEMBA, KENNETH MILLER, JAMES PRAGER, JULIAN PICARD, AKEL HASHIMI, Eagle Harbor Technologies — Switching power amplifiers (SPAs) have a wide variety of applications within the fusion science community, including feedback and control systems for dynamic plasma stabilization in tokamaks, inductive and arc plasma sources, Radio Frequency (RF) helicity and flux injection, RF plasma heating and current drive schemes, ion beam generation, and RF pre-ionizer systems. SiC MOSFETs offer many advantages over IGBTs including lower drive energy requirements, lower conduction and switching losses, and higher switching frequency capabilities. When comparing SiC and traditional silicon-based MOSFETs, SiC MOSFETs provide higher current carrying capability allowing for smaller package weights and sizes and lower operating temperature. Eagle Harbor Technologies (EHT) is designing, constructing, and testing a SiC MOSFET-based full-bridge SPA. EHT will leverage the proprietary gate drive technology previously developed with the support of a DOE SBIR, which will enable fast, efficient switching in a small form factor. The primary goal is to develop a SiC MOSFET-based SPA for fusion science applications.

3Work supported in part by the DOE under contract number DE-SC0011907.
2:00PM CI1.00001 Polar-Drive Experiments at the National Ignition Facility. M. HOHENBERGER, Laboratory for Laser Energetics, U. of Rochester — To support direct-drive inertial confinement fusion (ICF) experiments at the National Ignition Facility (NIF) [1], its indirect-beam drive configuration, the polar-drive (PD) concept, has been proposed. It requires direct-drive-specific beam smoothing, phase plates, and repointing the NIF beams toward the equator to ensure symmetric target irradiation. First experiments testing the performance of ignition-relevant PD implosions at the NIF have been performed. The goal of these early experiments was to develop a stable, warm implosion platform to validate laser deposition and laser-plasma instabilities at ignition-relevant plasma conditions, and to develop and validate ignition-relevant models of laser deposition and heat conduction. These experiments utilize the NIF in its current configuration, including beam geometry, phase plates, and beam smoothing. Warm, 2.2-mm-diam plastic shells were imploded with total drive energies ranging from ∼ 350 to 750 kJ with peak powers of 60 to 180 TW and peak on-target intensities from 4 × 10^{14} to 1.2 × 10^{15} W/cm^{2}. Results from these initial experiments are presented, including the level of hot-electron preheat, and implosion symmetry and shell trajectory inferred via self-emission imaging and backlighting. Experiments are simulated with the 2-D hydrodynamics code DRACO including a full 3-D ray trace to model oblique beams, and a model for cross-beam energy transfer (CBET). These simulations indicate that CBET affects the shell symmetry and leads to a loss of energy imparted onto the shell, consistent with the experimental data. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

2:30PM CI1.00002 Spherical Strong-Shock Generation for Shock-Ignition Inertial Fusion. W. THEOBALD, Laboratory for Laser Energetics, U. of Rochester — Recent experiments on the Laboratory for Laser Energetics’ OMEGA laser have been carried out to produce strong shocks in spherical (SSS) targets. The shocks are launched at pressures of several hundred megabars and reach gigabar pressures upon convergence. The results are relevant to the validation of the shock-ignition (SI) scheme and to the development of an OMEGA experimental platform to study material properties at gigabar pressures. The SSS experiments investigate the strength of the ablation pressure and the hot-electron production at overlapping beam laser intensities of ∼ 3 to 5 × 10^{13} W/cm^{2}. The measurements demonstrate the generation of convergent shocks launched by an ablation pressure of 300 Mbar, which is crucial to validate the SI concept and to develop an SI target design for the National Ignition Facility. The timing of the x-ray flash from shock convergence in the center of a solid plastic ball target doped with a small amount of Ti is used to infer the shock velocity and pressure in the experiment. It was found that the hot-electron temperature was moderate (<100 keV) and the instantaneous conversion efficiencies of laser energy into hot electrons reached ∼ 10% to 20% in the intensity spike. The large amount of hot electrons is correlated with an earlier x-ray flash time and a strong increase (∼ 25×) of the flash intensity. This suggests that hot electrons contribute to the augmentation of the shock strength. This work was supported by the U.S. DOE under DE-NA0001944, DE-FC02-04ER54789.


3:00PM CI1.00003 Secondary Nuclear Reactions in Magneto-Inertial Fusion Plasmas. PATRICK KNAPP, Sandia National Laboratories — The goal of Magneto-Inertial Fusion (MIF) is to relax the extreme pressure requirements of inertial confinement fusion by magnetizing the fuel. Understanding the level of magnetization at stagnation is critical for charting the performance of any MIF concept. We show here that the secondary nuclear reactions in magnetized deuterium plasma can be used to infer the magnetic field-radius product (BR), the critical confinement parameter for MIF [1,2]. The secondary neutron yields and spectra are examined and shown to be extremely sensitive to BR. In particular, embedded magnetic fields are shown to affect profoundly the isotropy of the secondary neutron spectra. Detailed modeling of these spectra along with the ratio of overall secondary to primary neutron yields is used to form the basis of a diagnostic technique used to infer BR at stagnation. Effects of gradients in density, temperature and magnetic field strength are examined, as well as other possible non-uniform fuel configurations. Computational results employing a fully kinetic treatment of charged reaction product transport and Monte Carlo treatment of secondary reactions are compared to results from recent experiments at Sandia National Laboratories’ Z machine testing the MAGnetized Liner Inertial Fusion (MagLIF) concept [2]. The technique reveals that the charged reaction products were highly magnetized in these experiments. Implications for eventual ignition-relevant experiments with deuterium-tritium fuel are discussed.

*Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.


3:30PM CI1.00004 Fast electron transport and spatial energy deposition in imploded fast ignition cone-in-shell targets. LEONARD JARROTT, University of California at San Diego — We report on the first experimental observation and model validation of the spatial energy deposition of fast electrons into the imploded, high-density core of integrated cone-in-shell fast ignition experiments on OMEGA. Spatial energy deposition was characterized via fast electron produced Kα fluorescence from a Cu tracer added to the CD shell. 2-D images of the Cu Kα fluorescence were obtained using a spherically bent Bragg crystal imager. 54 of the 60 OMEGA beams (18 kJ) were used for fuel assembly, and the high intensity EP beam (10 ps, 0.5 - 1.5 kJ, Ip > 10^{13} W/cm^{2}), was focused onto the inner cone tip to produce fast electrons. Cu Kα emission from a 300 μm region surrounding the cone tip correlated well with the predicted core size from radiation-hydrodynamic simulations of the shell implosion. The emission also emanated from as far back as 100 μm from the cone tip, indicative of an electron source position with a large standoff distance from the cone tip, consistent with the presence of an extended pre-spike well from the EP pre-pulse. We observed a simultaneous increase in both Kα yield (up to 70%) and thermal neutron number (up to 2x) with increasing EP beam energy. Kα yield data also show an improved energy coupling using the high contrast EP pulse. Comprehensive simulations of the electron production within the cone and subsequent transport into the imploded core have been performed using the implicit PIC code LSP and the hybrid-PIC code ZUMA. These simulations explain the observed Kα shape and yield trends and identify parameters that constrain energy coupling into the compressed core.

This work was performed under the auspices of U.S. DOE under contracts DE-FG02-04ER54789 (FSC), DE-FG02-05ER54834 (ACE) and DE-NA0000854 (NULF).
4:00PM CI1.00005 Demonstration of thermonuclear conditions in Magnetized Liner Inertial Fusion experiments. MATTHEW GOMEZ, Sandia National Laboratories — The Magnetized Liner Inertial Fusion concept [S. A. Slutz et al., Phys. Plasmas 17, 056303 (2010)] utilizes a magnetic field and laser heating to relax the implosion requirements to achieve inertial confinement fusion. The first experiments to test the concept were recently conducted utilizing the 19 MA, 100 ns Z machine, the 2.5 kJ, 1 TW Z Beamlet laser, and the 10 T Applied B-field on Z coils. Despite the relatively slow implosion velocity (70 km/s) in these experiments, electron and ion temperatures at stagnation were approximately 3 keV, and thermonuclear DD neutron yields up to 2e12 have been produced. X-ray emission from the fuel at stagnation had a width ranging from 60-120 microns over a roughly 6 mm height and lasted approximately 2 ns. X-ray spectra from these experiments are consistent with a stagnation density of the hot fuel equal to 0.4 g/cm3. In these experiments 1-5e10 secondary DT neutrons were produced. Given that the areal density of the plasma was approximately 2 mg/cm2, this indicates the stagnation plasma was significantly magnetized. This is consistent with the anisotropy observed in the DT neutron time of flight spectra. Control experiments where the laser and/or magnetic field were not utilized failed to produce stagnation temperatures greater than 1 keV and DD yields greater than 1e10. An additional control experiment where the fuel contained a sufficient dopant fraction to radiate away the laser energy deposited in the fuel also failed to produce a relevant stagnation temperature. The results of these experiments are consistent with a thermonuclear neutron source.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under Contract No. DE-AC04-94AL85000.

Monday, October 27, 2014 2:00PM - 3:00PM –
Session CT2 Tutorial: Whistlers, Helicons, Lower Hybrid Waves: the Physics of RF Wave Absorption Without Cyclotron Resonances

2:00PM CT2.00001 Whistlers, Helicons, Lower Hybrid Waves: the Physics of RF Wave Absorption Without Cyclotron Resonances1 R.I. PINSKER, General Atomics — In hot magnetized plasmas, two types of linear collisionless absorption processes are used to heat and drive noninductive current: absorption at ion or electron cyclotron resonances and their harmonics, and absorption by Landau damping and the transit-time-magnetic-pumping (TTMP) interactions. This tutorial discusses the latter process, i.e., parallel interactions between rf waves and electrons in which cyclotron resonance is not involved. Electron damping by the parallel interactions can be important in the ICRF, particularly in the higher harmonic region where competing ion cyclotron damping is weak, as well as in the Lower Hybrid Range of Frequencies (LHRF), which is in the neighborhood of the geometric mean of the ion and electron cyclotron frequencies. On the other hand, absorption by parallel processes is not significant in conventional ECRF schemes. Parallel interactions are especially important for the realization of high current drive efficiency with rf waves, and an application of particular recent interest is direct drive with the whistler or helicon wave at high to very high (i.e., the LHRF) ion cyclotron harmonics. The scaling of absorption by parallel interactions with wave frequency is examined and the advantages and disadvantages of fast (helicons/whistlers) and slow (lower hybrid) waves in the LHRF in the context of reactor-grade tokamak plasmas are compared. In this frequency range, both wave modes can propagate in a significant fraction of the discharge volume; the ways in which the two waves can interact with each other are considered. The use of parallel interactions to heat and drive current in practice will be illustrated with examples from past experiments; also looking forward, this tutorial will provide an overview of potential applications in tokamak reactors.

1Supported by the US Department of Energy under DE-FC02-04ER54698.

Monday, October 27, 2014 2:00PM - 5:00PM –
Session CO3 Equation of State

2:00PM CO3.00001 ABSTRACT WITHDRAWN –

2:12PM CO3.00002 Hugoniot measurements at pressures of 20-720 Mbar at the NIF1 ANDREA KRITCHER, TILO DOEPPNER, BENJAMIN BACHMANN, Lawrence Livermore National Laboratory, DOMINIK KRAUS, ROGER FALCONE, University of California Berkeley, GILBERT COLLINS, OTTO LANDEN, Lawrence Livermore National Laboratory, DAVE CHAPMAN, Atomic Weapons Establishment, JIM HAWRELIK, Lawrence Livermore National Laboratory, SIEGFRIED GLENZER, SLAC Accelerator National Laboratory, JOE NILSEN, DAMIAN SWIFT, Lawrence Livermore National Laboratory — Laboratory measurements of the Equation of State (EOS) of matter at high pressure, exceeding several hundred Mbar, are of great importance in the understanding and accurate modeling giant planetary formation and benchmarking dense matter models is relevant for fusion energy experiments. For example, at Gbar pressures atomic shell effects may come into play, which can change the predicted compressibility at given pressure due to pressure and temperature ionization. In this work we present the first laboratory measurements of the strong shock hugoniot at pressures up to 720 Mbar for CH and 630 Mbar for High Density Carbon (HDC). X-ray radiography has been applied to measure the shock speed and infer the mass density profile, enabling determination of the material pressure and absolute shock Hugoniot. We will also present a comparison to postshot HYDRA simulations.

1This work performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344 and supported by LDRD 08-ERI-003.
2:24PM CO3.00003 Penumbral Imaging of micrometer size plasma hot spots at shock stagnation in Gbar EOS experiments on the National Ignition Facility

Benjamin Bachmann, A.L. Kritcher, L.R. Benedetti, L.L.N., R.W. Falcone, L.B.L., S. Glenn, J. Hawreliak, N. Izumi, L.L.N., D. Kraus, U.C. Berkeley, O.L. Landen, S. Perez, D. Swift, T. Doepner, L.L.N. — We have developed an experimental platform for absolute equation of state (EOS) measurements up to Gbar pressures on the National Ignition Facility (NIF). We use a symmetry-tuned hohlraum drive to launch a spherical shock wave into a solid CH sphere. Streaked Radiography is the primary diagnostic to measure the density change at the shock front as the pressure increases towards smaller radii. At shock stagnation in the center of the capsule, we observe short and bright x-ray self emission from high density (50 g/cm^3) plasma at 1 keV. Here, we present results obtained with penumbral imaging, carried out to characterize the size of the hot spot emission. A detailed understanding of this size and emission strength allows for benchmarking radiation-hydro simulations in a regime that is not accessible to radiography. The application of penumbral imaging extends existing NIF diagnostic capabilities to higher spatial resolution (currently 10 µm to 1 µm) and higher sensitivity. At peak emission we find the hot spot radius to be as small as 5.8 +/- 1 µm, corresponding to a convergence ratio of 200.

3:12PM CO3.00007 Probing the Release of Shocked Material

D.N. Polsin, C.A. Mccoy, M.C. Gregor, T.R. Boeihly, D.D. Meyerhofer, Laboratory for Laser Energetics, U. of Rochester, D.E. Fratanduono, P.M. Celliers, LLNL — The behavior of shocked material as it releases to lower pressures is important for equation-of-state experiments and inertial confinement fusion research. We present results of experiments that used a 10-ps, 266-nm probe beam to image the release plumes of various target materials shocked to multi-megabar pressures by the Omega EP laser. Simultaneous VISAR (velocity interferometer system for any reflector) measurements provide the initial shocked state from which these materials release. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
3:48PM CO3.00010 Model for atomic dielectric response in strong, time-dependent laser fields, T.C. RENSINK, T.M. ANTONSEN, University of Maryland, College Park, J.P. PALASTRO, D.F. GORDON, Naval Research Laboratory — A nonlocal quantum mechanical model is explored for calculating the atomic response to a strong laser electric field. By replacing the Coulomb potential with a nonlocal potential in the Schrodinger equation, a 3+1D calculation of the time-dependent electric dipole moment is reformulated as a 0+1D integral equation that retains the matrix elements for a given ion. Knowledge of the EOS and opacity of this material is then critical for target design. We have performed calculation of the equation of states (EOS) and the reflectivity along the principal Hugoniot up to 8 Mbar for two highly doped (2% and 13%) CHOGe mixtures. We have used DFT-QMD simulation coupled with Kubo-Greenwood formulation for the optical properties. A special attention was paid on the PAW dataset design for the high pressure cases and on the Ge description. These calculations are compared to the experiment performed at Gekko XII on laser-shocked CHOGe where EOS data and optical properties were obtained in the same regime. On one hand, this study allows us to explore the mixing rule used for the EOS calculation in hydrodynamics simulations. On the other hand, this shows the capability of the description of the electronic structure modification along the metal to non-metal transition using QMD simulations.

4:00PM CO3.00011 Reflectivity of CHOGe along the principal Hugoniot, VANINA RECOULES, GAEL HUSER, PIERRE COLIN-LALU, CEA/DAM-DIF, Arpajon, France — One possible solution for the ablator of the ICF capsule is to use plastic(CH) doped with a mid-Z element such as Ge. Knowledge of the EOS and opacity of this material is then critical for target design. We have performed calculation of the equation of states (EOS) and the reflectivity along the principal Hugoniot up to 8 Mbar for two highly doped (2% and 13%) CHOGe mixtures. We have used DFT-QMD simulation coupled with Kubo-Greenwood formulation for the optical properties. A special attention was paid on the PAW dataset design for the high pressure cases and on the Ge description. These calculations are compared to the experiment performed at Gekko XII on laser-shocked CHOGe where EOS data and optical properties were obtained in the same regime. On one hand, this study allows us to explore the mixing rule used for the EOS calculation in hydrodynamics simulations. On the other hand, this shows the capability of the description of the electronic structure modification along the metal to non-metal transition using QMD simulations.

4:12PM CO3.00012 Equation of state and transport properties of silicates under extreme conditions, TINGTING QI, SEBASTIEN HAMEL, LLNL — Understanding the physical properties of silicates under high temperature and pressure is fundamental to an accurate description of planetary interiors and evolution models. For example, earth’s mantle is a rocky silicate shell constituting about 84% of Earth’s volume. Possible chemical compositions include SiO\(_2\) and some other silicates such as MgSiO\(_3\) and CaSiO\(_3\). Moreover, Moon forming scenarios often invoke giant impacts between silicate-rich objects. Similarly, the existence of a rocky core or mantle with silicate as the major component is frequently assumed in models of giant planets, such as Jupiter or Saturn and Uranus and Neptune. Consequently, constructing planetary interior and evolution models requires knowledge of silicate’s equation of state and its optical and transport properties at high pressures and temperatures.

4:24PM CO3.00013 VISAR blanking due to preheating in a 2-pulses planar experiment at LULI facility, LAURENT VIDEAU, STEPHANIE LAFITTE, CEA, DAM, DIF, SOPHIE BATON, LULI, Ecole Polytechnique, PATRICK CORBIS, JEAN CLEROUIN, CEA, DAM, DIF, MICHEL KENOIG, LULI, Ecole Polytechnique, VANINA RECOULES, CHRISTOPHE ROUSSEAU, CEA, DAM, DIF — Optical diagnostics, such as VISAR (Velocity Interferometer System for Any Reflector), have become essential in shock timing experiments. Their high precisions allow an accurate measurement of shock velocities and chronometry. But, measurements can be compromised by x-ray preheating. In planar shock coalescence experiments recently performed at the LULI facility [1], VISAR signal loss was observed. In these experiments, a strong shock, launched by a high-intensity spike, catches up with a first one, initially launched by a low-intensity beam. VISAR signal dispersion is due to x-ray generated by spike absorption in corona. It does not occur if high-intensity spike starts after VISAR probe beam begins to reflect off the first shock. Based on optical index assessment in quartz, VISAR diagnostic is modeled and compared favorably to experimental results. This provides evidence of the impact of x-ray preheating on VISAR absorption in quartz.

4:36PM CO3.00014 Characterization of Low-density Foams for Use in Strength Experiments at NIF\(^1\), L.R. BENEDETTI, A. ARSENILIS, C.M. HUNTINGTON, B.R. MADDOX, H.S. PARK, S. PRISBREY, B.A. REMINGTON, C. WEHRENBERG, LLNL, Y.P. OPACHICH, M. HAUGH, E. HUFFMAN, J. KOCH, E. ROMANO, F. WEBER, M. WILSON, National Security Technologies, P. GRAHAM, AWE — To infer strength in compressed solids by observation of Rayleigh-Taylor growth, we are engaged in an experimental campaign at NIF. To produce a drive that is sufficiently cool to prevent melting and also long enough to observe growth over tens of ns, we are developing a target that mediates the high-intensity NIF laser drive by shocking a multi-component reservoir and driving the target sample by the stagnation of the reservoir’s release after crossing a large gap (1 mm vacuum). This design depends on the shock and release of an ultra-low density foam layer (10-30 mg/cc), which in turn requires that these layers be well-characterized for uniformity and reproducibility. We describe efforts to characterize C and SiO\(_2\) based foam targets to quantify variations in rho-R. Our fabrication and measurement goal is taken from simulations that indicate that targets must be uniform at the 10% level over spatial scales from 20 microns to 2 mm. We present data from differential radiography of witness samples by soft x-rays (E<1.5keV) and compare our results to other techniques.

\(^1\)This work performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344, LLNL-ABS-656898

4:48PM CO3.00015 Laser-driven 6-16 keV x-ray imaging and backlighting with spherical crystals, M. SCHOLLMEIER, P.K. RAMBO, J. SCHWARZ, I.C. SMITH, J.L. PORTER, Sandia National Laboratories — Laser-driven x-ray self-emission imaging or backlighting of High Energy Density Physics experiments requires brilliant sources with keV energies and x-ray crystal imagers with high spatial resolution of about 10 \(\mu\)m. Spherically curved crystals provide the required resolution when operated at near-normal incidence, which minimizes image aberrations due to astigmatism. However, this restriction dramatically limits the range of suitable crystal and spectral line combinations. We present a survey of crystals and spectral lines for x-ray backlighting and self-emission imaging with energies between 6 and 16 keV. Ray-tracing simulations including crystal rocking curves have been performed to predict image brightness and spatial resolution. Results have been benchmarked to experimental data using both Sandia’s 4 KJ, ns Z-Beamlet and 200 J, ps Z-Petawatt laser systems.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2014-15552A.

Monday, October 27, 2014 2:00PM - 5:00PM – Session CO4 Hohlraum Physics and Indirect Drive

Salon E - Forrest Doss, Los Alamos National Laboratory
2:00PM CO4.00001 Stimulated Brillouin Scatter Reduction using Borated Gold Hohlraums on the National Ignition Facility

JOSEPH RALPH, DAVID STROZZI, RICHARD BERGER, PIERRE MICHEL, DEBRA CALAHAN, DENISE HINKEI, LAURENT DIVOL, BRIAN MACGOWAN, FELICIE ALBERT, JOHN MOODY, Lawrence Livermore National Laboratory, NIF HOHLRAUM TEAM — New target platforms for indirect drive ignition on NIF are being introduced to improve capsule and hohlraum performance. A number of these targets show increased Stimulated Brillouin Backscattering (SBS) late in the laser pulse on the outer cone beams. This scattering reduces the laser power available for x-ray drive in an hohlraum as well as poses a damage risk to the laser optics. We observe a factor of 5 reduction in the SBS power from outer cone beams by doping the Au hohlraum wall with 1.5 μm layer of 40% Boron in Au. The experiment used a room temperature Neopentane-filled ignition scale hohlraum and a 1 MJ, 370 TW laser pulse. The measured SBS backscatter from the outer cone beams on NIF is quantified temporally and spectrally. Comparing the measurements between a pure Au and a AuB hohlraum show approximately a 5x reduction in SBS power. Simulations show that the reduction is in the hohlraum wall plasma. A continuation of this study will extend the duration of the laser pulse to measure the time-dependence of the outer beam SBS. Experimental results from these experiments and detailed simulation results will be presented.

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

2:12PM CO4.00002 Hohlraum fill gas density scaling of x-ray drive, symmetry, and laser coupling backscatter in 6.72-mm NIF hohlraums

OGDEN JONES, N. IZUMI, L.B. HOPKINS, D.J. STROZZI, P.A. AMENDT, G.N. HALL, D.D. HO, S.F. KHAN, N.B. MEEZAN, J.D. MOODY, S.R. NAGEL, J.E. RALPH, R.P.J. TOWN, LLNL — Most ignition experiments carried out on the NIF to date have used hohlraums with helium gas fill at 1-1.6 mg/cc density in order to prevent excessive hohlraum wall motion and help to control drive symmetry. A unique feature of 2-shot high density carbon (HDC) ignition designs is that they require a much shorter (~7 ns) laser pulse than the ~20 ns duration pulses that are typically used for 3-shot or 4-shot CH ablator designs, so there is less time for the wall to move. As a result, it is possible to reduce the hohlraum gas fill density. We have done 2D convergent ablator experiments in a 6.72 mm diameter hohlraum at fill densities of 0.03 and 0.06 mg/cc. These experiments used HDC capsules driven by a 1.5 MJ, 370 TW peak power laser pulse. They demonstrated low backscatter (<4%) and effective drives that are much closer to high flux model predictions than for typical gas-filled hohlraums. The 0.06 mg/cc fill reduced the amount of unabсорbed inner cone power that is reflected out of the hohlraum for the 0.03 mg/cc case. Also, the 0.06 mg/cc has improved symmetry that is in good agreement with modeling.

2:24PM CO4.00003 Optimizing Near-vacuum NIF hohlraum drives for ICF

SEBASTIEN LE PAPE, LAURENT DIVOL, LANA BERZAK HOPKINS, ANDY MACKINNON, NATHAN MEEZAN, DARWIN HO, ARTHUR PAK, JOE RALPH, STEVEN ROSS, STEVE HAAN, PRAT JACQUINO, RICHARD BIONTA, LLNL, TAMMY MA, Lawrence Livermore National Laboratory, RYAN RYGG, DAVID FITTINGHOFF, SHAHAB KHAN, ALEX HAMZA, PETER CELLIERIS, LLNL, ALEX ZYLSTRA, MARIA GATU-JOHNSON, HANS RINDERKNECHT, JOHAN FREJNE, MIT, GARY GRIM, LANL, ROBERT HATARIK, LLNL — Near Vacuum Hohlraum (NVH) is a high coupling platform that might provide a path to ignition using High Density Carbon (HDC) with 10 ns long pulses. We have investigated in a series of experiments on the National Ignition Facility (NIF), our ability to control the symmetry of the implosion in this high efficiency platform. Keeping control of the symmetry as the hohlraum fills in with ablated gold is the main challenge of NVH hohlraum. To help inner beam propagation by increasing the distance from the hohlraum wall to the capsule, the hohlraum diameter was increased from 5.75 mm to 6.72 mm, results from of these experiments will be presented. To reach an ignition relevant design, the abidiat has to be lowered. To lower the adiabat, the 2 shock pulse shape length was increased from 4.5 ns up to 8 ns, results 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. [1] Le Pape, S. et al., Phys. Rev. Lett. 112, 250002 (2014) - Observation of a Reflected Shock in an Indirectly Driven Spherical Implosion at the National Ignition Facility. [2] Mackinnon, A. J., et al.. High-density carbon ablator experiments on the National Ignition Facilitya). PHYSICS OF PLASMAS 21, 056318 (2014).

2:36PM CO4.00004 Correspondence between laser coupling and x-ray flux measurements in a NIF hohlraum

J.D. MOODY, L. DIVOL, O. LANDEN, S. LEPAPE, P. MICHEL, J. RALPH, R.P.J. TOWN, K. WIDMANN, LLNL, A. MOORE, AWE — We describe a simple model relating measurements of the hohlraum x-ray emission (DANTE) to the coupled (incident less backscattered) laser power in NIF indirect drive hohlraum experiments. The model was motivated by observing that the measured x-ray emission showed a lag in rise corresponding to a reduced measurement in laser coupling due to backscatter. Two adjustable scalar parameters (a coupling efficiency and a time-scale) in the model are determined for each experiment. Comparing these parameters for different hohlraum gas-fill, ablator, pulse-length, and laser power conditions provides insight into the hohlraum behavior and performance. In some cases, the model can be inverted to estimate the backscatter loss using the measured hohlraum x-ray emission time-history and delivered laser power. We will describe the model and compare the adjustable parameters between different hohlraum platforms.

3:00PM CO4.00006 The application of quasi-steady approximation in atomic kinetics in simulation of hohlraum radiation drive

GUOLI REN, WENBING PEI, KE LAN, XIN LI, Institute of Applied Physics and Computational Mathematics, HOHLRAUM PHYSICS TEAM — In current routine 2D simulation of hohlraum radiation drive, we adopt the principal-quantum-number(n-level) average atom model(AAM) in NLTE plasma description. The more sophisticated atomic kinetics description is better choice, but the in-line calculation consumes much more resource. By distinguishing the much more fast bound-bound atomic processes from the relative slow bound-free atomic processes, we found a method to built up a bound electron distribution(n-level or n-level) using in-line n-level calculated plasma condition (such as temperature, density, average ionization degree). We name this method “quasi-steady approximation.” Using this method and the plasma condition calculated under n-level, we re-build the n-level bound electron distribution(Psi), and acquire a new hohlraum radiation drive by post-processing. Comparison with the n-level post-processes radiation drive shows that we get an almost ideal radiation flux but with more-detailed frequency-dependant structures. Also we use this method in the benchmark gold sphere experiment, the constructed n-level radiation drive resembles the experimental results and DCA results, while the n-level radiation does not.

3:00PM CO4.00006 The application of quasi-steady approximation in atomic kinetics in simulation of hohlraum radiation drive
3:12PM CO4.00007 Integrated P1 Hohlraum/Capsule Simulations for NIF Experiments1. DAVID EDER, BRIAN SPEARS, RICHARD TOWN, OGGIE JONES, TAMMY MA, ARTHUR PAK, ROBIN BENEDETTI, STEVE HATCHETT, JAMES KNAUER, ANDREW MACKINNON, CHARLES YEAMANS, JAMES MCNANEY, DANIEL CASEY, Lawrence Livermore National Laboratory — We discuss integrated hohlraum/capsule post-shot simulations of two full-scale cryogenic NIF experiments that drove a DT symcap capsule downward/upward by having the peak power in the upper laser beams 16% greater/less than the lower beams. This laser asymmetry results in a radiation drive P1/P0 at the capsule ablation surface of ~2% and a downward/upward capsule velocity of order 100 microns/ns in agreement with the data. The experimental velocity is determined by comparing measurements at different locations of both the arrival times of DD and DT neutrons at time-of-flight detectors, and by zincium activation measurements that are a function of neutron energy. We compare these two shots to a control shot for the same target with no specified laser asymmetries. We also discuss simulations of planned sub-scale warm symcap experiments that have a goal of measuring DT and DD ion temperatures and the electron temperature as a function of the imposed P1 to characterize the role of non-thermal velocity on temperature measurements.

1This work performed under the auspices of the U. S. Department of Energy by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-656659

3:24PM CO4.00008 The structure of the Laser Entrance Hole in NIF Ignition gas-filled hohlraums1, M.B. SCHNEIDER, T. DOEPPNER, C.A. THOMAS, K. WIDMANN, S.A. MACLAREN, N.B. MEEZAN, P.M. BELL, L.R. BENEDETTI, D.K. BRADLEY, D.A. CALLAHAN, D. EDER, J.H. HAMMER, D.E. HINKEL, O.S. JONES, P. MICHEL, J.L. MILOVICH, J.D. MOODY, Lawrence Livermore Natl Lab, A.J. MOORE, Atomic Weapons Establishment, H.S. PARK, J.E. RALPH, Lawrence Livermore Natl Lab, S.E. REGAN, Laboratory for Laser Energetics, D.J. STROZZI, R.P. TOWN, Lawrence Livermore Natl Lab — At the National Ignition Facility (NIF), the energy from 192 laser beams is converted to an x-ray drive in a gas-filled hohlraum. The drive heats and implodes a fuel capsule. The laser beams enter the hohlraum via laser entrance holes (LEHs) at each end. The LEH size decreases as heated plasma from the LEH material blows radially inward but this is largely balanced by hot plasma in the laser deposition region pushing radially outward. Compared to models, the LEH size is larger than predicted. In addition, the plasma in the LEH region is hotter than predicted. Instead of being at the radiation temperature of about 300 eV, it is at an electron temperature of 1 to a few keV. The experimental measurements for this conclusion are discussed. Data on the LEH as a function of laser pulse shape, gas fill, and energy transfer are presented.

1This work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

3:36PM CO4.00009 Low-foot rugby hohlraum experiments on the NIF: Wall-gas mix and a connection with missing x-ray drive energy1. PETER AMENDT, J. STEVEN ROSS, MARYLIN SCHNEIDER, OGGIE JONES, JOSE MILOVICH, JOHN MOODY, LLNL — Rugby-shaped hohlraums on the NIF have shown strong symmetry anomalies when simulated with the high-flux model [1]. The wall-gas interface is Rayleigh-Taylor unstable and may lead to the formation of a late-time mix layer that impedes inner-cone propagation, resulting in a drive asymmetry on the capsule. Due to the rugby curvature near the laser entrance hole, the effect of mix may be more pronounced than in cylinders. At the same time a persistent pattern of 15-25% missing energy has been inferred in gas-filled hohlraums (ρ ≥ 0.96 mg/cc). A possible physical connection between formation of a mix layer and the plasma adiabatic lapse rate [2], where a temperature-gradient reversal is predicted to occur, is explored. Such a profile reversal, in turn, hinders electron conduction to the dense (∆ρ ≥ 0).

1Prepared by LLNL under Contract DE-AC52-07NA27344.

3:48PM CO4.00010 The Quatrraon platform for measurement of cross-beam energy transfer on NIF1. L.A. PICKWORTH, M.B. SCHNEIDER, D.E. HINKEL, M.D. ROSEN, F. ALBERT, D.A. CALLAHAN, P.A. MICHEL, A.E. PAL, E.A. WILLIAMS, J.D. MOODY, S.S. WU, L.R. BENEDETTI, Lawrence Livermore Natl Lab, A. MOORE, AWE — NIF routinely utilizes cross-beam energy transfer (CBET) to control the symmetry of the ICF capsule implosion. In the ignition hohlraum, CBET occurs in the laser entrance hole region, transferring power from the outer to the inner beams. The amount of transfer is controlled by the Δλ between the beam cones and is proportional to laser intensity and n_e/T_e. It is most significant at peak power and during the picket of the pulse. Models indicate that energy transfer is not uniform across the beams spots, producing a non-uniform profile in the inner beam. The amount of transfer is controlled by the Δλ between the beam cones and is proportional to laser intensity and n_e/T_e. It is most significant at peak power and during the picket of the pulse. Models indicate that energy transfer is not uniform across the beams spots, producing a non-uniform profile in the inner beam. Due to the high optical density of the plasma in the ignition drive, the energy is transferred from the outer cone to the inner cone. The energy is then converted to x-rays in the inner cone.

1This work performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-656839

4:00PM CO4.00011 The hohlraum radiation temperature and M-band fraction on the SGIII-prototype laser facility. WENYI HUO, Institute of Applied Physics and Computational Mathematics, DONG YANG, Research Center of Laser Fusion, Chinese Academy of Engineering Physics, KE LAN, Institute of Applied Physics and Computational Mathematics, SANNEI LI, Research Center of Laser Fusion, Chinese Academy of Engineering Physics, YONGSHENG LI, Institute of Applied Physics and Computational Mathematics — The hohlraum radiation temperature and M-band fraction are determined by a shock-wave technique and measured by a broadband soft x-ray spectrometer. The peak radiation temperature T_R and M-band fraction f_m are simultaneously determined by using the observed shock velocities in Al and Ti. For the vacuum Au hohlraum used in the experiments, T_R is about 160 eV and f_m is between 4.3-6.3% under 1ns pulse laser of 2 kJ. T_R is about 202 eV and f_m is about 9% with laser energy 6 kJ. The Continuous Phase Plate (CPP) for beam smoothing is applied in the experiment, which increases T_R to 207 eV while has almost no influence on f_m. Comparisons between the results from the two kinds of technologies show that T_R from the shock wave technique is lower than that from SXS whether CPP is applied or not. However, f_m from the shock wave technique is consistent with that from SXS without CPP, but obviously lower than the SXS's result with CPP.
4:12PM CO4.00012 Hohlraum energetics study on Shenguang-III prototype laser facility .
DONG YANG, SANWEI LI, ZHICHAO LI, RONGQING YI, LIANG GUO, XIAOHUA JIANG, SHENYE LIU, JIAMIN YANG, SHAOEN JIANG, YONGKUN DING, 
Research Center of Laser Fusion, China Academy of Engineering Physics, SHIYANG ZOU, HUASEN ZHANG, YIQING ZHAO, WENYI HUO, XIN LI, 
YONGSHENG LI, KE LAN, Institute of Applied Physics and Computational Mathematics — Comprehensive and accurate characterization of the hohlraum drive needs to use a variety of methods resolving different photon ranges and multiple viewing areas. In recent years, hohlraum physics have been studied extensively on Shenguang-III prototype laser facility. These experiments employed mainly Au hohlraums (vacuum or gas-filled, with capsule or not) heated by smoothing beams where scattering loss is less than 10%. With compact flat-response x-ray detector array and 14-channel soft x-ray spectrometer, the radiation flux from several specific regions inside the hohlraum is measured through the laser entrance hole (LEH) or the diagnostic hole (DH) at different photon ranges and multiple lines of sight. The difference in radiation between the laser spot and the reemitting wall is quantitatively studied to interpret flux onto the capsule. The motion of laser ablated bubble and radiation ablated blow-off plasma is directly measured, and their effects on laser absorption and x-ray escaping LEH are evaluated. In addition, the radiation driven shock propagating in AI and Ti placed on the hohlraum wall, which is more representative of the drive inside the hohlraum, provides a unique information of radiation.

4:24PM CO4.00013 Scaling formula of ICF ignition targets and study of targets optimized in stability performance .
XIN LI, ZHENGSHENG DAI, WUDI ZHENG, Institute of Applied Physics and Computational Mathematics — LPI and RTI are the two main ingredients affecting the success of ignition. The gas fill near the Au wall along the inner laser cone is the main region which stimulates SRS instabilities. At this region, pressure balance and energy balance between the inside and the outside of inner laser cone path are obtained. A plasma scaling model in ignition hohlraums of ICF has been developed. RTI could be described by IFAR (InFlight Aspect Ratio) according to linear theory. Considering other scaling formula in capsule, a index, SPI (Stability Performance Index), has been proposed, which describes the balance between SPI and RTI. Designing of ignition targets is directed by using this index to obtain more margin for LPI and RTI.

4:36PM CO4.00014 Optimization of the x-ray spectrum and radiation symmetry in the hohlraum .
YONGKUN DING, SHAOEN JIANG, SHENYE LIU, SANWEI LI, TIANXUAN HUANG, Research Center of Laser Fusion, China Academy of Engineering Physics, Mianyang 621900, China, SHIYANG ZOU, KE LAN, WENHUA YE, YONGSHENG LI, GUOLI REN, JIANFA GU, Institute of Applied Physics and Computational Mathematics, Beijing 100088, China, BAHAN HAN ZHANG, XIAODONG CHEN, Research Center of Laser Fusion, China Academy of Engineering Physics, Mianyang 621900, China, WENBING PEI, SHAOPING ZHU, Institute of Applied Physics and Computational Mathematics, Beijing 100088, China, WEIYAN ZHANG, China Academy of Engineering Physics, Mianyang 621900, China — The ultimate goal of laser-driven hohlraum is to create a radiation environment that ablatively imploades a capsule to ignition and burn. To obtain high fusion yield with minimum laser energy, the hohlraum drive must meet both the limited non-Planckian emission (M-band) and excellent uniformity. On the series of Shenguang laser facilities, several experiments have been done to characterize the x-ray spectrum and radiation symmetry of the laser-heated hohlraum. By optimizing the hohlraum structures and materials, the hohlraum performance was improved in flux intensity, symmetry and spectrum.

4:48PM CO4.00015 Progress on Octahedral Spherical Hohlraum Study .
KE LAN, JIE LIU, WUDI ZHENG, WENYI HUO, GUOLI REN, DONGXIAN LAI, XIANTU HE, Institute of Applied Physics and Computational Mathematics — In this talk, we report our progress on octahedral spherical hohlraum study. First, we propose a spherical hohlraum with 6 Laser Entrance Holes (LEHs) of octahedral symmetry at a specific hohlraum-to- capsule radius ratio of 5.14, which has robust high symmetry during the capsule implosion. In addition, it also has potential superiority on low backscatter without supplementary technology. Second, we study the laser arrangement and constraints of the octahedral hohlraums. As a result, 6^520B to 6^0, the injection angle of laser beams, is proposed as the optimum candidate range for the octahedral hohlraums. Third, we propose a novel octahedral hohlraum with LEH shields and cylindrical LEHs, in order to increase the laser coupling efficiency and improve the capsule symmetry and to mitigate the influence of the wall blowoff on laser transport. Finally, we study the sensitivity of capsule symmetry inside the octahedral hohlraums to laser power balance, pointing accuracy, deviations from the optimal position and target fabrication accuracy.

Monday, October 27, 2014 2:00PM - 5:00PM —
Session C05 DIII-D Tokamak Galerie 2/3 - Stanley Kaye, Princeton Plasma Physics Laboratory

2:00PM C05.00001 Overview of Recent DIII-D Experimental Results 1, M.E. FENSTERMACHER, Lawrence Livermore National Laboratory, DIII-D TEAM — Recent DIII-D experiments have added to the ITER physics basis and to physics understanding for extrapolation to future devices. Physics mechanisms contributing to resonant magnetic perturbation ELM suppression and QH-mode were identified. The QH-mode operating parameters were extended to ITER-relevant parameters and predicted Super-H mode performance was observed at high shaping. Upgraded divertor Thomson data was combined with edge modeling to identify the core density limit at divertor detachment. Pedestal studies were done to determine the role of \( n_e \), \( Z_{eff} \) and kinetic ballooning mode instabilities in controlling pedestal structure. Injection of massive high-Z gas dissipates magnetic and kinetic energy of runaway electron beams. 3D magnetics data validate several linear MHD codes, including ability to predict neoclassical tearing viscosity torque. Feedback control of applied 3D fields facilitates access to increased \( \beta_n \) values above the no-wall limit. The effect of test blanket module (TBM) fields on fast ion losses and momentum transport, and partial correction of TBM fields at high \( \beta_n \) was achieved. Density gradient driven trapped electron modes and core \( n_e \) peaking were controlled by electron cyclotron heating suggesting a possible burn control technique.

1Work supported by the US DOE under DE-FC02-04ER54968 and DE-AC52-07NA27344.

2:12PM CO4.00002 Controlling DIII-D QH-Mode Particle and Electron Thermal Transport with ECH .
D.R. ERNST, MIT, K.H. BURRELL, GA, T.L. RHODES, UCLA, W. GUTTENFELDER, PPPL, G.R. MCKEE, U. Wisc., B.A. GRIERSON, PPPL, C. HOLLAND, UCSD, A. DIMITS, LLNL, C.C. PETTY, GA, L. SCHMITZ, UCLA, G. WANG, GA, L. ZENG, E.J. DOYLE, UCLA, M.E. AUSTIN, U. Texas — Quiescent H-mode core particle transport and density peaking are locally controlled by modulated electron cyclotron heating (ECH) at \( \rho \sim 0.2 \). Gyrokinegenic simulations show density gradient driven trapped electron modes (TEMs) are only unstable in the inner core, where the density profile flattens in response to ECH. Thus \( \alpha \)-heating could reduce density peaking, providing burn control. Density fluctuations from Doppler backscattering intensity at TEM wavenumbers \( k_{\perp} \) \( \sim 0.8 \) during ECH, while new quasi-coherent modes are observed with adjacent toroidal mode numbers consistent with TEMs. Separately, ECH at two-deposition locations \( (r/a \sim \rho = 0.5 \& 0.7) \) varied the electron temperature gradient. A jump in "heat pulse" diffusion during the scan indicates a critical gradient was crossed.

2Work supported by the US DOE under DE-FC02-08ER54966, DE-FC02-04ER54968, DE-FG02-08ER54984, DE-AC02-09CH11460, DE-FG02-89ER53296; DE-FC02-11ER55104, DE-AC52-07NA27344 & DE-FG03-97ER54415.
2:24PM CO5.00033 Experiments to Understand and Control Energetic Particle Transport by Alfvén Eigenmodes

W.W. HEIDBRINK, C. COLLINS, University of California Irvine, D.C. PACE, M.A. VAN ZEELAND, General Atomics, C.T. HOLCOMB, Lawrence Livermore National Laboratory — Alfvén eigenmodes (AE) cause appreciable fast-ion transport in both steady-state scenario and in L-mode current ramp plasmas. All fast-ion diagnostics that are sensitive to a populated portion of phase space observe reductions in signal relative to classical predictions in the presence of many, small-amplitude AEs. Theory indicates that the many wave-particle resonances in these plasmas results in stochastic transport and critical gradient behavior. Initial data from a modulation experiment is consistent with the hypothesis that the fast-ion transport becomes “stiff.” Another experiment investigates whether AE-induced transport from the core couples with edge losses induced by test-blanket module fields to enhance localized heating. Application of electron cyclotron heating to control the AEs gives mixed results: AEs are sometimes stabilized but the dependence on the fast-ion and q profiles is complex.

1 Work supported by the US Department of Energy under SC-G903402, DE-FC02-04ER54098 and DE-AC52-07NA27344.

2:36PM CO5.00044 Magnetic Measurements of MHD Toroidal Dynamics and Its Influence on Massive Gas Injection in DIII-D

D. SHIRAKI, N. COMMAUX, Oak Ridge National Laboratory, N.W. EIDIETIS, General Atomics, E.M. HOLLMANN, V.A. Izzo, R.A. MOYER, University of California San Diego — Measurements from the DIII-D magnetic diagnostic system are used to characterize the low-order MHD activity leading up to the thermal quench during fast shutdowns induced by massive gas injection (MGI). The evolution of the 3D fields measured at the vessel wall are found to be consistent with the destabilization of modes by the inwardly propagating cold front passing low-order rational surfaces. This MHD activity, which is dominantly n=1, can be characterized by the n=1 magnetic signal measured on the low-field side of the plasma. The toroidal evolution of this MHD is found to be influenced by three factors: the injector location, pre-MGI plasma rotation, and large n=1 error fields. The effects of the toroidal phase of this n=1 mode on toroidal radiation asymmetries are discussed. Experimental results are compared with simulations of MGI in DIII-D equilibria using the NIMROD code [1]. The effects of existing MHD structures prior to MGI, such as locked islands, are compared.


1 Work supported by the US Department of Energy under DE-AC50-00OR22725, DE-FC02-04ER54698, and DE-FC02-07ER54546.

2:48PM CO5.00055 Simulations of DIII-D Rapid Shutdown Experiments with One and Two Gas Jets

V.A. IZZO, E.M. HOLLMANN, R.A. MOYER, University of California San Diego, N. COMMAUX, D. SHIRAKI, Oak Ridge National Laboratory, N.W. EIDIETIS, P.B. PARKS, General Atomics — DIII-D has two massive gas jets for disruption mitigation, separated by 120° degrees toroidally and poloidally. Based on two radiated power measurements made at 90° and 210° degrees toroidally, little variation has been observed in the toroidal distribution of radiated energy between shots in which just one gas jet is fired, or both are fired. Three NIMROD simulations of massive neon injection - each jet individually and both simultaneously - are compared with the measurements. For each case, we calculate the radiation toroidal peaking factor (TPF) in two ways: 1) using only information from 90° and 210°, and 2) using full toroidal information. The two-point TPF reproduces the experimental result of little variation depending on gas jet(s) used. But, the real TPF shows significant variation, with a logical trend in which two jets produces more symmetric radiated power than one. This comparison suggests that the lack of experimental trend may be a measurement artifact.

1 Work supported by the US DOE under DE-FC02-95ER54309, DE-FC02-07ER54917, DE-AC05-00OR2275 and DE-FC02-04ER54698.

3:00PM CO5.00006 Plasma Imaging of the DIII-D Tokamak

S.L. ALLEN, C.J. LASNIER, W.H. MEYER, LLNL, H. HOWARD, ANU, A.R. BRIESEMEISTER, ORNL — The LLNL IR/visible periscope views the entire DIII-D plasma cross section and a new beamsplitter enables simultaneous measurements with IR and visible cameras. In the lower divertor, a Coherence Imaging System (CIS) measures the 2-D flow of CII ions with 1 ms time resolution. Visible color movies obtained during Li dropper operations, N2 puffing, and D2 puffing provide insight into SOL flows; trends are seen with the direction of the toroidal field. Localized changes in recycling are compared with changes in heat flux. A second CIS is being installed to measure impurity ion flow on the periscope. The lower divertor CIS system has been upgraded to include a new in-situ calibration system and temperature control, which has significantly increased the quality of the flow measurements. Rapid inversion of the coherence phase shift data maps the toroidal plasma flow to magnetic flux surfaces. The CIS carbon flow measurements are compared with conventional spectroscopy and Mach probe measurements of the main ion flow.

1 Work supported by the US DOE under DE-AC52-07NA27344, DE-AC05-00OR22725, DE-FC02-04ER54698.

3:12PM CO5.00007 Advances in Simulating Detached Plasmas in DIII-D Using EUDGE

M.E. GROTH, Aalto University, E.T. MEYER, G.D. PORTER, M.E. FENSTERMACHER, D.N. HILL, C.J. LASNIER, M.E. RENSKING, T.D. ROGLNLEI, LLNL, N.H. BROOKS, A.W. LEONARD, General Atomics, J.G. WATKINS, SNL — Simulations of detached divertor plasmas in lower single-null L-mode discharges in DIII-D with the fluid edge code EUDGE show that the measured total radiated power, total ion current and total power to both the inner and outer targets can be reproduced by the simulations within the uncertainty of the measurements. These results were obtained by including cross-field drifts and assuming chemical sputtering yields twice as high as published by Davis et al. [1]. However, by assuming higher chemical sputtering yields, the divertor carbon source, as indicated by low charge-state carbon emission, is overestimated by almost an order of magnitude indicating that deuterium radiation may play a dominant role. The impact of these imposed radiative losses on the electron density and temperature, as well as deuterium radiation across the outer divertor leg will be presented.


1 Work supported in part by the US Department of Energy under AC52-07NA27344, DE-FC02-04ER54698, and DE-AC04-94AL85000.

3:24PM CO5.00008 Reduced Net Erosion of High-Z PFC Materials in DIII-D Divertor

D.L. RUDAKOV, UCSD, P.C. STANGEBY, J.D. ELDER, UTIAS, W.R. WAMPLER, D.A. BUSCHENAUER, J.G. WATKINS, SNL, J.N. BROOKS, A. HASSANEIN, T. SIZYUK, Purdue, A.R. BRIESEMEISTER, ORNL, A.G. MCLEAN, LLNL, C.P. CHROBAK, H.Y. GUO, A.W. LEONARD, C.P.C. WONG, GA — DICH samples featuring 1 cm and 1 mm diameter W films deposited on a Si substrate were exposed in DIII-D near the attached outer strike point of LSN L-mode discharges. The measured net and gross erosion rates of W, determined from post-mortem ion beam analysis (IBA) of 1 cm and 1 mm samples, were 0.14 and 0.48 nm/s, respectively, giving net/gross erosion ratio of 0.29. REDEP/WBC modeling of this experiment yielded a very close ratio of 0.33. Projection of the modeling results to ITER shows very low net erosion of W. In another experiment Mo-coated samples were exposed with 13CH4 gas injected ~2 cm upstream of DII/ES. Reduction of Mo erosion was evidenced in situ by the suppression of Mol line radiation. Post-mortem IBA showed that the net erosion of Mo was below the measurement resolution of 0.5 mm, corresponding to a rate of ≤0.07 nm/s. Compared to the previously measured erosion rates, this constitutes a reduction of more than 10X.

1 Work supported in part by the US DOE under DE-FC02-07ER54917, DE-AC04-94AL85000, DE-AC05-00OR22725, DE-AC52-07NA27344 & DE-FC02-04ER54698.
3:36PM CO5.00009 H-mode Pedestal Enhancement and Improved Confinement in DIII-D with Lithium Injection1, G.L. JACKSON, T.H. OSBORNE, G.A. MAINGI, D.J. BATTAGLIA, D.K. MANSFIELD, A.L. ROQUEMORE, B.A. GRIERSON, PPPL, C.P. CHROBAK, UCSD, A.G. MCLLEAN, LLNL, G.R. MCKEE, Z. YAN, U. Wisc. — Lithium has been injected into DIII-D discharges leading to larger density and temperature pedestal widths and pedestal pressure increases. The lithium injection allowed transitions from ELMing to ELF free H-mode with energy confinement improvements up to 70%, compared to similar discharges without lithium. Lithium was injected directly into the plasma and SOL as an aerosol (44 μm dia particles) using a “lithium dropper” with no increase in radiated power. The lithium injection also led to density fluctuations of up to 8% in the pedestal region in the frequency range ≈40 - 150 kHz, measured by the BES diagnostic [1]. We will discuss experiments to obtain ELM-free performance and enhanced pedestals with lithium, EPED modeling to determine proximity to the peeling-ballooning boundary, and conditions for obtaining reduced recycling.

1Z. Yan, et al., these proceedings

3:48PM CO5.00010 Stability Limits in High Performance, Negative Central Shear Discharges1, J.M. HANSON, J. BIALEK, G.A. NAVRATIL, K.E.J. OLOFPSSON, F. TURCO, Columbia U., M. CLEMENT, U. California San Diego, J.R. FERRON, A.M. GAROFALO, R.J. LA HAYE, M.J. LANCOT, E.J. STRAIT, General Atomic, C.T. HOLCOMB, Lawrence Livermore National Laboratory — Exploration of negative central shear equilibria in DIII-D has yielded discharges that transiently achieve βN ≈ 4. The discharges exhibit broad current density profiles, leading to a significant separation in the no- and with-wall ideal kink stability limits predicted by MHD theory. As the no-wall limit is approached and exceeded in experiments, performance is often limited by n=1 resistive wall mode (RWM) instabilities that lead to abrupt collapses of the plasma stored energy. In addition, instabilities with n=1 rotating tearing precursors are observed when minimum q value drops below 2. Theoretical calculations predict that magnetic feedback control using the in-vessel coils (internal coils) can provide RWM stabilization to βN values approaching the n=1 ideal-wall limit. In experiments, applying l-coil control indeed facilitates access to increased βN values above the no-wall limit.

1Work supported by the US Department of Energy under DE-FC02-04ER54698, DE-AC02-09CH11466, DE-FG02-07ER54917, DE-AC52-07NA27344 and DE-FG02-89ER53296.

4:00PM CO5.00011 Coupling of Applied Non-axisymmetric Fields to Toroidal Torque1, N.C. LOGAN, J.-K. PARK, J.E. MENARD, Princeton Plasma Physics Laboratory, E.J. STRAIT, C. PAZ-SOLDAN, M.J. LANCOT, General Atomic — Recent advances in the modeling of neoclassical toroidal viscosity (NTV) have enabled realistic predictions of the coupling between applied non-axisymmetric fields and the resultant toroidal torque in the DIII-D tokamak. The strong dependence of the NTV on the amplified plasma kink response reduces the control of the non-resonant torque to a single mode model, in which the torque optimization is equivalent to an optimization of the net non-axisymmetric field’s overlap with the spatial structure of the dominant mode. This single mode model has enabled efficient feed-forward correction of the n = 1 and n = 2 intrinsic error fields and n = 1-3 proxy error fields in NTV dominated scenarios. In addition, rotation drive toward a neoclassical offset using multiple coil sets has been optimized in accordance with the single mode model. Similar linear optimization techniques could be used to design future coil sets for rotation control, while inclusion of multimodal effects will be necessary for rotation profile control.

1Work supported by the US Department of Energy under DE-AC02-09CH11466 and DE-FC02-04ER54698.

4:12PM CO5.00012 2D Measurements of TEM Structure at Varying Driven Toroidal Rotation on DIII-D1, S.E. ZEMEDKUN, Y. CHEN JR, T. MUNSAT, S.E. PARKER, W. WAN, U. Colorado, S. CHE, C.W. DOMIER, N.C. LUHMANN, L. YU, UC-Davis, B.J. TOBIAS, PPPL — The first experimental 2D mapping of drift modes, trapped electron mode (TEM) spatial evolution, Tq fluctuations, and dispersion relations are achieved using electron cyclotron emission imaging (ECEI) in a regime far from ITG parameter space in DIII-D. Linear gyrokinetic simulations with the GEM code find that the TEM is most unstable in the parameter regimes studied (a/Lo = 1.27, a/LTv= 1.9, a/LTe = 3.3), and exhibit a similar real frequency and eigenmode structure to that observed with ECEI. Measurements are made in L-mode discharges with neutral beam and electron cyclotron waves at fixed heating power over a range of driven toroidal rotation rates. 2D maps of the mode structure are determined using correlation techniques, and dispersion plots are constructed from the cross-phase and cross-spectral power. For different levels of NBI momentum input, Tq fluctuations and eigenmode structures show a similar real frequency and eigenmode structure to that observed with ECEI. Measurements are made in L-mode discharges with neutral beam and electron cyclotron waves at fixed heating power over a range of driven toroidal rotation rates. 2D maps of the mode structure are determined using correlation techniques, and dispersion plots are constructed from the cross-phase and cross-spectral power. For different levels of NBI momentum input, Tq fluctuations and eigenmode structures show a similar real frequency and eigenmode structure to that observed with ECEI.

1Supported by US DOE under DE-FC02-05ER54816, DE-SC0003913, DE-FG02-99ER54531, DE-AC02-09CH11466, DE-FC02-04ER54698.

4:24PM CO5.00013 Nonlinear Coupling Amongst Rotating Magnetic Islands in DIII-D1, B.J. TOBIAS, B.A. GRIERSON, M. OKABAYASHI, Princeton Plasma Physics Laboratory, C.M. MUSCATELLO, C.W. DOMIER, N.C. LUHMANN JR, UC-Davis, S.E. ZEMEDKUN, U. Colorado-Boulder, T. MUNSAT, U. Colorado — The appearance of magnetic islands at multiple rational surfaces limits performance and increases the risk of locked-mode discharges. These islands initially rotate independently, reflecting the differential flow of the background ion fluid. As the discharges progress, however, the phase-locking of two or more islands, e.g. 3/2 and 2/1, exacerbates confinement degradation by several mechanisms, including a flattening of the core rotation profile that increases the penetration depth of edge-localized modes (ELMs). However, neoclassical tearing mode structure can be manipulated to drive an inversion in the toroidal rotation profile, accelerating the edge plasma to maintain the local shearing rate, without additional neutral beam power. Although nonlinear 3-wave coupling is still observed, phase-locking is avoided and the thermoelectric neutron rate remains elevated, despite the discharge developing larger islands (at larger radii) that damp the toroidal angular momentum and reduce βN.

1This work is supported in part by the US DOE under DE-AC02-09CH11466, DE-FG02-99ER54531, DE-SC0003913, and DE-FC02-04ER54698.

4:36PM CO5.00014 3D Field-Induced Transport and Plasma Response Leading to ELM Suppression in DIII-D1, S.P. SMITH, C. PAZ-SOLDAN, R.J. GROEBNER, General Atomics, O. MENEGHINI, ORAU, R. NAZIKIAN, B.A. GRIERSON, PPPL, M.E. AUSTIN, U. Texas-Austin, J.D. CALLEN, U. Wisc.—Madison, E.M. DAVIS, UCSD, T.L. RHODES, G. WANG, L. ZENG, UCLA — A clear increase in trapped electron mode (TEM) scale density fluctuation levels ne is seen at the top of the pedestal as the plasma transitions from edge localized mode (ELM) to ELM suppression with applied 3D resonant fields. Additional increases in Tq fluctuations and line-integrated ne at the top of the pedestal are seen as the 3D field strength is increased. High resolution Tq and ne profile measurements near the top of the pedestal show strong transport scaling with the applied field (1/|LTq|, 1/|Lne| ~ l2) during ELM suppression. These latter results are consistent with the magnetic flutter model regulating transport at the top of the pedestal, possibly driven by kink mode coupling, however the former results support a 3D modification of microturbulence stability as the process by which ELMs are suppressed.

1Work supported by the US Department of Energy under DE-FC02-04ER54698, DE-AC02-09CH11466, DE-FG03-97ER54415, DE-FG02-92ER54139, DE-FG02-94ER54235, DE-FG02-07ER4917, and DE-FG02-08ER54984.
4:48PM CO5.00015 Using Quiescent H-mode to Access an Improved High Pressure Plasma Edge1, W.M. SOLOMON, B.A. GRIERSON, R. NAZIKIAN, PPPL, K.H. BURRELL, A.M. GAROFALO, T.H. OSBORNE, P.B. SNYDER, General Atomics, A. LOARTE, ITER, G.R. MCKEE, U. Wisc.-Madison, M.E. FENSTEMACHER, LLNL — Experiments on DIII-D have extended Quiescent H-mode (QH-mode) to high density through the use of strong shaping, overcoming a long-standing limitation in QH-mode operation, a high confinement state of the plasma that does not exhibit edge localized modes. These experiments have navigated a valley of improved edge peeling-balooning stability dubbed “Super H-mode,” which opens up at high density with strong plasma shaping. The thermal energy confinement time increases due to improvements in both the pedestal height and the core transport. Theoretical calculations of the pedestal height and width as a function of density using the EFED model are in quantitative agreement with the measurements. Together with the achievement of high beta, high confinement and low q95 for many energy confinement times, these results extend QH-mode as a potentially attractive operating scenario for ITER and point to a path for a new high performance regime that could improve the attractiveness of a fusion reactor.

1Work supported by the US Department of Energy DE-AC02-09CH11466, DE-FC02-04ER54698, DE-FG02-89ER53296, DE-FG02-08ER55499 and DE-AC52-07NA27344.

Monday, October 27, 2014 2:00PM - 5:00PM — Session CO7 Laser Wakefield Accelerators Galerie 6 - Wim Leemans, Lawrence Berkeley National Laboratory

2:00PM CO7.00001 Direct Laser Acceleration of Electrons in a Plasma Wakefield with Ionization Injection,J. L. SHAW, F.S. TSUNG, N. LEMOS, K.A. MARSH, N. VAFAEI-NAJAFABADI, W.B. MORI, C. JOSHI, University of California Los Angeles — We show through experiments and supporting simulations the role of direct laser acceleration (DLA) of electrons in a plasma accelerator when ionization injection of electrons is employed to inject charge into the laser-produced wake. If the laser pulse is intense enough to expel most of the plasma electrons but is nevertheless long enough to overlap the electrons trapped in the first accelerating potential well (bucket) of the wakefield, then the betatron oscillations of the electrons in the plane of the laser polarization in the presence of an ion column can lead to an energy transfer from the laser pulse to the electrons. DLA can be a major contributor to the maximum electron energy, and the energy gain due to DLA can exceed that due to laser wakefield acceleration for certain laser and plasma parameters.

1Experimental work supported by DOE grant DE-SC0010064. Simulation work done on the Hoffman2 Cluster at UCLA, and on NERSC. Fellowship provided by NSF Graduate Fellowship DGE-0707424.

2:12PM CO7.00002 GeV Electrons due to a Transition from Laser Wakefield Acceleration to Plasma Wakefield Acceleration, M.Z. MO, Department of Electrical and Computer Engineering, University of Alberta, Edmonton, Canada, P.-E. MASSON-LABORDE, CEA DAM DIF, A. ALI, Department of Electrical and Computer Engineering, University of Alberta, Edmonton, Canada, S. FOURMAUX, P. LASSONDE, J.-C. KIEFFER, INRS-EMT, Université du Québec, Varennes, Canada, W. ROZMUS, Theoretical Physics Institute, University of Alberta, Edmonton, Canada, D. TIEYCHENNE, CEA, DAM, DIF, R. FEDOSEJEVS, Department of Electrical and Computer Engineering, University of Alberta, Edmonton, Canada — The Laser Wakefield Acceleration (LWFA) experiments performed with the 200 TW laser system located at the Canadian Advanced Light Source facility at INRS, Varennes (Québec) observed at relatively high plasma densities (1x10^19 cm^-3) electron bunches of GeV energy gain, more than double of the predicted energy using Lu’s scaling law. This energy boost phenomena can be attributed to a transition from LWFA regime to a plasma wakefield acceleration (PWFA) regime. In the first stage, the acceleration mechanism is dominated by the bubble created by the laser in the regime of LWFA, leading to an injection of a large number of electrons. After propagation beyond the depletion length, where the laser pulse is depleted and it can no longer sustain the bubble anymore, the dense bunch of high energy electrons propagating inside the bubble will drive its own wakefield in the PWFA regime that can trap and accelerate a secondary population of electrons up to the GeV level. 3D particle-in-cell simulations support this analysis, and confirm the scenario.

2:24PM CO7.00003 Single-shot visualization of evolving laser wakefields using an all-optical streak camera1, ZHENGYAN LI, HAI-EN TSAI, XI ZHANG, CHIH-HAO PAI, YEN-YU CHANG, RAFAJ ZGADZAJ, XIAOMING WANG, VLADIMIR KHUDIK, GENNADY SHVETS, MICHAEL DOWNER, University of Texas at Austin — We visualize ps-time-scale evolution of an electron density bubble, a wake structure created in atmospheric density plasma by an intense ultrafast laser pulse, from the phase “streak” that the bubble imprints onto a probe pulse that crosses its path obliquely. Phase streaks, recovered in one shot using frequency-domain interferometry, reveal formation, propagation and coalescence of the bubble within a 3 mm long ionized helium gas target. 3D particle-in-cell (PIC) simulations validate the observed density-dependent bubble evolution, and correlate it with generation of a quasi-monoenergetic ~ 100 MeV electron beam. The results provide a basis for understanding optimized electron acceleration at plasma density ne ~ 2e19 cm^-3, at which the bubble formed and persisted until the jet exit, enabling acceleration over a distance slightly exceeding the dephasing length. In contrast, at lower density, electrons accelerated inefficiently due to weak laser self-focusing and late bubble formation. At higher density, very strong self-focusing also led to low quality electrons due to early bubble formation and strong dephasing. Bubble coalescence due to beam loading further degrades electron acceleration.

1This work was supported by DOE grants DESC0011617 and DE-SC0007889 and by the NSF-DOE Partnership in Plasma Science program.

2:36PM CO7.00004 Manipulating ionization-injection trapping in laser wakefield accelerators2, NUNO LEMOS, JESSICA SHAW, Univ of California - Los Angeles, C.J. ZHANG, Tsinghua university, K.A. MARSH, CHAN JOSHI, Univ of California - Los Angeles — Experiments have shown that when using tunneling ionization as an injection mechanism in laser wakefield acceleration (LWFA), electrons can be trapped and accelerated using roughly four times less laser power than required to self-trap electrons. Using the three-dimensional (3D) scaling laws for LWFAs in the blowout regime, it was found that injecting electrons directly into the wakefield significantly increases the potential difference for the electron to become trapped. This study further explores this injection mechanism in order to lower the electron energy spread and increase the available normalized wake potential. Two and 3D particle-in-cell simulations show that by changing the laser pulse duration and plasma density, one can control the trapping condition and energy spread.

2Experimental work supported by DOE grant DE-SC0010064. Simulation work done on the Hoffman2 Cluster at UCLA and on NERSC. Fellowship provided by NSF Graduate Fellowship DGE-0707424.
2:48PM CO7.00005 A two-stage –injector-accelerator– plasma wakefield accelerator at FACET

NAVID VAFAEI-NAJAFABADI, C.E. CLAYTON, K.A. MARSH, W. AN, W. B. MORI, C. JOSHI, UCL, W. LU, Tsinghua University, UCL, E. ADLI, University of Oslo, SLAC National Accelerator Laboratory, S. CORDE, J. FREDERICO, S.Z. GREEN, M. LITOS, S. GESNER, D. WALZ, C.I. CLARKE, M.J. HOGAN, V. YAKIMENKO, SLAC National Accelerator Laboratory, P. MUSSOGLI, Max Planck Institute for Physics — Ionization injection is important for a beam-driven plasma-wakefield accelerator because it can be used to embed electrons within a highly-relativistic wake. Furthermore, the placement of an acceleration stage following such an injector opens the possibility of controlling the charge, emittance, and energy spread of the beam. Such two-stage accelerators exhibit exceptional performance, with record high energy and bunch length. However, plasma wakefield acceleration in SLAC. The ionization injection stage is formed by a 10 cm density up-ramp of Li vapor, which overlaps with a density down-ramp of He. The He atoms provide a source of electrons for injection into the wake that is created by the 3nC, 20 GeV FACET electron beam. The injected electrons are then accelerated by the wakefield generated in either a 30 cm, 2.5x10^{-7} cm^{-3} or a 130 cm, 8x10^{-10} cm^{-3} Li plasma. Narrow-divergence electron bunches with energies as high as 30 GeV attributable to He electrons are observed.

3:00PM CO7.00006 First Results from Hollow-Channel Plasma Wakefield Acceleration Experiments with Positron Beams at FACET

SPENCER GESNER, ERIK ADLI, JAMES ALLEN, CHRISTINE CLARKE, SLAC, CHRIS CLAYTON, UCL, JOEL FREDERICO, SELINA GREEN, MARK HOGAN, SLAC, CHAN JOSHI, UCL, MICHAEL LITOS, SLAC, KEN MARSH, UCL, SEBASTIEN CORDE, SLAC, NAVID VAFAEI, UCL, VITALY YAKIMENKO, SLAC, WEIMING AN, UCL, E220 COLLABORATION — We report on the first results from a hollow-channel plasma wakefield acceleration experiment using positron beams at FACET. A meter-scale plasma channel is created by field ionizing lithium vapor using an intense laser pulse that has a transverse J8 Bessel profile. The plasma channel is roughly 600 µm in diameter and has ionized vapor at its center. A 20.35 GeV positron beam with spot size of roughly 50 µm was sent through the channel. We observed the transverse beam profile while varying the position of the beam relative to the channel. Our measurements clearly indicate that a plasma channel was formed. We characterize the strength of the wake and discuss plans for subsequent experiments.

3:12PM CO7.00007 Simulation studies on electron beam formation in high density plasmas in Laser Wake Field Acceleration

BHAVESHT PATEL, CHANDRASHEKAR JOSHI, UCL — In recent experimental work based on Laser Wakefield Acceleration, Rao et al. [1] have demonstrated production of monoenergetic, 35 MeV electron bunch using 3 TW pulse and high density, 5.8x10^{-3} plasma. The electron beam formation in such scenario relies greatly on physical processes like relativistic self-focusing and modulation instability. Further, in view of the fact that the laser pulse has a pulse-length several times the plasma wavelength, it may be surmised that the beam electrons may gain energy by direct laser acceleration in addition to that from the longitudinal fields. In present work, laser wakefield acceleration and electron bunch formation for this relatively low intensity laser pulse and a high density plasma is studied using particle-in-cell code OSIRIS. The objective here is to decipher the role of various physical mechanisms responsible for production of the surprisingly narrow energy electron bunch. The electrons are trapped only after the laser pulse is longitudinally compressed such that there is little overlap between the trapped electrons and the laser field. Thus the acceleration of beam electrons is due to the wakefield.


3:24PM CO7.00008 Optical Probing of Meter Scale Beam Driven Plasma Wakefield Accelerator

RAFAL ZGADZAJ, ZHENGYAN LI, M.C. DOWNER, University of Texas at Austin, SPENCER GESNER, SEBASTIEN CORDE, MIKE LITOS, CHRISTINE CLARKE, MAGAUX SCHMELTZ, JAMES ALLEN, SELINA GREEN, MARK HOGAN, VITALY YAKIMENKO, Stanford Linear Accelerator Center. E224 TEAM — We report results of optical visualization experiment at the FACET/SLAC user facility. Experiment E224, carried out in parallel to the ongoing e-beam driven wakefield experimental campaign at FACET, has the aim of optically observing both the short term and long term plasma structure produced by the e-beam driver. The SLAC plasma wakefield experiments have demonstrated the highest energy gain to date and continue work on further optimization. Direct visualization of the plasma wake structure would aid in the understanding of the dynamics of the beam plasma interaction and acceleration, and its optimization. It also would serve to benchmark simulations results which have been so far the main window into visualizing the beam plasma interaction. We will describe the optical probing geometry used in this initial run, a variation of a method previously developed in our group [1], as governed by the unique experimental challenges of the FACET beam driven experiments in their current configuration. We will discuss the current results, the limitations of the current experimental configuration, and the changes planned for future experiments.


3:36PM CO7.00009 Coherent phase space matching of staging plasma and traditional accelerator using longitudinally tailored plasma structure

XINLU XU, WEI LU, Tsinghua Univ, WARREN MORI, CHAN JOSHI, University of California Los Angeles, MARK HOGAN, SLAC National Accelerator Laboratory — For the further development of plasma based accelerators, phase space matching between plasma acceleration stages and between plasma stages and traditional accelerator components becomes a very critical issue for high quality high energy acceleration and its applications in light sources and colliders. Without proper matching, catastrophic emittance growth in the presence of finite energy spread may occur when the beam propagating through different stages and components due to the drastic differences of transverse focusing strength. In this paper we propose to use longitudinally tailored plasma structures as phase space matching components to properly guide the beam through stages. Theoretical analysis and full 3-dimensional particle-in-cell simulations are utilized to show clearly how these structures may work in four different scenarios. Very good agreements between theory and simulations are obtained.

3:48PM CO7.00010 Emittance Pressure Dominated Regimes for Resonant PWFA Experiments at SPARC Lab

ALBERTO MAROCCHINO, STEFANO ATZENI, dipartimento SBAI “La Sapienza” Roma, ENRICA CHIADRONI, MASSIMO FERRARIO, CLAUDIO GATTI, PASQUALE LONDRILO, INFN Italy, ANDREA MOSTACCI, dipartimento SBAI “La Sapienza” Roma, FRANCESCO MASSIMO, INFN Italy, LUIGI PALUMBO, dipartimento SBAI “La Sapienza” Roma, ANDREA ROSSI, INFN Italy, STEFANO SINIGARDI, Universita’ Bologna Italy — Considerable interest has been shown in the last few years in compact plasma accelerators characterized by extremely high accelerating gradients generated, e.g., by high brightness particle beams. PWFA is currently under investigation at SPARC Lab test facility [Frascati, Italy]. Despite ID model are too simple and limited to catch the whole underlying physics, they offer a simple and fast tool to assess possible working points. We discuss how these models can be analytically modified to extend their validity in the quasi-non-linear regime to phenomenologically account for damping effects. We also present 3D PIC simulations for emittance pressure dominated regimes. We discuss how elongated bunch, with a transverse dimension smaller than the longitudinal dimension, suffer from being drawn into the self-generated bubble and seed the two-stream instability in the witness bunch. A possible mechanism to reduce such an effect consists in using emittance-dominated bunch that can contrast the self-focusing force produced by the surrounding bubble.

This work performed [in part] under DOE Contract DE-AC02-76SF00515 [and any other funding agencies].

This research is supported by DOE grant number DE-SC0010064 and the plan programme 11P-1401 “Strong Field Science.”
4:00PM CO7.00011 High brightness electron beam generation through plasma density variation induced injection in beam or laser driven 3D nonlinear wakes, WEI LU, FEI LI, XINLU XU, Tsinghua University of Beijing, China, WARREN MORI, CHAN JOSHI, University of California, Los Angeles — High brightness electron beam generation is critical for the development of plasma wakefield accelerators. The generation of high current and low emittance electron beam through plasma density variation induced injection in charged beam or laser driven 3D nonlinear wakes is explored using full 3-dimensional particle-in-cell simulations. It is found out that the radial selection in the injection process and the transverse dynamics when the injected electrons move in the electron sheath of the wake determine the final beam quality, e.g., emittance, current and energy spread. Simulations show that brightness as high as $5 \times 10^{20} \text{Am}^{-2} \text{rad}^{-2}$ could be generated under proper condition.

4:12PM CO7.00012 Electron trapping condition of transverse ellipsoidal bubble in laser wake-field accelerator, MYUNGHOO CHO, YOUNGKUK KIM, MINSUP HUR, Ulsan Natl Inst of Sci & Tech — We present the condition of electron trapping in an ellipsoidal bubble in the LWFA, which is not well explained by the spherical bubble model. The formation of an ellipsoidal bubble, which is elongated transversely, frequently occurs when the spot size of the laser pulse is large compared to the plasma wavelength. First we introduce the relation between the bubble size and the field slope inside the bubble in longitudinal and transverse directions. Then we provide an ellipsoidal model of the bubble potential and investigate the electron trapping condition by numerical integration of the equations of motion. If the field slope in longitudinal direction reaches the maximum earlier than that in the transverse direction, the trapping condition is determined only by a transverse bubble radius. This gives a significantly less restrictive trapping condition than the spherical bubble model. The trapping condition is compared with three-dimensional particle-in-cell simulations and the electron trajectory in test potential simulation, from which we confirm the simulation result is consistent with the theoretical expectations.

4:24PM CO7.00013 Positron acceleration in doughnut wakefields in the blowout regime, JORGE VIEIRA, JOSE MENDONCA, RICARDO FONSECA, LUIS SILVA, GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal — Most important plasma acceleration results were reached in the so called bubble or blowout regime. Although ideally suited for electron acceleration, it has been recognized that non-linear regimes are not adequate to accelerate positrons. New configurations enabling positron acceleration in non-linear regimes would therefore open new research paths for future plasma based collider configurations. In this work, we explore, analytically and through 3D OSIRIS simulations, a novel configuration for positron acceleration in strongly non-linear laser wakefield excitation regimes using Laguerre-Gaussian laser drivers to drive doughnut shaped wakefields with positron focusing and accelerating fields [J. Vieira and J.T. Mendonca, PRL 112 215001 (2014)]. We demonstrate that positron focusing-fields can be up to an order of magnitude larger than electron focusing in the spherical blowout regime. The amplitude of the accelerating fields is similar to the spherical bubble model. Simulations demonstrate laser self-guiding and stable positron acceleration until the laser energy has been exhausted to the plasma. Other realisations of the scheme, using two Gaussian laser pulses, will also be explored.

4:36PM CO7.00014 Laser pulse group velocity in electrically-discharged capillary waveguides, JOOST DANIELS, Lawrence Berkeley National Lab, Eindhoven University of Technology, JEROEN VAN TILBOG, ANTHONY GONZALVES, CARLO BENEDETTI, CARL SCHROEDER, ERIC ESAREY, WIM LEMANS, Lawrence Berkeley National Lab, LOASIS/BELLA TEAM — Plasma channels are critical in maintaining high intensity laser fields over extended distances, such as required in efficient laser-plasma accelerators (LPAs). In LPAs, the background plasma electron density is a critical parameter as it influences the dephasing length - the distance of optimum acceleration - as well as laser guiding, accelerating wakefield amplitude and particle injection. In this talk a novel method is presented that measures the group velocity in the plasma through two-pulse spectral interferometry, from which we confirm the simulation result is consistent with the theoretical expectations.

4:48PM CO7.00015 Laser-Plasma Accelerator based compact, narrow bandwidth Thomson photon sources, C.G.R. GEDDES, S.G. RYKOVANOV, J.-L. VAY, A. BONATTO, C.B. SCHROEDER, E. ESAREY, W.P. LEMANS, LBNL — Compact, high-quality photon sources at MeV energies can be enabled by recent advances in Laser-Plasma Accelerator (LPA) beam quality (e.g. 1% level energy spread, low emittance) together with photon production strategies which take advantage of unique beam and plasma capabilities. LPA experiments will be reviewed which establish the basis for such a source. Simulations show that for electron beam parameters achieved in LPAs, plasma optics can be used to tailor beam divergence and minimize photon source bandwidth in a compact package. Source yield can be increased, for realistic laser parameters, via use of plasma channels to guide the scattering laser and/or control of laser pulse shape and chirp. The LPA can further be used to de-accelerate the electron beam after photon production to reduce undesired radiation. This is crucial to a laboratory or field operable source. The combination of these elements will be presented, towards a complete LPA-based high-flux photon source which is compact.

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.

3Now at Jena

2:00PM - 2:00PM – Session CP8 Poster Session II: International Tokamaks; ITER; Next-Step Devices; Turbulence & Transport; Intense Beam and Radiation Sources; Dusty and Complex Plasmas Preservation Hall -

CP8.00001 INTERNATIONAL TOKAMAKS; ITER; NEXT-STEP DEVICES; TURBULENCE & TRANSPORT –
CP8.00002 Experimental Measurements of the Lower Hybrid Electric Field and Induced Neutral Flow in Tore Supra by Optical Emission Spectroscopy\textsuperscript{1,} E.H. MARTIN, C.C. KLEPPER, R.C. ISLER, ORNL, M. GONICHE, IRFM, J.B.O. CAUGHMAN, ORNL. — Recently, the RF electric field vector ($\mathbf{E}_{\text{LH}}$) in front of a lower hybrid (LH) launcher, operating at 3.7 GHz, at the low field side of the Tore Supra tokamak was determined by spectroscopic analysis of passive $D_\alpha$ spectral emission from the near-antenna plasma. The $\mathbf{E}_{\text{LH}}$ was determined by globally minimizing the $\chi$ associated with the experimental and theoretical spectral line profile. The theoretical profile is calculated from a non-perturbative solution to the Schrödinger equation, which includes the magnetic and dynamic electric field vectors. The magnitude, the direction, and the scaling with LH power of the measured $\mathbf{E}_{\text{LH}}$ are fairly consistent with those calculated from a full-wave LH model. In addition to $\mathbf{E}_{\text{LH}}$, the inboard and an outboard neutral flow was determined from the Doppler shifts associated with the $D_\alpha$ and $D_\beta$ spectral profiles. It was found that excitation of the LH wave induced both an inboard and outboard co-current neutral flow, which is linearly dependent on injected power; preliminary results indicate ICRF decreases the LH wave-induced co-current neutral flow. Neutral flow velocities are consistent with measurements of ion flow velocities obtained by charge exchange recombination spectroscopy.

\textsuperscript{1}Work supported by the US DOE under Contract No. DE-AC05-00OR22725 with UT-Battelle, LLC., and by the European Communities under the contract of Assoc. EURATOM-CEA and within the framework of the EFDA.

CP8.00003 Dependence of plasma rotation braking on ion temperature and non-axisymmetric magnetic field spectra in high normalized beta KSTAR plasmas\textsuperscript{1}, Y.S. PARK, S.A. SABBAGH, J.W. BERKERY, J.M. BIALEK, Columbia University, W.H. KO, Y.M. JEON, J.G. BAK, S.H. HAHN, J. KIM, S.G. LEE, NFRI, Korea, S. JARDIN, PPPL, M.J. CHOI, G.S. YUN, POSTECH, Korea, H.K. PARK, UNIST, Korea. — H-mode plasma operation of KSTAR has surpassed the ideal MHD $n = 1$ no-wall limit by achieving high normalized beta up to 2.8 while reducing plasma internal inductance to near 0.7. Non-axisymmetric fields were applied using in-vessel control coils with varied $n = 2$ field spectra, ECH, and supersonic molecular beam injection to alter the plasma toroidal rotation profile in high beta H-mode plasmas and to analyze their distinct effects on the rotation. The rotation profile was significantly altered in a self-similar fashion with rotation level reduced by more than 60% without tearing activity or mode locking using the full range of techniques. Changes in the steady-state rotation profiles are analyzed to determine the physical aspects of NTV. The NTV scaling with $\alpha_1^2$ shows good agreement with the measured profile change. The NTV coefficient scales as $\gamma_1^2\alpha_1^2$, in general agreement with the low collisionality "1/\nu" regime scaling of NTV theory. Resistive tearing stability determined by examining the classical tearing stability index is discussed, and the result is compared with two-fluid resistive MHD solutions from the M3D-C\textsuperscript{1} code. The effect of plasma rotation profile on tearing stability is examined using the M3D-C\textsuperscript{1} analyses.

\textsuperscript{1}Supported by U.S. DOE grant DE-FG02-99ER54524.

CP8.00004 Simulation Study of EAST Scenarios with the Tokamak Simulation Code\textsuperscript{1}, C.E. KESSEL, R.V. BUDNY, W.M. SOLOMON, PPPL, YONG GUO, IPP-CAS, P.T. BONOLI, PSFC-MIT. — The EAST experiment has upgraded its heating and current drive systems to allow significant non-inductive current drive. The goal of 100% non-inductive plasma current is being sought with 10 MW of LH, 8 MW of NBI, and 12 MW of ICRF. For 2014, the target is H-mode for 30 s. A series of scenarios are examined for plasma currents of 350, 450, 550, and 650 kA, to examine the H/CD requirements and the rampup plasma strategies. The Tokamak Simulation Code is used with PF coils, structures, and feedback systems for plasma shape position and current. Based on previous EAST discharges that primarily used LH and ICRF, plasma and discharge parameters are determined. Examination of H/CD combinations, and energy transport models are reported.

\textsuperscript{1}Supported by U.S. DOE contract No. DE-AC02-09CH1146.

CP8.00005 TRANSP predictive modeling of EAST steady state plasmas\textsuperscript{1}, R.V. BUDNY, W.M. SOLOMON, B. GRIERSON, X. YUAN, C. KESSEL, PPPL, S. DING, IPP-Hefei, CN. — The EAST tokamak is starting operation with major upgrades to the heating, current drive, and diagnostic systems\textsuperscript{1}. We use the plasma transport code TRANSP to predict performance\textsuperscript{2} with nearly steady state non-inductive current conditions at plasma current near 500 kA and toroidal field near 2.3 T. The heating power is assumed to start with $\leq$ 4 MW of beam injection and continue with $\geq$ 3 MW of ICRH. Current drive of $\geq$ 2 MW of LHCD is assumed. The GLF23\textsuperscript{3} predictive model incorporated in TRANSP is used to predict temperatures, and TGLF\textsuperscript{4} to predict temperatures, toroidal rotation, and electron density profiles. We explore scans in parameters such as $I_p$, $B_t$, and boundary assumptions to maintain non-inductive and high performance.

\textsuperscript{1}Supported in part by U.S. DoE contract No. DE-AC02-09CH1146.

1\textsuperscript{[1]} G.Wan, et al., 41\textsuperscript{st} EPS Conf, Berlin (2014) O2.104;
\textsuperscript{2}R.V.Budny, Nucl. Fusion 52 (2012) 013001;

CP8.00006 Gyrokinetic simulation of microturbulence in EAST tokamak, YONG XIAO, TAIGE ZHANG, CHEN ZHAO, Institute for Fusion Theory and Simulation, Zhejiang University. — A complete understanding of anomalous transport is critical for designing future magnetic fusion reactors. It is generally accepted that the micro-scale turbulence leads to anomalous transport. For low beta toroidal plasmas, the electrostatic modes may dominate and ion temperature gradient (ITG) mode and trapped electron mode (TEM) are two very important candidates accounting for ion and electron turbulent transport respectively. Recently the massively parallel gyrokinetic simulation has emerged as a major tool to investigate the nonlinear physics of the turbulent transport. The newly-developed capabilities enable the gyrokinetic code GTC to simulate the turbulent transport for real tokamak plasma shape and profiles. These capabilities include a new gyrokinetic Poisson solver and zonal flow solver suitable for general plasma shape and profiles, improvements on the conventional four-point gyroaverage and newly-developed nonuniform initial marker loading. The GTC code is now able to import experimental plasma profiles and equilibrium magnetic field that come from the EFIT or TRANSP equilibrium reconstruction. Linear and nonlinear gyrokinetic simulations are carried out with the new capabilities in GTC for the electron coherent mode (ECM) recently observed in the EAST tokamak (EAST shot $\neq$ 38300). We found that in the pedestal region with strong electron temperature gradient, the unstable waves propagate in the electron diamagnetic direction, showing a trapped electron mode (TEM) feature. It is also found in the collisionless limit, the linear mode frequency is higher than that from the experiment.
CP8.00007 Investigation of the high density discharges on the J-TEXT Tokamak, PENG SHI, GE ZHUANG, LI GAO, JIE CHEN, QIANG LI, YANG LIU, XIAOLONG ZHANG, Institute of Fusion and Plasma Research, Huazhong University of Science and Technology, Wuhan 430074, PR China — Recently, the operation region has been explored for J-TEXT Ohmically heated discharges by means of gas puffing. The results showed that the maximum achievable density has been significantly expanded, from 0.43 nC (Greenwald limit) to 0.85 nC, after the stainless steel vacuum wall was covered by the graphite tiles. Nevertheless, the J-TEXT high density discharges were frequently terminated by a disruption. The investigation concluded that the maximum achievable density is strongly related to the total plasma current and density, but very weakly depended on the edge safety factor qρ. Some features of such disruption have been identified by analyzing the measured data from the 17-channel (covering ∼0.94a to 0.94a of the cross-section) FIR polarimeter-interferometer. For example, in the density ramp-up phase, asymmetry of density profile between the LFS (low field side) edge (r > 0.8a) and the HFS (high field side) edge (r < −0.8a) would appear gradually. In addition, a reversed density gradient on the HFS edge occurred. Before the disruption, edge density on the HFS suddenly dropped to a lower level and tended to restore the symmetry of density profile between the LFS and HFS edge. Simultaneously, the radiation measurements, including CIII impurity radiations, soft X-ray emissions and so on, indicated that plasma radiation increased dramatically. Such lower density level at the HFS edge can maintain for ∼100ms when qρ > 5, but less (or even null) for qρ < 3.5.

CP8.00008 Preliminary experimental observation of nonlocal transport due to SMBI on the J-TEXT tokamak, JINSHEI XIAO, ZHOUJUN YANG, GE ZHUANG, CHI ZHANG, MINGHAI LIU, Huazhong University of Science and Technology, STATE KEY LABORATORY OF ADVANCED ELECTROMAGNETIC ENGINEERING AND TECHNOLOGY TEAM — Experimental studies of nonlocal electron heat transport have been carried out in J-TEXT ohmic plasmas exploiting Supersonic Molecular Beam Injection (SMBI) system. By cooling the very edge plasma, a prompt (∼1ms) temperature rise of the plasma core can be induced. For a low density discharge with ne = 1.1 × 10^19 m^−3, the amplitude of ΔTe/Te exceeds 30% at r/a=0.17 (a is the minor radius). The duration of NLT phenomena is about 10ms, which is comparable with the energy confinement time of J-TEXT. The inverse radius in this discharge locates at r/a = 0.33 ∼ 0.4 and is outside the q=1 surface (r/a ∼ 0.3), which is estimated from the sawtooth inverse position. As plasma density increases, the nonlocal phenomena decay. Repetitive nonlocal phenomena can be induced by modulated SMBI, which distinctly exhibits the strong dependence on electron density. The critical density is about 1.6 × 10^19 m^−3.

CP8.00009 Halo and Runaway Currents in ITER1, ALLEN BOOZER, Columbia University — In ITER, halo currents can unacceptable increase maintenance requirements, and a strong current of runaway electrons cannot be allowed to occur. Halo-current mitigation may unacceptably exacerbate the problem of runaways. A strong halo current flows along magnetic field lines that intercept the walls just outside the main plasma body when the plasma becomes too kink unstable for the chamber walls to slow the growth rate. Basic physics constrains and simplifies the calculation of the effects of halo currents. The plasma current in ITER is naturally converted into a current of runaway electrons with a typical energy of about 10MeV by an exponential avalanche mechanism when the temperature drops much below 1keV for any reason. Pitch-angle scattering on high-Z impurities may be important but has not been adequately studied. Scattering may explain anomalies in runaway production seen in experiments. Scattering also affects the anisotropy of runaways, ea ≡ j_a/ne. The parallel current and number density of runaways are j_e and n_e. The power that runaway electrons lose by drag on background electrons is c_e0E_e. Runaway electron production is not energetically possible unless the parallel electric field satisfies E|| ≥ E_e/c_e.1

1 Supported by U.S. DoE grant DE-FG02-03ER54969

CP8.00010 ITER Plasma at Ion Cyclotron Frequency Domain: The Fusion Alpha Particles Diagnostics Based on the Stimulated Raman Scattering of Fast Magnetosonic Wave off High Harmonic Ion Bernstein Modes1, V. ALEXANDER STEFAN, Institute for Advanced Physics Studies, Stefan University, La Jolla, CA 92037 — A novel method for alpha particle diagnostics is proposed. The theory of stimulated Raman scattering (SRS) of the fast wave and ion Bernstein mode, IBM, turbulence in multi-ion species plasma is utilized for the diagnostics of fast ions. (4)He+(2), in ITER plasmas. Nonlinear Landau damping of the IBM on fast ions near the plasma edge leads to the space-time changes in the turbulence level, (inverse alpha particle channeling). The space-time monitoring of the IBM turbulence via the SRS techniques may prove efficient for the real time study of the fast ion velocity distribution function, spatial distribution, and transport.

2 Supported by Nikola Tesla Labs., La Jolla, CA 92037.

3 V. Alexander Stefan, Nonlinear Electromagnetic Radiation Plasma Interactions, (Stefan University Press, La Jolla, CA, 2008).

4 E. P. Velikhov, (Kurchatov Institute, Moscow, Russia), private communication in La Jolla, CA, 2007.

CP8.00011 Analysis and Measurements of 170 GHz ITER ECH Transmission Line Components1, SUDHEER JAWLA, SAMUEL SCHAUB, MICHAEL SHAPIRO, ELIZABETH KOWALSKI, RICHARD TEMKIN, Plasma Science and Fusion Center-MIT, USA, GREGORY HANSON, Oak Ridge National Laboratory, USA — In this paper we discuss two important issues related to the ITER 170 GHz ECH 63.5-mm diameter corrugated waveguide Transmission Lines (TL); 1 calculation of mode conversion losses in the expansion units for the TL and, 2) determination of mode contents in corrugated waveguides. Expansion units are needed to accommodate expansion and contraction along the TL from the gyrotron to the tokamak. A numerical mode matching code has been developed to estimate power losses due to mode conversion of the operating mode, HE11, to higher order modes as a result of the radial discontinuities in a sliding joint. Two designs were evaluated, a simple gap expansion unit and a more complex tapered expansion unit. We also present a novel method for determining the mode content of the linearly polarized (LP) modes of a corrugated waveguide using the method of moments. This method is based on calculating the low order irradiance moments of the measured radiated intensity profiles at several distances from the waveguide aperture. The proposed method is experimentally validated by the data measured from the 63.5-mm diameter corrugated waveguide using the vector network analyzer and a high purity HE11 mode generator at 170 GHz built by General Atomics.

1 Supported by the U.S. Department of Energy, Office of Fusion Energy Sciences and by the U.S. ITER Project managed by Battelle/Oak Ridge National Laboratory.

CP8.00012 Designing Diagnostics to Survive in ITER, CHRISTOPHER WATTS, ITER Organization, ITER TEAM — Adapting diagnostics to withstand the incredibly harsh environment of the ITER D-T plasma is a formidable engineering task. Hindrances include not only the nuclear environment, but also the high radiative heat fluxes, high particle fluxes and stray ECH radiation. Strategies to mitigate the impact of these run the gamut from shielding, through restricting, through appropriate materials selection, to refurbishment. Examples include the Langmuir probe system, where individual probes are protected by passive heat shields; retroreflectors recessed into the tokamak first wall in deep, baffled tunnels; plasma mirror cleaning systems; electronics components like piezo crystals and x-ray detectors vetted for the nuclear environment. These and other ITER diagnostic system designs will be highlighted to emphasize their strategies for dealing with the ITER environment. *The views and opinions expressed herein do not necessarily reflect those of the ITER Organization."
CP8.00013 Application of a GPU-Assisted Maxwell Code to Electromagnetic Wave Propagation in ITER 1, S. KUBOTA, W.A. PEEBLES, UCLA, D. WOODBURY, BYU, I. JOHNSON, A. ZOLFAHARI, PPPL — The Low Field Side Reflectometer (LSFR) on ITER is envisioned to provide capabilities for electron density profile and fluctuations measurements in both the plasma core and edge. The current design for the Equatorial Port Plug 11 (EPP11) employs seven monostatic antennas for use with both fixed-frequency and swept-frequency systems. The present work examines the characteristics of this layout using the 3-D version of the GPU-Assisted Maxwell Code (GAMC-3D). Previous studies in this area were performed with either 2-D full wave codes or 3-D ray- and beam-tracking. GAMC-3D is based on the FDTD method and can be run with either a fixed-frequency or modulated (e.g. FMCW) source, and with either a stationary or moving target (e.g. Doppler backscattering). The code is designed to run on a single NVIDIA Tesla GPU accelerator, and utilizes a technique based on the moving window method to overcome the size limitation of the onboard memory. Effects such as beam drift, linear mode conversion, and diffraction/scattering will be examined. Comparisons will be made with beam-tracing calculations using the complex eikonal method.

1Supported by U.S. DoE Grants DE-FG02-99ER54527 and DE-AC02-09CH11466, and the DoE SULI Program at PPPL.

CP8.00014 Benchmarking FASTRAN vs TSC in Integrated ITER Modeling Simulations1, S.J. DIEM, D.B. BATCHELOIR, W.R. ELWASIF, M. MURAKAMI, J.M. PARK, A.C. SONTAG, ORNL, F. POLI, PPPL — ITER steady state scenarios are examined using the Integrated Plasma Simulator (IPS) framework, which finds a self-consistent scenario of heating and current drive, MHD equilibrium, and transport. Both the FASTRAN solver and Tokamak Simulation Code (TSC) have been implemented in IPS to integrate a variety of models for transport, heating, CD, and stability. The objective of this exercise is to benchmark the TSC/IPS time-dependent simulation with the FASTRAN/IPS steady-state solution procedure. The benchmark case is a fully non-inductive ITER steady-state scenario. Both simulations include ion cyclotron resonance heating, modeled using TORIC, and neutral beam heating, modeled using NUBEAM. The transport is modeled using GLF23 for both codes. Electron cyclotron heating was modeled using GENRAY. The results at several times of a time-evolving TSC simulation will be used as an initial guess for FASTRAN runs to compare the FASTRAN steady-state solutions to the time evolving TSC simulation.

1Work supported by the US Department of Energy under DE-AC05-00OR22725, DE-FC02-04ER54698, and DE-AC52-07NA27344.

CP8.00015 Initial results for a 170 GHz high power ITER waveguide component test stand1, TIMOTHY BIGELOW, ALAN BARKER, CARL DUKES, STEPHEN KILLOUGH, MICHAEL KAUFMAN, JOHN WHITE, GARY BELL, GREG HANSON, DAVE RASMUSSEN, Oak Ridge National Laboratory — A high power microwave test stand is being setup at ORNL to enable prototype testing of 170 GHz cw waveguide components being developed for the ITER ECH system. The ITER ECH system will utilize 63.5 mm diameter evacuated corrugated waveguide and will have 24 >150 m long runs. A 170 GHz 1 MW class gyrotron is being developed by Communications and Power Industries and is nearing completion. A HVDC power supply, water-cooling and control system has been partially tested in preparation for arrival of the gyrotron. The power supply and water-cooling system are being designed to operate for >3600 second pulses to simulate the operating conditions planned for the ITER ECH system. The gyrotron Gaussian beam output has a single mirror for focusing into a 63.5 mm corrugated waveguide in the vertical plane. The output beam and mirror are enclosed in an evacuated duct with absorber for stray radiation. Beam alignment with the waveguide is a critical task so a combination of mirror tilt adjustments and a bellows for offsets will be provided. Analysis of thermal patterns on thin witness plates will provide gyrotron mode purity and waveguide coupling efficiency data. Pre-prototype waveguide components and two dummy loads are available for initial operational testing of the gyrotron.

1ORNL is managed by UT-Battelle, LLC, for the U.S. Dept. of Energy under contract DE-AC05-00OR22725.

CP8.00016 Transmission line component testing for the ITER Ion Cyclotron Heating and Current Drive System1, RICHARD GOULDING, G.L. BELL, C.E. DEIBELE, M.P. MCCARTHY, D.W. SWAIN, G.C. BARBER, C.N. BARBIER, I.H. CAMBELL, R.L. MOON, P.V. PESAVENTO, Oak Ridge National Laboratory, E. FREDD, N. GREENOUGH, C. KUNG, Princeton Plasma Physics Laboratory — High power RF testing is underway to evaluate transmission line components for the ITER Ion Cyclotron Heating and Current Drive System. The transmission line has a characteristic impedance $Z_0 = 500\,\Omega$ and a nominal outer diameter of 305 mm. It is specified to carry up to 6 MW at VSWR=1.5 for 3600 s pulses, with transient voltages up to 40 kV. The transmission line is actively cooled, with turbulent gas flow ($V_2$) used to transfer heat from the inner to outer conductor, which is water cooled. High voltage and high current testing of components has been performed using resonant lines generating steady state voltages of 35 kV and transient voltages up to 60 kV. A resonant ring, which has operated with circulating power of 6 MW for 1 h pulses, is being used to test high power, low VSWR operation. Components tested to date include gas bars, straight sections of various lengths, and 90 degree elbows. Designs tested include gas barriers fabricated from quartz and aluminum nitride, and transmission lines with quartz and alumina inner conductor supports. The latest results will be presented.

1This manuscript has been authored by UT-Battelle, LLC, under Contract No. DE-AC05-00OR22725 with the U.S. Department of Energy.

CP8.00017 Modeling ITER ECH Waveguide Performance1, M.C. KAUFMAN, C.H. LAU, Oak Ridge National Laboratory — There are stringent requirements for mode purity and for on-target power as a percentage of source power for the ECH transmission lines on ITER. The design goal is less than 10% total power loss through the line and 95% HE11 mode at the diamond window. The dominant loss mechanism is mode conversion (MC) into higher order modes, and to maintain mode purity, these losses must be minimized. Miter bends and waveguide curvature are major sources of mode conversion. This work uses a code which calculates the mode conversion and attenuation of an arbitrary set of polarized waveguide modes in circular corrugated waveguide with non-zero axial curvature and miter bends. The transmission line is modeled as a structural beam with deformations due to misalignment of waveguide supports, tilts at the interfaces between waveguide sections, gravitational loading, and the extrusion and fabrication process. As these sources of curvature are statistical in nature, the resulting MC losses are found via Monte Carlo modeling. The results of this analysis will provide design guidance for waveguide support span lengths, requirements for minimum alignment offsets, and requirements for waveguide fabrication and quality control.

CP8.00018 Optimizing Antenna Layout for ITER Low Field Side Reflectometer using 3D Ray Tracing Code, S. KUBOTA, W.A. PEEBLES, UCLA, D. WOODBURY, BYU, I. JOHNSON, A. ZOLFAHARI, PPPL — The Low Field Side Reflectometer (LFSR) is being designed to provide electron density profile measurements for both the core and edge plasma through the launching of millimeter waves into the plasma and the detection of the reflected wave by a receive antenna. Because the detection of the received signal is integral to the determination of the density profile, an important goal in designing the LFSR is to optimize the coupling between launch and receive antennas. This project investigates this subject by using GenRay, a 3D ray tracing code, to simulate the propagation of millimeter waves launched into and reflected by the plasma for a typical ITER case. Based upon the results of the code, beam footprints will be estimated for different cases in which both the height and toroidal angle of the launch antenna are varied. The footprints will be compared, allowing conclusions to be drawn about the optimal antenna layout for the LFSR. This method will be carried out for various frequencies of both O-mode and X-mode waves, and the effect of the scrape-off layer of the plasma will also be considered.
CP8.00019 Simulation of plasma current ramp-up with reduced magnetic flux consumption in JT-60SA using TOPICS transport code. TAKUMA WAKATSUKI, TAKAHIRO SUZUKI, NOBUHIKO HAYASHI, SHUNSUKU IDE. Japan Atomic Energy Agency, YUICHI TAKASE, The University of Tokyo — Feasibility of current ramp-up with reduced central solenoid (CS) magnetic flux consumption should be demonstrated in order to reduce the size of the magnetic systems. In this paper, plasma current ramp-up scenarios with reduced CS flux consumption has been investigated on JT-60SA using TOPICS transport code. Time evolution of the temperature profile is calculated using the CDBM model with prescribed density profile. In order to minimize the resistive flux consumption, we have investigated the possibility of current ramp-up scenarios with reduced CS flux consumption. A variety of improved confinement regimes are expected to be accessible by means of the available ICRH heating power in addition to the prevalent programmable Ohmic heating power and relying on the injection of high velocity pellets for density control. Studies of different evolution scenarios will be presented.

CP8.00020 Progress in integrated modeling of JT-60SA plasma operation scenarios with model validation and verification. NOBUHIKO HAYASHI, Japan Atomic Energy Agency, JERONIMO GARCIA, CEA, IRFM, MITSURO HONDA, KATSUHIRO SHIMIZU, KAZUO HOSHINO, SHUNSUKU IDE, Japan Atomic Energy Agency, GERALD GURRITZI, CEA, IRFM, YOSHIHARU SAKAMOTO, TAKAHIRO SUZUKI, HAJIME URANO, Japan Atomic Energy Agency. JT-60 TEAM, JET EFDA COLLABORATION — Development of plasma operation scenarios in JT-60SA [1] has been progressing by using integrated modeling codes. In order to obtain an optimum set of models for the prediction, models are validated by using JT-60U and JET experimental data, and verified by integrated codes such as TOPICS and CRONOS. Predictive simulations are performed to assess the performance of each scenario and to develop optimum scenarios. In the scenario development, various physics aspects are studied by using various types of integrated modeling. The integrated divertor code SONIC showed that Ar seeding can reduce the heat flux on divertor plates below the preferable level (10 MW/m^2) with keeping low separatrix density in the full non-inductive current drive scenario, however, there are some amounts of Ar influx to core region. We integrate TOPICS with a core impurity transport code IMPACT and study the Ar accumulation in the core and its effect on the performance. Other studies with integrated modeling will be also presented.


CP8.00021 Investigation of impurity radiation in Wendelstein 7-X startup plasmas with EMC3-Eirene. FLORIAN EFFENBERG, Department of Engineering Physics, University of Wisconsin - Madison, YUEHE FENG, SERGEY BOZHENKOV, IPP Greifswald, Germany, HEINKE FRERICHS, U.W Madison, HAUKE HOELBE, THOMAS S. PEDERSEN, IPP Greifswald, Germany, DETLEV REITER, Forschungszentrum Juelich GmbH, Germany, OLIVER SCHMITZ, U.W Madison — The optimized stellarator Wendelstein 7-X will be operated in a limiter configuration during the first plasma operation phase. In this field configuration the plasma boundary does not include magnetic islands and the scrape-off layer is defined by five poloidal graphite limiters located at the bean shaped symmetry planes. The limiters define the position of the last closed flux surface and are positioned such that for high heat flux onto the unprotected main chamber wall and metallic frame structure of the later divertor targets. Considering startup plasmas with heating power up to 4MW and densities up to 9×10^{14} m^{-3} heat loads to plasma facing components (PFCs) and the generation of impurities during plasma surface interaction become a concern. Plasma transport simulations are performed with the 3D fluid plasma edge and kinetic neutral transport code EMC3-Eirene. It is based on a fluid model for electrons and ions, a kinetic model for neutral particles, and a fluid approach for impurity ions. Results are discussed for a systematic scan of plasma scenarios assessing the production and transport of impurities. In particular radiation cooling is explored as means to reduce impurity production and heat loads to PFCs.

CP8.00022 ITB Dynamics in Fusion Self-Heated Plasmas. DAVID NEWMAN, Univ. of Alaska - Fairbanks, P.W. TERRY, Univ. of Wisconsin - Madison, RAUL SANCHEZ, Univ. Carlos III De Madrid — Simple dynamical models have been able to capture a remarkable amount of the observed dynamics of the barrier transport found in many devices, including the often disconnected nature of the electron thermal transport channel sometimes observed in the presence of a standard (‘ion channel’) barrier. The electron channel formation and evolution has been found to be more sensitive to the alignment of the various gradients making up the shear radial electric field than the ion barrier is. Because of this sensitivity and coupling of the barrier dynamics, the dynamic evolution of the fusion self-heating profile can have a significant impact on the barrier location and dynamics. To investigate this, self-heating has been added this model and the impact of the self-heating on the formation and controllability of the various barriers is explored. It has been found that the evolution of the heating profiles can suppress or collapse the electron channel barrier leading to the possibility of using NBI for profile/barrier control. Studies of different evolution scenarios will be presented.

CP8.00023 Nuclei Separation Issue for p-B\textsuperscript{11} Burning Plasmas*. L. MERRIMAN, B. COPPI, MIT — Proton-Boron\textsuperscript{11} fusing plasmas have the appealing characteristics of not producing neutrons but only charged particles and of involving easily available fuel nuclei. This feature has attracted the interest of distinguished scientists. On the other hand, as is well known, p-B\textsuperscript{11} cannot ignite. In addition, there is an unexplored issue related to a transport process [1] due to the relatively large ratio of the masses of the two fuel nuclei. Since for equal temperatures of the two species, the difference between the squares of their thermal velocities is wide, a mode with a phase velocity between the two thermal velocities has been found [2]. This has the effect of transporting the two species in different directions radially and of enhancing the nuclei thermal energy transport. The obtained results, although not as critical as the lack of an ignition condition, should be taken into account in the burn simulations of p-B\textsuperscript{11} plasmas that have to be carried out.

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


CP8.00024 Theoretical Issues for Plasma Regimes to be Explored by the Ignitor Experiment* . A. CARDINALI, ENEA, B. COPPI, MIT, G. SONNINO, Université Libre de Bruxelles — At present, the Ignitor experiment is the only one designed and planned to approach and explore ignition regimes under controlled DT burning conditions. The machine parameters [1] have been established on the basis of existing knowledge of the confinement properties of high density plasmas. A variety of improved confinement regimes are expected to be accessible by means of the available ICRH heating power in addition to the prevalent programmable Ohmic heating power and relying on the injection of high velocity pellets for density profile control. The relevance of the various known confinement regimes to the objectives of Ignitor is discussed. Among other theoretical efforts, a non-linear thermal energy balance equation is investigated to study the onset of thermonuclear instability in the plasmas expected to be produced in Ignitor. The equation for the temperature profile in the equilibrium state is solved with the resulting profiles in agreement with those obtained by a full transport code and commonly adopted scalings for them. The evolution of the thermonuclear instability that relies on the solution of the time dependent energy balance equation is obtained.

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

CP8.0025 Nonlinear Numerical Modeling of Shape Control in IGNITOR in the Presence of 3D Structures, R. ALBANESE, G. AMBROSINO, G. DE TOMMASI, A. PIRONTI, G. RUBINACCI, F. VILLONE, Consorzio CREATE, G. RAMOGIDA, ENEA, B. COPPI, MIT — IGNITOR is a high field compact machine[1] designed for the investigation of fusion burning plasmas at or close to ignition. The integrated plasma position, shape and current control plays an important role in its safe operation. The analysis of its behavior taking into account nonlinear and 3D effects can be of great interest for assessing its performances. In fact, the system was designed on the basis of an axisymmetric linearized model. To this purpose, we use a computational tool, called CarMa0NL, with the unprecedented capability of simultaneously considering three-dimensional effects of conductors surrounding the plasma and the inherent nonlinearity of the plasma behaviour itself, in the presence of the complex set of circuit equations describing the control system. Preliminary results already lead to the conclusion that the vertical position response is not much influenced by nonlinear and 3D effects, as the vertical stabilization controller is able to “hide” the differences in open-loop models. Here we assess the performance of the shape controller, by coupling the nonlinear plasma evolution in the presence of the 3D vessel with ports to the complex circuit dynamics simulating the integrated closed loop control system.


CP8.0026 Developments for the ICRH System of the Ignitor Machine*, M. SASSI, CREATE, S. MANTOVANI, CIFS, B. COPPI, MIT — The ICRH system that is suitable for the high-density plasmas to be produced by the Ignitor machine[1] has been designed and components of it have been tested. This system will operate over the range 80-120 MHz, consistently with magnetic fields in the range 9-13 T. The maximum delivered power is in the interval 8 MW (at 80 MHz) to 6 MW (at 120 MHz) distributed over 4 ports. A full size prototype of the VTL between the port flange and the antenna straps, with the external support and precise guiding system has been constructed. The innovative quick latching system located at the end of the coaxial cable has been successfully tested, providing perfect interference with the spring Be-Cu electrical contacts. Vacuum levels of $10^{-6}$ mbar have been obtained. *Sponsored in part by the US DOE.


CP8.0027 Who will save the tokamak – Harry Potter, Arnold Schwarzenegger, or Shaquille O’Neill? , J. FREIDBERG, F. MANGIAROTTI, J. MINERVINI, MIT Plasma Science and Fusion Center — The tokamak is the current leading contender for a fusion power reactor. The reason for the preeminence of the tokamak is its high quality plasma physics performance relative to other concepts. Even so, it is well known that the tokamak must still overcome two basic physics challenges before becoming viable as a DEMO and ultimately a reactor: (1) the achievement of non-inductive steady state operation, and (2) the achievement of robust disruption free operation. These are in addition to the PMI problems faced by all concepts. The work presented here demonstrates by means of a simple but highly credible analytic calculation that a “standard” tokamak cannot lead to a reactor — it is just not possible to simultaneously satisfy all the plasma physics plus engineering constraints. Three possible solutions, some more well-known than others, to the problem are analyzed. These visual image generating solutions are defined as (1) the Harry Potter solution, (2) the Arnold Schwarzenegger solution, and (3) the Shaquille O’Neill solution. Each solution will be described both qualitatively and quantitatively at the meeting.

CP8.0028 The Nonlinear Stationary State of Simple Interchange Turbulence, KENNETH GENTLE, W.L. ROWAN, C.B. WILLIAMS, M.W. BROOKMAN, University of Texas at Austin — 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. Interchange modes are the dominant instability. Radially-segmented isolated end plates allow application of radial electric fields to modify the plasma flow transverse to B and the radial equilibrium gradient. Measurements of the ion flow velocity profile are made by Doppler spectroscopy of the argon plasma ion. The level of non-linearly saturated turbulence has been measured over a wide range of collisionality, parallel connection length, and flow pattern, but none of the processes found effective for setting the level of saturated turbulence for the weaker turbulence in the plasma interior are found applicable. Quasi-linear theory is inconsistent with the observations, zonal flows are not observed, and local flow shear does not correlate with local turbulence level. Weak correlations are found between turbulence level and radial correlation length for some restricted data subsets, but no broad correlation or predictive power exists. Work supported by the Department of Energy OFES DE-FG02-04ER54766.

CP8.0029 Guiding center revisited and orbital spectral analysis for non-axisymmetric perturbations, K. HIZANIDIS, P.A. ZESTANAKIS, Y. KOMINIS, G. ANASTASIOU, NTUA, Greece — A systematic transformation algorithm from guiding center (GC) coordinates to action-angle variables for any type of magnetic field is presented. It exploits Hamiltonian methods for describing single and collective particle dynamics for various types of interactions. It accounts for finite orbit width effects and performs orbit averaging calculations for particles at any energy, pitch angle and radial position for any type of non-axisymmetric perturbations. Furthermore, the GC picture is revisited on the basis of the differential geometry features of the particle orbit and its transverse to the local magnetic field evolute. The latter yields the exact fully relativistic vectorial gyration radius which can be approximated by the respective Larmor ones under certain conditions. The approach incorporates inhomogeneous magnetic and electric fields as well as magnetic field perturbations. This project is partially funded by EU Horizon 2020 Research and Innovation Programme under GA No. 633053 (the views and opinions expressed herein do not necessarily reflect those of the European Commission and the Hellenic NPTFR).

CP8.0030 How to apply a turbulent transport model based on a gyrokinetic simulation for helical plasmas, S. TODA, M. NUNAMI, A. ISHIZAWA, National Institute for Fusion Science, T.-H. WATANABE, Department of Physics, Nagoya University, H. SUGAMA, National Institute for Fusion Science — A reduced transport model for the turbulent ion heat diffusivity due to the ion temperature gradient (ITG) mode was obtained from the gyrokinetic simulation using the GKV-X code for the high-T_i Large Helical Device discharge[1]. This model is given by the function of the linear growth rate of the ITG mode divided by the square of the poloidal wavenumber integrated over the poloidal wavenumber space, $L$ and the zonal flow decay time. The zonal flow decay time is calculated only at the initial state in the transport simulation, when the field configuration is temporally fixed. However, it takes a huge cost to carry out linear gyrokinetic simulations of the growth rate at each time step in the transport code. How to apply the reduced model to the temporal transport simulation is proposed with a low computational cost. Modeling of $L$ is necessary to be involved with a parameter dependence of the plasma instability in the transport code. The ion temperature gradient scale length is chosen to apply $L$ to the transport code for the ITG mode. The calculation in this study reproduces the results of the reduced model with an extremely low computational cost.


CP8.0031 Turbulence Parallel Wavenumbers in the Texas Helimak, CHAD WILLIAMS, KENNETH GENTLE, University of Texas at Austin — It is well known that wavenumbers, in particular the existence of a parallel wavenumber, play an important role in the classification of turbulence. In a paper published in 2010, Paolo Ricci and B.N. Rogers posited the existence of a previously undiscovered resistive interchange mode, similar to a tokamak resistive ballooning instability, that appears in simple magnetized toroidal plasmas at long connection length (PRL 104, 145001). As the pitch of the magnetic field lines is flattened, and thus the connection length is increased, the system was shown to undergo a transition from an ideal interchange mode with zero parallel wavenumber to a resistive interchange mode with non-zero parallel wavenumber. Adapting only the system underlies a change in mode numbers. In this work we seek to measure the parallel wavenumber in the Texas Helimak at several long connection lengths in order to characterize the turbulence. By so doing we attempt to find the resistive interchange mode to provide verification of its existence in the Texas Helimak.
CP8.0032 Gyrokinetic Simulation of HL-2A H-mode Turbulent Transports, HUA-SHENG XIE, YONG XIAO, Institute for Fusion Theory and Simulation, Department of Physics, Zhejiang University, 310027 Hangzhou, China — Gyrokinetic simulations using GTC code are carried out to study recent HL-2A H-mode experiments (shots 19298, 14048, 14052). In these experiments, both low frequency (LFT) and high frequency (HFT) turbulences are found. The LFT is found to be mainly electrostatic (E.S.) with poloidal mode number m ~ 14-33 and frequency f ~ 25-65 kHz. Meanwhile, the HFT is found to be mainly electromagnetic (E.M.) with poloidal mode number m ~ 16-38, toroidal mode number n ~ 6-14 and frequency f ~ 60-400 kHz. In the E.S. simulation, a low-frequency unstable mode is found in the electron diamagnetic direction and no unstable mode is found when the electrons are treated adiabatically. Hence, the HFT is identified to be trapped electron mode (TEM). In linear stage, the most unstable mode is found to be n ~ 20 and m ~ 50-80. The dominant poloidal mode number will downshift to n ~ 15-40 in the nonlinear stage, which is close to the experimental observation. In the E.M. simulation, strong ideal and high frequency kinetic ballooning modes (KBM) are found. To verify the KBM capability of GTC, detailed benchmarks with analytic equilibriums are also shown.

CP8.0033 On fast radial propagation of parametrically excited Geodesic Acoustic Modes, LIU CHEN, IFTS, ZJU and UCI, ZHYONG QIU, IFTS, ZJU, FULVIO ZONCA, ENEA, Frascati — It is known from linear theories that, Geodesic Acoustic Mode (GAM) linear group velocity is due to finite Larmor radius (FLR) effects, and is typically radially outward in consistency with GAM continuum associated with temperature profiles. In this work, we show that, since GAM is linearly stable, nonlinear effects must be considered to explain experimental observations. Our results show that the nonlinearly driven GAM propagates at a much larger group velocity, which is the mean of the linear group velocities of GAM and drift wave turbulence. The nonlinear theories presented here, can also be applied to interpret the discrepancies between the experimentally measured dispersion relation of GAM and that from linear theories. Further implications of these findings for proper understanding of experimental observations are discussed.


CP8.0034 Full-f gyrokinetic simulations for neoclassical toroidal viscosity in a perturbed tokamak configuration, SEIKICHI MATSUOKA, Research Organization for Information Science and Technology, YASUHIRO IDOMURA, Japan Atomic Energy Agency, SHINSUKE SATAKE, National Institute for Fusion Science — A magnetic field perturbation in tokamak plasmas plays a key role in determining the intrinsic rotation and velocity shear, since even a small perturbation can break the axisymmetry in the toroidal direction and induces the finite neoclassical toroidal viscosity (NTV). A simulation study for the NTV evaluation in an axisymmetric tokamak with a small resonant magnetic field perturbation using the full-f gyrokinetic Eulerian code GT5D is presented. The magnetic field perturbation is included in the particle orbit of GT5D only through the Hamiltonian by replacing the axisymmetric magnetic field with the sum of the axisymmetric field and the perturbation, which enables us to perform GT5D simulations without changing the symplectic structure of the single-particle Lagrangian constructed for the equilibrium (axisymmetric) magnetic field. Numerical results are benchmarked with those obtained by the neoclassical transport code, FORTEC-3D, which solves the drift kinetic equation by two-weight Monte Carlo method. The NTV of GT5D with a single-helicity perturbation is found to have a similar peaked profile around the resonant surface as that of FORTEC-3D.

CP8.0035 Nonlinear Gyrokinetic Simulation of Electron-Driven Turbulence in HSX, BENJAMIN FABER, M. J. PUESCHLE, GAVIN WEIR, KONSTANTIN LIKIN, JOSEPH TALMDALE, SIMON ANDERSON, DAVID ANDERSON, Univ of Wisconsin, Madison — The first nonlinear gyrokinetic simulations of plasmas in the Helically Symmetric eXperiment (HSX) are presented. Due to large electron cyclotron resonance heating (ECRH) and little ion heating, microturbulence in HSX is driven by electron dynamics and thus the simulations performed require two kinetic species. Linear growth rate calculations of plasmas at experimental parameters indicate HSX is unstable at low k_y/p_x to the Trapped Electron Mode (TEM) and the Electron Temperature Gradient (ETG) mode at high k_y/p_x, especially in the core region where the normalized temperature gradient is significantly larger than the normalized density gradient. Nonlinear simulations also show evolution of zonal flows, which are a possible candidate for the nonlinear saturation mechanism. Calculation of the dependence of the saturated heat flux on the normalized electron temperature gradient provides a computational comparison with the stiffness measurements obtained in heat pulse propagation experiments.

1Work supported by U.S. DOE Contract No. DE-FG02-93ER54222.
2G. M. Weir, invited talk, this conference.

CP8.0036 Relaxation to neoclassical flow equilibrium in gyrofluid simulations, BRUCE SCOTT, Max-Planck-IPP, Garching, Germany — The theorem for toroidal angular momentum conservation within gyrokinetic field theory is used as a starting point for consideration of slow transport of flows under quasistatic force balance. If conserved/transported quantities are taken as given, the radial electric field is solved in terms of the neoclassical poloidal flow of each species and the total toroidal angular momentum. Standard result is recovered if the latter is small. In a simple model and in gyrofluid computations, the neoclassical toroidal viscosity (NTV) is found to have a similar peaked profile around the resonant surface as that of FORTEC-3D. A simulation study for the NTV evaluation in an axisymmetric tokamak with a small resonant magnetic field perturbation determines the intrinsic rotation and velocity shear, since even a small perturbation can break the axisymmetry in the toroidal direction and induces the finite neoclassical toroidal viscosity (NTV). The theorem for toroidal angular momentum conservation within gyrokinetic field theory is used as a starting point.

CP8.0037 Recently Discovered Features of the Quasi Coherent Mode*, P. MONTAG, B. COPPI, L. SUGIYAMA, T. ZHOU, MIT — The Quasi Coherent Mode (QCM) is observed when the EDA H-Confinement regime is produced by the Alcator C-Mod machine and has been found [1] to 1) have a phase velocity in the direction of the electron diamagnetic velocity in the plasma reference frame 2) involve relatively high electron temperature fluctuations 3) be highly localized radially at the outer edge of the plasma column beyond the Last Closed Magnetic Surface (LCMS). A novel theoretical model is given for which: a) the relevant resistive mode driving factor is the sharp plasma pressure gradient that develops at the edge when the plasma enters the EDA H-Regime; b) the known “disconnected mode approximation” [2] cannot be applied to characterize the mode topology as the rotational transform ω/ω(0) is > 1/ω(0) on the LCMS; c) the mode localization in the poloidal direction (ballooning) is related to the limited region around the equatorial plane where the pitch of the magnetic field is about constant. The observed temperature fluctuations are consistent with the low values of the local longitudinal thermal conductivity. *Sponsored in part by the US DOE.

**CP8.00038 Hybrid Gyrokinetic / Gyrofluid Simulation of ITG Turbulence**

NOAH MANDELL, WILLIAM DORLAND, University of Maryland-College Park — One of the main sources of disagreement between gyrofluid and gyrokinetic models is the inability of gyrofluid models to accurately describe zonal flows. These nonlinearly-driven sheared poloidal $E \times B$ flows have been shown to play a key role in determining the turbulence saturation level. While attempts have been made to improve gyrofluid modeling of zonal flows, we show here that improved zonal flow closures are insufficient. We introduce a new hybrid algorithm that simulates the zonal flow modes with a fully gyrokinetic model, while simulating the remaining modes with the newly developed GPU gyrofluid code GrynX. GrynX contains a new model of nonlinear FLR phase mixing by zonal flows, which in addition to accurate zonal flow modeling brings the heat flux predictions of the hybrid code into agreement with the gyrokinetic code G2. The combination of GPU acceleration and the reduction of hundreds of velocity space grid points to six gyrofluid moments gives GrynX a roughly 7,000 times performance advantage over G2. Further, due to supercomputer configurations that contain nodes with multiple CPUs per GPU, the hybrid fluid/kinetic code has minimal additional computation time cost and maintains a significant performance advantage over G2.

1Present address: Princeton University

**CP8.00039 Intrinsic momentum transport in tokamaks with tilted elliptical flux surfaces**

JUSTIN BALL, FELIX PARRA, MICHAEL BARNES, University of Oxford, WILLIAM DORLAND, University of Maryland, GREGORY HAMMETT, Princeton Plasma Physics Laboratory, PAULO RODRIGUES, NUNO LOUREIRO, Universidade de Lisboa — Recent work demonstrated that breaking the up-down symmetry of tokamaks removes a constraint limiting intrinsic momentum transport, and hence toroidal rotation, to be small. We show, through MHD analysis, that ellipticity is most effective at introducing up-down asymmetry throughout the plasma. Using G2, a local $\delta f$ gyrokinetic code that self-consistently calculates momentum transport, we simulate tokamaks with tilted elliptical poloidal cross-sections and a Shafranov shift. These simulations show both the magnitude and poloidal dependence of nonlinear momentum transport. The results are consistent with TCV experimental measurements and suggest that this mechanism can generate rotation with an Alfvén Mach number of several percent in a tilted elliptical ITER-like machine. It appears that rotation generated with up-down asymmetry may be sufficient to stabilize the resistive wall mode in reactor-sized devices.

1J.R.B. and F.I.P. were partially supported by the RCUK Energy programme (grant number EP/I001045) and the European Unions Horizon 2020 research and innovation programme.


**CP8.00040 Interactions between Drift-Wave Microturbulence and the Tearing Mode**

S.D. JAMES, University of Tulsa, D.P. BRENNAN, Princeton University, O. IZACARD, C. HOLLAND, University of California San Diego — Turbulent dynamics are known to be affected by the presence of a magnetic island. The evolution of a magnetic island is also known to be affected by evolving turbulent fields. Capturing this interaction is a challenging computational problem due to the disparate scales involved. Using a Hasegawa-Wakatani model for the small spatial and temporal scale drift-wave microturbulence and coupling it to Ohm’s Law for evolving the larger-scale magnetic island we can capture the dynamics of this interaction self-consistently. We have developed a new code, TURBO, to simulate this system using an equilibrium with prescribed turbulent drives and magnetohydrodynamic stability properties. We present progress toward understanding this interaction via comparisons with analytic predictions for a turbulent resistivity and turbulent viscosity. These two transport coefficients are calculated as integrals over the wave spectrum and the scaling with wave number is investigated. An extension to a five-field model including the ion temperature gradient is also presented.

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**CP8.00041 Turbulent Transport in Presence of Magnetic Island**

OLIVIER IZACARD, CHRISTOPHER HOLLAND, University of California - San Diego, SPENCER JAMES, University of Tulsa, DYLAN BRENNAN, Princeton University — Understanding the physics of both large-scale magnetohydrodynamic instabilities and small-scale drift-wave microturbulence is essential for predicting and optimizing the performance of magnetic confinement based fusion energy experiments. While both types of instabilities have been investigated individually for many years now, less attention has been given to quantifying the interaction mechanisms between them. We report progress on understanding these interactions using both analytic theory and numerical simulation, with BOUT++ [1]. We used to evolve a simple four-field fluid model in a sheared slab geometry. This work focuses upon understanding the dynamics of the electrostatic ion temperature gradient instability in the presence of a background static magnetic island, as key parameters such as ion temperature gradient and magnetic gradients are varied. The simulation results are used then to calculate effective turbulent transport coefficients (e.g. viscosity, resistivity) that are compared against analytic predictions. As part of this work, a OMFIT module has been developed to enable execution of BOUT++ and post-processing on either local or remote systems.

**CP8.00042 A Quasilinear Description of Pedestal Transport induced by RMPs**

CHRISTOPHER MCDEVITT, XIAN-ZHU TANG, ZEHUA GUO, Los Alamos National Laboratory — The abrupt release of stored energy by large edge localized modes (ELM) and its subsequent deposition onto plasma facing components can place significant limitations on material lifetimes. Resonant magnetic perturbations (RMP) have been suggested as a means of tailoring pedestal profiles in order to suppress large ELM events. In this work, we utilize a quasilinear collision operator formulation in order to compute transport induced by a stochastic magnetic field. This formulation allows for phase transport induced by fluctuations (including field perturbations) as well as Coulomb collisions to be treated on an equal footing, hence allowing for general collisionality regimes to be treated. In addition, such a phase space formulation incorporates kinetic effects such as particle trapping as well as magnetic drifts, which are crucial to the description of pedestal transport. Particular emphasis is placed on determining the relative efficiency RMPs have on transporting density, current and heat in order to better understand how RMPs may be employed to shape pedestal profiles. Ongoing work is focused on the self-consistent description of the electric field induced by the response of the plasma to RMPs.

**CP8.00043 The Wave-Kinetic Landau Fluid**

ILON JOSEPH, ANDRIS DIMITS, Lawrence Livermore National Lab — Efficient representation of kinetic effects such as Landau damping and particle trapping is crucial for the accuracy of reduced fluid models used to describe collisionless plasma turbulence. A new method for representing nonlinear resonance effects has been developed for Landau fluid [1] models. Wave-kinetic basis functions that focus velocity space resolution on wave-particle resonances naturally generate correct linear and nonlinear Landau damping amplitudes. Perhaps surprisingly, closely spaced resonances are accurately treated using “inverse” or “pseudo” resonances [2] in velocity space. The closure for the fluid moment system is equivalent to the choice of a companion matrix that determines the linear response. This freedom can be used to generate multiple families of closures that generate the same Padé approximation to the linear response [1], but have different nonlinear behavior. Results have been formally generalized to include trapped particle effects and collisions.


CP8.00044 Steady state gyrokinetic PIC simulation of ITG turbulence$^1$, W.W. Lee, Princeton Plasma Physics Laboratory, Princeton, NJ, R. Ganesh, Institute for Plasma Research, Bhat, India, S. Ethier, Princeton Plasma Physics Laboratory, Princeton, NJ — We will report the implementation of the two-weight scheme [1] in the global gyrokinetic PIC code - GTC [2], for studying turbulence transport in tokamak plasmas along with our initial attempts to also include the neoclassical transport physics. With the two-weight scheme, which is based on multiscale expansion $F = F_0(x) + \delta f(x)$, where $\epsilon$ is a smallness parameter and $F_0$ is the background Maxwellian, we are able to simulate the transition from $\delta f$ particles in the linear stage to a certain percentage of full $p$ particles in the nonlinear stage in the same run. Such a scheme would help us to assess the correctness of $\delta f$ runs when $\delta f$ becomes large as well as for the cases where there are sources and sinks in the simulation. The behavior of theentropy for the new scheme and the effect of collisions will also be reported along with the comparisons with the size scaling obtained earlier [3] using only the $\delta f$ simulation.


$^1$Work supported by DoE Contract No. DE-AC02-09CH11466.

CP8.00045 Investigations of Turbulent Transport Channels in Gyrokinetic Simulations$^1$, A.M. Dimits, LLNL, J. Candy, GA, W. Guttenfelder, PPPL, C. Hollander, UCSD, N. Howard, MIT, W.M. Nevin, E. Wang, LLNL — Magnetic-field stochasticity arises due to microtearing perturbations, which can be driven linearly [1] or nonlinearly (in cases where they are linearly stable [2]), even at very modest values of the plasma beta. The resulting magnetic-flutter contribution may [1] or may not [2] be a significant component of the overall electron (particle and thermal) transport. Investigations of the effect of $ExB$ shear on electron-drift magnetic-flutter diffusion coefficient $D_{edr}(r,|v|)$ using perturbed magnetic fields from simulations, using the GYRO code [3], of ITG turbulence show a significant effect for electrons with parallel velocities $v_r$ surprisingly far from the resonant velocity. We further examine changes in the radial dependence of this diffusion coefficient vs. $v_r$ and which resonant magnetic-field perturbations are important to the values and radial structure of $D_{edr}$. The resulting electron transport fluxes are compared with the simulation results. Improvements over [2] in treating the ambipolar field in the relationship between the magnetic (or drift) diffusion coefficients and the transport have been made in these comparisons.


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CP8.00046 Study of no-man’s land physics in the total-f gyrokinetic code XGC1, Seung Hoe Ku, C.S. Chang, J. Lang, Princeton Plasma Physics Laboratory — While the “transport shortfall” in the “no-man’s land” has been observed often in delta-f codes, it has not yet been observed in the global total-f gyrokinetic particle code XGC1. Since global understanding of the interaction between the edge and core transport appears to be a critical element in the prediction for ITER performance, understanding the no-man’s land issue is an important physics research topic. Simulation results using the Holland case [1] will be presented and the physics causing the shortfall phenomenon will be discussed. Nonlinear nonlocal interaction of turbulence, secondary flows, and transport appears to be the key.


CP8.00047 MIB Probes for measurements of particle and energy fluxes in plasma of Wendelstein 7-X, V.I. Demidov, WVU, S.P. Belyaev, M.E. Koepke, WVU, I.P. Kurylyandskaya, SPbU SFS EMERCOM RF, Y. Raitse, PPPL — Magnetically insulated baffled (MIB) probes and probe arrays that share the simplicity of simple Langmuir probes but supersede them in their ability to make real-time measurements of plasma potential, temperature and energy/particle fluxes in W-7-X stellarator plasma are being developed. The probes offer the advantages of direct measurements of the plasma fluid observables, while being non-emitting and electrically floating. The principle of operation of the probe is based on the dependence of the voltage drop in the plasma-probe sheath on the direction of the local magnetic field. The core technology for these probes rests with the use of a special baffling configuration such that electron current to the probe is fully controllable in the closed, open or partially open orientation, by a simple rotation of the baffle with respect to the magnetic field alignment in the plasma. The baffled-probe designs proposed for edge diagnostics will increase the capability to characterize separately plasma properties in real-time for understanding of underlying physics in the edge plasma.

CP8.00048 L-H Transition Dynamics and Power Threshold Minimum$^1$, Mikhail Malkov, Patrick Diamond, UCSD, Kazuhiro Mikita, JAEA, Kashiwa, Japan, George Tytan, UCSD — The link between the microscopic and macroscopic attributes of the LH transition and their effect on power threshold scaling are investigated. Emphasis is placed on understanding the minimum in the power threshold. By extending a numerical 1D model to evolve electron and ion heat fluxes separately, we propose and examine the explanation that: (i) the initial trend of decrease in the power threshold with density is due to stronger collisional electron-to-ion heat transfer which enables the development of stronger diamagnetic electric field, crucial to the transition, (ii) the subsequent increase in the threshold is due to the increase in damping of shear flows with ion collisionality. Our studies reveal a power threshold minimum in density scans which is particularly pronounced for an electron heating dominating at low densities. The heating mix is important to the transition, again pointing to the interplay of electron-ion coupling. The model also demonstrates: (a) an increase in threshold power for off-axis electron heat deposition. This follows from the reduction of the transfer of energy from electrons to ions within a confinement time, (b) the absence of a clear minimum in the power threshold with density is due to stronger collisional electron-to-ion heat transfer which enables the development of stronger diamagnetic electric field, crucial to the transition, (ii) the subsequent increase in the threshold is due to the increase in damping of shear flows with ion collisionality. Our studies reveal a power threshold minimum in density scans which is particularly pronounced for an electron heating dominating at low densities. The heating mix is important to the transition, again pointing to the interplay of electron-ion coupling. The model also demonstrates: (a) an increase in threshold power for off-axis electron heat deposition. This follows from the reduction of the transfer of energy from electrons to ions within a confinement time, (b) the absence of a clear power threshold minimum for pure ion heat deposition.

$^1$Supported by the US DoE.

CP8.00049 Impurity effect on poloidal potential variation and plasma turbulence in edge pedestal, Kuyou Kim, Janghoon Seo, Korea Advanced Institute of Science and Technology, Daejeon, Korea, S.-H. Ku, C.-S. Chang, M. Churchill, R. Hager, Daren Stotler, PPPL — The poloidal variation of electrostatic potential in the H-mode edge pedestal can be significant, especially in diverted geometry [1,2]. Impurity particles may enhance such a poloidal variation [3]. The total-f gyrokinetic code XGC1 is used to study the impurity effect on poloidal potential variation in diverted magnetic field geometry. Even though the ExB shearing rate is strong in the edge pedestal, residual turbulence can exist [1]. Impurity effect on the residual turbulence will also be reported. Implication to plasma and impurity transport across the separatrix surface and pedestal region will also be discussed.


CP8.00050 INTENSE BEAM AND RADIATION SOURCES — .
CP8.00051 Laser Absorption and Particle Acceleration at the Critical Surface 1  J. MAY, J. TONGE. W.B. MORI, UCLA, F. FIUZA, LLNL, R. FONSECA, L.O. SILVA, IST — Using high intensity lasers (I ≥ 5 × 10^{19} W/cm^2) to accelerate particles at the critical surface offers the potential to deliver high fluence particle beams into dense matter. Potential applications include Fast Ignition Inertial Confinement Fusion, Radiation Pressure Acceleration, and probing high-density matter for basic plasma research. In order to tailor the beam characteristics of laser conversion efficiency, energy spectrum, beam divergence, and accelerated species (ions or electrons) to the given application – and of course to interpret the results of experiments – it is key to have an understanding of the underlying absorption and acceleration mechanisms. Much theoretical and simulation work has been done on this regime in recent years, and although it has become clear that mechanisms often invoked at lower intensities (i.e., JxB and Bruenel heating) are less or unimportant in these systems, debate still exists as to exactly what mechanisms will play the dominant role in laboratory relevant scenarios. We present recent results of simulations with the Particle-in-Cell code OSIRIS which sheds light on these issues.

1The authors acknowledge the support of the DOE Fusion Science Center for Extreme States of Matter and Fast Ignition Physics under DOE contract no. F020-04ER54789 and DOE contracts DE-NA0001833 and DE-SC-0008316, and NSF grant ACI-13398893.

CP8.00052 Discrete Variational Approach for Modeling Laser-Plasma Interactions 1  J. PAXON REYES, B.A. SHADWICK, University of Nebraska - Lincoln — The traditional approach for fluid models of laser-plasma interactions begins by approximating fields and derivatives on a grid in space and time, leading to difference equations that are manipulated to create a time-advance algorithm. In contrast, by introducing the spatial discretization at the level of the action, the resulting Euler-Lagrange equations have particular differing approximations that will exactly satisfy discrete versions of the relevant conservation laws. For example, applying a spatial discretization in the Lagrangian density leads to continuous-time, discrete-space equations and exact energy conservation regardless of the spatial grid resolution. We compare the results of two discrete variational methods using the variational principles from Chen and Sudan [1] and Brizard [2]. Since the fluid system conserves energy and momentum, the relative errors in these conserved quantities are well-motivated physically as figures of merit for a particular method.


CP8.00053 Relativistic soliton-like collisionless ionization wave 1  ALEXEY AREFIEV, Institute for Fusion Studies, The University of Texas at Austin, MATTHEW MCCORMICK, HERNAN QUEVEDO, ROGER BENGTSON, TODD DITMIRE, Center for High Energy Density Science, The University of Texas at Austin — It has been observed in recent experiments with laser-irradiated gas jets that a plasma filament produced by the laser and containing energetic electrons can launch a relativistic ionization wave into ambient gas [Phys. Rev. Lett. 112, 045002 (2014)]. Here we present a self-consistent theory that explains how a collisionless ionization wave can propagate in a self-sustaining regime. A population of hot electrons necessarily generates a sheath electric field at the plasma boundary. This field penetrates the ambient gas, ionizing the gas atoms and thus causing the plasma boundary to expand. We show that the motion of the newly generated electrons can form a potential well adjacent to the plasma boundary. The outwards motion of the well causes a bunch of energetic electrons to become trapped, while allowing the newly generated electrons to escape into the plasma without retaining much energy. The resulting soliton-like ionizing field structure propagates outwards with a bunch of hot electrons that maintain a strong sheath field despite significant plasma expansion. We also present 1D and 2D particle-in-cell simulations that illustrate the described mechanism.

1This work was supported by the U. S. Department of Energy under Contract No. DE-SC0008382 and by the National Science Foundation under Contract No. PHY-1104683.

CP8.00054 Interplay between Weibel, two-stream and oblique-mode instabilities of the ultra-relativistic electron beam 1  PANPAN RUAN, VLADIMIR KHUDIK, XI ZHANG, GENNADY SHVETS, Department of Physics, Institute for Fusion Studies, the University of Texas at Austin — Electromagnetic and electrostatic instabilities of ultra-relativistic electron beam propagating in dense plasma are studied analytically and through simulations. We develop a hybrid reduced-description code and show that it describes the beam evolution quite close to that reproduced by first-principle PIC VPLF code [1]. We demonstrate that when electromagnetic Weibel instability is suppressed by the large beam temperature, the electrostatic oblique modes quickly grow. The growth rates of the perturbations [2] from the simulations and theory match each other at different temperatures of the beam and plasma. During the non-linear stage, we study the saturation of the instabilities through simulations. The redistribution of the initial beam energy among the beam, plasma, electric and magnetic fields with time is analyzed. The nature of the final non-linear stage of the instability is explained.


CP8.00055 High repetition rate relativistic electron beam generation from dense laser solid interactions 1  THOMAS BATSON, JOHN NEES, BIXUE HOU, ALEXANDER THOMAS, University of Michigan, KARL KRUSENLICK, University of Michigan — Relativistic electron beams have wide-ranging applications in medicine, materials science, and homeland security. Recent advances in short pulse laser technology have enabled the production of very high focused intensities at kHz rep rates. Consequently this has led to the generation of high flux sources of relativistic electrons - which is a necessary characteristic of these laser plasma sources for any potential application. In our experiments, through the generation of a plasma by focusing a 5 × 10^{18} W/cm^2, 500 Hz, Ti:Sapphire laser pulse onto a fused silica target, we have measured electrons ejected from the target surface having energies in excess of an MeV. The spectrum of these electrons, as well as the spatial divergence of the resulting beam, was also measured with respect to incident laser angle, prepulse timing and focusing conditions. The experimental results are compared to particle in cell simulations.

1This work was supported by HPC resources provided by the Texas Advanced Computing Center. This work was supported by NNSA Contract No. DE-FG52-08NA28512 and U.S. DOE Contract No. DE-FG02-04ER54742.

CP8.00056 Proton probing using a “table-top-terawatt” laser 1  PETER KORDELL, LOUISE WILLINGALE, ANATOLY MAKSIMCHUK, KARL KRUSENLICK, University of Michigan, ELEANOR TUBMAN, NIGEL WOOLSEY, University of York — The Terawatt laser at the University of Michigan can provide up to 20 TW of laser power in 400 fs pulses. Proton beams of up to 4 MeV can be accelerated with a sufficient flux for measuring on radiochromic film (RCF). We use a split-beam set-up to allow two, co-aligned, relativistic intensity interactions; the first to produce the proton probe beam and the second to produce the interaction of interest. Our preliminary results of proton probing of a simple wire target interaction will be presented and future plans for this experiment will also be discussed.
CP8.00057 Systematic investigation of plasma filaments generated by Sub-TW laser pulses in N2 gases. TAKAMITSU OTSUKA, TAKEHARU HOMMYO, KAZUKI OGURI, YUSUKE HYUGA, Utsunomiya Univ, YASUHIKO SENTOKU, University of Nevada, NOBORU YUGAMI, Utsunomiya Univ. — Intense ultrashort laser pulses propagating through gases and plasmas induce many interesting physical phenomena such as optical Kerr self-focusing, defraction, and plasma induced defocusion, resulting in the formation of plasma filaments. Because the filaments can extend the Rayleigh length at high intensity, it is applicable to a wide range of applications, e.g. laser wakefield acceleration, and THz radiation. However, the characteristics and dynamics are not well defined, especially for laser-generated plasma filaments formed at lower gas pressure region. In this work, we have studied characteristics of plasma filament generated by a femtosecond laser pulse with less than critical power for giving rise to the relativistic effect. Plasma dynamics in the filament were observed using an interferometer under various conditions and compared with 1D- PIC calculation results. The experimental results agree well with numerical calculation results. Shadowgraphs were also taken, and complex structures were observed in filaments formed under certain conditions. In this presentation the experimental results obtained and the results of the numerical calculations results will be compared.

CP8.00058 Hole boring velocity measurements in near critical density plasmas by a CO2 laser pulse1, CHAO GONG, SERGEI TOCHITSKY, JEREMY PIGEON, CHAN JOSHI, University of California, Los Angeles — Measurements of plasma dynamics during the interaction of a high-power laser pulse with an above critical density plasma is important for understanding absorption, transport and particle acceleration mechanisms. An important process that affects these mechanisms is hole boring occurring at the critical density because of the radiation pressure of the laser pulse. Yet, no systematic measurements of the hole boring velocity’s correlation with laser intensity (I) have been made. In this talk, we present experimental results of v hb in near critical density plasmas produced by CO2 laser as a function of I in the range of 1*1015 to 1.6*1016 W/cm2. A novel four frame Mach-Zehnder interferometer using a 1 ps, 532 nm probe laser pulse was developed to record the evolution of the plasma density profile and the motion of the near critical density layer. Using this boring velocity, we observed the motion of the steepened plasma profile due to the incident, time-structured CO2 laser pulse. Experimental results show the hole boring velocity increases from 0.004c to 0.007c as the laser intensity is increased from 1*1015 to 1.6*1016 W/cm2.

1This work is supported by DOE grant DE-FG02-92-ER40727, NSF grant PHY-0936266 at UCLA.

CP8.00059 Petawatt laser absorption bounded, MATTHEW LEVY, LLNL, Rice Univ, SCOTT WILKS, MAX TABAK, STEPHEN LIBBY, LLNL, MATTHEW BARING, Rice Univ. — The interaction of petawatt (1015 W) lasers with solid matter forms the basis for advanced scientific applications such as table-top relativistic particle accelerators, ultrafast charged particle imaging systems and fast ignition inertial confinement fusion. Key metrics for these applications relate to absorption, yet conditions in this regime are so nonlinear that it is often impossible to know the fraction of absorbed light f, and even the range of f is unknown. In this presentation, using a relativistic Rankine-Hugoniot-like analysis, we show how to derive the theoretical maximum and minimum of f [1]. These boundaries constrain nonlinear absorption mechanisms across the petawatt regime, forbidding high absorption values at low laser power and low absorption values at high laser power. Close agreement is shown with several dozens of published experimental data points and simulation results, helping to confirm the theory. For applications needing to circumvent the absorption bounds, these results will accelerate a shift from solid targets, towards structured and multilayer targets, and lead the development of new materials.


CP8.00060 Conical terahertz radiation from femtosecond laser created filaments, NOBORU YUGAMI, TAKAMITSU OTSUKA, KAZUKI OGURI, TAKEHARU HOMMYO, MASATAKA HIDETA, Utsunomiya University, YASUHIKO SENTOKU, University of Nevada at Reno. — The mechanism of sub-THz emission with conical structure by laser and plasma interaction since the discovery of Yagami et al. W/cm2 A has left unresolved[2]. One tried to explain by the wakefield oscillation by laser pulse, however, it is impossible to generate sufficient electric field for sub THz radiation due to high neutral gas pressure and low intense laser intensity. Furthermore, the radiation frequency is not identical to and much lower than the plasma frequency which is estimated by the initial gas density and laser intensity. In this presentation, we will present recent experimental data and explain the radiation generation mechanism by 2DPIC code by taking plasma density gradient and the electron current behind the laser propagatin into account[3]. The calculation shows the existence of the radiation with lower than 1 THz, which is much lower than the local plasma frequency and distribution structure around focal point of the laser.


CP8.00061 ABSTRACT WITHDRAWN

CP8.00062 Describing electron motion in ultra-high intensity laser plasma interactions: the inclusion of a stochastic radiation reaction force, CHRISTOPHER RIDGERS, University of York — At intensities soon to be reached by next-generation laser facilities (exceeding 5x1022 W/cm−2) electrons are accelerated so violently in the laser fields that they radiate energy (as gamma-ray photons) comparable to that they gain from the laser pulse. In this case the radiation reaction force becomes important in determining their motion. However, at these intensities the electric field in the electron’s rest frame approaches the Schwinger field; the critical field of quantum electrodynamics where quantum effects on the radiation reaction force become crucial. In particular, the force transitions from a deterministic classical force to a stochastic force. I will compare electron motion when the radiation reaction is treated classically and stochastically, showing that the two treatments give the same result in the classical limit (correspondence) and that, surprisingly, a modified deterministic force (called the “semi-classical” model) can also be used when quantum effects are strong. I will also demonstrate that the semi-classical treatment fails to predict the rate of pair production by the emitted gamma-ray photons. To describe pair production one needs to adopt a new model for electron motion where the motion is described in terms of the evolution of a probability function in phase space as opposed to motion along a classical (deterministic) worldline.

CP8.00063 Ponderomotive Acceleration by Relativistic Waves1, CALVIN LAU, PO-CHUN YEH, ONNIE LUK, JOSEPH MCCLENAGHAN, Dept. of Physics and Astronomy, University of California, Irvine, CA, TOSHIKAZU EBISUZAKI, RIKEN, Wako, Saitama, Japan, TOSHIKI TAJIMA, Dept. of Physics and Astronomy, University of California, Irvine, CA — In the extreme high intensity regime of electromagnetic (EM) waves in plasma, the acceleration process is found to be dominated by the ponderomotive acceleration (PA). While the wakefields driven by the ponderomotive force of the relativistic intensity EM waves are important, they may be overtaken by the PA itself in the extreme high intensity regime when the dimensionless vector potential a0 of the EM waves far exceeds unity. The energy gain by this regime (in 1D) is shown to be (approximately) proportional to a2. Before reaching this extreme regime, the coexistence of the PA and the wakefield acceleration (WA) is observed where the wave structures driven by the wakefields show the phenomenon of multiple and folded wave-breakings. Investigations are various signatures of the acceleration processes such as the dependence on the mass ratio for the energy gain as well as the energy spectral features. The relevance to high energy cosmic ray acceleration and to the relativistic laser acceleration is considered.

1This work is supported by the Norman Rostoker Fund.
CP8.00064 Ultra-high intensity laser scattering with quantum corrections
JOANA L. MARTINS, MARJIA VRANIC, JORGE VIEIRA, THOMAS GRISMAIER, RICARDO FONSECA, LUIS O. SILVA, GoLP/Instituto de Plasma e Fusao Nuclear, Instituto Superior Tecnico, Universidade de Lisboa, Lisbon, Portugal — With the advances in plasma wakefield acceleration and in laser technology, electron beams with about 1 GeV of energy and ultra-high intensity lasers (up to $10^{22}$ W/cm$^2$) are now available. These provide a means to explore regimes with a small ratio between the electric field in the electron rest frame and the Schwinger field ($\chi$ parameter). In this work the radiation spectrum of electrons undergoing nonlinear Thomson/Compton scattering at small $\chi$ is explored through PIC simulations combined with the radiation post-processing diagnostic jRad. Quantum corrections are modeled with a quantum corrected emissivity formula that generalizes that of Lieu & Axford [ApJ vol 416, 700 (1993)] for arbitrary angles of observation. Scenarios with short ultra-intense linearly polarized laser pulses (au up to 30) interacting with electrons with up to few 10s GeV are modeled. Spatially resolved multidimensional (and integrated) spectra are presented and the effects of radiation damping and laser amplitude variation during the interaction are explored. Comparisons of the results with equivalent OSIRIS-QED simulations are also presented and the transition from the quantum corrected emissivity to QED Compton scattering is explored.

1also at DCTI/ISCTE Lisbon University Institute, 1649-026 Lisbon, Portugal

CP8.00065 Nonlinear pulse propagation and phase velocity of laser-driven plasma waves
CARLO BENEDETTI, Lawrence Berkeley Natl Lab, FRANCESCO ROSSI, Department of Physics and Astronomy, University of Bologna, Bologna, Italy, CARL SCHROEDER, ERIC ESAREY, WIM LEEMANS, Lawrence Berkeley Natl Lab — We investigate and characterize the laser evolution and plasma wave excitation by a relativistically intense, short-pulse laser propagating in a preformed parabolic plasma channel, including the effects of pulse steepening, frequency redshifting, and energy depletion. We derived in 3D, and in the weakly relativistic intensity regime, analytical expressions for the laser energy depletion, the pulse self-steepening rate, the laser intensity centroid velocity, and the phase velocity of the plasma wave. Analytical results have been validated numerically using the 2D-cylindrical, ponderomotive code INF&RNO. We also discuss the extension of these results to the nonlinear regime, where an analytical theory of the nonlinear wake phase velocity is lacking.

CP8.00066 Collision for the onset of the current filamentation instability of ultra-relativistic fireball bunches in plasmas
NITIN SHUKLA, JORGE VIEIRA, GoLP/Instituto de Plasma e Fusao Nuclear, Instituto Superior Tecnico, Lisbon, Portugal, PATRIC MUGGLI, Max Planck Institute for Physics, Munich, Germany, RICARDO FONSECA, LUIS SILVA, GoLP/Instituto de Plasma e Fusao Nuclear, Instituto Superior Tecnico, Lisbon, Portugal — Current Filamentation Instability (CFI) is capable of generating strong magnetic fields relevant to explain radiation processes in astrophysical objects and lead to the on-set of particle acceleration in collisionless shocks. Probing such extreme scenarios in the laboratory is still an open challenge. It has been proposed that the available 20 GeV electron and positron bunches at the Stanford Linear Accelerator Center could be used to mimic these scenarios by exploring CFI associated with the propagation of a neutral $e^−e^+$ beam into a plasma [P. Muggli et al., arXIV 1306.4380 (2013)]. In this work, we investigate this possibility by performing numerical 2D PIC simulations using Osiris [R. A. Fonseca et al., Lect. Notes Comput. Sci. 2331, 342 (2002)]. We show that CFI can occur unless the rate at which the beam expands due to finite beam emittance, is larger than the CFI growth rate. We also explore the competition between CFI and the electrostatic two-stream instability (TSI) by changing the $e^−e^+$ bunch duration. We found that, by keeping the same number of particles, the CFI dominates over the TSI for shorter bunches with larger peak densities.

CP8.00067 Radiation reaction and resulting photon emission from laser-irradiated solid targets
DAVID STARK, ALEXEY AREFIEV, Institute for Fusion Studies, The University of Texas at Austin, MANUEL HEGELICH, Center for High Energy Density Science, Department of Physics, The University of Texas at Austin — Once completed, an ongoing upgrade of the Texas-PW laser system will allow us to achieve on-target laser intensities of up to $5 \times 10^{22}$ W/cm$^2$. As experimental confirmation of the radiation reaction force and the variety of models describing it remains a challenge, here we present a scenario that would enable us to observe the effect by detecting the resulting photon emission. A laser with our planned intensity could accelerate an electron to hundreds of MeV, but the radiation reaction and thus the photon emissions would be relatively weak if the electron co-propagates with the wave. We consider a solid density target irradiated by a laser beam so that strong fields are generated due to charge separation. These fields can alter the electron trajectories, leading to strong radiation reaction and photon emission in the focal spot. Simulating this interaction using the particle-in-cell code EPOCH, we perform a target density scan that allows us to optimize the fraction of the laser energy converted into photons and to determine the photon spectrum. Knowing the spectrum and the angular emission is critical for measurements in the lab, since these photons must be distinguished from those from other processes.

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1We use HPC resources from the Texas Advanced Computing Center. This work is supported by DOD-Air Force Contract No. FA9550-14-1-0045, US DOE Contract No. DE-FG02-04ER55472, and DOE SCGF by ORISE-ORA under Contract No. DE-AC05-00OR22100.

CP8.00068 Mono-energetic ion acceleration in the RPA regime: a tale of two temperatures
VLADIMIR KHUDIK, GENNADY SHVETS, Department of Physics and Institute for Fusion Studies, The University of Texas at Austin — We develop an analytical theory of the laser-accelerated plasma target irradiated by a circularly polarized laser pulse in the RPA regime. We demonstrate that relationship between electron and ion temperatures is the key to understanding the structure of the accelerated target. To illustrate this point, we discuss two simplest analytically treatable limiting cases of (1) cold ions and hot electrons [1], and (2) hot ions and cold electrons. In the first case, hot electrons bounce back and forth inside the potential well formed by ponderomotive and electrostatic potentials while the ions are force-balanced by the electrostatic and non-inertial fields. In the second case the situation is very different: hot ions are trapped in the potential well formed by the ion-sheath's electric and non-inertial potentials while the cold electrons are force-balanced by the electrostatic and ponderomotive fields. Using PIC simulations we study the target stability with respect to Rayleigh-Taylor instability [1,2].


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CP8.00069 Ion acceleration by relativistic laser pulses from semitransparent targets
A.V. BRANTOV, E.A. GOVRAS, V. YU. BYCHENKOV, Lebedev Physics Institute, Moscow, Russia, W. ROZMUS, Univ. of Alberta, Edmonton, AB, Canada — A new, maximum proton energy, $E_p^\text{max}$, scaling law with the laser pulse energy, $E_L$, has been derived from the results of 3D particle-in-cell (PIC) simulations. According to numerical modeling, protons are accelerated during interactions of the femtosecond relativistic laser pulses with the plain semi-transparent targets of optimum thickness [Esirkpev, et al. Phys. Rev. Lett. 96, 105001 (2006)]. The scaling, $E_p^\text{max} \sim E_L^{1/3}$, has been obtained for the wide range of laser energies, different spot sizes, and laser pulse durations. Our results show that the proper selection of foil target optimum thicknesses, results in a very promising increase of the ion energy with the laser intensity even in the range of parameters below the radiation pressure (light sail) regime. The proposed analytical model is consistent with numerical simulations.
CP8.00070 Simulation study of a destructed target effects on proton acceleration by a circularly polarized laser pulse. YOUNG-KUK KIM, MYUNG-HOON CHO, Ulсан Natl Inst of Sci & Tech, HYONG JU PACK, MOON YOUN JUNG, Electronics and Telecommunications Research Institute, MIN SUP HUR, Ulсан Natl Inst of Sci & Tech, BIOMED TEAM — The minimum obtainable transverse emittance (thermal emittance) of electron beams generated and trapped in plasma-based accelerators using ionization injection is examined. The initial electron beam transverse phase space distribution following ionization and transit through the laser is derived. Expressions for the non-linear transverse beam emittance, both along and orthogonal to the laser polarization, are presented. Results are compared to particle-in-cell simulations. Ultra-low emittance electron beams can be generated using laser ionization injection into plasma accelerators.

CP8.00071 ABSTRACT WITHDRAWN

CP8.00072 Thermal emittance from ionization-induced trapping in plasma accelerators1, CARL SCHROEDER, JEAN-LUC VAY, ERIC ESAREY, CARLO BENEDETTI, CAMERON GEDDES, WIM LEEHANS, Lawrence Berkeley National Laboratory, STEPAN BULANOVA, University of California, Berkeley, LULE YU, MIN CHEN, Shanghai Jiao Tong University — The minimum obtainable transverse emittance (thermal emittance) of electron beams generated and trapped in plasma-based accelerators using ionization injection is examined. The initial electron beam transverse phase space distribution following ionization and transit through the laser is derived. Expressions for the normalized transverse beam emittance, both along and orthogonal to the laser polarization, are presented. Results are compared to particle-in-cell simulations. Ultra-low emittance electron beams can be generated using laser ionization injection into plasma accelerators.

1Supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

CP8.00073 Generation of high energy electron accelerated by using a tapered capillary discharge plasma. MINSEOK KIM, INHYUK NAM, TAEHEE LEE, SEUNGWOO LEE, HYONG SUK, Gwangju Institute of Science and Technology — The tapered plasma density in a gas-filled capillary waveguide can suppress the dephasing problem in laser wakefield acceleration (LWFA). As a result, the acceleration distance and the gained electron energy are expected to be increased. For this purpose, we developed a tapered capillary waveguide, which can produce a plasma density of $\sim 10^{18}$ cm$^{-3}$. Using this capillary discharge plasma, we performed the acceleration experiments with the high power laser system (20 TW/40 fs) constructed at GIST. In this presentation, the detailed electron acceleration experiments will be reported.

CP8.00074 Generation of multiple, mono-energetic electron bunches via ionization injection in a laser wakefield accelerator, C.J. ZHANG, Tsinghua University, C.-K. HUANG, National Central University, J.F. HUA, Tsinghua University, C.-H. CHEN, S.-Y. CHEN, National Central University, C. JOSHI, W.B. MORI, University of California Los Angeles, J. WANG, National Central University, W. LÜ, Tsinghua University — Electron bunches with multiple energy peaks are generated via ionization injection in a laser wakefield accelerator using a 40 fs, 10 TW laser. These electron bunches are highly asymmetric with an aspect ratio that varies from 2 to 5 and have a central energy about 80 MeV with multiple narrow-energy-spread peaks. Key features of the electron bunches seen in this experiment are observed in 3D PIC simulations using OSIRIS. In the simulations, ionization and injection of the inner-shell electrons is caused by the increase of laser intensity due to self-focusing ($p/p_0 \approx 1.1$) and is subsequently terminated after a propagation distance of less than $Z_{2B}$ as a result of laser evolution. Acceleration of these electrons then leads to mono-energetic bunches. The interaction between the back of the laser pulse and the accelerated bunch stretches the latter leading to a highly asymmetric spot.

CP8.00075 Ion-acoustic Shocks with Reflected Ions: Implications for laser-based proton accelerators1, ROALD SAGDEEV, UMD, MIKHAIL Malkov, UCSD, UMD, GALINA DUDNIKOVA, UMD, TATYANA LISEYKINA, Potsdam University, Germany, PATRICK DIAMOND, UCSD, C.-S. LUI, J.-J. SU, UMD — Analytic solution for an ion-acoustic collisionless shock with reflected ions is obtained. Its relation to classical non-reflecting solitons propagating at Mach numbers strictly limited by $M < M_c \approx 1.6$ (Boltzmann electrons) and $M_c \approx 3.1$ (trapped electrons), is quantified. Above $M = M_c$, the soliton begins to reflect upstream ions and turns into a shock. The shock has a double-structure consisting of two receding transitions. The first transition is the ion-acoustic shock itself formed in place of the soliton. The shock reflected ions progressively fill up an extended footprint ending with the second transition that propagates faster than the rear shock but slower than the most of reflected ions. A small fraction of these ions still remains trapped in the transition to maintain charge neutrality. Most of them pass through this front transition, and accelerate whereas their distribution becomes noteworthy monoenergetic. The obtained solution may thus have interesting implications for the laser-based ion accelerators. Applications to particle acceleration in geophysical and astrophysical shocks are discussed.

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CP8.00076 Overcoming the Dephasing Limit in the Bubble Regime by Synergybetween Direct Laser Acceleration and Laser Wakefield Acceleration1, XI ZHANG, VLADIMIR KHUDIK, GENNADY SHVETS, Department of Physics and Institute for Fusion Studies, The University of Texas at Austin — Direct Laser Acceleration (DLA) in the bubble regime is an acceleration mechanism [1] that combines the traditional plasma wakefield acceleration inside the plasma bubble with energy gain directly from the laser pulse. Recent experiments [2] demonstrated one of the signatures of the DLA: highly efficient gamma-rays from resonantly excited betatron oscillations of accelerated electrons inside the plasma bubble. Here we propose another potential benefit of DLA: the reduction of dephasing between the accelerated electrons and accelerating field of the bubble. A simple semi-analytic model is developed to investigate the synergy between DLA and LWA acceleration mechanisms. We propose to enhance the DLA by adding a second time-delayed weak laser pulse capable of interacting with bubble electrons right after self-injection [3]. This scenario is validated by direct PIC modeling using the 2D VLPL code. The prospects for achieving high-energy electrons at the Texas Petawatt laser are discussed.

1This work is supported by the US DOE grant DE-SC0007889.
CP8.00077 Modeling of Laser wakefield acceleration in the Lorentz boosted frame using UPIC-EMMA and OSIRIS. PEICHENG YU, UCLA, XINLI BU, Tsinghua University Beijing, VIKTOR DECYK, FRANK TSUNG, UCLA, JORGE VIEIRA, RICARDO FONSECA, IST Portugal, WEI LU, Tsinghua University Beijing, LUIS SILVA, IST Portugal, WARREN MORI, UCLA, UCLA TEAM, TSINGHUA UNIVERSITY BEIJING TEAM, IST PORTUGAL TEAM — We present the capability of investigating physics of laser wakefield accelerator (LWFA) in nonlinear regimes using various approaches. This includes simulating the physics using OSIRIS 3D code in the lab and boosted frame. We also implemented hybrid 3D algorithm into OSIRIS which uses an algorithm with a PIC description in r-z and a gridless description in phi [A.F. Lifschitz, et. al., JCP, 228, 1803 (2009)]. This algorithm greatly reduce the computation load by describing the three-dimensional (3D) physics problem of laser-plasma interaction with essentially two-dimensional if the expansion is truncated. The hybrid 3D OSIRIS code can be used to simulate the nonlinear physics in LWFA in both lab and boosted frames. Combining the hybrid 3D and boosted frame approaches potentially provides unprecedented speedups. Furthermore, we can simulate the same problems in a boosted frame using the spectral EM-PIC code UPIC-EMMA which solves the Maxwell’s equation in Fourier space. By applying a recipe to systematically reduce the numerical Cerenkov instability (NCI) in the sspectral code, we are able to conduct LWFA Lorentz boosted frame simulation at arbitrary gamma with no signs of NCI.

CP8.00078 Study on beam emittance evolution in a nonlinear plasma wake field accelerator with mobile plasma ions, WEIMING AN, CHAN JOSHI, WARREN MORI, UCLA, WEI LU, Tsinghua University, Beijing — We study the electron beam evolution in a nonlinear blowout PWFA when the accelerated beam has a very small matched spot size that can cause the plasma ion collapsing towards the beam. Contrary to the common belief, very small emittance growth of the accelerated electron beam is found when the plasma ion collapsing destroys the perfect linear focusing force in the plasma wake field. The improved quasi-static PIC code QuickPIC also allows us to use very high resolution and to model asymmetric spot sizes. Simulation results show that the accelerated beam will reach a steady state after several cm propagation in the plasma (which is why we can do simulations and not let the drive beam evolve). We find that for round beams the ion density (which is Li+) enhancement is indeed by factors of 100, but that the emittance only grows by around 20 percent. For asymmetric spot sizes, the ion collapse is less and emittance growth is zero in the plane towards the beam. Contrary to the common belief, very small emittance growth of the accelerated electron beam is found when the plasma ions collapsing destroys the perfect linear focusing force in the plasma wake field. The improved quasi-static PIC code QuickPIC also allows us to use very high resolution and to model asymmetric spot sizes. Simulation results show that the accelerated beam will reach a steady state after several cm propagation in the plasma (which is why we can do simulations and not let the drive beam evolve). We find that for round beams the ion density (which is Li+) enhancement is indeed by factors of 100, but that the emittance only grows by around 20 percent. For asymmetric spot sizes, the ion collapse is less and emittance growth is zero in the plane towards the beam.

CP8.00079 Self-modulation of a Long Electron Bunch in a Dense Plasma, PATRIC MUGGLI, Max Planck Institute for Physics, JORGE VIEIRA, NELSON LOPES, LIGIA DIANA AMORIM, IST, SPENCER GESSNER, MARK HOGAN, MICHAEL LITOS, SELINA LI, SLAC, NAVID VAFAEI-NAJAFABADI, CHAN JOSHI, KENNETH MARSH, CHRIS CLAYTON, UCLA, ERIK ADLI, Oslo University — The self-modulation instability of long charged particle bunches in plasmas was recently proposed as a means to drive large amplitude wakefields. This instability transforms a long particle bunch into a train of shorter bunches with a periodicity approximately equal to that of the plasma wavelength. We proposed to study this instability at SLAC-FACET with electron and positron bunches. The occurrence of the instability leads to three possible observables. First, bump particles lose energy driving wakefields while the instability develops and after it has saturated. Second, the bump particles are alternatively focused and defocused, leading to a transverse profile with a dense core and a wake halo. Third, the radius of the bunch becomes periodically modulated. Long particle bunches, meter-long high-density plasmas and well developed diagnostics are available at FACET. We present experimental results obtained with electron bunches that suggest the development of the instability. These results are supported by numerical simulations results.

CP8.00080 Quasi-monoenergetic electron beam generation from laser wakefield acceleration with tapered capillary gas cell, INHYUK NAM, MINSEOK KIM, SEUNG-WOO LEE, TAE-HEE LEE, HYYONG SUK, Gwangju Institute of Science and Technology (GIST), LASER PLASMA ACCELERATION LABORATORY TEAM — In this presentation, we experimentally investigated the enhancement of energy of electron beams with the untapered/tapered capillary gas cell. The energy of electron beams from the laser wakefield acceleration is mainly limited by the laser diffraction and the dephasing length. In order to overcome the dephasing the tapered plasma can increase the dephasing length which results in enhancement of the energy of electron beams. We have developed a tapered capillary gas cell with the variable gas pressure gradients by changing gas-feed line cross-sections. The capillary gas cell with untapered/tapered pressure will be used for high-energy electron acceleration experiments together with the 20 TW/40 fs laser system. We observed enhancement of the energy of electron beams with the tapered capillary gas cell.

CP8.00081 Generation of High Brightness Electron Beams via Ionization Induced Injection by Transverse Colliding Lasers in a Beam-Driven Plasma Wakefield Accelerator, F. LI, X. L. BU, W. W. LI, Tsinghua University, Beijing 100084, China, W.B. MORI, C. JOSHI, University of California Los Angeles, Los Angeles, California 90095, USA — The production of ultra-bright electron bunches using ionization injection triggered by two transversely colliding laser pulses inside a beam-driven plasma wake wave is examined via three-dimensional (3D) particle-in-cell (PIC) simulations. The relatively low intensity lasers are polarized along the wake axis and overlap with the wake for a very short time. The result is that the residual momentum of the ionized electrons in the transverse plane of the wake is reduced and the injection is localized along the propagation axis of the wake. This minimizes both the initial “thermal” emittance and the emittance growth due to transverse phase mixing. Simulations show that ultra-short (~8 fs) high-current (0.4 kA) electron bunches with a normalized emittance of 8.5 and 6 nm in the two planes respectively and a brightness greater than $1.7 \times 10^{19}A^{-2}\cdot m^{-2}$ can be obtained for realistic parameters.

CP8.00082 Positron self-driven hollow channel in non-linear plasma wakefields, LIGIA DIANA AMORIM, JORGE VIEIRA, RICARDO A. FONSECA, LUIS O. SILVA, GOLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Lisbon, GOLP/INSTITUTO DE PLASMAS E FUSSAO NUCLEAR TEAM — Plasma based accelerators are capable of sustaining very high acceleration gradients when compared to conventional accelerators. In particular plasma based accelerators operating in non-linear regimes reached the 100GV/m. One of the challenges for a future plasma based collider is to accelerate positrons in non-linear regimes. Although novel techniques have been investigated to this end [1], it is still important to propose and explore other new configurations for positron acceleration in non-linear regimes. In this context we suggest a novel process for positron acceleration in non-linear plasma wakefields, where a tightly focused positron drive beam expels the plasma ions forming a hollow channel with large accelerating and focusing wakefields suitable for positron acceleration. We introduce the setup of the proposed scheme and illustrate it with analytical and numerical results of a 3D numerical simulations performed with the PIC code OSIRIS [2]. Moreover, we discuss the optimal conditions for the positron drive beam stability.


This work was partially supported by FCT grant SFHR / BD / 84851 / 2012. We acknowledge PRACE for access to resources on SuperMUC (Leibniz Research Center).
Characterization of betatron x-ray emission from wakefield accelerators

KARL KRUSEL-NICK, University of Michigan, CHRIS MCGUFFEY, UCSD, PAUL CUMMINGS, University of Michigan, WILL SCHUMAKER, SLAC, VLADIMIR CHVYKOV, University of Michigan, FRANKLIN DOLLAR, University of Colorado, Boulder, GALINA KALINTCHENKO, University of Michigan, TAKESHI MATSUOKA, Osaka University, MICHAEL VARGAS, VICTOR YANOVSKY, ALEC THOMAS, University of Michigan — We investigate betatron x-ray emission from laser wakefield accelerated electron beams using the HERCULES laser facility at the University of Michigan. The x-ray emission was observed to increase substantially after propagation of the generated electron beam beyond the plasma dephasing length. This was likely due to electron beam hosing instabilities seeded by interaction of the electron beam with the co-propagating laser pulse. The development of the hosing instability is confirmed by numerical modeling. We also investigate phase contrast imaging with this source at high x-ray energies and have compared the betatron emission with K-alpha emission from laser solid interaction in a similar experimental geometry.

Ferroelectric Plasma Sources for Ion Beam Neutralization

A. STEPANOV, E.P. GILSON, L.R. GRISHAM, R.C. DAVIDSON, PPPL — A 40 keV Ar+ beam with a dimensionless perveance of 4×10^-4 is propagated through a Ferroelectric Plasma Source (FPS) to determine the effects of charge neutralization on the transverse beam profile. Neutralization is established 5 ms after the FPS is triggered, and lasts between 10 and 35 ms. When the beam is fully neutralized, the profile has a Gaussian shape with a half-angle divergence of 0.67°, which is attributed to ion optics. The effects of the resistance and capacitance in the pulser circuit on the FPS discharge are studied. The electron current emitted by the FPS is calculated from measurements of the forward and return currents in the circuit. Electron emission typically begins 0.5 μs after the driving pulse, lasting for tens of μs, which is similar to the duration of ion beam neutralization. The total emitted charge does not depend significantly on the resistance, but depends strongly on the storage capacitance. Lowering the capacitance from 141 nF to 47 nF results in a near-complete shut-off of charge emission, although the amplitude of the applied voltage pulse is as high as when high-density plasma is produced. Overall, the data suggest that ferroelectric effects are significant in the physics of the FPS discharge.

Numerical Studies of Electrode Plasma Formation and Expansion in High Power Charged Particle Beam Diodes

1, I.M. RITTERSDORF, S.B. SWANEKAMP, A.S. RICHARDSON, R.J. ALLEN, J.W. SCHUMER, Naval Research Laboratory — High-power diodes that generate intense electron beams are useful in many applications, such as producing x-rays for flash radiography and nuclear weapon effects simulations. Desorption and ionization of gases from electrodes can form a plasma during operation. Expansion of this plasma into the gap leads to a short circuit, which limits the radiation production. It is difficult for particle-in-cell codes to model the surface physics or the subsequent expansion of the plasma. NRL is beginning a multi-year research effort to study such plasmas. This paper will summarize the relevant literature on plasma formation in high-power diodes with a goal of developing dynamic models that describe the formation and expansion of these plasmas that are suitable for PIC codes.

Field Emitters


Bi-Frequency Linear Slow Wave Device

1, DAVID SIMON, PENG ZHANG, Y.Y. LAU, GEOFF GREENING, RONALD GILGENBACH, University of Michigan, Ann Arbor, BRAD HOFF, Air Force Research Laboratory — Bi-frequency sources are of interest to plasma processing, diagnostics, RF heating, and defense electronics. The recirculating planar magnetron [1] has been modified to produce two frequencies using two different slow wave structures in the planar regions. To highlight the coupling in the two frequencies, we consider here a linear TWT driven by a sheet beam inside such a structure. The cold tube dispersion is derived and is compared favorably with HFSS. The hot tube dispersion has also been derived, and is being compared with MAGIC simulations. Various nonlinear effects are explored, such as harmonic generation, parametric amplification, and intermodulation.

Experimental and Simulation Study of Electric Field Screenings of Carbon Fiber Field Emitters

1, WILKIN TANG, DON SHIFFLER, Air Force Rsc Lab-Albuquerque, MATTHEW LACOUR, KEN GOLBY, Leidos Inc., TIM KNOWLES, Energy Science Laboratory Inc. — Field emitter arrays have the potential to provide high current density, low voltage operation, and high pulse repetition for radar and communication. It is well known that packing density of the field emitter arrays significantly affects the emission current. Previous experiments were conducted with 1000s of field emitters which makes the analysis of electric field screening difficult. Here we describe experiments in a dual-cathode and four-cathode configuration. The experiments used different number of carbon fiber field emitters (two and four) with variable spacing to investigate the effect of electric field screening on current emission. Emission characteristic is compared for the case of two and four field emitters with different spacing. Analytic model and Particle-in-cell simulations are performed to compare with the experiments.

Temporarily Gated Liquid Scintillator Neutron Detectors

1, JOHN T. MORRISON, Natl. Research Council, KYLE D. FRISCHE, ISSI Inc., Dayton, OH, W. MELVYN ROQUEMORE, Air Force Research Laboratory, Dayton, OH — Laser based neutron sources are of interest for non-destructive testing of materials and detection of sensitive materials. These sources typically also generate large numbers of secondary x-rays and gammas which can saturate Photo Multiplier Tubes (PMT’s) measuring scintillating time of flight detectors if there is not sufficient time for them to recover before the arrival of the neutron signal. Improving the response time of scintillating of medium allows for closer placement of the detectors and improved sensitivity. Liquid scintillators have been employed to reduce the decay time of the scintillating medium and temporal gating of the PMT’s prevents saturation of the PMT’s by the preceding gamma flash. Detector design and results of the detector calibration will be presented.

Air Force Research Laboratory, Dayton, OH

DUSTY AND COMPLEX PLASMAS
CP08.00090 Dropper for micron and submicron size powders for a plasma mass filter1, EUGENE S. EVANS, STEWART J. ZWEBEN, RENAUD GUEROUlt, NATHANIEL J. FISCH, Princeton Plasma Physics Laboratory, FRED LEVINTON, Nova Photonics, Inc. — The goal of the Plasma Mass Filter (PMF) experiment at PPPL, in collaboration with Nova Photonics, Inc., is to achieve separation between high-Z and low-Z atoms, for possible application to processing of nuclear waste to remove the highly radioactive high-Z components. The PMF features a rotating plasma column in which centrifugal forces push high-mass ions out of the plasma radially, while low-mass ions exit the plasma axially. In order to control the injection location, high-Z materials are introduced in powder form into the PMF plasma. The current experiment is limited to ∼1 kW RF, giving a calculated maximum flow rate of ∼0.1 mg/s. An electron temperature of a few eV and assumptions about the residence time of the dust particles in the PMF plasma limits the calculated maximum particle size to ∼1 µm. While previous dust plasma experiments have dealt with particles on the order of 2-3 μm, submicron particles are comparatively more difficult to manipulate under vacuum due to increased Van Der Waals and electrostatic forces. A powder dropper capable of reliably dropping micron and submicron-size particles at this flow rate is being developed, consisting of a mesh-bottomed container that is coupled to vibration motors.

1This work supported by DOE contract DE-AC02-09CH11466

CP08.00091 Experimental investigation of differential confinement effects in a rotating helicon plasma2, RENAUD GUEROUlt, EUGENE EVANS, STEWART J. ZWEBEN, NATHANIEL J. FISCH, Princeton Plasma Physics Laboratory, FRED LEVINTON, Nova Photonics, Inc. — Although plasmas have long been considered for isotope separation, challenges presented by nuclear waste remediation and nuclear spent fuel reprocessing have recently sparked a renewed interest for high-throughput plasma based mass separation techniques. Different filter concepts relying on rotating plasmas have been proposed to address these challenges. However, one of the challenges common to these concepts is the need to control the plasma rotation configuration, which is generally achieved by the use of dedicated electrodes. An experimental effort aiming to evaluate the practicality of these plasma filter concepts has recently been started at PPPL. For this purpose, a linear helicon plasma source is used in combination with concentric ring electrodes. Preliminary biasing experiments results indicate floating potential profiles locally suitable for mass discrimination for different gas mixtures (Ar/Ne, Ar/N₂, Ar/Kr). Radially resolved spectroscopic measurements and neutral gas composition analysis at two different axial positions are being planned to assess the mass separation effect.

2Work supported by US DOE under contract No DE-AC02-09CH11466

CP08.00092 Nucleation, growth, and dynamics of water-ice grains in laboratory plasmas, PAUL BELLAN, KIL-BYOUNG CHAI, Caltech — An rf discharge with LN₂ cooled electrodes has been used to study nucleation, growth, and dynamics of water-ice grains spontaneously formed in weakly ionized H, D, He, Ne, Ar, or Kr plasmas. Ice grain nucleation occurs only when plasma exists and its density is below a critical value that is proportional to ambient gas pressure. Non spherical, fast grain growth occurs when the water molecule mean free path exceeds the ice grain screening length corresponding to molecules incident on the ice grain having collisional trajectories. Up to 10:1 elongated ice grains have been observed. Ice grains grow larger in lighter gas plasmas and in particular grow up to 500 μm long in H plasma. Magnetic fields sufficiently strong to make the electron gyro radius smaller than the ice grain screening length impede non spherical growth by reducing the charge residing on water-ice grains. Ice grains are aligned along the sheath electric field and rotate about their alignment axis with ~ 10² Hz angular frequency. Dust acoustic waves are observed in low pressure, low rf power plasmas.

CP08.00093 Simulation of ablation cloud shielding effects on Tungsten dust transport in edge plasmas, R.J. HAJJAR, R.D. SMIRNOV, S.I. KRASHENINNIKOV, A.Y. PIGAROV, UCSD, E.D. MARENKOv, MEPHI, T.D. RÖGNNLIE, LLNL — Significant amount of dust are expected to be produced during plasma/PFCs interactions in next generation tokamaks. To study dust transport in tokamaks, numerical codes such as DUSTT, were developed using plasma-dust interaction models based on OML theory. However in high temperature plasmas, dust grains are always surrounded by dust material vapor cloud, which when dense enough can alter the dust-plasma interactions for grain radii larger than ~ 1-10μm depending on plasma parameters. This reduces the grain ablation rate and extends its lifetime and penetration towards the plasma core as compared to models neglecting the cloud effects. A new model describing dust shielding effects for high-Z materials is developed and implemented in DUSTT code. This model considers the reduced heat flux to the dust grain in edge plasma, where it is shown to be due to electron heat conduction. In this work, we investigate the ion induced shielding effects on dust dynamics and transport, as well as its impact on parameters of ITER-like plasma using the modified DUSTT code. Impact of the shielding effects on the maximum tolerable amount of tungsten dust produced in ITER is investigated. The simulation results are also compared to those previously obtained using an ad hoc dust shielding factor.

CP08.00094 Dust Transport in Low Voltage Glow Discharges, C.A. ROMERO-TALAMAS, E.M. BATES, W.F. RIVERA, W. BIRMINGHAM, University of Maryland Baltimore County — Results from experiments of dust hopping under different electrode configurations are presented. The purpose of these experiments is to investigate conditions that lead to the dust in a low voltage dusty plasma to be transported and clumped on the lower electrode, by hopping throughout the bottom electrode. The setup consists of a pair of parallel electrode plates that can be oriented with respect to gravity and can have their separation changed without breaking vacuum. The electrodes are suspended by insulating rings in the vacuum chamber, away from walls, and both the top and bottom of each conducting plate is exposed. This configuration allows a glow discharge on all faces of the electrodes, with the glow between the plates having a low enough voltage to charge, but not to levitate the dust grains. Several initial conditions are tested, including the amount of dust on the plate, its distribution, and the presence of any obstacles. This research is relevant to the transport and accumulation of dust in high temperature plasma discharge chambers, as well as in airless planetary bodies.

CP08.00095 Mass Spectrometry of 3D-printed Materials in Vacuum, W.F. RIVERA, C.A. ROMERO-TALAMÁS, E.M. BATES, W. BIRMINGHAM, University of Maryland Baltimore County — We present the design and preliminary results of a mass spectrometry system to assess vacuum compatibility of 3D-printed parts. The setup consists of a vacuum chamber with a residual gas analyzer (RGA), a radiation heater, and windows for optical measurements of samples. The signal from the RGA is analyzed by creating a system of equations from the calibration signal from a large number of molecular species (the so-called cracking patterns). The equations are then inverted to find the most likely true elements in the chamber. The setup can be used as a stand-alone system, or attached to another vacuum chamber at higher pressure using differential pumping. The latter mode will be used in the Dusty Plasma Experiment at UMBC, since many of the plasma facing parts are 3D-printed. Mass spectra of electropolished plastic parts, which have a much better vacuum compatibility than non-plated plastic parts, is also obtained and compared to those without electropolishing.

CP08.00096 Development of a Split Bitter-type Magnet System for Dusty Plasma Experiments, EVAN BATES, CARLOS A. ROMERO-TALAMAS, WILLIAM J. BIRMINGHAM, WILLIAM F. RIVERA, UMBC — A 10 Tesla Bitter-type magnetic system is under development at the Dusty Plasma Laboratory of the University of Maryland, Baltimore County (UMBC). We present here an optimization technique that uses differential evolution to minimize the omhic heating produced by the coils, while constraining the magnetic field in the experimental volume. The code gives us the optimal dimensions for the coil system including: coil length, turn thickness, disks radius, resistance, and total current required for a constant magnetic field. Finite element parametric optimization is then used to establish the optimal design for water cooling holes. Placement of the cooling holes will also take into consideration the magnetic forces acting on the copper alloy disks to ensure the material strength is not compromised during operation. The proposed power and cooling water delivery subsystems for the coils are also presented. Upon completion and testing of the magnet system, planned experiments include the propagation of magnetized waves in dusty plasma crystals under various boundary conditions, and viscosity in rotational shear flow, among others.
CP8.00097 Cooling System Design for a Split High Field Bitter-type Electromagnet, WILLIAM BIRMINGHAM, EVAN BATES, CARLOS ROMERO-TALAMAS, WILLIAM RIVERA, University of Maryland, Baltimore County — For the purpose of analyzing magnetized dusty plasma at the University of Maryland Baltimore County (UMBC), we are designing a split resistive electromagnet. When completed, the magnet will be capable of generating fields of 10 T for 10 seconds. The type of design proposed here was originally developed by Francis Bitter, and achieves high magnetic fields by helically stacked disk-shaped solenoids with axially oriented cooling channels. In order to ensure the safety and functionality of the apparatus, the geometry and placement of the cooling passages must be designed to establish a manageable temperature profile throughout the coil. The estimated power consumption from resistive losses is nearly 7 MW, thus it is imperative to optimize the cooling capacity of the system. The cooling capacity is limited by the mass of chilled water available at one time and the maximum achievable mass flow through the coils. The system is also designed to withstand the resultant mechanical stresses from the Lorentz force. Slot-shaped cooling channels are used. The number and placement of these channels is optimized through an iterative and integrated design process which combines analytic calculations with finite element analyses. The methodology and results of the design process is presented.

CP8.00098 Initial Results from the Magnetized Dusty Plasma Experiment (MDPX)1, EDWARD THOMAS, UWU KONOPKA, BRIAN LYNCH, STEPHEN ADAMS, SPENCER LEBLANC, DARRICK ARTIS, Auburn University, AMI DUBOIS, University of Wisconsin, ROBERT MERLINO, The University of Iowa, MARLENE ROSENBERG, University of California - San Diego — The MDPX device is envisioned as a flexible, multi-user, research instrument that can perform a wide range of studies in fundamental and applied plasma physics. The MDPX device consists of two main components. The first is a four-coil, open bore, superconducting magnet system that is designed to produce uniform magnetic fields of up to 4 Tesla and non-uniform magnetic fields with gradients up to 2 T/m configurations. Within the warm bore of the magnet is placed an octagonal vacuum chamber that has a 46 cm outer diameter and is 22 cm tall. The primary missions of the MDPX device are to: (1) investigate the structural, thermal, charging, and collective properties of a plasma as the electrons, ions, and finally charged microparticles become magnetized; (2) study the evolution of a dusty plasma containing magnetic particles (paramagnetic, super-paramagnetic, or ferromagnetic particles) in the presence of uniform and non-uniform magnetic fields; and, (3) explore the fundamental properties of strongly magnetized plasmas ("i.e., dust-free" plasmas). This presentation will summarize the initial characterization of the magnetic field structure, initial plasma parameter measurements, and the development of in-situ and optical diagnostics.

CP8.00099 Filamentation of a Magnetized, Radio Frequency Discharge1, UWU KONOPKA, BRIAN LYNCH, Auburn University, 206 Allison Laboratory, Al 36849-5311, USA, PINTU BANDYOPADHYAY, DEVENDRA SHARMA, Institute for Plasma Research, Bhat, Gandhinagar-382428, India, EDWARD THOMAS, Auburn University, 206 Allison Laboratory, Al 36849-5311, USA — A filamentation instability has been observed in a radio-frequency (rf) discharge that was subject to an externally applied, homogeneous magnetic field. The instability arises in a uniform rf-discharge after the magnetic field strength is sufficiently increased. First, the plasma shows target-like glow structures, followed by spiral structures at higher fields. Finally, the plasma breaks up into individual, string-like, magnetic field aligned filaments that seem to repel each other. A variety of filamentation states can be observed, but their overall shapes follow the aforementioned rule of magnetic field strength dependency. The detailed picture of the discharge glow, however, depends on experiment specific conditions as the geometric shape and type of the discharge electrodes, the discharge pressure and power. In an effort to verify that the observed effect is universal, we compare experimental measurements made using two different high magnetic field, dusty plasma experiment facilities: the experiment that was located at the Max Planck Institute in Garching, Germany and the newly built MDPX (magnetized dusty plasma experiment) at Auburn University, Alabama. In both experimental setups we could observe filamentation.

CP8.00100 Real-Time 2-Dimensional Particle Tracking in Magnetized Plasmas1, BRIAN LYNCH, UWU KONOPKA, EDWARD THOMAS, Auburn University — Complex plasmas are a four component plasma system consisting of electrons, ions, neutral particles, and electrically charged (nanometer to micrometer sized) “dust” particles. In laboratory plasmas, collisional processes lead to a net negative charge residing on the dust grain surface. As a result, dust clouds may be suspended in a plasma sheaths vertical electric field and studied using digital imaging systems with laser sheet illumination. Particle Tracking Velocimetry (PTV) is an analysis technique in which each dust particle is tracked through imaging data. The velocity fields extracted using PTV provide a spatially resolved dust particle phase space distribution (PSD) function, which can be used to calculate transport and thermal properties of the system. In this presentation, we apply “real-time” PTV analysis to the Magnetized Dusty Plasma Experiment (MDPX). The introduction of a magnetic field is shown to significantly modify the global dust cloud PSD as well as individual dust particle dynamics. Finally, we present preliminary plans for the development of a new experimental study to use real-time PTV to observe single particle deflection in a magnetic field - as a means to investigate ion drag and charging of the dust grain.

CP8.00101 Observations and analysis of poloidal flows in dusty plasmas1, STEPHEN ADAMS, SHANE MOORHEAD, CHRISTIAN POLKA, DANIEL ROBINSON, UWU KONOPKA, EDWARD THOMAS, Auburn University, MANJIT KAUR, PRABAL CHAT-TOPADHYAY, DEVENDRA SHARMA, Institute for Plasma Research (IPR), India — Dusty plasmas are a four-component plasma system consisting of electrons, ions, neutral atoms, and charged nanometer- to micron-sized micro particles (i.e., “dust”). In recent experiments at the Institute for Plasma Research (IPR), observations of toroidally shaped dust rings, with strong poloidal rotation were reported. The Auburn dusty plasma group has reproduced these experiments using the large, octagonal vacuum chamber designed for the Magnetized Dusty Plasma Experiment. These studies use a dc discharge plasma at high pressure (p > 200 mTorr), over a broad range of discharge currents (up to 10 mA), to produce toroidal, semi-toroidal, disc-shaped, or ring-like dust structures. Frequently, these structures exhibit a steady-state poloidal flow. In these studies, particle image velocimetry (PIV) is used to characterize the transport of the charged microparticles. Initial results will be presented on the evolution of the particle flow as a function of the experimental parameters and a preliminary analysis of the particle motion using a balance between ion drag and gravitational forces will be presented.

1This work is supported by funding from the NSF and the DOE.
CP8.00102 Probe Diagnostics on the Magnetized Dusty Plasma Experiment (MDPX)

SPENCER LEBLANC, Auburn University, AMI DUBOIS, University of Wisconsin - Madison, MARK CIANCIOSA, UWE KONOPKA, EDWARD THOMAS, Auburn University — The Magnetized Dusty Plasma Experiment (MDPX) has recently begun operation at Auburn University. The MDPX device uses a superconducting magnet system to study plasmas at high magnetic field strengths of up to 4 Tesla. As a newly operating plasma experiment, it is essential to have careful measurements of the plasma parameters. However, the performance of in situ plasma diagnostics at high magnetic field strengths is not well understood. In order to characterize the plasma, initial measurements will be performed using single and triple cylindrical Langmuir probes without a magnetic field. These probes, in addition to a disk shaped probe, will then be used to make plasma measurements with increasing magnetic field strength. Understanding the measurements obtained from these diagnostics will be essential in order to study the charging properties of a plasma as particles are magnetized, as well as the evolution of a dusty plasma containing magnetic particles. This presentation will summarize the probe measurements obtained without magnetic fields and make comparisons with the probe performance at increasing magnetic field strengths. It will be shown that at high magnetic field strengths, the probes are strongly impacted by flux-tube limited collection.

This work is supported from funding from DOE and NSF.

CP8.00103 Investigating Ion Drag In Perturbed Dusty Plasmas

TAYLOR HALL, EDWARD THOMAS, UWE KONOPKA, Auburn University — Complex, or dusty, plasmas are plasmas which contain charged microparticles, for example small silicon dust grains. In this study, we are particularly interested in the interaction between the charged dust particles and plasma ions through the ion drag force in a dc glow discharge plasma. Measurements of the dust particles are carried out through a technique called Particle Image Velocimetry (PIV) which calculates the average velocity field based on small particle groups. As an electrostatic perturbation is applied to the dust cloud, the particle motion is observed to change its direction of motion as the gas pressure is increased. Density and temperature measurements on the background plasma are conducted for both low and high voltage states of the perturbation. An analysis of the dust particle motion suggests that there is a competition between the electrostatic force and the ion drag force on the particles. This presentation will discuss techniques and results of the calculations as well as the implications for future work on microgravity experiments.

This work is supported by funding from NASA/JPL.

CP8.00104 Time-resolved measurement of global synchronization in a weakly-coupled dusty plasma system

JEREMIAH WILLLIAMS, Wittenberg University — A complex (dusty) plasma is a four-component system composed of ions, electrons, neutral particles and charged microparticles. The presence of the microparticles gives rise to new plasma phenomena, including collective modes such as the dust acoustic wave (DAW). This naturally occurring wave mode has been the subject of intense theoretical and experimental study since it was predicted in 1990 and experimentally identified in 1995. In the experimental studies of this wave mode, it has been observed that the naturally occurring wave mode is the superposition of several wave modes and that the natural wave mode can be synchronized to an external modulation. In this presentation, a time-resolved Hilbert Transform (J. D. Williams, Phys Rev E 89, 023105 (2014)) is applied to high speed video imaging to provide a spatiotemporal measurement of the global synchronization of the DAW with an external modulation in a weakly-coupled dusty plasma in a dc glow discharge plasma.

This work supported by National Science Foundation Grant Number PHY-0953595.

CP8.00105 Experiments and simulations of the expansion of three dimensional dusty plasmas

JOHN K. MEYER, ROBERT L. MERLINO, University of Iowa, VIKRANT SAXENA, Center for Free Electron Laser Science, DESY, Hamburg, Germany, AVINASH KHARE, University of Delhi, ABHIJIT SEN, Institute for Plasma Research, Bhat, Gandhinagar, India — The expansion of a three-dimensional dust cloud was studied experimentally, and using molecular dynamics simulations. The dust clouds are composed of spherical glass particles of one micron diameter formed in a DC glow discharge of ion and electron. The dust clouds are confined by an electrostatic potential structure formed by a biased mesh electrode. The cloud expansion is initiated either by turning off the bias on the mesh or by turning off the anode voltage, or both. The cloud expansion is studied by imaging the particles with a thin sheet of 532 nm laser light and a fast video camera. Cloud expansions were studied for various neutral gas pressures. The simulation model is zero dimensional, which solves the equation of motion of screened dust particles along with temporal evolution equations for plasma density and electron temperature which determine the Debye length and the dust charge. The effect of background neutral gas enters through loss terms in the plasma density and electrons temperature evolution equations. In the high pressure regime the electron temperature decays faster than the plasma density while in the low pressure regime opposite is true. Results from the simulations at different background pressure are obtained and compared with the experimental observations.

Supported by DOE and NSF.

CP8.00106 A comparison of the local field approximation and the local mean energy approximation in a dusty plasma

ALTREA WILSON, The University of Alabama in Huntsville, MOHAMMAD DAVOUDBADIRI, ANSYS, Inc., BABAK SHOTORBAN, The University of Alabama in Huntsville — Two methods of determining rate coefficients, the local-field approximation and the local-mean-energy approximation, are compared for a dusty plasma. A low pressure cylindrical RF argon reactor is modeled computationally. Then multiple small dust grains are released and tracked in a three-dimensional framework. Gravity, neutral drag, ion drag, and grain-grain interaction forces are considered to act on dust. The differences in the plasma properties and in the resulting dust crystal generated through two methods are examined.

CP8.00107 Discrete Stochastic Charging of Dust Aggregates Immersed in Plasma

ABBEY HAINES, LORIN MATTHEWS, CASPER, Baylor University, BABAK SHOTORBAN, University of Alabama-Huntsville, TRUELL HYDE, CASPER, Baylor University — Numerical simulations treating the charge as a continuous variable have been used to model stochastic charge fluctuations on dust aggregates. These stochastic fluctuations in turn lead to differences in the interactions and dynamics of charged dust aggregates [Matthews et al., ApJ, 2013]. The continuity assumption is strictly valid when the overall charge collected on the grain is substantially larger than the elementary charge. However, small grains (with radii less than 1 \( \mu m \)) or grains in a tenuous plasma environment are sensitive to single additions of electrons or ions, as their overall gained charge is comparable in magnitude to the elementary charge. In this work, a discrete stochastic method is employed to allow for integer increments of fluctuations of elementary charges collected on dust grains. Dynamic charging calculations during particle interactions are used to resolve the effects of the changing charge distribution due to stochastic charging effects.
CP8.00108 Measurement of the Charge Reduction and Asymmetrical Interaction Force Created by the Ion Wakefield in a Dusty Plasma, MUDI CHEN, RAZIEN YOUSEFI, JIE KONG, KE QIAO, JORGE CARMONA-REYES, LORIN MATTHEWS, TRUELL HYDE, CASPER - Baylor University — The manner in which the ion wakefield forms has strong implications on the structure, stability and dynamics of a complex plasma. The majority of vertically aligned, ordered dust particle structures observed in a complex plasma result from a combination of the ion wakefield and the external confinement. The ion wakefield is also responsible for other interesting phenomena, such as the reduction in charge seen for a downstream particle in a vertically aligned dust particle chain and the asymmetrical interaction force between the upstream and downstream particles.

Unfortunately, few experimental measurements of these phenomena are available. In this experiment, one-dimensional (1-D) dust particle structures (i.e., particle chains) are formed in a GEC RF reference cell within a glass box sitting on the powered, lower electrode. The charge reduction on the downstream particle and the asymmetric interaction force are examined using an externally produced DC bias applied to the lower electrode and a diode pumped solid state laser (Coherent VERDI) for perturbation.

CP8.00109 Using Dust Particle Clusters as Probes for Mapping Trapping Potentials in Complex Plasmas, BO ZHANG, JIE KONG, LORIN MATTHEWS, TRUELL HYDE, CASPER - Baylor University — Dust particle clusters often manifest interesting phenomena when externally driven inside a complex plasma. Double vortices, structural phase transitions and aligned string structures have all been observed within the central region of such clusters. This paper examines whether dust particle clusters can be used as in-situ probes for investigating the trapping potential of the external confinement (driving) field within a rf discharge plasma in argon. The experiments to be discussed, were conducted inside a transparent, conductive, indium tin oxide (ITO) glass box with the walls of the box biased positively and negatively. By switching the biasing potential on and off while maintaining constant rf power, the morphology of the dust cloud can be analyzed providing insight on the topology of the trapping potential inside the ITO box.

CP8.00110 A small body in a plasma: effects of ion flow and capture on the potential and fluid flow velocities, CHRISTOS STAVROU, Imperial Coll, UMBERTO DE ANGELIS, University of Naples and INFN Sezione di Napoli, Italy, JOHN ALLEN, OCIAM, Mathematical Institute, University of Oxford, Oxford OX2 6GG, UK, MICHAEL COPPINS, Imperial Coll — Although the potential, ion density and fluid velocity profiles of a flowing plasma around a small charged object can be obtained by means of PIC simulations, a theoretical approach allows an easier understanding of the role of the basic parameters: the ion flow speed, the dust radius and the ion to electron temperature ratio. These results allow for the calculation of ion drag, a problem of basic importance for fusion. We investigate how the potential, ion density and ion fluid velocities are modified when ion streaming and capture by the object are taken into account by using the simplest possible model of linear kinetic theory. The point-sink model is used, with the assumption that all the effects (presence of charged object, capture of ions, ion flow) introduce a “small” perturbation in the ion distribution function. Both supersonic and subsonic velocities are investigated. The calculations are compared with PIC simulations.

CP8.00111 Particle in cell calculation of plasma force on a small grain in a non-uniform collisional sheath, IAN H. HUTCHINSON, MIT PSFC — Dusty plasma experiments often involve grains suspended in a sheath. The plasma forces on them are complicated by several factors. Ion-neutral collisions, essential to the pre-sheath physics, control the ion velocity distribution and can directly affect the ion drag force; there is no length-scale separation between the non-uniformity of the sheath itself and the grain’s plasma perturbation; and non-linearity is important in the ion-grain interactions. The multidimensional particle in cell code COP'TIC has been used to calculate fully self-consistently the plasma force, when charge and height in a (charge-exchange) collisional DC plasma sheath are specified. The background sheath ion velocity distribution functions for the unperturbed sheath are observed to vary substantially with collisionality. The grain force is found to agree quite well with a combination of sheath electric field force plus ion drag force. However, the drag force must take account of the non-Maxwellian (and spatially varying) ion distribution function, and the collisional drag enhancement. Practical formulas are provided to enable equilibrium including other forces such as gravity to be calculated.

CP8.00112 Orbital-motion-limited theory of dust charging and plasma response, GIAN LUCA DELZANNO, Los Alamos National Laboratory — The foundational theory for dusty plasmas is the dust charging theory that provides the dust potential and charge arising from the dust interaction with a plasma. The most widely used charging theory for negatively charged dust particles is the so-called orbital motion limited (OML) theory, which predicts the dust potential and heat collection accurately for a variety of applications, but was previously found to be incapable of evaluating the dust charge and plasma response in any situation. Here we report a revised OML formulation that is able to predict the plasma response and hence the dust charge. It involves a corrected OML ion density expression for the background plasma where the plasma potential rises faster than 1/r^2, which is always the case in the Debye shielding region. We also provide the first calculation of the plasma potential and the dust charge using the OML theory. Significant deviation from the Whipple approximation of the dust charge is found when the dust size is comparable to or larger than the Debye shielding length, which is a case of importance to laboratory applications, particularly magnetic plasma devices. This is attributed to the fundamental role of angular momentum conservation in setting the plasma electron and ion density near the dust particle.

CP8.00113 Breakdown of the Orbital-Motion-Limited charging theory in the positively charged regime, GIAN LUCA DELZANNO, XIAN-ZHU TANG, LANL — The Orbital-Motion-Limited theory (OML) is the most widely used theory for charging of a spherical dust grain in a plasma. It is normally applicable to grains whose radius is much smaller than the plasma Debye length, although Particle-In-Cell simulations have shown that, when the grain is negatively charged, OML is still accurate even for moderately large grains. In this work, we show that OML can become inapplicable in the positively charged regime when the grain is an electron emitter. It can completely miss the transition between negatively and positively charged dust (thus predicting a positive dust potential when simulations show a negative dust potential) and overestimates the power collected by the grain. This is due to the development of a non-monotonic potential (a potential well) near the grain, which affects the electron emission current. A parametric study of the critical parameters controlling the breakdown is presented, together with a revised OML theory that remains accurate when potential well effects are important.

1Supported in part by NSF/DOE Grant DE-SC0010491.
2Work supported by DOE OFES

CP8.00114 Ion response in a magnetized flowing plasma¹, HANNO KÄHLERT, JAN-PHILIP JOOST, PATRICK LUDWIG, MICHAEL BONITZ, Christian-Albrechts-Universität zu Kiel, ITAP — We investigate the influence of an external magnetic field on streaming ions in a dusty plasma. The magnetic field is chosen parallel to an external electric field, which accelerates the ions and gives rise to a non-Maxwellian distribution function [1]. The ion susceptibility is derived from a kinetic equation, where ion-neutral collisions are taken into account via a Bhatnagar-Gross-Krook collision term. The properties of the response function and the angular dependence in the anisotropic plasma are discussed. The modified ion response significantly changes the effective interaction between the dust particles. Here, we use the response function to study the influence of magnetized flowing ions on the dispersion of dust density waves and compare the screened dust potential with calculations based on a shifted Maxwellian distribution [2]. [1] A. V. Ivlev, S. K. Zhdanov, S. A. Khrapak, and G. E. Morfill, Phys. Rev. E 71, 016405 (2005) [2] J.-P. Joost, P. Ludwig, H. Kähler, C. Arran, and M. Bonitz, submitted for publication, arxiv.org/abs/1407.1645

¹We acknowledge financial support from the DFG via SFB-TR24, projects A7 and A9.

CP8.00115 ABSTRACT WITHDRAWN –

CP8.00116 Effect of dust rotation on the stability of dust ion-acoustic surface waves in a kappa plasma, MYOUNG-JAE LEE, KYU-SUN CHUNG, Hanyang University — In many literature, dust grains in astrophysical environments or terrestrial laboratories were often assumed to be negatively charged particles, hence their geometrical features were neglected. However, the dust grains in space or laboratory are often non-spherical and sometimes elongated or flattened. The non-spherical dusts can have non-zero dipole moment and can acquire a rotational motion due to the oscillating electric field or due to their interaction with photons or particles of surrounding gas. Therefore, the dispersive properties of dusty plasma should be modified by the influence of the dust rotation. Meanwhile, plasmas encountered in space and laboratories are not in thermally equilibrium states and often well described by a kappa distribution function because it can effectively represent the properties of the superthermal plasma particles in the high energy tail. In this work, the temporal behavior of electrostatically perturbed dust ion-acoustic surface wave propagating in a kappa plasma containing elongated and rotating dust grains is investigated. For this purpose, we employ the Vlasov-Maxwell system and the specular reflection condition to derive the dispersion relation. We have found that the wave is stable against the linear perturbation for the full spectrum of the wave number and the damping rate is obtained. We also have found that the increase of angular frequency of rotating dust grains can enhance the damping of the wave.

CP8.00117 Experimental and Simulation Studies on Dust Instabilities at the Microscopic Level, KATHERINE PACHA, University of Iowa — Dust instabilities have been widely studied for many years in RF and DC discharge devices as well as computer analysis. By using a direct simulation in conjunction with the experiment, the microscopic picture of the instabilities can be studied in more detail. This is particularly helpful when looking in detail at the turbulent structures that at edges of clouds and when looking into regions where dust is not as dense. These studies were looked at as a fluid and as a granular flow with surprising results.

Monday, October 27, 2014 2:00PM - 5:00PM – Session CM10 Mini-Conference: The Magnetic Universe – A Mini-Conference in Honor of Stirling Colgate I Salon FGH - Hui Li, Los Alamos National Laboratory

2:00PM CM10.00001 Is Transport in Accretion Disks Primarily Local or Non-local? , ERIC G. BLACKMAN, University of Rochester — Accretion disks likely involve some combination of local and non-local angular momentum transport. Coronae and jets provide evidence for large scale transport and disk thermal emission may provide evidence for local transport. Identifying the principles that determine the relative local vs. nonlocal fraction poses a set of challenges and highlights a significant gap between numerical simulation results and improved, practical mean field accretion theory. The dominant mechanisms of transport may in fact be non-local and non-viscous. Even the magneto-rotational instability (MRI) for example, often invoked as a source of local turbulence, may produce predominantly non-local transport. I will overview progress and open issues on these themes, drawing in concepts from disk theory, dynamo theory, and corona formation.

2:30PM CM10.00002 Magnetorotational dynamo instability in statistical models of shearing box turbulence¹, JONATHAN SQUIRE, AMITAVA BHATTACHARJEE, Princeton University — A large scale dynamo generating a strong azimuthal field is a fundamental component of the turbulence induced by the magnetorotational instability (MRI). The dynamo appears to be inherently time-dependent, producing well-defined butterfly diagrams, and is never kinematic even in its earliest stages, since without the magnetic field the MRI does not exist. In this talk we consider the dynamo in MRI turbulence in its simplest possible form, studying the zero net-flux unstratified shearing box. With the aim of isolating the core dynamo process, we remove as much of the nonlinearity as possible from the system, studying the statistics of driven linear fluctuations in a vertically dependent mean-field that evolves self-consistently due to Reynolds and Maxwell stresses. We find that homogeneous background turbulence becomes unstable above some critical parameter to a mean-field dynamo instability with a strong dependence on magnetic Prandtl number. This instability saturates to either time-independent or time-periodic states with characteristics that strongly resemble features of fully developed MRI turbulence. We discuss the driving and saturation terms in this MRI dynamo and the relation of these to the underlying nonmodal linear dynamics.

¹This work was supported by Max Planck/Princeton Center for Plasma Physics and U.S. DOE (DE-AC02- 09CH11466).

2:45PM CM10.00003 Superbubble Explosions and the Galactic Dynamo¹, RUSSELL KULSRUD, Princeton Plasma Physics Laboratory — The alpha-omega dynamo appears to be the most likely origin for the galactic magnetic field. However, it has a major problem in that to complete the dynamo operation, flux of the wrong sign must be expelled. For normal situations this is no problem. However, in the case of the galactic disc, the combination of almost perfect flux freezing and a strong gravitational field strongly inhibit this expulsion. It is energetically impossible to expel straight magnetic lines from the disc because they would carry all their ISM with them and their gravitational binding energy is much too large. I propose that the lines can be expelled in a topological manner. This can be done by massive superbubble explosions that can expel a tiny piece of each line leading to a situation where the lines in the disc are broken and act like lines of finite length. Such lines can be random turned in the disc and cause the disappearance of any negative flux. If this proposal should be valid then the alpha-omega dynamo can work to amplify the a very weak field to the present galactic value.

¹This work was supported by the DOE Contract No. DE-AC02-09CH11466
3:05PM CM10.00004 Experimental optimization of high magnetic Reynolds number, two-vortex flows on the Madison plasma dynamo experiment. - DAVID WEISBERG, University of Wisconsin-Madison - Laminar counter-rotating two-vortex flows, predicted to excite a large-scale dynamo, are generated and optimized in the Madison plasma dynamo experiment (MPDX). Numerical simulations show that the topology of these simply-connected flows may be optimal for creating a plasma dynamo in the lab and predict a critical threshold of \( Rm_{crit} = \mu_0 T V^2 = 250 \) for optimal flows. MPDX plasmas are shown to exceed this critical \( Rm \), generating large \( L = 1.4 \) m, hot \( (T_e > 10^4 \text{ eV}) \) plasmas where \( Rm = 600 \). Plasma flow is driven using eight thermally emissive LaB\(_6\) cathodes which generate a \( J \times B \) torque at the magnetized edge of spherical He plasmas. Mach probe measurements show counter-rotating flows at speeds of \( V > 10 \) km/s; the driven flow at the plasma edge viscously couples inward to the unmagnetized core via ion-ion collisions, and flow measurements along radial chords compare favorably to hydrodynamic calculations using Braginskii viscosity. To optimize flow for dynamo generation, cathode bias and positioning are varied along with plasma viscosity \( (\nu \sim T_e^{1/2}/\mu_0) \) and the frictional neutral-ion drag force \( (\mu = L^2/(\nu\tau_m)) \). Prospects for observing a dynamo, hydrodynamic transitions to turbulence, and eventual large \( Rm \) fast dynamos will be presented.

3:35PM CM10.00005 Soft-iron impellers in the Madison Sodium Dynamo Experiment. - MARK NORNBERG, M.M. CLARK, C.B. FOREST, Univ of Wisconsin, Madison, N. PLIHON, ENS-Lyon — In an attempt to increase the magnetic flux amplification of the two-vortex flow in the Madison Sodium Dynamo Experiment, the stainless steel impellers were replaced with soft-iron disks similar in design to the VKS dynamo experiment. Past attempts at creating a homogeneous dynamo in the Madison Sodium Dynamo Experiment relied on stainless steel impellers to drive a two-vortex flow predicted to be unstable to dynamo excitation. The resulting induction process was much weaker than laminar predictions due to the turbulent enhancement of the resistivity. The measured amplification and pulse-decay times with the soft-iron disks show an improvement in the flux amplification, but not sufficient for self-excitation. Despite the similarities in the impeller design with the VKS impeller experiment, the differences in geometry still play a significant role in determining the threshold conditions for dynamo action.

3:55PM CM10.00006 The New Mexico dynamo: the past, the present, and the future. - JIAHE SI, New Mexico Tech, STIRLING COLGATE, Los Alamos National Lab, ART COLGATE, RICHARD SONNENFELD, DAVID WESTPFAHL, JOE MARTINIC, New Mexico Tech, MARK NORNBERG, University of Wisconsin-Madison, HUI LI, Los Alamos National Lab — The New Mexico dynamo experiment was designed to simulate a star-disk collision. It consists of two co-axial cylinders to make Taylor-Couette (TC) flows simulating differential rotation of accretion disks. In response to a radial seed field of 10 Gauss, the \( \omega \)-effect wound up the field lines to produce an 80-Gauss toroidal field. This is, to date, the largest gain obtained by any experiment in the world. We attribute this success to the largely coherent TC flow field in the instrument. Turbulence dissipates magnetic energy by increasing the effective resistivity of the fluid (the \( \beta \)-effect) and has been observed by the Madison group. We will study this effect in our geometry by applying an external B-field and observing its penetration into the liquid sodium flows vs time for varying levels of turbulence. In addition, we will revisit the \( \omega \)-effect at varying levels of turbulence. The final challenge for the New Mexico dynamo is the pursuit of the \( \alpha \)-effect. A plume injection apparatus has been devised and instrumentation for the full simulation of a star-disk collision is being developed.

4:15PM CM10.00007 The role of magnetic helicity flux on the alpha dynamo effect. - FATIMA EBRAIMI, A. BHATTACHARJEE, H. JI, Princeton University — Self-organized plasmas are common throughout the universe. Examples include self-organized plasmas of flow-dominated astrophysical disks and magnetically-dominated star surfaces. We will treat the dynamo problem in both laboratory (magnetically dominated) and astrophysical (flow-dominated) plasmas from a common perspective. The constraint imposed by magnetic helicity conservation on the alpha effect, the correlated flow and magnetic field fluctuations, is considered for the two important, and very different, examples of tearing instability in laboratory plasmas and magneto-rotational instability in flow-driven astrophysical disks. Through direct numerical simulations, the role of magnetic helicity fluxes on the alpha effect and the final sustainment of large-scale magnetic field will be examined. For the two examples of an unstratified Keplerian cylinder and a reversed-field pinch, a dominant contribution to the alpha effect, in the functional form of a total divergence of an averaged helicity flux, called the helicity-flux-driven alpha effect, will be demonstrated. For the second example the results will be compared with MST data. The effect of averaging (both temporal and spatial) on the results for the helicity fluxes will be discussed. Supported by CMSO and DE-FG02-12ER55142.

4:30PM CM10.00008 Laboratory Study of Angular Momentum Transport in Astrophysical Accretion Disks. - HAN TAO JI, Princeton University — Studying astrophysical processes in the lab becomes increasingly possible and exciting, as one of Stirling’s favorite subjects throughout his scientific career. In this talk, I will describe experimental efforts to study mechanisms of rapid angular momentum transport required to occur in accretion disks to explain a wide range of phenomena from star formation, energetic activity of cataclysmic variables, to powering quasars, the most luminous steady sources in the Universe. By carefully isolating effects due to artificial boundaries, which are inherent to terrestrial experiments, certain astrophysical questions regarding hydrodynamic and magnetohydrodynamic stabilities are being addressed in the laboratory. Inspirations from Stirling as well as scientific exchanges with him will be mentioned during this talk as part of my scientific journey on this subject.

4:45PM CM10.00009 A spherical Couette experiment to observe inductionless MHD instabilities at medium Reynolds numbers. - ELLIOT KAPLAN, BENJAMIN GOHL, THOMAS GUNDRUM, MARTIN SEILMAYER, FRANK STEFANI, Helmholtz Zentrum Dresden Rossendorf — Turbulent spherical Couette flows in a strong axial magnetic field (Re \( \in (10^3, 10^4) \), Ha \( \in (0,3000) \)) have given rise to an interesting set of instabilities. Like the, long sought after, magnetorotational instability (MRI) they transport angular momentum outward. Unlike the MRI they are azimuthally nonaxisymmetric and change their equatorial symmetry as the applied field is increased [Sisan (2004)]. Subsequent theoretical and numerical investigations found a set of inductionless (\( Rm=0 \)) instabilities that replicate both these properties [Hollerbach (2009), Gissinger (2011)]. A liquid metal (GaN Sn) spherical Couette flow is being carried out at the Helmholtz-Zentrum Dresden-Rossendorf to explore a region of Reynolds-Hartmann space (Re \( \in (10^3, 10^4) \), Ha \( \in (0.160) \)) between the simulations and the experiments. The diagnostic coverage in the new experiment is also much denser (ultrasound Doppler velocimeter array for m \( \leq 3 \), electric potential probes for m \( \leq 12 \) ) than that of the 2004 experiment. Data from the initial runs of the experiment and results from the predictive simulations are discussed here.

Session D12 Waves in Plasmas
Bissonet - Joel Fajans, University of California, Berkeley
3:00PM DI2.00001 Stix Award: The ponderomotive effect beyond the ponderomotive force

I.Y. DODIN, PPPL — The classical ponderomotive effect (PE) is typically understood as the nonlinear time-average force produced by a rapidly oscillating electromagnetic field on a nonresonant particle. It is instructive to contrast this understanding with the common quantum interpretation of the PE as the ac Stark shift, i.e., phase modulation, or a Kerr effect experienced by the wave function. Then the PE can be naturally extended from particles to waves and can be calculated efficiently in general settings [1], including for strongly nonlinear interactions and resonant dynamics. In particular, photons (plasmons, etc.) are hence seen to have polarizability and contribute to the linear dielectric tensor exactly like “true” particles such as electrons and ions. The talk will briefly review the underlying variational theory [1-4] and some nonintuitive PE-based techniques of wave and particle manipulation that the theory predicts. It will also be shown that the PE can be understood as the cause for the basic properties of both linear and nonlinear waves in plasma, including their dispersion, energy-momentum transport, and various modulational instabilities. Linear collisionless dissipation (both on particles and classical waves, treated on the same footing [2]) also appears as a special case of the modulational dynamics.


The work was supported by NNSA grant DE274-FG52-08NA28553, DOE contract DE-AC02-09CH11466, and DTRA grant HDTRA1-11-1-0037.

3:30PM DI2.00002 Laboratory Studies of Nonlinear Interactions Relevant to Alfvén Wave Decay Instabilities

SETH DORFMAN, University of California, Los Angeles — Alfvén waves, a fundamental mode of magnetized plasmas, are ubiquitous in both laboratory and space plasmas. Many theoretical predictions show that these waves may be unstable to various decay instabilities (e.g. [1,2]). Despite the paramount importance of these processes in problems such as the heating of the solar wind, observational evidence is limited. The present work at UCLA’s Large Plasma Device (LPD) represents the first fundamental laboratory study of the non-linear Alfvén wave interactions responsible for this class of instabilities; in particular, we present 1) laboratory observation of the Alfvén-acoustic mode coupling at the heart of the Parametric Decay Instability [3] and 2) laboratory observations consistent with a decay instability in which a Kinetic Alfvén Wave (KAW) decays into two co-propagating KAWs. The first study is conducted by launching counterpropagating Alfvén waves from antennas placed at either end of the LPD. A resonance in the beat wave response produced by the two launched Alfvén waves is observed and is identified as a damped ion acoustic mode based on the measured dispersion relation. Results are consistent with theoretical predictions for a three-wave interaction driven by a nonlinear ponderomotive force. In the second experiment, a single high-frequency $\omega/\omega_{ci} \sim 0.7$ Alfvén wave is launched, resulting in two daughter modes with frequencies and wave numbers that suggest co-propagating KAWs produced by decay of the pump wave. The observed process is parametric in nature, with the frequency of the daughter modes varying as a function of pump amplitude. Efforts are underway to fully characterize the second set of experiments and compare with decay instabilities predicted by theory and simulations.


Supported by DOE, NSF, and DOE FES and NASA Eddy Postdoctoral Fellowships.

4:00PM DI2.00003 Landau Damping and the Onset of Particle Trapping in Quantum Plasmas

JEROME DALIGAULT, Los Alamos National Laboratory — The notion of wave-particle interactions, the couplings between collective and individual particle behaviors, is fundamental to our comprehension of plasma phenomenology. Such is the case when the electrons’ thermal energy $k_B T$ is of the order of or smaller than their Fermi energy $E_F = \frac{h^2}{2m} (3\pi^2 n)^{2/3}$ ($n$ and $m$ are the electron density and mass). The physics of quantum plasmas (e.g., of the warm dense matter regime) is a frontier of high-energy density physics with relevance to many laboratory experiments and to astrophysics. The question arises as to how wave-particle interactions are modified when the quantum nature of the electrons can no longer be ignored. Using analytical theory and simulations, we assess the impact of quantum effects on non-linear wave-particle interactions in quantum plasmas. Two regimes are identified depending on the difference between the time scale of oscillation $\tau_{B}(k) = \sqrt{m/eE}$ of a trapped electron and the quantum time scale $\tau_{q}(k) = 2m/hk$ related to recoil effect, where $E$ and $k$ are the wave amplitude and wave vector. In the classical-like regime, $\tau_{B}(k) < \tau_{q}(k)$, resonant electrons are trapped in the wave troughs and greatly affect the evolution of the system long before the wave has had time to Landau damp by a large amount according to linear theory. In the quantum regime, $\tau_{B}(k) > \tau_{q}(k)$, particle trapping is hampered by the finite recoil imparted to resonant electrons in their interactions with plasmons.


This research was supported by the DOE Office of Fusion Energy Sciences.

4:30PM DI2.00004 Cyclotron Mode Frequency Shifts in Multi-Species Ion Plasmas

MATTHEW AFFOLTER, University of California, San Diego — Plasmas exhibit a variety of cyclotron modes, which are used in a broad range of devices to manipulate and diagnose charged particles. Here we discuss cyclotron modes in trapped plasmas with a single sign of charge. Collective effects and electric fields shift these cyclotron mode frequencies away from the “bare” cyclotron frequencies $\Omega_k = qB/m_e c$ for each species $s$. These electric fields may arise from applied trap potentials, from space charge including collective effects, and from image charge in the trap walls. We will describe a new laser-thermal cyclotron spectroscopy technique, applied to well-diagnosed pure ion plasmas. This technique enables detailed observations of $\cos(mB\theta)$ surface cyclotron modes with $m = 0, 1, 2$ in near rigid-rotor multi-species ion plasmas. For each species $s$, we observe cyclotron mode frequency shifts which are dependent on the plasma density through the $E \times B$ rotation frequency, and on the charge concentration of species $s$, in close agreement with recent theory. This includes the novel $m = 0$ radial “breathing” mode, which generates no external electric field except at the plasma ends. These cyclotron frequencies can be used to determine the plasma $E \times B$ rotation frequency and the species charge concentrations, in close agreement with our laser diagnostics. Here, this plasma characterization permits a determination of the “bare” cyclotron frequencies to an accuracy of 2 parts in $10^4$. These new results give a physical basis for the “space charge” and “amplitude” calibration equations of cyclotron mass spectroscopy, widely used in molecular chemistry and biology. Also, at high temperatures there is preliminary evidence that radially-standing electrostatic Bernstein waves couple to the surface cyclotron modes, producing new resonant frequencies.


5:15PM EE1.00001 Women in Plasma Physics, KATHLEEN ALEXANDER, DOE/NNSA — Dr. Kathleen Alexander, a member of the Senior Executive Service, is the Assistant Deputy Administrator for Research, Development, Test, and Evaluation for the National Nuclear Security Administration (NNSA) Office of Defense Programs. Previously she was the Director of Interagency Work for the NNSA, at the Department of Energy. In that position, she oversaw work with other agencies, technology transfer and other cooperative work agreements. She also served as the sponsor of the Defense Programs Science Council, and Executive Secretary for the Mission Executive Council - a four-part agreement between Departments of Defense, Energy, Homeland Security, and the Office of the Director of National Security. Prior to that position, she was on assignment from Los Alamos National Laboratory (LANL), as Senior Advisor to Dr. Steven Koonin, the Under Secretary of Science for the Department of Energy. Kathleen was at LANL for over 13 years. At Los Alamos, she held nuclear weapons program management positions as well as several division-level management positions in Materials Science & Technology, Applied Physics, and Hydrodynamic Experiments Divisions. Nuclear weapons programmatic management positions included: Hydrodynamic Testing, Pit Certification, Dynamic Materials Properties, Advanced Radiography, Enhanced Surveillance and Dynamic Plutonium Experiments. From July 2009 to December 2010, she was a technical advisor in the Office of Defense Sciences of the NNSA. Prior to joining Los Alamos, Kathleen was at Oak Ridge National Laboratory for over 11 years. She was the group leader of the Microscopy and Microanalytical Sciences Group. Prior to being named Group Leader, she was a technical staff member performing high-resolution imaging and analytical electron microscopy studies of metals and ceramics. Kathleen obtained her Ph.D. from Carnegie Mellon University in Metallurgical Engineering and Materials Science, after receiving her B.S. and M.S. in Metallurgy and Materials Science from Carnegie Mellon University. Kathleen performed postdoctoral research as a NATO Postdoctoral Fellow at Cambridge University, Cambridge, UK. Kathleen was named a Fellow of ASM International in 1996 and the American Ceramic Society in 2001. In 1997, the U.S. Jr. Chamber of Commerce named her one of Ten Outstanding Young Americans. Kathleen has also been awarded multiple Defense Programs Awards of Excellence (team awards). She has served on the American Society for Metals International Board of Trustees (2000-2003) and was the elected Treasurer of the Microscopy Society of America (1998-2004). Kathleen has over 100 peer-reviewed publications in archival journals and conference proceedings, with over 1300 citations. She also has two patents as well as a technology transfer and licensing support award (1993). She became a member of the federal Senior Executive Service in 2011.

Monday, October 27, 2014 7:00PM - 8:00PM —
Session EE2 University Fusion Association General Meeting, Acadia - Dylan Brennan, Princeton University

7:00PM EE2.00001 University Fusion Association General Meeting —

Tuesday, October 28, 2014 8:00AM - 9:00AM
Session FR1 Review: Recent Progress on Spherical Torus Research and Implications for Fusion Energy Development Path, Acadia/Bissonet - Gerald Navratil, Columbia University

8:00AM FR1.00001 Recent Progress on Spherical Torus Research and Implications for Fusion Energy Development Path3, MASAYUKI ONO, Princeton Plasma Phys Lab — The spherical torus or spherical tokamak (ST) is a member of the tokamak family with its aspect ratio ($A = R_o/a$) reduced to $A$ near 1.5, well below the normal tokamak operating range of $A$ equal to 2.5 or greater. As the aspect ratio is reduced, the ideal tokamak beta (ratio of plasma to magnetic pressure) stability limit increases rapidly, approximately as $1/A$. The plasma current it can sustain for a given edge safety factor $q_{95}$ also increases rapidly. Because of the above, as well as the natural plasma elongation which makes its plasma shape appear spherical, the ST configuration can yield exceptionally high tokamak performance in a compact geometry. Due to its compactness and high performance, the ST configuration has various near term applications, including a compact fusion neutron source with low tritium consumption, in addition to the longer term goal of an attractive fusion energy power source. Since the start of the two mega-ampere ST facilities in 2000, the National Spherical Torus Experiment (NSTX) in the US and Mega Ampere Spherical Tokamak (MAST) in the UK, active ST research has been conducted worldwide. More than sixteen ST research facilities operating during this period have achieved remarkable advances in all areas of fusion research, including fundamental fusion energy science as well as technological innovation. These results suggest exciting future prospects for ST research in both the near and longer term. The talk will summarize the key physics results from worldwide ST experiments, and describe ST community plans to provide the database for FNSF design while improving predictive capabilities for ITER and beyond.

3This work supported by DoE Contract No. DE-AC02-09CH11466.

Tuesday, October 28, 2014 9:30AM - 12:30PM —
Session GI1 Runaways, Divertors, and Edge Physics, Acadia - Glen Wurden, Los Alamos National Laboratory

9:30AM GI1.00001 Relativistic Runaway Electrons3, BORIS BREIZMAN2, Institute for Fusion Studies, The University of Texas, Austin, Texas, 78712 USA — This talk covers recent developments in the theory of runaway electrons in a tokamak with an emphasis on highly relativistic electrons produced via an avalanche mechanism. The rapidly growing population of runaway electrons can quickly replace a large part of the initial current carried by the bulk plasma electrons. The magnetic energy associated with this current is typically much greater than the particle kinetic energy. The current of a highly relativistic runaway beam is insensitive to the particle energy, which separates the description of the runaway current evolution from the description of the runaway energy spectrum. A strongly anisotropic distribution of fast electrons is generally prone to high-frequency kinetic instabilities that may cause beneficial enhancement of runaway energy losses. The relevant instabilities are in the frequency range of whistler waves and electron plasma waves. The instability thresholds reported in earlier work have been revised considerably to reflect strong dependence of collisional damping on the wave frequency and the role of plasma non-uniformity, including radial trapping of the excited waves in the plasma. The talk also includes a discussion of enhanced scattering of the runaways as well as the combined effect of enhanced scattering and synchrotron radiation. A noteworthy feature of the avalanche-produced runaway current is a self-limited regime of marginal criticality: the electric field has to be close to its critical value (representing avalanche threshold) at every location where the runaway current density is finite, and the current density should vanish at any point where the electric field drops below its critical value. This nonlinear Ohm’s law enables complete description of the evolving current profile.

3Work supported by the U.S. Department of Energy Contract No. DEFG02-04ER54742 and by ITER contract ITER-CT-12-430000273. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

3In collaboration with P. B. Aleynikov (ITER Organization, Route de Vinon sur Verdon, 13115 St Paul Lez Durance, France)
10:00AM GI1.00002 Achievement of Runaway Electron Energy Dissipation by High-Z Gas Injection in DIII-D

E.M. HOLLMANN, University of California San Diego — Disruption runaway electron (RE) formation followed by RE beam-wall strikes is a concern for future tokamaks, motivating the study of mitigation techniques to reduce the RE beam energy in a controlled manner. A promising approach for doing this is the injection of high-Z gas into the RE beam. Massive (100 torr-I) injection of high-Z gas into RE beams in DIII-D is shown to significantly dissipate both RE magnetic and kinetic energy. For example, injection of argon into a typical 300 kA current RE beam is observed to cause a drop in kinetic energy from 50 kJ to 10 kJ in 10 ms, thus rapidly reducing the damage-causing capability of the RE beam. Both the RE kinetic energy and pitch angle are important for determining the resulting wall damage, with high energy, high pitch angle electrons typically considered most dangerous. The RE energy distribution is found to be more skewed toward low energies than predicted by avalanche theory. The pitch angle is not found to be constant, as is frequently assumed, but is shown to drop from \( \sin(\theta) \approx 1 \) for energies less than 1 MeV to \( \sin(\theta) \approx 0.2 \) for energies greater than 10 MeV. Injection of high-Z impurities does not appear to change the overall shape of the energy or pitch angle distributions dramatically. The enhanced RE energy dissipation appears to be caused primarily via collisions with the cold plasma leading to line radiation. Synchrotron power loss only becomes significant in the absence of high-Z impurities, while radial transport loss of REs is seen to become dominant if the RE beam moves sufficiently close to the vessel walls. The experiments demonstrate that avalanche theory somewhat underestimates collisional dissipation of REs in the presence of high-Z atoms, even in the absence of radial transport losses, meaning that reducing RE wall damage in large tokamaks should be easier than previously expected.

1Supported by the US Department of Energy under DE-FG02-07ER54917 and DE-FC02-04ER54698.

10:30AM GI1.00003 Broadening of the divertor heat flux footprint with increasing number of ELM filaments in NSTX

JOON-WOOK AHN, Oak Ridge National Laboratory — We report on the broadening (narrowing) of the ELM heat flux footprint with increasing (decreasing) number of filamentary striations from in-depth thermography measurements in NSTX. Edge localized modes (ELMs) represent a challenge to future fusion devices, due to the high heat fluxes on plasma facing surfaces. One ameliorating factor has been that the divertor heat flux characteristic profile width (\( \lambda_H \)) has been observed to broaden with the size of ELM, as compared with the inter-ELM \( \lambda_i \), which keeps the peak heat flux \( \left( q_{\text{peak}} \right) \) from increasing. In contrast, \( \lambda_H \) has been observed to narrow during ELMs under certain conditions in NSTX, for both naturally occurring and 3-D fields triggered ELMs. Fast thermographic measurements and detailed analysis demonstrate that the ELM \( \lambda_H \) increases with the number of observed filamentary striations, i.e., profile narrowing (broadening) occurs when the number of striations is smaller (larger) than 3-4. With profile narrowing, \( q_{\text{peak}} \) at ELM peak times is inversely related (proportional) to \( \lambda_H \) (the ELM size), exacerbating the heat flux problem. Edge stability analysis shows that NSTX ELMs almost always lie on the current-driven kink/peeling mode side with low toroidal mode number (n=1-5), consistent with the typical numbers of striations in NSTX (0-8); in comparison 10-15 striations are normally observed in intermediate-n peeling-Ballooning ELMs, e.g., from JET.

The NSTX characteristics may translate directly to ITER, which is also projected to lie on the low-n kink/peeling stability boundary.

1This work was supported by the U.S. DOE, contract DE-AC05-00OR22725 (ORNAL) and DE-AC02-09CH11466 (PPPL).

10:00AM GI1.00004 A convective divertor utilizing a 2nd-order magnetic field null:

THOMAS ROGNLIEN, LLNL — New results motivate a detailed study of a magnetic divertor concept characterized by strong plasma convection near a poloidal magnetic field \( B_p \) null region. The configuration is that of a near-2nd-order \( B_x \) null (\( B_x \propto \Delta r^2 \)), as in a snowflake divertor [1,2]. The concept has 2 key features: (A) Convection spreads the heat flux between multiple divertor legs and further broadens the heat-flux profile within each leg, thereby greatly reducing target-plate heat loads [2]. (B) The heat flux is further reduced by line radiation in each leg in detachment-like ionization zones. Theory indicates that convective turbulence arises when the poloidal plasma beta, \( \beta_p = 2 \mu \text{torr}/B_0^2 \gg 1 \). Measurements in TCV [4] now more fully quantify earlier NSTX and TCV observations of plasma mixing [5,6], and related modeling of TCV indicates that strongly enhanced null-region transport is present [7]. Convective mixing provides a stabilizing mechanism to prevent the ionization fronts (hydrogenic and impurity) from collapsing to a highly radiating core MARFE. Also, the radiating zone maps to a very small region at the midplane owing to the very weak \( B_p \) in the convective region, thus minimizing its impact on the core plasma. Detailed calculations are reported that combine features A and B noted above. The plasma mixing mechanisms are described together with the corresponding transport model implemented in the 2D UEDGE edge transport code [2]. UEDGE calculations are presented that quantify the roles of mixing, impurity radiation, and detachment stability for a realistic snowflake configuration. Work in collaboration with D.D. Ryutov, S.I. Krasheninnikov, and M.V. Umansky.

1Supported by the US Department of Energy DE-FG02-07ER85429.

11:00AM GI1.00005 X-point-position-dependent intrinsic rotation in the edge of TCV

TIMOTHY STOLTZFUS-DUECK, Princeton University — A simple transport-based theoretical model predicts that intrinsic toroidal rotation in the tokamak edge should depend strongly on \( R_X \), the major-radial position of the X-point, including a sign change to counter-current rotation for adequately outboard X-point. To test the prediction, an \( R_X \) scan was conducted in Ohmic L-mode shots on TCV, in both USN and LSN configurations. The strong linear dependence on \( R_X \) was experimentally observed, with quantitative magnitude corresponding to a realistic value for the theory’s corresponding input parameter. Although peaked rotation profiles correlate the comparison of absolute rotation values, the data is consistent with the predicted sign change. The core rotation profile shifted fairly rigidly with the edge rotation value, maintaining a relatively constant core rotation gradient. Core rotation reversals, triggered accidentally in a few shots, had little effect on the edge rotation velocity. Edge rotation was modestly more counter-current in USN than LSN discharges.

1This work was supported in part by the Swiss National Science Foundation and in part by the European Atomic Energy Community, and is subject to the provisions of the European Fusion Development Agreement.
12:00PM GI1.00006 The influence of Filaments in the Private Flux Region on Divertor Power and Particle Deposition. JAMES HARRISON, CCFE. — Recent advances in imaging of the MAST divertor have revealed, for the first time, evidence for filaments in the private flux region (PFR). Detailed analysis of the image data shows 3 distinct types of fluctuations occurring within the divertor volume: highly sheared filaments in the SOL originating from the outer midplane, high frequency (>50kHz) filaments near the separatrix of the outer divertor leg and filaments in the private flux region originating from inner divertor leg. With the need to extrapolate divertor performance from existing machines to future devices, these observations can contribute to our quantitative understanding of transport in the PFR. In particular, they suggest that transport in the PFR is, at least in part, driven by turbulence, which may not be well captured by the Eich/Wagner description of the divertor footprint [1], expressed in terms of exponential decay in space above the X-point and Gaussian spreading below the X-point. The PFR filaments are observed to move largely parallel with the flux surfaces in a way equivalent to a toroidal angular velocity of order 2x10^4 rad/s in H-mode, and slower by a factor of order 2 in L-mode. During their transit parallel to the flux surfaces across the PFR, the filaments eject plasma in bursts, away from the separatrix, deeper into the private flux region. Correlation analysis suggests that they are generated by processes local to the inner divertor leg, as there is a weak correlation between fluctuations in the SOL and PFR above what is expected from line integration effects. Scaling of filament properties with machine operating parameters, such as plasma current, density and auxiliary heating power will be presented, together with a comparison with data from divertor Langmuir probes and IR thermography to estimate the role PFR filaments play in determining the width of the divertor footprint.

Tuesday, October 28, 2014 9:30AM - 12:30PM
Session GI2 Fundamental High Energy Density Physics Bissonet - Carolyn Kuranz, University of Michigan

9:30AM GI2.00001 Scaling a High-Energy-Density Shear Experiment from Omega to the National Ignition Facility (NIF). FORREST W. DOSS, Los Alamos National Laboratory (LANL). — Shear instability in high-energy-density (HED) physics is important for elucidating issues in compressible turbulence and in understanding the late time quenching of, for example, inertial fusion capsules. A counterflowing shear experiment initially designed for the Omega Laser Facility studies shear instability in isolation by launching 100+ km/s shocks into opposite sides of a foam-filled shock tube terminated by an Al tracer plate. When the shocks cross at the tube center, a region of intense shear is created (~150 km/s velocity difference from one side of the plate to the other). As the tracer layer goes unstable it mixes with the surrounding foam and expands into the tube volume. Radiography recording the spreading of the mixing layer is compared to simulations using the LANL hydrocode RAGE. Analysis of this data demonstrated the likely presence of features, such as strong coupling between the thermodynamics and turbulence during the experiment, of special or unique importance to the HED regime. However, the Omega experiments are limited to 1 ms impulsive drive, compared to the 16 ms of observation times, and are dominated by transients, barely if at all reaching the state of developed turbulence. Our recent shots on the NIF take the experiment to larger volumes, to faster speeds, and to the use of indirect drive halfrooms to launch steadily supported shocks. These improvements take advantage of the increased energy of the NIF to eliminate transients and drive more steadily the approach to turbulent transition. Analysis of radiographs confirms our ability to model the hydrodynamic drive and evolution, while comparing images of the developing turbulence between the two facilities suggests morphological differences related possibly to the change in drive conditions. This work was supported by the US DOE and operated by LANLS under Contract No. DE-AC52-06NA25396.

10:00AM GI2.00002 Relativistic electron-positron jets and plasmas using intense lasers. HUI CHEN, Lawrence Livermore National Laboratory. — High-flux jets of electron-positron antimatter with temperatures of a few trillion degrees have been produced in experiments at high-intensity laser facilities [1-5]. These breakthrough experiments open up a novel area of experimental high-energy-density plasma astrophysics identified in several recent national reports. These experiments are on a path toward the production of relativistic electron-positron “pair” plasmas [2], allowing for interactive study of a state of matter otherwise found only in exotic astrophysical systems such as active galaxies, quasars, gamma ray bursts, black holes, and conditions existing shortly after the Big Bang. This presentation describes the physical processes for making pairs and summarizes recent results from several large intense laser facilities [2, 3]. These results include the pair jet energy, angular divergence and emittance [4], the pair jet temperature and density; pair production scalings [5] and collimation by external magnetic fields [5]; and sensitivity to laser intensity (10^18 - 10^19 Watts/cm^2), contrast (10^-7 - 10^-9), and energy (100 - 2000 J). The presentation concludes with discussion of possibilities to exploit laser-produced pair jets and plasmas.

This work was performed under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344.

10:30AM GI2.00003 Dynamic compression experiments on liquid deuterium above the melt boundary to investigate the insulator-to-metal transition. MARCUS KNUDSON, Sandia National Laboratories. — Recently we have been exploring various pulsed power experimental concepts to access off-Hugoniot states in liquids at the Sandia Z Accelerator. One very promising technique utilizes a so-called shock-ramp platform. Here a relatively small gap is introduced between the ramp compression load electrode and a liquid sample cell. The accelerator is configured to deliver a two-step current pulse; the first step accelerates the electrode to a reasonably constant velocity, which upon impact with the sample cell creates a well-defined shock, while the subsequent current rise produces ramp compression from the initially shocked state. This technique makes it possible to achieve relatively cool (~1000-2000 K), high pressure (>300 GPa), high compression states (~10-15 fold compression), allowing experimental access to the region of phase space where hydrogen is predicted to undergo a first-order phase transition from an insulating molecular-like liquid to a conducting atomic-like fluid. In this talk we will discuss the development of the liquid shock-ramp platform, survey the various theoretical predictions for the liquid-liquid transition in hydrogen, and present the results of initial experiments performed that access this region of phase space. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

11:00AM G12.00004 Observation of Self-Similarity in the Magnetic Fields Generated by the Ablative Nonlinear Rayleigh-Taylor Instability\(^1\) , LAN GAO, Department of Astrophysical Sciences, Princeton University — The Rayleigh-Taylor (RT) instability has been extensively studied because of its relevance to ignition target designs in inertial confinement fusion, material strength studies in high energy density physics, and astrophysical systems. This talk presents the first measurements of magnetic field generation by the nonlinear RT instability in laser-accelerated planar foils using ultrafast proton radiography at the OMEGA EP Laser System. Thin plastic foils were irradiated with 4-kJ, 2.5-ns laser pulses at focused laser intensities of \(\sim 10^{14} \text{ W/cm}^2\). Target modulations were seeded by laser nonuniformities and amplified during the target-acceleration phase by the RT instability growth. A high-energy proton beam tracked the hydrodynamic evolution of the target and mapped the magnetic field spatial distribution with high spatial and temporal resolution. The experimental data show self-similar behavior \([1]\) in the growing cellular magnetic field structures \([2-3]\). The calculated magnetic cell-merging rate is consistent with the value determined by earlier x-ray measurements \([4]\), linking the cellular magnetic field structures with the RT bubble and spike growth. The results are consistent with two-dimensional magnetohydrodynamic simulations, showing MG-level magnetic field generation in the laser-driven foil \([3]\). The work could benefit the understanding of magnetic-seed-field generation in high energy density plasmas and the flow-driven processes that induce global magnetic structures prior to their turbulent amplification by the dynamo process.


\(^{1}\)This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

11:30AM G12.00005 Experimental Measurements and Density Functional Theory Calculations of Continuum Lowering in Strongly Coupled Plasmas , SAM VINKO, Department of Physics, Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, UK — An accurate description of the ionization potential depression (IPD) on ions in plasmas due to their interaction with the environment is a fundamental problem in plasma physics, playing a key role in determining the ionization balance, charge state distribution, opacity and plasma equation of state. Here I present the first experimental investigation of the IPD as a function of ionic charge state in a range of dense Mg, Al and Si plasmas, using the Linac Coherent Light Source X-ray free-electron laser. The measurements show significantly larger IPDs than are predicted by the most commonly used models, such as that of Stewart-Pyatt, or the ion-sphere model of Zimmerman-More. Instead, plasma simulations using finite-temperature density functional theory with excited-state projector augmented-wave potentials show excellent agreement with the experimental results and explain the stronger-than-expected continuum lowering through the electronic structure of the valence states in these strong-coupling conditions, which retain much of their atomic characteristics close to the ion core regions. These results have a profound impact on the understanding and modelling of plasmas over a wide range of warm- and hot-dense matter conditions.

\[1\] S.M. Vinko et al., Nature 482, 59 (2012).
\[2\] O. Ciricosta et al., PRL 109, 065002 (2012).

12:00PM G12.00006 Free-electron laser measurements of plasmons in warm dense matter , ELISEO GAMBOA, SLAC National Accelerator Laboratory — Strong plasmon resonances characteristic of electron density fluctuations in warm dense matter (WDM) plasmas have recently been observed for the first time at the Linac Coherent Light Source (LCLS). These experiments record forward scattering from ultrabright 8 keV x-ray pulses to probe dynamically compressed solids driven by shaped ns laser pulses at the Matter in Extreme Conditions (MEC) instrument. From the x-ray scattering spectra we observe well-pronounced plasmon peaks that directly access the electron densities and temperatures. We can access densities \(>5 \text{ g/cm}^3\) and pressures approaching 5 Mbar that are important for planetary and material science as well as inertial confinement fusion research. In this talk we characterize the plasmon loss against wavenumber-resolved x-ray scattering that provides an independent density measurement through shifted Bragg and ion-ion correlation scattering features. We will compare ideal plasma states achieved in heated aluminum with those measured from unexpanded and compressed CVD diamond. The latter shows plasmon energies strongly affected by the band structure up to the highest experimental pressures of several Mbar. This method is presently being applied in numerous experiments to characterize the physical properties of dense plasmas. We will describe the first demonstration of this technique at LCLS, present applications to characterize shocks in dense plasmas, and discuss novel ideas for measuring the properties of high-pressure materials.

Tuesday, October 28, 2014 9:30AM - 12:30PM — Session G03 NSTX, Spherical Tori and KSTAR

9:30AM G03.00001 Overview of MAST results , IAN CHAPMAN, CCFE, MAST TEAM — MAST addresses key issues for ITER and DEMO. ELM mitigation with spheromaks with \(n=3,4,6\) has been demonstrated: at high and low collisionality; for the first ELM; during the current ramp; when in-vessel coils fail; and with rotating \(n=3\) spheromaks. \(n=4,6\) spheromaks cause less braking whilst H-mode access is easiest with \(n=4\). Refuelling allows reduced peak heat flux but only 10% drop in confinement. Gyrokinetic simulations of micro-tearing modes are consistent with ELM precursors strongly observed by beam emission spectroscopy. Global gyrokinetic runs show kinetic ballooning modes mediate the pedestal width. A scan in beta at L-H transition shows that pedestal height scales strongly with core pressure. The observed tilt of low-k turbulent vortices increases with flow shear, due to a decrease in poloidal wave number. Highly efficient electron Bernstein wave current drive (1A/W) has been achieved in solenoid-free start-up. Langmuir probes and a high-speed camera suggest filaments play a role in particle transport in the private flux region whilst coherence imaging has measured scrape-off layer flows. MAST Upgrade is due to operate in 2015 to support ITER preparation and importantly to operate with a Super-X divertor to test extended leg geometries for particle and power exhaust.

9:42AM G03.00002 Towards a Predictive Capability for Local Helicity Injection Startup\(^1\) , J.L. BARR, M.W. BONGARD, M.G. BURKE, R.J. FONCK, E.T. HINSON, B.T. LEWICKI, J.M. PERRY, A.J. REDD, D.J. SCHLOSSBERG, University of Wisconsin-Madison — Local helicity injection (LHI) is a non-solenoidal tokamak startup technique under development on the Pegasus ST. New designs of the injector cathode geometry and plasma-facing shield rings support high-voltage operation up to 1.5 kV. This leads to reduced requirements in injector area for a given helicity input rate. Near-term experiments in Pegasus are testing the gain in \(I_0\) obtained with a 1.5 \(x\) increase in the helicity input rate and the efficacy of helicity injection in the lower divertor region. A predictive model for LHI is needed to project scalable scenarios for larger devices. A lumped-parameter model using power and helicity balance is being developed for LHI on Pegasus-U and NSTX-U. The model indicates that MA-class startup on NSTX-U will require operating in a regime where the drive from LHI dominates the inductive effects arising from dynamically evolving plasma geometry. The physics of this new regime can be tested in Pegasus-U at \(I_0 = 0.3\) MA. The LHI systems on the proposed Pegasus-U will be expanded to provide 3 - 4 x helicity injection rate and the toroidal field doubled to reach this regime. Predictive models to be validated on Pegasus-U include the 0-D power balance model, NIMROD, and TSC.

\(^{1}\)Work supported by US DOE grants DE-FG02-96ER54375 and DE-SC0006928.

...RF voltage measured at the Langmuir probe. Future experimentation on NSTX-U will employ a wide-angle IR camera and coaxial Langmuir probes to quantify the RF showing that the RF sheath losses at the divertor are significant. We will compare sheath voltage determined using the AORSA code with the Langmuir probe sheath transmission factor to infrared camera (IR) measurement estimates. At the probe, the sheath transmission increases by a factor of 2. One contributing loss mechanism is RF sheaths forming at the divertor at strike points of the magnetic field lines. Here we compare calculations of a major loss of high-harmonic fast wave (HHFW) power to the upper and lower divertor regions along scrape-off layer (SOL) field lines passing in front of the antenna. The unique operating characteristics available at A = 1 in Pegasus allow small-signal measurements of the time evolution of the J_{edge}(R) pedestal collapse during an ELM event. They show a complex, multimodal pedestal collapse and the subsequent ejection of a current-carrying filament.

1Work supported by US DOE grant DE-FG02-96ER54375.

10:06AM GO3.00004 Characteristics of Neoclassical Toroidal Viscosity in NSTX and KSTAR for Rotation Control and the Evaluation of Plasma Response, S.A. SABBAGH, J.W. BERKERY, Y.S. PARK, Columbia U., R.E. BELL, D.A. GATES, S.P. GERHARDT, I. GOUMIRI, PPPL, T.E. EVANS, N. FERRARO, General Atomics, Y.M. JEON, W. KO, NFRI, K.C. SHAING, Nat'l Cheng Kung U., Y. SUN, ASIPP — Three-dimensional magnetic fields producing non-resonant magnetic braking allow control of the plasma rotation profile, \( \omega_\nu \), in tokamaks. Experimental angular momentum alteration created by 3D field configurations with dominant \( n = 2 \) and \( n = 3 \) components in NSTX is compared to theoretical neoclassical toroidal viscosity (NTV) torque density profiles, \( T_{NTV} \). Large radial variations of \( T_{NTV} \) are typically found when flux surface displacements are computed using ideal MHD assumptions. In contrast, experimentally measured \( T_{NTV} \) does not show strong toroidal localization. This may be explained by ion banana width orbit-averaging effects. A favorable characteristic for \( \omega_\nu \) control clearly illustrated by KSTAR experiments is the lack of hysteresis of \( \omega_\nu \) when altered by non-resonant NTV. Results from a model-based rotation controller designed using NBI and NTV from the applied 3D field as actuators are shown. The dependence of \( T_{NTV} \) on \( A^2 \) significantly constrains the available field amplification in plasma response models when compared to experiment. Initial analysis suggests that the single fluid model in the M3D-\( C^1 \) resistive MHD code produces a flux surface-averaged \( A^2 \) consistent with the experimentally measured \( T_{NTV} \).

1Supported by US DOE Contracts DE-FG02-99ER54524 and DE-AC02-09CH11466.

10:18AM GO3.00005 The Potential Contribution of RF Sheaths to Field-Aligned SOL Losses on NSTX, R.J. PERKINS, R.E. BELL, N. BERTELLI, S. GERHARDT, J.C. HOSEA, M.A. JAWORSKI, G.J. KRAMER, B.P. LEBLANC, R. MAINGI, C.K. PHILLIPS, G. TAYLOR, PPPL, J.-W. AHN, T.K. GRAY, E.F. JAEGER, ORNL, A. MCLEAN, None, S.A. SABBAGH, Columbia U. — NSTX can exhibit anions and surface oxidation on the rate of Li spreading on stainless steel will be reported. And Li-O showed that surface diffusion of Li had taken place at room temperature, well below the 181 \( ^{\circ}\)C Li melting temperature. The influence of temperature and surface oxidation on the rate of Li spreading on stainless steel will be reported.

1Supported by US DOE Contract No. DE-AC02-09CH11466.

10:30AM GO3.00006 Application of 3D Synthetic Reflectometry Diagnostics to Comparing Results from PIC Simulations with Reflectometry Measurements in NSTX, LEI SHI, AHMED DIALLO, GERRIT KRAMER, SEUNG-HOE KU, WILLIAM TANG, ERNEST VALEO, Princeton Plasma Phys Lab — Synthetic diagnostics are powerful tools to connect advanced numerical simulations with experimental measurements. They can be used for validation studies of the simulations as well as providing insights for experimental observations. Since individual synthetic diagnostic codes are usually developed independently from predictive simulation codes, interfacing them is a significant task. In this talk, we will report on new results obtained from interfacing a recently-developed 3D synthetic reflectometry code (FWR3D) - as well as the well-established 2D version (FWR2D) — against the global particle-in-cell (PIC) code - XGC1 - generally regarded as the most advanced integrated edge/core code that is characterized by high phase-space and coordinate-space resolution including complex separatrix geometry in the edge region of tokamak plasmas. The simulation results are compared with the reflectometry signals measured between an edge localized mode (ELM) cycle in an actual NSTX discharge. Associated findings regarding to what degree the features observed by the actual reflectometry diagnostic deployed in the experiment are reproduced will be reported. In addition, information from the XGC-1 code on the characteristics and spectral properties of the turbulence will be provided.

1This work is supported by DOE contract #DEAC02-09CH11466.

10:42AM GO3.00007 Lithium wetting of stainless steel for plasma facing components, C.H. SKINNER, A.M. CAPECE, PPPL, J.P. ROSZELL, B.E. KOEL, Princeton University — Ensuring continuous wetting of a solid container by a liquid metal is a critical issue in the design of liquid metal plasma facing components foreseen for NSTX-U and FNSF. Ultrathin wetting layers may form on metallic surfaces under ultrahigh vacuum (UHV) conditions if material reservoirs are present from which spreading and wetting can start. The combined scanning electron microscopy (SEM), Auger electron spectroscopy (AES) and ion beam etching capabilities of a Scanning Auger Microprobe (SAM) have been used to study the wetting of lithium films on stainless steel substrates. A small (mm-scale) amount of metallic lithium was applied to a stainless steel surface in an argon glove box and transferred to the SAM. Native impurities on the stainless steel and lithium surfaces were removed by Ar+ ion sputtering. Elemental mapping of Li and Li-O showed that surface diffusion of Li had taken place at room temperature, well below the 181 °C Li melting temperature. The influence of temperature and surface oxidation on the rate of Li spreading on stainless steel will be reported.

1Support was provided through DOE Contract Number DE-AC02-09CH11466.
10:54AM GO3.00008 Sputtering rates of lithium and lithium hydride due to low energy ion impact. JOHN ROSZELL, Princeton University, ANGELA CAPECE, CHARLES SKINNER, Princeton Plasma Physics Laboratory, BRUCE KOEL, Princeton University — The presence of lithium coatings on plasma facing components (PFCs) has been shown to improve plasma performance through the reduction of hydrogen recycling. Understanding the interactions between plasma species and lithium-covered PFCs is important to the successful implementation of lithium in a tokamak environment. Fundamental surface science experiments performed in a controlled UHV environment are used to investigate the interactions between deuterium ions and lithium films. Sputtering yields of lithium from pure and deuterated lithium films due to the impact of low energy deuterium and rare gas ions are measured with a well characterized ion beam capable of achieving energies of <10 eV/D. Lithium films are deposited on a molybdenum single crystal substrate from an SAES getter source allowing for pure Li film growth with a highly reproducible thickness. These films are characterized with Auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS), while sputtering yield is measured with temperature programmed desorption (TPD) to quantify the number of atoms remaining on the surface after ion bombardment. Sputtering yields are measured as a function of ion energy, film composition, and substrate temperature.

11:06AM GO3.00009 Lithium vapor trapping at a high-temperature lithium PFC divertor target. MICHAEL JAWORSKI, T. ABRAMS, R.J. GOLDSTON, R. KAITA, D.P. STOTLER, Princeton Plasma Phys Lab, G. DE TEMMERMAN, ITER Organization, J. SCHOLTEN, M.A. VAN DEN BERG, H.J. VAN DER MEIDEN, FOM-DIFFER — Liquid lithium has been proposed as a novel plasma-facing material for NSTX-U and next-step fusion devices but questions remain on the ultimate temperature limits of such a PFC during plasma bombardment. Lithium targets were exposed to high-flux plasma bombardment in the Magnum-PSI experimental device resulting in a temperature ramp from room-temperature to above 1200°C. A stable lithium vapor cloud was found to form directly in front of the target and persist to temperature above 1000°C. Consideration of mass and momentum balance in the pre-sheath region of an attached plasma indicates an increase in the magnitude of the pre-sheath potential drop with the inclusion of ionization sources as well as the inclusion of momentum loss terms. The low energy of lithium emission from a surface measured in previous experiments (<1 eV) is conducive to trapping within this modest potential well. The scale length derived from the ionizing pre-sheath model of 3mn is consistent with the observed neutral lithium emission in the experiment. The strong trapping inferred from the lifetime of the coating indicates previously calculated temperature limits for lithium PFCs need to be re-evaluated.

11:18AM GO3.00010 VUV/XUV measurements of impurity emission in plasmas with liquid lithium surfaces on LTX. KEVIN TRITZ, M. FINKENTHAL, D. STUTMAN, Johns Hopkins University, R.E. BELL, D.P. BOYLE, R. KAITA, T. KOZUB, M. LUCIA, R. MAJESKI, E. MERINO, J.C. SCHMITT, Princeton Plasma Phys Lab, B. BIERSDORFER, J. CLEMENTSON, LNL, S. KUBOTA, UCLA — The VUV/XUV spectrum has been measured on the Lithium tokamak eXperiment (LTX) using a spatially-resolved transmission grating imaging spectrometer (TIGS) coupled to a direct-detection X-ray CCD camera. TGIS data show significant changes in the ratios between the lithium and oxygen impurity line emission during the discharges with different lithium wall conditions. Lithium coatings that have been passivated by lengthy exposure to significant levels of impurities contribute to a large O/Li ratio measured during LTX plasma discharges. Furthermore, results from previous experiments have indicated that a passivated lithium film on the boundary shells can function as a stronger impurity source when in the form of a liquid layer compared to a solid lithium layer. However, recent TGIS measurements of plasma discharges in LTX with hot stainless steel boundary shells and a fresh liquid lithium coating show significantly lower O/Li impurity line ratios when compared to discharges with a solid lithium film on cooler shells. These new line ratio measurements help clarify the somewhat contradictory results of the effects of solid and liquid lithium on plasma confinement observed in previous experiments.

11:30AM GO3.00011 Recent experimental results and future plan in KSTAR. JONG-GU KWAK, SANG-GON LEE, YOUNG-SUN BAE, BOUNG-HO PARK, JIN-YOUNG KIM, National Fusion Research Institute, KSTAR TEAM — In this talk, the recent results of KSTAR will be presented focusing on extension of operational boundary in long-pulse discharges and highlights in experimental physics. H-mode discharges has been sustained longer and the operational regime of plasma parameters has been significantly extended in terms of heating power and plasma current. The long-pulse operation is in accordance with ITER requirement, i.e., in ITER similar shape, low safety factor (q95∼3) and normalized beta (∼2.0) with real-time control of density and power. Both ELM suppression and mitigation are considered in wide range of RMP coil configuration and the suppression window in the edge safety factor has extended from 6.5 to 3.9 indicating the strong impact of resonant component. Beside RMP ELM suppression, it is also investigated the effect of other techniques on ELMs, such as edge heating by ECH and cooling by SMBI. Detailed evaluation of error field (EF) has been performed by 4 segmented compass scan by the internal coils and the measured level of intrinsic error field is an order of magnitude lower than other tokamaks. In addition to the above topics, it is summarized the recent results on rotation & transport physics, newly installed diagnostics, MHD and fast ion activities, followed by the near future plan.

11:42AM GO3.00012 Long pulse and steady state operation activities at KSTAR. YOUNG-foon BAE, National Fusion Research Institute, KSTAR TEAM, KAERI COLLABORATION, JAEA COLLABORATION, PPL COLLABORATION, SNU COLLABORATION The mission of Korea Superconducting Tokamak Advanced Research (KSTAR) is to develop a steady state capable advanced tokamak (AT) operation. The original KSTAR is at the edge of a high magnetic field of 3.5 T. The safety factor q95 of 3.7. Recently, the stationary long pulse H-mode discharge is sustained for maximum pulse duration of 20 s using heating of 2.5-MW NBI and 0.7-MW, X3 170 GHz ECH with low density level of ∼0.3x10^20 m^-3. The main activities of long pulse and steady state operation in KSTAR are the density feedback control, optimization of plasma shape and vertical control, real-time β control, and steady state capable heating upgrade. For the longer pulse H-mode discharge at the increased plasma current upcoming KSTAR system, there have been improvements in plasma control system and upgraded heating systems. Meanwhile, steady state operation scenario in KSTAR for the next year is being investigated using time-dependent integrated transport simulation code with possible heating upgrade-schemes. The promising steady state scenario near future is a reversed shear using a new 4 MW off-axis neutral beam injector for broad pressure profile peaked at off-axis, and using ECH for local current profile control aiming at NBI > 3 with Ip ~ 1 MA. This paper present activities and plan for steady state operation in KSTAR as well as the long pulse H-mode discharge results in the recent KSTAR campaign.

11:54AM GO3.00013 Research Activities on MHD and Energetic Particle Physics in KSTAR. BYOUNG-HO PARK, JONG-GU KWAK, SANG-GON LEE, SI-WOO YOON, YOUNG-SUN BAE, JIN-YOUNG KIM, National Fusion Research Institute, KSTAR TEAM — In this talk, the recent achievements in MHD and energetic particle physics in KSTAR will be presented. Throughout the 2014 campaign, strategically important works in achieving KSTAR milestone including NTM stabilization, error field measurement, establishing disruption mitigation system, and identification of Alfvenic eigenmode are conducted. Real-time feedback control of 2/1 NTM is successfully demonstrated with the search and suppression algorithm and the improved ECCD mirror control system. 3-D structure of n=1 intrinsic error field are fully explored with L- and H-mode plasma aiming not only to complete MID IVCC compass scan but also to set a groundwork toward understanding of KSTAR’s unique feature, ELM suppression by n=1 RMP. Elaborated q95 - 2 discharge regime is achieved without any error field correction by virtue of the extremely low intrinsic error field of KSTAR. The integrated disruption avoidance/mitigation system for the safety secured MA-class operation is well assessed. Further investigations of the energetic particle mode have been done with various control knobs of ECH, RMP and tailoring of NBI profile and mode identification efforts have been followed. Besides high priority works above, studies on sawtooth and run-away electron have made progresses.
12:06PM GO3.00014 First Trial of Real-time Poloidal Beta Control in KSTAR1. HYUNSUN HAN, S.H. HAHN, J.G. BAK, National Fusion Research Institute, M.L. WALKER, General Atomics, M.H. WOO, J.S. KIM, Y.J. KIM, Y.S. BAE, National Fusion Research Institute, KSTAR TEAM — Sustaining the plasma in a stable and a high performance condition is one of the important control issues for future steady state tokamaks. In the 2014 KSTAR campaign, we have developed a real-time poloidal beta (\(\beta_p\)) control technique and carried out preliminary experiments to identify its feasibility. In the control system, the \(\beta_p\) is calculated in real time using the measured diamagnetic loop signal (DLM03) with coil pickup corrections, and compared with the target value leading to the change of the neutral beam (NB) heating power using a feedback PID control algorithm. To match the required power of NB which is operated with constant voltage, the duty cycles of the modulation were adjusted as the ratio of the required power to the maximum achievable one. This paper will present the overall procedures of the \(\beta_p\) control, the \(\beta_p\) estimation process implemented in the plasma control system, and the analysis on the preliminary experimental results.

1This work is supported by the KSTAR research project funded by the Ministry of Science, ICT & Future Planning of Korea.

12:18PM GO3.00015 Toroidal rotation studies in KSTAR1. S.G. LEE, H.H. LEE, National Fusion Research Institute, J.W. YOO, Korea University of Science and Technology, Y.S. KIM, W.H. KO, L. TERZOLO, National Fusion Research Institute, M. BITTER, K. HILL, Princeton Plasma Physics Laboratory, KSTAR TEAM — Investigation of the toroidal rotation is one of the most important topics for the magnetically confined fusion plasma researches since it is essential for the stabilization of resistive wall modes and its shear plays an important role to improve plasma confinement by suppressing turbulent transport. The most advantage of KSTAR tokamak for toroidal rotation studies is that it equips two main diagnostics including the high-resolution X-ray imaging crystal spectrometer (XICS) and charge exchange spectroscopy (CES). Simultaneous core toroidal rotation and ion temperature measurements of different impurity species from the XICS and CES have shown in reasonable agreement with various plasma discharges in KSTAR. It has been observed that the toroidal rotation in KSTAR is faster than that of other tokamak devices with similar machine size and momentum input. This may due to an intrinsically low toroidal field ripple and error field of the KSTAR device. A strong braking of the toroidal rotation by the \(n = 1\) non-resonant magnetic perturbations (NRMPs) also indicates these low toroidal field ripple and error field. Recently, it has been found that \(n = 2\) NRMPs can also damp the toroidal rotation in KSTAR. The detail toroidal rotation studies will be presented.

1Work supported by the Korea Ministry of Science, ICT and Future Planning under the KSTAR project.

Tuesday, October 28, 2014 9:30AM - 12:06PM –
Session GO4 Magnetized Liner Inertial Fusion Salon E - Wolfgang Theobald, University of Rochester

9:30AM GO4.00001 First Experiments with Planar Wire Arrays on U Michigan’s Linear Transformer Driver1, A.S. SAFFRONOVA, V.L. KANSTSYREV, M.E. WELLER, I.K. SHRESTHA, V.V. SHLYAPTSEVA, M.C. COOPER, M. LORANCE, A. STAFFORD, University of Nevada, Reno, NV 89557, S.G. PATEL, A.M. STEINER, D.A. YAGER-ELORRIAGA, N.M. JORDAN, R.M. GILGENBACH, The University of Michigan, Ann Arbor, MI 48109 — For petawatt-class Z-pinch accelerators, a Linear Transformer Driver (LTD)-driven accelerator promises to be (at a given pinch current and implosion time) more efficient than the conventionally used Marx-driven accelerator. Because there exists almost no data on how wire arrays radiate on LTD-based machines in the USA, it is very important to perform radiation and plasma physics studies on this new type of generator. We report on the first outcome of the new partnership with University of Michigan (UM), which resulted in successful UNR-UM experiments on the low-impedance MAIZE generator with planar wire arrays (PWA). PWA is a novel wire array load that was introduced and tested in detail on high-impedance Zebra at UNR during the last years and found to be the most efficient radiator. Implosion of Al Double PWAs of different configurations were achieved on MAIZE, observed with a set of various diagnostics which include x-ray diode detectors, x-ray spectroscopy and imaging, and shadowgraphy. Al and Mg plasmas of more than 450 eV were studied in detail.

1Research supported by NNSA under DOE Cooperative Agreement DE-NA0001984. S.G. Patel and A.M. Steiner supported by Sandia National Laboratories. D.A. Yager-Elorriaga supported by NSF GF.

9:42AM GO4.00002 Theory of formation of helical structures in a perfectly conducting, pre-magnetized Z-pinch liner1, EDMUND YU, Sandia National Labs, ALEXANDER VELIKOVICH, Naval Research Laboratory, KYLE PETERSON, Sandia National Labs — The magnetized liner inertial fusion (MagLIF) concept [1] uses an azimuthal magnetic field to collapse a thick metallic liner containing preheated fusion fuel. A critical component of the concept is an axial magnetic field, permeating both the fuel and surrounding liner, which reduces the compression necessary to achieve fusion conditions. Recent experiments [2] demonstrate that a liner premagnetized with a 10 T axial field develops helical structures with a pitch significantly larger than an estimate of \(\beta\) estimation process implemented in the plasma control system, and the analysis on the preliminary experimental results.

1Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the National Nuclear Security Administration under DE-AC04-94AL85000

9:54AM GO4.00003 Magneto-Rayleigh-Taylor, Sausage And Kink Mode In Cylindrical Liners2, Y.Y. LAU, PENG ZHANG, MATTHEW WEIS, RONALD GILGENBACH, Univ of Michigan - Ann Arbor, MARK HESS, KYLE PETERSON, Sandia National Laboratories — This paper analyzes the coupling of magneto-Rayleigh-Taylor (MRT), sausage (azimuthal mode number \(m=0\)) and kink mode (\(m=1\)) in an imploding cylindrical liner, using ideal MHD. A uniform axial magnetic field of arbitrary value is included in each region: liner, its interior, and its exterior. The dispersion relation, the feedthrough factor, and the temporal evolution of perturbations were solved exactly, for arbitrary values of \(g\) (\(=\) gravity), \(k\) (\(=\) axial wavenumber), \(\lambda\), aspect ratio, and equilibrium quantities in each region. For small \(k\), a positive \(g\) (inward radial acceleration in the lab frame) tends to stabilize the sausage mode, but destabilize the kink mode. For large \(k\), a positive \(g\) destabilizes both the kink and sausage mode. This analysis might shed lights into some puzzling features in Harris’ classic paper [1], and in the recent cylindrical liner experiments [2] on MRT.

2M. R. Weis was supported by the Sandia National Laboratories

10:06AM GO4.00004 2D HYDRA Calculations of Magneto-Rayleigh-Taylor Growth and Feedthrough in Cylindrical Liners1, MATTHEW WEIS, PENG ZHANG, Y.Y. LAU, RONALD GILGENBACH, Univ of Michigan - Ann Arbor, KYLÉ PETERSON, MARK HESS, Sandia National Laboratories — Cylindrical liner implosions are susceptible to the magneto-Rayleigh-Taylor instability (MRT), along with the azimuthal current-carrying modes (sausage, kink, etc). “Feedthrough” of these instabilities has a strong influence on the integrity of the liner/fuel interface in the magnetized liner inertial fusion concept (MagLIF) [1]. The linearized ideal MHD equations can be solved to quantify these effects, including the presence of an effective gravity and an axial magnetic field. We investigate the potential of this field to mitigate feedthrough, due to MRT growth from various initial surface finishes (seeded, rough), throughout the implosion using our analytic results and the LLNL code, HYDRA. We will present both low and high convergence cases. Lastly, we illustrate the effect shock compression can have on feedthrough in seeded liners for various fill gases (cold and pre-heated) and magnetic field configurations.


3M. R. Weis was supported by the Sandia National Laboratories

10:18AM GO4.00005 Comparison between initial Magnetized Liner Inertial Fusion experiments and integrated simulations1, A.B. SEFKOW, M.R. GOMEZ, M. GESSEL, K.D. HAHN, S.B. HANSEN, E.C. HARDING, K.J. PETERSON, S.A. SLUTZ, Sandia National Laboratories, J.M. KONING, M.M. MARINAK, Lawrence Livermore National Laboratory — The Magnetized Liner Inertial Fusion (MagLIF) approach to ICF has obtained thermocapillary fusion yields using the Z facility. Integrated magnetohydrodynamic simulations provided the design for the first neutron-producing experiments using capabilities that presently exist, and the initial experiments measured stagnation radii \( r < 75 \mu m \), temperatures around 3 keV, and isotropic neutron yields up to \( Y_{n} = 2 \times 10^{12} \) from imploded liners reaching peak velocities around 70 km/s over an implosion time of about 60 ns. We present comparisons between the experimental observables and post-shot degraded integrated simulations.

1Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the National Nuclear Security Administration under contract DE-AC04-94AL85000.

10:30AM GO4.00006 ABSTRACT WITHDRAWN —

10:42AM GO4.00007 Laser heating challenges of high yield MagLIF targets1, STEPHEN SLUTZ, ADAM SEFKOW, ROGER VESEY, Sandia National Laboratories — The MagLIF (Magnetized Liner Inertial Fusion) concept is predicted by numerical simulation to produce fusion yields of about 100 kJ, when driven by 25 MA from the existing Z accelerator [S.A. Slutz et al Phys. Plasmas 17, 056303, 2010] and much higher yields with future accelerators delivering higher currents [Slutz and Vesey PRL 108, 025003, 2012]. The fuel must be heated before compression to obtain significant fusion yields due to the relatively slow implosion velocities (~ 100 km/s) of magnetically driven liners. Lasers provide a convenient means to accomplish this pre-compression heating of the fusion fuel, but there are challenges. The laser must penetrate a foil covering the laser entrance hole and deposit 20-30 kJ within the ~ 1 cm length of the liner in fuel at 6-12 mg/cc. Such high densities could result in beam scattering due to refraction and laser plasma interactions. Numerical simulations of the laser heating process are presented, which indicate that energies as high as 30 kJ could be deposited in the fuel by using two laser pulses of different wavelengths. Simulations of this process will be presented as well of results for a MagLIF design for a potential new machine delivering 50 MA of current.

1Acknowledgements: Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

10:54AM GO4.00008 Development of azimuthally correlated instabilities for MagLIF seeded by electro-thermal and material strength effects, JAMES PECOVER, MARCUS WEINWURM, JEREMY CHITTENDEN, Imperial College London — Magnetized liner inertial fusion (MagLIF) is a promising route to controlled thermonuclear fusion. The concept involves magnetically imploding a metal liner; a key limitation of such systems is the magneto-Rayleigh-Taylor (MRT) instability. MagLIF relevant liner implosions carried out at Sandia showed high amplitude MRT growth. 3D simulations with our MHD code Gorgon have shown that azimuthal correlation required to explain this can be contributed to by early time effects the electro-thermal instability (ETI) and an “electro-choric instability” (ECI). Shear forces can damp short wavelength perturbations while the liner remains solid, potentially setting axial wavelengths for the ETI and ECI. We can now model shear stresses in solids with Gorgon using a Johnson-Cook strength model and a bulk modulus calculated from the FEOS equation of state. Gorgon results with the strength model are compared to results from the shock hydrodynamics code iSALE. Results for liners show elongation of perturbations at the outer edge relative to the case without strength. We present results showing the model applied to liner implosions with axial magnetic fields of 0T and 10T.

11:06AM GO4.00009 Magneto-acoustic waves driven by self-generated magnetic field: relevance to helical structures in MagLIF experiments, JONATHAN DAVIES, DANIEL BARNAK, RICCARDO BETTI, ADAM CARREON, PO-YU CHANG, GENNADY FIKSSEL, University of Rochester — The observation of coherent helical structures in liner implosions on Z when an axial magnetic field more than 10 times smaller than the azimuthal field is added has yet to be adequately explained [1]. The results have been reproduced in a 3D MHD code by initializing helices on the outer surface, but this produces helices independently of the axial magnetic field [1]. We present the hypothesis that helices are seeded by self-generated magnetic field, which adds a driving term to the dispersion relation for magneto-acoustic waves when there is a temperature gradient perpendicular to the fluid motion. The key feature of this instability is that it is stable when magnetic pressure exceeds a fraction of the thermal pressure, therefore, instability driven by the helical field resulting from the combination of the initial axial field and the growing azimuthal field will stabilize before the net field has a small pitch angle and before the implosion starts, seeding helices on the surface. This work was supported by the Department of Energy National Nuclear Security Administration, Award Number DE-NA0001944, and the Fusion Science Center supported by the Office of Fusion Energy Sciences, Number DE-FG02-04ER54786.

11:18AM GO4.00010 Point Design of Scaled-Down Magnetized Liner Inertial Fusion on OMEGA. P-Y. CHANG, J.R. DAVIES, D.H. BARNAK, G. FIKSEL, R. BETTI, Laboratory for Laser Energetics and Fusion Science, U. of Rochester, A. HARVEY-THOMPSON, D. SINARS, SNL — Significant yield enhancement in cylindrical liner implosions using the Z machine at Sandia was observed when the deuterium fuel was laser heated and magnetized prior to compression. A higher initial temperature improves flux conservation and reduces the radial convergence required to achieve the final temperatures necessary for high neutron yield when heat flow is suppressed by the axial magnetic field. A scaled-down experiment with a 100-km/s implosion velocity using laser-driven implosions will be conducted on OMEGA. The implosion was simulated using the 1-D hydrocode LILAC with the addition of resistive magnetohydrodynamic subroutines. For an initial D and Neutron-averaged ion temperature increases from 0.8 keV to more than 4 keV, and the neutron yield increases by 100× compared to the case without the gas being heated and magnetized prior to compression. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.


11:30AM GO4.00011 Adaptive Beam Smoothing with Plasma-Pinholes for Laser-Entrance-Hole Transmission Studies1. MATTHIAS GEISSEL, LAWRENCE E. RUGGLES, IAN C. SMITH, JONATHN E. SHORES, C. SHANE SPEAS, JOHN L. PORTER, Sandia Natl Labs — The concept of Magnetized Liner Inertial Fusion (MagLIF) requires the deposition of laser energy into a fuel-filled cylinder that is exposed to a magnetic field. To improve process, it is essential to optimize transmission through the foil covered laser entrance hole (LEH), which involves minimizing laser-plasma-instabilities (LPI). Laser beam smoothing is the most common approach to minimize LPI. It typically involves a Random-Phase-Plate (RPP) and smoothing by spectral dispersion (SSD). This approach can still cause LPI issues due to intensity “hot-spots” on a ps-time scale, and it inconveniently fixes the usable spot size. Changing laser spot sizes requires multiple dedicated RPPs. To study ideal spot sizes on a MagLIF LEH, the RPP/SSD approach gets cost prohibitive. As alternative, we use sacrificial thin foils (500 nm or less) at the laser focus, which instantly turn into a plasma-pinhole, acting as spatial filter. The smoothed laser spot size grows linearly with distance from best focus. We present experimental data for smoothing performance and resulting LEH transmission.

1Sandia is a multi-program laboratory managed and operated by Sandia Corp., a wholly owned subsidiary of Lockheed Martin Corp., for the U.S. DOE’s Nat’l Nucl. Sec. Admin. under contract DE-AC04-94AL85000.

11:42AM GO4.00012 ABSTRACT WITHDRAWN —

11:54AM GO4.00013 Performance of the Plasma Focus with Monolithic Tungsten Electrodes. ERIC LERNER, HAMID YOUSEFIF, FRED VRONASSEK, ANTHONY ELLIS, IVANA KARAMITSO, LPPFusion, Inc. — Fusion yield in plasma focus devices scales faster than I², where I is peak current, for I < 1 MA, but then appears to plateau at around 1 joule for pure D fill gas. Recent experimental results with the FF-1 plasma focus and new calculations indicate that the cause of this plateau may be metal impurities in the plasma due to increased erosion of the electrodes at higher currents, causing asymmetries that reduce compression in the pinch. To reduce this impurity problem, we are installing in FF-1 monolithic tungsten electrodes, so that no electrical contacts will be inside the vacuum chamber, thus eliminating arcing and minimizing erosion. Tungsten electrodes will also reduce sputtering as compared with the copper electrodes previously used. We expect that this will greatly reduce impurities, preserve filament magnetization and increase density and thus fusion yield of plasmas used in pure D. In addition, we will be using pre-ionization of the fill gas to prevent erosion by runaway electrons when the current pulse is initiated. We will measure the impurity level through timing the speed of the rundown, and through optical spectroscopy, as well as by measuring the actual amount of material eroded from the electrodes. Filamentation will be observed with a 4-frame ICCD camera. The dimensions of the plasmoid will be measured both in the optical and with an x-ray pinhole camera. We will report here on the result of initial experiments, including the effects of nitrogen-deuterium mixes, which we expect to further increase density.

Tuesday, October 28, 2014 9:30AM - 12:30PM — Session G05 Hydro Instabilities I

9:30AM GO5.00001 A revision to the hydrodynamic instability theory of Chandrasekhar1, R. PAUL DRAKE, University of Michigan — To address waves and instabilities in systems having volumetric vorticity, one cannot use potential flow theory and must instead work from the Euler equations (for iniovid flows). The standard model, provided for example in the relevant book by Chandrasekhar, has disturbing features, one of which is that the pressure may not be continuous across an interface. This conflicts with our basic conceptual understanding of fluids and also with derivations using potential flow. Resolving the troubling issues requires that one take a different approach to the instability derivation. One way to do so will be described herein. The revised derivation reproduces the standard results for simple Kelvin Helmholtz and Rayleigh Taylor instabilities, but obtains very different results for the case of an extended shear layer.

1This work is funded by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, grant number DE-NA0001840.

9:42AM GO5.00002 Hydrodynamic instabilities of finite width layers. MARC HENRY DE FRAHAN, ERIC JOHNSEN, R. PAUL DRAKE, Univ of Michigan — Ann Arbor — The understanding of multi-material mixing in areas such as inertial confinement fusion and astrophysics relies on accurate characterization of fluid mixing from hydrodynamic instabilities, including the Rayleigh-Taylor, and Kelvin-Helmholtz instabilities. We investigate these instabilities by studying the problem of an extended perturbed shear layer with and without the presence of gravity. An initially perturbed fluid layer is placed in a shear flow. The velocity difference at the interfaces leads to the development of vortical structures and fluid mixing at the interfaces. The presence or absence of gravity dictates the strength of the Rayleigh-Taylor instability relative to the Kelvin-Helmholtz instability. Using a high-order numerical method that accurately represents material and flow discontinuities, we identify stable and unstable configurations depending on the Richardson number, and the ratios of the initial perturbation amplitude and layer thickness to the wavelength.

9:54AM GO5.00003 Overview of the Marble experiment. M. R. DOUGLAS, J.R. FINCKE, G.P. GRIM, B.M. HAINES, T.J. MURPHY, R.E. OLSON, R.C. SHAH, J.M. SMIDT, I.L. TREGILIS, J.A. OERTEL, LANL — Work is underway to develop a new ICF platform on the Omega and NIF facilities to better quantify the influence of heterogeneous mix on fusion burn. Results of these experiments will be compared to a probability distribution function (PDF) burn model that has been developed to address yield from separated reactant experiments. CH capsules comprised of CH or CD solid foam cores containing tritium gas are being proposed along with capsules filled with a mixture of deuterated propane and tritium gas. For configurations in which the D and T are spatially separated, subsequent DT yield is used to characterize the mix. An overview of the experimental concept will be presented, and simulations in preparation for the platform will be discussed. This work is supported by the US DOE performed by LANL under contract DE-AC52-06NA25396.
The ablative RTI is investigated in 3-D geometry using our newly developed code. The Rayleigh–Taylor instability (RTI) at the ablation front causes a severe degradation in implosion performance by reducing the hot-spot pressure, temperature, and density. During the linear phase, the RTI growth is mitigated by mass ablation. However, during the nonlinear phase, mass ablation can be destabilizing. The ablative RTI is investigated in 3-D geometry using our newly developed code ART3D. It is found that mass ablation causes an accumulation of vorticity inside the bubble in the nonlinear regime. The vorticity-acceleration mechanism drives the bubble velocity faster than in the classical RTI for a 2-D geometry.

ART3D simulations indicate that the 3-D bubble velocity increases monotonically to values faster than in 2-D without reaching an asymptotic speed in neuterium and tritium shells. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.

10:30AM GO5.00006 Hydrodynamic Scaling of the Deceleration-Phase Rayleigh–Taylor Instability for Inertial Confinement Fusion Implosions. A. BOSE, R. BETTI, K. WOO, R. NORA, Laboratory for Laser Energetics and Fusion Science Center, U. of Rochester — Hydrodynamic equivalence and ignition theory allow for the extrapolation of OMEGA experiments to ignition-scale implosions. The yield-over-clean (YOC = measured yield/1-D yield) depicts the effect of hydro-instabilities on inertial confinement fusion implosions. A 2-D study of the deceleration-phase Rayleigh–Taylor instability (RTI) is carried out to assess the YOC scaling with target size at varying nonuniformity levels. The deceleration-phase ablative RTI is mitigated by the hot-spot thermal and radiation transport, which do not scale hydro-equivalently. Scaling of the thermal conduction shows that hot-spot ablative velocity is higher on OMEGA than on the National Ignition Facility (NIF), resulting in higher RTI growth factors on the NIF. Radiation emitted in the hot-spot makes the implosion nearly hydro-equivalent by increasing the density gradient scale length on the NIF. Thermal conduction and radiation both are nonscalable physics in the deceleration phase, with complementary impacts. The scaling of deceleration-phase RTI. Analytic and numerical study of the deceleration-phase RTI on OMEGA and NIF-scale targets show that YOC_{NIF} < YOC_{Ω} considering identical laser imprinting and normalized ice roughness levels. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.

10:42AM GO5.00007 Results from directly driven implosions of deuterated plastic shells filled with tritium gas. GARY GRIM, Los Alamos National Laboratory, DANIEL CASEY, Lawrence Livermore National Laboratory, JIM FINCKE, Los Alamos National Laboratory, ROBERT TIPTON, Lawrence Livermore National Laboratory — Results from implosions of tritium filled plastic shells containing thin deuterated sub-layers, as well as comparisons with 1-D capsule only simulations will be reported. The implosions were directly driven using a square, 1 ns wide, 27 kJ laser pulse, provided by the Laboratory for Laser Energetics, University of Rochester, Rochester, NY. The 15 um thick, by 865 µm OD. CH capsules were fabricated with 1 µm thick, deuterated plastic layers, located either in direct contact with the tritium gas, or offset by a layer of CH. Neutrons produced by deuterium-tritium fusion signify atomic mixing between the deuterated shell and the gas payload, allowing for a detailed study of the dynamics of mix in 3-D implosions. Data has been collected on implosions from capsules with a depth of burial of 0, 1, and 2 um of CH, as well as non-deuterated control shots. Capsules were shot with two gas fill pressures, 4 and 10 atm., to provide information on mix as a function of convergence. We report nuclear and X-ray data collected from these experiments. Further, we present comparisons with, 1-D and 2-D, capsule only simulations.

Prepared by LANL under Contract-DE-AC-52-06-NA25396, TSPA.

References:

11:06AM GO5.00009 Results of a supersonic, single-mode, shockwave-driven Kelvin-Helmholtz instability experiment. W.C. WAN, University of Michigan, USA, G. MALAMUD, Nuclear Research Center, Israel, C.A. DI STEFANO, M.R. TRANTHAM, S.R. KLEIN, University of Michigan, USA, A. SHIMONY, D. SHVARTS, Nuclear Research Center, Israel, C.C. KURANZ, R.P. DRAKE, University of Michigan, USA — The Kelvin-Helmholtz instability is a hydrodynamic process that causes mixing at an interface with shear flow. It is prevalent in many high-energy-density systems such as fusion research, core-collapse supernovae, and protoplanetary disks. Although it is common to simplify the Euler equations by assuming incompressibility, this assumption does not account for the inhibited growth rate found in supersonic flows. Here, we present the first laboratory observations of single-mode, compressible Kelvin-Helmholtz instability growth. This observation was performed at the OMEGA-EP facility using three beams stitched into a 28 ns square pulse to sustain a shockwave in low-density foam. The shockwave generated shear along the interface between the foam and a high-density plastic, seeded with a precisely machined single-mode sinusoidal perturbation. The system was diagnosed using radiography with a spatial resolution of 0.1 mm. This work is supported by the National Science Foundation under Grant No. PHY-1823568 and the Office of Naval Research.
11:18AM GO5.00010 Oblique Shock Experiments on the OMEGA-EP Laser1. JONATHAN HAGER, KIRK FLIPPO, FORREST DOSS, JOHN KLINE, Los Alamos National Laboratory, WESLEY WAN, CARLOS DI STEFANO, CAROLYN KURANZ, PAUL DRAKE, University of Michigan — In inertial confinement fusion (ICF), understanding the evolution of hydrodynamic instability growth is an essential part of designing an implosion target that is robust to mix between the cold target shell and the hot fusion core. Early in time, shocks traversing the target amplify seed modulations through the slow growing Richtmyer-Meshkov (RM) and Kelvin-Helmholtz (KH) instabilities. These instabilities seed the faster growing Rayleigh-Taylor (RT) instability during the acceleration and deceleration phases of the implosion. We present an experimental platform designed to investigate coupling between the RM and KH instabilities by launching a planar shock through a polyamide-imide cylinder on the OMEGA-EP laser. The rear surface of the target has a single mode sinusoidal seed modulation that is machined on an interface that is at an angle with respect to the planar shock, creating an oblique shock breakout. The evolution of the rear surface modulation is measured using side-on x-ray radiography with a spherical crystal imager backlight by a copper k-alpha source. Experimental data will be presented along with comparisons with 1-D and 2-D simulation predictions.

1This work performed under the auspices of the U.S. Department of Energy by LANL under contract DE-AC52-06NA25396.

11:30AM GO5.00011 Effects of Self-Generated Magnetic Fields in Rayleigh–Taylor Unstable Laser-Irradiated Plastic Foils, I.V. IGUMENSHCHEV, Laboratory for Laser Energetics, U. of Rochester — Self-generated magnetic fields during the nonlinear Rayleigh–Taylor (RT) growth in laser-driven plastic foils are studied using 2-D magnetohydrodynamic simulations. The simulations show that at intensities of $\sim 6 \times 10^{14}$ W/cm$^2$, the dynamics of the fields sourced by the Biermann battery effect ($\sim \nabla T_e \times \nabla n_e$) are strongly affected by the Nernst convection, which compresses the fields toward the ablation surface. As a result, the fields are localized in areas of high resistivity and related magnetic dissipations limit the field growth, determining the magnitude of the fields. The fields saturate at about 2 to 3 MG for perturbation wavelengths $L <$ 100 $\mu$m and at less than 0.1 MG for $L < 10 \mu$m because of increased magnetic dissipations at small spatial scales. Self-generated fields can moderately affect the nonlinear RT growth by redistributing heat fluxes for perturbations with $L > 100 \mu$m. The simulations show good agreement with measurements of magnetic fields in recent direct-drive planar experiments on the OMEGA EP laser. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


11:42AM GO5.00012 Significant reduction of instability growth in magnetically driven liner implosions1, KYLE PETERSON, TOM AWE, STEVE ROSENTHAL, RYAN MCBRIDE, DANIEL SINARS, EDMUND YU, GRAFTON ROBERTSON, MIKE CUNEO, MARK SAVAGE, PATRICK KNAPP, PAUL SCHMIT, STEVE SLUTZ, Sandia National Laboratories, BRENTH BLUE, DIANA SCHROEN, General Atomics, KURT TOMLINSON, Sandia National Laboratories — Recent experiments on Sandia’s Z facility have shown a significant reduction of instability growth [1] in solid metallic rods driven with a ∼ 20 MA, 100ns current pulse when thick, ∼ 70 $\mu$m dielectric coatings were employed to mitigate nonlinear growth of the electrothermal instability [2]. In this paper, we present new electrothermal mitigation experiments with MagLIF [3] relevant aluminum (aspect ratio 9) and beryllium liners (aspect ratio 6). These experiments show a similar improvement in instability performance while implosing to much higher convergence ratios and undergoing much greater acceleration.


1Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

11:54AM GO5.00013 Effect of initial amplitude on the interfacial and bulk dynamics in Richtmyer-Meshkov iInstability under conditions of high energy density1, ZACHARY R. DELL, Carnegie Mellon University, ROBERT F. STELLINGWERF, Stellingwerf Consulting Inc., SNEZHANA I. ABDARZHI, Carnegie Mellon University — We systematically study the effect of the initial amplitude on the interfacial and bulk dynamics of the Richtmyer-Meshkov instability (RMI) induced by strong shocks. The shock propagates from the light to the heavy fluid. The fluid densities are contrast. The fluid interface is initially perturbed with a cosine wave perturbation. Its amplitude is varied from 0% to 100% of the initial inter-particle wavelength. A broad range of the shock strengths and density ratios is considered. Smoothed particle hydrodynamics code is employed to ensure shock capturing and interface tracking. Detailed diagnostics of the flow scalar and vector fields is performed. Whenever possible the simulation results are compared with existing theoretrical analyses achieving good agreement. The focus question of our study is how the energy deposited by the shock is partitioned between the interfacial and volumetric components. We analyze the dependance of the initial growth-rate of RMI, the velocity away from the interface, and the transmitted shock velocity as functions of the initial amplitude. Particularly, we found that for a Mach number 5 and an Atwood number 0.8, the initial growth rate is highest and the interfacial energy is the largest when the initial amplitude is about a quarter of the wavelength.

1The work is supported by the US National Science Foundation.

12:06PM GO5.00014 Accelerated dynamics of blast wave driven Rayleigh–Taylor instabilities in high energy density plasmas1, N. SWISHER, Carnegie Mellon University, USA, C. KURANZ, R.P. DRAKE, University of Michigan at Ann Arbor, USA, S.I. ABDARZHI, Carnegie Mellon University, USA — We report the systematic analysis of experimental data describing the late time evolution of the high Mach number and high Reynolds number Rayleigh-Taylor instability which is driven by a blast wave. The parameter regime is relevant to high energy density plasmas and astrophysics. The experiments have been conducted at the Omega laser facility. By processing the experimental x-ray images, we quantified the delicate features of RT dynamics, including the measurements of the curvature of the transmitted shock and the interface envelopes, the positions of RT bubbles and spikes, and the quantification of statistics of RT mixing. The measurements were performed at four time steps and for three different initial perturbations of the target (single mode and two two-mode). We found that within the noise level the curvatures of the shock and interface envelope evolve steadily and are insensitive to laser imperfections. At late times, the bubble merging does not occur, and the flow keeps significant degree of order. Yet, the blast-wave-driven RT spikes do accelerate with the power-law exponent smaller than that in case of sustained acceleration. We compared the experimental results with the momentum model of RT mixing and stochastic model achieving good agreement.

1The work is supported by the US National Science Foundation.
XAVIER RIBEYRE, EMMA LLOR, ALEXANDRA VALLET, PHILIPPE NICOLAI,
well as laser-imprinted nonuniformities from laser speckle. This material is based upon work supported by the Department of Energy National Nuclear Security
2-D simulations at implosion velocities varying from 260 to 300 km/s. Stability studies will include both polar-drive beam geometry and beam repointing as
with multidimensional stability characteristics. Polar-drive SI designs for the NIF at 700 kJ will be reviewed and compared for stability and margin in 1-D and
precompressed capsule, raising the hot-spot pressure and temperature. This spike pulse allows SI targets to achieve ignition temperatures at lower shell velocities
ignition at the National Ignition Facility (NIF). In SI, a high-intensity laser spike added at the end of the compression pulse launches a strong shock into the
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ignition in the Shock Ignition scheme

Tuesday, October 28, 2014 9:30AM - 12:18PM –
Session G06 Shock and Fast Ignition  Galerie 3 - Matthias Hohenberger, University of Rochester

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9:42AM G06.00002 Shock Ignition Theoretical Studies: From Hot Electrons Pressure Converging to Conversion Amplification Effects, XAVIER RIBEYRE, EMMA LLOR, ALEXANDRA VALLET, PHILIPPE NICOLAI,
VLADIMIR TIKHONCHUK, CELIA — The shock ignition (SI) concept in inertial confinement fusion uses an intense power spike at the end of an assembly laser
pulse. The power spike launches a strong shock wave with an ablation pressure of ~ 0.3 Gbar that increases in strength when converging through the imploding
shell. However, the detail understanding of the role hot electrons in the pressure generation and the converging shell effects on pressure amplification is crucial in SI. First, we present a model describing the effect of the fast electron energy distribution on the dynamics of shock wave formation and the compression of matter behind its front. We have studied analytically and numerically the penetration and the energy deposition of fast electrons in a dense plasma and the shock wave formation. A criterion of a strong shock formation with an electron beam is obtained for an arbitrary distribution function. Finally, we present a new semi-analytical hydrodynamic model to describe the shock from its generation until fuel ignition. The shock pressure amplification follows mainly the overall imploded shell pressure enhancement but is not sufficient for SI. The shock is further amplified when it collides inside the shell with diverging shocks coming from the assembly phase. The shock is partially transmitted to the hot spot when it crosses the shell/fuel interface depending on the shock timing. A semi-analytical criterion for ignition on the shock pressure is expressed.

9:54AM G06.00003 Assessing target design robustness for Shock Ignition using 3D laser raytracing, ANGELO SCHIAVI, STEFANO ATZENI, ALBERTO MAROCCHINO, Dipartimento SBAI, Università di Roma “La Sapienza” — Shock ignition (SI)[1] is a laser direct-drive Inertial Confinement Fusion scheme in which fuel compression and hot spot formation are separated. Shock ignition shows potential for high gain at laser energy below 1 MJ (see review Ref.[2]), and could be tested on present large scale facilities. We produced an analytical model for SI which allows rescaling of target and laser drive parameters starting from a given point design [3]. The goal is to redefine a laser-target configuration increasing the robustness while preserving its performance. We developed a metric for ignition margins specific to SI [4]. We report on simulations of rescaled targets using 2D hydrodynamic fluid model with 3D laser raytracing. The robustness with respect to target fabrication parameters and laser facility fluctuations will be assessed for an original reference design as well as for a rescaled target, testing the accuracy of the ignition margin predictor just developed. Work supported by the Italian MIUR project PRIN2012AYSEEL.


10:06AM G06.00004 Combined effects of laser and non-thermal electron beams on hydrodynamics and shock formation in the Shock Ignition scheme, PH. NICOLAI, J.L. FEUGEAS, M. TOUATI, J. BREIL, B. DUBROCA, T. NGUYEN-BUY, X. RIBEYRE, V. TIKHONCHUK, CELIA, Univ. Bordeaux, France, S. GUS’KOV, P.N. Lebedev Inst., Moscow, Russia — An issue to be addressed in Inertial Confinement Fusion (ICF) is the detailed description of the kinetic transport of relativistic or non-thermal electrons generated by laser within the time and space scales of the imploded target hydrodynamics. We have developed at CELIA the model M1 [1], a fast and reduced kinetic model for relativistic electron transport. The latter has been implemented into the 2D radiation hydrodynamic code CHIC [2]. In the framework of the Shock Ignition (SI) scheme, it has been shown in simplified conditions that the energy transferred by the non-thermal electrons from the corona to the compressed shell of an ICF target could be an important mechanism for the creation of ablation pressure [3]. Nevertheless, in realistic configurations, taking the density profile and the electron energy spectrum into account, the target has to be carefully designed to avoid deleterious effects on compression efficiency [4]. In addition, the electron energy deposition may modify the laser-driven shock formation and its propagation through the target. The non-thermal electron effects on the shock propagation will be analyzed in a realistic configuration.

10:18AM GO6.00005 Spherical Strong-Shock Inferences on OMEGA, R. NORA, M. LAFOUN, R. BETTI, Laboratory for Laser Energetics and Fusion Science Center, U. of Rochester, W. THEOBALD, W. SEKA, J.A. DELETTREZ, Laboratory for Laser Energetics, U. of Rochester — A milestone for shock ignition is to experimentally verify the generation of several hundred Mbar shocks at shock-ignition-relevant laser intensities. This paper presents the first experimental evidence of strong shocks generated in a spherical geometry. Using the temporal delay between the launch of the strong shock at the outer surface of the spherical target and the time when the shock converges at the center, the shock properties can be inferred using radiation—hydrodynamic simulations. Peak ablation pressures exceeding 200 Mbar are inferred at laser intensities of \( \sim 3 \times 10^{17} \text{ W/cm}^2 \). The shock strength is significantly higher than those which can be generated by the use of high amounts of hot electrons, up to 2 kJ with \( T_{\text{elec}} \sim 50 \) to 100 keV. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and the Office of Fusion Sciences Number DE-FG02-04ER54786.

10:30AM GO6.00006 Effects of Preplasma in 10-ps Relativistic Laser Matter Interaction, M.S. WEI, R.B. STEPHENS, General Atomics, J. PEEBLE, C. MCGUFFEY, B. QIAO, F. BEG, UCSD, Y. SENTOKU, UNR, A. LINK, H. CHEN, H.S. MCLCEN, LLNL, W. THEOBALD, D. HABERBERGER, A. DAVIES, LLE — Experiments were performed using the kJ 10-ps OMEGA EP laser to study the effect of preplasma on fast electron generation and energy coupling in relativistic laser plasma interaction (LPI) with a controlled preplasma at various scale length created by a 1-ns UV laser. Targets were multilayered planar foil consisting of an Al substrate, a buried Cu layer and a thick conductive CH layer. Preplasma density profile and relativistic LPI generated fields were characterized using a 10-ps 4ω optical probe (angular filter refractometry and polarimetry) together with radiography using a high-energy proton beam produced by the second kJ 10-ps EP beam. Fast electrons were diagnosed by measuring Cu K-shell fluorescence emission and bremsstrahlung radiation. Electron energy spectrum was monitored by a magnetic spectrometer. Preliminary results showed nonlinear interaction instabilities and a reduced electron temperature with increasing preplasma scalelength. Dynamics of the relativistic LPI and the resultant fast electron beam characteristics and energy coupling will be presented.

10:42AM GO6.00007 Impact of Pre-Plasma on Fast Electron Generation and Transport from Short Pulse High Intensity Lasers, J. PEEBLE, C. MCGUFFEY, C. KRAUSLAND, L.C. HARROD, A. SOROKOVIKOVA, B. QIAO, S. KRASHENINNIKOV, F.N. BEG, Univ of California - San Diego, M.S. WEI, General Atomics, J. PARK, A. LINK, H. CHEN, H.S. MCLCEN, Lawrence Livermore National Laboratory, C. WAGNER, V. MINELLO, E. MCCARRY, A. MEADOWS, M. SPINKS, E. GAUL, G. DYER, B.M. HEGELICH, M. MARTINEZ, M. DONOVAN, T. DITMIRE, University of Texas - Austin — We present the results and analysis from recent short pulse laser matter experiments using the Texas Petawatt laser to study the impact of pre-plasma on fast electron generation and transport. The experimental setup consisted of 3 separate beam elements: a main, high intensity, short pulse beam for the interaction, a secondary pulse of equal intensity interacting with a separate thin foil target to generate protons for side-on proton imaging and a third, low intensity, wide beam to generate a varied scale length pre-plasma. The main target consisted of a multilayer planar Al foil with a buried Cu layer. The electron beam was characterized with multi diagnostics, including various bremsstrahlung spectrometers, magnetic electron spectrometers and \( \text{Cu-K}_\alpha \) imaging. The protons from the secondary target were used to image the fields on the front of the target in the region of laser plasma interaction. Features seen in the interaction region by these protons will be presented along with characteristics of the generated electron beam. This work performed under the auspices of the US DOE under contracts DE-FOA-0005853 (FES, NNSA).

10:54AM GO6.00008 Irradiation of intense laser on the inner surface of CD shell to generate the hot spark in the fast ignition, ATSUSHI SUNAHARA, Institute of Laser Engineering, Osaka Univ., TAKASUO NAGAI, YUKI ABE, SEUNG HO LEE, YASUNOBU ARIKAWA, SHINSUKE FUJIOKA, ILE Osaka Univ., TOMOYUKI TOHZAKI, Hiroshima Univ., KUNIHIRO MIYAMA, HIROYUKI SHIRAGA, HIROYUKI AZECHI, ILE Osaka Univ., FIREX PROJECT TEAM — We propose the new heating scheme of the fast ignition. In this scheme, the inner surface of CD shell is irradiated by the relatively longer 100ps pulse with the intensity ranging from \( 10^{16} \text{ W/cm}^2 \) to \( 10^{17} \text{ W/cm}^2 \). In this laser intensity region, the laser absorption fraction is relatively low and most of the laser light reflects many times, and heats of the inner surface of the shell. Also, fast electrons with moderate energy ranging from 50keV to 100keV are generated and contribute the shell heating. Then, the heated shell expands toward the center of the target and generates the high temperature hot spark. In order to confirm this concept, we conducted the preliminary experiment by using 1.06 micron wavelength and 100ps duration beams of GXII laser system. We observed that high temperature region of several hundred Mbar was formed at the center of the shell. We will show the concept and its possibility as a alternative method of spark formation in the inertial confinement fusion.

11:06AM GO6.00009 Computational Study of Hydrodynamic Instability under the Strong Magnetic Field, HIDEO NAGATOMO, TAKASHI ASAHINA, Institute of Laser Engineering, Osaka University, ATSUSHI SUNAHARA, Institute for Laser Technology, TOMOYUKI JOHZAKI, Hiroshima University — Recent studies suggest that the magnetic field can improve the heating efficiency of Fast Ignition scheme, if high energy electrons are guided toward the compressed core plasma. However, the imposed magnetic field of which intensity is sub-Tesla may affect to the electron thermal conductivity. Our preliminary simulation result suggests that the hydrodynamic instability is seeded by the strong magnetic field. In order to investigate the mechanism of the seed of the hydrodynamic instability in early stage of laser driven acceleration, 2-D magnetic field transport calculations are performed. Features seen in the interaction region by these protons will be presented along with characteristics of the generated electron beam. This work was supported by the JSPS KAKENHI Grant Number 26400532.

11:18AM GO6.00010 Laser Channeling in an Inhomogeneous Plasma for Fast-Ignition Laser Fusion, S. IVANCIC, D. HABERBERGER, W. THEOBALD, K.S. ANDERSON, D.H. FROULA, D.D. MEYERHOFER, Laboratory for Laser Energetics, U. of Rochester, K. TANAKA, H. HABARA, T. IWAYAKI, Osaka University — The evacuation of a plasma cavity by a high-intensity laser beam is of practical importance to the channeling fast-ignition concept. The channel in the plasma corona of an imploled inertial confinement fusion capsule provides a clear path through the plasma so that the energy from a second high-intensity laser can be deposited close to the dense core of the assembled fuel to achieve ignition. This study reports on experiments that demonstrate the transport of high-intensity (> \( 10^{17} \text{ W/cm}^2 \)) laser light through an inhomogeneous kilojoule-laser-produced plasma up to overcritical density. The multikilojoule high-intensity light evacuates a cavity inside the focal spot, leaving a parabolic trough that is observed using a novel optical probing technique—angular filter refractometry. The cavity forms in less than 100 ps using a 20-TW laser pulse and bores at a velocity of \( \sim 2 \text{ m/u} \). The experimentally measured depths of the cavity are consistent with a ponderomotive hole-boring model. The experiments show that 100-ps IR pulses with an intensity of \( \sim 5 \times 10^{17} \text{ W/cm}^2 \) produced a channel up to the critical density, while 10-ps pulses with the same energy but higher intensity did not propagate as far. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.
11:30 AM GO6.00011 Auxiliary Heating of Inertial Confinement Fusion Targets. PETER NORREYS, STFC — The role of collisionless ion heating arising from the propagation of petawatt-laser driven relativistic electron beams in dense plasma will be discussed. The energy cascade mechanism begins first with the rapid growth of electrostatic waves near the electron plasma frequency. These waves reach high amplitudes and break, which then results in the generation of a strongly driven turbulent Langmuir spectrum. Parametric decay of these waves, particularly via the modulational instability, then gives rise to a coupled turbulent ion acoustic spectrum. These waves, in turn, experience significant Landau damping, resulting in the rapid heating of the background ion population. In this talk, I will review the evidence for this cascade process in laboratory plasmas and describe the theoretical background that underpins this process. I will then present the most recent analytic modeling, particle-in-cell and Vlasov-Poisson simulation results of my team within Oxford Physics and the Central Laser Facility that explores the optimum parameter space for this process, focusing in particular on the requirements for auxiliary heating of the central hot spot in inertial confinement fusion target experiments now underway on the National Ignition Facility. I will also describe new methods for hole-boring through the coronal plasma surrounding the fuel using strongly relativistic laser beams that demonstrates the strong suppression of the hosing instability under these conditions.

11:42 AM GO6.00012 Auxiliary Heating with Fast Electrons. NAREN RATAN, University of Oxford, RAOUl TRINES, STFC Rutherford Appleton Laboratory, NATHAN SIRCOMBE, AWE plc, ROBERT BINGHAM, University of Strathclyde / STFC Rutherford Appleton Laboratory, PETER NORREYS, University of Oxford / STFC Rutherford Appleton Laboratory — Indirect drive inertial confinement fusion experiments can now achieve hot spot temperatures and densities tantalizingly close to ignition conditions. We are investigating the use of a fast electron beam to provide auxiliary heating to tip an existing scheme over the edge to ignition. Experiments on the stopping of fast electron beams have demonstrated that fast electrons are stopped in a much shorter distance than can be accounted for by collisions. Beam-plasma instabilities, a collective phenomenon, are a good candidate for explaining this anomalous stopping. Simulations of electron beams in plasmas have shown heating of the ions in the plasma. A possible explanation for these observations is that a beam-plasma instability produces Langmuir waves which decay to produce ion-acoustic waves, and that these ion-acoustic waves are subsequently damped leading to ion heating. We are studying the possibility of using such a mechanism to provide auxiliary heating of the hot spot using fast electron beams. We will present analytical work and simulations of each stage of this heating mechanism: the beam-plasma system becoming unstable, the decay of the resulting Langmuir waves, and the damping of the ion waves produced.

11:54 AM GO6.00013 A novel laser plasma interaction geometry to generate a convergent fast-electron beam. ROBBIE SCOTT, STFC Rutherford Appleton Laboratory — A simple, novel, geometry for the laser-plasma interaction is presented that generates a convergent fast-electron beam. The fast-electron beam focuses within the target, with the focal length determined by the interaction geometry. As the fast electron beam’s intensity peaks within the target (i.e. within the Deuterium-Tritium fuel region), this scheme may offer a route to achieving fast-ignition with reduced laser energy. Particle-in-cell simulations are used to demonstrate the potential efficacy of this scheme.

12:06 PM GO6.00014 Implosion of indirect-drive fast ignition targets with CH coated reentrant cone. WEIMIN ZHOU, LIAOQIANG SHAN, YUQIU GU, BAOHAN ZHANG, Research Center of Laser Fusion, China Academy of Engineering Physics, FAST IGNITION TEAM — Compared with central ignition of laser fusion, fast ignition separates compression and ignition thus it can relax the requirements on the implosion symmetry and the driven energy. The implosion of indirect-drive fast ignition targets with CH coated reentrant cone was experimentally researched on SHENGUANG (SG) II laser facility. The small scale cone-in-shell target fast ignition was pre-compressed by the SG II eight 260J/1ns/3µ beam lasers indirectly since beam smoothing was not available currently. The maximum density of the compressed cone-in-shell target 1.37 ns after the lasers’ irradiation on the inside wall of hohlraum is about 8.7 g/cm³, and the areal density is close to 8.9 mg/cm², which are well consistent with the simulation results with two-dimensional radiation hydrodynamic code. To minimize the mixing of the compressed fuel and high-Z vapor produced by the M-line emission from the gold hohlraum, a 3µm CH foil was coated on the full outer surface of the cone and guiding wire. Experimental results and simulation results also demonstrated the coated CH foil could minimize the mixing effectively. It can be seen that the CH coating can maintain robust against the maximum compression, that is, the time while the hot electrons produced by ignition laser pulse deposit energy in the compressed fuel.

Tuesday, October 28, 2014 9:30AM - 11:30AM
Session GO7 Waves, Turbulence, Transport and Theory Galerie 6 - Ami Dubois, University of Wisconsin-Madison

9:30 AM GO7.00001 Ion Heating Due to Low-Frequency Wave Propagation in Partially Ionized Plasmas With a Strong Density Gradient in the Hot Helicon Experiment (HELIx). STEPHANIE SEARS, ROBERT VANDERVORT, GREG LÜSK, MARK SODERHOLM, JOHN MCKEE, EARL SCIME, West Virginia University — Ion heating is observed in the solar corona but is still poorly understood. Alvén wave damping is one of the most plausible mechanisms proposed to explain coronal ion heating. With time-resolved Laser Induced Fluorescence (LIF), we have measured the increase in ion temperature in HELIX in the presence of low-frequency waves generated by a small antenna near the high-density core. We have taken LIF measurements across the plasma column to characterize how the local density and density gradient affect ion heating. Wavelet analysis of localized, small-scale (smaller than an ion gyroradius) magnetic probe measurements suggest that plasma turbulence also plays a role in ion heating.

9:42 AM GO7.00002 The stability of freely-propagating ion acoustic waves in 2D systems. THOMAS CHAPMAN, RICHARD BERGER, JEFFREY BANKS, LLNL, STEPHAN BRUNNER, EPFL, Switzerland — The stability of a freely-propagating ion acoustic wave (IAW) is a basic science problem that is made difficult by the need to resolve electron kinetic effects over a timescale that greatly exceeds the IAW period during numerical simulation. Recent results examining IAW stability using a 1D+1V Vlasov-Poisson solver indicate that instability is a fundamental property of IAWs that occurs over most if not all of the parameter space of relevance to ICF experiments [1]. We present here new results addressing the fundamental question of IAW stability across a broad range of plasma conditions in a 2D+2V system using LOKI [2,3], ranging from a regime of relatively weak to a regime of relatively strong ion kinetic effects.


1Work performed under the auspices of the U.S. DOE by LLNL (DE-AC52-07NA27344) and funded by the LDRD Program at LLNL (12-ERD-061).
9:54AM GO7.00003 Intermittent Profile Collapse in a Basic Heat Transport Experiment

B. Van Coppernolle, G.J. Morales, J.E. Maggs, UCLA, R. Sydora, University of Alberta, Canada — Results of a basic heat transport experiment involving an off-axis heat source are presented. Experiments are performed in the Large Plasma Device (LPAD) at UCLA. A ring-shaped electron beam source injects low energy electrons (< 20 eV) along the magnetic field. The injected electrons are thermalized within a short distance and provide an off-axis heat source that results in a long, hollow, cylindrical filament of elevated electron temperature embedded in a colder plasma. The electron heat transport is studied as a function of heating power. At low heating power classical heat transport is observed. At high heating powers drift-wave fluctuations dominate the transport. At intermediate heating powers a regime has been found in which intermittent collapses of the temperature profile occur. The heating causes the radial temperature profiles to steepen until a threshold is reached at which time drift waves grow and cause a rapid collapse. After the profile collapses the drift wave activity disappears. On a longer time-scale the profile slowly recovers and steepens again and the process repeats. The repetition frequency of the collapses is a sensitive function of heating power, with only a few collapses at low heating powers, and many in rapid succession at higher heating powers.

The work was supported at the LARege Plasma Device at the Basic Plasma Science Facility (BaPSF) at UCLA, funded by DOE/NSF.

10:06AM GO7.00004 3D Gyrokinetic Simulation of Heat Transport in a Magnetized Ring-Shaped Temperature Filament

R. Sydora, University of Alberta, Canada, B. Van Coppernolle, G.J. Morales, J.E. Maggs, UCLA — 3D electromagnetic gyrokinetic particle simulations of drift-Alfven fluctuations and thermal transport have been carried out using plasma conditions similar to those in the recent off-axis heat source experiment performed in the Large Plasma Device (LPAD) at UCLA. The novel heat source resulted in a long, hollow cylindrical temperature filament of elevated electron temperature(\(T_e\)) embedded in a colder plasma. The drift wave fluctuations and thermal transport and profiles have been characterized experimentally. The gyrokinetic simulations (cylindrical geometry) are initialized using experimental parameters including the radial and axial extent of the hollow cylindrical \(T_e\)-filament. The inner ring diameter is taken to be approximately four times its width. The \(T_e\) gradient is mainly determined by the ratio of the peak temperature in the ring to the background temperature and above a certain gradient threshold, drift-Alfven fluctuations were excited and induced a rapid thermal collapse on time scales consistent with experiment. The spatio-temporal pattern of the electrostatic potential, density, and magnetic fluctuations have been analyzed in the linear and nonlinear, saturated state of evolution. Detailed comparisons with experiment are presented.

This work is supported by NSERC, Canada and performed at the Basic Plasma Science Facility(BaPSF), funded by DOE/NSF.

10:18AM GO7.00005 Profile evolving tokamak plasma edge turbulence simulations

Bo Li, Peking University, D.R. Ernst, MIT, C. Sun, A. Zhou, H. Zhang, Peking University — We have developed a new flux-driven 3D two-fluid code for the simulation of resistive ballooning modes in the tokamak edge and SOL. The plasma pressure and potential profiles are evolved self-consistently using the drift-reduced Braginskii equations. The simulation domain is radially global with both closed and open field line regions. We find that the plasma potential structures play an important role in the edge turbulence and transport. The simulations show that the nonlinear evolution of the curvature-driven mode produces the large-scale convective cells. These radially broad eddies result in the flattened pressure profiles in the turbulent, steady state.

1Work supported by ITER-CN 2013GB112006.

10:30AM GO7.00006 Non-diffusive suprathermal ion transport associated with blobs in TORPEX plasmas

Alexandre Bovet, Ecole Polytechnique Federale de Lausanne, Centre de Recherches en Physique des Plasmas, Lausanne, Switzerland, Fabio Avino, Ambrogio Fasoli, Ivo Furfaro, EPFL-CRPP, Kyle Gustafson, EPFL-SV, Paolo Ricci, EPFL-CRPP — We present unprecedented space and time-resolved measurements of the transport of a suprathermal ion beam injected in the toroidal device TORPEX. Experiments are performed in turbulence dominated by an ideal-interchange mode using a Li6+ ion source and a set of energy analyzers. Depending on the suprathermal ion energy, the transport exhibits subdiffusive or superdiffusive behaviors. The fast ion current fluctuations are quasi-Gaussian in the former regime and strongly intermittent in the latter. In the superdiffusive case, using conditional sampling, we show that the transport is associated with intermittent field-aligned blobs. In the subdiffusive case, suprathermal ions average the turbulent structures during their gyro-motion and their vertical drift. These results complement our investigations of the suprathermal ion transport using 3D time-averaged measurements, which are in agreement with numerical simulations. Numerical modeling is performed by computing the trajectories of traces in a turbulent electrostatic field generated by a 2D global fluid model. Gyro- and drift-averaging reduce the transport. The evolution of the radial distribution of fast ions can be modeled by a fractional diffusion equation describing fractional Levy motion.

1This work was supported in part by the Swiss National Science Foundation and European Union’s Horizon 2020 program (grant number 633053).

10:42AM GO7.00007 Coherent and Turbulent Fluctuation Dynamics in a Linear Magnetized Plasma with Biasing

Tiffany Desjardins, Mark Gilmore, University of New Mexico, Dustin Fisher, Dartmouth College, Jose-Miguel Reynolds-Barrero, University Carlos III de Madrid — The Helicon-Cathode (HelCat) Device at the University of New Mexico is a linear plasma device that exhibits a wide range of plasma dynamics. HelCat has intrinsic fluctuations that vary from coherent to fully turbulent, depending on variables such as magnetic field strength, source power, and neutral background fill. In addition, biased grid and ring electrodes are found to strongly affect the fluctuation dynamics. A detailed study of the transition from a coherent state to a fully turbulent states with the variation of operating parameters and electrode bias is underway. It is seen that with increased magnetic field, fluctuation mode and character changes, and the plasma may become chaotic, before becoming turbulent. With biasing, it is possible to fully suppress instabilities and in some cases excite new ones. In addition to experimental measurements, a linear eigenmode solver is used to accurately identify the instabilities present. A basic overview of results and analysis will be presented.

10:54AM GO7.00008 On the validity of drift-reduced plasma fluid models

Jarrod Leddy, Ben Dudson, University of York, Michele Romanelli, Culham Centre for Fusion Energy — Fluid approximations are often used in the simulation of plasmas to reduce the dimensionality of the system from the full kinetic description. A further simplification can be made to reduce the full velocity vector field in the Braginskii equations to parallel velocity and parallel vorticity by taking the curl of the velocity equation. This so-called drift-reduced simplification assumes small drift velocities perpendicular to the magnetic field lines. The Hazeltime 4-field model makes use of this reduction and assumes an isothermal plasma minimising the full fluid equations to solve for pressure, poloidal flux, parallel velocity, and parallel vorticity. This model has been implemented using the BOUT++ framework and benchmarked against the full Braginskii code CENTORI. It was predicted that as gradients and drives were increased, the resulting increase in drift velocities would render the model inaccurate; however, initial results indicate that linear growth rates continue to match analytical values. Further study will reveal how the nonlinear behaviour is affected in this regime.
11:06AM GO7.00009 Can time-spectral methods improve turbulence modelling? , JAN SCHEFFEL. Fusion Plasma Physics, KTH Royal Institute of Technology, Stockholm, Sweden — In computational fusion physics, the widely separated time and space scales often demand extremely long computer simulations and vast memory resources, using finite time steps. Gyrokinetic turbulence modelling at high Reynolds or Lundquist numbers may be allocated millions of CPU hours for parallel processing on supercomputers. It is thus worthwhile to explore new avenues that may alleviate requirements on computer power. Indeed, time-stepping may be completely avoided for initial-value problems. In the recently developed Generalized Weighted Residual Method GWRM [1], temporal, spatial and parameter domains are all handled using a solution ansatz in the form of a sum of Chebyshev polynomials. The coefficients of the ansatz are determined using a weighted residual method for which a new efficient equation solver has been developed [2]. In addition, the temporal and spatial computational region has been successfully treated using subdomain methods in a number of test problems, more efficiently than relevant finite difference methods. The GWRM, however, relies on solution of linear systems of equations in each subdomain, and memory requirement is an issue. In this presentation we will discuss recent subdomain approaches for efficient and convergent modelling of drift-wave turbulence.


11:18AM GO7.00010 Chaotic motion of charged particles in toroidal magnetic configurations . XAVIER LEONCINI, BENJAMIN CAMBON, Centre de Physique Theorique, Aix-Marseille University, MICHEL VITTOT, Centre de Physique Theorique, CNRS, REMI DUMONT, XAVIER GARBET, IRFM, CEA — We study the motion of a charged particle in a toroidal magnetic field and discuss its chaotic nature. First considering an idealized magnetic configuration, we add a non generic perturbation corresponding to a magnetic ripple, breaking one of the invariant of the motion. Chaotic motion is then observed and opens questions about the link between chaos of magnetic field lines and chaos of particle trajectories. Second, we return to an axi-symmetric configuration and tune the safety factor (magnetic configuration) in order to recover chaotic motion. In this last setting with two constants of the motion, the presence of chaos implies that no third global constant exists. We are facing a mixed phase space with both regular and chaotic regions and point out the difficulties in performing a global reduction such as gyrokinetics.

9:30AM - 9:30AM –
Session GP8 Poster Session III: DIII-D Tokamak; Computer Simulation Methods: Shocks, Waves, Dynamo and Dipole; Low Temperature Plasmas Science and Engineering Preservation Hall –

GP8.00001 DIII-D TOKAMAK –

GP8.00002 Evolution of Radial Electric Field due to RMP-induced density pump-out1 , R.J. GROEBNER, S.P. SMITH, T.E. EVANS, X. CHEN, C. PAZ-SOLDAN, K.H. BURRELL, GA, R. NAZIKIAN, B.A. GRIERSON, PPPL, R.A. MOYER, D. ORLOV, C. CHRYSTAL, UCSD, G.R. MCKEE, U. Wisc. — The history of shear in the ExB field during application of resonant 3D magnetic perturbations (RMP) in DIII-D is studied with CER spectroscopy. Application of the RMP typically causes density pump-out and can ultimately lead to ELM suppression. Thus, understanding the origin of the density transport is an important issue for understanding ELM suppression by this technique. One hypothesis is that the RMP causes a reduction of ExB shear at the pedestal top, which then allows for an increase in density transport [1].


GP8.00003 Boundary and PMI Diagnostics for the DIII-D National Fusion Facility2 , D.M. THOMAS, B.D. BRAY, C. CHROBAC, A.W. LEONARD, General Atomics, S.L. ALLEN, C.J. LASNIER, A.G. MCLEAN, LLNL, A.R. BRIESEMESTER, ORNL, J.A. BOEDO, UCSD, D. ELDER, J.G. WATKINS, SNL — The Boundary and Plasma Materials Interaction Center is planning an improved set of boundary and divertor diagnostics for DIII-D in order to develop and validate robust heat flux solutions for future fusion devices on a timescale relevant to the design of NIFSNF. We intend to develop and test advanced divertor configurations on DIII-D using high performance plasma scenarios that are compatible with advanced tokamak operations in NIFSNF as well as providing a comprehensive testbed for modeling. Simultaneously, candidate PFC material solutions can be easily tested in these scenarios. Additional diagnostic capability is vital to help understand and validate these solutions. We will describe a number of desired measurements and our plans for deployment. These include better accounting of divertor radiation, including species identification and spatial distribution, divertor/SOL main ion temperature and neutral pressure, fuller 2D T_e/n_e imaging, and toroidally separated 3D heat flux measurements.

[2] Work supported in part by the US DOE under DE-FC02-04ER54698, DE-AC02-09CH11466, DE-FG02-05ER54809, DE-FG02-89ER53296, and DE-FG02-08ER54999

GP8.00004 Inferring DIII-D Edge Neutral Density from Fast-Ion D-Alpha Emission3 , N.G. BOLTE, W.W. HEIDBRINK, UC Irvine, D. PACE, M. VAN ZEELAND, GA — Promptly-lost beam ions produce Doppler-shifted Balmer-Alpha light after charge exchanging with edge neutrals. Spectra of this edge-localized fast-ion D-alpha (FIDA) emission have been measured at DIII-D using six chords that view the edge region. A new simulation P-FIDASim has been developed that models prompt-loss radiation. P-FIDASim uses modules from the active FIDA code, FIDASIM [1] but uses fast-ion orbits from a single beam in place of FIDASIM’s use of a theoretical fast-ion distribution function and considers CX with edge, not beam or halo neutrals. Initial results show good correlation between experiment and simulation in spectral shape. Intensity variations between chords show that empirical results are inconsistent with neutral density being a pure flux function. Modeling a neutral source term at the wall gives the z-dependence of the neutral density by inversion. Results will be presented of 2D (R,z) cross-sectional values of neutral density found by this method.

[2] Work supported in part by the US DOE under SC-G903402 and DE-FC02-04ER54698

Work supported in part by the US DOE under DE-FC02-04ER54698, DE-AC02-09CH11466, DE-FG02-05ER54809, DE-FG02-89ER53296, and DE-FG02-08ER54999.
GP8.00005 The Effects of Non-axisymmetric Fields on Divertor Conditions in the DIII-D Tokamak. A.R. BRIESEMEISTER, R.C. ISLER, J.-W. AHN, E.A. UNTERBERG, D.L. HILLS, Oak Ridge National Laboratory, A.G. MCLEAN, Lawrence Livermore National Laboratory — Measurements of impurity ion density, temperature and flow velocity made using the multichord divertor spectrometer (MDS) on DIII-D are presented for plasmas both with and without externally applied resonant magnetic perturbations (RMPs). Large parallel flows, measured to be on the order of 25 km/s, are driven by the Bohm sheath criteria at the plasma/wall interface. Changes in the connection lengths of the magnetic field, which can cause changes in the flow in the divertor, are predicted to occur when the RMPs are applied. Measurements of both C II and C III are analyzed to assess changes in both the flow and the spatial localization of the different carbon ionization states when RMPs are applied. In high-density plasmas, where RMPs had no effect on the core plasma conditions, no measurable changes were seen in the carbon flow in the divertor. Flows measured in lower density conditions will be used to investigate the relationship between density and the effects of RMPs on divertor plasmas.

1Work supported by the US Department of Energy under DE-AC05-00OR22725, DE-AC52-07NA27344 and DE-FC02-04ER54698.

GP8.00006 Validation of the SOLPS Parallel Heat Transport Model. J.M. CANIK, A.R. BRIESEMEISTER, Oak Ridge National Laboratory, C.J. LASNIER, A.G. MCLEAN, M.A. MAKOWSKI, Lawrence Livermore National Laboratory, A.W. LEONARD, General Atomics, J.G. WATKINS, Sandia National Laboratory — Recent SOLPS 2D fluid plasma/neutrals edge transport simulations have shown a consistent under-prediction of radiated power that when accounted for allows simulations to successfully match high resolution divertor and scrape-off-layer density (ne) and temperature (Te) measurements near detached conditions in DIII-D. The parallel heat transport model has been evaluated in simulations with the upstream ne and Te and divertor heat flux matched to experiments. Simulations of L-mode discharges near detachment onset require either increased carbon sources or hydrogenic recombination radiation to match measured radiative losses. With this increase, the poloidal Te profile shows good agreement with 2D divertor Thomson scattering data, including an extended region with very low Te, which cannot be reproduced without the additional radiative loss. Similar scaling of the radiated power also results in agreement for the Te profile measured in H-mode experiments; however, in this case the plasma data show a poloidally extended region of high ne that is not captured in simulations.

2Work supported by the US DOE under DE-AC05-00ER22725, DE-FC02-04ER54698 and DE-AC52-07NA27344.

GP8.00007 EDGE Modeling of Power Balance in DIII-D Density Scan Discharges Leading to Detachment. J.D. ELDER, P.C. STANGEBY, U. TORONTO, A.W. LEONARD, B.D. BRAY, N.H. BROOKS, G.A. J.G. WATKINS, S.N.L., E.A. UNTERBERG, ORNL, A.G. MCLEAN, LLNL — The EDGE code is used to model the outer divertor plasma for discharges from a density scan experiment on DIII-D. In this experiment the plasma density was increased over a series of L-mode and H-mode discharges starting with both targets attached and ending with both targets detached. These discharges used large X-point sweeps to obtain 2D Thomson profiles of the divertor plasma, target Langmuir probe profiles and spectroscopic emission profiles. EDGE is run with a plasma solution consistent with divertor Thomson measurements and target recycling fluxes. This reproduces the experimental hydrodynamic emissions. Carbon sources are then modeled in EDGE to try to match the carbon experimental spectroscopic emissions. The combination of total hydrocarbon and total carbon radiated power is then compared to outer divertor bolometric measurements. This process assesses the consistency of both the model and the experimental measurements of radiative power balance and identifies whether additional power terms may be required.

3Supported in part by the US DOE under DE-FC02-04ER54698, DE-FG02-04ER54578, DE-AC04-94AL85000, DE-AC05-00OR22725 & DE-AC52-07NA27344.

GP8.00008 The role of parallel and poloidal heat flux in setting the detachment threshold in DIII-D. D.N. HILL, S.L. ALLEN, C.J. LASNIER, A.G. MCLEAN, LLNL, T.W. PETRIE, A.W. LEONARD, GA, M. GROTH, Aalto U. — Experimental results show that the threshold density for divertor detachment is reduced even as the parallel scrape-off-layer (SOL) heat flux (qpol) is more than doubled, contrary to expectation. The work is part of a systematic study to identify the physics basis for obtaining detached divertors in future high power burning plasma experiments, consistent with requirements for high confinement steady-state operation. Parallel heat flux (P SOL ∗(Bi/σp)/2πRN Pol) is the SOL width) is independent of poloidal flux expansion and is commonly used to quantify the divertor heat flux challenge. In these experiments, the parallel heat flux was varied either by changing the heating power (thereby P SOL), plasma current (the SOL width), or toroidal field (the projection of P SOL onto Btor). The data point to poloidal-field physics effects (e.g., neutral penetration field, line length, and impurity radiation volume) playing a dominant role in setting the detachment threshold. Comparison with 2D simulation will be shown.

1Work supported by the US DOE under DE-AC52-07NA27344 and DE-FC02-04ER54698.

GP8.00009 Compatibility of Detached Divertor Operation with Robust Edge Pedestal Performance. A.W. LEONARD, T.H. OSBORNE, P.B. SNYDER, General Atomics, M.A. MAKOWSKI, A.G. MCLEAN, Lawrence Livermore National Laboratory — The compatibility of robust divertor operation with the maintenance of a robust H-mode pedestal is examined in DIII-D. A density scan with deuterium injection into H-mode spanned a range of divertor conditions from fully attached, ~30 eV at the target, with little divertor radiation to a fully detached with Te < 5 eV throughout the divertor up to the X-point. Over this scan of pedestal density from n_n/60 = 30% to 60% the pedestal Te was reduced from 800 eV to 350 eV, representing a ~20% reduction in pedestal pressure with a similar reduction in normalized energy confinement. The reduction in pedestal pressure at high density was found to be consistent with a reduced pedestal ELM MHD stability limit at high collisionality. The scaling of the pedestal top pressure with density was also consistent with the EPED model, which assumes an additional constraint on the local pressure gradient. The MHD stability limit at the highest collisionality depends on details of the ELM instability growth rate normalization. This result is encouraging for future burning plasmas where a lower collisionality pedestal is expected to be maintained even for high density detached divertor operation.

1Work supported by the US DOE under DE-FC02-04ER54698 and DE-AC52-07NA27344.

GP8.00010 Characterizing the transition from high recycling to partial detachment. A.G. MCLEAN, S.L. ALLEN, M. FENSTERMACHER, C. LASNIER, W.H. MEYER, G. PORTER, V. SOUKHANOVSKII, LLNL, B.D. BRAY, T.N. CARLSTROM, A.W. LEONARD, C. LIU, GA, D. ELDON, USCD, M. GROTH, Aalto U., P.C. STANGEBY, C. TSUI, U. TORONTO — Experiments at DIII-D have explored the transition from the high recycling to the partially detached divertor condition in L- and H-mode with an unprecedented level of detail. Improved divertor and core Thomson scattering diagnostics were coupled with high resolution spectroscopic studies of molecular and neutral emissions. 2-D Te and ne profiles of the outer leg reveal the earlier indications of formation of the detachment front at the target plate, reducing local Te at the outer strike point from 8-10 eV to 2-3 eV with a marginal (~10%) increase in < ne > upstream. These data help guide and expose any missing physics in simulations of detachment onset using state-of-the-art boundary codes, and in predictions for operation with a partial detached divertor in future devices.

1This work supported in part by the US Department of Energy under DE-AC52-07NA27344 and DE-FC02-04ER54698.
GP8.00011 Dependence of the Heat Flux Width on the Connection Length in DIII-D\textsuperscript{1}, M.A. MAKOWSKI, C.J. LASNIER, V.A. SOUKHANOVSKI, Lawrence Livermore National Laboratory, A.W. LEONARD, T.H. OSBORNE, T.W. PETRIE, P.B. SNYDER, General Atomics — The heat flux width characterizes the scale length of peak power deposition in the divertor. The total heat flux width, $\lambda_{\text{eff}} \approx \lambda_\parallel \times 1.74 S$, has contributions from the scrape-off layer itself, characterized by the quantity $\lambda_\parallel$, and from the private flux region, characterized by a Gaussian-like width, $S$. Most work to date has focused on the physics of $\lambda_\parallel$, with the essential finding that it depends approximately inversely on the plasma current. Here, it is shown that the $S$ parameter and, in particular, its dependence on the connection length, $L_{\text{conn}}$. Data from high X-point discharges ($L_{\text{conn}} \sim 30$ m) have been used to extend the DIII-D heat flux width database beyond discharges with a standard divertor configuration ($L_{\text{conn}} \sim 20$ m). Snowflake divertor discharges ($L_{\text{conn}} > 40$ m) will also be analyzed to further extend the range of $L_{\text{conn}}$. Preliminary results indicate that $S$ increases with $L_{\text{conn}}$, consistent with $S$ being determined by a diffusive process. This result has important implications for advanced divertor designs as it demonstrates that long connection lengths increase the heat flux width.

\textsuperscript{1}Supported by the US DOE by LLNL under DE-AC52-07NA27344 and the US DOE under DE-FC02-04ER54698 and DE-FG02-95ER54309.

GP8.00012 Heat Deposition on Inner and Outer Wall During Diverted DIII-D Discharges\textsuperscript{1}, C.J. LASNIER, W.H. MEYER, S.L. ALLEN, LLNL, M.A. VAN ZEELAND, GA — In order to get more complete information on power loss, we have quantified heating of the inner and outer wall of DIII-D in diverted DIII-D discharges due to several effects, using a wide-angle tangential viewing IR camera system. These effects include prompt fast ion losses to outer wall and bumpers during counter-toroidal-field neutral beam injection; shine-through of neutral beam power on the inner wall accentuated during low-density operation; small amounts of heat deposited on inner and outer walls during edge localized modes, and anomalous heat deposition on the outer wall near beam ports, which may be due to re-ionization of neutral beam particles. Prompt losses of fast ion losses distributed on the outer wall with counter-injected beams have resulted in a surface temperature rise of 25°C, but localized heating of a bumper limiter has resulted in a temperature rise of up to 245°C. Heating of the same limiter by an ELM has been observed to increase the surface temperature by 50°C.

\textsuperscript{1}Work supported by the US Department of Energy under DE-AC52-07NA27344 and DE-FC02-04ER54698.

GP8.00013 Snowflake Divertor Configuration Studies in DIII-D Tokamak\textsuperscript{1}, V.A. SOUKHANOVSKI, S.L. ALLEN, M.E. FENSTERMACHER, C.J. LASNIER, M.A. MAKOWSKI, A.G. MCLEAN, W.H. MEYER, Lawrence Livermore National Laboratory, E. KOLEMEN, Princeton Plasma Physics Laboratory, T.G. GROEBNER, A.W. HYATT, A.W. LEONARD, T.H. OSBORNE, T.W. PETRIE, General Atomics — Recent DIII-D studies have shown that the snowflake (SF) divertor enables significant manipulation of divertor heat transport for power exhaust in attached and radiative divertor conditions, between and during edge localized modes (ELMs), while maintaining good H-mode confinement. Results include: 1) Increased scrape-off layer (SOL) width suggesting enhanced divertor heat transport; 2) Direct measurements of divertor null-region poloidal beta $\beta_p >> 1$ in support of the theoretically proposed instability mechanism leading to fast convective plasma redistribution, especially efficient during ELMs, and contribution to 1; 3) Weak effect on pedestal profile and stability resulting in essentially unchanged ELM regime; 4) Reduction of Type-I ELM energy loss; 5) In radiative SF divertor regimes with D2 seeding, a significant reduction of peak heat fluxes between and during ELMs, as in standard H-modes.

\textsuperscript{1}Work supported by the US Department of Energy under DE-AC52-07NA27344, DE-AC02-09CH11466, DE-FC02-04ER54698, and DE-AC04-94AL85000.

GP8.00014 Divertor Optimization via Control at DIII-D\textsuperscript{1}, E. KOLEMEN, P.P.P., S.L. ALLEN, M.A. MAKOWSKI, V.A. SOUKHANOVSKI, LLNL, B.D. BRAY, D.A. HUMPHREYS, R. JOHNSON, A.W. LEONARD, C. LIU, B.G. PENAFLOR, T.W. PETRIE, D. ELDON, UCSD, A.G. MCLEAN, E.A. UNTERBERG, ORNL — DIII-D divertor performance and heat-handling capabilities are optimized using advanced control techniques. The world’s first real-time snowflake divertor detection and control system was implemented on DIII-D in order to stabilize and optimize this configuration. A new control system was implemented to regulate and study detachment and radiation, since future fusion reactors will require detached or partially detached plasma to achieve acceptable divertor target heat fluxes. The algorithm regulates the $D_2$ and impurity gas injection level by using the divertor temperature measurements from real-time Thomson diagnostics to compute the detachment level, and the real-time bolometer diagnostics to determine core and divertor radiation. This control system optimizes the optimization of the detachment and radiation from the core and the divertor to achieve high core performance compatible with reduced heat-flux to the divertor.

\textsuperscript{1}Work supported by the US DOE under AC02-09CH11466, AC02-07NA27344, DE-FC02-04ER54698, and DE-AC05-00OR22725.

GP8.00015 Application of the Radiating Divertor Approach to Innovative Divertor Concepts\textsuperscript{1}, T.W. PETRIE, A.W. LEONARD, T.C. LUCE, General Atomics, F. TURCO, Columbia U., S.L. ALLEN, M.E. FENSTERMACHER, C.T. HOLCOMB, C.J. LASNIER, V.A. SOUKHANOVSKI, LLNL, E. KOLEMEN, P.P.P., J.G. WATKINS, SNL — Recent experiments on DIII-D have assessed the effectiveness of 3 innovative tokamak concepts under radiating divertor (RD) conditions: (1) high performance standard double-null divertor (DND) plasmas, (2) high performance double-null “snowflake” (SF-DN) plasmas, and (3) single-null H-mode plasmas with different isolation from their divertor targets but otherwise identically prepared. Significant reductions in both divertor heat flux and divertor electron temperature were observed in both standard DND and SF-DN plasmas under neutral/deuterium-based RD conditions, while maintaining high performance metrics, such as $\beta_N \approx 3.0$ and $H_{98}(X_{98}) \approx 1.4$. Not only is the peak heat flux reduced by extending the parallel connection length ($L_{\text{conn}} \sim X_{98}$) between the X-point and divertor targets, thereby enhancing the effect of cross-field diffusion, but also the effectiveness of the RD conditions is markedly improved at larger $L_{\text{conn}} \sim X_{98}$. In general, our analyses support the attractiveness of all three of the above concepts under RD conditions, both in reducing peak heat flux and in maintaining good to excellent H-mode energy confinement.

\textsuperscript{1}Work supported by the US DOE under DE-FC02-04ER54698, DE-FG02-04ER54761, DE-AC05-00OR22725, DE-AC04-94AL85000, DE-AC52-07NA27344 and DE-FG02-07ER54917.

GP8.00016 The boundary effects on tokamak edge instabilities, WEIGANG WAN, SCOTT PARKER, YANG CHEN, University of Colorado — Tokamak edge instabilities are extremely difficult to model with gyrokinetic simulation because of the strong pressure gradients and the sensitivity to the magnetic equilibrium near the x-point. Our previous global simulations have assumed fixed radial boundary conditions with the simulation domain inside the last closed flux surface, i.e. the separatrix. The pressure profiles have to be smoothed near the boundary. Although it is typical that edge instabilities peak inside the separatrix, these restrictions may affect the physical results. Here, we extend the simulation domain into the scrape-off layer, still assuming closed flux surfaces, and keep the original density and temperature profiles to study any possible boundary effects in the previous model. With the newly implemented general magnetic equilibrium in GEM (rather than Miller parametrization), this model is even more realistic. Simulations are carried out using direct experimental parameters of recent DIII-D discharges.

\textsuperscript{1}Supported by the US DOE by LLNL under DE-AC52-07NA27344 and the US DOE under DE-FC02-04ER54698 and DE-FG02-95ER54309.

\textsuperscript{1}Work supported by the US Department of Energy under DE-AC52-07NA27344 and DE-FC02-04ER54698.

\textsuperscript{1}Supported by the US DOE by LLNL under DE-AC52-07NA27344 and the US DOE under DE-FC02-04ER54698, DE-FC02-95ER54309.
— The triggering of small ELMs by pellet injection has been demonstrated as a method to prevent large ELMs that can erode plasma facing components [1]. Small deuterium pellets < 1 mm in size have been shown to reliably trigger ELMs on the DIII-D tokamak in the ITER like scenario plasmas. A variation in pellet size and speed was used to determine the minimum pellet size needed to trigger ELMs as a function of edge pedestal pressure. Pellets < 0.8 mm in size were found to be insufficient to trigger ELMs. These results show smaller pellets than predicted by nonlinear MHD simulations can destabilize high-n ballooning modes from a local pressure perturbation well in excess of the pedestal pressure [2]. The implications of these results for pellet ELM mitigation and the design of the pellet injection system for ITER will be discussed.


¹Work supported by the US DOE under DE-AC05-00OR22725, DE-AC52-07NA27344, DE-FC02-04ER54598, and DE-FC02-07EAR54917.

— The key to QH-mode operation is an edge electromagnetic mode, the edge harmonic oscillation (EHO), which provides the extra transport to allow the edge plasma to reach a transport equilibrium with edge pressure gradient and current density just below the edge localized mode (ELM) limit [1]. Experimental results are consistent with the theoretical prediction that the EHO is a kink-peeling mode destabilized by edge rotational shear at edge conditions just below the ELM limit [1]. Theory suggests that the essential rotation speed is \( \nu_{E} / R \); initial analysis of experimental data is consistent with this expectation [2,3]. Recent results show that the change in shear between QH-mode and ELMeing H-mode occurs in the small radius side of the edge \( E_{r} \) well near the top of the edge pedestal. Experiments have been carried out to test the whether \( E_{r} / R \) is the essential shear and, if so, how that critical shear varies with \( \nu^{*} \).


¹Work supported by the US DOE under DE-FC02-04ER54598, DE-FC02-95ER54309 and DE-AC02-09CH11466.

— Net particle transport through the H-mode pedestal is dictated by anomalous transport mechanisms; however, a significant fraction of the energy transport is governed by enhanced transport of high-energy ions on collisionless orbits. The pedestal radial electric field (\( E_{r} \)) is constrained to the value that balances this ion flux with a pinch of colder main ions and impurities as demonstrated using XGC0, a self-consistent full-f multi-species neoclassical calculation that includes neutral recycling and transport. These calculations resolve how edge modes can increase the anomalous particle transport while having a small effect on energy transport, the observed scaling of the height of the density pedestal with \( I_{p} \), and the structure of \( E_{r} \) in the pedestal. Quantitative agreement between XGC0 and the unique features of QH-mode, such as \( T_{i} \) anisotropy, large scrape-off layer \( T_{i} \) and intrinsic co-\( r \) edge rotation provide confidence that the simulation captures the kinetic effects in the pedestal that drive the neoclassical energy transport.

¹Work supported in part by the US DOE under DE-AC02-09CH11466 and DE-FC02-04ER54598.

GP8.00020 Modeling EHO Formation in QH-mode on DIII-D¹. X. CHEN, K.H. BURRELL, N.M. FERRARO, T.H. OSBORNE, A.M. GAROFALO, R.J. GROEBNER, L.L. LAO, P.B. SNYDER, GA, R. NAZIKIAN, W.M. SOLOMON, B.J. TOBIAS, PPPL, G.R. MCKEE, Z. YAN, U. WISC., C.M. MUSCATELLO, UC-Davis — The 3D MHD code M3D-C1 is being used to model the edge harmonic oscillation (EHO) in QH-mode plasmas. Preliminary simulations show unstable low-n modes in some reconstructed QH-mode equilibria with high edge density fluctuations similar to experiments. QH-mode is a stationary edge localized mode (ELM)-stable high confinement operation mode while EHO drives the additional particle transport allowing the edge plasma to reach a transport equilibrium just below the ELM limit [1]. Experiments and theory suggest that the EHO is a kink-peeling mode destabilized by edge rotational shear at edge conditions just below the ELM limit [1] and the essential rotation is the toroidal angular ExB drift frequency [2]. Detailed comparison of two-fluid M3D-C1 simulations and fluctuation measurements from multiple diagnostics on DIII-D will be presented, along with the EHO onset condition between experiment and simulation from various pedestal ExB shear.


¹Supported by US DOE under DE-FC02-04ER54598, DE-AC02-09CH11466, DE-FC02-89ER53296, DE-FC02-08ER54999 and DE-FC02-99ER54531.

GP8.00021 Super H-Mode: Prediction and Discovery of a New High Performance Regime¹. P.B. SNYDER, E.A. BELL, K.H. BURRELL, A.M. GAROFALO, R.J. GROEBNER, T.H. OSBORNE, GA, W.M. SOLOMON, PPPL, H.R. WILSON, U. of York — Fusion performance of tokamak plasmas increases strongly with the pressure at the top of the edge transport barrier (or “pedestal height”). As understanding of the physics controlling the pedestal improves, this can be used not only to predict performance in existing regimes, but also to uncover new regimes of operation. The EPED model predicts pedestal height by combining calculated peeling-ballooning and kinetic ballooning mode constraints, and has been extensively tested. EPED predicts that, for strongly shaped plasmas, the pedestal bifurcates at high density into the usual H-mode solution, and a very high pressure “Super H-Mode” solution.

Prediction of Super H-Mode access via dynamic variation of the density has led to its recent discovery on DIII-D, including observations of bifurcation and very high pedestal pressure. We discuss pedestal theory, DIII-D observations, and coupling to core physics to globally optimize Super H-Mode.

¹Work supported by the US DOE under DE-FC02-95ER54309, DE-FC02-04ER54598, and DE-AC02-09CH11466.

GP8.00022 Limit Cycle Oscillations and L/H Transitions From Mean Field Momentum Transport Equations¹. G.M. STAEBLER, R.J. GROEBNER, GA — The momentum transport of the mean field ExB toroidal and ion parallel velocities are modeled with both collisional and turbulent contributions to the transport equations. It will be shown that there are normal one-step L/H transitions to suppressed turbulence and newly discovered limit cycle oscillations (LCO), from this two dimensional system. The suppression of turbulence by ExB velocity shear provides the drive for both types of transitions converting fluctuation intensity into parallel and ExB flow. The results of the new model will be compared with recent high-resolution measurements. The frequency of the LCO and the L/H transition timescale can be matched by the model. The phase shift between the density fluctuation amplitude of the turbulence and the ExB velocity shear is shown to depend on the evolution of the linear growth rate of the turbulence. The density dependence of the H-mode power threshold is consistent with the model with a strong increase in the H-mode threshold at low density.

¹Work supported by the US DOE under DE-FC02-95ER54309 and DE-FC02-04ER54598.
GP8.00023 RMP-Induced Plasma Transport Near X point\(^1\). J.D. CALLEN, C.C. HEGNA, U. Wisconsin-Madison — The experimentally most noticeable effect of resonant magnetic perturbations (RMPs) on H-mode plasmas is “density pump-out.” This effect is most evident in the near-separatrix region where RMPs can cause the electron density gradient there to decrease by a factor of up to two. The previously developed flutter model \([1]\) produces some RMP-induced transport in this region. However, two other electron effects need to be taken into account in the X point region of the divertor separatrix. First, small 3D fields can cause significant (many cm) radial motion of field lines in “homoclinic tangles” very near the X point which have been observed experimentally in DIII-D. A flute-type plasma transport model based on parallel electron collisional effects caused by RMP-induced “radial” motion of field lines away from the lowest order axisymmetric magnetic flux surfaces in the X point region is being developed. The second effect is that a small fraction of long length magnetic field lines in the near-separatrix region are “open” ones which are directly connected to material walls in the divertor region. Electrons on such field lines could conduct significant electron heat to the divertor plates.

\(^1\)Work supported by the US DOE under DE-FG02-92ER41139 and DE-FG02-86ER53218.

GP8.00024 Developing Boundary/PMI Solutions for Next-Step Fusion Devices\(^1\), H.Y. GUO, A.W. LEONARD, D.M. THOMAS, GA, S.L. ALLEN, D.N. HILL, LLNL, Z. UNTERBERG, ORNL — The path towards next-step fusion development requires increased emphasis on the boundary/plasma-material interface. The new DIII-D Boundary/Plasma-Material Interactions (PMI) Center has been established to address these critical issues on a timescale relevant to the design of FNSF, adopting the following transformational approaches: (1) Develop and test advanced divertor configurations on DIII-D compatible with core plasma high performance operational scenarios in FNSF; (2) Validate candidate reactor PFC materials at reactor-relevant temperatures in DIII-D high-performance plasmas, in collaboration with the broad material research/development community; (3) Integrate validated boundary-materials interfaces with high performance plasma solutions for next-step fusion devices. This program leverages unique DIII-D capabilities, promotes synergistic programs within the broad PMI community, including linear material research facilities. It will also enable us to build a compelling bridge for the US research on long-pulse facilities.

\(^1\)Work supported by the US DOE under DE-FC02-04ER54698 and DE-AC52-07NA27344, DE-AC05-00OR2725

GP8.00025 Formation of Counter-Flows by Magnetic Perturbations in Computer Simulations of the Plasma Boundary of Tokamaks\(^1\). H. FRERICHS, U. Wisconsin-Madison, O. SCHMITZ, U. of Wisconsin-Madison, T.E. EVANS, General Atomic, Y. FENG, MPI, D. REITER, FZI — Simulations of the plasma boundary of an ITER similar shape H-mode plasma at DIII-D with the EMC3-EIRENE code have shown that a pattern of counter-flow channels emerges when resonant magnetic perturbations (RMPs) are applied. This pattern is found to be correlated with a flow-reversal in the perturbed scrape-off layer bounded by the perturbed separatrix. As a result of small non-axisymmetric perturbations to an axisymmetric equilibrium field, stable and unstable invariant manifolds associated with the separatrix split and intersect transversely. This so-called homoclinic tangle determines where field lines may connect from inside of the original separatrix to plasma facing components, and it introduces a checkerboard pattern of field lines with short and long connection lengths. In the present contribution we focus on the resulting plasma flows and we give a detailed analysis of the emerging flow pattern.

\(^1\)Work supported in part by the US DOE under DE-FC02-04ER54698 and by Start-Up Funds of the U. Wisconsin-Madison.

GP8.00026 Role of plasma response in determining density pump-out with Resonant Magnetic Perturbations (RMPs) in DIII-D\(^1\). S. MORDUCK, William & Mary, S.P. SMITH, GA — We are studying the effect of RMPs on the density pump-out threshold in order to determine whether the transport change are the result of change in turbulence or rotation. Applying RMPs strongly reduces the core rotation and increases the edge rotation, which reduces the ExB shear thus increasing turbulent transport. The toroidal rotation measurements made at two different toroidal location show no phase lag during rotating n = 2 RMP experiment, which is an indication that there is a strong n = 0 response. This n = 0 response could be the result of MHD effects, or due to changes in turbulence characteristics. New low n \(\times\) \(r\) experiments at lower RMP strength allow us to test, whether this change in the toroidal rotation is the main drive behind the increase in particle transport in low collisionality H-mode plasmas on DIII-D as well as examine what is causing the n = 0 response to the toroidal rotation.

\(^1\)Work supported in part by the US DOE under DE-SC0007880 and DE-FC02-04ER54698.

GP8.00027 Imaging of Boundary Plasma Displacements During RMPs in DIII-D\(^1\), R.A. MOYER, D.M. ORLOV, UCSD, T.E. EVANS, N. FERRARO, J. KING, T. STRAIT, C. PAZ-SOLDAN, GA, A. WINGEN, ORNL, R. NAZIKIAN, B. GRIERSON, PPPL, L. ZENG, UCLA — Visible imaging is used to measure the boundary displacement due to n = 2 and n = 3 RMPs in H-mode plasmas in DIII-D. Displacements \(\approx 2\) cm on the outer midplane are measured in LSN H-modes using active imaging of Doppler shifted deuterium beam emission with n = 2 RMPs rotating in the co-current direction \([1]\) where the kink response is expected to be maximized. In contrast, displacements due to static n = 3 RMPs are \(\approx 4\) mm in similar LSN H-modes, with no measurable change when the n = 3 RMP phase is “flipped” by 60° toroidally. Plasma shape is also found to have a strong effect on the plasma response: n = 3 RMPs in Double Null Divertor plasmas are \(\approx 2\) mm, 10x smaller than the displacements in similar LSN plasmas, consistent with magnetics measurements. We will compare boundary displacements measured with active beam emission and passive C III imaging to separatrix manifold displacements and kink response in plasma response models.

\(^1\)Work supported in part by the US DOE under DE-FG02-05ER54809 and DE-AC05-06OR23100, DE-FC02-04ER54698, DE-AC05-00OR22725, DE-AC02-09CH11466, DE-FC02-08ER54984

GP8.00028 Effect of Perturbation Spectrum on RMP ELM Suppression in DIII-D\(^1\), D.M. ORLOV, R.A. MOYER, C. HOLLAND, UCSD, T.E. EVANS, N.M. FERRARO, C. PAZ-SOLDAN, P.B. SNYDER, J.S. DGRASSIE, C.M. GREENFIELD, GA, R. MAINING, R. NAZIKIAN, J.-K. PANG, N. LOGAN, PPPL, M.E. FENSTERMACHER, LLNL — Recent experiments in DIII-D have demonstrated that while the edge localized modes (ELMs) in a tokamak can be controlled with only 5 of 12 magnetic perturbation coils with only a small increase in the coil current, the width of the \(q_{95}\) resonant window for ELM suppression is smaller with a reduced coil set due to an overall reduction of the resonant n = 3 field in the plasma. In each l-coil configuration tested, a strong similarity of the plasma parameters was observed during ELM suppression phase in the core and pedestal regions. Vacuum and M3D-C1 plasma response modeling elucidate the role of the toroidal sidebands for resonant magnetic perturbation (RMP) ELM suppression. TGLF and TGyro simulations are performed to understand the effect of the perturbation spectrum on the core transport.

\(^1\)Supported by US DOE under DE-FG02-05ER54809, DE-FG02-07ER54917, DE-FG02-04ER54698, DE-FG02-05ER54309, DE-AC02-09CH11466, and DE-AC52-07NA27344.
GP8.00029 ELM Suppression in DIII-D ITER-like Plasmas Using n=2 Magnetic Perturbations1, R. NAZIKIAN, B.A. GRIERSON, M. OKABAYASHI, B.J. TOBIAS, PPPL, D. ELDON, T.E. EVANS, N.M. FERRARO, R.J. GROEBNER, C. PAZ-SOLDAN, E.I. STRAIT, GA, S.R. HASKEY, ANU, J.D. KING, ORISE, G.R. MCKEE, U. Wisc., R.A. MOYER, D.M. ORLOV, UCSD, M.W. SHAFAER, ORNL — A robust window of edge localized mode (ELM) suppression was observed at elevated magnetic safety factor (q95 ≈ 4.1) in ITER-like plasmas with even parity n=2 resonant magnetic perturbation (RMP) using the internal I-coils. Variation of the upper and lower I-coil phasing was used to explore the importance of pitch alignment vs kink alignment for ELM suppression. Both the pedestal density and ELM suppression were strongly dependent on I-coil phasing and a large variation in the plasma response amplitude was measured on multiple discharges. Surprisingly, toroidal rotation of the even parity n=2 RMP led to the loss of ELM suppression, indicating that components of the residual error field orthogonal to the kink mode may be important near the threshold for ELM suppression.

1Work supported by the US Department of Energy under DE-AC02-09CH11466, DE-FC02-04ER54598, DE-AC05-06OR23100, DE-FG02-89ER53296, DE-FG02-08ER54999, DE-FG02-07ER54917, and DE-AC05-05OR22275.

GP8.00030 Measurements of Islands and Screening with Resonant Magnetic Perturbations on DIII-D1, M.W. SHAFAER, E.A. UNTERBERG, A. WINGEN, J.M. CANIK, J.D. LORE, J.H. HARRIS, D.L. HILLIS, S.P. HIRSHMAN, ORNL, T.E. EVANS, N.M. FERRARO, GA, M.E. AUSTIN, U. Texas-Austin — Recent experiments on DIII-D have advanced the understanding of plasma response to resonant magnetic perturbations (RMPs) in low magnetic shear, inner wall limited, L-mode plasmas. Fine torque scans using mixtures of co- and counter-current neutral beam injection reveal that large RMP-induced n=1 islands are present at multiple mode-rational surfaces (m=2,3,4) at low rotation, but are completely screened at higher rotation. There is an observed nonlinear threshold for this torque, where small torque increments lead to a completely screened plasma response. Initial analysis indicates that near-zero \( \omega_n \) is found not to be a sufficient condition for island formation, as it is observed to be approximately zero in cases where islands are completely screened. Comparisons are underway with two-fluid MHD modeling via the M3D-C1 code, 3D fluid transport with the EMC3-EIRENE code and nonlinear resistive MHD with the SIESTA code.

1Work supported by the US DOE under DE-AC05-05OR22275, DE-FC02-04ER54698 and DE-FG03-97ER54415.

GP8.00031 Edge Radial Electric Field and Ion Orbit Loss in DIII-D1, J.S. DEGRASSIE, R.J. GROEBNER, GA, J.A. BOEDO, UCSD, B.A. GRIERSON, PPPL — The edge radial electric field, \( E_r \), may be largely determined by the value necessary to supply the neoclassical return current to balance the loss current due to ion orbit loss. This is the indication from a phenomenological model, motivated by recent Mach Probe measurements of the edge co-I_0 flow layer in DIII-D [1,2], based on a simple empty loss cone orbit loss model [3,4]. Probe and charge exchange recombination measurements also show a relatively large positive edge \( E_r \), just inside the LCFS in Ohmic conditions, \( \sim 10 \) kV/m, which is explained in this model by the propensity of the flow layer to drive return current. The Er level is also dependent on Z_{eff} in the edge lower Z_{eff} promotes greater negative E_r for current balance. The model will be compared with measurements in Ohmic, L- and H-mode conditions.

1Work supported by the US DOE under DE-FC02-04ER54698, DE-FG02-07ER54917 and DE-AC05-04ER54698.

GP8.00032 Ion Orbit Loss Effect on Structure of Radial Electric Field1, T.M. WILKS, W.M. STACEY, GA Tech, T.E. EVANS, GA — The radial electric field is an important factor in the L-H transition, the suppression of ELMs, etc. Therefore, the modeling of the causes and the dynamics of the radial electric field in the edge and scrape off layer regions is of interest. We are investigating the interdependence of ion orbit loss, the compensating ion return current, rotation, and magnetic flux surface geometry on the radial electric field in the edge region and the coupling to the electric fields in the scrape off layer. Both thermalized plasma ions and fast beam ion losses are modeled in realistic geometry. The importance of toroidal and poloidal rotation in relating ion orbit loss to the radial electric field is examined. The ion orbit loss is modeled with conservation equations and supplemented by Lorentz orbit tracking calculations of the fraction of ions that recross the separatrix back into the edge plasma.

1Work supported by the US Department of Energy under DE-FG01-ER54538 and DE-FC02-04ER54698.

GP8.00033 Inter-ELM Edge Transport Evolution in DIII-D H-mode Plasmas1, J.P. FLOYD, W.M. STACEY, S.C. MELLARD, GA Tech, R.J. GROEBNER, GA — This study examines the time evolution and pedestal recovery dynamics of ion transport in the edge pedestal between ELMs on DIII-D. Three plasmas from a DIII D H-mode current scan are analyzed: discharges (I_p = 0.5 MA, I_p = 1.0 MA) and (I_p = 1.5 MA). The profile evolution during these shots is interpreted to infer thermal diffusivities, ion diffusion coefficients, ion pinch velocities, and other important transport properties constructed using the momentum balance framework of Ref. [1]. The evolution of these computed properties is examined alongside the evolution of measured quantities, such as the densities, temperatures, rotation velocities, and radial electric field strength, in order to gain insight about the mechanisms of edge transport and pedestal recovery after Type-I ELMs. Both diffusive and non-diffusive (e.g. ion orbit loss) edge transport processes are quantified using the aforementioned framework and the GTEDGE code developed for DIII-D data interpretation. The analysis is focused on maximizing the time resolution of the profile evolutions.

1Work supported by the US DOE under DE-FG01-ER54538 and DE-FC02-04ER54698.
GP8.00034 The characteristics of the micro-turbulence in the pedestal region of DIII-D Tokamak, JINGFEI MA, Univ of Texas, Austin, XUEQIAO XU, Lawrence Livermore National Laboratory, RICH GROEBNER, General Atomics. Two types of the electromagnetic micro-instabilities have been identified in the pedestal region of DIII-D H-mode ELM-free plasmas (shot number 133016) numerically, using a six-field landau-fluid model under BOUT++ framework. One is the Alfvénic ion temperature gradient (AITG) mode, localized at the outer mid plane, and the other is the drift Alfvén instability, localized at the top and bottom of the Tokamak. The AITG mode is driven by the ion temperature gradient and finite $\beta$, which is affected by the kinetic effects, such as Finite Larmor Radius (FLR) and Landau resonance. Typically, the FLR destabilizes the modes while the Landau resonance stabilizes them. Besides, the global simulation shows that the pedestal height and width have an evident impact on the growth rate and mode structure of the AITG instability. In order to identify the AITG instability, a set of the global self-consistent equilibria with different pedestal height (“Varyped”) are generated, which later are also used to explore the strong impact of $\beta$ on the AITG. The drift Alfvén instability, however, has a very weak dependence on $\beta$. Moreover, the drift Alfvén instability is the dominant mode, while the AITG is subdominant mode in the steep gradient region of the pedestal.

1This work was performed under the auspices of the US DoE by LLNL under Contract DE-AC52-07NA-27344 and by IFS under Contract DE-FG02-04ER-54742.

GP8.00035 Effect of Collisionality and Effective Charge on the H-mode Pedestal Structure in DIII-D and JET, M.J. LEYLAND, K.J. GIBSON, U. of York, T.H. OSBORNE, R.J. GROEBNER, P.B. SNYDER, General Atomics, M.N.A. BEURSKENS, C. GIROUX, S. SAARELMA, CCFE, X. CHEN, ORISE, R. NAZIKIAN, PPPL, DIII-D TEAM, JET TEAM. — After the installation of the ITER-like-wall, the energy confinement of high triangularity $D_2$ fueled JET pedestal plasmas was degraded by up to 40% due to a reduction in pedestal performance. This could be partially recovered by changing the collisionality ($\nu^*\tau^*$) and/or effective charge ($Z_{eff}$) when seeding $N_2$. Pedestal measurements revealed a widening of the pedestal and a variation in gradient. Comparison to EPED pedestal-model predictions highlights the potential importance of a low-Z, carbon-like, impurity at the plasma edge. We report on a dedicated DIII-D experiment that studied the role of $\nu^*$ and $Z_{eff}$ on the pedestal structure through means of $D_2$-fueling, $N_2$-seeding and Li-dropping. Initial analysis shows with increasing $D_2$ fueling the pedestal does not widen and the ELM frequency increases in contrast to equivalent JET plasmas.

1Work supported by the RCUK Energy Programme and EUROfusion and the US Department of Energy under DE-FG02-04ER54698, DE-FG02-95ER54309, DE-AC05-06OR23100, and DE-AC02-09CH11466.

GP8.00036 Bifurcation to Expanded H-mode Pedestal Width and Height with Lithium Dust Injection in DIII-D, R. MAINGI, D.K. MANSFIELD, D.J. BATTAGLIA, B. GRIERSON, R. NAZIKIAN, A.L. ROQUEMORE, PPPL, G.L. JACKSON, T.H. OSBORNE, C. CHROBAK, J.S. DEGRASSIE, R.J. GROEBNER, P.B. SNYDER, GA, Z. YAN, G.R. MCKEE, U. Wisc, A.G. MCLEAN, LLNL, DIII-D TEAM — Lithium (Li) aerosol injection into the SOL of the DIII-D tokamak has facilitated a rapid $\sim$ 100% expansion of the H-mode pedestal width in a class of ELMy discharges. ELM-free H-modes with $\tau^*$ increasing by $\sim$ 60% are observed; the radiated power held steady during ELM-free periods. The pedestal $T_e$ and $P_e$ doubled, while the $T_i$ increased by $\sim$ 20%. Substantial $L_i$ density was observed in the core, reaching up to 15% at the top of the pedestal. The onset of a continuous pedestal-localized instability measured on beam emission spectroscopy correlated with the pedestal expansion, which can occur on a $\sim$ 10 ms timescale. These enhanced pedestals are limited by onset of giant ELMs, which appear to be consistent with ideal stability calculations.

1Work supported by the US DOE under DE-AC02-09CH11466, DE-FC02-04ER54698, DE-FG02-95ER54309, DE-FG02-89ER53296, DF02-08ER54999 and DE-AC52-07NA27344.

GP8.00037 Impact of Lithium Injection on the H-mode Pedestal in DIII-D, T.H. OSBORNE, G.L. JACKSON, C. CHROBAK, J.S. DEGRASSIE, R.J. GROEBNER, P.B. SNYDER, GA, R. MAINGI, D.K. MANSFIELD, D.J. BATTAGLIA, B.A. GRIERSON, R. NAZIKIAN, A.L. ROQUEMORE, PPPL, Z. YAN, G.R. MCKEE, U. Wisc, A.G. MCLEAN, LLNL, DIII-D TEAM — Lithium injection into ELMy H-mode discharges triggered unusual, up to 350 ms, ELM-free periods (EFPs) during which the pedestal width, $w_{PED}$, increased on a short time scale $\sim$ 10 ms reaching $2\times$ the width seen in the ELMy phase. The electron pedestal pressure in Li was 2$\times$ that of the ELMy phase and 1.5$\times$ that of similar $\epsilon$ was reduced by similar factors in EFPs with Li. Rapid $w_{PED}$ expansion and enhanced particle transport was associate with pedestal localized density fluctuations seen on BES. $w_{PED}$ during EFPs with $L_i$ was 40% larger than predicted by $P_{PED}$$E_{PED}$ scaling, while $w_{PED}$ in EFPs without $L_i$ agreed with this scaling. EFPs terminated in a large ELM when the peeling-balloon mode stability limit was reached. Sustainment of large $w_{PED}$, $P_{PED}$ could open a regime of improved energy confinement and high $\beta$ stability.

1Work supported in part by US Department of Energy under DE-FC02-04ER54698, DE-AC02-09CH11466, -FG02-89ER53296, DE-FG02-08ER54999, & DE-AC52-07NA27344.

GP8.00038 Onset of a “Broadband Bursty” with Lithium Aerosol Injection in DIII-D, Z. YAN, G. MCKEE, U. Wisc-Madison, R. MAINGI, D.K. MANSFIELD, D.J. BATTAGLIA, B.A. GRIERSON, R. NAZIKIAN, A.L. ROQUEMORE, PPPL, G.L. JACKSON, T.H. OSBORNE, C.P. CHROBAK, J.S. DEGRASSIE, R.J. GROEBNER, P.B. SNYDER, GA, A.G. MCLEAN, LLNL, DIII-D TEAM. — A long wavelength density fluctuation with moderately broad spectral structure (40 kHz-150 kHz) was observed with 2D beam emission spectroscopy (BES) in DIII-D plasmas when lithium aerosol was injected into the scrape-off layer region. The onset of such modes happens on a very fast $<10$ ms time scale and seems to correlate with the pedestal expansion, increase in pedestal height and increase on energy confinement time that occur at higher lithium injection levels. The mode fluctuations seem very bursty in time. It is localized to the region 0.90<r/a<0.95 with poloidal wavenumber about 0.46 rad/cm. The normalized density fluctuation amplitude peaks $\sim$ 8% at $r/a=0.92$. This mode may drive additional particle transport that can alter gradients and allow for pedestal growth by changing pedestal stability parameters.

1Work supported by the US DOE under DE-FG02-89ER53296, DE-FG02-08ER54999, DE-AC02-09CH11466, DE-FC02-04ER54698, and DE-AC52-07NA27344.
Evolution of High-Frequency Turbulence During Limit-Cycle Oscillations on DIII-D

J.C. ROST, A. MARINONI, E.M. DAVIS, M. PORKOLAB, MIT, K.H. BURRELL, GA — Limit-cycle oscillations (LCO) can provide insight into the interplay between shear and turbulence in triggering the H-mode transition. The Phase Contrast Imaging (PCI) diagnostic on DIII-D is particularly sensitive to density fluctuations in the highly sheared flow in the H-mode/LCO edge due to sensitivity to finite radial wave number ($k_r \sim k_y$) and large bandwidth (10 kHz $< f < 2$ MHz). Each roughly 1 ms oscillation in the LCO (10s of ms) exhibits a period of highly Doppler shifted, highly sheared turbulence which terminates at a burst of low-f turbulence. As the Doppler backscattering (DBS) diagnostic records a gradual increase in fluctuation amplitude rather than a burst [1], the PCI signal can be explained by a sudden decrease in radial correlation length caused by a burst in zonal flows. Both diagnostics are consistent with results of 1D models [2]. Comparison of LCOs of different durations reveals a threshold-like behavior in mean flow.


A Novel Approach for Estimating Edge Pedestal Density Gradients Using Reflectometer Time Delay Data

L. ZENG, E.J. DOYLE, W.A. PEEBLES, T.L. RHODES, UCLA, G. WANG, Retired — A new technique for fast pedestal density gradient estimation has been developed, using profile reflectometer time delay data without a direct profile inversion. Such a fast profile gradient estimator is a potentially key to providing new “real-time” analysis of profile reflectometer data, suitable for use in plasma control systems. The new approach utilizes a simple edge plasma model to provide an analytic estimate for the measured differential time delay between two adjacent reflectometer frequencies. The model predicts that the measured differential time delays should be inversely proportional to the local pedestal density gradient. Using existing DIII-D profile reflectometer data, it has been demonstrated that the estimated gradient using this new technique is in good agreement with the actual density gradient for a number of DIII-D discharges. Further tests of this technique in a variety of DIII-D plasma conditions will be presented.

Bayesian Inference of Edge Pedestal Density Parameters in the DIII-D Charge-Exchange Recombination Spectroscopy System

C. BOWMAN, K.J. GIBSON, U. of York, R.J. LA HAYE, R.J. GROEBNER, GA, N.Z. TAYLOR, ORAU, B.A. GRIERSON, PPPL — A Bayesian inference framework has been developed for the DIII-D charge-exchange recombination (CER) system, capable of computing probability distribution functions (PDFs) for desired parameters. CER is a key diagnostic system at DIII-D, measuring important physics parameters such as plasma rotation and impurity ion temperature. This work is motivated by a case in which the CER system was used to probe the plasma rotation radial profile around an $m/n=2/1$ tearing mode island rotating at $\sim 1$ kHz. Due to limited resolution in the tearing mode phase and short integration time, it has proven challenging to observe the structure of the rotation profile across the island. We seek to solve this problem by using the Bayesian framework to improve the estimation accuracy of the plasma rotation, helping to reveal details of how it is perturbed in the magnetic island vicinity. Examples of the PDFs obtained through the Bayesian framework will be presented, and compared with results from a conventional least-squares analysis of the CER data.

Improved Beam Diagnostic Spatial Calibration Using In-Situ Measurements of Beam Emission

C. CHRYSAL, UCSD, K.H. BURRELL, D.C. PACE, GA, B.A. GRIERSON, N.A. PABLANT, PPPL — A new technique has been developed for determining the measurement geometry of the charge exchange recombination spectroscopy diagnostic (CER) on DIII-D. This technique removes uncertainty in the measurement geometry related to the position of the neutral beams when they are injecting power. This has been accomplished by combining standard measurements that use in-vessel calibration targets with spectroscopic measurements of Doppler shifted and Stark split beam emission to fully describe the neutral beam positions and CER views. A least squares fitting routine determines the measurement geometry consistent with all the calibration data. The use of beam emission measurements allows the position of the neutral beams to be determined in-situ by the same views that make the CER diagnostic. Results indicate that changes in the measurement geometry are required to create a consistent set of calibration measurements. However, changes in quantities derived from the geometry, e.g. ion temperature gradient and poloidal rotation, are small.

Synthetic Image Correction of Microwave Imaging Reflectometer Signals

C.M. MUSCATELLO, N.C. LUHMANN, JR., UC Davis, G.J. KRAMER, R. NAZIKIAN, B.J. TOBIAS, PPPL — A microwave imaging reflectometer (MIR), capable of simultaneously measuring the poloidal and radial structure of density fluctuations, is operational on DIII-D. MIR probes the plasma at 4 simultaneous frequencies, generating a poloidal array of fluctuation measurements at 4 different radial locations. When probing the pedestal in the steep gradient region, the active cutoffs are closely spaced and MIR performs well as an imaging system. However, in the lower gradient regions of the core, the active cutoffs are often spaced farther apart than the optical depth-of-field, thereby inhibiting simultaneous imaging over multiple radial locations. A numerical procedure is implemented that propagates the electric field at the cutoff layer to the location of the optical focus. The procedure relies on symmetric detection of sidebands of the scattered field. This synthetic correction is applied to MIR data during Alfvén eigenmode activity to demonstrate its ability to resolve images at multiple core-localized locations as well as to demonstrate its limitations.

Upgraded High Spatial Resolution ECE System for DIII D

Z. YANG, M.E. AUSTIN, U Texas-Austin, D.D. TRUONG, U. Wisconsin-Madison — An upgrade to the DIII D high resolution electron cyclotron emission (HREE) diagnostic is being implemented by replacing the eight fixed frequency filters with tunable Yttrium-Iron-Garnet (YIG) filters. The YIG filters are adjustable between 3.75 and 18 GHz and have a varying bandwidth that increases with increasing center frequency, from 110-290 GHz. The exceptionally wide tuning range permits high spatial resolution measurements over a broad range of DIII-D radii without adjusting B_out. The ability to vary the center frequencies independently offers the means to optimize radial coverage to view plasma structures of different sizes. Correlation ECE techniques have been evaluated to take advantage of the new channels’ ability to have overlapping filter spans. Additionally, a B-field ramp technique has been developed to do relative calibration between the HREE channels.

ABSTRACT WITHDRAWN —
**GP8.00046 COMPUTER SIMULATION METHODS**

**GP8.00047 Overview of Recent NIMROD-Based Computational Work at the Univ. of Wisconsin-Madison**

C.R. SOVINEC, A.L. BECERRA, T.A. BECHTEL, K.J. BUNKERS, T.A. COTE, E.C. HOWELL, J.B. O’BRYAN, J.P. SAUPPE, P. ZHU, University of Wisconsin-Madison — The NIMROD code (https://nimrodteam.org) is a versatile and well tested computational tool for modeling macroscopic dynamics in magnetized plasma. The Center for Plasma Physics and Simulation at the University of Wisconsin-Madison presently applies NIMROD in studies of drift instabilities in reversed-field pinches and tokamaks, non-inductive edge drive in spherical tokamaks, vertical-displacement instability, resistive-wall mode, edge localized modes and resonant magnetic perturbation in tokamaks, and magnetic topology evolution in a stellarator-tokamak hybrid. Recent contributions to NIMROD development include spectral-element stabilization, nodal trigonometric basis functions, resistive-wall options, and magnetization effects in viscosity. A summary of this application and development work is presented, along with a perspective on NIMROD modeling.

**GP8.00048 High-beta extended MHD simulations of toroidal stellarators**

T.A. BECHTEL, C.C. HEGNA, M.G. SCHLUTT, University of Wisconsin-Madison, J.D. HEBERT, Auburn University — The nonlinear, extended MHD code NIMROD is used to study high-beta, 3D magnetic topology evolution of a toroidal stellarator. The configurations under investigation derive from the geometry of the Compact Toroidal Hybrid (CTH) experiment. However, the vacuum rotational transform profile is artificially raised in an effort to examine the sensitivity of low order rational surfaces and/or magnetic islands. Finite beta plasmas are created using a heating source and anisotropic heat conduction in a manner similar to previous calculations of CTH where the effects of Ohmic current drive were simulated. The onset of MHD instabilities and nonlinear consequences are monitored as a function of beta as well as the fragility of the magnetic surfaces.

**GP8.00049 Fully Parallel MHD Stability Analysis Tool**

VLADIMIR SVIDZINSKI, SERGEI GALKIN, JIN-SOO KIM, FAR-TECH, Inc., YUEQIANG LIU, UKAEA — Progress on full parallelization of the plasma stability code MARS will be reported. MARS calculates eigenmodes in 2D axisymmetric toroidal equilibria in MHD-kinetic plasma models. It is a powerful tool for studying MHD and MHD-kinetic instabilities and it is widely used by fusion community. Parallel version of MARS is intended for simulations on local parallel clusters. It will be an efficient tool for simulation of MHD instabilities with low, intermediate and high toroidal mode numbers within both fluid and kinetic plasma models, already implemented in MARS. Parallelization of the code includes parallelization of the construction of the matrix for the eigenvalue problem and parallelization of the inverse iterations algorithm, implemented in MARS for the solution of the formulated eigenvalue problem. Construction of the matrix is parallelized by distributing the load among processors assigned to different magnetic surfaces. Parallelization of the solution of the eigenvalue problem is made by repeating steps of the present MARS algorithm using parallel libraries and procedures. Initial results of the code parallelization will be reported.

**GP8.00050 A Fast Multipoole Method based Grad-Shafranov solver**

ANTOINE CERFON, TRAVIS ASHKHAM, Courant Institute, NYU, ZYDRUNAS GIMBUTAS, National Institute of Standards and Technology, JUNGPYO LEE, LESLIE GREENGARD, Courant Institute, NYU — We present a fast, high order accurate, adaptive Grad-Shafranov solver for complex plasma geometries with or without X-points. The solver uses two main ingredients: 1) the reformulation of the Grad-Shafranov equation as a nonlinear Poisson problem; 2) a fast Poisson solver based on integral equation methods. To be more specific regarding the second ingredient, the solution of Poisson’s equation is written as the sum of a volume potential and a double layer potential. The volume potential is calculated in optimal time with the Fast Multipole Method (FMM), and the layer potential is computed using high order quadrature techniques. Besides its speed, this new solver has two properties that make it a desirable option for transport, heating, or stability codes that require coupling with an equilibrium solver. First, the solver automatically refines the mesh in regions of steep gradient, such as the edge pedestal. Second, the integral equation formulation does not only lead to high order accuracy for the solution of the Grad-Shafranov equation, but also for its derivatives. This means that the safety factor and the magnetic shear, among other quantities, can be computed with very good accuracy.

**GP8.00051 Linear hybrid kinetic-MHD model of rotating plasmas via the interface of MINEVA stability and VENUS-LEVIS delta-f PIC codes**

DAVID PFIEFFERLE, Ecole Polytechnique Federale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas (CRPP), CH-1015 Lausanne, Switzerland, NOBUYUKI AIBA, Japan Atomic Energy Agency (JAEA), Rokkasho, Aomori 039-3212, Japan, JONATHAN P. GRAVES, WILFRED A. COOPER, Ecole Polytechnique Federale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas (CRPP), CH-1015 Lausanne, Switzerland — In the framework of hybrid kinetic-MHD with plasma rotation, this project focuses on computing, via a delta-f PIC scheme, the non-adiabatic contribution to the MHD pressure tensor from supra-thermal populations. The orbit code VENUS-LEVIS is employed to evolve an ensemble of weighted markers in the rotating magnetic equilibria produced by the MHD stability code MINEVA. The linearly perturbed Vlasov equation is solved by evolving the marker weights in the presence of MINEVA’s most unstable MHD modes. Moments of the perturbed distribution are sequenced to yield the hot ion kinetic response. The Laplace transform of the perturbed parallel and perpendicular pressure is calculated at the resonance as a function of the radial position and the poloidal and toroidal mode number. The resulting profiles are fed back into MINEVA as an additional source term in the MHD force balance equation. The mode structure, the frequency and the growth rate of the perturbations are modified due to resonances with the hot particles’ bounce/transit motion and their toroidal precession drift. The effect of toroidal plasma rotation on the mode stability is assessed.

**GP8.00052 Variational Algorithms for Drift and Collisional Guiding Center Dynamics**

C. LELAND ELLISON, Princeton Plasma Physics Laboratory, JOHN M. FINN, Los Alamos National Laboratory, HONG QIN, WILLIAM M. TANG, Princeton Plasma Physics Laboratory — The simulation of guiding center test particle dynamics in the upcoming generation of magnetic confinement devices requires novel numerical techniques. Geometric algorithms, which retain conserved quantities in the numerical time advances, are well-known to exhibit excellent long simulation time behavior. Due to the non-canonical Hamiltonian structure of the guiding center equations of motion, it is only recently that geometric algorithms have been developed for guiding center dynamics. This paper will discuss and compare several families of variational algorithms for application to 3-D guiding center test particle studies, while benchmarking the methods against standard Runge-Kutta techniques. Time-to-solution improvements using GPGPU hardware will be presented. Additionally, collisional dynamics will be incorporated into the structure-preserving guiding center algorithms for the first time. Non-Hamiltonian effects, such as polarization drag and simplified stochastic operators, can be incorporated using a Lagrange-d’Alembert variational principle. The long-time behavior of variational algorithms which include dissipative dynamics will be compared against standard techniques.

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3Work is supported by the U.S. DOE SBIR program.
GP8.00053  Trinity Multiscale Transport Code Development for Experimental Comparison1, E. HIGHCOCK, M. BARNES, G. COLVER, U. of Oxford, J. CITRIN, FOM Institute DIFFER, D. DICKINSON, U. of York, N. MANDEL, Princeton U., F. VAN WYK, U. of Oxford, C. ROACH, CCFC, A. SCHKOCCHIN, U. of Oxford, W. DORLAND, U. of Maryland — The Trinity multiscale transport code has been extensively upgraded to further its use in experimental comparison. The upgrades to Trinity have extended its capability to work with experimental data, allowing it to evolve the magnetic equilibrium self-consistently (at fixed current) and significantly enhanced the range and performance of its turbulent transport modeling options. To enhance its capability to reproduce experiment, Trinity is now able to take output from the CRONOS integrated modeling suite, which is able to provide high quality reconstructions of experimental equilibrium of, for example, JET. Trinity has also been integrated with the CHEASE Grad-Shafranov code. This allows the magnetic equilibrium to be re-computed self consistently as the pressure gradient evolves. Trinity has been given new options for modeling turbulent transport. These include the well-known TGLF framework, and the newly developed GPU-based nonlinear code GRYFX. These will allow rapid initial scans with Trinity before more detailed gyrokinetic modeling. Trinity’s performance will benefit from an extensive programme to upgrade one of its primary gyrokinetic turbulence modeling options, GS2. We present a summary of these improvements and preliminary results.

1This work was supported by STFC and the Culham Centre for Fusion Energy. Computing time was provided by IFERC grants MULTIEI and GKDELBI, The Hartree Centre, and EPSRC grants EP/H002081/1 and EP/L000237/1

GP8.00054 Guiding-centre and full-Lorentz orbit solving in 3D magnetic coordinates for fast particle simulations, WILFRED A. COOPER, DAVID PFEFFERLE, JONATHAN P. GRAVES, Ecole Polytechnique Federale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas (CRPP), CH-1015 Lausanne, Switzerland — Designed to accurately solve the motion of energetic particles in the presence of 3D magnetic fields, the VENUS-LEVIS code lever on a non-canonical general coordinate Lagrangian formulation of the equations of motion. It switches between full-orbit particle following and guiding-centre tracing by verifying the perpendicular variation of magnetic vector field, not only including gradients and curvature terms but also the shearing of field-lines. The criteria is particularly relevant for the study of fast ion redistribution in the kinked core of any artificial and the core of tokamak plasmas. Averaging over the passage of energetic ion in the tokamak edge region where gradient scale lengths are short. In the presence of a strong guide field, however, the applicability of the model is limited due to the time step size required to fully resolve the ion gyromotion. The aim of this research is to develop GPU accelerated sub-cycling and orbit averaging methods to be used with the Lorentz ion model making its utilization more viable. Sub-cycling pushes computational particles independently over several micro time steps for each macro time step interval over which the fields are advanced. Orbit averaging uses the deposition data from the sub-cycled particles to obtain time averaged source terms used in the field solving stage. This provides a filtering effect, allowing for clean simulations at low frequencies. Simulation results and analysis for an ion acoustic model are presented along with performance results for GPUs.

GP8.00055 Implicit δf Lorentz Ion Sub-Cycling and Orbit Averaging, SCOTT PARKER, BENJAMIN STURDEVANT, YANG Chen, BENJAMIN HAUSE, Univ of Colorado - Boulder CIPS — A second order, implicit Lorentz ion drift-kinetic electron model has been developed to study low-frequency, quasi-neutral plasmas [1,2]. This model is useful, for example, as an alternative to gyrokinetics in the tokamak edge region where gradient scale lengths are short. In the presence of a strong guide field, however, the applicability of the model is limited due to the time step size required to fully resolve the ion gyromotion. The aim of this research is to develop GPU accelerated sub-cycling and orbit averaging methods to be used with the Lorentz ion model making its utilization more viable. Sub-cycling pushes computational particles independently over several micro time steps for each macro time step interval over which the fields are advanced. Orbit averaging uses the deposition data from the sub-cycled particles to obtain time averaged source terms used in the field solving stage. This provides a filtering effect, allowing for clean simulations at low frequencies. Simulation results and analysis for an ion acoustic model are presented along with performance results for GPUs.


GP8.00056 3D field solver in toroidal geometry for the long wavelength E&M modes1, SCOTT PARKER, BENJAMIN STURDEVANT, YANG CHEN, BENJAMIN HAUSE, Univ of Colorado - Boulder CIPS — A second order, implicit Lorentz ion drift-kinetic electron model has been developed to study low-frequency, quasi-neutral plasmas [1,2]. This model is useful, for example, as an alternative to gyrokinetics in the tokamak edge region where gradient scale lengths are short. In the presence of a strong guide field, however, the applicability of the model is limited due to the time step size required to fully resolve the ion gyromotion. The aim of this research is to develop GPU accelerated sub-cycling and orbit averaging methods to be used with the Lorentz ion model making its utilization more viable. Sub-cycling pushes computational particles independently over several micro time steps for each macro time step interval over which the fields are advanced. Orbit averaging uses the deposition data from the sub-cycled particles to obtain time averaged source terms used in the field solving stage. This provides a filtering effect, allowing for clean simulations at low frequencies. Simulation results and analysis for an ion acoustic model are presented along with performance results for GPUs.

1Center for Edge Physics Simulation

GP8.00057 On the Numerical Dispersion of the Electromagnetic Particle-In-Cell Code: Finite Grid Instability, M.D. MEYERS, Los Alamos National Laboratory, University of California Los Angeles, C.-K. HUANG, Y. ZENG, S. YI, B.J. ALBRIGHT, Los Alamos National Laboratory — The widely used Particle-In-Cell (PIC) method in relativistic particle beam and laser plasma modeling is subject to numerical instabilities that can render unphysical simulation results or even destroy the simulation. For electromagnetic relativistic beam and plasma modeling, the most relevant numerical instabilities are the finite grid instability and the numerical Cherenkov instability. We rigorously derive the faithful 3D PIC numerical dispersion relation, and specialize to the Yee FDST scheme. The manner in which the PIC algorithm updates and samples the fields and distribution function, along with any temporal and spatial phase factors, is accounted for. Numerical solutions to the 1D dispersion relation are obtained for parameters of interest. We investigate how the finite grid instability arises from the interaction of the numerical modes admitted in the system and their aliases. The most significant interaction is due critically to the correct placement of the operators in the dispersion relation. We obtain a simple analytic expression for the peak growth rates due to these interactions.

GP8.00058 Gyrokinetic simulation studies on the energetic-particle-induced geodesic acoustic mode, KAZUHIRO MIKI, YASUhiro IDOMURA, Japan Atomic Energy Agency — Understanding of the energetic particles physics is of great interest in the future burning plasmas. Particularly, particle loss in the presence of EGAM may be critical for ITER. We thus need to know how EGAM is excited and interacts with turbulence. We here introduce energetic particles in a full-f gyrokinetic code (GT5D). (i) We find linear dynamics of the EGAM driven by bump-on-tail particle distributions. We examine flat-q, homogeneous, axisymmetric, electrostatic gyrokinetic simulations. Above a certain level of the beam intensity, an interaction is due critically to the correct placement of the operators in the dispersion relation. We obtain a simple analytic expression for the peak growth rates due to these interactions.

(iii) We find nonlinear dynamics of the EGAM driven by bump-on-tail particle distributions. We examine the axisymmetric gyrokinetic simulations with DIH-D-like parameters. The observed growth rates and frequencies are consistent with observations derived from experiments. The theoretical analyses also indicate a bifurcation of the excited modes depending on q-value. The finite-orbit-width effects can provide a size dependency of the EGAM growth rate. (ii) We find linear and nonlinear dynamics of the EGAM driven by bump-on-tail particle distributions. We examine flat-q, homogeneous, axisymmetric, electrostatic gyrokinetic simulations. Above a certain level of the beam intensity, an interaction is due critically to the correct placement of the operators in the dispersion relation. We obtain a simple analytic expression for the peak growth rates due to these interactions.

(iii) We find nonlinear dynamics of the EGAM driven by bump-on-tail particle distributions. We examine the axisymmetric gyrokinetic simulations with DIH-D-like parameters. The observed growth rates and frequencies are consistent with observations derived from experiments. The theoretical analyses also indicate a bifurcation of the excited modes depending on q-value. The finite-orbit-width effects can provide a size dependency of the EGAM growth rate.
GP8.00059 Computational Diagnostics for Extreme Scale Toroidal Gyrokinetic Particle Simulations, YUAN SHI, Princeton Plasma Physics Laboratory, BEI WANG, Princeton Institute of Computational Science and Engineering, BRUCE SCOTT, Max-Planck-Institut für Plasmaphysik, WILLIAM TANG, Princeton Plasma Physics Laboratory, PRINCETON UNIVERSITY TEAM, MAX-PLANCK-INSTITUT COLLABORATION — The capability of monitoring processes in extreme scale simulation is crucial for extracting information about global and non-linear dynamics, as well as checking the integrity of the simulation. A set of post-processing computational diagnostics for toroidal gyrokinetic particle simulations is developed and optimized for efficient performance on multi- and many-core modern computational platforms. These diagnostics track the time evolution of parallel mode structure, radial profile, toroidal/poloidal spectra, and nonlinear energy transfer spectra. To demonstrate the performance of this diagnostic tool set, diagnosis results for drift wave turbulence with numerical dissipation are presented.

GP8.00060 Benchmarking of the Gyrokinetic Microstability Codes GENE, GS2, and GYRO over a Range of Plasma Parameters1, RONALD BRAVENEC, Fourth State Research, TOBIAS GOERLER, DANIEL TOLD, FRANK JENKO, Max Planck Institute for Plasma Physics, M.J. PUESCHEL, GEORGE MCKEE, Univ. Wisconsin, Madison, JEFF CANDY, ANDREA GAROFALO, STERLING SMITH, GARY STAEBLER, General Atomics, MICHAEL BARNES, Oxford University, CHRIS HOLLAND, Univ. California, San Diego, SIYE DING, Institute of Plasma Physics, Chinese Academy of Sciences, TERRY RHODES, Univ. California, Los Angeles — Comparing results from different gyrokinetic codes as a means of verification (benchmarking) is only convincing if the codes agree over a wide range of plasma conditions. Otherwise, agreement may simply be fortuitous. We present here linear and nonlinear comparisons of the Eulerian codes GENE, GS2, and GYRO for a variety of discharges and radii. These include the outer regions of DIH-D discharges with localized electron-cyclotron heating applied at different locations, the steep-gradient region of an EAST H-mode pedestal, a high poloidal beta DIH-D discharge with reversed magnetic shear in the core, and well-matched DIH-D discharges with varying degrees of toroidal rotation.

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GP8.00061 Gyrokinetic simulation of the tearing mode instability1, EDWARD STARTSEV, WEIXING WANG, WEI-LI LEE, Princeton Plasma Physics Laboratory — A recently developed split-weight perturbative particle simulation scheme for finite-\(\beta\) plasmas in the presence of background inhomogeneities which analytically separates the additional adiabatic response of the particles associated with the quasi-static bending of the magnetic field lines [1] has been generalized to the sheared magnetic field geometry. The new scheme has been implemented in a 2D particle-in-cell code in slab geometry with drift-kink and gyrokinetic electrons. The electrons pitch-scattering collision operator has also been implemented to study collisionless as well as collisional tearing, and drift-tearing instabilities. In this paper we report the linear simulations of tearing and drift-tearing modes for realistic mass ratio \(m_i/m_e = 1837\) and different values of \(\beta\), electron-ion collision frequency, density and temperature gradients are presented and compared to the solution of the eigenvalue equation [2]. We will also present preliminary results of collisionless tearing mode simulations in cylindrical geometry using tokamak turbulence code GTS.

1Research supported by the U. S. Department of Energy.

GP8.00062 SHOCKS, WAVES, DYNAMO AND DIPOLE –

GP8.00063 First results of transcritically magnetized collisionless shock studies on MSX1, T.E. WEBER, Los Alamos National Laboratory, R.J. SMITH, T.M. HUTCHINSON, University of Washington, Seattle, S.F. TAYLOR, University of Wisconsin, Madison, S.C. HSU, LANL, Los Alamos — MSX is uniquely positioned to generate the conditions for collision-less magnetized supercritical shocks with Alfvén Mach numbers up to \(\sim 10\) over a wide range of plasma beta with embedded perpendicular, oblique, and parallel magnetic field. Macroscopic skin-depth and long ion-gyroparticle enable diagnostic access to relevant shock physics using common methods. Variable plasmoid velocity, density, temperature, and magnetic field provide access to a wide range of shock conditions, and a campaign to study the physics of transcritical and supercritical shocks within the FRC plasmoid is currently underway. An overview of the experimental design, diagnostics suite, physics objectives, and recent results will be presented.

1Supported by DOE Office of Fusion Energy Sciences under DOE contract DE-AC52-06NA25369.

GP8.00064 Pulsed Polariometry and magnetic sensing on the Magnetized Shock Experiment (MSX)1, R.J. SMITH, T.M. HUTCHINSON, Univ. of Washington, Seattle, T.E. WEBER, LANL, Los Alamos, S.F. TAYLOR, Univ. of Wisconsin, Madison, S.C. HSU, LANL, Los Alamos — MSX is uniquely positioned to generate the conditions for collisionless magnetized supersonic shocks with Alfvén Mach numbers \((M_A)\) on the order of 10 and higher. Significant operational strides have been made in forming plasmas over wide parameter ranges: \((T_e+T_i)\) of 10-200 eV, average \(n_e\) of 5-60x10\(^{11}\) m\(^{-3}\), speeds up to 150 km/s and fields up to 1 T with a highest plasma flow \(M_A\) of 5 to date. The MSX plasma is unique in regards to large plasma size of 10 cm and average \(\beta\) higher than 0.8 making the FRC and the magnetized shock structure candidates for the application of Pulsed Polariometry, a polarization sensitive Lidar technique. The shock dynamics are presently being investigated using internal probes, interferometry and imaging. Internal probe results and an assessment of the shock parameters will dictate the use of the UW pulsed polarimeter system in which internal \(n_e\), \(T_e\), and \(B\) are to be measured. Recent results will be presented.

1Supported by DOE Office of Fusion Energy Sciences Funding DE-FOA-0000755.

GP8.00065 Three Dimensional Hybrid Simulations of Super-Alfvénic Laser Ablation Experiments in the Large Plasma Device, STEPHEN CLARK, Univ of California - Los Angeles, DAN WINESKE, Los Alamos National Laboratory, DEREK SCHAFFER, ERIK EVISON, ANTON BONDARENKO, CARMEN CONSTANTIN, CHRISTOPH NIEMANN, Univ of California - Los Angeles — We present 3D hybrid simulations of laser produced expanding debris clouds propagating though a magnetized ambient plasma in the context of magnetized collisionless shocks. New results from the 3D code are compared to previously obtained simulation results using a 2D hybrid code. The 3D code is an extension of a previously developed 2D code developed at Los Alamos National Laboratory. It has been parallelized and ported to execute on a cluster environment. The new simulations are used to verify scaling relationships, such as shock onset time and coupling parameter \((R_{sh}/\rho_d)\), developed via 2D simulations. Previous 2D results focus primarily on laboratory shock formation relevant to experiments being performed on the Large Plasma Device, where the shock propagates across the magnetic field. The new 3D simulations show wave structure and dynamics oblique to the magnetic field that introduce new physics to be considered in future experiments.
Characterization of Laser-Produced Plasmas Relevant to Magnetized Collisionless Shocks

Recent experiments performed at the University of California, Los Angeles (UCLA) have generated magnetized collisionless shocks driven by a laser-mediated magnetic piston. The effectiveness of the piston at coupling energy between a laser-plasma and an ambient plasma depends highly on the nature of the laser-plasma, which has been hitherto poorly characterized. We present experiments that provide new details on the composition and evolution of laser-produced plasmas relevant to a magnetic piston. Thomson scattering was used to probe the electron temperature and density up to several cm from the target and several microseconds after ablation. Ionization states and blowoff were further measured with emission spectroscopy and fast-gate filtered photography. The data compares well to analytic models describing the spatial and temporal temperature and density evolution of the plasma. 1D HELIOS simulations of the laser-target interaction also agree favorably with data that shows fast ions dominated by a single charge state primarily drive the magnetic piston.

Non-axisymmetric Perturbations of the LDX Laboratory Magnetosphere by Lithium Pellet Injection

In most toroidal magnetic plasma confinement systems, transport within helical flux surfaces serve to symmetrize the plasma temperature and density. In contrast, a plasma torus confined by a dipole field lacks a rotational transform and therefore the confined plasma is not necessarily axisymmetric. The plasma, however, self organizes into a time-averaged symmetric state through particle drifts and turbulent transport. Recent experiments in the LDX laboratory magnetosphere have been conducted to study large non-axisymmetric perturbations of the dipole confined plasma. A high speed gas gun was used to inject lithium pellets tangentially through the plasma. The pellets ablate as they traverse the bulk plasma and encounter the deeply trapped energetic electron ring (formed during ECH) and absorb energy deeply into the pellets. This causes a rapid ablation fracturing of the peak of the plasma density profile. High speed video shows the pellet ablating as it traverses the bulk plasma. As the pellets approach the midplane they encounter the deeply trapped energetic electron ring (formed during ECH) and absorb energy deeply into the pellet. This causes a rapid ablation fracturing of the pellet into multiple droplets, the exploding pellets will vaporize and then ionize leading to a tripling of the line integrated density. Similar processes occur when objects enter the Van Allen belts. The high density plasma presents an improved target for ICRF heating. We present recent experimental results.

Linear and Quasilinear Model for Pressure-Driven Interchange and Entropy Modes in a Warm Electron Dipole Plasma

The measured structures of electrostatic interchange modes in dipole-confined plasma cause global mixing when driven by energetic trapped electrons, sonic plasma, or warm electron pressure. Global circulation also appears in planetary magnetospheres driven by solar wind, but differences exist in underlying physics. Breaking azimuthal symmetry in magnetospheres caused currents to flow through the ionosphere, which regulate interchange motion. In the laboratory, there are no field-aligned currents and perturbations induce ion-inertial currents, which determine the global linear model structure. In this poster, the linear description of global interchange and entropy modes are presented for the CTX and LDX laboratory magnetospheres computed from the flux-tube averaged gyrofluid equations. Additionally, the quasilinear particle and heat flux are calculated and show turbulent self-organization that drives profiles to become centrally-peaked.

Supported by the NSF-DOE Partnership in Plasma Science Grants DE-FG02-00ER54585 and PHY-1201896.
GP8.00071 Bounce-Averaged Gyrokinetic Simulation of Current-Collection Feedback in a Laboratory Magnetosphere

T.M. ROBERTS, D. GARNIER, Columbia University, J. KESNER, MIT Plasma Science and Fusion Center, M.E. MAUEL, Columbia University — A self-consistent, nonlinear simulation of interchange dynamics including the bounce-averaged gyro-kinetics of trapped electrons was previously used to understand frequency sweeping and the turbulent cascade observed in dipole-confined plasmas. Through adjustment of the particle and heat sources this code reproduces dynamics that resemble the turbulence measured experimentally, both in spectral power-law trends and in the onset of a steepened density profile. Time stepping is performed in an explicit leap-frog manner and a flux-corrected transport algorithm is implemented. In this presentation, we discuss the physics and numerical methods of the simulations as well as plans for including the effects of a biasing electrode which can collect or inject electrons. By varying this source/sink of electrons at the electrode location based on the potential fluctuations occurring elsewhere, we study the effects of current-collection feedback to compare to recent experiments observed to regulate interchange turbulence.

1Supported by NSF-DOE Partnership for Plasma Science and DOE Grant DE-FG02-00ER54585 and NSF Award PHY-1201896.

2B. Levitt, Phys Plasmas, 9, 2507 (2002).


GP8.00072 Gyrokinetic theory of auroral arc formation and electron acceleration in the magnetosphere-ionosphere coupling

TOMO-HIKO WATANABE. Department of Physics, Nagoya University — We have constructed a unified theoretical model of auroral arc growth and electron acceleration by means of the gyrokinetic and two-fluid equations for the magnetosphere-ionosphere (M-I) coupling system. The new theory describes destabilization of kinetic (or dispersive) Alfvén waves (KAWs) in the M-I coupling, where development of upward and downward field aligned currents carried by the KAWs leads to ionospheric density enhancement and depletion, respectively. The feedback effect of the arc on the KAWs elucidates growth of auroral arcs, excitation of KAWs, and field-aligned acceleration of electrons self-consistently. The unified theoretical model of M-I coupling provides a possible explanation to the Alfvénic auroras observed by the FAST spacecraft, and is also appreciated as a successful application of gyrokinetics to auroral physics.

This work is partly supported by research collaboration programs of National Institute for Fusion Science and of Solar Terrestrial Environmental Laboratory, Nagoya University.

GP8.00073 Initial Results from the Magnetorotational Instability Experiment (MRI) Upgrade

ERIK GILSON, ERIC EDLUND, Princeton Plasma Physics Laboratory, JEREMY GOODMAN, Princeton University, HANTAO JI, Princeton Plasma Physics Laboratory, Princeton University, AVEEK KAPAT, University of Illinois at Urbana-Champaign, ETHAN SCHARTMAN, Nova Photonics, Inc., PETER SLOBODA, Princeton Plasma Physics Laboratory, XING WEI, Princeton University — The Magnetorotational Instability experiment (MRI) has been upgraded to enable reliable operation at the high rotation rates required to obtain the MRI by implementing mechanical improvements, and to increase the expected saturation amplitude of the MRI by installing electrically conductive end caps. Initial experimental results are presented that determine the extent to which the optimized baseline configuration matches the ideal Taylor-Couette rotation profile in the absence of a magnetic field. Radial velocity measurements with an improved ultrasound Doppler velocimetry configuration are compared to numerical simulations of the Ekman configuration. High-speed runs extend the results of Roach [1] to speeds between 60% and 100% of the design limit in order to investigate whether the observed simple scaling of the normalized azimuthal velocity with the normalized magnetic field can serve as a suitable baseline against which to identify the MRI. Plans are discussed for an experimental campaign to identify the MRI by measuring radial velocities and magnetic fields, in addition to changes to the azimuthal velocity, as predicted by simulations.


This research is supported by the U. S. Department of Energy.

GP8.00074 Upgrade of the Magnetorotational Instability Experiment Apparatus

E. SCHARTMAN, Nova Photonics, Inc., E. GILSON, E. EDLUND, Princeton Plasma Physics Laboratory, J. GOODMAN, Princeton University, H. JI, P. SLOBODA, Princeton Plasma Physics Laboratory, X. WEI, Princeton University — The Princeton Magnetorotational Instability (MRI) Experiment was designed to investigate the MRI in a liquid gallium alloy Taylor-Couette flow generated between concentric spinning cylinders. To achieve magnetic Reynolds numbers sufficiently large to excite the MRI, flow velocities of order 20 m/s are required. Experimental operation at such velocities has been hampered by mechanical limitations of the apparatus. Dynamic pressures generated by the alloy cause distortion and binding, which is laborious to correct. High surface speeds lead to excessive seal wear. Modifications to the apparatus were implemented to enable extended operation at full design speed. The inner cylinder was also modified to carry diagnostics such as Doppler ultrasound, torque and magnetic field sensors. Details of the modifications will be presented. This work is supported by U.S. DOE, NASA and NSF.

GP8.00075 Theoretical study of plasma confinement by magnetic multicusp field

IVAN KHALZOV, CARY FOREST, University of Wisconsin-Madison — Plasma confinement in a magnetic multicusp field is studied numerically using both collisional particle-in-cell and isothermal two-fluid MHD codes and tested against the empirical model. The simulation domain is two-dimensional, periodic in one direction and bounded by absorbing boundaries with multicups field in other direction. First, we study the dependence of plasma loss width on plasma parameters and field strength and compare the results with the well-known empirical formula \( w = 2\sqrt{\nu / \eta R} \) (two hybrid gyro-radius). Our results show that the loss width has the same scaling with magnetic field \( w \propto 1/B \), but dependence on other plasma parameters does not agree with this formula. Second, we study the plasma flow drive in the cusp region due to electric field applied by discrete electrodes. The electrode positions are optimized for achieving the highest plasma flow. Comparison with available experimental data from Madison Plasma Dynamo Experiment (MPDX) is made.

The work is supported by NSF and DoE.

GP8.00076 Theoretical foundations of MHD spectroscopy in Madison Plasma Dynamo Experiment

ROBERT SILLER, IVAN KHALZOV, CARY FOREST, Univ of Wisconsin, Madison — We develop a theoretical basis of active MHD spectroscopy for Madison Plasma Dynamo Experiment (MPDX). This new diagnostic is based on an analysis of incompressible shear Alfvén modes and compressible acoustic modes for spherical plasmas, and the influence of plasma flow on the corresponding eigen-spectrum. Alfvén modes in plasma are assumed to be excited in the presence of an external axial magnetic field. The mode frequencies depend on the distribution of plasma parameters. Inverting this dependence for a given (experimentally measured) set of modes, we are able to infer the spatial structure of plasma characteristics. We demonstrate this inversion technique by determining the rigid plasma rotation from the splitting of the low-frequency resonance Alfvén modes driven by a localized antenna. Compressible acoustic waves in plasma are assumed to be excited with and without the presence of an external magnetic field. For the acoustic waves we determine the velocity dependence of the normal mode spectrum and magnetic field structure. We consider the feasibility of using the developed diagnostic in MPDX.
GP8.00077 Helioseismology in the Lab , ETHAN PETERSON, MATTHEW BROOKHART, MIKE CLARK, CHRIS COOPER, JAN EGEDAL, JOHN WALLACE, DAVID WEISBERG, CARY FOREST. University of Wisconsin - Madison, MPDX TEAM — A novel diagnostic technique for measuring plasma flows in the Madison Plasma Dynamo Experiment (MPDX) has been designed and implemented. The technique, inspired by helioseismology, launches ion acoustic waves from the boundary of a spherical (1.5m radius), unmagnetized, spinning plasma and measures the doppler shifted wave at two longitudinal locations of the same latitude. These two measurements yield a line integrated velocity measurement from the source to the receiver. The ion acoustic waves are produced via the mode conversion of a magnetosonic wave excited by a current loop antenna located in the confining cusp field of MPDX. Probe measurements of the electric field in the plasma and the magnetic field fluctuations (Bdot) in the cusp are used to observe the wave and deduce velocities along two chords. This technique is used to measure 10 km/s flows and to validate mach probe measurements near the edge of the plasma. The Bdot measurements in the cusp provide the proof-of-concept for a surface array of probes to measure global velocities.

GP8.00078 Taylor-Dean flow on the Plasma Couette Experiment (PCX) , K. FLANAGAN, M. CLARK, C. COLLINS, C. COOPER, I. KHALZOV, J. WALLACE, C. FOREST. University of Wisconsin-Madison — A Taylor-Dean flow profile is implemented on the upgraded Plasma Couette Experiment (PCX) aimed at exciting the magnetorotational instability (MRI). Taylor-Dean flow profiles are set up by injecting torque via a radial current crossing an axial magnetic field. A “virtual cathode” is set up in the center of PCX by applying a bias from a cathode located at the top center of the vessel to an anode at the bottom. This circuit is biased with respect to anodes at the outer wall to drive a radial current. A small vertical magnetic field is then applied via external Helmholtz coils in order to induce a J × B torque. Theoretical investigations have shown that high Rm PCX plasmas with low ionization fractions negatively affect the MRI threshold and growth rate. In order to increase the ionization fraction in PCX, upgrades to the multicusp magnet system and microwave power are underway. New SmCo magnets, like those used on the Madison Plasma Dynamo Experiment (MPDX), will provide better confinement and tolerate higher plasma temperatures than the previous ceramic ones. A MRI stability analysis of Taylor-Dean flows under relevant PCX parameters as well as early flow data will be presented.

GP8.00079 Development of an ECH System on the Madison Plasma Dynamo Experiment , JASON MILHONE, University of Wisconsin, Madison, ALF KOEHN, IGVP, University of Stuttgart, PAUL NONN, CARY FOREST, University of Wisconsin, Madison, MPDX TEAM — The Madison plasma dynamo experiment (MPDX) is a 3 meter diameter spherical vessel lined with 3000 SmCo permanent magnets (B ≥ 3 kG) that create an axisymmetric multi-cusp ring for confining the plasma. The MPDX is designed to study flow driven MHD instabilities and dynamo action in the regime of high magnetic Reynolds number Rm = vL/η. This will be achieved through electron cyclotron heating of the electrons leading to good electrical conduction and large ionization fraction. The system consists of five 20 kW, CW magnetrons operating at 2.45 GHz. The system will be described in detail, including the power supplies, RF vacuum feedthroughs, and modulator/regulator circuit used to control the magnetrons. The power will be injected at various latitudes and is resonant at the fundamental cyclotron frequency in the multi-cusp edge. Prototype experiments in a smaller version of the device routinely operate in a density regime that is overdense. Experiments and numerical modeling will be described that determine how the power is absorbed in this mode.

GP8.00080 Experimental Optimization of High Magnetic Reynolds Number, Two-Vortex Flows on the Madison Plasma Dynamo Experiment , DAVID WEISBERG, CHRISTOPHER COOPER, MIKE CLARK, KEN FLANAGAN, IVAN KHALZOV, JASON MILHONE, MARK NORNBERG, JOHN WALLACE, CARY FOREST. Univ of Wisconsin, Madison — Laminar counter-rotating two-vortex flows, predicted to excite a large-scale dynamo, are generated and optimized in the Madison plasma dynamo experiment (MPDX). Numerical simulations show that the topology of these simply-connected flows may be optimal for creating a plasma dynamo in the lab and predict a critical threshold of Rm = vL/η = 250 for optimal flows. MPDX plasmas are shown to exceed this critical Rm, generating large (L = 1.1 m), hot (T_e > 10 eV) plasmas where Rm = 600. Plasma flow is driven using eight thermally emissive LaB_6 cathodes which generate a J × B torque at the magnetized edge of spherical He plasmas. Mach probe measurements show counter-rotating flows at speeds of V > 10 km/s; the driven flow at the plasma edge viscously couples inward to the unmagnetized core via ion-ion collisions, and flow measurements along radial chords compare favorably to hydrodynamic calculations using Braginskii viscosity. To optimize flow for dynamo generation, cathode bias and positioning are varied along with plasma viscosity (ν ∼ t^{11/6}/n_i) and the frictional neutral-ion drag force (μ = L^2/(v_{ion})). Prospects for observing a dynamo, hydrodynamic transitions to turbulence, and eventual large Rm fast dynamos will be presented.

GP8.00081 Optical Emission Spectroscopy in an Unmagnetized Hot Plasma , BLAIRE SEIDLITZ, CHRIS COOPER, DAVE WEISBERG, MARK NORNBERG, JOHN WALLACE, CARY FOREST. University of Wisconsin - Madison — Recently, a new technique has been developed to create the laboratory, a large (1.5m), weakly magnetized, fast flowing (0.1 < V/|C_T| < 1), and hot (10-20eV) plasma. These unique conditions make it possible to study a wide variety of phenomena in plasma astrophysics which is the goal of the Madison plasma dynamo experiment. Accurate measurements of plasma properties such as density and temperature can be challenging with Langmuir probes due to contamination, their perturbative nature, plasma flow, and probe overheating due to large T_e. To achieve a non-invasive measurement of relevant parameters, optical emission spectroscopy techniques have been implemented using a 1.5m resolution fiber-coupled broad wavelength spectrograph. Measurements of HeI and HeII are utilized to predict relative density ratio using the coronal model. This has yielded Hell ground state measurements which is particularly important in MPDX’s plasma regime containing HeI, HeII, and Hell. Radially resolved measurements are also made with a periscope like device. Finally, full collisional radiative modeling is being explored to characterize T_e via HeI emission.

GP8.00082 Establishing high magnetic Reynolds numbers (Rm) in MPDX for dynamo studies , CHRISTOPHER COOPER, MICHAEL CLARK, KEN FLANAGAN, IVAN KHALZOV, JASON MILHONE, ETHAN PETERSON, BLAIRE SEIDLITZ, JOHN WALLACE, DAVID WEISBERG, CARY FOREST. University of Wisconsin-Madison — The Madison plasma dynamo experiment (MPDX) is a basic plasma research device designed to investigate flow driven MHD instabilities, such as the dynamo, in parameter regimes relevant to astrophysical systems and numerical simulations. A 3 meter diameter vacuum vessel lined with an axisymmetric magnetic multipole cusp confines a nearly magnetic-field-free plasma. Thermally emissive lanthanum hexahide cathodes biased < 400 V create the plasma and generate toroidal J × B torques in the cusp region. Plasma viscosity propagates this momentum throughout the unmagnetized core, driving poloidal and toroidal flows for studying the interactions between flows and magnetic fields in high conductivity regimes. In plasma, the viscosity and conductivity scale dramatically with T_e, n_e, and Z_{eff} which are uniquely determined by particle and energy confinement. Varying the MPDX input power and field pressure with the achieved 10 km/s driven flows creates a scaling of the fluid Reynolds number 10 < Re < 1000 with Rm > 1000. Numerical simulations of MPDX predict both fast and slow type dynamo action across this scaling. Initial measurements of plasma parameters, flow and comparisons to confinement and dynamo models will be presented.

1Work supported by NSF and DOE
GP8.00083 Status of the Wisconsin Plasma Astrophysics Laboratory1. JOHN WALLACE, MATTHEW BROOKHART, MIKE CLARK, CHRIS COOPER, KEN FLANAGAN, IVAN KHALZOV, JÁSÖN MILHONE, ETHAN PETERSON, JOSEPH OLSON, AARON STEMO, DAVE WEISBERG, JAN EGEDAL, CARY FOREST, University of Wisconsin - Madison, MPDX TEAM — The Wisconsin Plasma Astrophysics Laboratory (WiPALS) is a facility that now encompasses a collection of novel plasma astrophysics experimental configurations. In the MPDX configuration large, un-magnetized, fast flowing, hot plasma is being used to investigate a variety of flow driven MHD instabilities. The experiment is 3 meters in diameter and utilizes a permanent magnet multicusp plasma confinement. Five 20KW, 2.45 GHz, CW magnetrons produce electron cyclotron heating for plasma generation. Ten lanthanum hexaboride (LaB6) stirring rods and molybdenum anodes are inserted into the vessel to produce JxB flows. The chamber has a variety of multiport, and is able to split open to allow experimental apparatus to be inserted. This poster will describe future experimental configurations including reconnection (TREX), jet and plasma wind experiments.

1Construction was funded by the NSF Major Research Instrumentation program (ARRA), DOE, and CMSO.

GP8.00084 Complex Dynamics of Line-tied Flux Ropes and Screw Pinches1. MATTHEW BROOKHART, AARON STEMO, AMANDA ZÜBERBIER, CARY FOREST, University of Wisconsin - Madison — It has been suggested that flux ropes – self-contained plasma structures with axial current and magnetic field – may be the basic building blocks of many astrophysical plasmas. Many of these plasmas – including coronal loops, the solar wind, and astrophysical jets – also show “line-tying” where the ends of flux ropes are magnetically fixed. The Line-tied Reconnection Experiment is a basic plasma research facility designed to study the behavior, instability, and self-organization of multiple line-tied flux ropes in a variety of geometries and plasma conditions. The recent construction of a 300 coil magnetic probe array has allowed for direct, time and space resolved observations of flux rope dynamics in a wide range of conditions. Complex dynamics of 2 and 3 flux ropes are observed both with and without background plasma. These plasma exhibit complex instabilities and interactions. Observations show that larger numbers of flux ropes merge into azimuthally-symmetric screw pinch equilibria. High safety factor kink-like instabilities are seen in both hollow and reversed current profile plasmas, akin to tokamak current holes and certain models of solar flares. The equilibria, instability criteria, and dynamics of these plasmas are explored.

1Supported by DOE

GP8.00085 Construction of 4 meter diameter Helmholtz coils using square cross section hollow conductor on the Madison Plasma Dynamo Experiment (MPDX)1. M.M. CLARK, A. ALT, J. EGEDAL, D. ENDRIZZI, S. GREESS, A. JAEGER, E. JEWELL, J. OLSON, J.P. WALLACE, C.B. FOREST, Univ of Wisconsin, Madison — A pair of Helmholtz coils has been constructed in situ for the Madison Plasma Dynamo Experiment (MPDX). The MPDX vessel itself is a 3 meter diameter spherical vacuum chamber. Each Helmholtz coil consists of 88 turns of 13mm square conductor with a 9mm diameter round channel centered in the cross section. The coils will produce 277Gauss of magnetic field at 800Amps DC. A steel roller frame and aluminum wheel to support the conductor was built in the MPDX lab. The conductor was then wound onto the wheel making 16 pancakes per coil. The ends of the conductor needed finishing so that series electrical connections would result as well as parallel water cooling. The resistance of each coil was measured to be 187mOhm. The design and construction process will be shown.

1Construction was funded by the NSF Major Research Instrumentation program (ARRA), DOE, and CMSO.

GP8.00086 Exciting Alfvén Waves using Modulated Electron Heating by High Power Microwaves1. YUHOU WANG, WALTER GEKELMAN, PATRICK PRIBYL, BART VAN COMPENNOLLE, UCLA Dept of Physics, KONSTANTINOS PAPADOPOULOS, Univ of Maryland, Dept of Physics — Experiments exploring the physics of ionospheric modification with intense perpendicular propagating waves ($\vec{k} \perp \vec{B}_0$) on the Large Plasma Device (LaPD) at UCLA have been upgraded with the addition of a high power rapidly pulsed microwave source. The plasma is irradiated with ten pulses (250 kW X-band) near the upper-hybrid frequency. The pulses are modulated at a frequency of a fraction (0.1-1.0) of $f_{ce}$ (ion cyclotron frequency). Based on a previous single-pulse experiment [1], the modulated electron heating may drive a large amplitude shear Alfvén wave ($f < f_{ce}$), making the plasma a virtual antenna. This wave driving mechanism may have important application in terrestrial radio communications by low frequency waves, which are difficult to launch directly due to their enormous wavelengths. Various heating methods involving X-mode, O-mode, and electron Bernstein mode are investigated in plasmas with controllable parameters ($n_e = 10^8 \sim 10^{12} cm^{-3}$, $T_e = 0.1 \sim 6 eV$, $T_i = T_e$, $B_0 = 100 \sim 3000 G$, $\nabla n_e/n_e = 0 \sim 1 cm^{-1}$). Mode-conversion between these waves and the subsequent structural changes of the plasma near the conversion region are also under investigation.

1Supported by AFOSR MURI award, and conducted at the Basic Plasma Science Facility at UCLA funded by DoE and NSF.

GP8.00087 Solar-relevant plasma loop expansion in strapping field1. BAO HA, PAUL BELLAN, California Institute of Technology — Tokamak-like forces may explain fundamental behaviors of solar plasma arches. The hoop force causes arched, current-carrying plasma loops to expand. This expansion was slowed and even inhibited by a magnetic “strapping” field in previous solar loop experiments at Caltech [1] but no attempt was made to control the field’s spatial profile. Klim and Torok [2] predicted an explosive-like transition from slow expansion to fast eruption if the spatial decay rate of the strapping field exceeds a threshold. Smaller, independently-powered auxiliary coils placed inside the vacuum chamber produce strapping fields with above-threshold decay rate and strong enough to act on the plasma. The plasma is observed, however, to bypass regions of stronger strapping field and expand into regions of weaker field. Added external inductance slows plasma expansion allowing the strapping coils to hold down the plasma. Different interactions between arched plasma loops and strapping magnetic fields will be presented.

1This work is supported by the NSF Major Research Instrumentation program (ARRA), DOE, and CMSO.

GP8.00088 Gendriner mode vortices and helicons in unbounded plasmas1. J. MANUEL URRUTIA, REINER STENZEL, Dept of Physics and Astronomy, UCLA — Magnetic loop antennas are used to excite cw whistler modes in a large laboratory plasma for parameters $\omega \ll 0.3n_{ei}c \ll \omega_{ce}$. The wave topology and propagation is measured in 3D space and time with magnetic probes. When the antenna dipole field is aligned with the uniform background field $B_0$, the spatial wave packets have conical phase fronts and linked toroidal and poloidal fields. These whistler “vortices” resemble $m = 1$ helicon modes in bounded plasmas. The topology resembles that of $m = 1$ helicon modes when the antenna dipole field is perpendicular to $B_0$, except the phase fronts are inclined at the Gendrin angle. The 3D field lines form two nested and opposing helices along $B_0$. The wave field is force free. Using linear superposition, the fields from two phased loops, spaced axially apart by $\lambda/4$, are superimposed, resulting in directional radiation. It is more efficient than rotating field antennas. Whistler standing waves have been generated with oppositely propagating helicons. These waves produce no perfect nodes and have wave polarizations varying spatially between linear and circular. The results are of interest to space and laboratory plasmas.

1Work supported by NSF/DOE.
GP8.00089 Antenna arrays for producing plasmas with whistler waves, REINER STENZEL, J. MANUEL URRUTIA, Dept of Physics and Astronomy, UCLA — Linear whistler modes with $\omega \sim 0.33v_A < \omega_p$, are excited in a large laboratory plasma with magnetic loop antennas. A single antenna always produces a spatially bounded wave packet whose propagation cannot be directly compared to plane wave theories. By superimposing the fields from spatially separated antennas, the wave-number along the antenna array can be nearly eliminated. 2D arrays nearly produce plane waves. The angle $\theta$ of wave propagation has been varied by a phase shift along the array. The refractive index surface $n(\theta)$ has been measured. The parallel phase and group velocities for Gendrin modes have been demonstrated. The interference between two oblique plane waves creates a “waveguide” mode, i.e., standing waves for $k \perp B_0$ and propagation for $k \parallel B_0$. It also describes the radial phase of oblique whistlers from a sharp discontinuity in the refractive index or conductivity. Radial reflections are also a dominant factor in small plasma columns of helicon devices. These results are of interest to space and laboratory plasmas.

1Work supported by NSF/DOE.

GP8.00090 Measurements of the linear kinetic plasma response to Alfvén waves, J.W.R. SCHROEDER, F. SKIFF, G.G. HOWES, C.A. KLETZING, University of Iowa Department of Physics and Astronomy, T.A. CARTER, S. DORFMAN, UCLA Department of Physics and Astronomy — Alfvén waves likely account for a significant fraction of auroral electron acceleration. However, a direct test of electron acceleration and associated energetic particle populations and limited success have hitherto been precluded by the difficulty in completing thorough tests of existing theory. Until now, laboratory diagnostics have not been sensitive to the predicted small fluctuations in the tail of the electron distribution function $f_e$. A novel diagnostic developed at the University of Iowa uses the absorption of a small-amplitude whistler wave to measure $f_e$ up to $1 \text{keV}$ with 0.1% accuracy. Inertial Alfvén waves ($v_A/v_A \sim 0.2$) with $\delta B/B \sim 10^{-5}$ are launched in an overdense plasma at the Large Plasma Device (LPD) with $B_0 = 1800 \text{G}$. Under these conditions, only the whistler mode propagates parallel to the background magnetic field at frequencies just below the electron cyclotron frequency. Results show fluctuations in the tail of the distribution function at the frequency of the Alfvén wave. An analytic solution from the Boltzmann equation is used to describe experimental results. Further analysis of measurements is presented and is compared to theoretical predictions.

GP8.00091 Generation of shear Alfvén waves due to resonant interactions with a spiraling ion beam on the Large Plasma Device, SHREEKRISHNA TRIPATHI, B. C. VAN COMPERNOLLE, WALTER GEKELMAN, PATRICK PRIBYL, Univ of California - Los Angeles, WILLIAM HEIDBRINK, Univ of California - Irvine — The role of Landau and Doppler-shifted ion-cyclotron resonances (DICR) in extracting the free-energy from an ion-beam and destabilizing Alfvén waves was explored. The experiment was conducted on the Large Plasma Device (LPD) with $B_0 = 1800 \text{G}$. Under these conditions, only the whistler mode propagates parallel to the background magnetic field at frequencies just below the electron cyclotron frequency. Results show fluctuations in the tail of the distribution function at the frequency of the Alfvén wave. An analytic solution from the Boltzmann equation is used to describe experimental results. Further analysis of measurements is presented and is compared to theoretical predictions.

GP8.00092 Spatial and temporal measurements of electrostatic fields of a field-aligned, magnetized laser-produced plasma expansion, JEFFREY BONDE, STEPHEN VINCENA, WALTER GEKELMAN, Univ of California - Los Angeles — Laser-produced plasmas (LPPs) in laboratory environments form supersonic and super-Alfvenic flows that, when properly scaled, can model naturally occurring phenomena such as shock structures in supernovae and astrophysical jets. Our interest lies in understanding the evolution of these flows and how they interact with ambient, magnetized plasma. An LPP was generated using a $10^{11} \text{W/cm}^2$ laser pulse on a solid target. It expanded into a pre-formed, magnetized plasma and was directed along the background magnetic field ($v_A << v_{exp} < v_A$). The total electric field was measured during the expansion of the LPP and its transition to a collimated, field-aligned jet using magnetic field and emissive probe measurements. The electrostatic component, which arises from charge separation during the expansion, had a peak strength of $|E| \sim 200 \text{V/cm}$ and is 10 times larger than the inductive component associated with the diamagnetic cavity. Particle orbit solvers indicate these fields can accelerate ambient ions to sound speed velocities on short time scales, $t << \omega_e^{-1}$, and small spatial scales, $\tau \sim c/\omega_p << c/\omega_{pe}$. The strength, scale size, and non-zero divergence of the electrostatic fields suggest MHD and hybrid codes may have difficulty resolving some of the key physics. Data on potentials, electric fields, and associated $E \times B$ drifts will be presented.

1This experiment was conducted at the Large Plasma Device at the Basic Plasma Science Facility funded by grants from the US Department of Energy and the National Science Foundation.

GP8.00093 Observation of Rayleigh-Taylor instability growth and evolution toward longer wavelengths at a decelerating magnetized-plasma interface, COLIN ADAMS, UNM, AUNA MOSER, SCOTT HSU, JOHN DUNN, LNL, MARK GILMORE, UNM — The interaction of a high-Mach-number plasma jet propagating into a background magnetic field is studied experimentally on the Plasma Liner Experiment [1]. The jets, generated by plasma railguns, have densities and temperatures of order $10^{14} \text{cm}^{-3}$ and 1 eV, respectively, at the time of interaction with the magnetic field ($\sim 100 \text{G}$). Due to ringing railgun current, the jet is comprised of a series of “blobs” traveling at $\sim 10-70 \text{km/s}$, arriving at the region with the applied field at $\sim 20-30 \mu \text{s}$ intervals. When a trailing jet arrives and interacts with the remnants of the leading jet, oscillating magnetic field, growing fingers are observed with a multi-frame camera at the front of the trailing jet. The fingers evolve along a constant mode wavelength ($\sim 1 \text{cm}$) as the incoming jet penetrates into the magnetized region. Spectrometer and interferometer data show deceleration of the incoming jets against the lower-density magnetized background at approximately $10^{10} \text{m/s}^2$. We compare experimental results to theoretical and computational predictions, showing consistency of the observations with Rayleigh-Taylor instabilities with magnetic and/or viscous stabilization.


GP8.00094 Vlasov simulations of negative mass instability of Langmuir waves, KENTARO HARA, University of Michigan, THOMAS CHAPMAN, JEFFREY BANKS, RICHARD BERGER, ILON JOSEPH, Lawrence Livermore National Laboratory, STEPHAN BRUNNER, EPFL, IAIN BOYD, University of Michigan — An unambiguous signal of the negative mass instability (NMI) of large amplitude Langmuir waves has been observed for the first time using a 1D-1V Vlasov simulation code. During the NMI, recently predicted by Dodin (PRL 110, 215006 (2013)), particles trapped in the potential well move to different trapped orbits with different bounce frequencies due to mutual Coulomb repulsion and potentially undergo phase bunching. The NMI in Langmuir waves has been studied using the Vlasov simulation with initial conditions conducive to comparison with theoretical estimates of the growth rate of the NMI and group velocity, and also to allow predictions of the statistical distribution of the number of negative mass particles and the time at which they reach the trapped-motion region. Theoretical and numerical growth rates of the NMI are in good agreement when the trapped particle population is initialized as a delta-like function in energy. The mechanism of nonlinear saturation of the NMI is also 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 supported by the U.S. Department of Energy Office of Science, Fusion Energy Sciences Program, Grant DESC0001899.
GP8.00095 Study of Coupling between a Plasma Source and Plasma Fluctuations\textsuperscript{1}, JORGE BERUMEN, FENG CHU, RYAN HOOD, SEAN MATTINGLY, ANTHONY ROGERS, FRED SKIFF. The University of Iowa — An experimental study on the coupling between a plasma source and plasma fluctuations in a cylindrical, magnetized, singly-ionized Argon inductively-coupled gas discharge plasma that is weakly collisional is presented. Typical plasma conditions are \( n \sim 10^{13}\text{cm}^{-3} \), \( T_e \sim 3\text{ eV} \) and \( B \sim 1\text{ KG} \). Amplitude Modulation (AM) of the inductively-coupled RF plasma source is produced near the fundamental-mode ion-acoustic wave frequency (\( \sim 1\text{ kHz} \)) to study the effects of the source-wave interaction and plasma production. Density fluctuation measurements are implemented using Laser-Induced Fluorescence techniques and Langmuir probes. We apply coherent detection with respect to the wave frequency to obtain the perturbed ion distribution function associated with the waves. Measurements of fluctuating I-V traces from a Langmuir probe array and antenna current load are also used to show the effects of the interaction.

\textsuperscript{1}We would like to acknowledge DOE DE-FG02-99ER54543 for their financial support throughout this research.

GP8.00096 Simulation of mode conversion of lower hybrid waves, GUOZHANG JIA, NONG XIANG, Institute of Plasma Physics, Chinese Academy of Sciences, XUEYI WANG, YU LIN, Physics Department, 206 Allison Laboratory, Auburn University — Conversion between slow- and fast-waves in the lower hybrid range of frequencies in an inhomogeneous plasma is investigated using the particle-in-cell simulation code based on the gyrokinetic electron and fully kinetic ion (GeFi) model [Yu Lin, Xueyi Wang, Zhihong Lin and Liu Chen, Plasma Phys. Control. Fusion 47, 2005, 657]. For a low input power, it is found that the occurrence of the mode conversion sensitively depends on the value of the parallel wave refractive index as shown by the linear theory, and good agreement with the linear theory is obtained. With the input power increasing, it is shown that the mode conversion process is significantly affected by nonlinear plasma-wave interactions.

GP8.00097 Electrostatic instabilities induced by counter streaming ions in supersonic wake\textsuperscript{1}, CHUTENG ZHOU, I.H. HUTCHINSON, CHRISTIAN BERNT HAAKONSEN, MIT PSFC — The wake behind an object moving at supersonic speed in a plasma contains a region of depleted density into which the plasma expands. This replenishing mechanism results in counter streaming ion beams accelerated by ambipolar electric fields, which can be inherently unstable. It is widely believed, for example, that the intense electrostatic noise in the central lunar wake arises from such instabilities. To understand better this and related phenomena, a code has been developed to calculate the linear wave growth rates in the Vlasov-Poisson system for arbitrary ion distribution functions. The research aims to give a comprehensive description of the electrostatic instabilities and their parametric dependences. A contour plot of maximum growth rates in parameter space will be presented in cases where the ion distribution function can be represented by a sum of Gaussians. Our calculations consider unequal beams and oblique modes in contrast to previous published results, which mostly treat equal beams and parallel modes.

\textsuperscript{1}Supported in part by NSF/DOE Grant DE-SC0010491.

GP8.00098 Excitation and control of autoresonant ion acoustic waves\textsuperscript{1}, LAZAR FRIEDLAND, Hebrew University of Jerusalem — Controlled excitation of nonlinear waves is one of the important goals of both basic and applied research. We study the excitation of large amplitude ion acoustic waves in plasmas from a trivial equilibrium by the adiabatic nonlinear phase-locking (autoresonance) with a chirped frequency drive. In this case, under certain conditions, the nonlinearity and variation of parameters work in tandem to preserve the phase-locking in the system via excursions of the ion acoustic wave in its parameter space, yielding controlled growth of the wave amplitude. We analyze formation of autoresonant ion acoustic waves via both the fluid and kinetic Vlasov-Poisson models. A weakly nonlinear, long wavelength limit of the fluid approximation for the ion acoustic waves is frequently associated with the KdV equation. We go beyond the driven KdV problem and study the formation of driven, strongly nonlinear, fluid-type ion acoustic waves. The Whitham's averaged variational principle is applied in analyzing these autoresonant excitations. At larger ion temperatures, our simulations show the possibility of formation of a phase-locked void (hole) in the ion distribution, yielding a particular type of autoresonant ion Bernstein, Green, and Kruskal (BGK) mode.

\textsuperscript{1}Supported by Israel Science Foundation

GP8.00099 Two-stream instability with time-dependent drift velocity\textsuperscript{1}, HONG QIN, RONALD DAVIDSON, Princeton University — The classical two-stream instability driven by a constant relative drift velocity between two plasma components is extended to the case with time-dependent drift velocity. For periodic oscillating relative velocity, the linear dynamics can be characterized by a one-period map from which the growth rate of the perturbation can be rigorously defined and calculated. Using this tool, we are able to obtain a comprehensive picture of the linear two-stream stability driven by a general time-dependent drift velocity. Stability diagrams for the oscillating two-stream instability are presented over a large region of parameter space. It is shown that the maximum growth rate for the classical two-stream instability can be significantly reduced by adding an oscillatory component to the relative drift velocity.

\textsuperscript{1}Research supported by the U.S. Department of Energy.

GP8.00100 The Birth of Kinetic Electrostatic Electron Nonlinear (KEEN) Waves Weakly Driven by the Ponderomotive Force of Crossing Laser Beams in High Energy Density Plasmas Compared to Strongly Driven KEEN Waves\textsuperscript{1}, MICHEL MEHRENBERGER, IPP, Garching Germany, BEDROS AFEYAN, Polymath Research Inc., ADILA DODHY, ERIC SONNENDRÜKER, IPP, Garching Germany — We vary the amplitude and duration of the ponderomotive force driving KEEN waves in Vlasov-Poisson simulations. We use variable-resolution velocity-grids, so as to maintain accuracy, no matter how small the driven waves get relative drift velocity. In this case, under certain conditions, the nonlinearity and variation of parameters work in tandem to present the phase-locking in the system via excursions of the ion acoustic wave in its parameter space, yielding controlled growth of the wave amplitude. We analyze formation of autoresonant ion acoustic waves via both the fluid and kinetic Vlasov-Poisson models. A weakly nonlinear, long wavelength limit of the fluid approximation for the ion acoustic waves is frequently associated with the KdV equation. We go beyond the driven KdV problem and study the formation of driven, strongly nonlinear, fluid-type ion acoustic waves. The Whitham's averaged variational principle is applied in analyzing these autoresonant excitations. At larger ion temperatures, our simulations show the possibility of formation of a phase-locked void (hole) in the ion distribution, yielding a particular type of autoresonant ion Bernstein, Green, and Kruskal (BGK) mode.

\textsuperscript{1}This work was supported by DOE OFES HEDP Grant.
**GP8.00101** Nonlinear growth and damping rates of a plasma wave\(^1\), DIDIER BENISTI, CEA, DAM, DIF — We provide, within the same theoretical framework, a full description of the nonlinear stage of the beam-plasma instability and the derivation of the nonlinear Landau damping rate of a plasma wave. The latter issue is addressed whether the duration of the plasma pulse is long or comparable to the plasma period. Therefore, the present work generalizes previous derivations of the nonlinear Landau damping rate of an electron plasma wave [1], that were only for slowly varying waves, as those generated by Raman scattering in a laser fusion device. Such a generalization is needed to address backward Raman amplification, and to discuss how nonlinear effects may enlarge the parameter window for amplification of short wave lengths [2].


**GP8.00102** LOW TEMPERATURE PLASMA SCIENCE AND ENGINEERING —

**GP8.00103** Numerical Confirmation of the Dramatically Reduced Secondary Electron Emission Yield of Velvet-like Surfaces\(^1\), C. SWANSON, I.D. KAGANOVICH, Y. RAITSES, Princeton Plasma Physics Laboratory, Princeton, NJ 08543 — Recent experimentation with Hall Thrusters [1] has shown that the effective secondary electron emission yield of Hall Thruster walls is dramatically reduced by application of velvet-like fibers to the walls. This secondary electron emission suppression is presumably due to re-collision of secondary electrons with the fibers before emitted electrons can return to plasma. A numerical evolution of the resulting electron velocity distribution function of emitted electrons returning to the plasma was performed for this surface geometry, and the results were benchmarked against analytic calculations and experimental findings.


\(^1\)This research was supported by AFOSR and DOE.

**GP8.00104** Gradient Drift Instabilities in Two Dimensional Hybrid Hall Thruster Simulations\(^1\), JACOB ALEY, CALEB DOWDY, EDUARDO FERNANDEZ, Eckerd College — Instabilities triggered by a variety of mechanisms have been theoretically predicted for Hall thruster plasmas. Experimentally, fluctuations spanning a wide range of frequencies and wave numbers have been observed. Perhaps more importantly, fluctuations have been postulated to play a role in regulating cross-field electron transport in Hall thrusters. However, a clear understanding of what instabilities are responsible for transport is currently lacking. In this work we focus on analysis of long wavelength gradient drift instability in the Hall thruster via two dimensional hybrid fluid-PIC simulations that resolve azimuthal dynamics. Recent theoretical analysis by Frias et al. shows that previous stability criteria for drift instabilities are modified due to compressibility of the electron flow. In our simulations, we test this improved criterion by examining the transient waves that emerge in the simulation from a smooth initial condition. The simulations give good agreement with the theory, both in the frequency/growth rate characteristics of the waves as well as the region of the thruster where such disturbances are predicted to emerge. These results suggest that gradient drift instabilities play a significant role in Hall thruster plasmas.

\(^1\)Caleb Aley, Caleb Dowdy, and Eduardo Fernandez are supported by a grant from the II-VI Foundation.

**GP8.00105** Saturated Fluctuations and Transport in Axial, Azimuthal Hybrid Hall Thruster Simulations\(^1\), CALEB DOWDY, JACOB ALEY, EDUARDO FERNANDEZ, Eckerd College — Simulation studies of Hall thrusters aimed at describing the global domain typically employ hybrid schemes instead of more expensive kinetic approaches. Such simulations are generally in the radial and axial coordinates, assuming axisymmetry in order to circumvent azimuthal dynamics. Cross-field electron transport is enhanced (in an ad-hoc manner) in order to sustain the plasma and produce simulation profiles in semi-quantitative agreement with experimental measurements. In this work we present results from an axial/azimuthal hybrid fluid-PIC model of Hall thrusters that treats the azimuthal dynamics self-consistently, without employing ad-hoc transport parameters. Unlike previous simulation efforts with this model, the current work has succeeded at obtaining fully saturated states at high voltage, resolving the longest (breathing mode) timescales in the system. Equilibrium profiles and fluctuations predicted by the simulation will be presented. The latter are analyzed in terms of their frequency and propagation characteristics, as well as their contribution to transport. Linear stability theory is used to comment on the possible origin of the disturbances. Finally, the role of EXB flow shear on the potential regulation of fluctuation-induced electron transport is discussed.

\(^1\)Caleb Dowdy, Jacob Aley and Eduardo Fernandez are supported by a grant from the II-VI Foundation.

**GP8.00106** Study of Breathing Oscillations in a Hall Thruster\(^1\), SCOTT KELLER, YEVGENY RAITSES, AHMED DIALLO, Princeton Plasma Phys Lab — Breathing oscillations are the most powerful low frequency (10-30 kHz) oscillations that are typically observed in different types of Hall thrusters [1,2]. We report on investigations of the effects of both natural and artificially driven breathing oscillations on the discharge and plasma properties of a cylindrical Hall thruster. In order to produce artificially coherent oscillations, a sinusooidal modulation up to 30 V\(_{AC}\) of the anode potential in the range of 5-30 kHz is applied to the thruster. These driven modes are studied in operating regimes with and without naturally occurring oscillations. The imposed periodicity allows for measurement of the time-dependent ion velocity distribution through a novel heterodyne approach to laser-induced fluorescence (LIF) using phase-sensitive detection. Further comparison between natural and driven modes is performed through the analysis of the discharge and ion currents, as well as high-speed imaging data. Results serve both to validate the LIF technique and to improve understanding of breathing oscillations. In particular, we show oscillations of the ion velocity distribution function due to breathing oscillations and explain their correlation with oscillations of the discharge and ion currents.


\(^1\)This work was supported by DOE contract DE-AC02-09CH11466.

**GP8.00107** Time-Averaged and Oscillatory Characterization of a Hall Plasma Discharge, CHRIS V. YOUNG, ANDREA LUCCA FABRIS, NICOLAS GASCON, MARK A. CAPPELLI, Stanford Univ — We characterize a 70 mm diameter stationary plasma thruster operating on xenon at 200-500 W using nonintrusive laser measurements. This study resolves both time-averaged properties and oscillatory phenomena in the plasma discharge. Specifically, we explore how the plume ion velocity field evolves in time with respect to periodic discharge current oscillations using time-synchronized laser induced fluorescence (LIF) techniques. In this LIF scheme, a triggered signal acquisition gate is locked at a given phase of the current oscillation period, allowing for drift in the oscillation. The laser is modulated at a characteristic frequency and the induced fluorescence signal is extracted out of the bright background emission using homodyne detection with a lock-in amplifier.
GP8.00108 Incorporating a Turbulence Transport Model into 2-D Hybrid Hall Thruster Simulations, EUNSUN CHA, MARK A. CAPPELLI, Stanford Univ, EDUARDO FERNANDEZ, Eckerd College — 2-D hybrid simulations of Hall plasma thrusters that do not resolve cross-field transport-generating fluctuations require a model to capture how electrons migrate across the magnetic field. The simulations treat the electrons as a fluid and the heavy species (ions/neutral) as discrete particles. The transport model assumes that the turbulent eddy cascade in the electron fluid to smaller scales is the primary means of electron energy dissipation. Using this model, we compare simulations to experimental measurements of the plasma temperature, electron density, and ion velocities. The results agree favorably with experiments, where a simple Bohm transport model tends to perform poorly in capturing much of the discharge behavior.

GP8.00109 Experimental investigation of drift instabilities in ExB discharges, NICOLAS GASCON, CHRIS V. YOUNG, ANDREA LUCCA FABRIS, Stanford Univ, TSUYOHITO ITO, Osaka University, MARK A. CAPPELLI, Stanford Univ — Drift plasma instabilities are characterized in three ExB discharges operating on noble gases: two Hall-type plasma thrusters with ionizing channel walls (70mm outer diameter, 20 mm long, and 90mm outer diameter, 80mm long), and a small magnetron discharge (5mm diameter). Plasma instabilities in the ExB discharges are investigated using arrays of electrostatic probes. The signals from the probes arrays are processed with wavelet filtering, and frequency–wavelength dispersion analysis tools. Results are compared to hybrid PIC-fluid axial azimuthal simulations and analyzed in light of recent theories of gradient-driven drift instabilities, in an effort to better understand the relation between drift instabilities and anomalous electron transport in these discharges.

GP8.00110 Low-temperature plasma simulations with the LSP PIC code, JOHAN CARLSSON, ALEX KHRABOV, IGOR KAGANOVICH, PPPL, DAVID KEATING, UC Berkeley, SVETLANA SELEZNEVA, TIMOTHY SOMMERER, GE Global Research — The LSP (Large-Scale Plasma) PIC-MCC code has been used to simulate several low-temperature plasma configurations, including a gas switch for high-power AC/DC conversion, a glow discharge and a Hall thruster. Simulation results will be presented with an emphasis on code comparison and validation against experiments. High-voltage, direct-current (HVDC) power transmission is becoming more common as it can reduce construction costs and power losses. Solid-state power-electronics devices are presently used, but it has been proposed that gas switches could become a compact, less costly, alternative. A gas-switch conversion device would be based on a glow discharge, with a magnetically insulated cold cathode. Its operation is similar to that of a sputtering magnetron, but with much higher pressure (0.1 to 0.3 Torr) in order to achieve high current density. We have performed 1D (axial) and 2D (axial/radial) simulations of such a gas switch using the LSP. The 1D results were compared with results from the EDIPIC code. To test and compare the collision models used by the LSP and EDIPIC codes in more detail, a validation exercise was performed for the cathode fall of a glow discharge. We will also present some 2D (radial/azimuthal) LSP simulations of a Hall thruster.

GP8.00111 Influence of power on the surface loss reaction of F radicals in a low pressure CF$_4$:O$_2$ ICP discharge, MAHSA SETAREH, MORTZEFA FARNIA, ALI MAGHARI, University of Tehran, UNIVERSITY OF TEHRAN TEAM — A zero dimensional modeling code Global_kin, developed by Kushner is applied to model the CF$_4$/O$_2$ radio frequency inductively coupled plasma at applied powers of 80–300W, pressure of 25mTorr and temperature of 400K. The calculated results indicated that the Fluorine (F) is the dominant radical produced in CF$_4$:O$_2$ discharge which is lost mostly at the walls rather than in formation of F$_2$ molecules. We calculated the time integrated rate of F loss at the wall together with the relative contribution of wall reactions on the total loss of F corresponding to the sticking probabilities. The model predicts that the absolute time integrated loss rates at the walls increase with power, but the relative contribution of the wall loss process decreases slightly upon higher powers. Furthermore, at lower O$_2$ contents (or high CF$_4$ contents), the relative contribution of the wall loss process is much lower because F radicals can also get lost in reactions with other plasma species such as CF$_4$ to form again CF$_4$. At equal contents of O$_2$ and CF$_4$, 35–45% of the F radicals are lost at the wall, depending on the power. The numerical modeling results for CF$_4$ decomposition into new products are validated based on experimental data from literature.

GP8.00112 Modification of polypropylene foils by low pressure oxygen plasma and its influence on the formation of titanium dioxide films, RAFAŁ SADOWSKI, WOJCIECH MACYK, Faculty of Chemistry, Jagiellonian University, Kraków, Poland — Commercially available polypropylene foils were pre-treated with low pressure, room temperature radio frequency (RF) oxygen plasma at constant power and pressure. Various durations of pre-treatment process were applied. Afterwards the samples were covered with titanium dioxide thin film by dip-coating technique and photo-sensitized by titanium(IV) surface complexes formed upon impregnation with catechol-like ligands. Optical emission spectroscopy (OES) measurements were used for determining plasma species. The surface properties before and after plasma treatment were characterized by contact angle measurements, FTIR-ATR, UV-Vis, and X-ray photoelectron spectroscopy (XPS). Titanium dioxide thin films were characterized by scanning electron microscopy (SEM) and UV-Vis spectroscopy. The photoactivity of TiO$_2$ films was tested by photocurrent measurements. It was shown that plasma pre-treatment is essential for oxygen groups formation which contribute to titanium dioxide binding to polymer surface.

GP8.00113 A high voltage nanosecond pulser with independently adjustable output voltage, pulse width, and pulse repetition frequency, JAMES PRAGER, TIMOTHY ZIEMBA, KENNETH MILLER, JOHN CARSCADDEN, ILIA SLOBODOV, Eagle Harbor Technologies — Eagle Harbor Technologies (EHT) is developing a high voltage nanosecond pulser capable of generating microwave and non-equilibrium plasmas for plasma medicine, material science, enhanced combustion, drag reduction, and other research applications. The EHT nanosecond pulser technology is capable of producing high voltage (up to 60 kV) pulses (width 20 – 500 ns) with fast rise times (<10 ns) at high pulse repetition frequency (adjustable up to 100 kHz) for CW operation. The pulser does not require the use of saturable core magnets, which allows for the output voltage, pulse width, and pulse repetition frequency to be fully adjustable, enabling researchers to explore non-equilibrium plasmas over a wide range of parameters. A magnetic compression stage can be added to improve the risetime and drive lower impedance loads without sacrificing high pulse repetition frequency operation.

GP8.00114 Solutions of Boltzmann Equation for Simulation of Particle Distributions in Plasmas, JASON HAMMOND, Air Force Research Laboratory — We are investigating the time evolution of the electron and excited state distribution functions. To accomplish this, we solve the time dependent Boltzmann equation to overcome some typical limitations of modeling high pressure plasmas using Monte Carlo methods. Here we focus on the numerical approach to solving the time dependent Boltzmann equation using a multi-term approximation of the electron distribution function. We also compare Boltzmann results for electron distribution evolution against multiple plasma simulations using experimental collisional cross-section data.
Development of a laser diagnostic using Raman and Thomson scattering in atmospheric microplasma sources1. BRADLEY SOMMERS, STEVEN ADAMS, Air Force Research Laboratory — A laser scattering system utilizing a triple grating spectrometer and a 266 nm ultraviolet laser has been developed in order to investigate Rayleigh, Raman, and Thomson scattering within atmospheric plasma sources. Such laser scattering interactions offer a non-invasive technique for investigating atmospheric microplasma sources, which have potential applications in remote optical sensing, materials processing, and environmental decontamination. In this work, laser scattering measurements were performed on atmospheric discharges composed of nitrogen and air. The laser signal was calibrated using a heated nitrogen vacuum cell held at atmospheric pressure. Preliminary temperature measurements were performed on a D.C. microdischarge operating in normal glow mode. This provides a non-thermal plasma in which the translational, rotational, vibrational and electron temperatures are not in equilibrium. All gas temperatures were calculated by fitting simulated scattering spectra to the experimental data obtained using the triple grating spectrometer. Measured temperatures were also compared with those obtained using standard optical emission spectroscopy methods.

1Special thanks to the NRC Research Associateship Program

GP8.00117 Self-Organization of Plasma and Material Processes in the Carbon Arc Discharge1. YEVGENY RAITSES, JONATHAN NG, Princeton Plasma Phys Lab — The atmospheric pressure carbon arc in helium is an important method for the production of nanomaterials [1]. Typical arcs operate in a dc mode between a graphite anode, which is consumed, and a cathode which may be a lower melting point material, which remains undamaged [2,3]. During the arc operation, a carbon deposit is formed on the cathode surface and plays a crucial role in conducting the arc current. Temperature measurements demonstrate that a sufficiently large area of the cathode deposit is hot enough for thermionic emission to be the source of most of the arc current [4,5]. Structural evaluation of the carbon deposit and an analysis of the energy balance at the anode and the arc-cathode interface suggest that the evaporation of the graphite anode and formation of the carbon deposit on the cathode are self-organized to maintain the current conduction in the arc and can probably be generalized for other arc synthesis methods with consumed anodes [5].

1This work was supported by DOE contract DE-AC02-09CH11466.

GP8.00118 Investigation of Sterilization Effect by various Gas Plasmas and Electron Microscopic Observation of Bacteria. YOTA SASAKI, TOSHIHIRO TAKAMATSU, KODAI UEHARA, TAKAYA OSHITA, HIDEKAZU MIYAHARA, AKITOHI OKINO, KEIKO IKEDA, YURIKO MATSUMURA, ATSUO IWASHI, MASAHARU KOHNO, Tokyo Institute of Technology — Atmospheric non-thermal plasmas have attracted attention as a new sterilization method. It is considered that factor of plasma sterilization are mainly reactive oxygen species (ROS). However, the sterilization mechanism hasn’t been investigated in detail because conventional plasma sources have a limitation in usable gas species and lack variety of ROS. So we developed multi-gas plasma jet which can generate various gas plasmas. In this study, investigation of sterilization effect by various gas plasmas and electron microscopic observation of bacteria were performed. Oxygen, nitrogen, carbon dioxide, argon and air were used as plasma gas. To investigate gas-species dependence of sterilization effect, S.aureus was treated. As a result, nitrogen plasma and carbon dioxide plasma were effective for sterilization. To investigate sterilization mechanism, the surface of S.aureus was observed by scanning electron microscope. As a result, dimples were observed on the surface after irradiation of nitrogen plasma, but no change observed in the case of carbon dioxide plasma. These results suggest that bactericidal mechanism of nitrogen and carbon dioxide plasma should be different. In the presentation, Measurement result of ROS will be reported.

GP8.00119 ABSTRACT WITHDRAWN –

GP8.00120 Comparison of short-lived medical isotopes activation by laser thin target induced protons and conventional cyclotron proton beams. JOSEPH MURRAY, GALINA DUDNIKOVA, TUNG-CHANG LIU, DENNIS PAPADOPOULOS, ROALD SAGEDEV, J.J. SU, Dept. of Physics, Univ. of Maryland, UMD MICROPET TEAM — Production diagnostic or therapeutic nuclear medicines are either by nuclear reactors or by ion accelerators. In general, diagnostic nuclear radioisotopes have a very short half-life varying from tens of minutes for PET tracers and few hours for SPECT tracers. Thus supplies of PET and SPECT radiotracers are limited by regional production facilities. For example 18F-fluorodeoxyglucose (FDG) is the most desired tracer for positron emission tomography because its 110 minutes half-life is sufficient long for transport from production facilities to nearby users. From nuclear activation to completing image taking must be done within 4 hours. Decentralized production of diagnostic radioisotopes will be idea to make high specific activity radiotracers available to researches and clinicians. 11C, 13N, 15O and 18F can be produced in the energy range from 10-20 MeV by protons. Protons of energies up to tens of MeV generated by intense laser interacting with hydrogen containing targets have been demonstrated by many groups in the past decade. We use 2D PIC code for proton acceleration, Geant4 Monte Carlo code for nuclei activation to compare the yields and specific activities of short-lived isotopes produced by cyclotron proton beams and laser driven protons.

Tuesday, October 28, 2014 9:30AM - 12:30PM –
Session GM9 Mini-Conference: Van Allen 100: Radiation Belt Physics — Salon ABC - Stanslav Boldyrev,
University of Wisconsin
indicate the direction of propagation for each of these waves. The experiment supports the theory of electromagnetic whistler wave generation through nonlinear electrons. Measurements of the magnetic field vectors for the pump and daughter waves allow for the determination of wave distribution functions, which magnetospheric conditions. Experiments conducted in the SPSC have demonstrated induced nonlinear scattering of quasi-electrostatic pump waves by thermal contributors to radiation belt dynamics. Given sufficient whistler energy density, nonlinear scattering from thermal electrons can substantially change the wave GURU GANGULI, Naval Research Lab, LEONID RUDAKOV, Icarus Research Inc — Nonlinear interactions involving whistler wave turbulence are important to radiation belt dynamics. Given sufficient whistler energy density, nonlinear scattering from thermal electrons can substantially change the wave normal angle, while inducing a small frequency shift. This nonlinear process is being studied in the NRL Space Physics Simulation Chamber (SPSC) in scaled magnetospheric conditions. Experiments conducted in the SPSC have demonstrated induced nonlinear scattering of quasi-electrostatic pump waves by thermal electrons. Measurements of the magnetic field vectors for the pump and daughter waves allow for the determination of wave distribution functions, which indicate the direction of propagation for each of these waves. The experiment supports the theory of electromagnetic whistler wave generation through nonlinear scattering of electrostatic lower hybrid waves by thermal electrons in the Earth’s magnetosphere.

This work is supported by the NRL base program.

10:05AM GM9.00002 Observations of Whistler-Mode Chorus with Van Allen Probes, WILLIAM KURTH, GEORGE HOSPODARSKY, University of Iowa, ONDREJ SANTOLIK, Institute of Atmospheric Physics and Charles University, Prague, Czech Republic, CRAIG KLETZING, SCOTT BOUNDS, University of Iowa — The Van Allen Probes mission provides an excellent opportunity to observe whistler-mode chorus and its role in the radiation belts. The plasma wave instrument on the two probes, called Waves, includes six identical waveform receivers covering the frequency range from 10 Hz to 12 kHz. The instrument measures three orthogonal magnetic field components and three orthogonal electric field components of waves. This complement supports wave-normal and Poynting flux analyses of chorus as well as other wave modes that interact with radiation belt particles. Extensive use of burst modes provides multicomponent waveforms enabling the study of individual chorus elements, including their substructure. The early-mission publications confirm the importance of chorus to the local acceleration of electrons in the outer radiation belts. The orbital precession of the twin Van Allen Probes through a complete range of local times now allows for a new survey of the distribution of chorus emissions. Hence, we now have the tools to study chorus from the nonlinear growth in chorus element substructures through synoptic studies of the near-equatorial occurrence of chorus out to a distance of approximately 5.8 Earth radii.

10:40AM GM9.00003 Generation mechanism of whistler-mode chorus emissions, YOSHIHARU OMURA, Research Institute for Sustainable Humanosphere, Kyoto University — There has been significant progress in understanding the generation mechanism of whistler-mode chorus emissions in recent years. This is partly due to the successful reproduction of chorus emissions by computer simulations and partly due to the precise observatory of the emissions by spacecraft. We review nonlinear theory and simulations on the generation mechanism of chorus emissions that have been revealed by the simulations and observations. We describe the nonlinear dynamics of resonant electrons and the formation of electromagnetic electron holes or hills that result in resonant currents generating rising-tone emissions or falling-tone emissions, respectively. Each chorus element comprises many sub-packets in which nonlinear wave growth takes place above the threshold amplitude and saturates at the optimum wave amplitude for triggering emissions. We also describe the mechanism of nonlinear wave damping due to quasi-oblique propagation, which results in formation of a gap at half the electron cyclotron frequency, separating a single chorus element generated at the magnetic equator into upper band and lower band elements in off-equatorial regions.

11:15AM GM9.00004 A model for falling tone chorus in the Earth’s magnetosphere, A. RUALDO SOTO-CHAVEZ, GE WANG, AMITAVA BHATTACHARJEE, GUO-YONG FU, Princeton Univ, HAKAN SMITH, Max Planck Institute for Plasma Physics — Motivated by the fact that geomagnetic field inhomogeneity is weak close to the chorus generation region and the observational evidence that falling-tone chorus tend to have large oblique angles of propagation, we present a new model for falling-tone chorus in which we propose that they start as a marginally unstable mode. The marginally unstable mode requires the presence of a relatively large damping, which has its origins in the Landau damping of oblique waves in this collision-less environment. A marginally unstable mode produces phase-space structures that release energy changing its frequency content. We show that the present model produces results in reasonable agreement with observations.

11:40AM GM9.00005 Nonlinear Scattering of VLF Waves in the Radiation Belts, CHRIS CRABTREE, Naval Research Laboratory, LEONID RUDAKOV, Icarus Research, GURU GANGULI, MANISH MITHAIWALA, Naval Research Laboratory — Electromagnetic VLF waves, such as whistler mode waves, control the lifetime of trapped electrons in the radiation belts by pitch-angle scattering. Since the pitch-angle scattering rate is a strong function of the wave properties, a solid understanding of VLF wave sources and propagation in the magnetosphere is critical to accurately calculate electron lifetimes. Nonlinear scattering (Nonlinear Landau Damping) is a mechanism that can strongly alter VLF wave propagation [Ganguli et al. 2010], primarily by altering the direction of propagation, and has not been accounted for in previous models of radiation belt dynamics. Laboratory results have confirmed the dramatic change in propagation direction when the pump wave has sufficient amplitude to exceed the nonlinear threshold [Tejero et al. 2014]. Recent results show that the threshold for nonlinear scattering can often be met by naturally occurring VLF waves in the magnetosphere, with wave magnetic fields of the order of 50-100 pT inside the plasmapause. Nonlinear scattering can then dramatically alter the macroscopic dynamics of waves in the radiation belts leading to the formation of a long-lasting wave-variety (Crabtree et al. 2012) and, when amplification is present, a multi-pass amplifier [Ganguli et al. 2012]. By considering these effects, the lifetimes of electrons can be dramatically reduced.

This work is supported by the NRL base program.

12:05PM GM9.00006 Nonlinear Generation of Electromagnetic Waves Through Induced Scattering by Thermal Electrons, ERIK TEJERO, CHRIS CRABTREE, DAVID BLACKWELL, BILL AMATUCCI, MANISH MITHAIWALA, GURU GANGULI, Naval Research Lab, LEONID RUDAKOV, Icarus Research Inc — Nonlinear interactions involving whistler wave turbulence are important contributors to radiation belt dynamics. Given sufficient whistler energy density, nonlinear scattering from thermal electrons can substantially change the wave normal angle, while inducing a small frequency shift. This nonlinear process is being studied in the NRL Space Physics Simulation Chamber (SPSC) in scaled magnetospheric conditions. Experiments conducted in the SPSC have demonstrated induced nonlinear scattering of quasi-electrostatic pump waves by thermal electrons. Measurements of the magnetic field vectors for the pump and daughter waves allow for the determination of wave distribution functions, which indicate the direction of propagation for each of these waves. The experiment supports the theory of electromagnetic whistler wave generation through nonlinear scattering of electrostatic lower hybrid waves by thermal electrons in the Earth’s magnetosphere.

This work is supported by the NRL base program.

Tuesday, October 28, 2014 9:30AM - 12:30PM –
Session GM10 Mini-Conference: The Magnetic Universe – A Mini-Conference in Honor of Stirling Colgate II
Salon FGH - Eric Blackman, University of Rochester

9:30AM GM10.00001 Stirling Colgate and Gamma-Ray Bursts, DONALD LAMB, Department of Astronomy and Astrophysics, University of Chicago — Even before the discovery of gamma-ray bursts (GRBs), Stirling Colgate proposed that bursts of x rays and gamma rays might be produced by a relativistic shock created in the supernova explosion of a massive star. We trace the scientific story of GRBs from their detection to the present, highlighting along the way Stirling’s interest in them and his efforts to understand them. We summarize our current understanding that short, soft, repeating bursts are produced by magnetic neutron stars; short, hard bursts are produced by the mergers of neutron star-neutron star binaries; and long, hard bursts are produced by the core collapse of massive stars that have lost their hydrogen and helium envelopes. We then discuss some important open questions about GRBs and how they might be answered. We conclude by describing the recent serendipitous discovery of an x-ray burst of exactly the kind he proposed, and the insights into core collapse supernovae and GRBs that it provided.
10:00AM GM10.00002 Generation and amplification of magnetic fields in laser-driven collisionless shocks. **FREDERICO FIUZA, WM RYUTOV,** Lawrence Livermore National Laboratory, ANATOLY SPTIKOVSKY, Princeton University, CHANNING HUNTINGTON, STEVEN ROSS, Lawrence Livermore National Laboratory, LUIZ SILVA, OPL-IPFN, Instituto Superior Tecnico, WARREN MORE, UCLA, BRUCE REMINGTON, HYE-SOOK PARK, Lawrence Livermore National Laboratory — Collisionless shocks are ubiquitous in astrophysical plasmas and are believed to play an important role in magnetic field amplification; however, the magnetic field dynamics in shocks is still poorly understood as in situ measurements are not available. Recent developments in high-power lasers are bringing the study of collisionless shocks into the realm of laboratory experiments. We have performed detailed 2D and 3D particle-in-cell simulations to explore the generation of collisionless shocks for laboratory conditions associated with counter-streaming high-velocity plasma flows. We capture all the relevant physics, which range from the generation of Biermann battery fields at the laserfoil region, to the micro-instabilities associated with the counter-streaming flows, and to the generation of turbulence at the shock. We show the generation of strong (>1%) of equipartition) magnetic fields mediated by the Weibel instability and the conversion from well-defined filaments to magnetic turbulence as the shock is formed. We identify the conditions required to observe this magnetic field dynamics in shocks for the first time in the upcoming experiments at the National Ignition Facility.

10:20AM GM10.00003 Could the universe get magnetized by galaxy cluster accretion shocks? **MIKHAIL MEDVEDEV,** University of Kansas — The origin of the micro-Gauss magnetic fields in galaxy clusters is one of the outstanding problem of modern cosmology. We propose that accretion shocks on galaxy clusters accelerate cosmic rays, which in turn are natural and inevitably generate magnetic fields from scratch via a streaming, Weibel-type plasma instability. We develop a self-similar model of a cosmic-ray-modifies foreshock and demonstrate that, in contrast to the conventional lore, the generated magnetic fields (i) are large-scale (in order of the shock curvature radius, ~ tens of kpc or more) hence they are effectively decoupled from dissipation and are long-lived on the Hubble time and (ii) are strong enough, of the order of a fraction of the cosmic ray pressure, to meet observational constraints. Unlike other shock-related models of the field generation (e.g., via the Bell instability or the Richtmeyer-Meshkov vorticity instability), our model does not require preexisting seed fields; the fields are generated in the intracluster at essentially a few cluster light-crossing times.

11:10AM GM10.00005 Formation of Hard Power-laws in the Energetic Particle Spectra Resulting from Relativistic Magnetic Reconnection. **FAN GUO, HUI LI, WILLIAM DAUGHTON, YI-HSIN LIU,** Los Alamos Natl Lab, XIAOCAN LI, University of Alabama in Huntsville — Using fully kinetic simulations, we demonstrate that magnetic reconnection in relativistic plasmas is highly efficient at accelerating particles through a first-order Fermi process resulting from the curvature drift of particles in the direction of the electric field induced by the relativistic flows. This mechanism gives to the formation of hard power-law spectra in parameter regimes where the energy density in the reconnecting field exceeds the rest mass energy density and when the system size is sufficiently large. The power law slope approaches “-1” for closed systems and gets softer when particle loss from the acceleration region is included. A simple analytic model is proposed which explains these key features and predicts a general condition under which hard power-law spectra will be generated from magnetic reconnection. We demonstrate that both continuous inflow and Fermi-type acceleration lead to the power-law distributions. Finally, we discuss the role of particle anisotropy in particle acceleration during magnetic reconnection. The work shows that hard power-law distributions are a common feature in relativistic magnetic reconnection region, which may be important for explaining the high-energy emissions in systems like pulsars, jets from black holes, and gamma-ray bursts.

11:30AM GM10.00006 Regular acceleration in magnetically-driven turbulence. **ANDREY BERESNYAK,** HUI LI, Los Alamos National Laboratory — Astrophysics and space science knows many examples of magnetically-dominated environments. Often, due to the lack of detailed measurements, we are not sure how magnetic fields are generated and how they evolve in these environments. We have shown that collisionless particles in such environments will be regularly accelerated while experiencing curvature drift. This could be applied, e.g. to the spontaneous reconnection above the solar surface that results in the heating of particles and production of non-thermal tails. Interestingly, the opposite processes, such as dynamo, will actually result in the net cooling of particles by the curvature drift. Being very generic, this acceleration mechanism is likely to be responsible in production of non-thermal particle distribution in many magnetized environments such as pulsar magnetospheres, jets from supermassive black holes, jets from imploding stars, etc.

10:40AM GM10.00004 Magnetic Field Generation and Particle Energization in Relativistic Shear Flows. **EDISON LIANG, WEN FU,** Rice University, MARKUS BOETTCHER, PARISA ROUSTAZADEH, North-West University, South Africa — This paper summarizes recent results obtained from 2 - and 3 D particle-in-cell (PIC) simulations of relativistic shear boundary layers (SBL). In addition to the creation of sustained, ordered magnetic fields due to counter-current instabilities, we find efficient energization of nonthermal electrons to high energies, making the SBL a strong candidate for enhanced synchrotron emission in relativistic jets, from blazars to gamma-ray bursts. The case of mixed electron-positron-ion shear flows is particularly interesting as it leads to the formation of an electron spectrum with both a high-energy peak near the ion kinetic energy, plus a hard power-law tail of slope near −3, which strongly resembles electron distributions responsible for the emissions of GRB and blazars. The electron momentum distribution exhibits extreme anisotropy, making the SBL a strong candidate for narrowly beamed synchrotron-self-Compton (SSC) radiation in some cases.

12:10PM GM10.00007 Ion Acceleration by Magnetic Pinch Instabilities– Powerful Neutron Sources **ANNA HAYES, HUI LI,** Los Alamos Natl Lab — Since the 1950s pinch discharges with deuterium gas have been known to produce large neutron bursts. During these early quests for laboratory fusion it was initially believed that the heat produced in the pinch led to sufficiently high temperatures that these neutrons resulted from thermonuclear (TN) burn. However, a series of careful measurements led by Stirling Colgate was carried out to show that these neutrons did not result from TN burn. Rather, they resulted from an m=0 sausage mode instability that accelerated the ions, causing beam-target interactions. Today, this same mechanism is used in dense plasma focus machines to generate intense neutron pulses for neutron activation experiments. One such experiment, to test the criticality of aging plutonium, is currently being planned at the Nevada Test Site. Helping to characterize the neutrons from the dense plasmas focus to be used in this large experiment was the last applied physics project that Stirling work on. In this talk we will summarize the physics issues involved both in the original discovery in the 1950s and in today’s experiments.
Tuesday, October 28, 2014 1:00PM - 2:00PM –
Session HE1 Town Meeting on Concerns of Junior Scientists Carondelet - Timothy Tharp, University of California, Berkeley

1:00PM HE1.00001 Town Meeting on Concerns of Junior Scientists –

Tuesday, October 28, 2014 2:00PM - 5:00PM –
Session JI1 ITER Physics Acadia - Chuck Greenfield, General Atomics

2:00PM JI1.00001 Narrow limiter SOL power channels and their impact on ITER first wall shaping , MARTIN KOCAN, ITER Organization — Until recently, it was generally accepted that the profile of parallel heat flux density in the SOL of limited tokamak plasmas can be well approximated by a single exponential with decay length $\lambda_\parallel$. This popular belief was emphatically shown to be erroneous in 2012, when IR measurements on the inner column of JET limiter discharges revealed the presence of a narrow heat flux channel adjacent to the last closed flux surface, resembling a feature seen elsewhere two decades ago, but never seriously pursued by the edge physics community. This near-SOL decay occurs with $\lambda_\parallel$ few mm, much shorter than the main SOL $\lambda_\perp$, and can raise the heat flux at the limiter apex a factor 1-4 above the value expected from a single, broad exponential. The JET observations were of great practical consequence, demonstrating that the logarithmically-shaped ITER inner wall (IW), foreseen as a limiter surface for plasma start-up, would be unsuited to handling the power loads produced by such a narrow feature. Alerted by this JET data, the ITER Organization (IO) initiated a multi-machine effort to examine this new physics, with the C-Mod, DIII-D, COMPASS and TCV tokamaks all finding the narrow heat flux channel in dedicated experiments. This talk will describe how these new data are helping to unravel the physics of the narrow feature and how they have provided a strong enough basis for the IO to modify the IW toroidal shape profile. The new IW shape is optimized for a double-exponential profile with $\lambda_\parallel = 4$ and 50 mm, both derived from multi-machine databases for the near and main-SOL features. It has the interesting property of mitigating the impact of the narrow feature, whilst paying no penalty if the latter is not eventually found in ITER. If it were, and without the modification, IWL limiter operation up to several MA, as required by the ITER Heat Load Specifications, would not be possible. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

2:30PM JI1.00002 Impurity transport experiments in Alcator C-Mod to address high priority R and D for ITER* , MATTHEW REINKE, University of York — The decision to start ITER operation in the non-active phase (H/He plasmas) with a W divertor has brought increased attention to physics issues related to high Z impurity transport and control. Lack of impurity control would lead to the radiative collapse of plasmas by W accumulation and increased disruptivity, which is detrimental to ITER operation. Prediction of plasma contamination by high Z impurities in ITER and its control requires understanding of W production and transport in the SOL through the edge transport barrier (in H-mode) and into the core plasma in conditions as similar as possible to those in ITER. Experiments in Alcator C-Mod have been carried out to understand these physics processes and their control in electron heated (ICRH+LHCD) L-mode and H-mode plasmas without significant core particle or momentum sources as in ITER. Core transport of impurities injected by laser blow off in L-modes shows that, in the absence of sawteeth, W develops stationary peaked profiles (for 100s of ms vs. $\tau_\gamma = 14$ ms) while lower Z impurities (e.g. Ar) do not. Sawteeth are observed to be very effective in flushing out W on timescales of the sawtooth period (=10 ms) in these L-mode plasmas. Injection of Ca shows that the impurity diffusivity in the core plasma decreases by a factor of 10 in H-mode with respect to L-mode and that an inwards pinch is necessary at the H-mode edge to match observed increases in impurity confinement time in H-mode, up a factor of 5-50 compared to L-mode. Initial results of impurity transport in He L-mode plasmas show similar results to D plasmas. The results of these and other ongoing C-Mod experiments (including impurity transport and impurity peaking control by heating sources (magnitude, fast particle population, radial location, etc.) in H-mode plasmas with ITER-like peaked density profiles and $T_e = T_i$) will be described and consequences for ITER impurity transport control will be drawn. Supported by the US DOE under DoE Contract No. DE-FC02-99ER54512.

3:00PM JI1.00003 The Quiescent H-mode Regime for High Performance ELM-Stable Operation in Future Burning Plasmas, A.M. GAROFALO, General Atomics — Recent experiments on DIII-D have increased confidence in the ability to achieve high confinement, ELM-stable operation on ITER through implementation of the quiescent H-mode (QH-mode) regime. By tailoring the plasma shape to improve the edge stability, the QH-mode operating space has been extended to densities exceeding 70% of the Greenwald limit, overcoming the long-standing low-density limit of QH-mode operation. In addition, the simultaneous achievement of QH-mode at ITER relevant values for beta, confinement, and safety factor sustained for many energy confinement times in an ITER similar shape has been demonstrated for the first time. QH-mode provides excellent energy confinement, even at near zero plasma rotation, while operating without ELMs and with strong impurity transport via the benign edge harmonic oscillation (EHO). Peeling-ballooning theory of the plasma edge explains the EHO as a saturated kink-peeling mode, and predicts that ITER will operate in the edge regime where QH-mode can exist. In the theory, the density range over which the plasma encounters the kink-peeling boundary widens as the plasma cross-section shaping is increased, thus increasing the QH-mode density threshold. The DIII-D results are in excellent agreement with these predictions, and non-linear MHD analysis of reconstructed QH-mode equilibria shows unstable low n kink-peeling modes growing to a saturated level, consistent with the theoretical picture of the EHO. Furthermore, high density operation in the QH-mode regime has opened a path to a new, previously predicted region of parameter space dubbed “Super-H-mode,” characterized by very high pedestals that can be more than a factor of two above the peeling-ballooning stability limit for similar ELMing H-mode discharges at the same density.

1Supported by the US Department of Energy under DE-FC02-04ER54698.
The High-$\beta_H$ Hybrid Scenario for ITER and FNSF Steady-State Mission$^1$. FRANCESCAS TURCO, Columbia University — New experiments on DIII-D have demonstrated the steady-state potential of the hybrid scenario, with 1 MA of plasma current driven fully noninductively and $\beta_H$ up to 2.7 for ~3 s (~1 current diffusion time, $\tau_{\text{RD}}$, in DIII-D), providing the basis for an attractive option for steady-state operation in ITER and FNSF. Excellent confinement is achieved ($H_{\text{98%}2} \sim 1.6$) without performance limiting tearing modes. The usual Advanced Tokamak (AT) approach relies on a large fraction of off-axis current drive and careful current drive alignment to reach $\beta_H > 2$ and high bootstrap current (~70%). In contrast, the hybrid regime overcomes the need for off-axis current drive efficiency, taking advantage of the poloidal magnetic flux pumping, believed to be the result of a saturated 3/2 tearing mode, to produce a self-organized current density profile. This allows for efficient current drive close to the axis, without deleterious sawtooth instabilities. In these new experiments, the edge surface loop voltage is driven down to zero for $\Delta N > 4.5$. For the first time, off-axis NBI power has been used to broaden the pressure and current profiles in this scenario, seeking to take advantage of higher predicted kink stability limits and lower values of tearing stability index $\Delta_n$, as calculated by the DCON and PEST3 codes. Preliminary results based on measured profiles predict ideal limits at $\Delta N \sim 4.5$. With collisionality and edge safety factor values comparable to those envisioned for ITER and FNSF, the high-$\beta_H$ hybrid represents an attractive high performance option for the steady-state missions of these devices.

$^1$Supported by the US Department of Energy under DE-FG02-04ER54761 and DE-FG02-04ER54698.

4:00PM JI1.00005 Improved confinement in ELM-suppressed high-density H-modes at the ITER field via modification of the plasma boundary with Lower Hybrid RF$^{1,2}$, J.L. TERRY, MIT-PSFC — Injecting Lower Hybrid (LH) power into Alcator C-Mod’s high-density H-mode plasmas has enhanced global confinement by increasing pedestal temperature gradients, modifying edge rotation, and decreasing edge and SOL turbulence. These new experiments indicate that edge LHRF can be used as a tool to increase confinement via direct modification of boundary quantities. Ray-tracing modeling and accessibility calculations for the LH waves indicate that the LH waves do not penetrate to regions inside the top of the pedestal and are not driving current in these plasmas; instead the LH power modifies the boundary conditions. When moderate amounts of LH power ($P_{\text{LH}}/P_{\text{NBI}} = 20\%$) are applied to high-density EDA H-modes ($n_e = 3.5 \times 10^{19}$ m$^{-3}$), we observe the following effects: edge/SOL fluctuation power decreases by roughly an order of magnitude; pedestal temperature gradients are increased; global energy confinement time and H-factor increase by 30-40% ($\text{H}_{\alpha 0.05}$ from 0.7 to 1.0); co-current core and pedestal rotation velocities increase; power to the (outer) divertor target increases promptly with an increment that is roughly 1/2 of the injected LH power, qualitatively consistent with the inaccessibility of the LH waves; and the central frequency of the edge-localized Quasi-Coherent Mode down-shifts and becomes much more coherent. These H-mode confinement improvements brought about by the edge LHRF are the result of changes in the pedestal (e.g., changes in rotation/shear and increased pedestal temperature gradients), with no substantial change in peaking of core density or temperature profiles. There is not perfect correlation with edge turbulence suppression, indicating that the turbulence decrease may be a necessary, but not sufficient, condition for the pedestal and confinement improvements.

$^1$Supported by US DoE awards DE-FC02-99ER54512 and DE-AC02-09CH11466.

4:30PM JI1.00006 Impact of the plasma response in three-dimensional edge plasma transport modelling for RMP ELM control scenarios at ITER$^1$, OLIVER SCHMITZ, Univ of Wisconsin, Madison — The constrains used in magneto-hydrodynamic (MHD) modeling of the plasma response to external resonant magnetic perturbation (RMP) fields have a profound impact on the three-dimensional (3-D) shape of the plasma boundary induced by RMP fields. In this contribution, the consequences of the plasma response on the actual 3D boundary structure and transport during RMP application at ITER are investigated. The 3D fluid plasma and kinetic neutral transport code EMC3-Eirene is used for edge transport modeling. Plasma response modeling is conducted with the M3D-C1 code using a single fluid, non-linear and a two fluid, linear MHD constrain. These approaches are compared to results with an ideal MHD like plasma response. A 3D plasma boundary is formed for all cases consisting of magnetic finger structures at the X-point intersecting the divertor surface in a helical footprint pattern. The width of the helical footprint pattern is largely reduced compared to vacuum magnetic fields when using the ideal MHD like screening model. This yields increasing peak heat fluxes in contrast to a beneficial heat flux spreading seen with vacuum fields. The particle pump out as well as loss of thermal energy is reduced by a factor of two compared to vacuum fields. Reduced compared to vacuum magnetic fields when using the ideal MHD like screening model. This yields increasing peak heat fluxes in contrast to a beneficial heat flux spreading seen with vacuum fields. The particle pump out as well as loss of thermal energy is reduced by a factor of two compared to vacuum fields.

$^1$Supported by ITER grant IO/CT/11/4300000497 and F4E grant GRT-055 (PMS-PE) and by Start-Up Funds of the University of Wisconsin - Madison.

Tuesday, October 28, 2014 2:00PM - 3:00PM
Session JT2 Tutorial: Hydrodynamic Instabilities and Turbulent Mixing: What is It, What is Known, What is New, and What Remains to be Done? Bissonet - Mark Herrmann, Sandia National Laboratories

2:00PM JT2.00001 Hydrodynamic Instabilities and Turbulent Mixing: what is it, what is known, what is new, and what remains to be done?$^1$, DOV SHVARTS, Physics Department, Nuclear Research Center - Negev — Hydrodynamic instabilities 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 overturn of massive stellar cores in supernovae, and has affected attempts at ICF ignition. The Rayleigh-Taylor (RT) instability occurs at an accelerated interface between two fluids with the lower density accelerating the higher density fluid, and the Richtmyer-Meshkov (RM) instability occurs when a shock wave passes an interface between the two fluids. Buoyancy causes “bubbles” of the light fluid to penetrate the denser fluid, while ‘spikes’ of the heavy fluid penetrate the lighter fluid. In the deep nonlinear regime, this interpenetration evolves into turbulent mixing which has been notoriously difficult to predict quantitatively. 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: $h = \alpha_{RT} \text{Ag}^2$ for RT and $h = \alpha_{RM} \text{Ag}^4$ for RM. While this characteristic behavior has been known for about 30 years, the self-similar parameters $\alpha_{RT}$ and $\alpha_{RM}$ depend on dimensionality and density ratio have continued to be intensively studied and a relatively wide distribution of those values have emerged. A new, physically intuitive formulation of mode-coupling and bubble-competition models can yield a unified and compact description of this turbulent mixing evolution, greatly reducing the spread in $\alpha_{RT}$ and $\alpha_{RM}$. This allows building more effective engineering models for the extent of the turbulent mixing in such diverse settings as ICF capsule implosions and stellar explosions. The implications for ignition and the potential to use NIF for quantitative testing of this theoretical advance will also be discussed.

$^1$The author would like to express his deep appreciation to his many students, especially Uri Alon, Dror Ofer and Dan Oron who started the work almost more than 20 years ago, and Yonatan Elbaz, who finished it in the last year.
2:00PM JO3.00001 Wavenumber-resolved core turbulence studies in the ASDEX Upgrade tokamak and comparison with non-linear gyrokinetic simulations with the GENE code \textsuperscript{1} , TIM HAPPEL, ALEJANDRO BANÓN NAVARRO, GARRARD CONWAY, TOBIAS GÖRLER, FRANK JENKO, FRANCOIS RYTER, ULRICH STROTH, Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching, Germany — The ASDEX UPGRADE TEAM — Core plasma turbulence determines transport properties and impacts on the efficiency of a fusion reactor. Gyrokinetic codes are developed to predict dominant instabilities and the turbulence level, which causes the observed particle and heat losses. A careful validation of these codes is mandatory to improve the reliability of predictions. To this end, core turbulence is investigated in ASDEX Upgrade by means of Doppler reflectometry, which provides the perpendicular velocity of turbulent structures and their fluctuation level. H-mode discharges have been performed in which ECRH is used to drive the turbulence from the ITG turbulence regime towards the TEM regime. In general, the turbulence level increases from core towards the edge. With increasing $R/L_T$, core large scale structures show larger fluctuation amplitudes while their phase velocity is altered with respect to that of small structures. Results are compared with gyrokinetic simulations with the GENE code. Linear results show a transition from ITG towards TEM turbulence close to the radial ECRH deposition location. After matching of heat fluxes to results from power balance analysis, the radial trend in the turbulence level is reproduced. The response to additional heating is opposite to the experimental findings.

2:12PM JO3.00002 The effect of electron-ion collisionality on ETG turbulence\textsuperscript{1} , GREG COLYER, Culham Centre for Fusion Energy, ALEX SCHERKOCHIHIN, University of Oxford, COLIN ROACH, Culham Centre for Fusion Energy, MICHAEL BARNES, University of Oxford, YOUNG-CHUL GHIM, KAIST, BILL DORLAND, University of Maryland, FELIX PARRA, University of Oxford — In electrostatic simulations of MAST plasma at electron-gyroradius scales with adiabatic ions, using the local flux-tube gyrokinetic code GS2, we find that the saturated electron heat flux decreases as the electron collisionality decreases. At early simulation times the heat flux quasi-saturates at a level independent of electron collisionality; however the zonal fluctuation component continues to grow slowly until much later simulation times, eventually reducing the heat flux at low collisionality. The heat flux at the longest simulation times is the saturated level relevant to energy transport, in the gyrokinetic expansion. We outline an explanation based on zonal-nonzonal interactions and the scaling of the zonal damping rate with electron-ion collisionality, and we discuss the correlation times of the zonal and nonzonal components of the microturbulence. Improved energy confinement with decreasing collisionality has previously been observed on NSTX and MAST, and is favourable towards the performance of future, hotter devices.

2:24PM JO3.00003 The measurement of geodesic acoustic mode magnetic field fluctuations in J-TEXT tokamak\textsuperscript{1} , T. LAN, J. WU, H.G. SHEN, T.J. DENG, A.D. LIU, J.L. XIE, H. LI, W.D. LIU, C.X. YU, USTC, China, Y. SUN, H. LIU, Z.P. CHEN, G. ZHUANG, HUST, China — Geodesic acoustic mode (GAM) magnetic field oscillations have been investigated using three-dimension magnetic probe and Langmuir probe arrays in the edge of J-TEXT tokamak. The probe arrays are placed on the two top windows of tokamak, separated toroidally. Inside the LCFS, GAM shows apparent oscillations in floating potential. In contrast, GAM magnetic field oscillations are not significant in raw magnetic fields signals. Using toroidal correlation technique, the GAM magnetic field oscillations are distinguished from ambient magnetic field. The amplitudes of three dimension GAM magnetic field fluctuations, as well as the dependence with local plasma parameters such as safety factor and plasma beta, are coincident with theoretical predictions. And its toroidal symmetry mode structure, i.e. $n=0$, is identified. Furthermore, the GAM current sheet, in which GAM oscillates, is firstly verified with magnetic probes arrays in different radial positions, which may help us to understand the radial structure of GAM.

2:36PM JO3.00004 Toroidal drift modes in tokamaks: a new model for small ELMs \textsuperscript{1} , ARKAPRAVA BOKSHI, DAVID DICKINSON, HOWARD WILSON, Univ of York — Toroidal drift instabilities, such as the ion-temperature gradient (ITG) mode, are likely drivers of turbulent transport in tokamaks. Depending on the radial drive profile, two distinct mode structures can emerge: for a peaked profile, the violent Isolated Mode (IM) exists on the outboard-midplane, whereas for a linear profile, the more benign General Mode (GM) sits at the top/bottom of the plasma. The IM only exists in special conditions, so we expect the GM to usually drive turbulence. A new global code, based on an electrostatic gyrokinetic toroidal ITG model, has been developed and benchmarked to study the time-evolution of these linear modes. While we consider the ITG mode, the results are expected to be valid for most microinstabilities. A key result is that as the flow-shear evolves through a critical value, the GM evolves into the IM and then back to the GM. Curiously, the mode structure transiently passes through the violent IM phase independent of how fast the equilibrium evolves! For a pedestal evolving between ELMs, if a GM-IM-GE transition occurs, the burst in linear growth during the ELM phase could drive a small ELM. The associated transport would maintain the pedestal pressure gradient below the peeling-balloonizing limit, avoiding Type I ELMs.

2:48PM JO3.00005 TEM-turbulence in stellarators and its optimization\textsuperscript{1} , JOSEFINE H.E. PROLL, Max-Planck/Princeton Center for Plasma Physics, PER HELANDER, Max Planck Institute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany, SATANJEEV LAZERSON, HARRY MYNICK, Plasma Physics Laboratory, Princeton University, P.O. Box 451 Princeton, New Jersey 08543-0451, PAVLOS XANTHOPULOS, Max Planck Institute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany — Quasi-isodynamic stellarators, which are especially optimized for neoclassical transport, have been shown to be resilient towards trapped-electrons modes (TEMs) in large regions of parameter space. In these configurations, all particles have average “good curvature.” It was shown analytically that, thanks to this property, particles that bounce faster than the mode in question draw energy from it near marginal stability, so that the ordinary density-gradient-driven TEM has to be stable in the electrostatic and collisionless limit. This has been confirmed in linear flux-tube simulations that were performed with the GENIE code. Several magnetic field configurations were compared, and it was found that the growth rates of the TEMs drop with increasing degree of quasi-isodynamicity. These findings can be used to optimize stellarators with respect to TEM turbulence by reducing the fraction of trapped particles with bounce averaged “bad curvature.” An appropriate proxy function has therefore been designed to be implemented in STELLOPT, a stellarator optimization tool that can now be used to further explore the configuration space of neoclassically optimized stellarators with the aim to extract designs with improved turbulent transport.

\textsuperscript{1}This work was facilitated by the Max-Planck/Princeton Center for Plasma Physics.
3:00PM JO3.00006 Gyrokinetic particle simulations of kinetic ballooning mode in tokamak pedestal\(^1\), IHOR HOLOD, Univ of California - Irvine — The pedestal height and width in tokamak H-mode operation are widely believed to be constrained by mesoscale peeling-balloonning modes and microscopic kinetic ballooning modes (KBM). However, direct evidences of the KBM turbulence in pedestal are very limited. The role of the drift-Alfvenic microturbulence during the pedestal recovery period is not clear. Here we use gyrokinetic toroidal code (GTC) to study the edge instability of a DIII-D discharge \#131997 using realistic geometry and plasma profiles and focusing on the pedestal region with steep pressure gradient. First, electrostatic simulations find a reative trapped electron mode with an unusual eigenmode structure, which peaks at the poloidal angle \(\theta = \pm \pi/2\). The electron collisions decrease the growth rate by about one-half. Next, the plasma pressure is scanned in GTC electromagnetic simulations to identify the boundary for the KBM onset. At the finite electron beta an electromagnetic instability is found with KBM characteristics. The linear growth rate increases with \(\beta_e\) and the mode propagation is in the ion diamagnetic direction. Nonlinear simulations of the KBM turbulence will also be presented.

\(^1\)Work supported by DOE grant DE-SC0010416, and in collaborations with GTC team.

3:12PM JO3.00007 Gyrokinetic study of edge blobs and divertor heat-load footprint, C.-S. CHANG, S.-H. KU, M. CHURCHILL, S. ZWEBEN, PPPL — In an attempt to better understand the complicated physics of the inter-related “intermittent plasma objects (blobs)” and divertor heat-load footprint, the full-function gyrokinetic PIC code XGC1 has been used in realistic diverted geometry. Neoclassical and turbulence physics are simulated together self-consistently in the presence of Monte Carlo neutral particles. Blobs are modeled here as electrostatic nonlinear turbulence phenomenon. It is found that the “blobs” are generated, together with the “holes,” around the steep density gradient region. XGC1 reasserts the previous findings [1] that blobs move out convectively into the scrape-off layer, while the holes move inward toward plasma core. The measured radial width of the divertor heat load, mapped to the outer midplane, is found to be much less than the median radial size of the intermittent plasma objects, but is rather closer to the width of neoclassical orbit excursion from pedestal to divertor, yielding approximately the 1/Ip-type scaling found from our previous pure neoclassical simulation [3] or a heuristic neoclassical argument by Goldston [4]. However, it also shows some spreading by the intermittent turbulence. In ITER plasma edge, where the ion banana width at separatrix becomes negligibly small compared to the meso-scale blob size, blobs may saturate the 1/Ip scaling.


3:24PM JO3.00008 Intrinsic momentum generation in diverted tokamak edge by interaction between turbulence and neoclassical particle dynamics, JANGHOON SEO, Korea Advanced Institute of Science and Technology, Daejeon, Korea, C.-S. CHANG, S.-H. KU, PPPL, J.-M. KWON, National Fusion Research Institute, Daejeon, Korea — Fluid Reynolds stress from turbulence has usually been considered to be responsible for the anomalous toroidal momentum transport in tokamak plasma. Experiment by S. H. Müller et al. [Phys. Rev. Lett. 106, 115001 (2011)], however, reported that neither the observed edge rotation profile nor the inward momentum transport phenomenon at the edge region of an H-mode plasma could be explained by the fluid Reynolds stress measured with reciprocating Langmuir-probe. The full-function gyrokinetic code XGC1 is used to explain, for the first time, Müller et al’s experimental observation. It is discovered that, unlike in the plasma core, the fluid Reynolds stress from turbulence is not sufficient for momentum transport physics in plasma edge. The “turbulent neoclassical” physics arising from the interaction between kinetic neoclassical orbit dynamics and plasma turbulence is key in the tokamak edge region across the plasma pedestal into core.

3:36PM JO3.00009 Use of Uncertainty Quantification Techniques for Interpretive and Predictive Transport Analysis of Burning Plasmas\(^2\), ALEXEI PANKIN, Tech-X Corporation (Boulder, CO), MASAYUKI YOKOYAMA, RYOHSUKE SEKI, CHIHIRO SÜZUKI, National Institute for Fusion Science (Toki, Japan), ARNOLD KRITZ, TARIQ RAFIQ, Lehigh University (Bethlehem, PA) — Development of the uncertainty quantification (UQ) and sensitivity analysis (SA) techniques in the applied mathematics community brings new opportunities in the analysis, interpretation and validation of experimental data as well as in the development of new discharge scenarios in predictive transport modeling. The UQ techniques have been recently used to develop a new validation method for predictive transport codes [A.Y. Pankin et al. Phys. Plasmas 20 (2013) 102501]. In this research, the use of UQ and SA techniques is extended to the interpretive analysis of experimental data. The progress achieved in implementing UQ methods in the TASK3D-a1 code is described. TASK3D-a1 is a suite of codes for the interpretive transport analysis of LHD experimental data. The DAKOTA toolkit for calculating UQ is implemented in TASK3D-a1, and it is used to investigate the effects related to the instrumental errors and numerical errors resulting from the interpolation of experimental data. The uncertainties in the computation of effective diffusivities and in the verification of the energy and momentum balances associated with these two types of errors are evaluated. The possible application of these techniques for other interpretive modeling codes such as TRANSP and ONETWO is discussed.

\(^2\)This research was partially supported by the US Department of Energy.

3:48PM JO3.00010 Predicting Heat Transport across Multiple Devices with Neural Networks\(^3\), C.J. LUNA, ASU, R.V. BUDNY, PPPL, O. MENEGHINI, ORNL, S.P. SMITH, GA, J. PENNA, MIT — Three multi-layer, feed-forward, back-propagation neural networks have been built and trained on heat transport data from DIII-D, TFTR, and JET, respectively. A comparative analysis shows that previous success of neural networks in predicting heat transport in DIII-D [1] is reproduced for both TFTR and JET. The effect of using different neural network topologies has been investigated across all of the devices. It is found that the neural networks can consistently predict the total species’ heat fluxes for all of the devices, however they have difficulty in predicting the individual components of the heat fluxes in presence of significant transient variations in stored energy (i.e. non steady-state conditions). Such limitation has been addressed by providing the time-derivative information of the plasma parameters that are input to the neural network. Finally, an attempt is made to draw a connection between the most consistently successful neural network topologies and their relevance to the physics of heat transport in tokamak plasmas.


\(^3\)Supported in part by U.S. DoE contracts No. DE-AC02-09CH1146 and No. DE-FG02-95ER54309

Tuesday, October 28, 2014 2:00PM - 5:00PM – Session JO4 Direct- and Polar Direct-Drive Salon E - Brian Spears, Lawrence Livermore National Laboratory
2:00PM JO4.00001 Design of a Polar-Drive, Alpha-Heating Platform for the National Ignition Facility, T.J.B. COLLINS, J.A. MAROZAS, J.A. DELETTREZ, P.W. MCKENTY, S. SKUPSKY, Laboratory for Laser Energetics, U. of Rochester, D. CAO, J. CHENHALL, G. MOSES, U. of Wisconsin — Polar drive (PD) allows one to conduct direct-drive-ignition experiments at the National Ignition Facility (NIF) while the facility is configured for x-ray drive. A PD-ignition design has previously been developed with the goal of achieving alpha-heating and deuterium–tritium yields in excess of \(10^{16}\) at the NIF with the final optics and direct-drive cryogenic target positioner intended for subsequent PD-ignition experiments. This design uses a higher fuel diabat, which precludes scaling to ignition but results in greater stability and experimental control, minimizing fuel–shell mix during the deceleration phase of the implosion. The new design also incorporates the effects of cross-beam energy transfer and nonlocal electron transport. This platform will make it possible to test radiation–hydrodynamic codes in preparation for PD-ignition experiments. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.  


2:12PM JO4.00002 Achieving Symmetry with Polar Drive Design1, N. KRASHENINNIKOVA, T. MURPHY, J. COBBLE, I. TREGILLIS, P. BRADLEY, P. HAKEL, S. HSU, G. KYRALA, K. OBREY, M. SCHMITT, R. KANZLEITER, J. BAUMGAERTEL, S. BATHA, Los Alamos Natl Lab — Direct Drive, widely used on Omega, provides high coupling energy and core temperatures per drive. NIF’s much higher power offers a prospect for attaining hotter, larger cores enabling higher fidelity burn experiments. To use Omega’s knowledge on NIF involves understanding the differences between PDD and SDD. Achieving symmetric implosions in PDD is essential for attaining high temperatures and neutron yields. LANL team used laser core–power tuning designs done with rad-hydro code HYDRA utilizing a flux-limited heat conduction (FLHC) model on NIF and Omega. Both campaigns produced symmetric implosions in PDD configuration. Omega campaign confirmed P2 tunability that was 100’s ps at NBT (similar to indirect drive and SDD). However, we need to recognize the role of LPI effects which are often left out in simulations. We found that when \(I > 10^{18}\)W/cm² on NIF, FLHC model in HYDRA was insufficient to accurately predict symmetry, bright equatorial self-emission band, and enhanced hot electron population. We were able to account for these effects by including CBET and non-local heat transfer models. Here we present our analysis of PDD symmetry data. We report on hot electron and CBET effects and assess our ability to model them with rad-hydro codes. We will also discuss laser intensity limits in PDD.  

1 Work performed by LANL under contract DE-AC52-06NA25396 for the National Nuclear Security Administration of the USDOE.

2:24PM JO4.00003 Determining Acceptable Limits of Fast-Electron Preheat in Polar-Drive–Ignition Designs, J.A. DELETTREZ, T.J.B. COLLINS, Laboratory for Laser Energetics, U. of Rochester, C. YE, Webster Schroeder High School — In direct-drive–ignition designs, preheat by fast electrons created by the two-plasmon-decay instability at the quarter-critical density surface can increase the adiabat in the fuel layer and prevent ignition. Since eliminating the preheat entirely is not possible, it is necessary to understand the levels of preheat our targets can withstand before ignition is precluded. The current polar-drive design is used as the basis for examining the effects of increasing the levels of fast electrons using the one-dimensional, radiation–hydrodynamics code LILAC. Once ignition is achieved using Telos, a downhill simplex method program, to recover ignition. This cycle is repeated until the design can no longer be reoptimized to produce ignition. Mappings of these final results provide insight into ignition failure caused by preheat and what specific target parameters serve to best stave off the effects of the preheat. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

2:36PM JO4.00004 Using the outgoing shock wave to characterize low mode ablator symmetry1, Arthur Pak, Laurens Divoli, Til Doepfner, John Field, Andrea Kritcher, Tammy Ma, Laura Benedetti, Debbie Callahan, Denise Hinkel, Laura Berzak Hopkins, Omar Hurricane, Shahab Khan, Nobuhiro Izumi, Andrew Mackinon, Nathan Mezian, Brian Spears, Richard Town, David Bradley, Lawrence Livermore National Laboratory, Lawrence Livermore National Laboratory — At the National Ignition Facility, experiments are being conducted to optimize the performance of indirectly driven inertial confinement fusion implosions. To ignite the fuel in this scheme, a cascade of nuclear reactions must first be triggered by achieving a central hot spot pressure of several hundred Gbar over a duration of ~ 100 ps. Low mode asymmetries in the shape of the assembled fuel and ablator are indicative of momentum asymmetries that reduce the transfer of kinetic energy to hot spot internal energy, thus reducing the hot spot yield and overall implosion performance. Here details of a new method that utilizes the x-ray emission created by the outgoing shock to probe the low mode asymmetry of the ablator at radius of 100 \(\mu\)m and time of ~ 150 ps after stagnation will be presented. This signal can provide information on the shape of the ablator at convergence ratios ~ 2X higher than current area-backlight radiographs and can be made in-situ on layered cryogenic implosions that require all the laser beams. Experimental results of the inferred ablator shape from implosions performed with cryogenic thermonuclear fuel will be compared to radiation hydrodynamic calculations.  

1 This work performed under the auspices of the USDoE by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-656467

2:48PM JO4.00005 Inferring Low-Mode Asymmetries from the Elastically Scattered Neutron Spectrum in Layered Cryogenic DT Implosions on OMEGA, C.J. FORREST, V.YU. GLEBOV, V.N. GONCHAROV, T.C. SANGSTER, C. STOECKL, Laboratory for Laser Energetics, U. of Rochester, J.A. FRENJE, M. GATU JOHNSON, PSFC, MIT — High-resolution neutron spectroscopy is used to probe the areal density of layered cryogenic DT direct-drive implosions in inertial confinement fusion experiments on OMEGA. Advanced scintillation detectors record the neutron spectrum using time-of-flight techniques. 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 with low-mode perturbations in the DT fuel assembly have been simulated in the Monte Carlo n-particle transport code. Experimental data shows good agreement with the model when the mass distribution of the compressed DT shell is highly asymmetric with one side having a factor-of-2 higher areal density. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

3:00PM JO4.00006 Understanding the Performance of Low-Adiabat Cryogenic Implosions on OMEGA, V.N. GONCHAROV, T.C. SANGSTER, R. EPSTEIN, S.X. HU, I.V. IGUMENSHCHEV, C.J. FORREST, D.H. FROULA, F.J. MARSHALL, D.T. MICHEL, P.B. RADHA, W. SEKA, C. STOECKL, Laboratory for Laser Energetics, U. of Rochester, J.A. FRENJE, M. GATU JOHNSON, PSFC, MIT — While the moderate-adiabat (\(\alpha > 3.5\)) cryogenic implosions on OMEGA are well understood using multidimensional hydrocode simulations, the performance of lower-adiabat implosions is degraded relative to these predictions. The potential degradation mechanisms (not fully accounted for in simulations) include target-nonuniformity sources (excessive laser imprint, target debris, beam-overlap nonuniformity) and inaccuracies in laser-coupling modeling, especially during the pulse rise. To address the target-stability issues, target designs with thicker ice layers and smaller implosion velocities are considered. These targets have smaller in-flight aspect ratios, making them less susceptible to hydrodynamic instability growth. To address inaccuracies in laser coupling, a design with a slower main pulse rise is considered. This talk will summarize progress made on these issues. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.
3:12PM JO4.00007 Fuel–Shell Mix and Pressure Measurements Based on X-Ray Continuum Emission from Isobaric Implosion Cores on OMEGA | R. EPSTEIN, F.J. MARSHALL, V.N. GONCHAROV, Laboratory for Laser Energetics, U. of Rochester, R. BETTI, R. NORA, A.R. CHRISTOPHERSON, Fusion Science Center and Laboratory for Laser Energetics, U. of Rochester — At a spectral energy matched to the anticipated hot-spot temperature range, the x-ray emissivity of an imploded target hot spot is dependent almost entirely on pressure. In this way, the hot-spot pressure at the time of peak emission can be inferred from the spatially resolved core emission. The pressure and temperature dependences of the x-ray emissivity and the neutron production rate explain a simple scaling of the total filtered x-ray emission as a power of the total neutron yield for target implosions of similar design over a broad range of shell implosion adiabats. Excess emission from less-stable, low-adiabat implosions (above the level expected from this neutron-yield scaling) attributed to the higher emissivity of shell carbon mixed into the hot spot, indicates “fuel–shell” mix fractions in the 2% to 5% range. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.

3:24PM JO4.00008 Analysis of a High-Adiabat Cryogenic Implosion on OMEGA | A.R. CHRISTOPHERSON, R. BETTI, R. NORA, S.P. OBENSCHAIN, Plasma Physics Division, Naval Research Laboratory, Washington DC — The performance of high-adiabat implosions > 10 is marginally affected by nonuniformities because of the strong ablative stabilization. To test the validity of the one-dimensional (1-D) physics included in existing hydrocodes, a study of high-Z cryogenic direct DT implosions is carried out by comparing the results of 1-D simulations with several measured quantities. It is found that after including nonlocal transport, cross-beam energy transfer, and hot electrons. 1-D simulations reproduce most of the observables with reasonable accuracy. Since the analysis is applied to the only high-adiabat DT implosion fielded on OMEGA, these results do not fully validate the 1-D physics of current hydrocodes. However, this work shows the framework for establishing a validation capability of the 1-D physics of inertial confinement fusion implosions. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.

3:36PM JO4.00009 Constraining the Rocket Efficiency in Hydrodynamic Simulations of Direct-Drive Cryogenic Implosions by Simultaneous Measurements of the CD Burnthrough and the Shell Trajectory | D.T. MICHEL, A.K. DAVIS, R. EPSTEIN, V.N. GONCHAROV, S.X. HU, I.V. IGUMENSHCHEV, D.D. MEYEROFER, T.C. SANDSTG, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester — Time-resolved imaging of the soft x rays emitted by the coronal plasma of a directly driven imploding cryogenic target on the OMEGA Laser System is used to measure the shell trajectory and the time to ablate the outer CD layer. These simultaneous measurements constrain both the shell velocity and the mass ablation rate. Two simulations have been performed and compared to the measurements: (1) including cross-beam energy transfer (CBET) and nonlocal thermal transport models and (2) using a flux limiter adapted to match the measured shell trajectory. Good agreement with both the trajectory and mass ablation rate is found with CBET and nonlocal models. While the modified flux limiter matches the trajectory (by construction), the CD burnthrough occurs ~ 200 ps later than in experiments. This demonstrates that by adapting a flux limiter, both the shell velocity and the mass ablation rate cannot be reproduced simultaneously. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

3:48PM JO4.00010 Simulations of laser-driven targets with thin high-Z coatings | ANDREW J. SCHMITT, MAX KARASIK, JASON BATES, STEVE OBENSCHAIN, Plasma Physics Division, Naval Research Laboratory — Previous theoretical and experimental work at NRL has shown that very thin (100's of A) of high-Z — e.g., Au or Pd — layers coated onto targets can be used to suppress early-time laser imprint and RM growth of hydrodynamic instabilities during the low-intensity foot of directly-driven targets. This work has been extended recently to include the use of higher intensity laser spikes that are used for adiabat-tailoring of the target. In these studies, it was shown that a minimum layer thickness (dependent upon the material) was needed before the suppression was observed. Additionally, it was observed that the condition of the layer prior to the drive laser pulse can be crucial to the accurate simulation of these physics. We will address here the physics behind the imprint suppression effects and explore the limitations and sensitivities of modeling these systems. The implications and limits of using even thicker layers to extend the effect further into the laser drive will also be discussed.

3:54PM JO4.00011 Benefits of Moderate-Z Ablators for Direct-Drive Inertial Confinement Fusion | M. LAFON, R. BETTI, Laboratory for Laser Energetics and Fusion Science Center, U. of Rochester, K.S. ANDERSON, T.J.B. COLLINS, S. SKUPSKY, P.W. MCKENTY, Laboratory for Laser Energetics, U. of Rochester — Control of hydrodynamic instabilities and DT-fuel preheating by hot electrons produced by laser-plasma interaction is crucial in inertial confinement fusion. Moderate-Z ablators have been shown to reduce the laser imprinting on target and suppress the generation of hot electrons from the two-plasmon-decay instability. These results have motivated the use of ablators of higher-Z than pure plastic in direct-drive-ignition target designs for the National Ignition Facility (NIF). Two-dimensional radiation-hydrodynamic simulations assess the robustness of these ignition designs to laser imprint and capsule nonuniformities. The complex behavior of the hydrodynamic stability of mid-Z ablators is investigated through single and multibeam simulations. A polar-drive configuration is developed within the NIF Laser System specifications for each ablator material. The use of multilayer ablators is also investigated to enhance the hydrodynamic stability. Results indicate that ignition target designs using mid-Z ablators exhibit good hydrodynamic properties, leading to high target gain for direct-drive implosions on the NIF. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.

4:00PM JO4.00012 Imprinting of Pre-Imposed Laser Perturbations on Targets With a High-Z Overcoat | MAX KARASIK, J.L. WEAVER, Plasma Physics Division, Naval Research Laboratory, Washington DC, Y. AGLITSKIY, Leidos, Reston VA, J. OH, RSI, Lanham MD, A.J. SCHMITT, J.W. BATES, V. SERLIN, S.P. OBENSCHAIN, Plasma Physics Division, Naval Research Laboratory, Washington DC — In direct drive ICF, most of the laser imprint is expected to occur during the initial part of the laser pulse, which generates the first shocks necessary to compress the target to achieve high gain. Previous experiments found that a thin (400–800Å) high-Z (Au or Pd) overcoat on the laser side of the target is effective in suppressing broadband imprint. The overcoat initially absorbs the laser and emits soft x-rays that ablate the target, forming a large stand-off distance between laser absorption and ablation and smoothing the drive perturbations. We investigate the effectiveness of imprint suppression for different spatial wavelengths via perturbations imposed on top of the beams smoothed by Induced Spatial Incoherence (ISI). Measurements of areal mass non-uniformity on planar targets driven by the Nike KrF laser are made by curved crystal x-ray radiography. Simultaneous side-on radiography allows observation of the layer dynamics and monitoring of the laser absorption – target ablation stand-off. X-ray flux from the high-Z layer is monitored using absolutely calibrated time-resolved x-ray spectrometers. Work supported by the Department of Energy/NNSA.

2Karasik et al., submitted for publication.
discuss novel – and physically observable – effects that attend the BB effect at shocks. We converge using an implementation of the algorithm within the FLASH code, and verify that the algorithm yields physically sensible results at shocks. We demonstrate this breakdown, show its origin, and present an alternative algorithm that gives finite and convergent results. We demonstrate this experiment for different outer-layer thicknesses, time-resolved measurements of the mass ablation rate were obtained. Simulations validated the methods and verified that the measurement techniques are not sensitive to perturbation growth at the ablation surface. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

— In this study we present high-resolution numerical simulations of laboratory experiments that study the turbulent amplification of magnetic fields generated in OMEGA implosions. GIANLUCA GREGORI, University of Oxford — X-ray and radio observations of the supernova remnant Cassiopeia A reveal the presence of magnetic fields about 100 times stronger than those in the surrounding interstellar medium. Field coincident with the outer shock probably arises through a non-linear feedback process involving cosmic rays. The origin of the large magnetic field in the interior of the remnant is less clear but it is probably stretched and amplified by turbulent motions. Turbulence may be generated by hydrodynamic instability at the contact discontinuity between the supernova ejecta and the circumstellar gas. However, optical observations of Cassiopeia A indicate that the ejecta are interacting with a highly inhomogeneous, dense circumstellar cloud formed prior to the supernova explosion. We have conducted a series of laboratory experiments using high power laser facilities in order to reproduce the essential features of the supernova shock interacting with strong density perturbations. Our results indicate the magnetic field is amplified when the shock interacts with a plastic grid. We show that our experimental results can explain the observed synchrotron emission in the interior of the remnant. These experiments provide an example of magnetic field amplification by turbulence in plasmas, a physical process thought to occur in many astrophysical phenomena.

This work was supported in part at the University of Chicago by DOE NNSA ASC.

— The Biermann Catastrophe in Numerical MHD CARLO GRAZIANI, PETROS TZEFERACOS, MILAD FATENEJAD, NORBERT FLOCKE, CARLO GRAZIANI, University of Chicago, GIANLUCA GREGORI, University of Oxford, DONALD LAMB, University of Chicago, DONGWOOK LEE, University of California-Santa Cruz, JENA MEINECKE, University of Oxford, ANTHONY SCOPATZ, University of Wisconsin-Madison, KLAUS WEIDE, University of Chicago — In this study we present high-resolution numerical simulations of laboratory experiments that study the turbulent amplification of magnetic fields generated by laser-driven colliding jets. The radiative magneto-hydrodynamic (MHD) simulations discussed here were performed with the FLASH code and have assisted in the analysis of the experimental results obtained from the Vulcan laser facility. In these experiments, a pair of thin Carbon foils is placed in an Argon-filled chamber and is illuminated to create counter-propagating jets. The jets carry magnetic fields generated by the Biermann battery mechanism and collide to form a highly turbulent region. The interaction is probed using a wealth of diagnostics, including induction coils that are capable of providing the field strength and directionality at a specific point in space. The latter have revealed a significant increase in the field’s strength due to turbulent amplification. Our FLASH simulations have allowed us to reproduce the experimental findings and to disentangle the complex processes and dynamics involved in the colliding flows.

This work was supported in part at the University of Chicago by DOE NNSA ASC.

Tuesday, October 28, 2014 2:00PM - 4:48PM – HEDP Laboratory Astrophysics

2:00PM JO5.00001 Turbulent amplification of supernova magnetic fields in the laboratory. GIANLUCA GREGORI, University of Oxford — X-ray and radio observations of the supernova remnant Cassiopeia A reveal the presence of magnetic fields about 100 times stronger than those in the surrounding interstellar medium. Field coincident with the outer shock probably arises through a non-linear feedback process involving cosmic rays. The origin of the large magnetic field in the interior of the remnant is less clear but it is probably stretched and amplified by turbulent motions. Turbulence may be generated by hydrodynamic instability at the contact discontinuity between the supernova ejecta and the circumstellar gas. However, optical observations of Cassiopeia A indicate that the ejecta are interacting with a highly inhomogeneous, dense circumstellar cloud formed prior to the supernova explosion. We have conducted a series of laboratory experiments using high power laser facilities in order to reproduce the essential features of the supernova shock interacting with strong density perturbations. Our results indicate the magnetic field is amplified when the shock interacts with a plastic grid. We show that our experimental results can explain the observed synchrotron emission in the interior of the remnant. These experiments provide an example of magnetic field amplification by turbulence in plasmas, a physical process thought to occur in many astrophysical phenomena.

G. Gregori et al., Nature 481, 480 (2012)

2:12PM JO5.00002 Numerical modeling of laser-driven experiments of colliding jets: Turbulent amplification of seed magnetic fields. PETROS TZEFERACOS, MILAD FATENEJAD, NORBERT FLOCKE, CARLO GRAZIANI, University of Chicago, GIANLUCA GREGORI, University of Oxford, DONALD LAMB, University of Chicago, DONGWOOK LEE, University of California-Santa Cruz, JENA MEINECKE, University of Oxford, ANTHONY SCOPATZ, University of Wisconsin-Madison, KLAUS WEIDE, University of Chicago — In this study we present high-resolution numerical simulations of laboratory experiments that study the turbulent amplification of magnetic fields generated by laser-driven colliding jets. The radiative magneto-hydrodynamic (MHD) simulations discussed here were performed with the FLASH code and have assisted in the analysis of the experimental results obtained from the Vulcan laser facility. In these experiments, a pair of thin Carbon foils is placed in an Argon-filled chamber and is illuminated to create counter-propagating jets. The jets carry magnetic fields generated by the Biermann battery mechanism and collide to form a highly turbulent region. The interaction is probed using a wealth of diagnostics, including induction coils that are capable of providing the field strength and directionality at a specific point in space. The latter have revealed a significant increase in the field’s strength due to turbulent amplification. Our FLASH simulations have allowed us to reproduce the experimental findings and to disentangle the complex processes and dynamics involved in the colliding flows.

This work was supported in part at the University of Chicago by DOE NNSA ASC.

2:24PM JO5.00003 The Biermann Catastrophe in Numerical MHD CARLO GRAZIANI, PETROS TZEFERACOS, University of Chicago Flash Center, DONGWOOK LEE, Univ of California, Santa Cruz and University of Chicago Flash Center, KLAUS WEIDE, DONALD LAMB, MILAD FATENEJAD, JOSHUA MILLER, University of Chicago Flash Center — The Biermann Battery (BB) effect is widely invoked as a mechanism to generate cosmic magnetic fields from unmagnetized plasmas. The BB effect, which relies on large, non-aligned gradients of electron density and pressure, is expected to function most efficiently at shocks, where such gradients are largest. Simulations of cosmic magnetogenesis have accordingly relied on shocks to enhance the BB effect. What went unnoticed until recently is the fact that straightforward algorithmic implementations of the BB effect in MHD codes break down precisely at hydrodynamic discontinuities such as shocks — where the BB effect is of greatest interest — yielding results that fail to converge with resolution. We discuss this breakdown, show its origin, and present an alternative algorithm that gives finite and convergent results. We demonstrate convergence using an implementation of the algorithm within the FLASH code, and verify that the algorithm yields physically sensible results at shocks. We discuss novel – and physically observable – effects that attend the BB effect at shocks.

This work was supported in part at the University of Chicago by DOE NNSA ASC.
2:36PM JO5.00004 Self-generated Magnetic Fields in Blast-wave Driven Rayleigh-Taylor Experiments, MARKUS FLAIG, TOMASZ PLEWA, Florida State University — We study the generation of magnetic fields via the Biermann battery effect in blast-wave driven Rayleigh-Taylor experiments. Previous estimates have shown that in a typical experiment, one should expect fields in the MG range to be generated, with the potential to influence the Rayleigh-Taylor morphology. We perform two- and three-dimensional numerical simulations, where we solve the extended set of MHD equations known as the Braginskii equations. The simulation parameters reflect the physical conditions in past experiments performed on the OMEGA laser and potential future experiments on the NIF laser facility. When neglecting the friction force between electrons and ions in the simulations, magnetic fields of the order of a few 0.1 MG (with a plasma beta greater than 10000) are generated, and are found to be dynamically significant. However, it turns out that even once the friction force is included, the magnetic fields become much smaller (with a plasma beta greater than 10000) which have negligible influence on the dynamics of the system. Our results therefore indicate that, contrary to previous speculations, it is highly unlikely that self-generated magnetic fields can influence the morphology of a typical blast-wave driven Rayleigh-Taylor experiment.

1 MF and TP were supported by the DOE grant DE-FG52-09NA29548 and the NSF grant AST-1109113. This research used resources of the National Energy Research Supercomputer Center.

2:48PM JO5.00005 Shock formation in counter-streaming jets on the MAGPIE pulsed-power generator, F. SUZUKI-VIDAL, S. LEBEDEV, L.A. PICKWORTH, G.F. SWADLING, G. BURDIÄK, J. SKIDMORE, G.N. HALL, M. BENNETT, S.N. BLAND, J.P. CHITTENDEN, P. DE GROUCHY, J. HARE, J. MUSIC, L. SUITTLE, Imperial College London, A. CIARDI, Observatorio de Paris, R. RODRIGUEZ, J.M. GIL, G. ESPINOSA, Universidad de las Palmas de Gran Canaria, E. HANSEN, A. FRANK, University of Rochester — Experiments looking at formation of shocks from the collision between two counter-streaming jets are under investigation. The experiments are in the context of high-energy density laboratory astrophysics looking at the formation of internal shocks in jets from young stars. The jets in the experiments are driven by the ablation of plasma from two opposite radial foil Z-pinches, subjected to a 1.4MA, 250ns current pulse from the MAGPIE pulsed-power generator. The dynamics of shock formation from the collision are determined by a combination of advected toroidal magnetic field carried with the jets, and other effects such as radiative cooling in the plasma. The dynamics of the collision are compared with numerical simulations using the code GORGON, whereas radiative cooling effects are investigated with the codes ABAKO/RAPCAL and the astrophysical code AstroBEAR.

1 Work supported by The Royal Society.

3:00PM JO5.00006 The dynamics of high energy density plasma jets magnetized by large dipole magnetic fields, PIERRE GOURDAIN, University of Rochester, TOM BYVANK, DAVE HAMMER, BRUCE KUSSE, CHARLIE SEYLER, Cornell University, SIMON BLAND, SERGEY LEBEDEV, GEORGE SWADLING, Imperial College — Astrophysical plasma jets expelled by proto-stars or galactic nuclei are often magnetized by the magnetic field that the star or galaxy generates. This field resembles the one of a dipole and, while strong near the celestial body, the field decays rapidly away from the source. Experimental observations of supersonic high energy density plasma jets generated in the laboratory by radial foils have shown that the field impacts strongly the dynamics of the jet. Such jets share some similarities with astrophysical jets in the magneto-hydrodynamics sense, e.g. large Reynolds, magnetic Reynolds and Peclet number. This work shows how a dipole field affects jet characteristics and the plasma dynamics. In regions where the plasma beta is low (near the base of the jet), the jet is conical. At higher altitudes, where the beta is high, the jet is strongly collimated. Numerical computations highlight the mechanisms responsible for such transitions.

1 Research supported by NSF Grant # PHY-1102471, the DOE Grant # DE-SC0002151 and the NNSA/DOE Cooperative Agreement DE-NA0001836 and DE-NA0001847.

3:12PM JO5.00007 An experimental investigation of the collision of counter-streaming magnetized plasma flows with oppositely aligned embedded magnetic fields, LEE SUITTLE, SERGEY LEBEDEV, GEORGE SWADLING, FRANCISCO SUZUKI-VIDAL, GUY BURDIÄK, MATTHEW BENNETT, JÄCK HARE, Imperial College, DAVID BURGESS, ADAM CLEMENS, Queen Mary, NICHOLAS NIASSE, JERRY CHITTENDEN, ROLAND SMITH, SIMON BLAND, SIDDHARTH PANTANKAR, NIC STUART, Imperial College — We present first results from a new experimental platform designed to study the quasi-1D collision of counter-streaming plasma flows produced by the ablation from a pair of inverse wire array Z pinches at the MAGPIE pulsed power facility. The flows are magnetized (B ∼ 2T, Re ∼ 100) and enter the interaction region with supersonic velocity (M∞ > 5, Mach > 3). The advected magnetic fields are perpendicular to the flow and aligned in anti-parallel directions, allowing studies of magnetic reconnection in a strongly driven regime. The setup allows parameters of the plasma to be measured in the reconnection region with a set of diagnostics which includes Thomson scattering, Faraday rotation, interferometry and detectors of energetic particles. The collisionality of the interaction and the relative role of the radiative cooling can be varied by choice of material of the colliding flows (e.g. Al or W).

3:24PM JO5.00008 Accretion Shocks on Young Stars: A Laboratory-Astrophysics Investigation, R.P. YOUNG, University of Michigan — We intend to present results of a laboratory-astrophysics investigation of accretion shocks at the surface of young stars. We have scaled a stellar accretion shock to an OMEGA experiment by creating a plasma jet (representing the accreting material) and colliding it with a solid block (representing the surface of the young star). Magnetic fields are thought to play crucial role in this phenomenon, and therefore we conducted our experiments with imposed magnetic fields of 0 T, 3 T and 7 T. The experiments are funded by the U.S. Department of Energy, through the NNSA-DS and SC-OES Joint Program in High-Energy-Density Laboratory Plasmas, grant number DE-NA0001840, and the National Laser User Facility Program, grant number DE-NA0000850, and through the Laboratory for Laser Energetics, University of Rochester by the NNSA/OICF under Cooperative Agreement No. DE-FS02-08NA28302.

3:36PM JO5.00009 Creating astrophysically relevant jets from locally heated targets irradiated by a high-intensity laser, HOLGER SCHMITZ, ALEX ROBINSON, Central Laser Facility, STFC Rutherford Appleton Laboratory, Didcot OX11 OQX — The formation mechanism of jets in the vicinity of young stellar objects has been the subject of investigations for many years. It is thought that jets are formed by the stellar wind interacting with an inhomogeneous plasma. A density gradient from the equator to the poles causes the wind to encounter the inward facing reverse shock at an oblique angle. The wind is focused into a conical flow towards the poles where it emerges as a narrow jet. This mechanism is inaccessible to direct observations due to the small scales on which it operates. Using high intensity lasers to produce comparable jets offers a way to investigate the mechanisms in the laboratory. Previous investigations of jets in the laboratory have directly generated the conical flow, skipping the first part of the formation mechanism. We present simulations of a novel method of generating jets in the laboratory by using magnetic fields generated by resistivity gradients to control the fast electron flow. The return current selectively heats a small region inside the target which drives a blast wave into the low density region behind the target. A conical high density shell focuses the outflow into a narrow jet. We find jets with aspect ratios of over 15 and Mach numbers between 2.5 and 4.3.

1 This work is funded by the European Research Council, grant STRUCMAGFAST.
3:48PM JO5.00010 Formation of Radiatively cooled, Supersonically Rotating, Plasma Disks in Z-pinch experiments, M. BENNETT, S.V. LEBEDEV, L. SUTTLE, G. BURDIAK, F. SUZUKI-VIDAL, J. HARE, G.F. SWADLING, S. PATANKAR, G.N. HALL, M. BOCCHI, J.P. CHITTENDEN, R.A. SMITH, Imperial College, A. FRANK, E. BLACKMAN, University of Rochester, R.P. DRAKE, University of Michigan, A. CIARDI, Paris observatory — We present data from Z-pinch experiments aiming to simulate aspects of accretion disk physics in the laboratory. Using off axis ablation flows from a wire array Z-pinch we demonstrate the formation of a hollow disk structure that rotates supersonically with velocity of ~60 km/s and M~2 for ~150 ns. We use interferometry to measure the electron density as >10^{19} cm^{-3} and analyze Thomson Spectra to estimate the ion and electron temperatures; we find T_e ~60 eV and T_Z ~150 to 200 eV. Using these parameters we calculate the Reynolds number for the plasma on the order 10^7 putting the experiment within the correct viscous regime for turbulent flow and scaling to accretion disks.

4:00PM JO5.00011 Laboratory astrophysics experiments relating to ionising and weakly radiative shocks, JOSEPH CROSS, University of Oxford, JOHN FOSTER, PETER GRAHAM, AWE, CLOTILDE BUSSCHAERT, LUTH Observatoire de Paris, NICOLAS CHARPENTIER, CEA-DAM-DIF, COLIN DANSON, AWE, HUGO DOYLE, University of Oxford, R. PAUL DRAKE, University of Michigan, EMERIC FAIZIE, CEA-DAM-DIF, JIM FYRTH, EDWARD GUMBRELL, AWE, MICHEL KOENIG, LULI, Ecole Polytechnique, CAROLYN KURANZ, University of Michigan, BERENICE LOUPIAS, CEA-DAM-DIF, CLAIRE MICHAUT, LUTH Observatoire de Paris, SID PATANKAR, JONATHAN SKIDMORE, AWE, CHRISTOPHER SPINDLOE, STFC, Rutherford Appleton Laboratory, ELLIE TUBMAN, NIGEL WOOLSEY, University of York, ROMAN YURCHAK, LULI, Ecole Polytechnique, GIANLUCA GREGORI, University of Oxford — The aim of the POLAR project is to simulate, in the laboratory, the accretion shock region of a magnetic cataclysmic variable binary star system. Scaling laws have shown that laser experiments can be related to astrophysical phenomena by matching relevant dimensionless parameters. As well as forming a reverse shock, relevant to the POLAR project, the experimental system is also likely formed of a weakly radiating shock and an ionisation front. Results from our experiment at the Orion Laser are presented here, alongside comparisons to simulation and the astrophysical case (of relevance to triggered star formation.). References: 1. Busschaert et al., NJP, 15, 3, 035020 (2013), 2. Falize et al., ApJ. 730, 96 (2011), 3. Ryutov et al., ApJ. 518, 821 (1999), 4. Dale et al., MNRAS 377, 535 (2007), 5. Tremblin et al., A&A 564, A106 (2014)

4:12PM JO5.00012 Scaled Laboratory Experimental Design of Radiation-Driven Cloud Implosions, PAUL KEITER, University of Michigan, JAMES STONE, Princeton University, MATT TRANTHAM, University of Michigan, GUY MALAMUD, Nuclear Research Center - Negev, SALLEE KLEIN, University of Michigan — When hot, massive stars form they ionize and heat the surrounding interstellar medium (ISM), forming an expanding region of hot, high-radiation-pressure, ionized hydrogen gas called an H II region. The H II region itself can then induce further star formation. The two main mechanisms of star formation involving H II regions are collect and collapse, and radiative shocks. Theoretical models of star formation are based on computer simulations and models. To improve our understanding of these models, data are required. We present the design of a scaled experiment to study the interaction of an ionization front with a high-density sphere, which acts as a surrogate for the molecular cloud. Irradiating a high-Z foil with laser beams generates the ionization front. The ionization front will propagate in a low-density medium before interacting with the sphere.

This work is funded by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, grant number DE-NA0001840.

4:24PM JO5.00013 Experimental investigation of Eagle nebula pillars using a multiple hohlraum array, DAVID MARTINEZ, JAVE KANE, Lawrence Livermore National Laboratory, BRUNO VILLETTE, CEA, MARK POUND, University of Maryland, ALEXIS CASNER, CEA, ROBERT HEETER, Lawrence Livermore National Laboratory, ROBERTO MANCINI, University of Nevada, Reno — The “pillars of creation” are stunningly beautiful and physically puzzling molecular cloud structure in the Eagle nebula. Formation of these pillars has been subject of debate since their observation. Although extensive observation and modeling have attempted to answer the question of the creation of the observed pillars, experiments have not adequately tested the theoretical models surrounding the photoevaporation of the molecular clouds. Recent Omega EP experiments at the LLE developed a 30ns x-ray drive using a multiple hohlraum array (“Gatling gun” approach) to drive the photoevaporation process and test pillar formation. This proof of principle experiment imaged the initial stages of a pillar using Ti area backlighter through a driven 50mg/cc R/F foam with an embedded solid density CH ball. This presentation will give an overview of the experimental design and results from this experiment. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-656872

4:36PM JO5.00014 X-ray line formation in radiation dominated astrophysical plasmas, G. LOISEL, J.E. BAILEY, S.B. HANSEN, T. NAGAYAMA, G.A. ROCHAU, Sandia National Laboratories, New Mexico, D. LIEDAHL, Lawrence Livermore National Laboratory, California, R. MANCINI, University of Nevada, Nevada, M. KOEPKE, West Virginia University, West Virginia — A remarkable opportunity to observe matter in a regime where the effects of General Relativity are significant has arisen through measurements of strongly red-shifted iron x-ray lines emitted from black hole accretion disks. A major uncertainty in the spectral formation models is the efficiency of Resonant Auger Destruction (RAD), in which fluorescent Ka photons are resonantly absorbed by neighbor ions. The absorbing ion preferentially decays by Auger ionization, thus reducing the emerging Ka intensity. If Ka lines from L-shell ions are not observed in iron spectral emission, why are such lines observed from silicon plasma surrounding other accretion powered objects? To help answer this question, we are investigating photoionized silicon plasmas produced using intense x-rays from the Z facility. For the first time in a terrestrial lab, we measured simultaneous absorption and emission spectra from these plasmas at high resolution. The charge state distribution, electron temperature, and electron density are determined through space-resolved absorption spectra. The emission spectra have been recorded at different column densities thus testing different radiative transport regime. These should allow us to answer quantitatively the original RAD hypothesis.

This project is supported by the Office of Combustion Sciences in the US Department of Energy’s Office of Energy Efficiency and Renewable Energy under Contract DE-AC04-94AL85000.

Tuesday, October 28, 2014 2:00PM - 5:00PM –
Session JÖ6 Intense Laser Plasma Physics, and Technology Applications of Plasmas

Galerie 3 -
Tony Ting, Naval Research Laboratory
2:00PM JO6.00001 Quantum radiation reaction in laser–electron-beam collisions, T.G. BLACKBURN, Clarendon Laboratory, University of Oxford, C.P. RIDGERS, Department of Physics, University of York, J.G. KIRK, Max-Planck-Institut fur Kernphysik, A.R. BELL, Clarendon Laboratory, University of Oxford — The ever-increasing intensity produced by high power, short pulse lasers has led to substantial interest into how radiation reaction and QED processes such as pair production will affect the plasma physics studied in future laser facilities. It is likely that the interaction of a laser pulse of intensity $> 10^{19}$Wcm$^{-2}$ with another laser pulse or with a solid density target will produce copious high energy gamma rays and critical density electron-position pair plasmas. Recently we have shown how an experiment that could be accomplished in today’s high intensity laser facilities, the collision of a GeV electron beam with a laser pulse of intensity $> 10^{19}$Wcm$^{-2}$, could provide clear signatures of quantum radiation reaction. These are the increased yield of the highest energy gamma rays and the broadening in energy of the electron beam, caused by the stochastic nature of photon emission.


2:12PM JO6.00002 The generation of tens kT magnetic fields by transport instability of laser generated electrons in a near critical preformed plasma, TOMA TONCIAN, BJORN MANUEL HEGELIC, University of Texas at Austin, OSWALD WILLI, GOETZ LEHMANN, Heinrich Heine University Düsseldorf — First direct measurements of the electron transport along extended wire targets by Quinn et al [PRL 102 (2009)] revealed a charging current and associated magnetic field moving close to the speed of light away from focal volume of the employed heating laser. The motion of the electrons is bound electrostatic to the proximity of the solid. A return current compensating the escaping charge is formed at the surface of the solid, the overall current loop sustaining kT magnetic fields, with traversal decay lengths of $\mu$m. In our study we show by means of numerical 2 dimensional particle in cell simulations that the motion of the hot electrons and dynamic of the charge compensating return current can be dramatically affected by a preformed $\mu$m scale length plasma gradient on the solid surface. In particularly the two velocities distribution and two antiparallel currents developing in the near critical plasma are unstable in respect of two stream and Kevin Helmholtz instability. The particle motion becomes locally magnetized resulting in current eddies trapping particles and localized magnetic and electric fields with values of tens of kT and TV/m sustained on $\mu$m scales and with characteristic decay times of ps.

2:24PM JO6.00003 Amplification of ultra-short laser pulses via strongly-coupled Brillouin backscattering1, GOETZ LEHMANN, FRIEDRICH SCHLUCK, KARL-HEINZ SPATSCHEK, Heinrich-Heine University Duesseldorf — Plasma based amplification of laser pulses is currently discussed as a key component for the next generation of high-intensity laser systems, possibly enabling the generation of ultra-short pulses in the exawatt-zetawatt regime [1]. In these scenarios the energy of a long pump pulse (several ps to ns of duration) is transferred to a short seed pulse via a plasma oscillation. Strongly-coupled Brillouin (sc-SBS) backscattering is identified as potential candidate for robust amplification scenarios [2]. With the help of three-wave interaction models, we investigate the multi-dimensional dynamics the seed pulse undergoes during amplification. The influences of filamentation and self-focusing are analyzed and mitigation strategies are discussed.


2:36PM JO6.00004 Deploying electromagnetic particle-in-cell (EM-PIC) codes on Xeon Phi accelerators boards, RICARDO FONSECA, ISCTE - IUL, Portugal — The complexity of the phenomena involved in several relevant plasma physics scenarios, where highly nonlinear and kinetic processes dominate, makes purely theoretical descriptions impossible. Further understanding of these scenarios requires detailed numerical modeling, but fully relativistic particle-in-cell codes such as OSIRIS [1] are computationally intensive. The quest towards Exaflop computer systems has lead to the development of HPC systems based on add-on accelerator cards, such as GPGPUs and more recently the Xeon Phi accelerators that power the current number 1 system in the world. These cards, also referred to as Intel Many Integrated Core Architecture (MIC) offer peak theoretical performances of 1 TFlop/s for general purpose calculations in a single board, and are receiving significant attention as an attractive alternative to CPUs for plasma modeling. In this work we report on our efforts towards the deployment of an EM-PIC code on an Xeon Phi architecture system. We will focus on the parallelization and vectorization strategies followed, and present a detailed performance evaluation of code performance in comparison with the CPU code.

1 R. A. Fonseca et al., LNCS 2331, 342. (2002)

2:48PM JO6.00005 High angular momentum density physics of intense laser, BAIFEI SHEN, YIN SHI, LINGANG ZHANG, XIAOMEI ZHANG, WENPENG WANG, ZHIZHAN XU, Shanghai Institute of Optics and Fine Mechanics, CAS — Relativistic laser pulse has been used as an important research tool in well known high energy density physics as well as in ultrahigh momentum density which has many important applications like radiation pressure acceleration. But another important character of relativistic laser, orbital angular momentum (OAM) effect was ignored. When a relativistic laser pulse with a high photon density interacts with a specially tailored thin foil target, a strong torque is exerted on the resulting spiral-shaped foil plasma, or “light fan.” Because of its structure, the latter can gain significant orbital angular momentum (OAM), and the opposite OAM is imparted to the reflected light, creating a twisted relativistic light pulse. Such an interaction scenario is demonstrated by particle-in-cell simulation as well as analytical modeling, and should be easily verifiable in the laboratory. As an important characteristic, the twisted relativistic light pulse has a strong torque and ultrahigh OAM density. Relativistic light has opened new research fields in high-field physics, including laser acceleration and relativistic high-order harmonics, because it has a high energy density. Now, relativistic twisted light has high angular momentum density, which may result in many new physical phenomena.

1 Yin Shi, Baifei Shen et al., PRL 112, 235001 (2014).

3:00PM JO6.00006 Propagation of high power, quasi-radially polarized $TEM_{01}$ modes in a plasma waveguide, ANDREW GOERS, GEORGE HINE, JENNIFER ELLE, LINUS FEDER, HOWARD MILCHBERG, University of Maryland, College Park — The longitudinal electric field of a tightly focused radially polarized laser pulse has been proposed and investigated as a compact means of accelerating femtosecond scale electron bunches. However, generation of high power, short pulse lasers with radial polarization has presented a significant technical challenge. We present a simple method of generating quasi-radial polarization by creating a pi-phase delay between two halves of a linearly polarized laser. When focused, the quasi-radially polarized pulse creates an approximately $TEM_{01}$ mode. We investigate guiding of the $TEM_{01}$ mode in a plasma waveguide over a range of intensities approaching $a_0 = 1$.

3 This work is supported by DTRA and DOE.
3:12PM JO6.00007 The aero-optical performance of inductively-coupled plasma adaptive lenses\textsuperscript{1}  
JAVIER URZAY, MILAD MORTAZAVI, ALI MANI, Center for Turbulence Research, Stanford University — In this presentation, we address the optical performance of a plasma adaptive lens for ground-surveillance applications by using three-dimensional numerical simulations and scaling analyses. The principle of operation of a plasma lens consists of controlling the refractive-index distribution, or equivalently, the electron-density field in an ionized-gas environment. A closed cylindrical chamber filled with Argon plasma is used as a model lens. In principle, scaling analyses show that increasing the input electric power increases the optical performance of the plasma lens. However, the numerical simulations reveal that this design shift makes the plasma lens more susceptible to buoyant and centrifugal hydrodynamic instabilities, which are caused by gravity-driven thermal convection and cycle-averaged Lorentz forces. This destabilization effect, in turn, breaks the initial axisymmetry and leads to the occurrence of discrete electron-rich spots, which degrade the optical performance of the plasma lens.

\textsuperscript{1}Funded by DARPA

3:24PM JO6.00008 Absolute Instability in Coupled-Cavity TW\textsuperscript{T}Ts\textsuperscript{1}  
D.M.H. HUNG, I.M. RITTERSDORF, PENG ZHANG, Y.Y. LAU, D.H. SIMON, R.M. GILGENBACH, University of Michigan, Ann Arbor, MI, D. CHERNIN, Leidos Corp., Reston, VA, T.M. ANTONSEN, JR., University of Maryland, College Park — This paper will present results of our analysis of absolute instability in a coupled-cavity traveling wave tube (TW\textsuperscript{T}). The structure mode at the lower and upper band edges are respectively approximated by a hyperbola in the \((\omega, k)\) plane. When the Briggs-Bers criterion is applied, a threshold current for onset of absolute instability is observed at the upper band edge, but not the lower band edge. The nonexistence of absolute instability at the lower band edge is mathematically similar to the nonexistence of absolute instability that we recently demonstrated for a dielectric TW\textsuperscript{T}. The existence of absolute instability at the upper band edge is mathematically similar to the existence of absolute instability in a gyrotron traveling wave amplifier. These interesting observations will be discussed, and the practical implications will be explored.

\textsuperscript{1}This work was supported by AFOSR, ONR, and L-3 Communications Electronic Devices.

3:36PM JO6.00009 TWT Driven by a Large Diameter Annular Electron Beam in a Disk-on-Rod Slow-Wave Structure\textsuperscript{1}  
P. WONG, D.H. SIMON, PENG ZHANG, Y.Y. LAU, R.M. GILGENBACH, University of Michigan, Ann Arbor, MI, B. HOFF, Air Force Research Laboratory — This paper studies the viability of a high-power traveling wave tube (TW\textsuperscript{T}) using a disk-on-rod slow-wave structure (SWS), which admits a large diameter, high current, annular electron beam. The annular electron beam would achieve much higher current than a pencil beam. The cold-tube as well as the hot-tube dispersion relations are analytically studied and compared to numerical simulations. The Pierce gain parameter, \(C\), is calculated by two very different methods: the exact formulation of the space-charge wave on the disk-on-rod slow-wave structure, as well as the hot-tube dispersion relations are analytically studied and compared to numerical simulations. The Pierce gain parameter, \(C\), is calculated rigorously for the first time for the disk-on-rod SWS TW\textsuperscript{T}. Proofs-of-principle experiment is designed based on the combined analytic and simulation studies.

\textsuperscript{1}This work is supported by AFOSR, and by L-3 Communications Electronic Devices.

3:48PM JO6.00010 Experiments and Simulations on a Prototype Recirculating Planar Magnetron\textsuperscript{1}  
G. GREENING, N. JORDAN, R. GILGENBACH, S. EXELBY, P. ZHANG, D. SIMON, M. FRANZI, Y.Y. LAU, Nuclear Eng. & Rad. Sciences Department, University of Michigan — The Multi-Frequency Recirculating Planar Magnetron (MFRPM) is a high power microwave source, with the added benefit of simultaneous oscillation at more than one primary frequency. Prior research focused on the design of a dual L/S-band MFRPM prototype to demonstrate simultaneous operation at 1 GHz and 2 GHz. Dual frequency microwave emission on this prototype was recently demonstrated on the Michigan Electron Long Beam Accelerator with a ceramic insulator (MELBA-C), which drives the MFRPM by applying \(-300\) kV, \(0.3-1.0\) \(\mu\)s pulse to the cathode. Experiments were underway to characterize operation of the MFRPM prototype. Microwave power extraction and different cathode designs are also being explored to improve operation. Results are compared to simulations of the experimental setup using the MAGIC particle-in-cell and HFSS finite-element codes.

\textsuperscript{1}Research supported by ONR grant N00014-13-1-0566, L-3 Communications EDD, ATK via the use of MAGIC, and the DEPS.

3:54PM JO6.00011 Microwave Power Measurements on the Recirculating Planar Magnetron\textsuperscript{1}  
N.M. JORDAN, M. FRANZI, G.B. GREENING, R.M. GILGENBACH, D.H. SIMON, Y.Y. LAU, Nuclear Eng. & Rad. Sciences Dept., Univ of Michigan, Ann Arbor, B.W. HOFF, AFRL, J.W. LUGINSLAND, AFOSR — The recirculating planar magnetron (RPM) is a high power microwave generator that recirculates the beam in two-coupled, planar magnetrons. Experiments on the first L-band prototype\textsuperscript{1} have successfully produced 50-200 \(\mu\)s, 30-130 MW microwave pulses with instantaneous electronic efficiencies of up to 30\% at approximately 1 GHz. The device is driven using MELBA-C, with parameters of \(-300\) kV for \(0.3-1.0\) \(\mu\)s, and 0.15-0.3 T axial magnetic fields. Recent RPM experiments have explored the effect of cathode surface treatment on the extracted microwave power efficiency, and pulse width. This work utilized a proof of principle extraction system with antennas on the center vane of each oscillator to couple RF power into two, coaxial transmission lines. An advanced design, the Coaxial All Cavity Extractor, is in fabrication and will be discussed.

\textsuperscript{1}Research supported by AFOSR grant #FA9550-10-1-0104 and by AFRL.

4:00PM JO6.00012 Microwave Power Measurements on the Recirculating Planar Magnetron\textsuperscript{1}  
N.M. JORDAN, M. FRANZI, G.B. GREENING, R.M. GILGENBACH, D.H. SIMON, Y.Y. LAU, Nuclear Eng. & Rad. Sciences Dept., Univ of Michigan, Ann Arbor, B.W. HOFF, AFRL, J.W. LUGINSLAND, AFOSR — The recirculating planar magnetron (RPM) is a high power microwave generator that recirculates the beam in two-coupled, planar magnetrons. Experiments on the first L-band prototype\textsuperscript{1} have successfully produced 50-200 \(\mu\)s, 30-130 MW microwave pulses with instantaneous electronic efficiencies of up to 30\% at approximately 1 GHz. The device is driven using MELBA-C, with parameters of \(-300\) kV for \(0.3-1.0\) \(\mu\)s, and 0.15-0.3 T axial magnetic fields. Recent RPM experiments have explored the effect of cathode surface treatment on the extracted microwave power efficiency, and pulse width. This work utilized a proof of principle extraction system with antennas on the center vane of each oscillator to couple RF power into two, coaxial transmission lines. An advanced design, the Coaxial All Cavity Extractor, is in fabrication and will be discussed.

\textsuperscript{1}Research supported by AFOSR grant #FA9550-10-1-0104 and by AFRL.

\textsuperscript{2}Present address: Stanford Linear Accelerator Center (SLAC)


We gratefully acknowledge support from DARPA MTO for research on microplasmas. We thank Brian Naranjo, Keith Weninger, Carlos Camara, Gary Williams, and John Kouklakis for valuable discussions.

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4:12PM JO6.00012 Impedance Dynamics in the Self-Magnetic Pinch (SMP) Diode on the RITS-6 Accelerator*, TIMOTHY RENK, MARK JOHNSTON, JOSHUA LECKBEE, TIMOTHY WEBB, MICHAEL MAZARAKIS, MARK KIEFER, Sandia National Laboratories, NICHELLE BENNETT, National Security Technologies The RITS-6 inductive voltage adder (IVA) accelerator (3.5-8.5 MeV) at Sandia National Laboratories produces high-power (TW) focused electron beams (<3mm diameter) for flash x-ray radiography applications. The Self-Magnetic Pinch (SMP) diode utilizes a hollowed metal cathode to produce a pinched focus onto a high Z metal converter. The electron flow from the IVA driver into the load region complicates understanding of diode evolution. There is growing evidence that reducing cathode size below some “optimum” value in order to achieve desired spot size reduction results in pinch instabilities leading to either reduced dose-rate, early radiation power termination, or both. We are studying evolving pinch dynamics with current and x-ray monitors, optical diagnostics, and spectroscopy, as well as with LSP [1] code simulations. We are also planning changes to anode-cathode materials as well as changes to the diode aspect ratio in an attempt to mitigate the above trends and improve pinch stability while achieving simultaneous spot size reduction. Experiments are ongoing, and latest results will be reported. [1] LSP is a software product of ATK Mission Research, Albuquerque, NM. *Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

4:24PM JO6.00013 ABSTRACT WITHDRAWN –

4:36PM JO6.00014 ABSTRACT WITHDRAWN –

4:48PM JO6.00015 A nonlinear plasma retroreflector for single pulse Compton backscattering , J.P. PALASTRO, Icarus Research, D. KAGANOVICH, D. GORDON, B. HAFIZI, J. PENANO, M. HELLE, A. TING, Naval Research Laboratory — A long laser pulse focused onto the edge of a gas jet nozzle launches a shock wave. The shock wave and gas jet flow collide forming a density spike [1]. The leading edge of an incident ultrashort laser pulse ionizes the gas, while the bulk undergoes a nonlinear Poynting flux reversal from the ionized spike. The resulting counterpropagating field can Compton backscatter from electrons accelerated in the ultrashort pulse’s wakefield, upshifting the frequency. We examine the reversal mechanism and properties of the counterpropagating field to optimize the Compton scattered radiation.

Tuesday, October 28, 2014 2:00PM - 4:48PM – Session JO7 Strongly Coupled Plasmas, Quantum Plasmas, and Numerical Techniques Galerie 6 - Jerome Daligault, Los Alamos National Laboratory

2:00PM JO7.00001 A new class of strongly coupled plasmas inspired by sonoluminescence1 . ALEXANDER BATALLER, GUILLAUME PLATEAU, BRIAN KAPPUS, SETH PUTTERMAN, Univ of California - Los Angeles — Sonoluminescence originates in a strongly coupled plasma with a near liquid density and a temperature of ~10,000 K. This plasma is in LTE and therefore, it should be a general thermodynamic state. To test the universality of sonoluminescence, similar plasma conditions were generated using femtosecond laser breakdown in high pressure gases. Calibrated streak spectroscopy reveals both transport and thermodynamic properties of a strongly coupled plasma. A blackbody spectrum, which persists long after the exciting laser has turned off, indicates the presence of a highly ionized LTE microplasma. In parallel with sonoluminescence, this thermodynamic state is achieved via a considerable reduction in the ionization potential.

1 We gratefully acknowledge support from DARPA MTO for research on microplasmas. We thank Brian Naranjo, Keith Weninger, Carlos Camara, Gary Williams, and John Kouklakis for valuable discussions.

2:12PM JO7.00002 Non-Markovian Collisional Dynamics in a Strongly Coupled Ultracold Neutral Plasma1, TREVOR STRICKLER, THOMAS LANGIN, PATRICK MCQUILLEN, Rice University, GEORG BANNASCH, THOMAS POHL, Max Planck Institute For The Physics of Complex Systems, THOMAS KILLIAN, Rice University — Collision rates in weakly coupled plasmas are well-described by the Landau-Spitzer formula; however, the formula breaks down for plasmas in the strongly coupled regime where collisions may be governed by non-Markovian dynamics. In this work, we present experimental results concerning non-Markovian processes in a strongly coupled ultracold neutral plasma (UCNP) created by photoionizing strontium atoms in a magnetooptical trap. Our diagnostic uses optical pumping to create spin “tagged” subpopulations of ions having skewed velocity distributions that then relax back to equilibrium. In previous work, we used this technique with LIF imaging to extract ion-ion collision rates of strongly coupled UCNPs. With newly improved time resolution (down to 30 ns), we have now explored the very early time dynamics of these skewed ion distributions within a few 100 ns after the optical pumping, where molecular dynamics simulations predict non-Markovian deviations from the exponential velocity damping expected for weakly coupled systems. We observe evidence of non-exponential damping and compare results across a range of plasma parameters.

2:12PM JO7.00002 Non-Markovian Collisional Dynamics in a Strongly Coupled Ultracold Neutral Plasma1, TREVOR STRICKLER, THOMAS LANGIN, PATRICK MCQUILLEN, Rice University — Collision rates in weakly coupled plasmas are well-described by the Landau-Spitzer formula; however, the formula breaks down for plasmas in the strongly coupled regime where collisions may be governed by non-Markovian dynamics. In this work, we present experimental results concerning non-Markovian processes in a strongly coupled ultracold neutral plasma (UCNP) created by photoionizing strontium atoms in a magnetooptical trap. Our diagnostic uses optical pumping to create spin “tagged” subpopulations of ions having skewed velocity distributions that then relax back to equilibrium. In previous work, we used this technique with LIF imaging to extract ion-ion collision rates of strongly coupled UCNPs. With newly improved time resolution (down to 30 ns), we have now explored the very early time dynamics of these skewed ion distributions within a few 100 ns after the optical pumping, where molecular dynamics simulations predict non-Markovian deviations from the exponential velocity damping expected for weakly coupled systems. We observe evidence of non-exponential damping and compare results across a range of plasma parameters.

2:24PM JO7.00003 Ion Temperature Evolution in an Ultracold Neutral Plasma, PATRICK MCQUILLEN, TREVOR STRICKLER, THOMAS LANGIN, Rice University Department of Physics and Astronomy & Rice Quantum Institute — Ultracold neutral plasmas (UNPs), created by photoionizing laser-cooled atoms have ions which inherit very low temperatures. However, a process known as disorder induced heating quickly heats the ions, limiting the equilibrium shielded ion Coulomb coupling parameter to approximately two, regardless of initial conditions. This places UNPs just within the strongly coupled (non-ideal) regime. Subsequently, competing cooling and heating mechanisms have been predicted to determine the ion temperature evolution. Using laser induced fluorescence spectroscopy and taking care to minimize extraneous heating processes like heating from ion-acoustic-wave excitations; we have measured the ion temperature evolution of UNPs, observing both adiabatic cooling of the ions, by up to an order of magnitude and collisional heating by the electrons. These measurements will be presented along with efforts to model the ion temperature evolution as well as discussion of the Coulomb coupling parameter. We gratefully acknowledge support from the Department of Energy and National Science Foundation (PHY-0714603) and the Air Force Office of Scientific Research (FA9550-12-1-0267).
2:36PM JO7.00004 Linear Electrostatic Instabilities in a Quantum Plasma with Arbitrary Level of Degeneracy, SHANE RIGHTLEY, DMITRI UZDENSKY, CIPS, University of Colorado — In this study, a fully kinetic complex solution of the linear dispersion relation for electrostatic waves in a quantum electron plasma with arbitrarily-degenerate Fermi-Dirac equilibrium distribution is extended to cases with multiple drifting populations of electrons. Building on a previous numerical procedure, we allow for a full linear analysis of quantum kinetic effects in one-dimensional streaming instabilities. The bump-on-tail instability is analyzed for an arbitrarily degenerate electron background. Additional focus is on instabilities in systems with counter-streaming populations with varying degrees of degeneracy. These instabilities have been previously studied analytically in a simple theory. This presentation will focus specifically on these instabilities, which are of well-known importance to classical plasmas. Additionally, our use of a physically realistic Fermi-Dirac distribution function is novel. The intent of the analysis is towards increasing the understanding of quantum plasma physics as a field and laying a foundation for further studies.

2:48PM JO7.00005 Evidence of a new quantization constant in collisionless plasmas, GEORGE LIVADIOTIS, Southwest Res Inst — Recent plasma analyses revealed strong evidence about the value and nature of the new quantization constant $\hbar_*$, that is similar to the Planck constant $\hbar$, but 12 orders of magnitude larger. Planck’s constant constitutes the phase-space quantum for individual and uncorrelated particles, while the new constant $\hbar_*$ describes the phase-space quantum for particle systems characterized by local correlations, such as collisionless plasmas. In plasmas, the phase correlations induced by the correlations between particles. This divides the system into an ensemble of clusters of correlated particles. The particles within each of these “correlation clusters” participate altogether to this new type of quantization. Quantum mechanics requires the existence of a non-zero least action, the quantization constant, but do not provide its specific value. The new developments point toward a new quantum-mechanical approach that will be based on the new quantization constant. If true, plasmas can be studied in a new way, following the framework of quantum and statistical mechanics, but on a much larger scale.

3:00PM JO7.00006 Fano-like resonances in strongly coupled binary Coulomb systems, LUCIANO SILVESTRI, GABOR J. KALMAN, Boston College, ZOLTÁN DONKÓ, PETER HARTMANN, Wigner Research Centre for Physics, Hungarian Academy of Sciences, HANNO KÄHLERT, Institute for theoretical physics and astrophysics, Kiel, Germany — Molecular Dynamics (MD) simulation of a strongly coupled binary ionic mixture has revealed the presence of a sharp minimum of several orders of magnitude in the dynamical density (current) fluctuation spectrum of the system. This phenomenon is reminiscent of the well-known Fano anti-resonance observed in various physical systems. The Fano resonance effect can be understood on the basis of a classical model as a feature of the response function of a multi-resonant system, and therefore it is a phenomenon that should occur in classical systems as well. What, however, is not widely recognized is that there must be a corollary to this phenomenon as demanded by the Fluctuation Dissipation Theorem: the equilibrium fluctuation spectrum of a strongly coupled system has to display a similar spectral feature. We present a theoretical description based on the principle of Localized Charge Distribution, reformulated to include collisional effects, in order to explain the simulation results. The essence of the phenomenon is that the minimum is due to the interference between the two damped plasmon modes of a binary system. The validity of the theoretical model has been verified by further MD simulations and an excellent agreement between theory and observation has been demonstrated.

3:12PM JO7.00007 ABSTRACT WITHDRAWN

3:24PM JO7.00008 Experimental determinations of the sound speed and the Gruneisen coefficient of liquid Deuterium along the principal Hugoniot using a first order perturbation analysis, DAVYE FRATANDUONO, PETER CELLIERS, DAMIAN HICKS, Lawrence Livermore National Laboratory, TOM BOEHLY, Laboratory for Laser Energetics, DAVID MUNRO, GILBERT COLLINS, Lawrence Livermore National Laboratory — Using a first order perturbation analysis, we have measured the sound speed and Gruneisen coefficient of liquid Deuterium along the principal Hugoniot. Experiments were conducted at the OMEGA laser facility in which perturbations in the drive were measured at the shock front in both the transparent standard (Quartz) and liquid Deuterium sample. Since the EOS of the transparent standard is well known, a first order perturbation analysis enables extraction of the sound speed and Gruneisen coefficient through the correlation of events on the shock front in both materials. These measurements, represent the first high-pressure (>100 GPa) dynamic measurements of Deuterium EOS derivatives which will further advance EOS modeling capabilities important to astrophysics, planetary physics and ICF. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

3:36PM JO7.00009 Introduction to a new computational method of electron-ion quantum plasmas of an arbitrary degeneracy, IN-GEE KIM, New Mexico Consortium, MICHAEL MURILLO, Los Alamos National Laboratory — A new computational approach for calculating the physical properties of quantum mechanical electron-ion plasmas of an arbitrary degeneracy in terms of the random-phase approximation is introduced. The numerical computation for the arbitrarily degenerated plasmas is achieved by employing the sinc quadrature rule for the corresponding improper integrals. Although the model system is assumed to be isotropic and homogeneous, the method provides high degrees of freedom for choosing the model interactions. We are able to investigate the possible elementary excitations, as well as instabilities, for the interacting quantum two-component system for the broad range of parameter space.

3:48PM JO7.00010 Unusual simulated Raman scattering in a plasma metamaterial, EDUARDO P. ALVES, RICARDO FONSECA, LUÍS O. SILVA, GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Tecnico, Universidade de Lisboa, Lisbon, Portugal — Electromagnetic (e.m.) metamaterials using plasmas have recently been demonstrated to exhibit extraordinary e.m. features [Sakai, 2012]. We aim to exploit plasma nonlinearity combined with metamaterial structures to assess new and unexplored nonlinear e.m. phenomena. We have developed a unique numerical framework to study nonlinear plasma processes in the presence of a strong background magnetic permeability (e.g., background SRR metamaterial [Pendry, 1999]). We combine the particle-in-cell method, to describe the plasma dynamics self-consistently, with a dispersive-FDTD Maxwell solver to incorporate the effects of a strong background magnetic permeability [Taflove, 2000]. This framework allows us to investigate the extraordinary character of fundamental nonlinear plasma effects in the presence of a strong magnetic permeability, which is generally neglected in standard plasma physics. In this work, we explore simulated Raman scattering (SRS) in a plasma metamaterial. We have generalized the SRS theory to incorporate the effect of an arbitrary background magnetic permeability. The generalized theory is in good agreement with our numerical framework and we demonstrate the unusual operation of SRS in a parameter window that is not accessible in a simple plasma medium.

4:00PM JO7.00011 Exploration of LWFA Parameter Regimes Using Truncated Azimuthal Modal Geometry in the OSIRIS Simulation Framework, ASHER DAVIDSON, UCLA — In plasma based accelerators (LWFA and PWFA), the methods of injecting high quality electron bunches into the accelerating wakefield is of utmost importance for various applications. Numerous particle-in-cell (PIC) simulations are conducted in order to study various methods of injection and the ideal parameters thereof. 2D slab-geometry simulations are computationally inefficient, but they are quantitative, and sometimes even qualitatively inaccurate. One method for reducing the computational load of a 3D simulation is by utilizing a truncated azimuthal mode expansion into the OSIRIS simulation framework [A. Lifschitz et. al 228 (5) (2009)]. Comparison with 3D LWFA simulations shows a great degree of consistency in the characteristics of the self-trapped beam. In addition, higher order cylindrical modes may capture effects such as beam bosing and asymmetric spot size modulation. With this highly efficient 2D-hybrid algorithm it is possible to simulate parameter regimes and scaling laws that are difficult to do in a full 3D Cartesian simulation. Relativistic spot-size self-focusing, which cannot be accurately described in a 2D slab geometry, is also studied.
A finite mass based method for Vlasov-Poisson simulations\textsuperscript{1}, DAVID LARSON, LLNL, CHRISTOPHER YOUNG. Stanford Plasma Physics Laboratory — A method for the numerical simulation of plasma dynamics using discrete particles is introduced. The shape function kinetic (SFK) method is based on decomposing the mass into discrete particles using shape functions of compact support. The particle positions and shape evolve in response to internal velocity spread and external forces. Remapping is necessary in order to maintain accuracy and two strategies for remapping the particles are discussed. Numerical simulations of standard test problems illustrate the advantages of the method which include very low noise compared to the standard particle-in-cell technique, inherent positivity, large dynamic range, and ease of implementation.\textsuperscript{2}

This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344. C. V. Young acknowledges the support of the DOE NNSA Stewardship Science Graduate Fellowship under contract DE-FC52-08NA28752.

A Electromagnetic Particle-In-Cell Framework with Cut-Cells and Unstructured Mesh Regions\textsuperscript{1}, COLLIN MEIERBACHTOL, ANDREW GREENWOOD, Air Force Research Laboratory, JOHN VERBONCOEUR, ANDREW CHRISTLIB, Michigan State University — Many electromagnetic particle-in-cell (EM-PIC) simulations are solved on Cartesian meshes, where curved or slanted metallic boundaries are approximated via staircasing. As a result, numerical errors are introduced in both the field and particle behaviors. Cut-cells inserted near these irregular metallic boundaries can eliminate staircasing, but have difficulty in resolving small geometric features. Unstructured meshes can successfully resolve irregular boundaries and small features via local mesh refinement, but can also increase simulation run time. In order to achieve good geometric representation while minimally increasing the simulation run time, we propose a hybrid mesh EM-PIC framework. The simulation domain is mostly filled with a Cartesian mesh. Slanted or large radius metallic boundaries are represented via cut-cells, while the mesh surrounding any small physical features is unstructured. Electromagnetic fields are updated via explicit finite difference methods in both the Cartesian and cut-cells, and finite element methods within any unstructured mesh regions. Particle positions are updated and tracked throughout the hybrid mesh.

This research was performed while CM held a National Research Council Research Associateship Award at the Air Force Research Laboratory.

A Geometrical Version of the Maxwell-Vlasov Hamiltonian Structure, MICHEL VITTOT, Centre de Physique Theorique (CPT), C.N.R.S. UMR 7332 - Aix-Marseille Universite, Luminy, 13288 Marseille - FRANCE, PHILIP MORISON, The University of Texas at Austin, Physics Department, Austin, TX 78712-1192 - USA — We present a geometrization of the Hamiltonian approach of classical electrodynamics, via (non-canonical) Poisson structures. This relativistic Hamiltonian framework (introduced by Morrison, Marsden, Weinstein) is a field theory written in terms of differential forms, independently of the gauge potentials. This algebraic and geometric description of the Vlasov kinetics is well suited for a perturbation theory, in a strong inhomogeneous magnetic field (expansion in 1/B, with all the curvature terms...), like in magnetically confined plasmas, and in any coordinates, for instance adapted to a Tokamak (toroidal coordinates, or else...).
NAKEISHA JOHNSON, ALKESH PUNJABI, HALIMA ALI, Hampton University — The simple map is the simplest symplectic map that has the generic magnetic topology of divertor tokamaks. The generating function of the simple map is $S(x,y) = x^2/2 - y^2/2 - y^3/3$. The equilibrium magnetic surfaces of the simple map are calculated from the generating function. $0 < S < 1/6$ gives closed surfaces and private flux surfaces; $S = 1/6$ gives the separatrix, and $S > 1/6$ gives open surfaces. The scaling of safety factor on the magnetic axis, $q_0$, with map parameter $k$ is calculated. The scaling of root mean square deviation of energy on the $q_0$ surface with map parameter $k$ is calculated and taken as the estimate of magnetic asymmetry to represent the magnetic perturbation. The results of this work will be reported. These results are used to calculate homoclinic tangle of the separatrix of simple map. This work is supported by grants DE-FG02-01ER54624, DE-FG02-04ER54793, and DE-FG02-07ER54937.

NAKEISHA JOHNSON, ALKESH PUNJABI, HALIMA ALI, Hampton University — The simple map is the simplest symplectic map that has the generic magnetic topology of divertor tokamaks. The generating function of the simple map is $S(x,y) = x^2/2 - y^2/2 - y^3/3$. The equilibrium magnetic surfaces of the simple map are calculated from the generating function. $0 < S < 1/6$ gives closed surfaces and private flux surfaces; $S = 1/6$ gives the separatrix, and $S > 1/6$ gives open surfaces. The scaling of safety factor on the magnetic axis, $q_0$, with map parameter $k$ is calculated. The scaling of root mean square deviation of energy on the $q_0$ surface with map parameter $k$ is calculated and taken as the estimate of magnetic asymmetry to represent the magnetic perturbation. The results of this work will be reported. These results are used to calculate homoclinic tangle of the separatrix of simple map. This work is supported by grants DE-FG02-01ER54624, DE-FG02-04ER54793, and DE-FG02-07ER54937.

JP8.00009 Construction of a hybrid rf/dc discharge source for dusty plasma studies1, JUSTIN KRUPA, JEREMIAH WILLIAMS, Wittenberg University — A complex (dusty) plasma is a four-component system composed of ions, electrons, neutral particles and charged microparticles. The presence of the microparticles gives rise to new plasma phenomena at time scales on the order of Hertz. Over the last several years, the Wittenburg University Plasma Laboratory has studied these dusty plasma systems in a dc discharge plasma. In this poster, we present work on a dual rf/dc hybrid discharge system to replace the dc glow discharge system currently in use. Details of the design and use of 3D printing in the construction will be presented.

1This work supported by National Science Foundation Grant Number PHY-0953595.

JP8.00010 Comparison of open-source particle image velocimetry (PIV) programs for dusty plasma studies1, MEGAN HEITKEMPER, JEREMIAH WILLIAMS, Wittenberg University — Particle Image Velocimetry (PIV) is a non-invasive diagnostic technique that provides a quantitative measure of fluid flow and particle transport. Recent advances in imaging technology have led to the development of a time-resolved version of this diagnostic technique, which replaces a dedicated PIV diagnostic setup with a high-speed camera and a CW laser. This technique has been used to examine a wide range of phenomena in the dusty plasma community. Additionally, the availability of open-source PIV software has made this diagnostic technique accessible at a relative modest cost. This poster will present an overview of how the PIV technique can be applied to image data acquired with a high speed camera, the image requirements, and will provide a comparison of a number of open-source PIV software.

1This work supported by National Science Foundation Grant Number PHY-0953595

JP8.00011 Spectral characterization of Compact Toroidal Hybrid plasmas in preparation for Thomson scattering measurements1, M.M. GOFORTH, S.D. LOCH, D.A. MAURER, A.J. PEARCE, P.J. TRAVERSO, Auburn University — A Thomson scattering system is in development for the Compact Toroidal Hybrid (CTH) experiment to provide localized, internal electron temperature and density measurements. Thomson scattering yields accurate information on the internal plasma electron pressure profile, which will aid in the equilibrium reconstruction of CTH plasmas using the V3FIT code [1]. The expected Thomson scattered signal is approximately $10^{15}$ times less than the incident laser light, and can be overwhelmed by stray laser light, background plasma emission, and intrinsic detector noise. Background plasma emission measurements in the visible spectral region near the planned laser wavelength of 532nm are underway using a Holospec f/1.8 spectrometer and an Andor iStar image intensified CCD camera to quantify line and continuum background levels. In addition, impurity line identification and plans for a separate line-of-sight averaged impurity measurement capability employing the Thomson spectrometer are in progress.

1This work supported by US DOE Grant DE-FG-02-00ER54610 and by the Auburn University Undergraduate Research Fellowship

JP8.00012 Determining Point of Structural Failure of a Foil Liner Under High Magnetic Fields, HANNAH MOORE, EMMA BELL, ROBBERT DUGGAN, NATHAN LAMBERT, DANIEL LIANG, LAUREN RANSHOFF, GRIGORY TABAK, PIERRE GOURDAIN, WILLIAM POTTER, JOHN GREENLY, Cornell University — At the National Ignition Facility (NIF), the path to nuclear fusion relies on indirect drive, where the fuel capsule is irradiated by x-rays produced by a MJ laser heating the wall of a hohlraum. However laser plasma interactions prevent optimal focusing and the quality of the implosion may suffer from it. One way to mitigate this issue is to impose an external magnetic field on the hohlraum, reducing plasma outflows thereby limiting plasma-laser interaction. While the optimal magnetic field strength is still under debate, one major issue is the effect of the field on hohlraum integrity. Our goal is to study the effect of large magnetic fields (>100 T) on a thin aluminum liner (thickness 10 microns) and identify the maximum magnetic field (<150T) where the liner maintains its structural integrity. In past COBRA experiments using a coaxial coil design, we were able to consistently produce magnetic fields above 150 T. We will use this setup coupled with the liner and use a B-dot probe to measure the field penetration inside of the liner. From laser interferometry and XUV measurements we will also be able to observe how the liner reacts to the different magnetic field strengths.

This work was supported by the US. D.O.E. contract DE-AC50-00OR22725, and the Oak Ridge Associated Universities ARC program.

JP8.00007 The simple map - equilibrium, safety factor on magnetic axis, and perturbation from map parameter, NAKEISHA JOHNSON, TANZANIA GUEST, LATOYA PRESSLEY, HALIMA ALI, ALKESH PUNJABI, Hampton University — The simple map is the simplest symplectic map that has the generic magnetic topology of divertor tokamaks. The generating function of the simple map is $S(x,y) = x^2/2 - y^2/2 - y^3/3$. The equilibrium magnetic surfaces of the simple map are calculated from the generating function. $0 < S < 1/6$ gives closed surfaces and private flux surfaces; $S = 1/6$ gives the separatrix, and $S > 1/6$ gives open surfaces. The scaling of safety factor on the magnetic axis, $q_0$, with map parameter $k$ is calculated. The scaling of root mean square deviation of energy on the $q_0$ surface with map parameter $k$ is calculated and taken as the estimate of magnetic asymmetry to represent the magnetic perturbation. The results of this work will be reported. These results are used to calculate homoclinic tangle of the separatrix of simple map. This work is supported by grants DE-FG02-01ER54624, DE-FG02-04ER54793, and DE-FG02-07ER54937.

JP8.00008 Homoclinic tangle of separatrix of the simple map, LATOYA PRESSLEY, TANZANIA GUEST, NAKEISHA JOHNSON, ALKESH PUNJABI, HALIMA ALI, Hampton University — The simple map is the simplest symplectic map that has the generic magnetic topology of divertor tokamaks. The generating function of the simple map is $S(x,y) = x^2/2 - y^2/2 - y^3/3$. $S = 1/6$ gives the separatrix surface. The scaling of safety factor on the magnetic axis, $q_0$, with map parameter $k$ is used to calculate the number of iterations of the simple map, $N$, that is equivalent to a single toroidal circuit of the tokamak. The scaling of root mean square deviation of energy on the $q_0$ surface with map parameter $k$ is taken as the estimate of magnetic asymmetry to represent the magnetic perturbation from map parameter $k$. These data is used in the forward and backward simple maps to calculate the homoclinic tangle of the separatrix of divertor tokamaks from magnetic asymmetries. This work is supported by grants DE-FG02-01ER54624, DE-FG02-04ER54793, and DE-FG02-07ER54937.

JP8.00006 Measurements of the relative transmission properties of optical fiber for use on Proto-MPEX$, T.M. BIEWER, Oak Ridge National Laboratory, Oak Ridge, TN, USA, K. COLLINS, Monroe County High School, Tompkinsville, KY, USA, B. JOHNSON, Wilkes Central High School, Wilkes County, NC, USA, A. LANCASTER, Allegheny High School, Cumberland, MD, USA, R. MOSBY, Oak Ridge High School, Oak Ridge, TN, USA, H. RAY, G. SHAW, Oak Ridge National Laboratory, Oak Ridge, TN, USA, B. YOUNG, Clay County High School, Clay, WV, USA — The prototype Material Plasma Exposure eXperiment (Proto-MPEX) is a linear plasma device being developed at Oak Ridge National Laboratory (ORNL). This machine plans to study plasma-material interaction (PMI) physics relevant to future fusion reactors. Measurements of plasma emission will be made on Proto-MPEX using spectrometers and filterscopes, which are coupled to the plasma by fiberoptic cables. The transmission properties of these fiberoptics are critical to the accurate estimation of the plasma emission levels. This presentation will highlight some of the issues encountered during calibration of hardware for use on Proto-MPEX.

1This work was supported by the US. D.O.E. contract DE-AC50-00OR22725, and the Oak Ridge Associated Universities ARC program.
JP8.00013 Designing and testing a high power rf matching network circuit for helicon plasma antennas, KYLE ADRIANY, RYAN DE LEON, SAIKAT CHAKRABORTY THAKUR, GEORGE TYNNAN, Univ of California - San Diego — Controlled Shear Decorrelation eXperiment [CSDX] is a helicon plasma device dedicated to basic plasma studies of turbulence and transport in a very controlled and well-diagnosed plasma environment. Previous studies in argon helicon plasmas were performed at relatively low power thresholds, typically 1.5 kWatts (maximum of 1.8 kWatts), mainly because of arcing in the rf matching circuit at higher powers. We are designing a completely new rf matching network circuit with higher power rated capacitors and better insulation to prevent arcing even at much higher powers. We shall report initial results of using this new matching network circuit to couple rf power, up to 5 kWatts, to the helicon antenna in CSDX. We believe that this capability shall significantly improve upon the range of plasma parameters previously studied at CSDX.

JP8.00014 Characterizing ICF Neutron Diagnostics on the nTOF line at SUNY Geneseo, ANGELA SIMONE, STEPHEN PADALINO, ETHAN TURNER, MARY KATE GINNANE, NATALIE DUBOIS, KURTIS FLETCHER, MICHAEL GIORDANO, PATRICK LAWSON-KIESTER, HANNAH HARRISON, HANNAH VISCA, State University of New York at Geneseo, CRAIG SANGSTER, SEAN REGAN, Laboratory for Laser Energetics — Charged particle beams from the Genesee 1.7 MV tandem Pelletron accelerator produce nuclear reactions that emit neutrons in the range of 0.5 to 17.9 MeV via the d(d,n)3He and 11B(d,n)12C reactions. The neutron energy and flux can be adjusted by controlling the accelerator beam current and potential. This adjustable neutron source makes it possible to calibrate ICF and HEDP neutron scintillator diagnostics. However, gamma rays which are often present during an accelerator-based calibration are difficult to differentiate from neutron signals in scintillators. To identify neutrons from gamma rays and to determine their energy, a permanent neutron time-of-flight (nTOF) line is being constructed. By detecting the scintillator signal in coincidence with an associated charged particle (ACP) produced in the reaction, the identity of the neutron can be known and its energy determined by time of flight. Using a 100% efficient surface barrier detector to count the ACPs, the absolute efficiency of the scintillator as a function of neutron energy can be determined. This is done by determining the ratio of the ACP counts in the singles spectrum to coincidence counts for matched solid angles of the SBD and scintillator. Funded in part by a LLE contract through the DOE.

JP8.00015 Design of a triple plasma device for double layer and turbulence investigations, JUSTIN KIM, CORY JACKSON, NOAH HERSHKOWITZ, M. UMAIR SIDDQUI, Univ of Wisconsin, Madison — A triple plasma device is being constructed at the University of Wisconsin-Madison for basic plasma physics investigations. The device consists of two outer chambers and a central chamber. Separate plasmas are generated in the two outer chambers, and their interactions are measured in the central chamber. DC plasma is generated via thermionic emission of electrons from a hot-filament and rf plasma is generated either capacitively or inductively. The device is used to investigate double layer structures [Coakley and Hershkowitz, Physics of Fluids 22, 1171 (1979)] and beam plasma instabilities. The design, construction, and operation of this device are discussed. Initial results are presented here.

This work is funded by U.S. Department of Energy Grant No. DE-FG02-97ER54437 and NSF Undergraduate Funding.

JP8.00016 ABSTRACT WITHDRAWN —

JP8.00017 Permutation entropy analysis of dynamical turbulence in the SSX MHD wind tunnel and the solar wind, P.J. WECK, E.R. HUDSON, D.A. SCHAFFNER, M.R. BROWN, Swarthmore College, R.T. WICKS, GSFC, V.S. LUKIN, NRL — The statistical character of turbulence in the plasma wind tunnel configuration at the Swarthmore Spheromak Experiment (SSX) and the solar wind is evaluated using ordinal pattern-based measures of complexity. The SSX MHD wind tunnel measures fluctuations in magnetic field, velocity, and density as highly magnetized spheromaks (typical values are \( B \approx 0.1 \, \text{T}, n \geq 10^{20} \, \text{m}^{-3}, \) and \( T \geq 20 \, \text{eV} \)) evolve dynamically into a relaxed state. Flow speeds are measured with a visible light array. \( B \) time series for 3 spatial directions recorded by a 16-channel, high-resolution probe array embedded in the chamber are analyzed using the permutation entropy and Jensen-Shannon statistical complexity. By calculating the position of signals on a complexity-entropy plane, the degree of stochastic, periodic, or chaotic dynamics can be evaluated. Complexity-entropy positions of SSX signals are compared to those of turbulent fluctuations in the solar wind and the Large Plasma Device (LAPD) as well as Hall-MHD simulations of the SSX plasma, and it is found that the dynamics in the SSX plasma source are more truly turbulent than those in the LAPD but less stochastic than fluctuations in the solar wind.

Work supported by DOE OFES and NSF CMSO.

JP8.00018 Study of the probe-induced plasma perturbation on magnetic field measurements using an insertable probe, M. LEEDS, J.B. TRIANA, J.C. TITUS, A.F. ALMAGRI, J.S. SARFF, Physics Department, University of Wisconsin-Madison — One of the most utilized diagnostics in magnetized plasma research is an insertable probe with pickup loops to measure the local magnetic field. When an insulated probe is inserted into the plasma field, the current is forced to flow around the probe body. The geometry of both the particle shield and the coil arrangement within the current-free probe volume affect the measurement’s sensitivity to this perturbation. A probe has been constructed for use in 200 kA, \( n_e \approx 10^{13} \, \text{cm}^{-3} \) MST plasmas with interchangeable particle shields (diameters of 1.6-2.5 cm) to investigate the influence of the probe’s perturbation of measured fields. Magnetic pickup coils are arranged both centered and offset inside the probe body to measure all field components including the perturbation. The impact on both large-scale equilibrium and short wavelength magnetic fluctuations is studied. A simple lump-current wire model will be presented to interpret the data.

Work supported by DoE.

JP8.00019 Magnetic field and velocity fluctuations with and without a reversal surface in the RFP, D. MARTIN, D. CRAIG, Wheaton College (IL), D.J. DEN HARTOG, M.R. NORNBERG, J.A. REUSCH, University of Wisconsin - Madison, MST TEAM — Fluctuations in the standard Reversed Field Pinch (RFP) are dominated by poloidal mode numbers \( m = 0 \) and \( m = 1 \). The velocity and magnetic fluctuations generate an emf which redistributes current in the plasma. In experiments, the \( m = 0 \) mode amplitude and the emf due to \( m = 1 \) modes are both highly dependent on the existence of the reversal surface in the plasma. We investigate the role of the reversal surface on magnetic and velocity fluctuations using the DEBS resistive magnetohydrodynamic (MHD) code. As in the experiment, we find that \( m = 0 \) modes are suppressed through the removal of the reversal surface but \( m = 1 \) magnetic fluctuation amplitudes are not strongly affected. However, the suppression of \( m = 0 \) fluctuations is much more sudden in the experiment than in the code. Using the outputs of the code, we calculate the line-integrated velocity fluctuation correlated with specific magnetic modes measured at the edge. This facilitates comparisons between experimental and computational measures of velocity fluctuations. As in experiment, decreased \( m = 1 \) velocity fluctuations are observed in the code without a reversal surface present but the change in phase between \( v \) and \( b \) observed in experiment is not reproduced in the code. We speculate that the phase change observed in the experiment may be due to the contribution of advection of the mean flow profile by the magnetic fluctuations, an effect not present in the code. This work has been supported by the USDOE and NSF.
JP8.00020 Absolute Wavelength Calibration of the IDSII Spectrometer for Impurity Ion Velocity Measurements in the MST, M. BALZTER, D. CRAIG, Wheaton College (IL), D.J. DEN HARTOG, M.D. NORNBERG, University of Wisconsin - Madison, MST TEAM — The MST operates two Ion Doppler Spectrometers (IDS) for high time-resolution passive and active measurements of impurity ion emission. Absolutely calibrated measurements of flow are difficult because the spectrometers record data within 0.3 nm of the line of interest, and commercial calibration lamps do not produce lines in this narrow range. Four calibration methods were investigated. First, emission along the chord bisecting the poloidal plane was measured as it should have no time-averaged Doppler shift. Second, a calibrated CCD spectrometer and the IDSII were used to observe the same plasma from opposing sides so as to measure opposite Doppler shifts. The unshifted line is located halfway between the two opposing measurements. Third, the two fibers of the IDSI were positioned to take absolute flow measurements using opposing views. Substituting the IDSII for one of the IDSI fibers, absolute measurements of flow from the IDSI were used to calibrate the IDSII. Finally, an optical system was designed to filter an ultraviolet LED, providing a known wavelength source within the spectral range covered by the IDSII. The optical train is composed of an air-gapped etalon and fused silica lenses. The quality of calibration for each of these methods is analyzed and their results compared. Preliminary impurity ion velocity measurements are shown. This work has been supported by the US DOE and the NSF.

JP8.00021 The High Fidelity Plasma Speaker1, JAMES MCGALL, Salisbury University — A plasma speaker is a device that uses ionized gas as the driving source of sound production, rather than the traditional magnetic coil and membrane setup found on a standard speaker. Similar to how lightning produces sound, or even a small static shock, a plasma speaker uses a modulating electric arc between two electrodes to produce sound. An electric circuit is built that allows the variance of the high voltage electric potential to be controlled by a 3.5mm standard audio headphone jack, allowing sound energy to be transferred from the plasma to the air by means of pulse width modulation. For my summer project I have built two different models of plasma speakers and am working on a third. The speaker benefits from having a nearly massless driver, and I hypothesize that it should show a response rate faster than that of a traditional speaker and a decreased impulse response while having the drawbacks of inefficiency and a low maximum decibel output. The speakers are currently being optimized with magnetic stabilization of the plasma and will be tested soon for impulse response, frequency generation, efficiency, and audio coloration.

1Supported by DOE and NSF.

JP8.00022 Measurement of Ion Temperature in a Laboratory Plasma1, JIACHEN LIU, SETH DORFMAN, TROY CARTER, WALTER GEKELMAN, PATRICK PRIBYL, ANTON BONDARENKO, University of California, Los Angeles — Alfvén waves are low-frequency oscillating waves in a magnetized plasma. These modes may play a significant role in the heating of the solar corona, solar wind turbulence, and in fast ion transport in tokamaks. Effects that arise in a hot ion plasma are of particular interest; a new plasma source has been installed in the Large Plasma Device (LAPD) at UCLA to study this regime. In the present work, the ion temperature in this new plasma is measured using the width of the Helium ion spectral line emission. A monochromator is first used to measure cold (~0.1ev) spectral lines of a mercury lamp to account for instrumental broadening. After acquiring this calibration data, we convolve it with plasma simulation (PrismSPECT) data for a series of known ion temperatures. The result is then compared to the actual plasma measurements to obtain the plasma ion temperature. Currently, we are working to implement a matching F-number lens system to improve the resolution of the spectral line. Results of these measurements will aid future Alfvén wave research in hot ion plasmas; this research may shed light on some of the plasma physics problems mentioned above.

1Supported by US DOE Grant DE-FG02-99ER54543.

JP8.00023 ABSTRACT WITHDRAWN —

JP8.00024 A Variable Frequency, Mis-Match Tolerant, Inductive Plasma Source1, ANTHONY ROGERS, DON KIRCHNER, FRED SKIFF, Department of Physics and Astronomy, University of Iowa — Presented here is a survey and analysis of an inductively coupled, magnetically confined, singly ionized Argon plasma generated by a square-wave, variable frequency plasma source. The helicon-style antenna is driven directly by the class "D" amplifier without matching network for increased efficiency while maintaining independent control of frequency and applied power at the feed point. The survey is compared to similar data taken using a traditional exciter—power amplifier—matching network source. Specifically, the flexibility of this plasma source in terms of the independent control of electron plasma temperature and density is discussed in comparison to traditional source arrangements.

1Supported by US DOE Grant DE-FG02-99ER54543.

JP8.00025 Plasma Globe Filamentary Structure and Propagation Trends by Voltage Waveform Change, H.G. CEJA, M.J. BURIN, G.G. SIMMONS, CSJSM, A. NAGY, S.J. ZWEBEN, PPPL — Filamentary structures are seen in many types of plasma discharges. However, principal aspects of their physics are unclear. In order to study plasma filaments we have used popular commercial plasma globes, which typically have a Neon based mixture near atmospheric pressure. Previous work has provided initial estimates of the speed of plasma globe filaments [Campanell et al. 2010]. Our work analyzes the effects of voltage amplitude and frequency on filament speed and structure using a programmable high voltage supply with phase triggered high-speed photography. Observed trends are discussed in detail along with their possible relation to discharge structures found in nature (e.g. lightning leaders) and various industrial applications.

JP8.00026 Fast Method for Radial Electric Field Correction of Motional Stark Effect Data in DIII-D, L.J. BERGSTEN, Dartmouth College, C.C. PETTY, T.C. LUCE, General Atomics, C.T. HOLCOMB, Lawrence Livermore National Laboratory — A fast and easy method to correct the motional Stark effect (MSE) data used in equilibrium reconstruction on the DIII-D tokamak by including the radial electric field effect in the determination of the magnetic pitch angles has been created. Previously, two methods for calculating motional Stark effect were possible - one in which the radial electric field is completely ignored and the other in which the radial electric field is determined by manually fitting the radial force balance equation. This project develops a new equilibrium reconstruction procedure that is automatic and easy to use, in which only the toroidal rotation component of radial force balance is used to correct the MSE data for the radial electric field. This is expected to give a more accurate result than ignoring the radial electric field effect for discharges with co-neutral beam injection. Comparisons of equilibrium reconstructions using the approximate and complete determination of the radial electric field will be made.

1Work supported in part by the National Underground Fellowship Program in Plasma Physics and Fusion Energy Sciences and the US Department of Energy under DE-FC02-04ER54698 and DE0AC52-07NA27344.
JP8.00027 Analysis of Sawtooth Post-Cursor Oscillations in Low Safety Factor DIII-D Plasmas
d by J.D. CABRERA, U. California Irvine, C. PAZ-SOLDAN, E.I. STRAIT, General Atomics, D. SHIRAKI, Oak Ridge National Laboratory — Large sawtooth oscillations are a commonly observed phenomenon in very low safety factor (q95 ≈ 2) plasmas. Following the sawtooth crash phase, low frequency (~200 Hz) post-sawtooth oscillations in the magnetic field, with amplitudes ~2 G decaying in time, are excited. These post-sawtooth oscillations do not exhibit the usual m=odd poloidal structures of sawtooth oscillation, but instead are found to be m=even in structure, suggesting the excitation of global kink modes. A novel means of modeling such post-sawtooth oscillations is presented via computational analysis of data obtained from high-resolution magnetic sensors installed at the DIII-D tokamak facility. Nonlinear regression analysis is used to obtain modeling parameters such as rates of decay and rotation. Trends in parameters over many oscillations are then compared with equilibrium plasma parameters. The impact of measured parameters on global instability onset and disruption prediction is considered.

1Supported by the National Undergraduate Fellowship Program in Plasma Physics and Fusion Energy Sciences and the US DOE under DE-FC02-04ER54698.

JP8.00028 Power Law Regression Analysis of Heat Flux Width in Type I ELMs
by C.D. STEPHENS, Columbia U., M.A. MAKOWSKI, Lawrence Livermore National Laboratory, A.W. LEONARD, T.H. OSBORNE, General Atomics — In this project, a database of Type I ELM for the DIII-D tokamak has been assembled and will be used to investigate possible dependencies of the heat flux width on plasma and engineering parameters. At the edge near the divertor, high impulsive heat loads are imparted onto the surface. The impact of these ELMs can cause a reduction in divertor lifetime if the heat flux is great enough due to material erosion [1]. A program will be used to analyze data, extract relevant, measurable quantities, and record the quantities in the table. Care is taken to accurately capture the complex space/time structure of the ELM. Then correlations between discharge and equilibrium parameters will be investigated. Power law regression analysis will be used to help determine the dependence of the heat flux width on these various measurable quantities and parameters. This will enable us to better understand the physics of heat flux at the edge.


JP8.00029 Evolution of Phase Space Sensitivity for Energetic Ion Loss Measurements in DIII-D
by N. COTHARD, U. Rochester, D.C. PACE, General Atomics — The Fast Ion Loss Detector (FILD) diagnostic system installed on the DIII-D tokamak is a scintillator-based magnetic spectrometer that measures the energy and pitch angle of energetic ions that escape confinement and reach the diagnostic on the outer wall. Different areas of the FILD scintillator correspond to the energies and pitch angles of the impacting ions. This strike map is dependent on the local magnetic field vector that sets the geometry of the ion orbits upon entering the detector. The phase space sensitivity of the FILD, therefore, varies with plasma conditions. The FILD combines a slow camera (100 Hz) viewing the entire scintillator simultaneously with narrow viewing photomultiplier tubes that provide fast time-resolved (1 MHz) measurements in narrow bands of energy and pitch angle. New analysis methods allow for tracking the phase space coverage throughout shots, thereby improving the fidelity of ion loss measurements due to plasma instabilities that change in time.

1Work supported in part by the National Undergraduate Fellowship Program in Plasma Physics and Fusion Energy Sciences and the US Department of Energy under DE-FC02-04ER54698.

by J.M. PENNA, Massachusetts Institute of Technology, S.P. SMITH, General Atomics, O. MENEGHINI, Oak Ridge Associated Universities, C.J. LUNA, Arizona State University — The neural network transport model BRAINFUSE has been developed to produce transport fluxes based on local parameters [1]. The BRAIN-FUSE model has been integrated into the transport modeling framework ONETWO [2,3] in order to develop time dependent solutions and has been validated by artificially varying the input neutral beam power and comparing the output to DIII-D scans. These efforts have led to the development of a time-dependent workflow within the OMFIT integrated modeling framework. The new work flow can evolve the electron and ion temperatures as a function of time dependent sources and equilibria. The effects of different engineering parameters can be explored and optimized in support of DIII-D operations. The efficiency of this workflow enables planning plasma operations of next-day experiments, as will be required for ITER.


1Work supported in part by the National Undergraduate Fellowship Program in Plasma Physics and Fusion Energy Sciences and the US Department of Energy under DE-FG02-94ER54235 & DE-FC02-04ER54698.

JP8.00031 Emittance Analysis of the DIII-D Neutral Beam Source
by N.A. LOPEZ, Massachusetts Institute of Technology, B. CROWLEY, General Atomics — In a high powered neutral beam system ions are extracted from a low temperature plasma, through apertures in the arc chamber, by application of a potential to an external electrode. It has been determined that to increase the beam energy of the DIII-D neutral beam system beyond 95 keV the accelerator must be reconfigured to avoid excessive electrical breakdown in the grid gaps. Deciding exactly what modifications are to be made requires modeling and experimental effort. A basic problem is to find a geometry with which the extracted beam is intense, low divergence, free of aberrations, and does not strike the focusing electrodes. We present the results of modeling proposed reconfigurations to the accelerator geometry and source conditions. The quality of the beam produced from the various accelerator configurations is quantified through metrics such as the beam emittance and the average divergence per beamlet. By comparing the beam quality and power delivered for each proposed reconfiguration an optimal design is selected and recommended.

1Work supported in part by the National Undergraduate Fellowship Program in Plasma Physics and Fusion Energy Sciences and the US DOE under DE-FG02-94ER54235, DE-FC02-04ER54698.
to measure this cross section involved counting the positron annihilation gamma rays from the
\(^{11}\)C decays requires an accurate value for the full-peak coincidence efficiency for the detector system. A new technique has been developed to measure this coincidence efficiency by detecting the positron prior to its annihilation, and vetoing events in which decay gamma rays other than \(^{12}\)C(n, 2n)\(^{11}\)C reaction. A recent experiment to measure this cross section involved counting the positron annihilation gamma rays from the \(^{11}\)C decay by using sodium iodide detectors in coincidence. To determine the number of \(^{11}\)C decays requires an accurate value for the full-peak coincidence efficiency for the detector system. A new technique has been developed to measure this coincidence efficiency by detecting the positron prior to its annihilation, and vetoing events in which decay gamma rays other than the \(^{11}\)keV annihilation gamma rays could enter the detectors. Measurements and simulation results for the absolute coincidence total and full-efficiencies are presented.

\footnote{Funded in part by a grant from the DOE through the Laboratory for Laser Energetics.}

JP8.00037 Measurements of proton energy spectra using a radiochromic film stack . T.M. FIKKINS, JESSICA STEIDLE, D.M. ELLISON, JEFFREY STEIDLE, C.G. FREEMAN, S.J. PADALINO, SUNY Geneseo, C. FIKSEL, S.P. REGAN, T.C. SANGSTER, Laboratory for Laser Energetics — The energy spectrum of protons accelerated from the rear-side of a thin foil illuminated with ultra-intense laser light from the OMEGA EP laser system at the University of Rochester’s Laboratory for Laser Energetics (LLE) was measured using a stack of radiochromic film (RCF). The film stack consisted of four layers of Gafchromic HD-V2 film and four layers of Gafchromic MD-V2-55 film. Aluminum foils of various thicknesses were placed between each piece of RCF in the stack. This arrangement allowed protons with energies of 30 MeV to reach the back layer of RCF in the stack. The stack was placed in the detector plane of a Thomson parabola ion energy (TPIE) spectrometer. Each piece of film in the stack was scanned using a commercially available flat-bed scanner (Epson 10000XL). The resulting optical density was converted into proton fluence using an absolute calibration of the RCF obtained at the SUNY Geneseo 1.7 MV Pelletron accelerator laboratory. In these calibration measurements, the sensitivity of the radiochromic film was measured using monoenergetic protons produced by the accelerator. Details of the analysis procedure and the resulting proton energy spectra will be presented. Funded in part by a grant from the DOE through the Laboratory for Laser Energetics.
JP8.00038 Analysis of CME and CIR driven storms based on observations made by TWINS.

BIANCA TRIGO, GUNNER ROBINSON, JERRY CARR JR., Texas Lutheran University, AMY KEESEE, West Virginia University. TLU PLASMA RESEARCH TEAM, WVU PLASMA RESEARCH TEAM — Geomagnetic storms are categorized into two different groups: coronal mass ejection (CME) and corotating interaction regions (CIR) driven storms. This work will analyze a CIR-driven storm observed on 13 Oct 2012 to see if it follows similar patterns observed in a superposed epoch analysis discussed in Keesee et al. (2014) and compared to the 22 July 2009 CIR-driven storm discussed in Keesee et al. (2012). The temperature and movement of the ions will be studied as the storm progresses. The ion temperature will be monitored during the recovery phase of the storm and the ion temperatures of the night side and the day side will be evaluated. To verify the accuracy of the analysis for the October storm, the data from the CME driven September storm on the 26 in 2011 referenced by Keesee et al. (2014) will be used as a baseline model for comparison.

3Keesee (2014)


JEFFREY BREITSCHOFF, Texas Lutheran University, VADIM DUDNIKOV, ROL JOHNSON, Muons, Inc., JERRY CARR JR., Texas Lutheran University, ROBERT WELTON, BAOXI HAN, SYDNEY MURRAY JR., TERRY PENNISI, CHIP PILLER, MANUEL SANTANA, MARTIN STOCKLI, ORNL, GALINA DUDNIKOVA, University of Maryland, College Park — A SA RF SPS was tested at the Spallation Neutron Source (SNS) at Oak Ridge National Lab. Hydrogen ions were extracted from the source as described in Dudnikov et al. (2011) Modifications were installed to increase ion beam output and optimize cooling. The source was tested under a DF of 5-20% at 150 Hz as well as a continuous beam with power ranging from 0.8 kW to 3.3 kW. Cesium was also used to optimize H+ beam output The highest beam produced was 13 mA at 2.5 kW. The SA RF SPS has an ion production efficiency of ~5 mA/kW while the current ion source at the SNS produces ~1 mA/kW. The SA RF SPS will be tested with the conditions of the linear accelerator at the SNS so the recent accelerator-based pulsed neutron record of 20 GW (1.4 MW average power) can be surpassed.

4A Record-Breaking Month for ORNL’s Spallation Neutron Source www.ornl.gov/ornl/news/features/2014

JP8.00040 Offline Development of Plasma Boundary Controllers for the KSTAR Tokamak.

S. BALLINGER, Columbia U., N.W. EIDETIS, D.A. HUMPHREYS, A.W. HYATT, A.S. WELANDER, General Atomics, S.H. HAHN, NFRI — The KSTAR TokSys tokamak simulator, implemented in Matlab/Simulink, has been extended to include a plasma boundary control system to allow automated offline tuning of shape control feedback loops. Offline control development minimizes resources expended tuning controllers during actual run time, and automated tuning is desirable in order to optimize the large number of shape control gains. The new simulation includes simplified versions of the rtEFIT/Isolux controller used in the KSTAR plasma control system, allowing full-closed-loop analysis of the plasma shape control. Results presented include application of robust design methods to optimizing control of KSTAR’S plasma boundary, and analysis to understand observed differences in boundary control within KSTAR and other superconducting devices.


1Work supported in part by the National Undergraduate Fellowship Program in Plasma Physics and Fusion Energy Sciences and the US Department of Energy under DE-FC02-04ER54698.

JP8.00041 Particle-in-cell Simulations of Cross-field Propagation by a Beam Composed of Positive and Negative Ions.

RYAN GALE, Cornell University, NATHANIEL HICKS, University of Anchorage Alaska — Particle-in-cell simulations of a beam composed of positive and negative ions are performed to explore beam propagation in the presence of a transverse magnetic field. The dependences of propagation on parameters such as beam density and energy, spatial profiles of magnetic field and beam, and beam species are investigated. Initially, 2-D simulations of a slab beam are performed, with the possibility of moving to 3-D to assess effects on the head of the beam. The ability of such a beam to achieve cross-field propagation without dramatic beam losses may be of interest for applications in which delivery of a charge-neutral beam to a target in the presence of a magnetic field is desired.

1Special thanks to Tech-X for supplying free student licensing.


CONNOR A. HART, University of Maryland, College Park, CHARLES H. SKINNER, ANGELA M. CAPECE, Princeton Plasma Physics Laboratory, BRUCE E. KOEL, Princeton University — Lithium conditioning of plasma facing components has enhanced the performance of several fusion devices. However, metallic lithium is very reactive and it is important to quantify the processes leading to the passivation of lithium upon exposure to air. Passivation, as used here, refers to the absorption of atmospheric gases by lithium to ultimately form lithium species including lithium hydride, carbonate, and oxide. The current work uses a mass balance with microgram sensitivity to measure the mass gain during the absorption of atmospheric gases by bulk lithium. Metallic lithium films with thicknesses of 0.3 and 1.0 mm are exposed to humid air as well as dry synthetic air at atmospheric conditions in order to reproduce the environment of a tokamak exposed to air during maintenance activities and venting. The data yield the reaction rates and interdiffusion of these lithium species as functions of thickness and time. These results provide critical insight into the chemical state of a lithiated surface after air exposure. In addition, the depth of passivation versus time is of interest in determining the length of exposure required to completely passivate a lithium layer of a given thickness, making it safe to handle.

1Science Undergraduate Laboratory Internship funded by Department of Energy
JP8.00043 Electron beam modeling on LTX, GREGORY SZALKOWSKI, Georgia Inst of Tech, RICHARD MAJESKI, JOHN SCHMITT, Princeton Plasma Physics Laboratory — The lithium tokamak experiment (LTX) is a low aspect ratio tokamak with a steel clad copper shell that can be heated to 300-400 °C and coated with lithium. The lithium coating has been shown to decrease impurities in the plasma and decrease the recycling coefficient, improving plasma performance. The coating is applied to the wall by heating the shells, then using an electron beam to evaporate a pool of lithium located at the bottom of the shell. The beam is steered using the magnetic field generated by the field coils. This method allows for rapid evaporation of the lithium, producing a 50-100 nm coating in approximately 5 minutes. The current electron beam system can only coat half of the shell surface. A new electron beam system has been installed on LTX to coat the remaining shell surface. A model of this electron gun has been created using the AMaze program series (Field Precision LCC). The model will be used to find the magnetic fields needed to steer the electron beam produced by the gun to the lithium pool. The model will also show the electropotential produced both at the electron gun head and in the vessel. The model may also be used to find the dispersion of the beam and therefore the effective power density of the beam as it impacts the lithium pool.

Supported by US DOE contracts DE-AC02-09CH11466 and DE-AC52-07NA27344 and in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internship Program.

JP8.00044 Investigation of Liquid Metal Embrittlement of Materials for use in Fusion Reactors, DANIEL KENNEDY, University of Kansas, MICHAEL JAWORSKI, Princeton Plasma Physics Laboratory — Liquid metals can provide a continually replenished material for the first wall and extraction blankets of fusion reactors. However, research has shown that solid metal surfaces will experience embrittlement when exposed to liquid metals under stress [1]. Therefore, it is important to understand the changes in structural strength of the solid metal materials and test different surface treatments that can limit embrittlement. Research was conducted to design and build an apparatus for exposing solid metal samples to liquid metal under high stress and temperature. The apparatus design, results of tensile testing, and surface imaging of fractured samples will be presented.


This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI).

JP8.00045 Reconstruction of electron temperature and density profiles from Thomson scattering system using neural networks, VETRI VELAN, Rutgers University- Department of Physics & Astronomy, AHMED DIALLO, BENNOIT LEBLANC, Princeton Plasma Physics Laboratory — Neural networking analysis is implemented on NSTX Thomson scattering measurements in order to provide fast, real-time control of temperature and density profiles. Raw voltages from an array of 30 radially-variant polychrometers [1] are transformed into T_e and N_e measurements by using a multi-layer perceptron approach. The neural net, designed with the Torch7 package, is trained on Thomson Scattering data taken between 2008 and 2011, and tested on different data taken during the same period. The net can be modified by changing the number of hidden layers, the optimization procedure used, the size of each epoch, or the batch size (in the case of batch optimization methods); different permutations of these are tested to optimize accuracy and computation time. If the analysis succeeds, the next step is to use it on 2012 data, which contains an array of 42 polychrometers, to predict temperatures and densities and compare them to actual calculations. Furthermore, the analysis’s success will motivate inclusion of the neural net into the NSTX-Upgrade, so that electron temperatures and densities can be extracted in real time.


This work was done as part of the National Undergraduate Fellowship, sponsored by the US Department of Energy.

JP8.00046 Development of a GPU-Accelerated 3-D Full-Wave Code for Electromagnetic Wave Propagation in a Cold Plasma, D. WOODBURY, Brigham Young Univ - Provo, S. KUBOTA, UCLA, I. JOHNSON, PPPL — Computer simulations of electromagnetic wave propagation in magnetized plasmas are an important tool for both plasma heating and diagnostics. For active millimeter-wave and microwave diagnostics, accurately modeling the evolution of the beam parameters for launched, reflected or scattered waves in a toroidal plasma requires that calculations be done using the full 3-D geometry. Previously, we reported on the application of GPGPU (General-Purpose computing on Graphics Processing Units) to a 3-D vacuum Maxwell code using the FDTD (Finite-Difference Time-Domain) method. Tests were done for Gaussian beam propagation with a hard source antenna, utilizing the parallel processing capabilities of the NVIDIA K20M. In the current study, we have modified the 3-D code to include a soft source antenna and an induced current density based on the cold plasma approximation. Results from Gaussian beam propagation in an inhomogeneous anisotropic plasma, along with comparisons to ray- and beam-tracing calculations will be presented. Additional enhancements, such as advanced coding techniques for improved speedup, will also be investigated.


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JP8.00047 Carbon Density Asymmetry and Beam Density Verification in DIII-D, R.S. BIELAJEW, Retired, C. CHRYSAL, U. California San Diego, B.A. GRIERSON, Princeton Plasma Physics Laboratory, K.H. BURRELL, General Atomics — Carbon density asymmetry in DIII-D plasmas has been measured using charge exchange spectroscopy coupled with main ion measurements. These main ion charge exchange measurements are used to verify the neutral beam density. Centrifugal effects in plasmas with high toroidal rotation and electrostatic effects due to trapped fast ions can both drive impurity density asymmetries within flux surfaces. Measuring impurity density asymmetry is important for verifying theories of parallel impurity transport. New main ion charge exchange measurements implemented on the high field side of the plasma are instrumental to this work. Impurity density asymmetry is measured in plasmas with low and high \( \frac{V_d}{V_{\text{imp}}(1)} \) rotation and low and high \( \frac{\eta_{\text{imp}}}{\eta_e} > 0.2 \).

Work supported in part by the National Undergraduate Fellowship Program in Plasma Physics and Fusion Energy Sciences and the US Department of Energy under DE-FC02-04ER54698, DE-FG02-07ER54917, DE-AC02-09CH11466.
JP.00048 Progress on Pre-Stage Magnetic Coil to Enhance Helicon Mode Excitation and Data Acquisition Software on the Helicon Plasma Experiment (HPX)

JUSTIN SHERMAN, PHILLIP AZZARI, P.B. CRILLY, OMAR DUKÉ-TINSON, ROYCE W. JAMES, JACKSON KARAMA, E.J. PAGE, CARTER SCHLANK, JONATHAN ZUNIGA, US Coast Guard Academy Plasma Lab — CGAPL is conducting small investigations in plasma physics and magneto-hydrodynamics buoy positioning. For data management, we are developing capability to analyze/digitize data with a National Instruments Data Acquisition board, 2MS/s sampling rate (long time scale), and an Express Octopus card, 125MS/s sampling rate (short scale). Sampling at 12bits precision, we use LabVIEW as a programing language; GUIs will control variables in 1 or more concurrent runs and monitor of diagnostics. HPX utilizes high density(10^{13}cm^{-3}) up, low pressure,(0.1 T) T Ar gas (fill pressure: on 10^4mTorr order). Helicon/W Mode plasmas become a diagnostics test-bed for other investigations and a tool for future spacecraft propulsion devices. Plasmas created by directing energy into gas-filled Pyrex tube; power supply and matching box, up to 250W power in 20-100MHz frequencies, provide energy to ignite. Uniform magnetic field needed to reach the W-Mode [1]. We employ an electromagnet to B-field while an accelerating coil positions plasma in vacuum chamber, facilitating analysis. Initial field requirements and accuracy calibration have been completed. Progress on development and implementation of probes and DAQ/GUI system will be reported. [1] K. Toki, et al, Thin Solid Films 506-507(2005)

Supported by U.S. DEPS Grant [HEL-JTO] PRWJFY13.

JP.00049 Updates on the Optical Emission Spectroscopy and Thomson Scattering Investigations on the Helicon Plasma Experiment (HPX)

OMAR DUKÉ-TINSON, JACKSON KARAMA, PHILLIP AZZARI, JAMES ROYCE, ERIC PAGE, CARTER SCHLANK, JUSTIN SHERMAN, BROOKÉ STUTZMAN, JONATHAN ZUNIGA, Coast Guard Academy Plasma Physics Lab — HPX at the Coast Guard Academy Plasma Laboratory (CGAPL) have set up spectral probes to verify plasma mode transitions to the W-mode. These optical probes utilize movable filters, and ccd cameras to gather data at selected spectral frequency bands. Raw data collected will be used to measure the plasma’s relative density, temperature, structure, and behavior during experiments. Direct measurements of the plasma’s properties can be determined through modeling and by comparison with the state transition tables, using Optical Emission Spectroscopy (OES). The spectral probes will take advantage of HPX’s magnetic field structure to define and measure the plasma’s radiation temp as a function of time and space. In addition, the Thomson Scattering (TS) device will measure temperature and density data as the HPX plasma transitions through capacitive and inductive modes while developing into helicon plasma. Currently CGAPL is focused on building its laser beam transport and scattered light collection optical systems. Recently, HPX has acquired an Andor ICCD spectrometer for the spectral analysis. Data collected by the TS system will be logged in real time by CGAPL’s Data Acquisition (DAQ) system with LabView remote access. Further progress on HPX will be reported.

Supported by U.S. DEPS Grant [HEL-JTO] PRWJFY13.

JP.00050 FUNDAMENTAL THEORY AND COMPUTATION –

JP.00051 Particle-In-Cell Modeling of Hall-Driven Magnetic Penetration and Species Separation in Two-Species Plasmas

ANDREW RICHARDSON, STEPHEN SWANEKAMP, Naval Research Laboratory, PAUL OTTINGER, Engility, JUSTIN ANGUS, IAN RITTERSDORF, JOSEPH SCHUMER, Naval Research Laboratory — Understanding the interaction of a strong magnetic field with a plasma is a key problem in plasma physics. In this poster we report on a new systematic study using two-dimensional particle-in-cell simulations designed to explore the interplay between magnetic pushing and Hall-driven magnetic field penetration. In plasma where the ions are infinitely massive and \( \nu \), the magnetic field penetrates into the plasma at a specific fraction of the Hall speed, \( v_H \). When the ions have finite mass, the penetrating magnetic field gives an impulse to the ions, accelerating them to speed \( v_i \). In a two-species plasma, simulations show simultaneous pushing of the light-ion species and magnetic field penetration through the heavy-ion species when \( v_{heavy} < v_H < v_{light} \). This leads to a separation of the two ion species. If the mass of the light ions is increased, a transition to magnetic penetration of both species is observed when \( v_{heavy} < v_{light} < v_H \). Analytic estimates for both \( v_i \) and the mass at which this transition occurs agree well with simulations.

This work was supported by the NRL Basic and Applied Research Program.

JP.00052 Plasma Model V&V of Collisionless Electrostatic Shock

ROBERT MARTIN, HAI LE, ERC Inc., DAVID BILYEU, NRC Research Associate, STEPHEN GILDEA, AFRL/RQRS — A simple 1D electrostatic collisionless shock was selected as an initial validation and verification test case for a new plasma modeling framework under development at the Air Force Research Laboratory’s In-Space Propulsion branch (AFRL/RQRS). Cross verification between PIC, Vlasov, and Fluid plasma models within the framework along with expected theoretical results will be shown. The non-equilibrium velocity distributions (VDF) captured by PIC and Vlasov will be compared to each other and the assumed VDF of the fluid model at selected points. Validation against experimental data from the University of California, Los Angeles double-plasma device will also be presented along with current work in progress at AFRL/RQRS towards reproducing the experimental results using higher fidelity diagnostics to help elucidate differences between model results and between the models and original experiment.

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JP.00053 High-Performance Kinetic Plasma Simulations with GPUs and load balancing

KAI GERMASCHESKII, NARGES AHMADI, STEPHEN ABBOTT, LIWEI LIN, LIANG WANG, University of New Hampshire, AMITAVA BHATTACHARJEE, WILL FOX, Princeton University / PPPL — We will describe the Plasma Simulation Code (PSC), a modern particle-in-cell code with GPU support and dynamic load balancing capabilities. For 2-d problems, we achieve a speed-up of up to 6x on the Cray XK7 “Titan” using its GPUs over the well-known VPIC code, which has been optimized for conventional CPUs with SIMD support. Our load-balancing algorithm employs a space-filling Hilbert-Peano curve to maintain locality and has shown to keep the load balanced within approximately 10% in production runs which otherwise slow down up to 5x with only static load balancing. PSC is based on the libmrc computational framework, which also supports explicit and implicit time integration of fluid plasma models. Applications include magnetic reconnection in HED plasmas, particle acceleration in space plasmas and the nonlinear evolution of anisotropy-based kinetic instabilities like the mirror mode.

JP8.00054 A new PIC noise reduction technique. D.C. BARNES, Coronado Consulting — Numerical solution of the Vlasov equation is considered in a general situation in which there is an underlying static solution (equilibrium). There are no further assumptions about dimensionality, smallness of orbits, or disparate time scales. The semi-characteristic (SC) method for Vlasov solution is described. The usual characteristics of the equation, which are the single particle orbits, are modified in such a way that the equilibrium phase-space flow is removed. In this way, the shot noise introduced by the usual discrete particle representation of the equilibrium is static in time and can be removed completely by subtraction. An almost exact algorithm for this is based on the observation that a (infinitesimal or) discrete time step of any equilibrium MC realization is again a realization of the equilibrium, building up strings of associated simulation particles. In this way, the only added discretization error arises from the need to extrapolate backward in time the chain end points one dt using a canonical transformation. Previously developed energy-conserving time-implicit methods are applied without modification. 1D ES examples of Landau damping and velocity-space instability are given to illustrate the method.

JP8.00055 Particle-in-cell simulations on graphic processing units. C. REN, X. ZHOU, J. LI, M.C. HUANG, Y. ZHAO, University of Rochester — We will show our recent progress in using GPU’s to accelerate the PIC code OSIRIS [ Fonseca et al. LNCS 2331, 342 (2002)]. The OSIRIS parallel structure is retained and the computation-intensive kernels are shipped to GPU’s. Algorithms for the kernels are adapted for the GPU, including high-order charge-conserving current deposition schemes with few branching and parallel particle sorting [ Kong et al., JCP 230, 1676 (2011)]. These algorithms make efficient use of the GPU shared memory. This work was supported by U.S. Department of Energy under Grant No. DE-FC02-04ER54789 and by NSF under Grant No. PHY-1314734.

JP8.00056 Comparison of velocity distribution function errors introduced by particle reweighting schemes in PIC-DSMC simulations. CHRISTOPHER MOORE, JEREMY BOERNER, STAN MOORE, KEITH CARTWRIGHT, TIMOTHY POINTON, Sandia Nat. Labs — Many PIC simulations span many orders of magnitude in the plasma density and therefore a constant particle weight results in too few particles in regions (or time periods) of low density or too many particles when the density is high. The standard solution is to employ a reweighting scheme in which low-weight particles are merged in order to keep the number of particles per cell roughly constant while conserving mass and momentum. Unfortunately merger schemes distort a general velocity distribution function (VDF) of particles (one can conserve arbitrarily higher moments such as energy flux by merging N to M particles for N>M>1) and often merge routines act like artificial collisions that thermalize the distribution and lead to simulation error. We will compare the unique reweighting scheme used in our PIC-DSMC code and common reweighting schemes (e.g., redrawing from a constructed VDF or rouletting) through two benchmarks. The first compares the time varying VDF from various merge routines to an analytic solution for relaxation of a bimodal VDF to a Maxwellian through elastic collisions. The second benchmark compares error introduced in the VDF due to merging electrons during a breakdown simulation.

JP8.00057 A Variational Formulation of Particle Algorithms for Kinetic E&M Plasma Simulations in the Moving Window. ALEXANDER STAMM, BRADLEY SHADWICK, University of Nebraska-Lincoln — The recent variational technique [1] for rigorously deriving discrete, self-consistent equations for electromagnetic particle codes has been further developed in the moving window. The primary advantage of the Lagrangian formulation is the connection between symmetries of the system and conservation laws, which in the present case resolves the grid-heating issue. However, the approach also simplifies coordinate transformations and enables the particle method to be formulated in moving window coordinates. For some laser-plasma interaction scenarios, this leads to computational savings from working in a coordinate system where the evolution of the laser is intrinsically slow. New time advance integrators were developed in this coordinate system and compared to one another; namely, a symplectic method and a split explicit particle and implicit field advance method were developed in the moving window to show the extent of available optimization and improvements over the traditional particle-in-cell (PIC) method. In addition, we examine the phase-space fidelity of our method in cases where the conventional PIC algorithm exhibits unphysical particle trapping [2]. The recent variational algorithm exhibits unphysical particle trapping [2].

JP8.00058 Finite Time Step and Finite Grid Size Numerical Analysis of Warm Plasmas in δf Simulations. BENJAMIN STURDEVANT, SCOTT PARKER, YANG CHEN, Univ of Colorado - Boulder CIPS — The effects on the dispersion relation for warm plasmas due to numerical time integration methods and finite spatial grids can be analyzed for many conventional particle in cell(PIC) models using the mathematical framework developed by Langdon [1,2]. This analysis can be useful to gain an understanding of overall system accuracy and nonphysical behaviors including instabilities caused by numerical integration and finite difference methods. To derive a numerical dispersion relation for δf method simulations, however, a different approach is required for the time integration analysis. Here, this analysis is performed using a discrete version of the method of characteristics applied to an implicit δf particle weight equation. A numerical dispersion relation including both finite time step size and finite grid size effects has been derived for an implicit ion acoustic wave model which shows agreement with simulation results and reduces to the continuous result in the limits that the discrete time and spatial sizes go to zero. Comparisons with conventional PIC will be performed to determine differences in the numerical dispersion between the two simulation models.

JP8.00059 Gyrokinetic Simulations of Low-n Tearing Modes. YANG CHEN, JUGAL CHOWDHURY, WEIGANG WAN, SCOTT PARKER, University of Colorado at Boulder — Low-n tearing modes in cylindrical plasmas are studied with the GEM code using the gyrokinetic ion/liquid electron model. Particle trajectories and the evolution equations for $A_{\perp}$ and $\phi$ are advanced in the field-line-following coordinates, but new field solvers for the vorticity equation and the Ampere’s law are developed for global, low-n modes to avoid the usual high-n approximations made in the Laplacian $\nabla^2$ operator in gyrokinetic simulations. Since the tearing mode growth rate is small, numerical dissipation must be minimized. The hybrid model properly reduces to the reduced MHD model when ion kinetic effects are neglected. Eigenmode analysis for the reduced MHD cylindrical tearing mode problem has been developed to provide a direct verification of the simulation algorithms. Excellent agreement between the simulation and the eigenmode analysis is obtained for the tearing mode growth rate. When the finite-Larmor-radius effect in the ion polarization term in the vorticity equation is fully retained, simulations show an increase of the growth rate. The effects of gyrokinetic ions on the tearing mode stability will be studied and reported.

1Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s NNSA under contract DE-AC04-94AL85000.

2This work was supported by the DoE under grant DE-SC0008382 and by the NSF under grant PHY-1104683.
JP8.00060 Gyrokinetic description of high intensity beams in cyclotrons, JOSEPH GUADAGNI, ANTOINE CERFON, Courant Institute, NYU — Continuum kinetic and fluid theories are a useful complement to Particle-in-Cell simulations to study the dynamics of intense beams in cyclotrons. We recently derived a reduced fluid model for cyclotron beams in the regime in which 1) the ratio of the self-electric field force to the externally imposed magnetic force is small; 2) the amplitude of the mismatch oscillations is small compared to the characteristic size of the beam. The fluid equations in this model are formally identical to the vorticity-streamfunction form of the incompressible 2D-Euler equations. Based on this analogy, we were able to use well-known results of fluid dynamics to offer intuitive explanations for beam spiraling and breakup. In our present work, we relax assumption 2) to include the effects of large mismatch oscillations in our model. We still assume that the beam is strongly magnetized, corresponding to a large scale separation between the betatron time scale and the space charge time scale. Averaging over the betatron time scale, we show that the evolution of the beam on the space charge time scale is determined by the gyrokinetic Vlasov-Poisson system. We describe the numerical scheme we developed to solve these equations and present initial results.

JP8.00061 Deviations from Axisymmetry in Rotating Multiscale Gyrokinetics, IAN ABEL, Princeton Center for Theoretical Science, Princeton University, Princeton, NJ 08544, USA, MATT LANDREMAN, Department of Physics, University of Maryland, College Park, MD 20742-4111, USA — We extend Multiscale Rotating Gyrokinetics [Abel et. al. Rep. Prog. Phys. 2013] to include small non-axisymmetric magnetic fields, including both ripple and applied magnetic fields. We develop a framework in which neoclassical toroidal viscosities can compete with turbulent momentum fluxes in regulating the size of the global toroidal flow. In addition, we gain the capability to study the effects of small non-axisymmetric magnetic fields on the gyrokinetic turbulence itself. This work will also enable the study of how turbulence can affect the penetration of non-axisymmetric fields into the plasma.

JP8.00062 Discontinuous Galerkin schemes for a class of Hamiltonian evolution equations with applications to gyrokinetic edge turbulence problems, AMMAR HAKIM, GREGORY HAMMETT, Princeton Plasma Physics Laboratory, ERIC SHI, IAN ABEL, Princeton University — We present a new gyrokinetic code, Gkeyll, for use in edge plasma simulations. The code implements novel energy conserving discontinuous Galerkin schemes, applicable to a general class of Hamiltonian equations. The inclusion of magnetic fluctuations with kinetic electrons has been challenging for many gyrokinetic algorithms in the past, requiring special treatment to reduce the Ampere cancellation problem. An important feature of this work is that we have developed novel versions of DG that can handle gyrokinetic magnetic fluctuations in an efficient way while preserving the energy invariant. To illustrate our improved algorithm, we show that Gkeyll reproduces the Alfven wave dispersion relation even at very low $k_{\perp} \rho_s$ in an efficient way with just the normal time step needed to resolve the electron dynamics. Initial results will be shown for a 1D axisymmetric problem and a higher dimensional turbulent problem with a simple geometry, to illustrate the applications of this approach for fusion problems.

JP8.00063 Extension of Gkeyll Discontinuous Galerkin Kinetic Code to 2D, E.L. SHI, Princeton University, A. HAKIM, G.W. HAMMETT, Princeton Plasma Physics Laboratory — Gkeyll is a discontinuous Galerkin (DG) code under development for modeling the edge plasma in fusion devices and basic plasma experiments. High-order accurate, energy-conserving numerical algorithms for general Hamiltonian systems are implemented in Gkeyll. Details of the recent extension of the code dimensionality to 2D2V will be presented. Since DG schemes allow for flexibility in the choice of basis functions, we will discuss how various types of basis functions affect code accuracy and efficiency. Test problems in 2D, such as toroidal ITG instabilities and turbulence in a scrape-off layer, will be presented. We will also show initial results from 2D kinetic simulations of transport in a scrape-off layer plasma, using a specified diffusion coefficient to model radial transport.

JP8.00064 Gyrokinetic Magnetic Fluctuations in an ELM Heat Pulse Scrape-Off-Layer Test Problem, G.W. HAMMETT, A.H. HAKIM, E.L. SHI, I.G. ABEL, T. STOLTZFUS-DUECK, Princeton Plasma Physics Laboratory and the Max-Planck/Princeton Center for Plasma Physics — We have applied an electromagnetic gyrokinetic-based model to simulate parallel plasma transport in the scrape-off layer (SOL) to a divertor plate, employing the Discontinuous-Galerkin code Gkeyll. We focus on a test problem that has been studied previously using parameters chosen to approximate a heat pulse driven by an edge localized mode (ELM) in JET. With the use of the gyrokinetic quasineutrality equation and logical sheath boundary conditions, spatial and temporal resolution requirements are no longer set by the electron Debye length and plasma frequency. This test problem also helps illustrate some of the physics contained in the Hamiltonian form of the gyrokinetic equations and some of the numerical challenges in developing an edge gyrokinetic code. In particular, we will describe some of the special techniques needed to handle magnetic fluctuations in this nonlinear gyrokinetic problem.

JP8.00065 Nonlinear bounce-gyrokinetic formulation of Neoclassical Tearing Modes, N. TRONKO, IPP Garching, A.I. BRIZARD, SMC — The nonlinear bounce-gyrokinetic formulation of neoclassical tearing modes in axisymmetric tokamak geometry is presented. The guiding-center/gyrocenter and bounce-center/bounce-gyrocenter phase-space transformations are successively introduced in order to self-consistently describe the nonlinear bounce-gyrocenter dynamics of trapped/passing-particle orbits in axisymmetric tokamak geometry in the presence of a magnetic-island perturbation. The bounce-gyrokinetic Poisson (i.e., quasineutrality condition) and parallel Ampere equations are written explicitly in terms of magnetic flux-surface-averaged expressions that clearly highlight the role of the reduced polarizations that result from dynamical reduction. This work generalizes previous reduced kinetic descriptions of neoclassical tearing modes [1,2].


3Work by AJB was supported by a grant from U.S. DoE.
JP8.00066 Energy-momentum-conserving Landau form of the guiding-center Fokker-Planck collision operator

Fluxes which agree with those derived from the conventional recursive formulation with the WKB representation are investigated by using the gyrokinetic Boltzmann equation which includes Landau's collision operator represented in the gyrocenter coordinates. Particle, momentum for collisionless magnetized plasmas are derived by applying the Noether's theorem. In this work, effects of collisions on conservation laws are examined by using the gyrokinetic Vlasov equation, Poisson's equation, and Ampere's law are all obtained from the Lagrangian formulation, and conservation laws of energy and momentum in terms of full guiding-center distributions without the need of linearization. For the field-particle guiding-center representation, guiding-center Rosenbluth potentials are introduced. The phase-space divergence form of the guiding-center Fokker-Planck collision operator immediately guarantees its particle-conserving property, while its Landau form guarantees its energy-momentum-conserving properties, even when the guiding-center transformation is truncated at finite order. A linearized guiding-center Fokker-Planck collision operator suitable for gyrokinetic particle simulations is derived and compared with recent linearized gyrokinetic collision operators.

JP8.00067 Gyrokinetic investigation of ITG turbulence in helical RFPs
I. Predebon, Consorzio RFX, Padova, Italy, P. Xanthopoulos, Max Planck Institute for Plasma Physics, Greifswald, Germany, D. Terranova, Consorzio RFX, Padova, Italy — Micro-instabilities in reversed field pinch (RFP) plasmas have been investigated in the last years from several viewpoints and with various numerical tools. So far, axisymmetry of the magnetic equilibrium has always been postulated. Nevertheless, experimental evidence suggests that the physical conditions mostly favoring the onset of electrostatic/electromagnetic turbulence, e.g., the occurrence of large pressure gradients, emerge when magnetic surfaces become helical, during the single helicity states. In this work, we investigate ion-temperature-gradient driven turbulence focusing on the 3D feature, with the aim to describe its distinct properties compared to the axisymmetric geometry. For this study, we will apply the 3D nonlinear gyrokinetic code GEN2 to RFP equilibria generated by the VMEC code.

JP8.00068 Effects of collisions on conservation laws in gyrokinetic field theory
H. Sugama, National Institute for Fusion Science, T.-H. Watanabe, Nagoya University, M. Nunami, National Institute for Fusion Science — In gyrokinetic field theory, the gyrokinetic Vlasov equation, Poisson's equation, and Ampere's law are all obtained from the Lagrangian formulation, and conservation laws of energy and momentum for collisionless magnetized plasmas are derived by applying the Noether's theorem. In this work, effects of collisions on conservation laws are investigated by using the gyrokinetic Boltzmann equation which includes Landau's collision operator represented in the gyrocenter coordinates. Particle, energy, and momentum transport equations including collisional transport fluxes are systematically derived by modifying Noether's theorem. Then, the ensemble-averaged transport equations of particles, energy, and toroidal momentum given in the present work are shown to include both collisional and turbulent transport fluxes which agree with those derived from the conventional recursive formulation with the WKB representation.

JP8.00069 Global Microtearing Modes in Collisionless Large Aspect Ratio Tokamaks
Aditya Krishna Swamy, Rajaraman Ganesh, Institute for Plasma Research, Jugal Chowdhury, University of Colorado, Boulder, S. Brunner, J. Vaclavik, L. Villard, CRPP, EPFL, 1015 Lausanne, Switzerland — Microtearing Modes (MTM) are high-n electromagnetic microinstabilities in tokamak plasmas deriving their free energy from the equilibrium electron temperature gradient. The modes exhibit an even (tearing) parity in the 5-dimensional phase space around the magnetic midplane, while their Landau form guarantees its energy-momentum-conserving properties, even when the guiding-center transformation is truncated at finite order. A linearized guiding-center Fokker-Planck collision operator suitable for gyrokinetic particle simulations is derived and compared with recent linearized gyrokinetic collision operators.

JP8.00070 One and two dimensional electromagnetic gyrokinetic PIC simulation by \( \delta f \) method
C.M. Chen, Y. Nishimura, C.Z. Cheng, Institute of Space and Plasma Sciences, National Cheng Kung University — An electromagnetic gyrokinetic Particle-in-Cell simulation is studied aiming at long-wave-length magnetohydrodynamic instabilities. A fully nonlinear characteristic method (\( \delta f \) method) of electrostatic gyrokinetic theory is employed. For a one dimensional geometry, “0.5 dimension” is taken in “y-direction” of the configuration space and another “0.5 dimension” is taken in the “x-direction” of the velocity space. Recent electromagnetic \( \delta f \) simulation shows optimistic results.

1Work partially supported by US DoE.
JP8.00071 A multi-dimensional nonlinearly implicit, electromagnetic Vlasov-Darwin particle-in-cell (PIC) algorithm, GUANGYE CHEN, LUIS CHACÓN, LANL, COCOMANS TEAM — For decades, the Vlasov-Darwin model has been recognized to be attractive for PIC simulations (to avoid radiative noise issues) in non-relativistic electromagnetic regimes. However, the Darwin model results in elliptic field equations that renders explicit time integration unconditionally unstable. Improving on linearly implicit schemes, fully implicit PIC algorithms for both electrostatic and electromagnetic regimes, with exact discrete energy and charge conservation properties, have been recently developed in 1D [1]. This study builds on these recent algorithms to develop an implicit, orbit-averaged, time-space-centered finite difference scheme for the particle-field equations in multiple dimensions. The algorithm conserves energy, charge, and canonical-momentum exactly, even with grid packing. A simple fluid preconditioner allows efficient use of large timesteps, $O(\sqrt{\frac{c^2}{\Delta x}})$ larger than the explicit CFL. We demonstrate the accuracy and efficiency properties of the of the algorithm with various numerical experiments in 2D3V.


JP8.00072 Performance of VPIC on Sequoia, WILLIAM NYSTROM, HPC-5, Los Alamos National Laboratory — Sequoia is a major DOE computing resource which is characterized of future resources in that it has many threads per compute node, 64, and the individual processor cores are simpler and less powerful than cores on previous processors like Intel’s Sandy Bridge or AMD’s Opteron. An effort is in progress to port VPIC to the Blue Gene Q architecture of Sequoia and evaluate its performance. Results of this work will be presented on single node performance of VPIC as well as multi-node scaling.


JP8.00073 High-gain aneutronic fusion1, M.J. HAY, N.J. FISCH, Princeton University — Fusion reactions which release most of their energy in charged particles are desirable for power applications. The proton-boron reaction $p^+ + _7\text{Li} \rightarrow 2\alpha + 8.7\text{MeV}$ is ideal due to the low incidence of neutron-generating side reactions and the natural abundance of the reactants. However, an optically thin proton-boron plasma radiates a substantial amount of energy via bremsstrahlung. To compensate, we consider ways of increasing the fusion reactivity above the Maxwellian value. Using the fusion alpha particle energy to heat specific parts of the proton velocity distribution is one such approach. In principle, waves could channel the alpha energy to protons near the cross section maximum in energy, resulting in a substantial reactivity gain. By making aggressive assumptions regarding how energy might be channeled, we present upper bounds on the extent to which a proton-boron fusion reaction can be self-sustaining.

1. Work supported by DOE Contract No. DE-AC02-09CH11466 and DOE NNSA SSAA Grant No. DE274-FG52-08NA28553. M. J. H. was supported in part by the DOE NNSA SSGF under Grant No. DE-FG52-08NA28752.

JP8.00074 Spectral method for the solution of the Vlasov equation based on Hermite polynomials, BEN BERGEN, GIAN LUCA DELZANNO, J. DAVID MOULTON, BHUVANA SRINIVASAN, LANL, ENRICO CAMPOREALE, CWI — We present a spectral method for the solution of the Vlasov equation for a collisionless plasma by means of an expansion of the distribution function in Hermite polynomials, which leads to a system of partial differential equations for the coefficients of the expansion. With a spectral (Fourier) technique for the spatial discretization and a fully-implicit time integrator, the numerical scheme can achieve exact mass, momentum and energy conservation. In the one-dimensional electrostatic limit, comparisons with a Particle-In-Cell (PIC) method on standard test cases show that the Hermite method can be much more accurate and faster than PIC [1]. We also discuss our further development of this method, which includes a finite element spatial discretization, the extension of the method to multi-dimensions and to the fully electromagnetic case and the use of preconditioning techniques to speed-up the convergence of the inner iterations of the Newton-Krylov method used to solve the discrete non-linear system.


JP8.00075 Efficient simulation of pitch angle collisions in a 2+2-D Eulerian Vlasov code1, JEFF BANKS, R. BERGER, Lawrence Livermore National Laboratory, S. BRUNNER, T. TRAN, Ecole Polytechnique Federale de Laussane — Here we discuss pitch angle scattering collisions in the context of the Eulerian-based kinetic code LOKI that evolves the Vlasov-Poisson system in 2+2-dimensional phase space (Banks et al., Phys. Plasmas 18, 052102 (2011)). The collision operator is discretized using 4th order accurate conservative finite-differencing. The treatment of the Vlasov operator in phase-space uses an approach based on a minimally diffuse, fourth-order-accurate discretization (Banks and Hittinger, IEEE T. Plasma Sci. 39, 2198–2207). The overall scheme is therefore discretely conservative and controls unphysical oscillations. Some details of the numerical scheme will be presented, and the implementation on modern highly concurrent parallel computers will be discussed. We will present results of collisional effects on linear and non-linear Landau damping of electron plasma waves (EPWs). In addition we will present initial results showing the effect of collisions on the evolution of EPWs in two space dimensions.

1. 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 at LLNL under project tracking code 12-ERD-061.

JP8.00076 Solving the 1D1P relativistic Vlasov-Poisson system of equations: case study of the linear Landau damping and two-stream instability1, MICHAEL CARRIE, BRADLEY SHADWICK, Department of Physics and Astronomy, University of Nebraska, Lincoln — We present the initial development of an implicit method to solve the collisionless relativistic Vlasov-Poisson system of equations on a 1D1P Eulerian grid and we benchmark the numerical results against the relativistic Landau damping and two-stream instability linear theory. Since the code is dissipation free, oscillations can be produced in the solution — when the characteristic gradient length becomes comparable to the grid size — and the distribution function can take negative values. One would expect negative values to give unphysical results: particles number, total momentum and enstrophy ($\int \int f^2$) are perfectly conserved down to the machine precision, damping and growing rates and frequency are recovered, even when negative values are produced, and the energy conservation is surprisingly good. For electron distribution parameters relevant to the ICF context, the two-stream instability study shows excellent agreement with the linear theory and highlights the detrimental effect of low energy, low temperature counter-propagating electron beams.

1. This work was supported by the U. S. Department of Energy under Contract No. DE-SC0008382 and by the National Science Foundation under Contract No. PHY-1104683.
JP8.00077 High-order continuum kinetic Vlasov-Poisson simulations of magnetized plasmas1. G.V. VOGMAN, Applied Science & Technology Program, University of California - Berkeley. P. COLELLA, Computational Research Division, Lawrence Berkeley National Laboratory, U. SHUMLAK, Aerospace & Energetics Research Program, University of Washington — Continuum methods offer a high-fidelity means of simulating plasma kinetics as modeled by the Boltzmann-Maxwell equation system. These methods are advantageous because they can be cast in conservation law form, are not susceptible to noise, and can be implemented using high-order numerical methods. Thereby the methods can conserve mass, momentum, and energy to a high degree. A fourth-order accurate finite volume method has been developed to solve the continuum kinetic Vlasov-Poisson equation system in one spatial and two velocity dimensions. The method is validated in cartesian coordinates using the Dory-Guest-Harris instability, which is a special case of a perpendicularly-propagating kinetic electrostatic wave in a warm uniformly magnetized plasma. The instability dispersion relation, and its generalization to arbitrary distribution functions, are demonstrated to be well-suited benchmarks for continuum algorithms in higher-dimensional phase space. The numerical method has also been extended to two spatial dimensions, and has been implemented in cylindrical coordinates to simulate axisymmetric configurations such as a Z-pinch.

1This work was supported by the DOE SCGF fellowship, and grants from DOE ASCR and AFOSR.

JP8.00078 Continuum kinetic plasma modeling by the Vlasov-Maxwell system in multiple dimensions1. NOAH REDDELL, URI SHUMLAK, Aerospace & Energetics Research Program, University of Washington — A kinetic plasma model for multiple particle species described by the Vlasov equation and coupled to fully dynamic electromagnetic forces is presented. The model is implemented as evolving continuous PDFs (probability density functions) in particle phase space (position-velocity) as opposed to particle-in-cell (PIC) methods which discretely sample the PDF. The hyperbolic model is evolved using a high-order finite element method (discontinuous Galerkin), with excellent conservation of system mass, momentum, and energy — an advantage compared to PIC. Simulations of two- to six-dimensional phase space while resolving the plasma frequency and cyclotron frequency are computationally expensive. To maximize performance and scaling to large simulations, a new framework, WARPM, has been developed for many-core (e.g. GPU) computing architectures. WARPM supports both multi-fluid and continuum kinetic plasma models as coupled hyperbolic systems with nearest neighbor predictable communication. Simulation results are compared to existing benchmark problems and newly achievable studies of wave-particle interactions are presented.

1This research was supported by a grant from the United States Air Force Office of Scientific Research and Dept. of Energy Computational Science Graduate Fellowship.

JP8.00079 Capturing marginally collisional effects with the 13N-moment plasma model1. SEAN MILLER, URI SHUMLAK, University of Washington — Fluid-based plasma models have typically been applied to parameter regimes where a local thermal equilibrium is assumed. While this parameter regime is valid for low temperature applications, it begins to fail as plasmas enter the collisionless regime and kinetic effects dominate the physics. This research extends the validity of the collisional fluid regime using an anisotropic 13-moment fluid model derived from the Pearson type-IV probability distribution. The model explicitly evolves the heat flux hyperbolically alongside the density, momentum and an energy tensor to capture dynamics usually restricted to costly Boltzmann models. Each particle species is modeled individually and collectively coupled through electromagnetic and collision operators. Electromagnetic fields are evolved using Maxwell’s equations. The model is implemented within the the University of Washington’s WARPXM code for use on accelerated clusters using an unstructured central essentially non-oscillatory finite volume method, and is currently being extended to an unstructured discontinuous Galerkin method.

1This research was supported by a grant from the United States Air Force Office of Scientific Research.

JP8.00080 Integration of Full Particle Orbit in Toroidal Plasmas Using Boris Scheme, XISHUO WEI, YONG XIAO, Zhejiang Univ — When studying particle dynamics in high frequency electromagnetic waves, such as low hybrid wave heating, it is important to integrate full particle orbit accurately to very long time in tokamaks. Here we derived a formulation under magnetic coordinate based on the Boris Scheme, which can be used effectively to push particles in long time scale. After several hundred gyro-periods, the banana orbit can be observed and the toroidal precession frequency can be measured. The toroidal precession frequency is found to match that from the guiding center simulation. This new method shows superior numeric properties than the traditional Runge-Kutta method in terms of conserving particle energy and magnetic moment.

JP8.00081 Simulations of Laboratory Astrophysics Experiments using the CRASH code, MATTHEW TRANTHAM, CAROLYN KURANZ, MARIO MANUEL, PAUL KEITER, R.P. DRAKE, University of Michigan — Computer simulations can assist in the design and analysis of laboratory astrophysics experiments. The Center for Radiative Shock Hydrodynamics (CRASH) at the University of Michigan developed a code that has been used to design and analyze high-energy-density experiments on OMEGA, NIF, and other large laser facilities. This Eulerian code uses block-adaptive mesh refinement (AMR) with implicit multigroup radiation transport, electron heat conduction and laser ray tracing. This poster/talk will demonstrate some of the experiments the CRASH code has helped design or analyze including: Kelvin-Helmholtz, Rayleigh-Taylor, imploding bubbles, and interacting jet experiments. This work is funded by the Predictive Sciences Academic Alliances Program in NNSA-ASC via grant DEFC52-08NA28616, by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, grant number DE-NA0001840, and by the National Laser User Facility Program, grant number DE-NA0000850.

JP8.00082 Relabeling symmetry in relativistic fluids and plasmas1, YOHEI KAWAZURA, ZENSHO YOSHIDA, Graduate School of Frontier Sciences, University of Tokyo, YASHUDE FUKUMOTO, Institute of Mathematics for Industry Kyushu University — The conservation of the recently formulated relativistic canonical helicity is derived from Noether’s theorem with the fluid elements’ relabeling symmetry. Upon Eulerianizing the Noether current, the purely spatial volume integral on the Lagrangian coordinates is mapped to a space-time mixed three-dimensional integral on the four-dimensional Eulerian coordinates. The relativistic conservation law in the Eulerian coordinates is no longer represented by any divergence-free current. We have also formulated a relativistic action principle of MHD on the Lagrangian coordinates, and have derived the relativistic MHD cross helicity.

1Work supported by Grant-in-Aid for JSPS Fellows 241010.


Dissipative Ballooning Modes in Accretion Disks and Toroidal Configurations

ELIEZER HAMEIRI, New York University — Recently there has been an attempt [1] to investigate the stability of dissipative rotating accretion disks imbeded with a magnetic field, with respect to localized (i.e., ballooning) modes. Some mistakes were made in the analysis, which we correct in this work. The more technically challenging issue is the choice of the dependent variables to be used. In ideal MHD stability analyses, it is common to use the Lagrange displacement vector $\xi$, but in dissipative systems this choice does not appear obvious since it is not possible to solve most other perturbed quantities in terms of $\xi$. We nevertheless show that the perturbation equations are simplified this way, and in particular, if we are interested in small diffusivity, the $\xi$-equations lend themselves to more easily obtaining the small deviation of the growth rate from ideal plasma.

1 Work supported by USDoe under grant no. DE-FG02-86ER53225.

Quasineutrality, self-adjointness and parallel force balance in Kinetic-MHD

JESUS J. RAMOS, M.I.T. — An alternative to the traditional formulations of Kinetic-MHD is presented, based on drift-kinetic equations in the reference frame of the complete fluid velocity. In this approach, the electric field is eliminated by exact algebraic transformations and the quasineutrality condition is satisfied without the need of any explicit enforcement. The moving frame drift-kinetic equations provide only the variables needed to close the fluid moment equations and are not redundant with any information contained in the fluid system such as the parallel force balance. Linearization about a Maxwellian equilibrium without flow yields a standard eigenvalue problem for the normal mode squared frequencies. A transparent proof of real squared frequency spectrum follows, when the plasma is spatially bounded by either a rigid superconducting wall or a plasma-vacuum interface where the equilibrium density goes continuously to zero. At zero-frequency marginal stability, the Rosenbluth-Rostoker closures for the parallel and perpendicular pressures are obtained, in a solution with vanishing parallel electric field and non-zero fluid displacement that is identically consistent with quasineutrality and parallel force balance.

1 Work supported by the U.S. D.O.E.

Derivation of Hamiltonian magnetofluid models with gyroviscous-like contributions using a gyro-map

ALEXANDER WURM, Department of Physical and Biological Sciences, Western New England University, Springfield, MA 01119, MANASVI LINGAM, P.J. MORRISON, Institute for Fusion Studies and Department of Physics, University of Texas at Austin, Austin, TX 78712 — Ideal MHD and various reduced magnetofluid models exhibit a noncanonical Hamiltonian structure when expressed in Eulerian variables [1]. Extending the work of Ref.2, we investigate the possibility of systematically including contributions due to finite ion gyroradii in three dimensions while preserving a noncanonical Hamiltonian structure. Starting with the Morrison-Greene 3D ideal MHD noncanonical Poisson bracket[1] and a Hamiltonian including gyroviscous terms, we derive equations of motion using a three-dimensional generalization of the gyro-map introduced in Ref.[2]. The origin of the gyro-map is motivated and explained using an action principle formulation as in Ref.[3]. Through a systematic reduction procedure, we also recover the (noncanonical) bracket and the gyroviscous tensor, which are identical to the ones obtained via the Hamiltonian formalism.


Two-Dimensional Current Carrying Bernstein-Greene-Kruskal (BGK) Modes for the Vlasov-Poisson-Ampere System

C.S. NG, University of Alaska Fairbanks — Electrostatic structures have been observed in many regions of space plasmas, including the solar wind, the magnetosphere, the auroral acceleration region. One possible theoretical description of some of these structures is the concept of Bernstein-Greene-Kruskal (BGK) modes, which are exact nonlinear steady-state solutions of the Vlasov-Poisson-System of equations in collisionless kinetic theory. We generalize exact solutions of two-dimensional BGK modes in a magnetized plasma with finite magnetic field strength [Ng, Bhattacharjee, and Skiff, Phys. Plasmas 13, 055903 (2006)] to cases with azimuthal magnetic fields so that these structures carry electric current as well as steady electric and magnetic fields. Such nonlinear solutions now satisfy exactly the Hamiltonian formalism of the Vlasov-Poisson-Ampere system of equations.

1 This work is supported by a National Science Foundation grant PHY-1004357.

Anomalous diffusion of field lines and charged particles in Arnold-Beltrami-Childress force-free magnetic fields

B. DASGUPTA, CSPAR, Alabama, A.K. RAM, F. HOLGUIN, PSFC-MIT, V. KRISHNAMURTHY, George Mason — The cosmic magnetic fields in regions of low plasma pressure and large currents, such as in interstellar space and gaseous nebulae, are force-free in the sense that the Lorentz force vanishes. The three-dimensional Arnold-Beltrami-Childress (ABC) field is an example of a force-free, helical magnetic field. The ABC magnetic field lines exhibit a complex and varied structure that is a mix of regular and chaotic trajectories in phase space [1]. The characteristic features of field line trajectories are illustrated through the phase space distribution of finite-distance and asymptotic-distance Lypunov exponents. In regions of chaotic trajectories, the field lines are superdiffusive. The time evolution of an ensemble of charged particles moving in the chaotic ABC fields is divided into three time domains. For short times, the motion of the particles is essentially ballistic. The intermediate times are characterized by a decay of the velocity autocorrelation function. For longer times, the particles undergo anomalous superdiffusion. Detailed theoretical and numerical results will be presented.


Supported by DoE, NSF, U. Alabama

Refined Calculations of Secondary Nuclear Reactions in Magneto-Inertial Fusion Plasmas

PAUL SCHMIT, PATRICK KNAPP, STEPHANIE HANSEN, MATTHEW GOMEZ, KELLY HAHN, DANIEL SINARS, KYLE PETERSON, STEPHEN SLUTZ, ADAM SEFKOW, THOMAS AWE, ERIC HARDING, CHRISTOPHER JENNINGS, Sandia National Laboratories — Diagnosing the degree of magnetic flux compression at stagnation in magneto-inertial fusion (MIF) is critical for charting the performance of any MIF concept. In pure deuterium plasma, the transport of high-energy tritons produced by the aneutronic DD fusion reaction depends strongly on the magnetic field. The tritons probe and occasionally react with the fuel, emitting secondary DT neutrons. We show that the DT/DD neutron yield ratio and the secondary DT neutron spectra can be used to infer the magnetic field-radius product (BR), the critical confinement parameter for MIF [1,2]. The amount of fuel-pusher mix also can be constrained by secondary reactions. We discuss the sensitivity to plasma inhomogeneities of the calculations and outline methods to relate secondary yields to alpha particle energy deposition in ignition-relevant experiments employing DT fuel. We compare our calculations to recent tests of the Magnetized Liner Inertial Fusion (MagLIF) concept [2] on the Z Pulsed Power Facility. [1] M.M. Basko et al., Nuclear Fusion, Vol. 40, No. 1 (2000). [2] S.A. Slutz et al., Phys. Plasmas 17, 056303 (2010).

1 Supported in part by the SNL Truman Fellowship, which is part of the LDRD Program, and sponsored by Sandia Corporation (a wholly owned subsidiary of Lockheed Martin Corporation) as Operator of SNL under its U.S. DoE Contract No. DE-AC04-94AL85000

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The present research, collimated plasma jets form from ablation of a radial foil (Al 20 µg at 50 km/s). This method can provide standoff magnetization in an imploding high energy density plasma as envisioned in magnetized target fusion schemes. We discuss the results of particle-in-cell simulations of laser beatwave current drive and magnetization in plasmas with densities on the order of 10^{15} cm^{-3}. The growth rate of large-amplitude density perturbations introduced by the discrete jets are computed and compared with predictions by the Bell-Plesset equation.

JP8.00090 Contoured-gap coaxial guns for imploding plasma liner experiments

Work supported by US DOE OFES under grants DE-FG02-08ER85114 and DE-FG02-05ER85114.

JP8.00091 Ram-pressure scaling and non-uniformity characterization of a spherically imploding liner formed by hypervelocity plasma jets

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Work supported by the Department of Energy Office of Science, Fusion Energy Sciences, under contract number DE-SC0010698.

JP8.00093 ABSTRACT WITHDRAWN

JP8.00094 Theoretical investigation of Laser Beatwave Magnetization of Liner-Compressed High Energy Density Plasmas

Work supported by the Department of Energy Office of Science, Fusion Energy Sciences, under contract number DE-SC0010698.

JP8.00095 MAGNETIC ICF & HEDP

Work supported by the Department of Energy Office of Science, Fusion Energy Sciences, under contract number DE-SC0010698.

JP8.00096 Plasma Jets Subject to Adjustable Current Polarities and External Magnetic Fields
JP8.00097 Pulsed-power driven reconnection and the inverse skin effect\textsuperscript{1}. JOHN GREENLEY, CHARLES SEYLER, XUAN ZHAO, Cornell University — The COBRA 1 MA generator at Cornell is used to drive magnetic reconnection experiments using wire plasmas. Typically two parallel wires are driven, accumulating magnetic and thermal energy during the current rise. This stored energy is converted into plasma flow kinetic energy by reconnection, driven by the “inverse skin effect” when the driving voltage reverses after peak current. The reversed voltage reverses the Poynting flux so that magnetic energy is being removed from the load, reducing the magnetic field at the boundary on a time scale short compared with resistive penetration time. Reversed current in the outer plasma drives reconnection of flux and creates supersonic and superalfvenic outflows. This effect may have relevance to other pulsed-power driven plasmas, such as the phenomenon of “trailing mass” in imploding Z-pinch. Recent measurements including first data from Thomson scattering will be presented.

\textsuperscript{1}Supported by US DOE NNSA grant DE-NA0001855.

JP8.00098 Particle energization in magnetic reconnection in high-energy-density plasmas. W. DENG, Princeton University & Princeton Plasma Physics Laboratory, W. FOX, Princeton Plasma Physics Laboratory, A. BHATTACHARJEE, Princeton University & Princeton Plasma Physics Laboratory — Significant particle energization is inferred to occur in many astrophysical environments and magnetic reconnection has been proposed to be the driver in many cases. Recent observation of magnetic reconnection in high-energy-density (HED) plasmas on the Vulcan, Omega, and Shenguang laser facilities has opened up a new regime of reconnection study of great interest to laboratory and plasma astrophysics. In these experiments, plasma bubbles, excited by laser shots on solid targets and carrying magnetic fields, expand into one another, squeezing the opposite magnetic fields together to drive reconnection. 2D particle-in-cell (PIC) simulations have been performed to study the particle energization in such experiments. Two energization mechanisms have been identified. The first is a Fermi acceleration process between the expanding plasma bubbles, wherein the electromagnetic fields of the expanding plasma bounce particles, acting as moving walls. Particles can gain significant energy through multiple bounces between the bubbles. The second mechanism is a subsequent direct acceleration by electric field at the reconnection X-line when the bubbles collide into each other and drive reconnection.

JP8.00099 Magnetic field measurement and evolution in high-energy-density plasmas. C. MOISSARD, École Normale Supérieure de Cachan, Princeton Plasma Physics Laboratory, W. DENG, Princeton University, Princeton Plasma Physics Laboratory, W. FOX, Princeton Plasma Physics Laboratory, A. BHATTACHARJEE, Princeton University, Princeton Plasma Physics Laboratory — Magnetic reconnection has been proposed to account for many astrophysical phenomena and is inferred to play an important role in fusion. Recent experiments have studied magnetic reconnection in high-energy-density (HED) plasmas at the Vulcan, Omega and Shenguang laser facilities. Plasma bubbles are created by laser irradiation of solid targets. These bubbles self-generate Mg-scale magnetic fields, and the collision of pairs of bubbles drives reconnection of this magnetic field. 2D first principles particle-in-cell (PIC) simulations with a collision operator have been used to study the evolution of the magnetic field in these experiments. The ablation of the target is modeled by a Gaussian heating function acting on an initially cold, high density plasma. It is shown that the Biermann battery effect ((\nabla \times \mathbf{B})/c + \nabla \times \mathbf{E}) in generalized Ohm’s law) can account quantitatively for the magnetic field produced. However, special attention must be given to the temperature, which can no longer be considered as a scalar in the regime of the experiments. In simulations with a collision operator, the evolution of the magnetic field is compared to Braginskii’s transport theory. Results of 3D simulations of magnetic reconnection with the self-consistent Biermann effect will be reported.

JP8.00100 Magnetic field measurements for study of fast electron transport in magnetized HED plasma. HIROSHI SAWADA, BRANDON GRIFFIN, RADU PRESURA, SHOWERA HAQUE, YASUHIKO SENTOKU, Department of Physics, University of Nevada Reno — Interaction of megagauss magnetic fields with high energy density (HED) plasma is of great interest in the field of magnetized plasma. The field changes fundamental properties of the HED plasma such as thermal and magnetic diffusion. A coupled capability utilizing the 1.0 MA Zebra pulsed power generator and the 50 TW Leopard laser at Nevada Terawatt Facility enables to create such a condition for studies of magnetized plasma properties. We have conducted an experiment to measure magnetic fields generated by a 1.0 MA, 100 ns Zebra pulsed current in stainless steel coils. Using a S32 nm continuous laser from a single longitudinal mode laser system, the temporal change in the magnetic field was measured with the Faraday rotation in F2 glass. The probe laser passing through the 1.5 mm in radius and 1.75 mm thick glass placed in the vicinity of the inductive coils was split with a Glan-Taylor prism to measure vertical and horizontal polarization components with photodiodes. We will present the analysis of the experimental result and a design of a coupled experiment for study of fast electron transport in the magnetized plasma.

JP8.00101 Z-PINCH, X-PINCH, exploding wire plasma and dense plasma focus —

JP8.00102 New Planar Wire Array Experiments on the LTD Generator at U Michigan\textsuperscript{1}. M.E. WELLER, A.S. SAFRONOVA, V.L. KANTSYREV, I. SHRRESTHA, V.V. SHLYAPTESEA, M.C. COOPER, M.Y. LORANCE, A. STAFFORD, E.E. PETKOV, University of Nevada, Reno, N.M. JORDAN, S.G. PATEL, A.M. STEINER, D.A. YAGER-ELORRIAGA, R.M. GILGENBACH, The University of Michigan — Experiments on planar wire array 2-pinches have been carried out on the MAIZE Linear Transformer Driver (LTD) generator at the University of Michigan (UM) for the first time. Specifically, Al (Al 5056, 95% Al, 5% Mg) double planar wire arrays (DPWAs) comprising six wires in each plane with interplanar gaps of 3.0 mm and 6.0 mm and interwire gaps of 0.7 mm and 1.0 mm were imploded with x-ray time-integrated spectra indicating electron temperatures of over 450 eV for K-shell Al and Mg, while producing mostly optically thin lines. In addition to x-ray time-integrated spectra, the diagnostics included x-ray time-integrated pinhole cameras, two silicon diodes, and shadowgraphy, which are analyzed and compared. The MAIZE LTD is capable of supplying up 1.0 MA, 100 kV pulses with 100 ns rise time into a matched load. However, for these experiments the LTD was charged to +70 kV resulting in up to 0.5 MA with a current rise time of approximately 150 ns. Future experiments and the importance of studying planar wire arrays on LTD devices are discussed.

\textsuperscript{1}This work supported by NNSA under DOE Cooperative Agreement DE-NA0001984. S. Patel & A. Steiner supported by Sandia. D. Yager-Elorriaga supported by NSF GF.

JP8.00103 Spectroscopic Measurements of Planar Foil Plasmas Driven by a MA LTD\textsuperscript{1}. SONAL PATEL, DAVID YAGER-ELORRIAGA, ADAM STEINER, NICK JORDAN, RONALD GILGENBACH, Y.Y. LAU, University of Michigan — Planar foil ablation experiments are being conducted on the Linear Transformer Driver (LTD) at the University of Michigan. The experiment consists of a 400 nm-thick, Al planar foil and a current return post. An optical fiber is placed perpendicular to the magnetic field and linear polarizers are used to isolate the pi and sigma lines. The LTD is charged to +70 kV with approximately 400-500 kA passing through the foil. Laser shadowgraphy has previously imaged the plasma and measured anisotropy in the Magneto Rayleigh-Taylor (MRT) instability. Localized magnetic field measurements using Zeeman splitting during the current rise is expected to yield some insight into this anisotropy. Initial experiments use Na D lines of Al foils seeded with sodium to measure Zeeman splitting. Several ion lines are also currently being studied, such as Al I III and C IV, to probe the higher temperature core plasma. In planned experiments, several lens-coupled optical fibers will be placed across the foil, and local magnetic field measurements will be taken to measure current division within the plasma.

\textsuperscript{1}This work was supported by US DoE. S.G. Patel and A.M. Steiner supported by NSPC funded by Sandia. D.A. Yager supported by NSF fellowship grant DGE 1256260.

This work was supported by US DoE. S.G. Patel and A.M. Steiner supported by NSFC funded by Sandia. D.A. Yager-Elorriaga supported by NSF fellowship grant DGE 1256260.


This work was supported by US DoE. S.G. Patel and A.M. Steiner supported by NSFC funded by Sandia. D.A. Yager-Elorriaga supported by NSF fellowship grant DGE 1256260.


Work supported by the Israel Science Foundation and DOE/NNSA.

JP8.00107 Magnetized jets and shocks in radial foil Z-pinch: experiments and numerical simulations.

JP8.00108 Magnetic flux compression experiments on the Z pulsed-power accelerator.

This work was supported by the United States Department of Energy and DOE/NNSA.
JP8.00109 Studies of Cylindrical Liner Z-Pinches at 1 MA on COBRA: LEVON ATOYAN, TOM BYVANK, ADAM CAHILL, WILLIAM POTTER, PHILIP DE GROUCHY, BRUCE KUSSE, DAVID HAMMER, Cornell University — Tests of the magnetized liner inertial fusion (MagLIF) concept will make use of the 27 MA Z-machine to implode a cylindrical metal liner onto a preheated plasma contained within it [1]. While most pulsed power machines produce much lower currents than the Z-machine, there are questions that can be addressed on smaller scale facilities. Recent work on the 1 MA Cornell Beam Research Accelerator (COBRA) has made use of 10 mm long cylindrical metal liners having a 4 mm diameter and a varying wall thickness to study the initiation of plasma on the liner’s outer surface as well as axial magnetic field compression [2]. We will present experimental results with both imploding and non-imploding liners, investigating the impact the liner’s external surface structure has on initiation, outer surface ablation, and implosion. The effect of a uniform axial external magnetic field on observed surface striations [3] will also be discussed.


1This research was supported by the National Nuclear Security Administration Stewardship Sciences Academic Programs under Department of Energy Cooperative Agreement DE-NA0001836.

JP8.00110 Study of the 3D Structure of the Stagnated Z-Pinch: AUSTIN ANDERSON, VLADIMIR IVANOV, University of Nevada Reno — Z pinches are the most powerful laboratory sources of x-ray radiation. Z pinches represent an unstable plasma configuration and are subject to strong plasma instabilities at the ablation, implosion, and stagnation stages. MHD instability produce necks, kinks, and micropinches at stagnation. Knowledge of the 3D plasma distribution is important for interpreting 2D images of the pinch, as well as understanding the effectiveness of models that assume azimuthal symmetry using Abel inversion. Recent experiments were conducted with 266 nm laser shadowgrams from 4 channels, evenly spaced in 45 degree increments. Channels were timed with 100 ps temporal accuracy to provide simultaneous imaging. Results and discussion on the azimuthal non-uniformity of the Z pinch are presented.

JP8.00111 The First Pulsed-Power Z-Pinch Liner-On-Target Hydrodynamics Experiment Diagnosed with Proton Radiography: C.L. ROUSCULP, W.A. REASS, D.M. ORO, J.R. GRIEGO, P.J. TURCHI, R.E. REINOVSKY, A. SAUNDERS, F.G. MARIAM, C. MORRIS, Los Alamos National Laboratory — The first pulse-power driven, dynamic, liner-on-target experiment was successfully conducted at the Los Alamos proton radiography (pRad) facility. 100% data return was achieved on this experiment including a 21 image pRad movie. The experiment was driven with the PHELIX pulsed-power machine that utilizes a high-efficiency (k ~ 0.93) transformer to couple a small capacitor bank (U ~ 300 kJ) to a low inductance meshed-matter experimental load in a Z-pinch configuration. The current pulse (Ipeak ~ 3.7 MA, dt ~ 10 μs) was measured via a fiber optic Faraday rotation diagnostic. The experimental load consisted of a cylindrical Al liner (6 cm diam, 3 cm tall, 0.8 mm thick) and a cylindrical Al target (3 cm diam, 3 cm tall, 0.1 mm thick) that was coated with a thin (0.1 mm) uniform layer of tungsten powder (1 micron diam). It is observed that the shock-launched powder layer fully detaches from the target into a spatially correlated, radially converging (v_r ~ 800 m/s) ring. The powder distribution is highly modulated in azimuth indicating particle interactions are significant. Results are compared to MHD simulations.

1Work supported by United States-DOE under contract DE-AC52-06NA25396.

JP8.00112 Diagnostics of deuterium gas-puff z-pinch experiments on the GIT-12 generator: J. CIKHARDT, D. KLIR, K. RÉZAC, P. KUBES, J. KRAVARIK, B. BATÓBOLOTÓVA, O. SILA, FEE CTU in Prague, K. TUREK, NPI AS CR, A. SHISHLOV, A. LABETSKY, V. KOŠKHENEV, R. CHEDIZOV, N. RATAKHIN, IHCE in Tomsk, V. VARLACHEV, A. GARAPSKY, G. DUDKIN, V. PADALKO, NRPDU, GIT-12 TEAM — Z-pinch experiments with a deuterium gas-puff and an outer plasma shell generated by plasma guns were carried out on the GIT-12 generator at the IHCE in Tomsk. Using this novel configuration of the load, the neutron yields from the DD reaction were significantly increased from 2x10^{12} up to 3x10^{13} neutrons per shot at the current level of about 3 MA. In addition to recent experiments, the threshold activation detectors were used in order to get the information about the energy spectrum of the generated neutrons. The copper, indium, and lead samples were irradiated by the pulse of the neutrons generated during the experimental shot. The decay radiation of the products from the reactions 63Cu(n,2n)62Cu, 117In(n,γ)116In and 206Pb(n,3n)203InPb was observed using gamma spectrometer. According to the used neutron ToF scintillation detectors, the energy of neutrons reaches up to 20 MeV.

1The work was supported by the MSMT of the Czech Republic research programs No. ME090871, No. LG13029, by the GACR grant No. P205/12/0454, grant CRA IAEA No. 17088 and RFBR research project No. 13-08-00479-a.

JP8.00113 Small-amplitude magnetic Rayleigh-Taylor instability growth in cylindrical liners and Z-pinches imploded in an axial magnetic field: A.L. VELIKOVICH, J.L. GIULIANI, Plasma Physics Division, Naval Research Laboratory, R.W. CLARK, Berkeley Research Associates, D. MIKITCHUK, E. KROUYP, Y. MARON, Weizmann Institute of Science, Israel, A. FISHER, Technion - Israel Institute of Technology, P.F. SCHMIT, Sandia National Laboratories — Recent progress in developing the MagLIF approach to pulsed-power driven inertial confinement fusion has stimulated the interest in observation and mitigation of the magnetic Rayleigh-Taylor instability (MRTI) of liners and Z-pinches imploded in an axial magnetic field. Theoretical analysis of these issues is particularly important because direct numerical simulation of the MRTI development is challenging due to intrinsically 3D helical structure of the fastest-growing modes. We review the analytical small-amplitude theory of the MRTI perturbation development and the weakly nonlinear theory of MRTI mode interaction, emphasizing basic physics, opportunity for 3D code verification against exact analytical solutions, and stabilization criteria. The theory is compared to the experimental results obtained at Weizmann Institute with gas-puff Z pinches and on the Z facility at Sandia with solid liners imploded in an axial magnetic field. Work supported by the US DOE/NNSA, and by the US-Israel Binational Science Foundation. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract AC-04-94AL85000.

JP8.00114 Focused X-ray Thomson Scattering Experiments using the Hybrid X-pinch Radiation Source: C. HOYT, SERGEI PIKUZ, TANIA SHELKOVENKO, BRUCE KUSSE, DAVE HAMMER, Cornell University — X-ray Thomson scattering (XRTS) experiments require intense sources of radiation to probe the high densities present in warm dense matter experiments. Past experiments have utilized free-electron lasers or kilojoule of laser energy coupled to foils to produce these sources. The brightness of X-pinch X-ray sources is shown to be comparable to the X-ray sources used in these previous experiments and suitable for application as an XRTS source with the Ti hybrid x-pinch providing 10^{15} ~ 10^{16} photons into 4π steradian. We present results of the first XRTS experiments utilizing the hybrid x-pinch as a probe source incorporated in a novel focusing scheme. We use a primary Bragg optic (Ge400) to collect and focus radiation onto a target and a secondary high-efficiency HAPG/HOPG optic to collect the scattered radiation. Results of scattering from heated targets driven by an independent pulser circuit are compared with cold scattering in the non-collective scattering regime.

1This research was sponsored by the NNSA Stewardship Sciences Academic Programs under DOE Cooperative Agreement DE-NA0001836.
JP8.00115 Heat Transport in the Precursor of Carbon and Metallic Wire Arrays*, JACK HARE, SERGEY LEBEDEV, MATTHEW BENNETT, SIMON BLAND, GUY BURDIAK, LEE SUTTLE, FRANCISCO SUZUKI-VIDAL, GEORGE SWADLING, Imperial College, ALEXANDER VELIKOVICH, Naval Research Laboratory — The complex interplay between the transport of heat and magnetic fields in high-$\beta$, magnetised plasmas is crucial to the feasibility of Magnetised Liner Inertial Fusion (MagLIF). We consider using the precursor plasma in a cylindrical wire array to reach the relevant dimensionless parameters for the initial state of the MagLIF plasma. The precursor is a hot, dense, stable plasma formed on the axis by the collision of material ablated from the wires. Simple models show that an axial magnetic field of $\approx 5$ T could magnetise the precursor ($\omega_{ce}/\gamma_e \approx 10$) at high-$\beta$ ($\beta \approx 10$). In this regime, high-$\beta$ may dominate the magnetic field. The experiments are conducted on MAGPIE (1.4 MA, 250 ns rise time). Metallic wire arrays are standard, but to reduce radiative losses and the electron-ion thermalisation time, we will also consider carbon in the form of 0.3 mm diameter graphite rods. The axial magnetic field can either be provided by external coils or by the drive current. We study the evolution of the plasma density and temperature using laser interferometry and Schlieren imaging, an optical streak camera and Thomson scattering. The magnetic field can be studied using fibre-based polarimetry.

JP8.00116 A study of runaway electrons on a university scale generator*, NICHOLAS OUART, JOHN GIULIANI, ARATI DASGUPTA, GEORGE PETROV, Naval Research Laboratory, DAVID AMPLEFORD, STEPHANIE HANSEN, Sandia National Laboratories, ALLA SAPRONOVA, DIMITER KAROY, ISHOR SHRESTHA, University of Nevada, Reno — Wire array implosions have produced characteristic K-shell emission. These K-alpha and K-beta photons are a result of high energy electrons removing an $n=1$ bound electron from lower ionization stages (e.g. Ne-like). The motivation for studying this emission is the possibility of providing an alternative plasma radiation source with photon energies above 10 keV. However, the mechanism producing these fast runaway electrons still remains elusive. We show results from following electrons in uniform cylindrical plasma with an axial electric field and an azimuthal magnetic field. Elastic and inelastic collisions are included via Monte Carlo techniques. Comparison with experimental Zebra data previously reported [1] will be discussed. *Work supported by DOE/NNSA. This work is partially funded by Sandia LDRD project 165733. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.


JP8.00117 Investigation of the role of ion stopping power in Z-pinch stagnation physics*, THOMAS MEHLHORN, JOHN GIULIANI, WARD THORNHILL, Naval Research Laboratory, YITZHAK MARON, Weizmann Institute — A recently published paper examining the pressure and energy balance of stagnating plasmas in K-shell radiating z-pinch experiments shows that the stagnating plasma pressure is balanced by the implosion pressure and the radiation energy is provided by the imploding-plasma kinetic energy. This result is shown to be valid for both neon gas-puff loads on the 500 kA, 500 ns Weizmann pulsed power generator and for nested aluminum-titanium wire array experiments on Sandia’s Z machine at 20 MA, 100 ns. Multi-frame pinhole photography and spectroscopic analysis of the neon gas puff has shown that the radius of the stagnation plasma increases from 0.2 mm to 0.45 mm over a 3.5 ns time period and that the density is nearly constant during the K-shell emission period. A very similar phenomenon of constant density and growing radius is observed on Sandia’s Z machine for imploding wire array experiments with radius growing from 0.6 to 2.1 mm over a 6 ns period. In this poster we will study what role the kinetic energy loss of the imploding plasma may play in determining the initial scale, density, and evolution of the stagnation plasmas in these two K-shell emission systems.

*Work supported by NRL Base Program and DOE/NNSA

JP8.00118 Effect of Doubly-excited States on Simulation of K- and L-shell Kr Gas Puff on ZR, ARATI DASGUPTA, WARD THORNHILL, JOHN GIULIANI, NICK OUART, Naval Research Laboratory, ROBERT CLARK, Berkeley Research Associates, BRENT JONES, DAVE AMPLEFORD, ADAM HARVEY-THOMPSON, STEPHANIE HANSEN, CHRISTINE COVERDALE, Sandia National Laboratories — A number of recent experiments employing multi-shell gas puffs of Ar and Kr on the Sandia National Laboratories Z accelerator have demonstrated unprecedented K-shell yields. The KAP TIXTL spectra of Ar gas puff shots with a Kr dopant in the middle shell show Kr L-shell lines near 2 keV. There have been also pure Kr shots on ZR. Krypton spectra from Z pinch implosions provide a wealth of information about the pinch dynamics and ionization history of the plasma. These spectra can be used together with experimental spectroscopic data to analyze the presence and dynamics of the emitting regions, which could dominate the Kr K- and L-shell yields. We will present synthetic K- and L-shell spectra with a detailed radiation transport scheme from the emission regions determined from Kr 1D simulations, employing a non-LTE collisional-radiative ionization kinetics model. We will also investigate the effects of state-specific dielectronic recombination on the populations and spectra of Z pinch Kr plasma. *Work supported by DOE/NNSA. Sandia National laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation for the US Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

JP8.00119 ZaP-HD: High Energy Density Z-Pinch Plasmas using Sheared Flow Stabilization*, U. SHUMLAK, B.A. NELSON, R.P. GOLINGO, C.A. BOWERS, S.A. DOTY, E.G. FORBES, D. GOLDSTONE, M.C. HUGHES, B. KIM, S.D. KNECHT, K.K. LAMBERT, W. LOWRIE, M.P. ROSS, J.R. WEEDE, Aerospace & Energetics Research Program, University of Washington — The ZaP-HD flow Z-pinch project investigates scaling the sheared flow to HEDP conditions by using sheared flow stabilization. Z-pinch experiments have produced that are 100 cm long with a 1 cm radius and are quiescent for many radial Alfvén times and axial flow times. Quiescent periods are characterized by low magnetic mode activity measured at several locations along the plasma column and by stationary visible plasma emission. Plasma evolution is modeled with high-resolution simulation codes: Mach2, WarpX, and Nimrod. A sheared flow profile is observed to be coincident with the quiescent period and is consistent with classical plasma viscosity. Equilibrium is determined by diagnostic measurements of density, flow, electron & ion temperature, and magnetic field. Wall stabilization is investigated computationally and experimentally by removing 70% of the surrounding conducting wall. The flow Z-pinch concept provides an approach to achieve high energy density plasmas in K-shell radiating z-pinch experiments.

*This work is supported by grants from US DoE and NNSA.

This work is supported by grants from the U.S. Department of Energy and the U.S. National Nuclear Security Administration.
JP00.0121 Spectroscopy Measurements on the ZaP-HD Experiment

Raymond Golongo, U. Shumlak, B.A. Nelson, S.A. Dotty, D. Goldstone, M.C. Hughes, S.D. Knecht, M.P. Ross, Univ of Washington — The ZaP-HD experiment is studying the scaling relationships necessary to bring a sheared-flow stabilized Z-pinch into the HEDP regime. In the ZaP experiment, a single spectrometer was used to measure velocities of up to $10^4$ m/s, ion temperatures of up to 100 eV, magnetic fields of 1 T, and densities of $10^{21}$ m$^{-3}$ using the Doppler shift and broadening, Zeeman splitting, and Stark broadening of the impurity line radiation. Local densities are found with a deconvolution method. The success of the measurements was partially due to an accurate calibration of the spectrometer using an image warping technique and a collection system that uses telecentric spectrometers. The adiabatic scaling relations predict that an increase in the pinch current from 50 kA to 750 kA will lead to velocities of $10^5$ m/s, temperatures of 4.5 keV, pinch radius of 0.17 mm, and densities of $2 \times 10^{26}$ m$^{-3}$ in the Z-pinch. A review of the results from the ZaP experiment will be given. The improvements to the system necessary to make measurements of the smaller, hotter plasma will be shown. Initial velocity and temperature measurements will also be presented.

1This work is supported by grants from the U.S. Department of Energy and the U.S. National Nuclear Security Administration.

JP00.0122 Investigating the density structure of the ZaP-HD Flow Z-Pinch with digital holographic interferometry

Michael Ross, Uri Shumlak, Brian Nelson, Raymond Golongo, Michael Hughes, Eleanor Forbes, Matt Paliwoda, University of Washington — The ZaP-HD Flow Z-Pinch experiment investigates how flow shear stabilized Z-pinch-scales to higher densities and temperatures. Determining how such plasmas scale up may reveal their utility as test beds for HEDP physics. Scaling towards HEDP conditions requires compressing the plasma to a smaller size with increased plasma current. Measuring the internal structure of a smaller, hotter plasma requires high-resolution diagnostics. To measure electron density profiles, the ZaP-HD team uses holographic interferometry with 30 micron resolution. A new Nd:YAG laser is employed in concert with a consumer digital camera to record holograms, which are numerically reconstructed to obtain the phase shift caused by the interaction of the laser with the plasma. The numerical reconstruction provides a two-dimensional map of chord-integrated electron density, which can be inverted to radial profiles under the assumption of axisymmetry. Measurements of Z-pinch density structure are presented.

2This work is supported by grants from the U.S. Department of Energy and the U.S. National Nuclear Security Administration.

JP00.0123 Wire array K-shell sources on the SPHINX generator

Thierry D’Almeida, Francis Lassalle, Julien Grunenwald, Patrick Maury, Frédéric Zucchini, CEA, Nicolas Niasse, Jeremy Chittenden, Imperial College — The SPHINX machine is a LTD based Z-pinch driver operated by the CEA Gramat (France) and primarily used for studying K-shell radiation effects. We present the results of experiments carried out with single and nested large diameter aluminium wire array loads driven by a current of $\sim$ 5 MA in $\sim$ 800 ns. The dynamic of the implosion is studied with filtered X-UV time-integrated pin-hole cameras. The plasma electron temperature and the characteristics of the sources are estimated with time and spatially dependent holographers and PCDs. It is shown that Al K-shell yields (>1 keV) up to 27 kJ are obtained for a total radiation of $\sim$ 230 kJ. These results are compared with simulations performed using the latest implementation of the non-LTE DCA code Spk in the 3D Eulerian MHD framework Gorgon developed at Imperial College. Filtered synthetic bolometers and PCD signals, time-dependent spatially integrated spectra and X-UV images are produced and show a good agreement with the experimental data. The capabilities of a prospective SPHINX II machine (20 MA $\sim$ 800ns) are also assessed for a wider variety of sources (Ti, Cu and W).

JP00.0124 Lasnex Predictions for Z Opacity Experiments Using Tamper of Increased Mass

La-UR-14-24932, Heidi Morris, Manolo Sherrill, Chris Fontes, Los Alamos National Laboratory, Jim Bailey, Greg Rochau, Taisuke Nagayama, Sandia National Laboratories — 2D Lasnex simulations have been performed for opacity experiments carried out at Sandia National Laboratories’ Z facility. The Z facility has a demonstrated capability for obtaining opacity measurements for iron in the 800-1800 eV x-ray range by showing agreement with PRISMSPECT, MUTA, and OPAL opacity models within experimental error bars. These experiments have been successfully repeated on the upgraded Z machine, ZR. More recently, efforts have focused on achieving opacity measurements for various materials with increased electron density and temperature. Increased mass CH and Be tamper have recently been used to attempt to increase the sample electron density and temperature to $8 \times 10^{22}$ e$^{-}$/cm$^{3}$ and 193 eV. The time-dependent sample conditions and hydrodynamics will be discussed for CH and Be tamper. Instantaneous and time integrated simulated transmission spectra for both tamper will be presented. Measurement of the spatially and temporally resolved x-ray spectrum is in progress for the new ZR, and could help constrain the simulations.

JP00.0125 Z-pinch x-ray spectra obtained with a polarization splitting crystal

R. Presura, M.S. Wallace, University of Nevada, Reno, N.R. Pereira, Ecopulse, Inc. — Anisotropy in a plasma may cause polarization of the spectral lines emitted. For example, the x-rays emitted by Z-pinch plasmas may be polarized if electron beams are present. To detect the polarization, we developed an X-ray spectropolarimeter using a single polarization-splitting crystal. Reflections on intersecting internal planes of the crystal select lines with mutually orthogonal linear polarization. The (10-10) internal planes of a quartz crystal can be used to split several lines of the Al K-shell spectrum according to polarization. We applied this technique to several types of Al wire arrays (cylindrical, conical, and X-pinches), expected to produce increasing beam contributions to the electron population. Peculiarities of the instrument set-up and of the spectra analysis will be presented.

This work was supported by DOE, NNSA grant DE-NA0001834 and cooperative agreement DE-FC52-06NA27616.

JP00.0126 Spatially-Resolved Argon and Neon K-Shell X-Ray Spectra from Triple-Nozzle Gas-Puff Z-Pinches on Cobra

Niansheng Qi, L-3 Communications, Oakland, Philip de Grouchy, Cad Hoyt, Cornell University, Tanja SheloKovenko, Sergei Pizuk, Lebedev Physical Institute, Moscow, Levon Atoyian, William Potter, Adam Cahill, John Greenly, Bruce Kusse, David Hammer, Cornell University — We present the x-ray spectra obtained during Ar/Ne gas-puff z-pinch experiments on the 1MA, 200ns COBRA pulsed power generator at Cornell University. A triple-nozzle gas-puff, which produces two annular (“outer” and “inner”) gas puffs and a high density center jet, is used to tailor the radial mass density distribution. Argon and/or neon plasmas are imploded. Filtered x-ray photo-conducting detectors are used for timing the neon and argon K-shell emission and a filtered x-ray pinhole camera images the K-shell x-ray source size. A spectrometer with three spherical mica crystals is used to capture the K-shell x-ray emission. Our objective is to diagnose the Ar and Ne pinch plasma densities (10$^{19}$-10$^{20}$ cm$^{-3}$) and temperatures (0.5 - 2 keV) with 0.1 mm axial and/or radial spatial resolution from the K-shell x-ray spectra. The He-like resonance to intercombination line ratio will be used to estimate the electron density and the He-like resonance to Li-like satellite line ratio will be used to estimate the electron temperature. We will also add CI as a dopant in either the center Ar gas jet or inner annular puff for K-shell x-ray spectrum studies.

Work supported by DOE Grant No. DE-NA0001836.

JP00.0127 ABSTRACT WITHDRAWN
JP8.00128 Pulsed power produced counter-propagating plasma flows and the study of shock wave formation for laboratory astrophysical phenomena. JULIO VALENZUELA, GILBERT COLLINS, TOM ZICK, JEFF NARKIS, IGOR KRASHENINNIKOV, FARHAT BEG, University of California, San Diego — We report on counter-propagating plasma flows produced by two vertically opposing conical wire arrays using a compact current driver capable of producing 250 kA in about 150 ns. Laser interferometry and extreme ultraviolet imaging were performed to study the collision of the jets. A shock formed by jets interaction was clearly observed and remained stationary for at least 50 ns, after this period a bow shock developed propagating downwards at ~ 20 km/s. Interferometry data showed that the ion density of the jets prior to collision was of the order of $2 \times 10^{23}$ cm$^{-3}$ and a jump in density of ~ 4 was observed at the shock region. A lower limit of ~ 100 km/s has been measured for the jets velocity. The inter ions mean free path has been estimated to be ~ 12 mm, which is larger than the shock wave scale ~ 5 mm, and hence the shock is not mediated by collisions. Magnetic field advection, which can drastically modify the conditions for shock formation, will be discussed. Kinetic particle-in-cell modeling using LSP code has also been implemented and benchmarked against the experimental results.

JP8.00129 Dense Plasma Focus With High Energy Helium Beams for Radiological Source Replacement, ANDREA SCHMIDT, JENNIFER ELLSWORTH, STEVE FALABELLA, ANTHONY LINK, BRIAN RUSNAK, JASON SEARS, VINCENT TANG, Lawrence Livermore National Laboratory — A dense plasma focus (DPF) is a compact accelerator that can produce intense high energy ion beams (multiple MeV). It could be used in place of americium-beryllium (AmBe) neutron sources in applications such as oil well logging if optimized to produce high energy helium beams. AmBe sources produce neutrons when 5.5 MeV Alphas emitted from the Am interact with the Be. However, due to the very small alpha-Be cross section for alphas <2 MeV, an AmBe source replacement would have to accelerate ~0.15 μC of He to 2+ MeV in order to produce $10^7$ neutrons per pulse. We are using our particle in cell (PIC) model in a tokamak plasma focus discharge to guide the optimization of a compact DPF for the production of high-energy helium beams. This model is fluid for the run-down phase, and then transitions to fully kinetic prior to the pinch in order to include kinetic effects such as ion beam formation and anomalous resistivity. An external pulsed-power driver circuit is used at the anode-cathode boundary. Simulations will be benchmarked to He beam measurements using filtered and time-of-flight Faraday cup diagnostics. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This work supported by US DOE/NA-22 Office of Non-proliferation Research and Development. Computing support for this work came from the LLNL Institutional Computing Grand Challenge program.

Tuesday, October 28, 2014 2:00PM - 5:00PM —
Session JM9 Mini-Conference: Van Allen 100: Cosmic Ray Transport
Salon ABC - Gregory Howes, University of Iowa

2:00PM JM9.00001 Cosmic ray transport in the heliosphere, REINHARD SCHLIEKIESER, Ruhr University Bochum — Since the development of satellite space technology about 50 years ago the solar heliosphere is explored almost routinely by several spacecrafts carrying detectors for measuring the properties of the interplanetary medium including energetic charged particles (cosmic rays), solar wind particle densities and electromagnetic fields. In 2012 the Voyager 1 spacecraft has even left what could be described as the heliosphere modulation region, as indicated by the sudden disappearance of low energy heliospheric cosmic ray particles. As other dilute cosmic plasmas have similar densities, temperatures and magnetic fields as the solar wind, the physical processes there probably are the same. With the available in-situ measurements of interplanetary turbulent electromagnetic fields and of the momentum spectra of different cosmic ray species in different interplanetary environments, the heliosphere is the best space laboratory to test our understanding of the transport and acceleration of cosmic rays in space plasmas. I review both, the historical development and the current state of various cosmic ray transport equations. Similarities and differences to gyrokinetic transport equations for terrestrial fusion plasmas are highlighted.

2:35PM JM9.00002 Where is the cosmic-ray modulation boundary of the heliosphere? MING ZHANG, KONSTANTIN GAMAYUNOV, HAMID RASSOUL, Florida Institute of Technology, NIKOLAI POGORELOV, University of Alabama in Huntsville — When cosmic rays (CRs) propagate through the heliosphere, they must overcome the effects of outgoing solar wind (SW), which results in CR modulation. Studies found that the modulation occurs mainly through adiabatic energy loss in the supersonic SW. We had expected it would cease beyond the termination shock, but CR modulation continues in the inner heliosheath. This is because CRs detected there have already spent time in the SW. In a similar argument, CRs seen outside of the heliosheath should still be modulated, rendering no precise modulation boundary. However, recent observations from Voyager 1 show that CR flux has reached its interstellar level almost immediately after the heliopause. To understand the difference between the inner and outer heliosheath, we have to consider the huge difference of particle transport in the heliospheric turbulence and interstellar turbulence. Due to the low level of interstellar turbulence inferred from IBEX observations, we expect the parallel diffusion to increase from its typical heliospheric value of $10^{23}$ cm$^2$/s to the interstellar value of $>10^{27}$ cm$^2$/s, while the perpendicular diffusion decreases significantly. Here we present model results that show the CR modulation boundary should be slightly beyond the heliopause.

3:10PM JM9.00003 Cosmic Ray Self-Confinement, Escape and Transport, MIKHAIL MALKOV, UCSD —Propagation of cosmic rays (CR) in a self-confinement regime is discussed. A self-similar solution for a CR-cloud expansion along the magnetic field strongly deviates from test-particle results. The normalized CR partial pressure is close to $\mathcal{P}(p,z,t) = 2 \left[ \frac{|z|^{1/3} + z^{2/3}}{d_{N_L}} (p,t) \right]^{5/3} \exp \left( -z^2 / 4 D_B (p,t) \right)$, where $p$ is the momentum of CR and $z$ is directed along the field. The core of the cloud expands as $z_{diff} \propto \sqrt{D_{N_L}} (p,t)$ and decays in time as $\mathcal{P} \propto 2 z^{-1} (t)$. The diffusion coefficient $D_{N_L}$ is strongly suppressed compared to its background value $D_B$: $D_{N_L} \sim D_B \exp (-\Pi) \ll D_B$ for sufficiently high field-line-integrated CR partial pressure, $\Pi$. When $\Pi \gg 1$, the CRs drive Alfvén waves efficiently enough to build a transport barrier ($\mathcal{P} \approx 2 |z|^{-4}$ pedestal) that strongly reduces the leakage. The solution has a spectral break in momentum spectrum at $p = p_{th}$, where $p_{th}$ satisfies the following equation $D_{N_L} (p_{th}) \propto z^2 / t$. Magnetic focusing effects in CR transport are briefly discussed.

1Partially supported by NASA through ATP NNX14AH36G.
3:45PM JM9.00004 On Cosmic Ray Propagation\textsuperscript{1} , MIKHAIL MEDVEDEV, University of Kansas — Cosmic ray propagation is diffusive because of pitch angle scattering by waves. We demonstrate that if the high-amplitude magnetic turbulence with $\delta B/B \sim 1$ is present on top of the mean field gradient, the diffusion becomes asymmetric. As an example, we solve this diffusion problem in one dimension analytically with a Markov chain analysis. The cosmic ray density markedly differs from the standard diffusion prediction. The equation for the continuous limit is also derived, which shows limitations of the convection-diffusion equation. We also explore how the difference of the diffusion coefficient for positively and negatively charged species may affect their distribution throughout the system (e.g., galaxy, heliosphere). The result is mostly relevant to low energy particles. The implications of the results are discussed. The results are mostly relevant to fairly low-energy cosmic rays. However, they are general enough to be applicable to any particle transport, not just cosmic rays.

\textsuperscript{1}Supported by grant DOE grant DE-FG02-07ER54940 and NSF grant AST-1209665.

4:05PM JM9.00005 Non-Maxwellian Core-electron Distribution Functions in the Solar Wind\textsuperscript{1} , MANISH MITHAIWALA, Naval Research Laboratory, LEONID RUDAKOV, Icarus Research Inc., GURUDAS GANGULI, CHRIS CRABTREE, Naval Research Laboratory — Electron velocity distribution functions in the solar wind are generally characterized by a thermal ‘core,’ a superthermal ‘halo,’ and field aligned ‘strahl’ electrons. The core distribution is mostly modeled as a bi-Maxwellian distribution, even though the solar wind is nearly collisionless and kinetic wave-particle interactions are expected to be dominant. It has been shown that the non-linear scattering (NLS) by plasma particles due to Landau resonance with beat waves play a fundamental role for low-beta magnetospheric plasmas [1, 2]. However for high-beta solar-wind plasma the rate of the linear Landau damping by electrons with a Maxwellian distribution could prevail over NLS [3]. Furthermore in the high-beta solar wind plasma kinetic Alfvén wave (KAW) and whistler waves meet the Landau resonance with electrons for velocities less than the electron thermal speed and greater than the Alfvén speed. The measured spectrum of KAW fluctuations in the turbulent solar wind plasma is used to calculate the electron distribution functions resulting from quasi-linear diffusion. Quasi-linear diffusion establishes a step-like profile in the electron distribution function for parallel velocity for speeds larger than the Alfvén speed. For parallel velocities less than the Alfvén velocity, evolution of the distribution due to the beat resonance of waves is considered. [1] Ganguli et al., (2010) Phys. Plasmas 17, 052310; [2] Rudakov et al., (2011) Phys. Plasma, 18, 012307; [3] Mithaiwala et al., (2012) Phys. Plasmas, 18, 055710

\textsuperscript{1}This work is supported by NRL base funds.

4:25PM JM9.00006 Magnetic pumping of the solar wind\textsuperscript{1} , JAN EGEDAL, EMILY LICHKO, UW-Madison, WILLIAM DAUGHTON, LANL — The transport of matter and radiation in the solar wind and terrestrial magnetosphere is a complicated problem involving competing processes of charged particles interacting with electric and magnetic fields. Given the rapid expansion of the solarwind, it would be expected that superthermal electrons originating in the corona would cool rapidly as a function of distance to the Sun. However, this is not observed, and various models have been proposed as plausible candidates for heating the solar wind as it super-sonically streams away from the sun. In the compressional pumping mechanism explored by Fisk & Gloeckler particles are accelerated by random compressions by the interplanetary wave turbulence. This theory explores diffusion due to spatial non-uniformities and provides a mechanism for redistributing particle. For investigation of a related but different heating mechanism, magnetic pumping, in our work we include diffusion of anisotropic features that develop in velocity space. The mechanism allows energy to be transferred to the particles directly from the turbulence. The efficiency of the process is explored using kinetic simulations.

\textsuperscript{1}Moved to poster by APS

4:45PM JM9.00007 Magnetic Reconnection in the Earth Magnetotail and Auroral Substorms\textsuperscript{*} , B. BASU, B. COPPI, MIT — By now it is well-accepted that magnetic reconnection is responsible for the generation of accelerated particle populations in space, such as that proposed to occur in the Earth’s magnetotail [1] and generate auroral substorms. In fact, reconnection is the most probable process to explain the observed high-energy particle populations at the edge of the Heliosphere. On the other hand, the theory of this process remains in need of further attention. Since the late sixties, it has been known that departures from Maxwellian distributions for the background plasmas, such as anisotropic electron temperatures, have an important effect on the growth rate of modes producing reconnection. However, the significant effect of transverse (to the field) electron temperature gradients has yet to be included in the theory. The relationship, between the theory of reconnecting modes emerging from plane one-dimensional neutral processes of charged particles interacting with electric and magnetic fields. Given the rapid expansion of the solarwind, it would be expected that superthermal electron parameters for 3C303 and recent attempts to measure its jet axial current. I discuss analogies with both electrical circuits, – and transmission lines. Power is delivered into a “load”, whose impedance, $Z$, is close to that of free space, and the jet power flow $I^2Z$ is $\sim 10^{35}$ erg s$^{-1}$ – broadly consistent with astronomically measured total power outputs, luminosities and lifetimes of AGN-powered radio lobes. The current and power levels are also consistent with SMBH accretion disk model predictions by Stirling Colgate, H. Li, V. Pariev, J. Finn, and others, beginning with Lovelace 1976 (Nature). A further analogy with transmission lines shows how the supragalactic power flows can be disrupted by a complex impedance in the “circuit.” Reactive components in space, i.e. a complex $Z$, can disrupt, reflect or deflect the power flow. This could explain the wide variety of magneto-plasma configurations seen in these systems.

\textsuperscript{*}Sponsored in part by the US DOE.


Tuesday, October 28, 2014 2:00PM - 5:00PM

Session JM10 Mini-Conference: The Magnetic Universe – A Mini-Conference in Honor of Stirling Colgate III

2:00PM JM10.00001 Extragalactic Jets as Electrical Circuits and Transmission Lines\textsuperscript{1} , PHILIPP KRONBERG, University of Toronto and LANL — I describe the first attempt to measure a current in an extended radio galaxy jet: $\sim 10^{18}$ A at $\sim 50$ kpc from the elliptical galaxy’s ultra-compact nucleus. This class of jet is known to transport its magnetic energy “intact”, up to supragalactic scales. I discuss plasma parameters for 3C303 and recent attempts to measure its jet axial current. I discuss analogies with both electrical circuits, – and transmission lines. Power is delivered into a “load”, whose impedance, $Z$, is close to that of free space, and the jet power flow $I^2Z$ is $\sim 10^{35}$ erg s$^{-1}$ – broadly consistent with astronomically measured total power outputs, luminosities and lifetimes of AGN-powered radio lobes. The current and power levels are also consistent with SMBH accretion disk model predictions by Stirling Colgate, H. Li, V. Pariev, J. Finn, and others, beginning with Lovelace 1976 (Nature). A further analogy with transmission lines shows how the supragalactic power flows can be disrupted by a complex impedance in the “circuit.” Reactive components in space, i.e. a complex $Z$, can disrupt, reflect or deflect the power flow. This could explain the wide variety of magneto-plasma configurations seen in these systems.

\textsuperscript{1}Funded by NSERC Discovery Grant A5713.
2:30PM JM10.00002 Lab experiments investigating astrophysical jet physics

— Dynamics relevant to astrophysical plasmas is being investigated in lab experiments having similar physics and topology, but much smaller time and space scales. High speed movies and numerical simulations both show that highly collimated MHD-driven plasma flows are a critical feature; these collimated flows can be considered to be a lab version of an astrophysical jet. Having both axial and azimuthal magnetic fields, the jet is effectively an axially lengthening plasma-confining flux tube with embedded helical magnetic field (flux rope). The jet velocity is in good agreement with an MHD acceleration model. Axial stagnation of the jet compresses embedded azimuthal magnetic flux and so results in jet self-collimation. Jets kink when they breach the Kruskal-Shafranov stability limit. The lateral acceleration of a sufficiently strong kink can provide an effective gravity which provides the environment for a spontaneously-developing, fine-scale, extremely fast Rayleigh-Taylor instability that erodes the current channel to be smaller than the ion skin depth. This cascade from the ideal MHD scale of the kink to the non-MHD ion skin depth scale can result in a fast magnetic reconnection whereby the jet breaks off from its source electrode.

1Supported by USDOE and NSF.

2:50PM JM10.00003 Inward radial transport in differentially rotated plasma discs formed in z-pinch experiments

— The essential feature of magnetic reconnection is the emergence from the central massive black hole and to the excitation of plasma modes associated with the non-thermal features of the proton distributions and d) the outward transport of angular momentum. The magneto-gravitational modes driven by temperature anisotropies and differential rotation; c) the generation of magnetic fields over macroscopic scale distances; in momentum space are considered. The case where significant temperature anisotropies are present is analyzed. In plasmas close to black holes these relevant collective processes in plasmas surrounding or emanating from black holes and containing high-energy particles with non-thermal distributions can be considered to be a lab version of an astrophysical jet. Having both axial and azimuthal magnetic fields, the jet is effectively an axially lengthening plasma-confining flux tube with embedded helical magnetic field (flux rope). The jet velocity is in good agreement with an MHD acceleration model. Axial stagnation of the jet compresses embedded azimuthal magnetic flux and so results in jet self-collimation. Jets kink when they breach the Kruskal-Shafranov stability limit. The lateral acceleration of a sufficiently strong kink can provide an effective gravity which provides the environment for a spontaneously-developing, fine-scale, extremely fast Rayleigh-Taylor instability that erodes the current channel to be smaller than the ion skin depth. This cascade from the ideal MHD scale of the kink to the non-MHD ion skin depth scale can result in a fast magnetic reconnection whereby the jet breaks off from its source electrode.

3:10PM JM10.00004 Rosby Wave Instability in Astrophysical Disks

— In this talk we will review the current understanding of the Rosby wave instability in laboratory experiments, theory and simulations are helping us to make progress. The fate of these jets and lobes could have important implications in terms of the overall magnetization of the wider inter-galactic medium. Many unsolved problems remain in trying to understand the physics of these systems and the need for more plasma physics is acute. We discuss how astronomical observations, laboratory experiments, theory and simulations are helping us to make progress.

3:40PM JM10.00005 Challenges of Astrophysical Disk-Jet-Lobe Systems

— We will present experimental results showing the development of instabilities and an inward transport of matter in a differentially rotating supersonic plasma disc with dimensionless parameters relevant to modeling physics of astrophysical discs. The converging off-axis plasma flow forming the disc is produced by ablation of wires in a cylindrical wire array z-pinch (1.4MA, 250ns) combined with a cusped magnetic field, and the rotating disc is supported in equilibrium by the ram pressure of the flow. The radial profile of rotation velocity in the disc is measured using Doppler shifts of the ion feature of Thomson scattering spectra, while the broadening of the spectra yields the plasma temperature. The evolution of the disc structure is observed with multi-frame XUV and optical cameras, and the plasma density is measured using end-on laser interferometry.

4:00PM JM10.00006 Accretion Disks and Cosmic Rays

— We model accretion disks as Faraday disks with current and mass flows perpendicular to 2D mean field flux surfaces. We model jets produced by accretion disks as weakly-unstable current layers. The Reynolds number in the disc is sufficiently large (>10^2) to allow development of turbulence on the time-scale of the observed experiment, and the observed inward transport of matter with the growth of small scale structures suggests that turbulence is responsible for the transport.

4:20PM JM10.00007 High Energy Plasmas Associated with Black Holes at “Near” and “Far” Distances

— The radiation emission from Shining Black Holes is most frequently observed to have non-thermal features. Therefore, relevant collective processes in plasmas surrounding or emanating from black holes and containing high-energy particles with non-thermal distributions in momentum space are considered. The case where significant temperature anisotropies are present is analyzed. In plasmas close to black holes these processes can be unified by an Ohm’s Law in which Spitzer resistivity is replaced by a generalized hyper-resistivity, ultimately yielding several predictions in rough agreement with observations.

4:40PM JM10.00008 Energetics of the magnetic reconnection in laboratory and space plasmas

— In this talk we will review the current understanding of the Rosby wave instability in laboratory experiments, theory and simulations are helping us to make progress. The fate of these jets and lobes could have important implications in terms of the overall magnetization of the wider inter-galactic medium. Many unsolved problems remain in trying to understand the physics of these systems and the need for more plasma physics is acute. We discuss how astronomical observations, laboratory experiments, theory and simulations are helping us to make progress.


Supported by DoE, NASA, NSF.
that this scattering process contains much of the physics relevant to laser-solid interactions at 10^10 experimental campaign aimed at probing the quantum effects which will radically change our understanding of laser-plasma interactions at next generation.

bunch collides with a high-intensity laser, will allow this regime to be reached for the first time. En route to these exotic regimes, the collider will provide a non-linear inverse Compton scattering and quantum corrections play a crucial role as laser intensities exceed 10^23 W cm^{-2}. The beam optimization to generate the best electron beam was not the one with the "best" focal spot. When a particular wavefront of laser ramp. The technique is based on optimization of the electron beam using a deformable mirror adaptive optical system with an iterative evolutionary genetic algorithm. The image of the electrons on a scintillator screen was processed and used in a fitness function as direct feedback for the optimization algorithm. The concept of coherent control - precise measurement or determination of a process through control of the phase of an applied oscillating field - has been applied to numerous systems with great success. Here, we demonstrate the use of coherent control on plasma dynamics in a laser wakefield electron accelerator experiment. A tightly focused femtosecond laser pulse (10 mJ, 35 fs) was used to generate electron beams by plasma wakefield acceleration in the density down ramp. The technique is based on optimization of the electron beam using a deformable mirror adaptive optical system with an iterative evolutionary genetic algorithm. The image of the electrons on a scintillator screen was processed and used in a fitness function as direct feedback for the optimization algorithm. This coherent manipulation of the laser wavefront leads to orders of magnitude improvement in the electron beam properties such as the peak charge and beam divergence. The laser beam optimized to generate the best electron beam was not the one with the "best" focal spot. When a particular wavefront of laser light interacts with plasma, it can affect the plasma wave structures and trapping conditions of the electrons in a complex way. For example, Raman forward scattering, envelope self-modulation, relativistic self-focusing, and relativistic self-phase modulation and many other nonlinear interactions modify both the pulse envelope and phase as the pulse propagates, in a way that cannot be easily predicted and that subsequently dictates the formation of plasma waves. The optimal wavefront could be successfully determined via the heuristic search easily exceeding the ∼ 100 µm level required for CT applications. Phase-contrast imaging of human prostate and mouse neonates at the micron level was also demonstrated. These studies indicate the usefulness of these sources in research and clinical applications. They also show that full 3D imaging can be made possible with this source in a fraction of the time that it would take with a corresponding x-ray tube.

This work was supported by Office of Science, Office of HEP, US DOE Contract DE-AC02-05CH11231

3:00PM KI2.00002 Applications of laser wakefield accelerators for biomedical imaging\(^1\), ZULFIKAR NAMJUDIN, John Adams Institute for Accelerator Science, Imperial College London — Laser-wakefield accelerators driven by high-intensity short-pulse lasers are a proven compact source of high-energy electron beams, with energy gains of ∼ GeV energy in centimeters of plasma demonstrated. One of the main proposed applications for these accelerators is to drive synchrotron light sources, in particular for x-ray applications. It has also been shown that the same plasma accelerator can also act as a wiggler, capable of the production of high brightness and spatially coherent hard x-ray beams. In this latest work, we demonstrate the application of these unique light-sources for biological and medical applications. The experiments were performed with the Astra Gemini laser at the Rutherford Appleton Laboratory in the UK. Gemini produces laser pulses with energy exceeding 10 J in pulse lengths down to 40 fs. A long focal length parabola (f/20) is used to focus the laser down to a spot of size approximately 25 µm (fwhm) into a gas-cell of variable length. Electrons are accelerated to energies up to 1 GeV and a bright beam of x-rays is observed simultaneously with the accelerated beam. The length of the gas cell was optimised to produce high contrast x-ray images of radiographed test objects. This source was then used for imaging a number of interesting medical and biological samples. Full tomographic imaging of a human trabecular bone sample was made with resolution easily exceeding the ∼ 100 µm level required for CT applications. Phase-contrast imaging of human breast and mouse neonates at the micron level was also demonstrated. These studies indicate the usefulness of these sources in research and clinical applications. They also show that full 3D imaging can be made possible with this source in a fraction of the time that it would take with a corresponding x-ray tube.

This work was supported by DARPA under Contract No. N66001-11-1-4208, the NSF under Contract No. 0955197 and MCubed at the University of Michigan.

4:00PM KI2.00003 Coherent control of plasma dynamics\(^1\), ZHAOHAN HE, Univ of Michigan - Ann Arbor — The concept of coherent control - precise measurement or determination of a process through control of the phase of an applied oscillating field - has been applied to numerous systems with great success. Here, we demonstrate the use of coherent control on plasma dynamics in a laser wakefield electron accelerator experiment. A tightly focused femtosecond laser pulse (10 mJ, 35 fs) was used to generate electron beams by plasma wakefield acceleration in the density down ramp. The technique is based on optimization of the electron beam using a deformable mirror adaptive optical system with an iterative evolutionary genetic algorithm. The image of the electrons on a scintillator screen was processed and used in a fitness function as direct feedback for the optimization algorithm. This coherent manipulation of the laser wavefront leads to orders of magnitude improvement in the electron beam properties such as the peak charge and beam divergence. The laser beam optimized to generate the best electron beam was not the one with the "best" focal spot. When a particular wavefront of laser light interacts with plasma, it can affect the plasma wave structures and trapping conditions of the electrons in a complex way. For example, Raman forward scattering, envelope self-modulation, relativistic self-focusing, and relativistic self-phase modulation and many other nonlinear interactions modify both the pulse envelope and phase as the pulse propagates, in a way that cannot be easily predicted and that subsequently dictates the formation of plasma waves. The optimal wavefront could be successfully determined via the heuristic search easily exceeding the ∼ 100 µm level required for CT applications. Phase-contrast imaging of human prostate and mouse neonates at the micron level was also demonstrated. These studies indicate the usefulness of these sources in research and clinical applications. They also show that full 3D imaging can be made possible with this source in a fraction of the time that it would take with a corresponding x-ray tube.

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4:30PM KI2.00004 First Demonstration of Nonlinear Compton Scattering from LWFA Electrons, CHRISTOPHER MURPHY, SUPA - University of Edinburgh — In the next decade, several large-scale laser projects will become operational allowing focused intensities exceeding 10^{24} W cm^{-2} to be reached for the first time. Theoretical models predict the onset of classical radiation reaction and QED effects which will dramatically alter the plasma dynamics. Such a QED-plasma will enable the generation of conditions analogous to those which are believed to exist in extreme astrophysical environments such as pulsar magnetospheres. While such high fields are not yet observable in the lab frame, they are accessible in the rest frame of a relativistic electron beam, providing a preview of the physics available at next generation facilities. In particular it has been shown that non-linear inverse Compton scattering and quantum corrections play a crucial role as laser intensities exceed 10^{23} W cm^{-2} yet inverse Compton scattering has not been experimentally observed in the relevant extremely non-linear and quantum regime. An “all-optical collider” setup, whereby a laser wakefield electron bunch collides with a high-intensity laser, will allow this regime to be reached for the first time. En route to these exotic regimes, the collider will provide a unique photon source complementary to conventional facilities. We present experimental results demonstrating a low divergence gamma ray source (> 4MeV) with short pulse duration (< 50fs). We also demonstrate, for the first time, inverse-Compton scattering of a laser pulse in the very nonlinear regime and show that this scattering process contains much of the physics relevant to laser-solid interactions at 10^{23} W cm^{-2}. We will outline the theory which supports an experimental campaign aimed at probing the quantum effects which will radically change our understanding of laser-plasma interactions at next generation facilities, aimed at reaching 10^{24} W cm^{-2}.
Dynamos based upon the relative values of the magnetic Reynolds number $R_m$ taxonomy of magnetic fields observed in nature, including those of stars, disks, galaxies and clusters of galaxies. Then, I will give an overview of the theory of field might take, be it small-scale turbulent magnetic fields or large scale magnetic flux is the dynamo problem. In this review, I will give an overview of the continuously transformed into magnetic energy through the dynamo process. Understanding this energy transformation and predicting what form the magnetic energy at small-scales is generated is now well understood, how a large scale field self-organizes from small-scale magnetic fluctuations clusters dynamos tend to generate magnetic energy but little net magnetic flux, whereas large-scale dynamos generate both net flux and energy. While the mechanism by which magnetic energy at small-scales is generated is now well understood, how a large scale field self-organizes from small-scale magnetic fluctuations clusters is a grand challenge for plasma astrophysics. Theoretical dynamos studies are now focused on understanding how subcritical transitions make some dynamos essentially non-linear and also how dynamos in nearly collisionless plasmas may differ from MHD dynamos. I will finish by reviewing how dynamo experiments have and may inform us about astrophysical dynamos.

Session NI1 Energy and Particle Transport Acadia - Ron Waltz, General Atomics

9:30AM NI1.00001 Weimer Award: Reduction of core turbulence and transport in I-mode and comparisons with nonlinear gyrokinetic simulations1, ANNE WHITE, MIT — Understanding transport in high performance ELM-suppressed tokamak plasmas is of great interest for ITER and other future experiments. ‘I-mode’ regime on Alcator C-Mod, also known as ‘improved L-mode’ on ASDEX Upgrade, has several favorable characteristics: pedestals in electron and ion temperature, with ITER98y2 H-factors similar to and exceeding H-mode [Hubbard et al Phys. Plasmas 18, 056115 (2011)], but without a density pedestal and without impurity accumulation and without ELMs. Most research on I-mode focuses on changes in edge, and pedestal turbulence/transport and stability. In this work, transport in I-mode is probed by measuring changes in core turbulence across L-I transitions at Alcator C-Mod and comparing with nonlinear gyrokinetic simulations. Long wavelength ($\kappa_p \rho_s < 0.5$) electron density fluctuation levels decrease from L-mode levels by up to 30% in I-mode, and long wavelength ($\kappa_p \rho_s < 0.3$) electron temperature fluctuation levels decrease by up to 70%, reaching the instrumental sensitivity limit. Gyrokinetic simulation results suggest that ExB shear in the core of these intrinsically rotating plasmas can reduce the fluctuation amplitude in I-mode. As the pedestal temperature increases across slow L-I transitions, core density fluctuations ($0.40 < \rho < 0.95$) are reduced prior to the onset of the edge-localized ($0.99 < \rho < 1.0$) weakly coherent mode (WCM) and prior to the reduction of low-frequency turbulence in the edge/pedestal region ($0.99 < \rho < 1.0$), which suggests that effects of profile stiffness across the radius can also lead to reduced core turbulence. By comparing experimental measurements from Alcator C-Mod to nonlinear gyrokinetic simulations and to different models of profile stiffness, this talk will explore the impact of core turbulence and transport on overall I-mode confinement and on the separation of particle and heat transport in I-mode.

1This work was supported by U.S. Department of Energy contract DE-FC02-99ER54512-CMOD.
10:00AM NI1.00002 Impurity Particle Transport in High Confinement Regimes Without ELMs on DIII-D1, B.A. GRIERSON, Princeton Plasma Physics Laboratory — Recent experiments on DIII-D using trace levels of fluorine gas injection have shown that high confinement regimes without ELMs can achieve rapid transport of impurity ions. Much attention has recently been given to regimes with H-mode energy confinement without edge-localized modes (ELMs), accessed either through Resonant Magnetic Perturbations (RMPs) or MHD such as edge harmonic oscillations or quasi-coherent edge oscillations. Experiments on DIII-D have used gas puffing of trace levels of fluorine to introduce this fully-striped, non-intrinsic and non-recycling impurity that can be easily measured with charge-exchange recombination spectroscopy. Trace fluorine is used because the time-history of the fluorine density profile permits direct extraction of the confinement time, particle diffusivity and convective velocity without relying on atomic modeling or assumptions about the source recycling. Results indicate impurity accumulation is more pronounced in RMP ELM suppressed plasmas with a pure n=3 spectrum compared with mixed n=1 and n=3 RMP fields with reduced number of control coils. In cases where strong central impurity accumulation occurs, trace fluorine analysis reveals a strong inward impurity pinch. Conversely, in plasmas with weak central carbon accumulation, the fluorine pinch is significantly lower. These measurements of impurity influx are consistent with TCLF modeling of the ELM-suppressed phase of the discharge revealing that strong impurity influx occurs when the ratio V/D is between -1 to -3. In this work, the dependencies of impurity transport on local driving gradients will be presented, and the means of increasing the impurity diffusion to recover high purity plasmas will be discussed providing a basis for achieving low-dilution, stationary ELM-free operation in ITER and future devices.

1Supported by the US DOE under DE-AC09-08CH11466 and DE-FG02-05ER54989.

10:30AM NI1.00003 Tungsten Transport in the Core of JET H-mode Plasmas, Experiments and Modelling1, CLEMENTE ANGIONI2, JET, Culham Science Centre, Abingdon, OX14 3DB, UK — The physics of heavy ion transport in tokamak plasmas plays an essential role towards the achievement of practical fusion energy. Reliable predictions of the behavior of these impurities require the development of realistic theoretical models and a complete understanding of present experiments, against which models can be validated. Recent experimental campaigns at JET with the ITER-like wall, with a W divertor, provide an extremely interesting and relevant opportunity to perform this combined experimental and theoretical research. Theoretical models of the radial flow (shear) reversal is consistent with the direction of the (ρ, Eρ) limit cycle observed just inside the LCFS in DIII-D (and recently in LCO-H-mode transitions in HL-2A and JFT-2M), and the reversed limit cycle direction observed in the inner shear layer. Causality of that the LCO is triggered at a critical value of turbulence-driven flow shear. Near the minimum of the electric field well, turbulence-driven flow in the electron synergy of turbulence-driven meso-scale flows, and pressure-gradient driven flows with high spatio-temporal resolution. A density/plasma current scan indicates in the L-mode phase. Low to high confinement (L-H) transitions characterized by limit cycle oscillations (LCO, [1]) allow probing the trigger dynamics and experimentally reconstructed 2D W densities allows the identification of the main mechanisms which govern W transport in the core of JET H-mode plasmas. Neoclassical transport is largely enhanced by centrifugal effects and the neoclassical convection dominates, leading to central accumulation in the presence of central peaking of the density profiles and insufficiently peaked ion temperature profiles. The strength of the neoclassical temperature screening is affected by poloidal asymmetries. Only around mid-radius, turbulent diffusion offsets neoclassical transport. Consistently with observations in other devices, ion cyclotron resonance heating in the plasma center can flatten the electron density profile and peak the ion temperature profile and provide a means to reverse the neoclassical convection. MHD activity may hamper or speed up the accumulation process depending on mode number and plasma conditions. Finally, the relationship of JET results to a parallel modelling activity of the W behavior in the core of ASDEX Upgrade plasmas is presented.

1This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

2Max-Planck-Institut fuer Plasmaphysik, D-85748 Garching, Germany

11:00AM NI1.00004 First Experimental Evidence of Turbulence-driven Main Ion Flow and ExB Flow Triggering the L-H Transition1, L. SCHMITZ, University of California Los Angeles — Simultaneous measurements of main ion flow, E x B flow, and turbulence level n/s inside the separatrix (LCFS) show for the first time that the initial turbulence collapse preceding the L-H transition is due to turbulence-driven ion flow and E x B flow in the ion diamagnetic direction, opposing the pressure-gradient-driven equilibrium E x B flow in the L-mode phase. Low to high confinement (L-H) transitions characterized by limit cycle oscillations (LCO, [1]) allow probing the trigger dynamics and synergy of turbulence-driven meso-scale flows, and pressure-gradient driven flows with high spatio-temporal resolution. A density/plasma current scan indicates that the LCO is triggered at a critical value of turbulence-driven flow shear. Near the minimum of the electric field well, turbulence-driven flow in the electron diamagnetic direction is observed. The radial flow (shear) reversal is consistent with the direction of the (ρ, Eρ) limit cycle observed just inside the LCFS in DIII-D (and recently in LCO-H-mode transitions in HL-2A and JFT-2M), and the reversed limit cycle direction observed in the inner shear layer. Causality of shear-flow generation has been established: early during LCO, the E x B shearing rate leads the ion pressure gradient increase; during the final phase of the LCO, the edge pressure gradient and ion diamagnetic flow are modulated and increase, and the shearing rate lags the ion pressure gradient. Pressure-gradient-driven shear then becomes sufficiently large to secure the final LCO-H-mode transition. A two-predator, one-prey model, similar to a previously developed model [2] but retaining arbitrary polarity of turbulence-driven flow with to respect pressure-gradient-driven E x B flow, captures essential aspects of the transition dynamics, including the magnitude and direction of the driven poloidal main ion flow.

1Supported by the US Department of Energy under DE-FG02-08ER54984 and DE-FC02-04ER54988.

11:30AM NI1.00005 Testing the High Turbulence Level Breakdown of Low-Frequency Gyrokinetics Against High-Frequency Cyclokinetic Simulations1, ZHAO DENG, Peking University — Gyrokinetic simulations of L-mode near edge tokamak plasmas with the gyro code underpredict both the transport and the turbulence levels by 5 to 10 fold [1], which suggest either some important mechanism is missing from current gyrokinetic codes like GYRO or the gyrokinetic approximation itself is breaking down. It is known that gyro drift-simulating the corresponding gyrokinetic simulations, we can test the conditions for the breakdown of gyrokinetics. rCYCLO nonlinearly couples \( vB \) driven ion temperature gradient (ITG) modes and collisional fluid electron drift modes to ion cyclotron (IC) modes. As required, rCYCLO cyclokinetic transport recovers gyrokinetics at high relative ion cyclotron frequency (\( \Omega_e \)) and low turbulence levels. However, because the IC modes are stable and act as a turbulence sink, we have found that at high turbulence levels and low-\( \Omega_e \) cyclokinetic transport is lower (not higher) than gyrokinetic transport. Work is in progress with unstable IC modes to explore the possibility of driving cyclokinetic transport higher than gyrokinetic transport.

1Supported by the CSC, NSFC No. 1126114032, No. 10975012 ITER-CN No. 2013GB112006 and the US DOE under DE-FG02-95ER54309.
12:00PM NI1.00006 Zonal Field Generation by Toroidal Alfvén Eigenmode. ZHIXUAN WANG, University of California, Irvine — Zonal fields (zonal flow and zonal current) have been shown to spontaneously generate and regulate microturbulence. The generation of zonal fields by Alfvén eigenmodes has attracted intense attention recently. Global hybrid-MHD and local gyrokinetic simulations of toroidal Alfvén eigenmode (TAE) indeed find zonal flow generation by mode coupling. However, a nonlinear gyrokinetic theory finds spontaneous generation of zonal fields by TAE modulation instability, arguing the need for kinetic simulations in realistic geometry. Here we use gyrokinetic toroidal code (GTC) to study the TAE in DIII-D discharge #142111 near 525ms by using experimental geometry. Global linear simulation finds a strongly unstable TAE driven by energetic particles (EP) for the dominant toroidal mode (n=4). The radial position of EP-driven TAE peaks at and moves with the location of the strongest EP pressure gradients as EP profile moves outward radially. Experimental data confirms the fast outward drift of the TAE eigenfunction, which is found to be caused by EP non-perturbative contribution. Global GTC nonlinear simulation finds that zonal fields are driven by TAE mode coupling such that the growth rate of zonal fields is twice of the TAE growth rate. Revisiting the nonlinear simulation model reveals a missing nonlinear term, which proves to be especially important for the zonal current. Although zonal current has little effect on the TAE saturation, zonal flow significantly reduces the TAE saturation amplitude.

Wednesday, October 29, 2014 9:30AM - 12:30PM – Session NI2 Basic Plasma Physics Bissonet - Troy Carter, University of California, Los Angeles

9:30AM NI2.00001 Local Regulation of Interchange Turbulence in a Dipole-Confined Plasma Torus using Current-Collection Feedback 1. T. MAXIMILLIAN ROBERTS2, Columbia University — Turbulence in a dipole-confined plasma is dominated by interchange fluctuations with complex dynamics and short coherence. We report the first laboratory demonstration of the regulation of interchange turbulence in a plasma torus confined by an axisymmetric dipole magnet using active feedback. Feedback is performed by varying the bias to an electrode in proportion to the electric potential measured at other locations. The phase and amplitude of the bias to the electrode is adjusted with a linear circuit, forming a relatively broad-band current-collection feedback system. Changing the gain and phase of collection results in modification of turbulent fluctuations, observed as amplification or suppression of turbulent spectrum. Significantly, power can be either extracted from or injected into the turbulence. When the gain and phase are adjusted to suppress turbulence, the external circuit becomes a controlled load extracting power from the plasma. This is analogous to the regulation of magnetosheath convection by ionospheric currents. When the gain and phase of the external circuit is adjusted to amplify turbulence, the direction of power flow from the electrode reverses, enhancing the fluctuations. Although we observe significant changes to the intensity and spectrum of plasma fluctuations, these changes appear only on those magnetic field lines within a region near the current collector equal in size to the turbulent correlation length and shifted in the direction of the electron magnetic drift. We conclude that the effects of this feedback on turbulence in a dipole plasma torus is localized. The clear influence of current-collection feedback on interchange turbulence suggests the possibility of global regulation of turbulent motion using multiple sensor and electrode pairs as well as the ability to perform controlled tests of bounce-averaged gyrokinetic theory of turbulence in the geometry of a dipole plasma torus.

1Supported by NSF-DOE Partnership for Plasma Science and DOE Grant DE-FG02-00ER54585 and NSF Award PHY-1201896.

Acknowledging contributions from Drs. D. Garnier, J. Kesner, M. Mauel, M. Worstell.

10:00AM NI2.00002 Observation of ionization-mediated transition from collisionless interpenetration to collisional stagnation during merging of two superponic plasmas 1. AUNA MOSER, Los Alamos National Laboratory — Colliding plasmas appear in systems ranging from inertial confinement fusion hohlraum plasmas to astrophysical plasmas such as supernova remnants. These interactions can be in a regime that is neither purely collisional nor purely collisionless, which complicates modeling, and the nature of many colliding plasmas makes their detailed characterization difficult. Experiments studying the head-on collision of two superponic plasma jets were performed on the Plasma Liner Experiment (PLX) [1] at LANL. We present experimental measurements demonstrating a transition from an initially collisionless interaction to a collisional one, due to a rising mean ionization level Z [2]. Jets of an argon/impurity mixture are launched from opposing ports of a 3-m-diameter spherical vacuum chamber, and when they meet have density n ≈ 1014 cm⁻³, temperature T ≈ 2.4 eV, Z ≈ 1.2, velocity v ≈ 45 km/s, and diameter d ≈ 30 cm. Laser interferometer measurements show that the two jet fronts interpenetrate as they arrive at chamber center, consistent with calculated inter-jet ion collision lengths, which are long. As they interpenetrate, a rising Z, attributable to fractional heating of electrons by counterstreaming ions, causes a rapid decrease in the inter-jet ion collision length (~ Z⁻⁴). As the inter-jet ion collision length drops to the scale of the interaction region, the interaction becomes collisional and the jets stagnate, eventually producing collisional shock waves. These measurements offer an opportunity to validate plasma collisionality models for plasmas with complex equation of state.


1Supported by the LANL LDRD Program; PLX facility construction supported by OFES.

10:30AM NI2.00003 High Power Heating of Magnetic Reconnection in Tokamak Merging Experiments 1. YASUSHI ONO, Graduate School of Frontier Sciences, University of Tokyo — Significant ion and electron heating of magnetic reconnection up to 1.2keV were documented in two tokamak plasma merging experiment on MAST with the significantly large Reynolds number R ~ 10⁵ [1]. Measured 2D contours of ion and electron temperatures reveal clearly the energy-conversion mechanisms of magnetic reconnection: huge outflow heating of ions in the downstream and localized ohmic heating of electrons at the X-point. Ions are accelerated up to the poloidal Alfvén speed in the reconnection outflow region, and are thermalized by density pileups or fast shocks formed in the downstreams, in agreement with recent solar satellite observations and PIC simulation results. The magnetic reconnection efficiently converts the reconnecting (poloidal) magnetic field energy mostly into ion thermal energy through the outflow, causing the reconnection heating energy proportional to square of reconnecting (poloidal) magnetic field B². The guide toroidal field does not affect the ion heating, probably because the reconnection/ outflow speeds are determined mostly by the external driven inflow by the help of several fast reconnection mechanisms. The localized electron heating increases sharply with the toroidal field, probably because the toroidal field increases electron acceleration length along the X-line. 2D measurements of magnetic field and temperatures in the TS-3 tokamak merging experiment also reveal the detailed reconnection heating mechanisms mentioned above [2]. The high-power heating of tokamak merging is useful not only for laboratory study of reconnection but also for economical startup and heating of tokamak plasmas. It enables us to increase the plasma beta by 10-30% within a short reconnection time. In collaboration with the MAST team.

11:00AM NI2.00004 Effect of q-profile structure on intrinsic torque reversals¹ ZHIXIN LU, UCSD — Intrinsic toroidal rotation plays an important role in mitigating macroinstability and regulating turbulent transport in ITER, where neutral beams are not sufficient to provide the requisite torque. Recent experiments on C-Mod with LHCD observed reversal rotation related to a change in the q profile [1]. In this work, we focus on understanding the physics of intrinsic rotation reversals in LHCD plasmas, using nonlinear, global gyro-kinetic simulations [2] and analysis of mode structure and spectrum symmetry breaking [3]. The sensitive dependence of turbulent residual stress on magnetic shear is identified and characterized. The basic residual stress is non-vanishing when the k-parallel spectrum symmetry is broken, e.g., by E x B shear induced radial shift, non-uniformity in turbulence intensity, etc. [3]. It is found that at low magnetic shear, the poloidal harmonics can shift strongly in the radial direction, as a feature of non-local effects, due to radial propagation and amplitude variation of the mode. This new symmetry breaking mechanism leads to a change in the sign of spectrum averaged parallel wave vector and thus the direction of intrinsic torque. Theoretical study [4] shows that the competition between magnetic drift and ion kinetic effects determines the non-local effects and the structure of the asymmetry. Specifically, it is found that the direction of the intrinsic torque changes from counter- to co-current in the core, when magnetic shear decreases through a critical value. A critical shear $\delta_R = 0.2 \sim 0.5$ for reversal of CTEM-induced intrinsic torque found by simulation is consistent with that from the LHCD C-Mod reversal experiments. In addition, simulations indicate $\delta_R = 1 \sim 2$ for the reversal of ITG-induced torque, a prediction which can be tested by experiments.

References:

¹This work is supported by CER and CMTFO, UCSD and U.S. DOE-PPPL Contract DE-AC02-09CH11466.

11:30AM NI2.00005 Probing the complex ionic structure of warm dense carbon. DOMINIK KRAUS, University of California, Berkeley — The carbon phase diagram at extreme pressure conditions has received broad interest for modeling planetary interiors and high energy density laboratory experiments. Numerous theoretical models and simulations have recently been performed but critical experimental data at the phase boundaries and of the microscopic physical properties remain very scarce. In this work, we present novel experimental observations of the complex ion structure in warm dense carbon at pressures from 20 to 220 GPa and temperatures of several thousand Kelvins. Our experiments employ powerful x-ray sources at kilo-joule class laser facilities and at the Linac Coherent Light Source to perform spectrally and angularly resolved x-ray scattering from shock-compressed graphite samples; the absolute static ion structure factor is directly measured by resolving the ratio of elastically and inelastically scattered radiation. Using different types of variables and their interplay, we were able to probe conditions below and above the melting line, resolving the shock-induced graphite-to-diamond and graphite-to-liquid transitions on nanosecond time scale. Our results confirm a complex ionic structure predicted by QMD simulations and demonstrate the importance of chemical bonds at extreme conditions similar to those found in the interiors of giant planets. The evidence presented here thus provides a firmer ground for modeling the evolution and current structure of carbon-bearing icy giants like Neptune, Uranus, and a number of extra-solar planets.

12:00PM NI2.00006 Advancing plasma turbulence understanding through a rigorous Verification and Validation procedure: a practical example PAOLO RICCI, Centre de Recherches en Physique des Plasmas - Ecole Polytechnique Fédérale de Lausanne — The methodology used to assess the reliability of numerical simulation codes constitutes the Verification and Validation (V&V) procedure. V&V is composed by two separated tasks: the verification process, which is a mathematical issue targeted to assess that the physical model is correctly solved, and the validation, which determines the consistency of the code results, and therefore of the physical model, with experimental data. In the present work, a V&V procedure, rigorous and unparalleled in plasma physics, is presented and applied showing, through a practical example, how it can advance our physics understanding of plasma turbulence. Bridging the gap between plasma physics and other scientific domains, in particular the computational fluid dynamics community, a rigorous methodology for the verification of a plasma simulation code is presented, based on the method of manufactured solution and Roache's grid converge index. This methodology assesses that the model equations are correctly solved, within the order of accuracy of the numerical scheme, and provides a rigorous estimate of the uncertainty affecting the numerical results. Two-dimensional and three-dimensional verified simulations of the basic plasma physics experiment TORPEX are then performed, and rigorously validated against the experimental data. The validation procedure allows progress in the understanding of the turbulent dynamics in TORPEX, by pinpointing the presence of a turbulent regime transition, due to the competition between the resistive and ideal interchange instabilities.

Wednesday, October 29, 2014 9:30AM - 11:30AM – Session N03 MHD, Energetic Particles, Heating and Current Drive Salon D - Eric Gillman, Naval Research Laboratory

9:30AM NO3.00001 Effects of pressure driven MHD instabilities in the Large Helical Device¹. SATOSHI OHDACHI, KIYOMASA WATANABE, SATORU SAKAKIBARA, YASUHIRO SUZUKI, HAYATO TSUCHIYA, TINGFENG MING, XIAODI DU, National Institute for Fusion Science, LHD EXPERIMENT GROUP TEAM — In the Large Helical Device (LHD), the plasma is surrounded by the so-called magnetic stochastic region, where the Kolmogorov length of the magnetic field lines is very short, from several tens of meters and to thousands meters. Finite pressure gradient are formed in this region and MHD instabilities localized in this region is observed since the edge region of the LHD is always unstable against the pressure driven mode. Therefore, the saturation level of the instabilities is the key issue in order to evaluate the risk of this kind of MHD instabilities. The saturation level depends on the pressure gradient and on the magnetic Reynolds number; there results are similar to the MHD mode in the closed magnetic surface region. The saturation level in the stochastic region is affected also by the stochasticty itself. Parameter dependence of the saturation level of the MHD activities in the region is discussed in detail.

¹It is supported by NIFS budget code ULPP021, 028 and is also partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research 20249144, by the JSPS-NRF-NSFC A3 Foresight Program NSFC: No.1126114032

9:42AM NO3.00002 Peeling-off modes at tokamak plasma edge¹. LINGJIN ZHENG, Institute for Fusion Studies, University of Texas at Austin, TX 78712, M. FURUKAWA, Graduate School of Engineering, Tottori University, Tottori 680-8552, Japan — It is pointed out that there is a current jump between the edge plasma inside the last closed flux surface and the scrape-off layer and the current jump can lead the external kink modes to convert to the tearing modes, due to the current interchange effects. This mode conversion is proved by deriving the extended Rutherford equation. The magnetic reconnection in the presence of tearing modes subsequently causes the tokamak edge plasma to be peeled off to link to the diverters. In particular, the peeling or peeling-ballooning modes can become the “peeling-off” modes in this sense. This phenomenon indicates that the tokamak edge confinement can be worse than the expectation based on the conventional kink mode picture.

¹This research is supported by U. S. Department of Energy, Office of Fusion Energy Science: Grant No. DE-FG02-04ER-54742 and by JSPS KAKENHI Grant No. 23760805.
9:54AM NO3.00003 Seed islands driven by turbulence and NTM dynamics, M. MURAGLIA, O. AGULLO, PIIM Laboratory UMR 7345, Aix-Marseille Univ, Marseille, France, A. POYE, CelIA, University Bordeaux - CNRS - CEA, Talence 33405, France, S. BENKADDA, PIIM Laboratory UMR 7345, Aix-Marseille Univ, Marseille, France, W. HORTON, Institute for Fusion Studies, University of Texas at Austin, N. DUBUIT, PIIM Laboratory UMR 7345, Aix-Marseille Univ, Marseille, France, X. GARBEZ, CEA, IRFM, Saint-Paul-Lez-Durance, France, A. SEN, Institute for Plasma Research, Bhat, Gandhinagar 382428, India — Magnetic reconnection is an issue for tokamak plasmas. Growing magnetic islands expel energetic particles from the plasma core leading to high energy fluxes in the SOL and may cause damage to the plasma facing components. The islands grow from seeds from the bootstrap current effects that oppose the negative delta-prime producing nonlinear island growth. Experimentally, the onset of NTM is quantified in terms of the beta parameter and the sawtooth period. Indeed, in experiments, (3;2) NTM magnetic islands are often triggered by sawtooth precursors. However (2;1) magnetic islands can appear without noticeable MHD event and the seed islands origin for the NTM growth is still an open question. Macroscale MHD instabilities (magnetic islands) coexist with micro-scale turbulent fluctuations and zonal flows which impact island dynamics. Nonlinear simulations show that the nonlinear beating of the fastest growing small-scale ballooning interchange modes on a low order rational surface drive a magnetic islands located on the same surface [1]. The island size is found to be controlled by the turbulence level and modifies the NTM threshold and dynamics. [1] M. Muraglia et al, Phys. Rev. Lett., 107, 095003 (2011)

10:06AM NO3.00004 ABSTRACT MOVED TO JO3.00005 —

10:18AM NO3.00005 Instability of the ion-ion hybrid Alfvén resonator in the presence of superthermal alpha-particles1, W.A. FARMER, Lawrence Livermore National Lab, G.J. MORALES, University of California, Los Angeles — A previous theoretical study has suggested that the ion hybrid wave (or shear Alfvén wave) will be unstable in a burning plasma environment due to fusion-born alpha particles [1]. It was concluded that instability occurs for a band of frequencies near the ion-ion hybrid frequency in a homogeneous D-T plasma. In a tokamak, the periodic variation in the strength of the magnetic field along a field-line causes the ion-ion hybrid frequency to vary between the outboard and inboard sides of the device. Because the shear Alfvén wave predominantly propagates along a field-line and experiences a parallel cut-off at the ion-ion hybrid frequency, this instability can lead to excitation of the ion-ion hybrid Alfvén resonator. Recent experiments [2] in the linear device LAPD at UCLA have demonstrated the existence of such a resonator in a magnetic mirror configuration through excitation by an antenna. In this study, instability of the shear Alfvén wave in the magnetic topology of a tokamak due to energetic alpha particles is considered [3].


1This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

10:30AM NO3.00006 Local wave particle resonant interaction causing energetic particle prompt loss in DIII-D plasmas, RUIBIN ZHANG, Fusion Simulation Center, School of Physics, Peking University, Beijing 100871, China, GUOYONG FU, ROSCOE WHITE, Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543, USA — A new resonance mechanism is introduced to explain the observed first-orrbit prompt beam ion losses induced by RSAE in the DIII-D tokamak [1]. Because of large banana width and localized radial structure, some trapped beam ions can only interact with RSAE on the inner legs of their banana orbits. A beam ion can interact resonantly with the RSAE when the mode phase is nearly constant within the local interaction region. We identify this strong local wave particle interaction as local resonance. The local resonance condition is determined by the local poloidal and toroidal velocity of beam ions and can be written as \( -m\dot{\theta} + n\dot{\phi} \geq \omega, -\omega = 0 \), where \(< >\) denotes local time average within the interaction region and \( gc \) stands for guiding center coordinates. A full orbit test particle code FOST confirms the local resonance theory. Both the linear scaling with the mode amplitude and the frequency of the loss signals detected by FILD on DIII-D as well as the measured fast ion radial kick size can be well explained by this local resonance theory and simulation.


10:42AM NO3.00007 Control of energetic particle driven modes in MAST1, DAVID KEELING, TOM BARRETT, CLIVE CHALLIS, NICK HAWKES, OWEN JONES, KEN MCCLEMENTS, ALEX MEAKINS, JOE MILNES, CCFE, UK, MARCO CECCONELLO, IWONA KLIMEK, Uppsala University, Sweden, MIKHAIL TURNYANSKIY, EFDA CSU, Garching, MAST TEAM — Core MHD is known to redistribute fast ions originating from Neutral Beam Injection (NBI). Theory suggests that these modes are driven by gradients in the fast ion distribution, providing the possibility for instability control by optimisation of the fast ion pressure profile to suppress these modes and prevent the redistribution or loss of the fast ions themselves. Experiments on MAST have demonstrated this approach by vertically displacing the plasma to achieve off-axis NBI fast ion injection [Turkanskiy M. et al. 2013 Nucl Fusion 53 053016] or by changing plasma density or NBI power to vary the magnitude of the fast ion pressure [Keeling DL et al submitted to Nucl Fusion]. Measurements using various fast-ion diagnostics show large redistribution in the absence of mitigating effects [Cecconnello M et al submitted to Plasma Phys Control Fusion] whilst measurements and comparisons with modelling have confirmed the suppression of redistribution by appropriate optimisations of the fast ion pressure. These results have led to design options for MAST-Ugrade to allow access to a wide range of plasma parameters without significant fast ion redistribution.

1This work was part-funded by the RCUK Energy Programme and the EU Horizon 2020 programme

10:54AM NO3.00008 Evolution of the radial electric field in high-Te ECH heated plasmas on LHD, NOVIMIR PABLANT, MANFRED BITTER, LUIS F. DELGADO APARICIO, Princeton Plasma Physics Laboratory, ANDREAS DINKLAGE, Max-Planck-Institut fur Plasmaphysik, DAVID GATES, Princeton Plasma Physics Laboratory, MOTOHSI GOTO, TAKUSHI IDO, National Institute for Fusion Science, KENNETH H. HILL, Princeton Plasma Physics Laboratory, SHIN KUBO, SHIGERU MORITA, KENICHI NAGAOKA, TETSUTAROU OISHI, SHINSUKE SATAKE, HIROMI TAKAHASHI, MASAYUKI YOKOYAMA, National Institute for Fusion Science, LHD EXPERIMENT GROUP TEAM — A detailed study is presented on the evolution of the radial electric field (Er) under a range of densities and injected ECH powers on the Large Helical Device (LHD). These plasmas focused on high-temperature electron heating which exhibit a transition of Er from the ion-root to the electron-root when either the density is reduced or the ECH power is increased. Measurements of poloidal rotation were achieved using the X-Ray Imaging Crystal Spectrometer (XICS) and are compared with neo-classical predictions of the radial electric field using the GSRAKE and FORTEC-3D codes. This study is based on a series of experiments on LHD which used fast modification of the gyrotron on LHD to produce a detailed power scan with a constant power deposition profile. This is a novel application of this technique to LHD, and has provided the most detailed study to date on dependence of the radial electric field on the injected power. Detailed scans of the density at constant injected power were also made, allowing a separation of the power and density dependence.
11:06AM NO3.00009 Transport equations for lower hybrid waves in a turbulent plasma\textsuperscript{1}. J.T. MENDONCA, IFPN, Instituto Superior Tecnico, 1049-001 Lisboa, Portugal, W. HORTON, University of Texas at Austin, R.M.O. GALVAO, Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo SP, 05508-090 Brasil, Y. ELSKENS, Aix-Marseille University, Saint Jerome, 13397 Marseille Cedex 20, France — Injection and control of intense lower hybrid (LH) wave spectra is required to achieve steady state tokamak operation in the new WEST tokamak at CEA France. The tungsten [W] environment [E] steadystate $S$ tokamak [T] has two high-power [20MW] lower hybrid antennas launching 3.7 GHz polarized waves for steady fusion-grade plasma control. The wave propagation and scattering is described in by ray equations in the presence of the drift wave turbulence. Theory for the wave transport equations for propagation of the wave momentum and energy densities are derived from the Wigner function method of QM. The limits of the diffraction and scattering for ray transport theory are established. Comparisons are made between the wave propagation in WEST and ITER tokamaks.

\textsuperscript{1}Supported by the University of Texas at Austin; PIIM/CNRS at Aix-Marseille University and University of Sao Paulo.

11:18AM NO3.00010 Global particle simulation of lower hybrid waves in fusion plasmas\textsuperscript{1}. JIAN BAO, ZHIHONG LIN, ANIMESH KULEY, Univ of California - Irvine, ZHIXIN LU, Univ of California - San Diego, ZHIXUAN WANG, Univ of California - Irvine — Global particle simulations of the lower hybrid (LH) waves have been carried out based on the first principle, which use the fully kinetic ion/ drift kinetic electron model with a realistic electron-to-ion mass ratio. The LH wave frequency, mode structure, and electron Landau damping from the electrostatic simulations agree very well with the analytic theory. Linear simulation of the propagation of a LH wave-packet in the toroidal geometry shows that the wave propagates faster in the high field side than the low field side, in agreement with a ray tracing calculation. This poloidal asymmetry arises from the non-conservation of the poloidal mode number due to the non-uniform magnetic field. In contrast, the poloidal mode number is conserved in the cylindrical geometry with the uniform magnetic field. Furthermore, an electromagnetic particle simulation model is developed to study the accessibility of LH waves based on the first principle, the dispersion relations of the slow and fast waves in LH frequency range are well benchmarked. The mode-conversion between slow and fast waves is observed, which is consistent with the theory.

\textsuperscript{1}This work is supported by China National Magnetic Confinement Fusion Science Program (Grant No. 2013GB111000) and U.S. Department of Energy SciDAC GSEP Center.

Wednesday, October 29, 2014 9:30AM - 12:30PM — Session NO4 Compression and Burn II  Salon E - Mordecai Rosen, Lawrence Livermore National Laboratory

9:30AM NO4.00001 Plans and status of the Beryllium ablator campaign on NIF\textsuperscript{1}. J.L. KLINE, S.A. YI, A.N. SIMAKOV, D.C. WILSON, R.E. OLSON, N.S. KRASHENINNIKOVA, G.A. KYRALA, T.S. PERRY, S.H. BATHA, LANL, D.S. CLARK, B.A. HAMMEL, J.L. MILOVICH, J.D. SALMONSON, LLNL — Beryllium has long been known to have excellent properties for indirectly driven ICF implosions including enhanced ablation pressure, implosion velocity, and mass ablation rate. The high ablation velocity leads to stabilization of ablative hydrodynamic instabilities and higher ablation pressures. Recent “high foot” experiments have shown ablative Rayleigh-Taylor to be a leading cause of degraded performance for ICF implosions. While Beryllium ablators have these advantages, there are also risks associated with Beryllium target designs. A campaign is underway to design and to test these advantages for comparison with other ablator options and determine which provides the best path forward for ICF. Experiments using Beryllium ablators are expected to start in the late summer of 2014. This presentation will discuss the status of the experiments and layout the plans/goals for the campaign.

\textsuperscript{1}This work is supported by the US DOE.

9:42AM NO4.00002 The First Indirect Drive, High-Foot Beryllium Campaign on the National Ignition Facility\textsuperscript{1}. A.N. SIMAKOV, D.C. WILSON, S.A. YI, J.L. KLINE, R.E. OLSON, N.S. KRASHENINNIKOVA, G.A. KYRALA, T.S. PERRY, S.H. BATHA, LANL, D.S. CLARK, B.A. HAMMEL, J.L. MILOVICH, J.D. SALMONSON, LLNL — For indirect drive ICF, beryllium (Be) ablators offer a number of important advantages over carbon-based ablators, which can be used to significantly improve the target ignition margin. Recently we designed a number of modern NIF Be high-foot targets optimized for hydrodynamic stability. They employ the standard 5.75 mm gold hohlraum and allow for a range of ablatas, laser drive powers/energies, and fuel ice thicknesses. Here, we will outline the first NIF Be experimental campaign that began in August of 2014. It is based upon a low-yield (high 10\textsuperscript{14} neutrons) but very hydrodynamically robust high-foot target driven by a 350 TW/1.4 MJ pulse and using a 130 $\mu$m DT ice layer. The goal is to obtain a near-1D implosion while quantifying Be target performance uncertainties, cross-comparing with other ablators to elucidate main limitations of our predictive capabilities, and testing superior Be ablator properties near high-foot plastic performance cliffs.

\textsuperscript{1}Work supported by the US Department of Energy.

9:54AM NO4.00003 Performance scalings for indirect drive high-foot NIF beryllium targets\textsuperscript{1}. S.A. YI, A.N. SIMAKOV, D.C. WILSON, J.L. KLINE, R.E. OLSON, N.S. KRASHENINNIKOVA, G.A. KYRALA, T.S. PERRY, S.H. BATHA, LANL, D.S. CLARK, B.A. HAMMEL, J.L. MILOVICH, J.D. SALMONSON, LLNL — Beryllium (Be) ablators offer an attractive path to ignition on the National Ignition Facility (NIF). We have designed a 1.4 MJ, 350 TW cryogenic target for the first NIF Be experiments, utilizing a 3-shock high-foot pulse shape. This initial target is designed to perform close to 1D predictions at the expense of absolute yield ($\sim$ 10\textsuperscript{15} neutrons). Two target parameters that can be used to scale to higher yields are the DT fuel layer thickness and the power in the initial portion of the laser pulse (i.e., the laser “foot”). Designs with thicker fuel layers and higher feet are more hydrodynamically stable, but at the expense of implosion velocity and compression. Targets with thinner fuel layers and lower foot drives achieve higher velocity, but are more susceptible to instabilities. Thus, different trade-offs are possible between 1D yield and 2D hydrodynamic stability. We present a range of NIF Be targets and quantify these trade-offs as we scale to higher performance designs.

\textsuperscript{1}This work is supported by the US Department of Energy.
10:06AM NO4.00004 Expectations and results from the first NIF beryllium shock timing experiment1, D.C. Wilson, S.A. Yi, A.N. Simakov, Los Alamos National Laboratory, H.F. Robey, D.E. Hinkel, J.E. Ralph, D.J. Strozzi, J.I. Milovich, Lawrence Livermore National Laboratory, J.L. Kline, R.E. Olson, N.S. Krasheninnikova, Los Alamos National Laboratory, L. Ber zak Hoppins, Lawrence Livermore National Laboratory, T.S. Perry, G.A. Kyralla, S.H. Batha, Los Alamos National Laboratory — The first NIF beryllium experiments are based on the highly successful hi-foot implosions fielded using plastic capsules. A VISAR diagnosed shock velocities and timing in a liquid DD filled Be capsule in both polar and equatorial directions. The laser pulse contains a 28 TW picket, a low power trough, a 2nd 45 TW pulse, and a 3rd high power pulse. To avoid laser damage from SBS backscatter, the 3rd pulse has 250TW inner beams and 350TW outer beams. The total laser energy is only 0.58 MJ. First shock breakout times at the pole and equator determine inner cone vs outer cone power fractions in the picket. Comparing measured and calculated shock velocities gives picket and 2nd pulse drive multipliers. The picket laser power will adjust the first shock to 28 µm/ns. Cone fraction changes to the 2nd pulse make the 1st and 2nd shocks merge simultaneously at pole and equator. The timing the 2nd pulse adjusts merger depth. The second Be experiment, a symmetry capsule with more energy, will incorporate these changes.

1 Funded by the US-DOE

10:18AM NO4.00005 High-density carbon (HDC) capsule designs for α-heating and for ignition1, D. Ho, A. Amendt, D. Clark, S. Haan, J. Milovich, J. Salmonson, G. Zimmermann, L. Ber zak Hoppins, J. Biener, N. Meezan, C. Thomas, L. Benedict, S. Le Pape, A. Mackinnon, S. Ross, LLNL — We show capsule designs that have HDC ablators, using 2, 3 and 4 shocks. Their advantages and disadvantages will be discussed. Two-shock designs have the shortest pulse length but have the worst 1-D ignition margin because of the high fuel adiabat. Four-shock designs have the highest 1-D ignition margin with the lowest ablatad, but have higher RT ablation front growth. This disadvantage can be overcome by using a picket to generate the 1st shock. The picket reduces the RT growth factor while the decaying 1st shock lowers the fuel ablation further. The picket has the additional advantage of shortening the pulse length. Dopant requirements for different hohlraums will be discussed. A 3-shock design for achieving alpha heating is described, which can use either high-gas-fill (1.6 mg/cc) or near-vacuum hohlraums. A symmetrically driven hohlraum with low gas-fill (0.5 mg/cc) has high laser coupling efficiency and provides good symmetry for a 4-shock design. Comparison of simulations for selected recent HDC shots with experimental data will be presented.

1Prepared by LLNL under Contract DE-AC52-07NA27344

10:30AM NO4.00006 Proposed NIF Experiments to Explore Convergence Ratio and Robustness of Hot Spot Formation in DT Liquid Layer HDC Capsules1, R. Olson, R. Leeper, G. Grim, J. Kline, R. Peterson, L. Ber zak Hoppins, A. Harmza, D. Ho, J. Jones, S. Lepape, A. Mackinnon, N. Meezan, H. Robey, LLNL — DT Liquid Layer ICF capsules allow for flexibility in hot spot convergence via the adjustment of the initial cryogenic capsule temperature and, hence, DT vapor density. High Density Carbon (HDC) is a leading candidate as an ablator material for ICF capsules and a technique has been developed for lining the inner surface of a HDC hohlraum with a low-density hydrocarbon foam that will survive wetting with liquid hydrogen. In this presentation, we propose a series of NIF experiments using liquid DT layer (wetted foam) HDC capsules to test the hypothesis that our predictive capability of hot spot formation is robust for a relatively low convergence ratio hot spot, but will become more difficult as vapor pressure is reduced and hot spot convergence ratio is increased. The proposed liquid DT layer HDC capsule “sub-scale” experiments utilize near-vacuum hohlraums with NIF laser pulse energies of about 1 MJ, but larger scale experiments are also considered.

1This work was performed under the auspices of the U. S. DOE by LANL under contract DE-AC52-06NA25396, and by LLNL under contract DE-AC52-07NA27344.

10:42AM NO4.00007 Development of a Two-shock, Vacuum Hohlraum, Plastic Capsule Implosion Experimental Platform on NIF1, J. Salmonson, S. Maclaren, T. Dittrich, T. McCoy, J. Pino, R. Tipton, Lawrence Livermore Natl Lab, Richard Olson, Los Alamos Natl Lab — A new experimental platform has been developed to study a variety of indirect drive capsule implosion characteristics. A relatively small, ~1700 micron outer diameter, and thick, ~200 microns, uniformly silicon doped, gas-filled plastic capsule is driven inside a standard size 5750 micron diameter ignition hohlraum. The hohlraum fill is near vacuum to reduce backscatter and improve laser/driver coupling. A two-shock pulse of about ~1 MJ of laser energy drives the capsule. The thick capsule prevents ablation front feed-through to the imploded core. Compared to an NIF ignition experiment, this relatively simple, low laser energy platform will allow detailed studies, via sequences of shots, scanning implosion symmetry, capsule gas-fill and convergence, roughness and mix, as well as optimizing stagnation pressure. Recent experimental results toward commissioning this platform will be discussed.

1Prepared by LLNL under Contract DE-AC52-07NA27344

10:54AM NO4.00008 NIF Sub-scale Platform Development1, R.P. Town, F. Albert, L.R. Benedetti, D.K. Bradley, P.M. Celliers, E.L. Dewald, L. Divol, D.E. Eder, G.N. Hall, O.S. Jones, S. Le Pape, B.J. Macgowan, J.I. Milovich, J.D. Moody, A. Pak, J. Ralph, H.F. Robey, J.R. Rygg, M.B. Schneider, D.J. Strozzi, Lawrence Livermore National Laboratory, Livermore, CA 94550 — In order to increase the shot rate on the National Ignition Facility (NIF) a smaller, lower-energy, room-temperature experimental capability has been designed. The goal of the sub-scale design was to reduce the energy requirement to 900kJ. The starting point for the sub-scale design was a layered plastic capsule in a full scale (575) gold hohlraum that was driven by a four shock, low ablatad, 1.8MJ, 420TW, 21-ns long laser pulse. Simple scaling arguments showed that scaling the capsule and hohlraum dimensions to 80% of full scale should meet the energy requirements. The capability includes sub-scale versions of the ignition-scale re-emit symmetry, backlit and hydro-growth radiographic platforms. An experimental campaign to commission these platforms was performed. This talk will review the design and results of these commissioning experiments.

1This work performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344.


11:06 AM NO4.00009 High Foot Target Design Without Cross-Beam Energy Transfer In a Cylindrical Hohlraum1. D.E. HINKEL, D.A. CALLAHAN, O.A. HURRICANE, P.A. MICHEL, W.L. KRUEER, Lawrence Livermore Natl Lab — Recent High Foot implosions at the National Ignition Facility (NIF), where the laser power is high early in time, during the “foot,” have resulted in record neutron yields [1]. To obtain near-spherical, low-mode implosion symmetry, these targets rely on cross-beam energy transfer (CBET), where outer beam power is transferred to the inner beams [2]. CBET has a temporal dependence, as large amounts of transfer occur early in the laser pulse, when the electron temperature is low, and at peak power, when the laser intensity is at its highest. Furthermore, there is also spatial non-uniformity across laser spots after transfer. We have designed a cylindrical High Foot target without CBET to mitigate these effects. Such a target is feasible because: (i) thinner ablator High Foot targets perform well at relatively low powers (~390 TW) and (ii) post-shot modeling of High Foot shots indicates that CBET is shutting off midway through peak power, and thus the average peak power cone fraction is typically less than 40%. Such a target design tests this hypothesis. We report here on the primary features of this design, comparing it with an analogous NIF shot where cross-beam energy transfer is used to achieve the desired peak power cone fraction.

1This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

11:18 AM NO4.00010 Optimizing the hohlraum gas density for better symmetry control of indirect drive implosion experiments1. NOBUHIKO IZUMI, G.N. HALL, S.R. NAGEL, S. KHAN, R.R. RYGG, A.J. MACKINNON, D.D. HO, L. BERZAK HOPKINS, O.S. JONES, R.P.J. TOWN, D.K. BRADLEY, Lawrence Livermore Natl Lab — To achieve a spherically symmetric implosion, control of drive uniformity is essential. Both the ablation pressure and the mass ablation rate on the capsule surface should be made as uniform as possible for the duration of the drive. For an indirect drive implosion, the drive uniformity changes during the pulse because of: (1) the dynamic movement of the laser spots due to blow-off of the hohlraum wall, and (2) cross-beam energy transfer caused by laser-plasma interaction in the hohlraum. To tamp the wall blow-off, we use gas filled hohlraums. The cross-beam energy transfer can be controlled by applying a wave length separation between the cones of the laser beams. However, both of those dynamic effects are sensitive to the initial density of the hohlraum gas fill. To assess this, we performed implosion experiments with different hohlraum gas densities and tested the effect on drive asymmetry. The uniformity of the acceleration was measured by in-flight x-ray backlight imaging of the capsule. The uniformity of the core assembly was observed by imaging the self emission x-ray from the core. We will report on the experimental results and compare them to hydrodynamic simulations.

1Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-626372

11:30 AM NO4.00011 Backward crossbeam energy transfer in indirect-drive ignition hohlraums1. DAVID TURNBULL, PIERRE MICHEL, JOSEPH RALPH, LAURENT DIVOL, ANDREA KRITCHER, JOHN MOODY, Lawrence Livermore National Laboratory — NIF has recently fielded near-vacuum hohlraums (NVHs) with lower gas fill density (.03mg/cc) than the earlier point design (.96mg/cc). Improved early time beam propagation can allow laser “glint” from inner cone beams to exit the opposing laser entrance hole. This light appears on the backscatter diagnostics with numerous features enabling its discrimination from typical backward Stimulated Brillouin Scattering (SBS). Near zero time, we infer signal levels and durations consistent with previous work. The presence of transmitted light also raises the possibility of inter-hemisphere seeding of scattered light, which we refer to as backward Crossed-Beam Energy Transfer (bCBET). Previously, there was no evidence of this process on indirect-drive targets, although it is understood to have a major impact on direct-drive targets. However, the NVHs produce relatively large SBS signals that appear on the backscatter interferograms and carry signatures indicative of bCBET. Upcoming experiments will attempt to clarify whether it is seeded as well as which beams are providing the energy in these signals.

1This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

11:42 AM NO4.00012 Inline Modeling of Cross-Beam Energy Transfer and Backscatter in Hohlraums1. D.J. STROZZI, S.M. SEPKE, G.D. KERBEL, P. MICHEL, M.M. MARINAK, O.S. JONES, LLNL — NIF Ignition experiments with gas-filled hohlraums use significant cross-beam energy transfer (CBET) to control implosion symmetry. They also display substantial stimulated Raman backscatter (SRS) from inner laser beams, and associated “hot” electrons. The radiation-hydrodynamics code HYDRA has been extended to include inline models for CBET and SRS. Coupled-mode equations in the strong damping limit (with linear, kinetic gain rates) are solved along the entire path of incident laser rays. Driven ion-acoustic and Langmuir waves, and inverse-bremsstrahlung absorption, are treated. The inline model includes heating by CBET-driven ion waves, which reduces subsequent CBET. SRS developing inside the target leads to more heating of the underdense fill - and more depletion of the inner beams reaching the hohlraum wall - than remapping the escaping SRS light from the incident laser. Thus, SRS also modifies the plasma conditions so as to limit CBET. We compare inline results with post-processing CBET calculations on plasma conditions that do not include CBET or SRS.

1Prepared by LLNL under Contract DE-AC52-07NA27344.


11:54 AM NO4.00013 A Pathway to Ignition-Hydrodynamic-Equivalent Implosions in OMEGA Direct Drive Through the Reduction of Cross-Beam Energy Transfer1. D.H. FROULA, G. FIKESEL, V.N. GONCHAROV, S.X. HU, H. HUANG, I.V. IGUMENSHCHEV, T.J. KESSLER, D.D. MEYERHOFER, D.T. MICHEL, T.C. SANGSTER, A. SHVYDKY, J.D. ZUEGEL, Laboratory for Laser Energetics, U. of Rochester — Cross-beam energy transfer (CBET) in OMEGA cryogenic ignition-hydrodynamic-equivalent designs reduces the ablation pressure from 230 Mbar to 140 Mbar. To maintain an ignition-relevant velocity of 3.7 × 107 cm/s, areal density of 300 mg/cm2, and hot-spot pressure greater than 100 Gbar on OMEGA, this reduction in ablation pressure requires that the mass of the shell and the abiat be reduced by 75% and 50%, respectively. Measurements and simulations of these implosions indicate that the ablation rate can be increased while maintaining relevant conditions when reducing CBET. To mitigate CBET, several methods to reduce the diameter of the laser beams while maintaining acceptable drive uniformity are being investigated for OMEGA: (1) direct reduction of the laser spots over the entire laser pulse and (2) reduction of the diameter of the laser spots after a sufficient conduction zone has been generated. This two-state zooming is predicted to maintain low-mode uniformity while mitigating CBET. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.
12:06PM NO4.00014 Cross-Beam Energy Transfer Mitigation Strategy for Polar Drive at the National Ignition Facility, J.A. MAROZAS, T.J.B. COLLINS, P.W. MCKENTY, J.D. ZUEGEL, P.B. RADHA, F.J. MARSHALL, W. SEKA, D.T. MICHEL, M. HOHENBERGER, Laboratory for Laser Energetics, U. of Rochester — Cross-beam energy transfer (CBET) causes two-beam energy exchange via stimulated Brillouin scattering which reduces absorbed light and implosion velocity, alters time-resolved scattered-light spectra, and redistributes absorbed light. These effects reduce target performance in symmetric direct-drive and polar-drive (PD) experiments on the OMEGA Laser System and the National Ignition Facility (NIF). The CBET package (Adaawam) incorporated into the 2-D hydrodynamics code DRACO is an integral part of the 3-D ray-trace package (Mazinisin). The CBET exchange occurs primarily over the equatorial region in PD, where successful mitigation strategies concentrate. Detuning the initial laser wavelength (∆λ0) reduces the CBET interaction volume, which can be combined with spot-shape alterations. Employing opposed ± ∆λ0 in each hemisphc offers the best single CBET mitigation option. The current NIF layout can be used to test detuning by altering the NIF PD repointing strategy while maintaining adequate symmetry. Simulations (2-D DRACO) predict measurable results: shell trajectory and shape and scattered-light spectrum and distribution. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


12:18PM NO4.00015 Evaluation of Wavelength Detuning to Mitigate Cross-Beam Energy Transfer Using the Nike Laser, P.W. MCKENTY, J.A. DELETTREZ, J.A. MAROZAS, Laboratory for Laser Energetics, U. of Rochester, J. WEAVER, S. OBENSCHAIN, A. SCHMITT, Naval Research Laboratory — Cross-beam energy transfer (CBET) has become a serious threat to the overall success of polar-drive-ignition experiments. CBET redirects incident laser light before it can be absorbed into the target, thereby degrading overall target performance. CBET is particularly effective over the equator of the target, which is hydrodynamically very sensitive to such losses. A promising solution uses laser wavelength detuning between beams to break the resonance between them and reduce energy transfer. Testing this process for direct drive has been limited because of the lack of sufficient dimming capabilities. However, the Naval Research Laboratory’s Nike laser has the capability of providing a wide range of detuning between its main drive and backlighter beams. This paper explores the design of an experimental platform on Nike to directly evaluate the benefit of frequency detuning in mitigating CBET. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

Wednesday, October 29, 2014 9:30AM - 12:30PM  
Session NO5 Space Plasma 
Galerie 2 - Jason TenBarge, University of Maryland

9:30AM NO5.00001 Properties of Plasma Turbulence in Two and Three Dimensions, TAK CHU LI, GREGORY HOWES, University of Iowa, JASON TENBARGE, University of Maryland — Two important time scales in a turbulent system are the time of nonlinear energy cascade, which occurs dominantly in the plane perpendicular to a strong background magnetic field B0, and the crossing time of Alfvén waves propagating parallel to B0. Two-dimensional (2D) turbulence studies assume the former to be much shorter than the latter and hence neglect the latter. Without the direction along B0, 2D studies can only account for a weak in-plane component of Alfvén waves, which does not fully describe the dynamics involving the propagation of Alfvén waves dominantly along B0. Using gyrokinetic simulations, we explore the properties of plasma turbulence with equivalent systems in two and three dimensions. Preliminary results show very different behavior in the two cases. The 3D system is much more dynamic than the 2D system, implying that processes in 3D are occurring at a different time scale than those in 2D. Key properties of the two systems are being investigated.

9:42AM NO5.00002 ABSTRACT WITHDRAWN

9:54AM NO5.00003 Current sheets and heating in fluid and kinetic simulations of MHD turbulence, KIRIT MAKWANA, FAUSTO CATTANEO, Univ of Chicago, HUI LI, WILLIAM DAUGHTON, Los Alamos National Laboratory, VLADIMIR ZHDANKIN, Univ of Wisconsin-Madison — Magnetohydrodynamic (MHD) turbulence is often invoked as a way to convert magnetic and kinetic energy in large scale plasma motions to thermal energy of plasma particles, thus leading to energy dissipation. However, collisional diffusion is very weak in plasmas. It is believed that kinetic diffusion processes might play an important role in the dissipation mechanism. To understand such processes, we analyze MHD turbulence using both fluid and particle-in-cell kinetic codes. We simulate an ensemble of strongly interacting shear-Alfvén waves and compare their turbulent spectra. The kinetic code produces a slightly steeper energy spectrum. The global energy dynamics for both the codes are very similar, despite their vastly different physics at the small scales. We focus on the formation of thin current sheets and the dissipation within them by comparing the current sheet morphology between the two codes. It is found that the current sheet thickness is related to the particle inertial length. Heating is correlated with the current sheets and is preferentially in the parallel direction. This provides a way for directly simulating physical dissipation in plasmas.

10:06AM NO5.00004 Energy Dissipation in Magnetohydrodynamic Turbulence: Coherent Structures or Nanoflares?, VLADIMIR ZHDANKIN, STANISLAV BOLDYREV, University of Wisconsin-Madison, JEAN CARLOS PEREZ, University of New Hampshire - Space Science Center, STEVEN TOBIAS, University of Leeds — Energy dissipation in magnetohydrodynamic (MHD) turbulence is known to be highly intermittent, occurring mainly in current sheets. However, the question remains whether the overall energy dissipation is dominated by small (dissipation-scale) structures or by large (inertial-range) structures. To systematically investigate this question, we develop and apply a procedure to identify and characterize dissipative structures in numerical simulations of reduced MHD. We find that the probability distribution of energy dissipation rates exhibits a power law with index very close to the critical value of -2.0, indicating that structures of all intensities contribute equally to the overall energy dissipation. We then measure the characteristic spatial scales of structures using two methods: one based on the linear scales across the structure and the other based on the Minkowski functionals, which rigorously characterize the morphology of any shape. We find that energy dissipation is dominated by coherent structures with lengths and widths uniformly distributed across the inertial range, while thicknesses lie deep within the dissipative regime. As the Reynolds number is increased, structures become thinner and more numerous, while the energy dissipation continues to occur mainly in large-scale coherent structures. The current sheets therefore exhibit features of both coherent structures and nanoflares.

10:18AM NO5.00005 Predictions for in situ Observations of Turbulent Power Spectra within the Alfvén Critical Point, KRISTOPHER KLEIN, Space Science Center, University of New Hampshire, BENJAMIN CHANDRAN, Space Science Center and Department of Physics, University of New Hampshire — In preparation for the launch of Solar Probe Plus, which will make unprecedented in situ measurements of the solar wind in the inner heliosphere, we present a series of predictions for these observed turbulent spectra. A number of mechanisms unique to the near-Sun solar wind will make the task of interpreting measurements quite difficult, including an imbalanced flux of turbulent Alfvénic fluctuations with possibly distinct spectral power laws, the possible violation of the Taylor hypothesis, and the rapidly varying motion both radial and transverse to the spacecraft. We incorporate these mechanisms into analytic predictions for the observed power spectra, as well as into previously validated techniques for creating synthetic time series from a spectrum of linear eigenmodes. These predictions for the observed spectra may be used to distinguish between competing turbulence theories which may impact solar wind acceleration and the heating of the Sun’s corona.

1Support provided by NSF grant number NSF AGS-1331355.
they evolve into kinetic Alfvén waves (KAWs) in the dipole-like field region. The fast flow braking. Kinetic compressional wave turbulence is present around the dipolarization front. A shear-flow instability is found on the dusk side flank consistent with recent satellite observations. Ion particle distributions reveal multiple populations/beams. Oscillation of the dipolarization front is developed at on the dawn (dusk) side. Correspondingly, more reconnection and more earthward ion injections occur on the dusk side than the dawn side. Such finding is fields in the thin current layer cause a systematic dawnward ion drift motion and thus a dawn-dusk asymmetry of the plasma sheet with a higher (lower) density penetration of the dawn-dusk electric field and thus a thinning of the plasma sheet, followed by the magnetotail reconnection with 3-D flux ropes. Hall electric

IMF is studied using a 3-D global hybrid simulation model that includes both the dayside and nightside magnetosphere. Dayside reconnection leads to the Auburn, AL, USA, QUANMING LU, USTC, China — Dynamics of the near-Earth magnetotail associated with substorms during a period of extended southward wind eVDFs.

10:42AM NO5.00007 Self-Similar Kinetic Theory in the Solar Wind: Data and Simulations . KONSTANTINOS HORAITES, STANISLAV BOLDYREV, University of Wisconsin-Madison, SERGEI KRASHENINNIKOV, University of California-San Diego, CHADI SALEM, STUART BALE, MARC PULUPA, Space Sciences Laboratory, University of California-Berkeley — If the temperature Knudsen number \( \gamma(x) = T(x)/\bar{T}(x)/T_e \) in a plasma is constant throughout the system, the collisional kinetic equation for electrons admits self-similar solutions. These solutions have the novel property that the 'shape' of the eVDF does not vary in space. Such a theory should be applicable in the solar wind, where the density and temperature are observed to vary as power laws with heliocentric distance r such that \( \gamma(r) \sim \text{constant} \). We present results of numerical simulations, where we find the steady-state eVDF for various \( \gamma \). We then compare the predictions of the theory with satellite observations from the Helios and Wind missions. Overall, the theory exhibits remarkable consistency with a variety of electron measurements, and provides an intuitive context for understanding the steady-state solar wind eVDFs.

10:54AM NO5.00008 Electron Magnetohydrodynamic Turbulence: Universal Features1 . BHIMSSEN SHIVAMOGGI, University of Central Florida — The energy cascade of electron magnetohydrodynamic (EMHD) turbulence is considered (Shivamoggi [1]). Several basic features of the EMHD turbulent system are found to be universal which seem to transcend the existence of the characteristic length scale \( d_e \) (which is the electron skin depth) in the EMHD problem—

• equipartition spectrum,
• Reynolds-number scaling of the dissipative microscales,
• scaling of the probability distribution function (PDF) of the electron-flow velocity (or magnetic field) gradient (even with intermittency corrections),
• dissipative anomaly,
• critical exponent scaling.


1This research was supported in part by NSF grant No. PHY05-51164.

11:06AM NO5.00009 Parallel and Perpendicular Diffusion of Cosmic Rays in Turbulent Plasmas: Analytical Theory and Simulation1 . MOHAMMAD HUSSEIN, ANDREAS SHALCHI, Univ of Manitoba, COSMIC RAY TRANSPORT TEAM — A fundamental problem in Space Science and Astrophysics is the interaction between energetic particles and a turbulent plasma. We have developed a test-particle code to simulate the interaction of charged particles with turbulent magnetic fields. Diffusion coefficients along and across the mean magnetic field are calculated and compared to different analytical theories. Different turbulence models where considered such as models with reduced dimensionality and full three-dimensional models. We have also included wave propagation effects. We explored the transport regimes in which the Bohm limit and the quasilinear limit are valid. We also shown that for perpendicular diffusion the so-called unified non-linear transport theory agrees very well with the numerical simulations.

1NSERC

11:18AM NO5.00010 The Use of Orbital Tethers to RemEDIATE Geomagnetic Radiation Belts . MATHIAS HUDOBA DE BADYN, University of Washington, RICHARD MARCHAND, RICHARD SYDORA, University of Alberta — The Van Allen radiation belts pose a hazard to spacecraft and astronauts, and similar radiation belts around other planets pose a hazard to interplanetary probes. We discuss a method of remediating these radiation belts proposed by Hoyt, Minor and Cash where a long, charged tether is placed in orbit inside a radiation belt. The electric field of the tether adiabatically scatters the belt particles into a pitch angle loss cone due to absorption of the particles in the atmosphere. We present a test particle calculation which computes the scattered pitch angle of belt particles as a function of initial pitch angle and gyrophase for different particle energies. We then use the moments of the resulting histogram of scattered angle versus initial pitch angle to compute the number density of the belt as a function of time using a Fokker-Planck diffusion model. Finally, we use the characteristic timescales of scattering for particles of different energies to discuss the feasibility of using such a system of tethers as a long and short-term remediation solution.

11:30AM NO5.00011 Investigation of Storm-Time Magnetotail and Ion Injection Using 3-D Global Hybrid Simulation . YU LIN, XUEYI WANG, Auburn Univ, Auburn, AL, USA, SAN LU, USTC, China, JOE PEREZ, Auburn Univ, Auburn, AL, USA, QUANMING LU, USTC, China — Dynamics of the near-Earth magnetotail associated with substorms during a period of extended southward IMF is studied using a 3-D hybrid simulation model that includes both the dayside and night side magnetosphere. Dayside reconnection leads to the penetration of the dawn-dusk electric field and thus a thinning of the plasma sheet, followed by the magnetotail reconnection with 3-D flux ropes. Hall electric fields in the thin current layer cause a systematic dawnward ion drift motion and thus a dawn-dusk asymmetry of the plasma sheet with a higher (lower) density on the dawn (dusk) side. Correspondingly, more reconnection and more earthward ion injections occur on the dusk side than the dawn side. Such finding is consistent with recent satellite observations. Ion particle distributions reveal multiple populations/beams. Oscillation of the dipolarization front is developed at the fast flow braking. Kinetic compressional wave turbulence is present around the dipolarization front. A shear-flow instability is found on the dusk side flank of the ring current plasma, whereas a kinetic ballooning instability appears on the dawn side. Shear Alfvén waves and compressional wave are generated, and they evolve into kinetic Alfvén waves (KAWs) in the dipole-like field region.
11:42AM NO5.00012 Equatorial Electrojet Instabilities - New Fluid Model Approach. EHAB HASSAN, WENDELL HORTON, University of Texas at Austin, ANDREI SMOLYAKOV, University of Saskatchewan, DAVID HATCH, University of Texas at Austin — A fluid model combines both Farley-Buneman (Type-I) and Gradient-Drift (Type-II) plasma instabilities in the equatorial electrojet. The ion viscosity and electron inertia are considered in the ion and electron equations of motion, respectively. These two terms play an important role in stabilizing the growing modes in the linear regime and in driving Farley-Buneman instability into the saturation state. The simulation is stable in the saturated state and the results show good agreements with a number of rocket measurements and radar observations, where we find (1) a saturation of the plasma density around 7% relative to the ionospheric background, (2) the horizontal secondary electric field stabilizes at 8.7 (mV/m), (3) the phase velocity of the perturbed density wave has a value close to the ion-acoustic speed inside the electrojet, (5) an up-down asymmetry in the vertical particle fluxes of plasma density, (5) an east-west asymmetry in the plasma drifts in the zonal direction, and (6) a generation of the small-scale; of the order of 3 meter scale length and less, irregularities embedded in the large-scale structures in the vertical direction. The break-up of the large-scale structures into small-scale structures explains the disappearance of Type-II echoes in the presence of Ty

11:54AM NO5.00013 Rossby-Khantadze Electromagnetic Planetary Waves Driven by Sheared Zonal Winds in the E-Layer Ionosphere. S. FUTATANI, LMFA-CNRS, Ecole Centrale de Lyon, Universite de Lyon, Ecully, France, W. HORTON, The University of Texas at Austin, L.Z. KAHLIN, Physics Department, Government College University, Lahore 54000, Pakistan, T. KALADZE, I. Vekua Institute of Applied Mathematics, Tbilisi State University, 0186 Tbilisi, Georgia — Nonlinear simulations are carried out for planetary scale [∼ 1000km] electromagnetic Rossby and Khantadze planetary waves in the presence of a sheared zonal flow in the weakly ionized ionospheric E-layer. A variety of sheared flow profiles are studied. We show that the nonlinear dynamics with the sheared zonal flows provides an energy source into the vortex structures. The energy transfer through the Reynolds stress tensor produces growth of the stable vortices under a variety of conditions. The energy accumulation breaks the vortex structure into multiple species according to the non-uniformity of profile of the external zonal shear flows. S. Futatani, W. Horton, T. D. Kaladze, Phys. Plasmas 20, 102903 (2013). T. D. Kaladze, T. Z. Kahlion, W. Horton, O. Pokhotelov, and O. Onishchenko, Shear flow driven Rossby-Khantadze electromagnetic planetary vortices in the ionospheric E-Layer, EPL, 106, A05302 (2014). doi: 10.1209/0295-5075/106/29001

12:06PM NO5.00014 Iron opacity experiments for the solar interior. T. NAGAYAMA, J.E. BAILEY, G. LOISEL, C.A. ROCHAU, S.B. HANSEN, Sandia National Laboratories, C. BLANCARD, PH. COSSE, G. FAUSSURIER, F. GILLERON, J.-C. PAIN, CEA, A.K. PRADHAN, C. ORBAN, M. PISONNEAULT, S.N. NAHAR, Ohio State University, Columbus, C.A. IGLESIAS, B. WILSON, Lawrence Livermore National Laboratories, Livermore, J. COLGAN, C. FONTES, D. KILCREASE, M. SHERRILL, Los Alamos National Laboratory, Los Alamos, J.J. MACFARLANE, I. GOLOVKIN, Prism Computational Sciences, Madison, R.C. MANCINI, University of Nevada, Reno — Iron opacity experiments near solar interior conditions are performed at SNL’s Z-machine to better constrain solar models. The SNL opacity science platform satisfies the many challenging requirements for opacity measurements and successfully determines iron opacities at multiple conditions. We found that the agreement between the modeled opacity and the measured opacity deteriorates as Te and ne are raised to approach solar interior conditions. While the inaccuracy of the modeled opacity partially resolves the solar abundance problem, the announcement of such discrepancies has a high impact on the astrophysics, atomic physics, and high energy density physics, and thus more scrutiny on the potential experimental flaws is critical. We report the synthetic investigation for potential sources of systematic uncertainties in the experiments. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

12:18PM NO5.00015 Analysis of Electron Evolution in Air using Updated Cross Section Data (LA-UR-14-25207). ELISE PUSATERI, Los Alamos National Laboratory, Rensselaer Polytechnic Institute, HEIDI MORRIS, Los Alamos National Laboratory, WEI Ji, Rensselaer Polytechnic Institute — For the purpose of modeling the time evolution of electron temperature in an Electromagnetic Pulse, a swarm model has been developed. This code uses an adaptive time step and solves a system of coupled differential equations for the electric field, electron temperature, electron number density, and drift velocity. Our comparisons with microwave and DC breakdown measurements have revealed that, for high values of E/p, the swarm model understimates the equilibrium temperature that is achieved in experiments. Our initial work used energy and momentum transfer collision frequencies that were reported in Higgins, Longmire, and O’Dell (1973). We have updated the electron-air cross sections using those reported in the Lxcat database as a part of the Plasma Data Exchange Project. New momentum and energy transfer collision frequencies, defined over a broader energy range, have been calculated using a two-term Boltzmann Equation solver, BOLSIG+. We report on the use of these updated collision frequencies in the swarm code and show the improvement in our calculation by comparing the results with experimental data.

Wednesday, October 29, 2014 9:30AM - 12:30PM Session NO6 HEDP Hydrodynamics Galerie 3 - Stephanie Hansen, Sandia National Laboratories

9:30AM NO6.00001 Perturbation Growth Seeded by a Metal Foam. S.G. GLENDINNING, K.L. BAKER, A.W. COOK, D.M. DOANE, T.R. DITTRICH, S.A. FELKER, R.M. SEUGLING, S.A. MACLAREN, Lawrence Livermore Natl Lab, A.S. MOORE, S. MCArpIN, AWE — We have designed experiments for the Omega laser investigating the growth of perturbations between a Cu foam (density ∼ 1 g/cc) and a carbonized resorcinol formaldehyde (CRF) foam (density ∼ 0.05 g/cc). The interface between the two foams is impulsively accelerated by a 1 ns (7.5 kJ) laser drive in a gold hohlraum (peak T ∼ 185 eV). The growth is seeded by internal structures in the Cu foam that are characterized by x-ray tomography. Because of the strong dependence of viscosity on ionization, the Cu plasma is expected to have a much lower viscosity (and higher Reynolds number) than a comparable experiment with plastic in place of the Cu, and the Cu experiment is predicted to quickly become turbulent. We have simulated this experiment with the radiation-hydrodynamics code LASNEX (integrated hohlraum simulations). Various void structures were then simulated using the codes KULL and MIRANDA to test the effect of differing initial conditions.

9:42AM NO6.00002 Mix Width Measurements of Accelerated Copper Foam. DANIELLE DOANNE, KEVIN BAKER, GAIL GLENDINNING, TOM DITTRICH, SEAN FELKER, STEVE MACLAREN, DAVID MARTINEZ, RICH SEUGLING, LLNL, ALASTAIR MOORE, STUART MCApLIN, AWE, CHUCK SORCE, NICHOLAS WHITING, LLE — We present results from a mix experiment conducted on the Omega laser, using a reduced density copper (Cu) foam, 1 g/cc, was accelerated into a low density material, carbonized resorcinol formaldehyde (CRF) at 50 mg/cc. The Cu foams, which could contain voids as large as 5 to 10 μm, were characterized via x-ray computed tomography. The mixing in the experiment is predicted to rapidly become turbulent. The experiment addresses whether the mix width is determined by the void structure in the foam itself. For these experiments the Omega laser is used to drive a halfraum up to a radiation temperature of ∼ 190 eV using a 1 ns flat top drive with 5 kJ of total laser energy to provide the ablation pressure for the foam. This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344.
10:06AM NO6.00004 Diagnosing Turbulent Shear in HED Experiments on NIF$^1$. K.A. FLIPPO, J.L. KLINE, F.W. DOSS, T.S. PERRY, B. DEVOLDER, T.J. MURPHY, E.C. MERRITT, I.A. TREGILLIS, E.N. LOOMIS, D. SCHMIDT, D. CAPELLE, Los Alamos National Laboratory, S.P. REGAN, U. of Rochester, M.A. BARRIOS, C.M. HUNTINGTON, S.A. MACLAREN, Lawrence Livermore National Laboratory — We report on experiments planned for and performed at the NIF to investigate turbulent mix in and HED regime using a platform scaled from the Omega laser facility. We are investigating turbulence-driven mix from the shear induced Kelvin-Helmholtz instability, like those experienced in an ICF capsule with instabilities present. Two shocks are generated at either end of cylinder, inside CH foams act as a light fluid and the evolution of an Al tracer layer heavy fluid in the center plane is observed using the Big Area Backlighter (BABL), an especially large area backlighter developed for this project. Simulations of the BABL were carried out to optimize spatial profile. Another backlighter, the Long Duration Backlighter (LDBL) a variation of the BABL has also been developed and shot on NIF. The LDBL has been tuned spatially and temporally to emit x-rays in a very flat profile over a 7 ns time frame. Comparison of this data with simulations using the Besnard-Harlow-Rauenzahn (BHR) model is used. BHR is intended for turbulent transport in fluids with large density variations and has the ability to improve our predictive capability of mix in ICF experiments.

$^1$Los Alamos National Laboratory is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396.

10:18AM NO6.00005 Examining the evolution towards turbulence through spatio-temporal analysis of multi-dimensional structures formed by instability growth along a shear layer$^1$. ELIZABETH MERRITT, FORREST DOSS, ERIC LOOMIS, KIRK FLIPPO, BARBARA DEVOLDER, LESLIE WELSER-SHERRILL, JAMES FINCKE, JOHN KLINE, Los Alamos National Laboratory — The counter-propagating shear campaign is examining instability growth and its transition to turbulence relevant to mix in ICF capsules. Experimental platforms on both OMEGA and NIF use anti-symmetric flows about a shear interface to examine isolated Kelvin-Helmholtz instability growth. Measurements of interface (an Al or Ti layer) dynamics are used to benchmark the LANL RAGE hydrocode with BHR turbulence model. The tracer layer does not expand uniformly, but breaks up into multi-dimensional structures that are initially quasi-2D due to the target geometry. We are developing techniques to analyze the multi-D structure growth along the tracer surface with a focus on characterizing the time-dependent structures’ spectrum of scales in order to appraise a transition to turbulence in the system and potentially provide tighter constraints on initialization schemes for the BHR model. To this end, we use a wavelet based analysis to diagnose single-time radiographs of the tracer layer surface (w/ low and amplified roughness for random noise seeding) with observed spatially non-repetitive features, in order to identify spatial and temporal trends in radiographs taken at different times across several experimental shots.

$^1$This work conducted under the auspices of the U.S. Department of Energy by LANL under contract DE-AC52-06NA25396.

10:30AM NO6.00006 Release and recompression measurements of multiple component reservoirs for strength drive experiments on the NIF$^1$. S.T. PRISBREY, H.S. PARK, C.E. WEHRENBERG, C.M. HUNTINGTON, B. MADDOX, R. BENEDETTI, Lawrence Livermore National Laboratory, P. GRAHAM, Atomic Weapons Establishment, T. BAUMAN, M. WILSON, R. RUDD, A. ARSENILIS, B.A. REMINGTON, Lawrence Livermore National Laboratory — The ability to infer strength in materials driven with staged shocks requires the development and accurate measurement of a multiple-shock drive. We have developed such a drive for use in Ta strength experiments up to $\sim 5$ Mbar [1], which utilizes an initial shock which is large enough to theoretically generate dislocations within the Ta itself. Our desire to investigate other materials, which melt at a lower pressure on their principle Hugoniot, along with the desire to have a drive with an initial shock below the homogeneous nucleation threshold of $\sim 660$ kbar [2] has prompted us to design and develop a different $\sim 5$ Mbar drive with a different initial shock. We report here on the proposed design and experimental results achieved at the National Ignition Facility of several of the new components of the drive – specifically the lower density foam layer, an iodinated plastic layer, and an aluminum layer.

$^1$This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344. LLNL-ABS-656841

10:42AM NO6.00007 Developing a 3-shock, low-adiabat drive for high pressure material science experiments on NIF$^1$. C. CHRISTOPHER WEHRENBERG, SHON PRISBREY, Lawrence Livermore National Laboratory, PETER GRAHAM, Atomic Weapons Establishment, HYE-SOOK PARK, CHANNING HUNTINGTON, BRIAN MADDOX, ROBIN BENEDETTI, ROBERT RUDD, TOM ARSENILIS, BRUCE REMINGTON, Lawrence Livermore National Laboratory — We describe a series of experiments for basic materials science on NIF to develop a planar, 3-shock, low-adiabat drive to reach peak pressures of 5 Mbar, while keeping the physics samples well below their melt temperatures. The primary diagnostic is VISAR, which measures the compression waves as they travel through a Ta witness plate. X-ray ablation from an indirect drive launches a strong ($>10$ Mbar) shock through a precision fabricated “reservoir,” consisting of a CH ablator, followed by layers of Al, CH18.75%, 350 mg/cc CRF foam, and a final layer of 10-30 mg/cc foam. This reservoir releases as plasma across a 1.5 mm vacuum gap, then stagnates on the 15 micron thick Ta witness plate, which is backed by a LiF or quartz window. The lowest density reservoir layer sets the strength of the leading shock, which needs to be controlled to keep the physics samples solid, and to control the dislocation density created by this leading shock. We will describe an extensive series of experiments done on NIF to develop this drive.

$^1$S. Prisbrey, P09, 1006311 (2012).

This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344.
10:54AM NO6.00008 Experimental Results of Tantalum Flow Stress at 5 Mbar from NIF

HYE-SOOK PARK, A. ARSENILS, L.R. BENEDETTI, R. CALAVOLO, C.M. HUNTINGTON, B.R. MADDOX, J.M. MCNANEY, S. PRISBREY, R.E. RUDD, S.V. WEBER, C.E. WEHRENBERG, B.A. REMINGTON, LLNL — We present our first experimental results from the NIF laser to test Ta strength models at high pressures (~5 Mbar), high strain rates (~10^7 s^-1) and high strains (>30%). We use 800 kJ of laser energy to create a ramped drive via a 4-layer reservoir - gap configuration. The target package includes sinusoidal Ta surface ripples that are used to infer the plastic flow stress of the sample from a measurement of the Rayleigh-Taylor instability ripple growth. The inferred flow stress is approximately twice greater than predictions by the multiscale strength model. It is conjectured that homogeneous nucleation behind the leading shock at ~1 Mbar promptly generates a very high dislocation density, thus increasing the strength through the work hardening term. It was also observed that larger amplitude ripples grow more than smaller initial amplitude ripples at the same wavelength, suggesting the so-called Drucker effect for solid-state flow due to the Rayleigh-Taylor instability [D. C. Drucker, Mechanics Today, 5, 36 (1980)].

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

11:06AM NO6.00009 Laser Shock-Induced Spalling in Tantalum

TANE REMINGTON, UCSD, CHRISTOPHER WEHRENBERG, BRIAN MADDOX, BRUCE REMINGTON, LLNL, MARC MEYERS, UCSD, LLNL UCSD TEAM — The process of dynamic failure by spalling was established in nano, poly, and mono crystalline tantalum in recovery experiments following laser compression and release. Samples were compressed over a range of pressures between 5-15 GPa. The waves were allowed to reflect at the back surface (specimen thickness ranged from 50-250 μm) and the process of separation was characterized by SEM. Spall strength was measured by the shock breakout and pull back signal using VISAR. The spall strength increases with increasing strain rate and grain size. In the nano and polycrystals, spalling occurred by ductile fracture favoring grain boundaries. In the monocrystals, the process was of ductile failure by void initiation, growth and coalescence. Work performed at the Jupiter Laser Facility (JLF), Lawrence Livermore National Laboratory (LLNL). This research is funded by the UC Research Laboratories Grant (09-LR-06-118456-MEYM) and the National Laser Users Facility (NLUF) Grant (PE-FG52-09NA-29043).

11:18AM NO6.00010 Experimental observation of Rayleigh-Taylor growth as a function of wavelength in the warm dense matter regime

C.M. HUNTINGTON, A. ARSENILS, B.R. MADDOX, H.-S. PARK, S.T. PRISBREY, S.V. WEBER, C.E. WEHRENBERG, B.A. REMINGTON, Lawrence Livermore Natl Lab — “Classical” Rayleigh-Taylor (RT) growth is characterized by a growth rate $\gamma = \sqrt{kg/k_n}$, where $k$ is the wavelength of the unstable mode, $g$ is the acceleration, and the Atwood $A_n$ number characterizes the magnitude of the density jump at the interface. Here we present the results of a set of experiments using face-on x-ray radiography to measure RT growth in a plastic rippled sample. Acceleration of the sample is provided by the stagnation of a releasing shocked plastic “reservoir,” which is directly driven by approximately 1 kJ of laser energy at the OMEGA facility. The growth of pre-imposed ripples is recorded using transmission x-ray radiography of a vanadium He source, where the opacity of the sample is calibrated to the ripple amplitude. We report the results of experiments at 30 μm and 60 μm initial wavelengths, and compare the data to 2D hydrodynamic simulations.

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

11:30AM NO6.00011 Numerical study of shock-driven cavity collapse using the front tracking method

BRETT TULLY, NICHOLAS HAWKER, First Light Fusion Ltd, MATTHEW BETNEY, University of Oxford, YIANNIS VENTIKOS, University College London — The front tracking method, including a tabular equation of state framework, has been previously used by the authors to numerically study the conditions generated during shock-driven cavity collapse. The dominant dynamics involve the formation of a high-speed transverse jet and the subsequent impact of this jet on the leeward bubble wall. The process of jet formation can be interpreted via the same driving mechanism as Richtmyer-Meshkov instability; the reflection of the shockwave causes a focusing of the flow. During impact a small amount of gas in the cavity is trapped against the leeward wall and is strongly compressed and heated. This jet impact also produces a strong point source shockwave which propagates outwards, further collapsing the now toroidal cavity. The collapse of the torus corresponds to minimum volume. There are thus two key moments during the collapse where the cavity contents form an inertially confined plasma: first jet impact and second toroidal minimum volume. The present paper elucidates these dynamics with numerical simulations and demonstrates a preliminary comparison to experiments. Basic metrics such as the first phase collapse time are compared, with good agreement.

11:42AM NO6.00012 Experimental study of shock-driven cavity collapse with a single-stage gas gun driver

PHILLIP ANDERSON, MATTHEW BETNEY, University of Oxford, HUGO DOYLE, NICHOLAS HAWKER, First Light Fusion Ltd., RONALD ROY, University of Oxford — This paper explores experimental studies of shock-driven cavity collapse using a single-stage gas gun. Shocks of up to 1 GPa are generated in a hydrogel with the impact of a planar-faced projectile (50 mm dia.). Within the hydrogel, a pre-formed cavity (5 mm dia.) is cast, which is collapsed by the interaction with the shockwave. The basic collapse process involves the formation of a high-speed transverse jet and then a second collapse phase driven from jet impact. Single-shot multi-frame schlieren imaging is used to show the position and timing of optical emission in relation to the collapse hydrodynamics. Further, temporally and spectrally-resolved measurements of the optical emission are made through simultaneous use of multiple band-passed PMTs and an integrating spectrometer. This reveals three distinct pulses of emission possessing different frequency content. The first corresponds to the trapping of gas during jet impact; the second and third correspond to the further inertial collapse of the now toroidal cavity. Plasma models are used to provide the first indication of the temperature of these inertially confined plasmas.

11:54AM NO6.00013 Experimental and numerical study of shock-driven collapse of multiple cavity arrays

MATTHEW BETNEY, PHILLIP ANDERSON, University of Oxford, BRET TULLY, HUGO DOYLE, NICHOLAS HAWKER, First Light Fusion Ltd., YIANNIS VENTIKOS, University College London — This study presents a numerical and experimental investigation of the interaction of a single shock wave with multiple air-filled spherical cavities. The 5 mm diameter cavities are cast in a hydrogel, and collapsed by a shock wave generated by the impact of a projectile fired from a single-stage light-gas gun. Incident shock pressures of up to 1 GPa have been measured, and the results compared to simulations conducted using a front-tracking approach. The authors have previously studied the collapse dynamics of a single cavity. An important process is the formation of a high-speed transverse jet, which impacts the leeward cavity wall and produces a shockwave. The speed of this shock has been measured using schlieren imaging, and the density has been measured with a fibre optic probe. This confirmed the computational prediction that the produced shock is of a higher pressure than the original incident shock. When employing multiple cavity arrays, the strong shock produced by the collapse of one cavity can substantially affect the collapse of further cavities. With control over cavity placement, these effects may be utilised to intensify collapse. This intensification is experimentally measured via analysis of the optical emission.
12:06PM NO6.00014 Direct Shock-Timing Measurements in CH Using Streaked X-Ray Radiography — P.M. NISON, M. LAFON, C.R. STILLMAN, C. MILEHAM, R. BONI, T.R. BOEHLY, D.H. FROULA, D.D. MEYERHOFER, Laboratory for Laser Energetics, U. of Rochester — One-dimensional streaked x-ray radiography is used to measure shock coalescence in multishocked plastic. A two-shock system was generated using a ramped drive on the OMEGA EP Laser System. The data show the first shock wave propagating into solid material, followed 2 ns later by the second shock wave. The measured shock trajectories were used to track the system dynamics and determine the shock-coalescence times for different initial shock strengths. The measured shock timings are compared to radiation-hydrodynamic model predictions. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

12:18PM NO6.00015 Use of Laser-Generated Ion Beams for Isochoric Heating to Study Plasma-Phase Mix at Heterogeneous Interfaces1 — J.D. COLVIN, F. PÉREZ, K.B. FOURNIER, M.J. MAY, S.A. GAMMON, K.B. FOURNIER, Lawrence Livermore National Laboratory — A high-energy laser (several kJ, 1015 W/cm2) can propagate inside an underdense plasma over millimeters, along its associated heat front. This creates a large volume of hot plasma (several keV) able to produce bright hard-x-ray sources when a high-Z dopant is included in the material. In the past years, we investigated the behavior of both gases and foams under these circumstances. Their design and predictability relies on the understanding of the heat front propagation. In the case of foams, several studies tried to assess the effect of their micro-structure in altering the laser interaction and the heat front propagation, but no experimental data has shown clear evidence. We present here the design and results of a recent experiment, using the OMEGA laser, where a Ge-doped silica foam was compared to a Ne/Kr gas of very similar characteristics, the only difference between these two materials being their micro-structure to allow for a straightforward determination of its influence. Recent experiments at the LANL Trident laser facility have used laser-generated aluminum ion beams created under conditions of relativistic induced transparency to heat solid-density, multi-material targets isochronically to temperatures of several eV and observations have been made of the subsequent evolution of the plasma media. Experiments such as these present a new path for the controlled preparation and study of high energy density physics and warm dense matter. This presentation will discuss recent results from these experiments, including supporting radiation-hydrodynamics and kinetic simulations and theory.

1Work performed under the auspices of the U.S. DOE by the LANS, LLC, Los Alamos National Laboratory under Contract No. DE-AC52-06NA25396. Funding provided by LDRD.

Wednesday, October 29, 2014 9:30AM - 12:30PM – Session NO7 Laser-driven X-ray Sources and Diagnostic Techniques Galerie 6 - Riccardo Tommasini, Lawrence Livermore National Laboratory

9:30AM NO7.00001 Laser-driven heat-front propagation in foam vs. gas1 — F. PÉREZ, J.D. COLVIN, M.J. MAY, S.A. GAMMON, K.B. FOURNIER, Lawrence Livermore National Laboratory — A high-energy laser (several kJ, 1015 W/cm2) can propagate inside an underdense plasma over millimeters, along its associated heat front. This creates a large volume of hot plasma (several keV) able to produce bright hard-x-ray sources when a high-Z dopant is included in the material. In the past years, we investigated the behavior of both gases and foams under these circumstances. Their design and predictability relies on the understanding of the heat front propagation. In the case of foams, several studies tried to assess the effect of their micro-structure in altering the laser interaction and the heat front propagation, but no experimental data has shown clear evidence. We present here the design and results of a recent experiment, using the OMEGA laser, where a Ge-doped silica foam was compared to a Ne/Kr gas of very similar characteristics, the only difference between these two materials being their micro-structure to allow for a straightforward determination of its influence. Recent experiments at the LANL Trident laser facility have used laser-generated aluminum ion beams created under conditions of relativistic induced transparency to heat solid-density, multi-material targets isochronically to temperatures of several eV and observations have been made of the subsequent evolution of the plasma media. Experiments such as these present a new path for the controlled preparation and study of high energy density physics and warm dense matter. This presentation will discuss recent results from these experiments, including supporting radiation-hydrodynamics and kinetic simulations and theory.

1This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract No. DE-AC52-07NA27344.

9:42AM NO7.00002 Does laser-driven heat front propagation depend on material microstructure?1 — J.D. COLVIN, F. PÉREZ, K.B. FOURNIER, M.J. MAY, LLNL, T.E. FELTER, SNL-CA, M. BAGGE-HANSEN, S. KUCHYEY, LLNL — We showed earlier that the laser-driven heat front propagation velocity in low-density Ti-silica aerogel and TiO2 foam targets was slower than that simulated with a 2D radiation-hydrodynamics code incorporating an atomic kinetics model in non-LTE and assuming initially homogeneous material (F. Pérez, et al., Physics of Plasmas 21, 023102, 2014). Some theoretical models suggest that the heat front is slowed over what it would be in a homogeneous medium by the microstructure of the foam. In more recent experiments with Cu-loaded carbon nanotube foam, however, we find the opposite behavior; that is, the simulations under-predict the measured heat-front velocity. We present details of the Cu foam experiments and comparisons with simulations, and then discuss implications for models of heat-front slowing in foams of a more-recent gas vs. foam comparison experiment. F. Pérez presents the design and results of this comparison experiment in a companion presentation.

1This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract No. DE-AC52-07NA27344, with partial support from a DTRA Basic Research grant.

9:54AM NO7.00003 Simulation study of optimizing the 3-5 keV x-ray emission from pure Ar K-shell vs. Ag L-shell targets on the National Ignition Facility1 — G.E. KEMP, J.D. COLVIN, K.B. FOURNIER, M.V. PATEL, H.A. SCOTT, M. MARINAK, LLNL, J.H. FISHER, Fifth Gait Technologies, Inc., J.F. DAVIS, Alme and Associates — High-flux x-ray sources are desirable for testing the radiation hardness of materials used in various civilian, space and military applications. For this study, there is an interest to design a source with primarily mid-energy (∼3 keV) but limited soft (∼1 keV) x-ray contributions; we focus on optimizing the 3–5 keV non-LTE emission from targets consisting of pure Ar (K-shell) or Ag (L-shell) at sub-critical densities (∼n_s/10) to ensure supersonic, volumetric laser heating with minimal losses to kinetic energy and thermal x rays. However, K and L-shell sources are expected to optimize at different temperatures and densities and it is a priori unclear under what target and laser conditions this will occur. Using HYDRA, a multi-dimensional, arbitrary Lagrangian-Eulerian, radiation-hydrodynamics code, we performed a simulation study by varying initial target density and laser parameters for each material as it would perform on the National Ignition Facility (NIF). We employ a model, benchmarked against Kr data collected on the NIF, that uses flux-limited Lee-More thermal conductivity and implicit Monte-Carlo photonics with non-LTE, detailed configuration accounting opacities from CRETIN.

1This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.
10:06AM NO7.00004 Development and Characterization of a 16.3 keV X-Ray Source at the National Ignition Facility. K.B. FOURNIER, M.A. BARRIOS, M.B. SCHNEIDER, S. KHAN, H. CHEN, F. C. COPPARI, R. RYGG, M. Hohenberger, F. ALBERT, J. MOODY, J. RALPH, G.E. KEMP, Lawrence Livermore National Laboratory, S.P. REGAN, Laboratory for Laser Energetics — X-ray sources at the National Ignition Facility are needed for radiography of in-flight capsules in inertial confinement fusion experiments and for diffraction studies of materials at high pressures. In the former case, we want to optimize signal to noise and signal over background ratios for the radiograph, in the latter case, we want to minimize high-energy emission from the backlighter that creates background on the diffraction data. Four interleaved shots at NIF were taken in one day, with laser irradiances on a 2r backlighter target ranging from 5 to 14 x 10^12 W/cm². Two shots were for source optimization as a function of laser irradiance, X-ray fluxes were measured with the time-resolved NIF X-ray Spectrometer (NXS) and the DANTE array of calibrated, filtered diodes. Two shots were optimized to make backscatter measurements with the FABS and NBI optical power systems. The backscatter levels are investigated to look for correlation with hot electron populations inferred from high-energy x rays measured with the FFLEX broadband spectrometer. Results from all shots are presented and compared with models. Work performed under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344.

10:18AM NO7.00005 Diagnosing Te of NiF plasmas using the isoelectronic ratios of microdot tracer elements. M.A. BARRIOS, LLNL, S.P. REGAN, LLE, K.B. FOURNIER, M.B. SCHNEIDER, D.A. LIEDEHL, G.E. KEMP, J.D. MOODY, G.V. BROWN, H. CHEN, O. LANDEN, D. BRADLEY, O. JONES, LLNL, R. EPSTEIN, LLE, LLNL COLLABORATION, LLE COLLABORATION — Experiments planned on NIF will diagnose the electron temperature (Te) of the hohlraum in the vicinity of the laser entrance hole (LEH) using x-ray spectroscopy. A microdot consisting of Ti and Cr will be coated on the surface of a CH implosion capsule and centered on the symmetry axis of the hohlraum. As the microdot is ablated it is ionized by the hohlraum plasma and flows into the LEH region. The experimental plan to use the isoelectronic line ratio technique [R.S. Majoribanks, et al. Phys. Rev. A 46(4), 1992.] to diagnose Te of the hohlraum plasma near the LEH will be presented. Exploratory experiments at NIF tested the Te sensitivity of the technique by recording time resolved K-shell emission of direct-drive spherical targets coated with a CrNiZn alloy. Application of the isoelectronic technique to the coronal plasma of these targets will be presented. This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344.

10:30AM NO7.00006 Development of backlit thin shells and foam balls on the NIF for diagnosing shape swings during the foot pulse. GARETH HALL, PETER AMENDT, OTTO LANDEN, ANDREA KRITCHER, DAVID BRADLEY, RICHARD TOWN, Lawrence Livermore National Laboratory — The performance of indirect-drive ICF capsules is extremely sensitive to low-mode P2 and P4 asymmetries during the foot of the pulse, the trough in particular. These asymmetries can cause non-radial velocity and density distortions that cannot be corrected later in the implosion, significantly degrading fusion yield. X-ray radiography of thin-shell capsules [1] and foamballs [2] has been demonstrated as a means of diagnosing foot asymmetries on the OMEGA and NOVA lasers. The design and implementation of these techniques for upcoming experiments on the NIF will be discussed. In these experiments, the target will be driven using only a picet and trough pulse, and x-ray radiography used to measure asymmetries that develop during implosion. (IM: LLNL-ABS-657009)

1 This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344.


10:42AM NO7.00007 Experiments on OMEGA EP to study the material dependence of the two-plasmon decay instability. J.R. FEIN, P.A. KEITER, D.H. FROULA, University of Michigan, D.H. Edgell, University of Rochester, Laboratory of Laser Energetics, P.X. BELANCOURT, J.P. HOLLOWAY, R.P. DRAKE, University of Michigan — For long-scale-length plasmas, two-plasmon decay (TPD) is a major LPI responsible for generating hot electrons (>10 keV). Hot electrons can present unintended effects, such as preheating the target and producing hard x-ray background that can interfere with diagnostics. Understanding hot electron production in laser-produced plasmas is important to control and mitigate these effects. TPD growth is limited by plasma collisionality hydrodynamics, which depend on plasma material Z. It has been predicted and demonstrated by preliminary experiments that hot electron production can be mitigated through varying these parameters, by increasing plasma Z [1,2]. We have performed experiments on OMEGA EP to thoroughly study the Z-dependence of the TPD instability, through varying the material with which the lasers interact. Hard x-ray diagnostics were used to measure hot electron production and optical diagnostics were used to measure the plasma density profile for each material. Preliminary results will be presented, showing how hot electron production and electron density scale lengths scale with Z.


1 This work was funded by the NNSADS and SCOFES Joint Program in HED Laboratory Plasmas, grant number DEAN0001840, the NLUP Program, grant number DE-NA0000850, by the DTRA, grant number DTRA1100077 and by the NSF Graduate Research Fellowship.

10:54AM NO7.00008 Testing Talbot–Lau X-Ray Moiré Fringe Deflectometry with a Laser Backlighter. D. STUTMAN, M.P. VALDIVIA, M. FINKENTHAL, Johns Hopkins University, S.P. REGAN, C. STOECKL, Laboratory for Laser Energetics, U. of Rochester, B. STOECKL, Monroe Community College, Rochester NY — Moiré fringe deflectometry is a simple and robust density diagnostic method, based on light refraction caused by electron density gradients. The Talbot-Lau (TL) grating interferometer could make it possible to apply this method for density diagnostics in high-energy-density plasmas using hard x rays from conventional backlighters. When compared to conventional radiography, the TL interferometer offers more sensitivity to refraction and is therefore less dependent on modeling. We adapted the TL interferometer to the high-energy-density-physics requirements by extending its operation to high magnification, 8 to 17 keV x-ray energy, and single-shot phase retrieval. The next step of development is to test its operation close to a high power laser backlighter. We designed an experiment on the Multi-Terawatt laser aimed at studying grating survival as a means of diagnosing foot asymmetries on the OMEGA and NOVA lasers. The design and implementation of these techniques for upcoming experiments on the NIF will be discussed. In these experiments, the target will be driven using only a picet and trough pulse, and x-ray radiography used to measure asymmetries that develop during implosion. (IM: LLNL-ABS-657009)

1 Work supported by DoE Awards DE-NA0001B35 and DE-NA0001944.

11:06AM NO7.00009 Measurements of the betatron spectrum around the Kedge of thin foils. KEEGAN BEHM, TONY ZHAO, University of Michigan, JONATHON WOODS, JASON COLE, Imperial College of London, ANATOLY MAKSIMCHUK, VICTOR YANOVA, ALEXANDER THOMAS, KARI KRUSHELNICK, University of Michigan, STUART MANGLES, Imperial College of London, CENTER FOR ULTRAFAST OPTICS TEAM, IMPERIAL COLLEGE OF LONDON TEAM — Presented here are single shot and integrated X-ray spectroscopy measurements of the betatron radiation spectrum produced from a laser wakefield accelerator (LWFA) using both single photon counting and different crystals. We measure critical energy and total flux of the betatron spectrum for various parameters in addition to absorption of the spectrum around the Kedge of different thin metal foils with high spectral resolution using curved and flat HOPG and Mica crystals.
11:18AM NO7.00010 Demonstration of x-ray fluorescence imaging to diagnose high-energy-density plasmas, M.J. MACDONALD, P.A. KEITER, University of Michigan, D.S. MONTGOMERY, Los Alamos National Lab, M.M. BIENER, Lawrence Livermore National Lab, J.R. FEIN, University of Michigan, K.B. FOURNIER, Lawrence Livermore National Lab, E.J. GAMBOA, SLAC National Accelerator Lab, S.R. KLEIN, C.C. KURANZ, H.J. LEFEVRE, M.J.-E. MANUEL, University of Michigan, J. STREIT, Schafer Corporation, W.C. WAN, R.P. DRAKE, University of Michigan — X-ray diagnostic techniques are used to diagnose high-energy-density experiments. Radiography is used to create 2D images of plasma density using the relative transmission of the source x-rays, but the path-integrated nature of this process limits its usefulness when diagnosing large-volume or geometrically-complex targets. A technique capable of measuring local conditions is required to characterize plasmas in these geometries. Here we describe an x-ray fluorescence imaging (XRFI) diagnostic that uses a collimated probe beam to sample a small portion of the system [1]. The x-ray fluorescence induced in the probed region was used to calculate material density, shock velocity, and temperature simultaneously using an imaging x-ray spectrometer. Data from recent experiments performed at the Trident laser facility at Los Alamos National Lab will be presented. *This work is funded by the NNSA-DS and SC-OFES Joint Program in HED Laboratory Plasmas, grant number DE-NA0001840 and supported by the NSF GRFP Grant No. 2013155705.

11:30AM NO7.00011 Experimental Generation of Backward-Propagating MeV Electrons in Ultra-Intense Laser Interactions, SCOTT FEISTER, Ohio State Univ. / Innovative Scientific Solutions, Inc. (ISSI), JOHN T. MORRISON, Fellow, National Research Council, USA, VLADIMIR M. OVCHINNIKOV, KYLE D. FRISCHIE, ISSI, JOHN A. NEES, Univ. of Michigan / ISSI, CHRIS ORBAN, Ohio State Univ. / ISSI, ENAM A. CHOWDHURY, Ohio State Univ. / Intense Energy Solutions, LLC., W. MELVYN ROQUEMORE, Air Force Research Laboratory, Dayton, USA — Electron beams with peak energies exceeding 1 MeV have been produced with kHz repetition by the interaction of normally-incident, intensely-focused (10^18 W/cm^2), 30 fs duration laser pulses with water-jet targets. A high-charge electron beam has been produced in the direction opposite laser propagation. Through interaction with aluminum in the parabolic focusing optic, this backward-going beam creates a ~ 1 rem/hr secondary X-ray source with ~ 800 keV peak spectral power density. A standing wave acceleration mechanism, originally identified for its relevance to forward-going electrons, acts to inject electrons into the reflected light where additional acceleration occurs. Experimental X-ray yield is drastically reduced when laser pre-pulse at nanosecond level is suppressed, which is corroborated by simulations showing similar reduction in accelerated electron energies and quantity in the absence of pre-plasma scale length.

11:42AM NO7.00012 Compact tunable Compton x-ray source from laser wakefield accelerator and plasma mirror, HAI-EN TSAI, XIAOMING WANG, JOSEPH SHAW, ZHENGYAN LI, RAFAL ZGADZAJ, ALEX AREFIEV, MIKE DOWNER, Univ of Texas, Austin, INSTITUTE FOR FUSION STUDIES, UNIVERSITY OF TEXAS AT AUSTIN TEAM — Compton backscatter (CBS) x-rays have been generated from laser wakefield accelerator (LWFA) electron beams by retro-reflecting the LWFA drive pulse with a plasma mirror (PM) [1] and by backscattering a secondary pulse split from the driver pulse [2]. However, tunable quasi-monoenergetic CBS x-rays have been produced only by the latter method, which requires challenging alignment. Here we demonstrate quasi-monoenergetic (~50% FWHM), bright (5 x 10^6 photon per shot) CBS x-rays with central energy tunability from 75 KeV to 200 KeV by combining a PM with a tunable LWFA. 30 TW, 30-fs (FWHM), laser pulses from the UF3 laser system were focused (f/12) to spot diameter 11 micron, intensity ~ 6x10^18 W/cm^2 (a=1.5) at a 1-mm long Helium gas jet, yielding quasi-monoenergetic relativistic electrons. A thin plastic film near the gas jet exit efficiently retro-reflected the LWFA driving pulse into oncoming electrons to produce CBS x-rays without detecting bremsstrahlung background. By changing gas jet backing pressure, electron energy was tuned from 60 to 90 MeV, thereby tuning the CBS x-ray energy, which was determined by measuring transmission through a metal filter pack. The x-ray beam profiles recorded on an image plate had 5-10-mrad divergence.

12:06PM NO7.00014 Experimental results from NIF radiography shots on HDC ablator capsules with and without Tungsten dopant, SHAHAB KHAN, NIKO IZUMI, PRAVESH PATEL, ANDREW MACPHEE, TAMMY MA, CHARLIE CERJAN, RICHARD TOWN, DAVID BRADLEY, Lawrence Livermore National Laboratory — The electron temperature (T_e) of the hot spot within the core of imploded inertial confinement fusion capsules is an effective indicator of implosion performance. A temporally resolved measurement of T_e helps elucidate the mechanisms for hot spot heating and cooling such as alpha-heating and mix. Additionally, comparison with simulations will aid in tuning models to effectively predict implosion performance. The Streaked Polar Instrumentation for Diagnosing Emerging Radiation (SPIIDER) is an x-ray streak camera designed to record the x-ray burn history during the stagnation phase. SPIIDER accurately reports bang time and burn duration of implosions on the National Ignition Facility (NIF). The addition of several filters of specific materials and thicknesses spread across the spatial axis of the streak camera imager allows for a least square fit of the signal through these filters to a bremsstrahlung hot spot model. The fitted parameters of the model are the T_e, opacity, and X-ray yield which is valuable for ablator mix estimates. The details of this calculation and results from several shots on NIF are presented.
12:18PM NO7.00015 Analysis of X-ray Spectra of High-Z Elements obtained on Nike with high spectral and spatial resolution. YEFIM AGILITSKIY, Leidos, Reston, VA, J.L. WEAVER, M. KARASIK, V. SERLIN, S.P. OBENSCHAHN, Plasma Physics Division, Naval Research Laboratory, Washington, DC. Yu. RALCHENKO, NIST, Gaithersburg, MD. — The spectra of multi-charged ions of Hf, Ta, W, Pt, Au and Bi have been studied on Nike krypton-fluoride laser facility with the help of two kinds of X-ray spectrometers. First, survey instrument covering a spectral range from 0.5 to 19.5 angstroms which allows simultaneous observation of both M- and N- spectra of above mentioned elements with high spectral resolution. Second, an imaging spectrometer with interchangeable spherically bent Quartz crystals that added higher efficiency, higher spectral resolution and high spatial resolution to the qualities of the former one. Multiple spectral lines with X-ray energies as high as 4 keV that belong to the isoelectronic sequences of Fe, Co, Ni, Cu and Zn were identified with the help of NOMAD package developed by Dr. Yu. Ralchenko and colleagues. In our continuous effort to support DOE-NNSA’s inertial fusion program, this campaign covered a wide range of plasma conditions that result in production of relatively energetic X-rays.

1Work supported by the US DOE/NNSA.

9:30AM - 9:30AM —
Session NP8 Poster Session V: DIII-D/Diagnostics; Measurement and Diagnostic Techniques; Low Temperature Plasmas; Production, Ionization Kinetics and Sheaths; Van Allen 100; LPI Short Pulse and Beams — Preservation Hall -
NP8.00001 DIII-D: DIAGNOSTICS —

NP8.00002 DIII-D Upgrade to Prepare the Basis for Steady-State Burning Plasmas. R.J. BUTTERY, H.Y. GUO, T.S. TAYLOR, M.R. WADE, General Atomics, D.N. HILL, Lawrence Livermore National Laboratory. — Future steady-state burning plasma facilities will access new physics regimes and modes of plasma behavior. It is vital to prepare for this both experimentally using existing facilities, and theoretically in order to develop the tools to project and to optimize these devices. An upgrade to DIII-D is proposed to address the three critical aspects where research must go beyond what we can do now: (i) torque free electron heating to address the energy, particle and momentum transport mechanisms of burning plasmas using electron cyclotron (EC) heating and full power balanced neutral beams; (ii) off-axis heating and current drive to develop the path to true fusion steady state by reorienting neutral beams and deploying EC and helicon current drive; (iii) a new divertor with hot walls and reactor relevant materials to develop the basis for benign detached divertor operation compatible with wall materials and a high performance fusion core. These elements with modest incremental cost and enacted as a user facility for the whole US program will enable the US to lead on ITER and take a decision to proceed with a Fusion Nuclear Science Facility.

1Work supported by the US Department of Energy under DE-FC02-04ER54698 and DE-AC52-07NA27344.

NP8.00003 Achieving Steady-State Conditions in the High-Beta Hybrid Scenarios in DIII-D C.C. PETTY, T.C. LUCE, J.R. FERRON, A.M. GAROFALO, A.W. HYATT, G.L. JACKSON, GA, F. TURCO, Columbia U., C.T. HOLCOMB, LLNL, E.J. DOYLE, UCLA. — The natural attributes of the hybrid scenario, especially the anomalously broad current profile, with \( q_{\text{in}} \gtrsim 1 \), allows steady-state conditions with zero surface loop voltage to be achieved at 1 MA plasma current in DIII-D. Using efficient central current drive, the surface loop voltage is driven down to zero for \( \tau_{\text{R}} > 1 \) with ~50% bootstrap current fraction when \( \beta_p \) is increased above 1.9. Interestingly, good alignment between the current drive and plasma current profiles is not necessary as the hybrid regime self-organizes the current density profile. Steady-state hybrid plasmas can achieve \( \beta_N = 3.6 \) for the full duration of the NB pulse (\( \tau_{\text{NB}} > 1 \)) without exciting the m/n=2/1 tearing mode, corresponding to \( \beta_I \) up to 3.4%. The thermal energy confinement time is excellent, with confinement factors up to \( H_{\text{BG}} = 1.6 \) even during strong EC heating. A 0-D physics model demonstrates that attractive scenarios with \( Q_{\text{fus}} = 3.5-3.8 \) exit for steady-state operation in ITER and FNSF.

1Work supported in part by the US DOE under DE-FC02-04ER54698, DE-FG02-04ER54761, DE-AC52-07NA27344, and DE-FG02-08ER54984.

NP8.00004 ITER Steady-State Demonstration on DIII-D J.M. PARK, M. MURAKAMI, A. SONTAG, S.J. DIEM, Oak Ridge National Laboratory, C.T. HOLCOMB, Lawrence Livermore National Laboratory, J.R. FERRON, T.C. LUCE, General Atomics, DIII-D TEAM. — A systematic scan of \( q_{\text{PS}} \approx 4.5, 5.5, 6.5 \) at constant \( \beta_N \approx 3 \) and high \( q_{\text{in}} \approx 1.8-2.1 \) has been obtained in a lower single null ITER-like shape to study confinement, stability and edge pedestal characteristics using off-axis neutral beam current drive for the ITER steady-state mission. A 2/1 tearing mode \( f_{\text{NL}} = 1, \Omega = 0 \) and the additional pedestal height is found substantially lower than in similar 2008 experiments, resulting in lower \( f_{\text{NL}} \) due to reduced edge pedestal bootstrap current. Toroidal Alfven Eigenmode power fluctuation is well correlated with the estimated beam ion diffusion (\( D_{\text{B}} \)). Strong dependency of \( D_0 \) on \( q_{\text{PS}}, q_{\text{in}} \) and neutral beam power (\( P_{\text{NB}} \)) has been found indicating that lower \( q_{\text{PS}} \approx 4.5 \) would have reasonably good beam ion confinement (\( D_0 \geq 0.3 \text{m}^2/\text{s} \)) even at \( q_{\text{in}} > 2 \) and high PNB=12 MW. The calculated ideal \( \beta_N \) stability limit increases with lower \( q_{\text{PS}} \), allowing access to high \( \beta_N \approx 3.5 \) needed for \( \beta_{\text{NJ}} = 1 \) and \( Q = 5 \). This study shows that optimum choice of \( q_{\text{PS}} \approx 5.5 \) and \( q_{\text{in}} > 2 \) is crucial to achieving \( Q = 5 \) steady-state mission for ITER.

1Work supported by the US Department of Energy under DE-AC05-00OR22725, DE-AC52-07NA27344 and DE-FC02-04ER54698.

NP8.00005 Analysis of Ideal Stability Limits in DIII-D Discharges with High \( \beta_N \) and \( l_i \) J.R. FERRON, T.C. LUCE, General Atomics, C.T. HOLCOMB, LLNL, J.M. PARK, ORNL, W.M. SOLOMON, PPPL. — Broad pressure profiles in DIII-D discharges with high \( l_i \) enable stable access to high plasma pressure. As \( \beta_N \) increases, the pressure peaking factor \( f_p = P(0)/(P) \) decreases from \( f_p \approx 3.7 \) at \( \beta_N \approx 2.9 \) to \( f_p \approx 2.4 \) at \( \beta_N > 4.5 \). Simultaneously, the ideal low-n stability limits calculated with a conducting wall increase from \( \beta_N \approx 3.6 \) to nearly 6, so that \( \beta_N \) remains below the limit. In addition, \( f_p \) decreases as \( l_i \) is increased. Thus, the high \( \beta_N \) stability limits result from both increased \( l_i \) and decreased \( f_p \). In a steady-state discharge, though, increased \( \beta_N \) limit with the practical value of \( l_i \) because of the increase in the bootstrap current density, particularly in the H-mode pedestal. Reducing the pedestal pressure with an n=3 magnetic perturbation increases \( l_i \) but also increases \( f_p \) so there is no net increase in the \( \beta_N \) limit. A change in the discharge shape to reduce the pedestal pressure, to the single-null diverter ITER shape from a double-null, results in an \( \approx 15\% \) drop in the \( \beta_N \) limit.

1Work supported by the US DOE under DE-FC02-04ER54698, DE-AC52-07NA27344, DE-AC05-00OR22725 and DE-AC02-09CH11466.
NP8.00006 Edge Modeling of DIII-D Steady-State Discharges1,  A.C. SONTAG, J.M. CANIK, L.W. OWEN, M. MURAKAMI, J.M. PARK, Oak Ridge National Laboratory — A 25% drop in the electron pressure at normalized minor radius of 0.8 corresponding to a 20% drop in the total pressure has been observed when comparing steady-state ITER demonstration discharges on DIII-D performed in 2013 to those performed in 2008. This drop significantly degrades fusion gain in integrated modeling simulations of ITER that scale the experimental DIII-D pedestal profiles to use as a boundary condition. Several differences in these discharges are being examined to determine the cause of this drop in pedestal pressure. Disparities in plasma shape could affect peeling/ballooning stability, and moving the outer strike point closer to the divertor cryopump duct for better particle control leads to a change in fueling. The toroidal field direction was also reversed between the two cases, in order to achieve better off-axis neutral beam current drive in the 2013 discharges; this changes the $\nabla B$ drift direction away from the X-point and reverses the $E \times B$ drift direction. EPED modeling will be used to examine differences in the MHD stability that could affect the pedestal pressure, and SOLPS is used in interpretive mode to look at the effects of changing drift directions and particle fueling.

1Work supported by the US DOE under DE-AC02-05ER22725.

NP8.00007 Core Turbulence and Transport Response to Increasing Toroidal Rotation and Shear in Advanced-Inductive Plasmas1,  G. MCKEE, Z. YAN, U. Wisc., C. HOLLAND, UCSD, T. LUCE, C. PETTY, GA, T. RHODES, L. SCHMITZ, UCLA, W. SOLOMON, PPPL — Multi-scale turbulence properties are altered as core toroidal rotation and $E \times B$ shear rates are systematically varied in relatively high-beta, advanced-inductive H-mode plasmas on DIII-D. The energy confinement time increases by 50% as the toroidal rotation is increased by a factor of 2.5 (to $\Omega_0=0.5$), while core turbulence, measured with BES, DBS and PCI, decreases in dimensionless matched plasmas ($\beta \approx 2.7, \eta_{q1}=5.1$). Low-wavenumber ($k_{\perp, p1}$) density fluctuations obtained with BES near mid-radius exhibit significant amplitude reduction along with a slight reduction in radial correlation length at higher rotation, while fluctuations in the outer region of the plasma, $\rho > 0.6$, exhibit, but little change in amplitude. Fluctuation measurements and transport behavior will be quantitatively compared with nonlinear simulations. The resulting reduction in confinement will need to be ascertained for low-rotation plasmas such as ITER and NIF/SFS.

1Work supported by the US DOE under DE-FG02-08ER54999, DE-FG02-07ER54917, DE-FG02-04ER54698, DE-FG02-08ER54984 and DE-AC02-09CH11466.

NP8.00008 Effect of ECH on Turbulent Fluctuations During ITER Baseline Scenario-like Discharges on DIII-D1,  A. MARINONI, J.C. ROST, M. PORKOLAB, E.M. DAVIS, Massachusetts Institute of Technology, R.I. PINSKER, K.H. BURRELL, General Atomics, DIII-D TEAM — Recent experiments on the DIII-D tokamak simulating ITER Baseline Scenario discharges have shown a strong increase in the intensity of low frequency fluctuations during intense electron cyclotron heating (ECH) phases [1]. The torque-free and spatially localized pure electron heating, compared to beam heating, is believed to modify flow shear and fluctuations, resulting in a slightly weaker dependence of stored energy on input power compared to the nominal ITER IPB 98(y,2) scaling. Within 30 ms after turning off ECH power, the phase contrast imaging (PCI) diagnostic detects an increase of the intensity of fluctuations at frequencies higher than 200 kHz, likely due to the prompt response of the electron temperature profile. Fluctuations at lower frequency decrease in intensity on a longer time scale, after other equilibrium quantities evolve. Nonlinear gyro-kinetic simulations are in progress and will be compared to PCI measurements via a synthetic diagnostic.


NP8.00009 Comparison of linear gyrokinetic and two-fluid stability analyses of DIII-D L-mode plasmas1,  C. HOLLAND, E.M. BASS, Center for Energy Research, University of California, San Diego — We present results from a linear stability study of the edge and near-edge regions of well-studied DIII-D tokamak L-mode discharges, using both the gyrokinetic-Maxwell equations (as implemented in the gyro code) and a range of two-fluid models implemented in the BOUT++ code. The goal is to identify instabilities that may help explain the well-known systematic under-prediction of near-edge DIII-D transport and fluctuation levels by some gyrokinetic codes, in particular those driven by edge physics not included within the gyrokinetic models. We first compare local and global gyrokinetic stability results spanning the region of $0.7 < \psi_{N} < 0.95$ to corresponding predictions from Braginski-like models implemented in BOUT++, focusing on the influence of magnetic shaping and collisionality scalings for a range of low- to moderate-$n$ modes, consistent with the observed discrepancies in fluctuation spectra. The closed-field line results are then compared against equivalent results that extend across the separatrix to the open field line region $0.7 < \psi_{N} < 1.05$, in order to assess whether inclusion of this region leads to any significant changes in linear stability. Progress on extending the linear analysis to inclusion of rotational and gyrofluid effects will also be reported.

NP8.00010 Study of the L-Mode tokamak plasma “shortfall” with local and global nonlinear gyrokinetic $\delta f$ simulation1,  JUGAL CHOWDHURY, WEIGANG WAN, YANG CHEN, SCOTT E. PARKER, University of Colorado, Boulder, Colorado 80309, USA, RICHARD J. GROEBNER, General Atomics, Post Office Box 85068, San Diego, California 92186, USA, CHRISTOPHER HOLLAND, University of California-San Diego, La Jolla, California 92093, USA, N.T. HOWARD, Oak Ridge Institute for Science and Education (ORISE), Oak Ridge, Tennessee 37831, USA — L-Mode plasmas in DIII-D and Alcator C-Mod tokamaks have been analyzed using the nonlinear gyrokinetic simulation GEM based on particle-in-cell method. It is observed that the simulation results for ion heat flux are close to the experimental values at the core, but substantially lower than the experimental results at the outer radial location in the DIII-D case. On the contrary, the simulations show good agreement with the experimental values of heat flux for ions in Alcator C-Mod. Global simulations are carried out for DIII-D L-Mode plasmas to study the effect of turbulence spreading from the edge into the outer core where the ion heat transport shortfall is observed. It is found that edge turbulence enhances the outer core ion heat transport significantly through turbulence spreading. However, ion heat flux in the shortfall region even in the presence of the edge drive is still much lower than the experimentally observed value.

NP8.00011 Comparison of Fluctuation Characteristics in High $q_{min}$ and Low $q_{min}$ Steady-State Scenario Plasmas on DIII-D1,  YAN ZHAO, Z. YAN, G.R. MCKEE, U. of Wisconsin-Madison, C.T. HOLCOMB, LLNL, J.R. FERRON, General Atomics, W.W. HEIDBRINK, UC-Irvine — Experiments investigating the impact of the safety factor ($q$) profile on transport and confinement have been carried out in steady-state scenario plasmas on DIII-D. The minimum safety factor was varied between $q_{min} \sim 1.4$ and $g_{min} \sim 2.3$ ($q_{95}=6.5$) using off-axis neutral beam current drive and early beam injection during moderately high beta plasmas ($\beta_N \sim 2.3$). The steady-state scenario plasmas with high $q_{min}$ have significantly lower global energy confinement. Long wavelength density fluctuations are measured with a 2D BES array located at $\rho \sim 0.35$-0.85 (scanned during a set of three repeat discharges). The normalized ($n/n_0$) density fluctuation amplitude integrated over 50-2500 kHz is found to be nearly double at higher $q_{min}$ in the region of $0.5 < \rho < 0.85$, which is consistent with the lower confinement at high $q_{min}$. In addition, a set of discrete coherent modes associated with energetic particle driven instabilities is observed in this frequency range.

1Work supported by the US DOE under DE-FG02-08ER54499, DE-FG02-89ER53296, DE-AC52-07NA27344, DE-FG02-04ER54698 and SC-G903402.
NP8.00012 Measurements of Fast Ion Transport Due to n=3 Magnetic Perturbations on DIII-D  D1
M.A. VAN ZEELAND, T.E. EVANS, N.M. FERRARO, M.J. LANCTOT, D.C. PACE, General Atomics, C. COLLINS, W.W. HEIDBRINK, UC-Irvine, M. GARCIA-MUNOZ, IPP-Garching, J.M. HANSON, Columbia U., B.A. GRIERSON, G.J. KRAMER, R. NAZIKIAN, PPPL, S.L. ALLEN, C.J. LASNIER, W.H. MEYER, LLNL — Measurements of fast ion (FI) transport due to applied n=3 magnetic perturbations on DIII-D have been made in both ELM suppressed H-mode as well as L-mode discharges. FIDA measurements probe the confined FI profile in the edge and losses to the wall are obtained with scintillator detectors as well as an infrared periscope. In ELM suppressed plasmas FIDA data show a significant depletion of the edge FI profile during application of n=3 fields. IR imaging of the D3He AE activity shows that AE transport is found to redistribute alphas within the core but not propagate to the loss boundary. Measurements of both the impact on the confined FI profile and prompt losses will be compared to full-orbit modeling which predicts up to 10%-15% of the injected beam ions are lost before thermalization. Orbit following simulations also predict an increase in losses due to resonance between the FI drift orbits and the applied n=3 fields. Measurements during L-mode current ramp plasmas used to scan for signatures of these resonances will be discussed.

3Work supported in part by the US DOE under DE-FC02-04ER54698, SC-G093402, DE-FG02-04ER54761, DE-AC02-06CH11466, DE-AC52-07NA27344.

NP8.00013 Inference of Fast-Ion Density Profile from Tomographic Reconstructions of Fast-Ion D00 Measurements  D1
L. STAGNER, W.W. HEIDBRINK, C. COLLINS, University of California Irvine, B.A. GRIERSON, Princeton Plasma Physics Laboratory — The fast-ion D00 (FIDA) diagnostic measures light that energetic particles emit in fusion plasmas. The diagnostic is sensitive to different velocity space regions depending on the viewing angle relative to the magnetic field. Consequently, viewing chords that share a radial location give different, yet still valid, results. Velocity space tomography allows for these viewing chords to be combined to infer the complete fast-ion distribution function from the different partial views. If this is done at many radial locations the fast-ion density profile is measured. We demonstrate this method for the case of a classically described, low power, MHD-quiescent plasma from actual FIDA measurements. FIDA measurements were taken at four radial positions, each with four different viewing angles. Simulation results are also shown.

3Work supported by the US Department of Energy under SC-G093402, DE-FC02-04ER54698 and DE-AC02-06CH11466.

NP8.00014 Transport of Fusion Alpha Particles in ITER Scenarios  D1
E.M. BASS, UCSD, R.E. WALTZ, GA — We predict the fusion-born alpha particle density in steady-state and hybrid (reverse shear) ITER scenarios with an integrated 1D transport model [1]. The model combines “stiff” critical gradient alpha-driven Alfvén eigenmode (AE) transport with a quasilinear approximation of microturbulent transport [2]. In an ITER baseline case [3], AE transport is found to redistribute alphas within the core but not propagate to the loss boundary. The remaining microturbulence at the edge causes negligible alpha-channel energy flux there (neglecting ripple loss). We set the AE stiff transport critical gradient threshold at gAE = 9tgcg, below which microturbulence can nonlinearly suppress AE transport [4], and the more stringent condition gAE = 0.

1R.E. Waltz and E.M. Bass, “Prediction of the fusion alpha density profile in ITER from local marginal stability to Alfvén eigenmodes,” accepted for Nucl. Fusion.
2C. Angioni et al., Nucl. Fusion 49, 055013 (2009)
3J.E. Kinsey et al., Nucl. Fusion 51 083001 (2011)

3Work supported in part by the US DOE under GA-Grant No. DE-FG02-95ER54309 and SciDAC-GSEP Grant No DE-FC02-08ER54977.

NP8.00015 Does a Critical Gradient Exist for Alfvén Eigenmode Induced Fast-Ion Transport?  D1
C.S. COLLINS, W.W. HEIDBRINK, U. California Irvine, M.A. VAN ZEELAND, C.C. PETTY, D.C. PACE, General Atomics, B.A. GRIERSON, PPPL — In the critical gradient model, if local energetic particle (EP) drive exceeds the Alfvén eigenmode (AE) stability limit, particles diffuse to flatten the pressure profile until marginal stability is maintained. A key signature is a sudden increase in transport above the critical gradient. In DIII-D, the onset of AE-induced EP transport is examined by modulating the EP pressure profile using an off-axis neutral beam while AE activity gradually diminishes during the current ramp. The time evolution of the EP density profile is measured with fast-ion D00 (FIDA) spectroscopy. During quiescent periods, the FIDA intensity rises and decays approximately linearly during and after the beam pulse, whereas during strong AE activity, the modulated FIDA intensity amplitude and decay rate decrease, suggesting additional AE-induced radial diffusion. Hardware upgrades are underway to increase spatial resolution and accommodate the full D00 spectrum, providing better constraints when comparing to predictive models.

3Work supported by the US Department of Energy under SC-G093402, DE-FC02-04ER54698, and DE-AC02-09CH11466.

NP8.00016 Plasma response and error field compensation with n=2 in DIII-D H-mode plasmas  D1
E.J. STRAIT, C. PAZ-SOLDAN, R.J. LA HAYE, M.J. LANCTOT, GA, J.M. HANSON, TURCO, Columbia U., S.R. HASKEY, ANU, J.D. KING, ORISE, N.C. LOGAN, R.M. NAZIKIAN, M. OKABAYASHI, J.K. PARK, B.J. TOBIAS, PPPL, R.A. MOYER, UCSD, M. SHAFAER, ORNL — Compensation of intrinsic error fields with toroidal mode number n=2 in DIII-D is found to reduce rotation braking. Some features of the response of H-mode plasmas to n=2 magnetic perturbations are similar to previous observations with both higher and lower mode numbers. As with n=1, the amplitude of the n=2 response rises with beta, consistent with excitation of a stable n=2 kink mode. As with n=3, n=2 perturbations above a threshold amplitude produce density pumpout. An n=2 field design was developed to maintain coupling to the stable kink creates little or no density pumpout, indicating that the kink mode coupling is important to particle transport. On the other hand, the part of the field that does not couple to the stable kink mode seems to play an important role in rotation braking, likely through neoclassical toroidal viscosity (NTV) effects.

3Work supported by US DOE under DE-FC02-04ER54698, DE-FG02-04ER54761, DE-AC05-06OR23100, DE-AC02-09CH11466, DE-FG0-07ER54917, DE-AC05-00OR22725.

NP8.00017 Free-Boundary 3D Equilibria and Resistive Wall Instabilities with M3D-C1  D1
N.M. FERRARO, L.L. LAO, General Atomics, S.C. JARDIN, Princeton Plasma Physics Laboratory, J.D. KING, Oak Ridge Associated Universities, M.W. SHAFAER, Oak Ridge National Laboratory, F. ZHANG, PIP — A resistive wall model has been implemented in the two-fluid, 3D MHD code M3D-C1. This capability allows M3D-C1 to be applied to several new applications that were not possible with conducting wall boundary conditions, including vertical displacement events, resistive wall modes, and free-boundary equilibria. Examples of each for both DIII-D and NSTX are presented. This also permits direct comparison of M3D-C1 results with magnetic probe data. Generally good agreement with magnetics data and qualitative agreement with soft x ray imaging is found in simulations of the non-axisymmetric response to applied 3D fields. It is found that the response can be sensitive to the treatment of the open field-line region. The boundary conditions and treatment of the open field-line region are especially important for the n=1 response. In M3D-C1, the resistive wall and the external vacuum region are included within the computational domain, which allows good implicit scaling, walls of arbitrary thickness, and the evolution of wall conditions.

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Work supported in part by the US Department of Energy under SC-G093402, DE-FC02-04ER54698 and DE-AC02-09CH11466.
NP8.00018 Computation of Low-$n$ Plasma Response to Resonant Magnetic Perturbations in DIII-D Experiments\textsuperscript{1}, PING ZHU, University of Science and Technology of China, University of Wisconsin-Madison, CARL R. SOVINEC, University of Wisconsin-Madison — To understand the effects of resonant magnetic perturbations (RMPs) on tokamak plasmas, we have computed the plasma response to RMPs in DIII-D experiments \#126006 and \#142603 using the extended MHD models implemented in the NIMROD code. The L-coil vacuum field is imposed as the initial perturbations and as the boundary conditions at the tokamak wall location. Whereas the edge pedestals in these discharges are found unstable to the high-$n$ perturbations, low-$n$ plasma responses to RMP are obtained by following the evolution of these low-$n$ components into quasi-steady state subject to the RMP initial and boundary conditions. Here $n$ is the toroidal mode number. Computation results indicate that the existence and properties of the steady states for the low-$n$ plasma response strongly depend on the plasma dissipation regime, equilibrium rotation, and two-fluid effects. Progress on the benchmarking with other 3D codes will be discussed.

\textsuperscript{1}Supported by Grants 2014GB124002 and DE-FC02-08ER54975.

NP8.00019 Statistical Analysis of Locked Modes and their Disruptivity at DIII-D\textsuperscript{1}, R. SWEENEY, W. CHOI, K.E.J. OLOFSSON, F.A. VOLPE, Columbia U. — A database has been developed to study locking and disruptivity of neoclassical tearing modes with poloidal and toroidal mode numbers $m=2$ and $n=1$. Approximately 30,000 DIII-D discharges are studied providing statistics on the fraction of disruptions containing locked modes (LMs) and the ratio of disruptive LMs to all LMs. Other quantities analyzed include the time-scales between mode-formation and locking, and between locking and disruption, the amplitude of the mode upon locking and disruption, the existence or lack of a rotating precursor, and the toroidal phase of locking. Correlations are examined between locking and disruptivity and parameters such as plasma beta and neutral beam torque. Simple interpretations are provided in terms of island size and torques acting on the island, and implications for an automatic locked mode controller are discussed.

\textsuperscript{1}This work was supported by the US Department of Energy under DE-SC0008520.

NP8.00020 Measurements of the Structure of the Plasma Rotation in Slowly Rotating Tearing Modes in DIII-D\textsuperscript{1}, N.Z. TAYLOR, Oak Ridge Associated Universities, N.M. FERRARO, R.J. LA HAYE, C.C. PETTY, General Atomics, C. BOWMAN, University of York — A helically modified ion flow by an island can lead to helical ion polarization currents which can affect tearing mode stability. This issue is of particular importance to ITER where large inertia and relatively low torque will likely result in low rotation. In DIII-D cases either (1) a $m/n=2/1$ mode is slowed down to $\sim$1 kHz (faster than the inverse wall time) by near balanced neutral beams or (2) an island is entrained by applied rotating $n=1$ magnetic field at 10 Hz (slower than the inverse wall time). The $n=1$ island structure is measured with electron cyclotron emission radiometry. The ion rotation and temperature are measured by fast resolution (274 $\mu$s) charge exchange recombination (CER) spectroscopy in the 1 kHz freely rotating case and by standard CER (5 ms) in the 10 Hz entrainment. Tangential and vertical CER arrays allow for the radial profile of the helically perturbed rotation to be determined. A comparison of the measured nonlinear island structures with that from the linear resistive stability code M3D-C1 will be presented.

\textsuperscript{1}Work supported in part by the US Department of Energy under DE-FG02-95ER54309 and DE-FG02-04ER54498.

NP8.00021 External Kink Mode in Diverted Tokamaks\textsuperscript{1}, A.D. TURNBULL, N.M. FERRARO, L.L. LAO, General Atomics, J.M. HANSON, F. TURCO, Columbia U., P. PIOVESAN, Consorzio RFX — In a straight tokamak model, the external kink mode with toroidal mode number $n$ and poloidal mode number $m$ is predicted to be unstable when the edge safety factor, $q_{edge}$, lies just below a rational value. In a torus, the picture is essentially unchanged and the $2/1$ instability in particular evolves encountered with $q_{edge} = 2$. For a diverted plasma, the $q$ is infinite, but the experimental limit is then $q_95 = 2$, where $q_95$ is at the 95% flux surface. However, no theoretical basis has been established for the importance of $q_95$ and ideal predictions indicate stability with $q_{edge} > 2$ and $q_95 < 2$; instability is found only when the actual $q$ at the edge is below 2. Two possible solutions present themselves. The observed mode may be destabilized as a result of a small 3D error fields. Alternatively, the observed mode may be destabilized by the rapidly increased resistivity at the plasma edge. Both possibilities are examined using ideal and resistive MHD tools in two and three dimensions.

\textsuperscript{1}Work supported in part by the US DOE under DE-FG02-95ER54309, DE-FG02-04ER54761, and DE-FG02-07ER54917.

NP8.00022 Magnetic Control of Locked Modes in Present Devices and ITER\textsuperscript{1}, F.A. VOLPE, S. SABBAGH, R. SWEENEY, Columbia U., T. HENDER, A. KIRK, CCFE, R.J. LA HAYE, E.J. STRAIT, General Atomics, Y.H. DING, B. RAO, HUST, S. FIETZ, M. MARASCHEK, IPP, L. FRASSINETTI, KTH, Y. IN, Y. JEON, NFRI, S. SAKAKIHARA, NIFS — The toroidal phase of non-rotating (“locked”) neoclassical tearing modes was controlled and the several devices by means of applied magnetic perturbations. Evidence is presented from various tokamaks (ASDEX Upgrade, DIII-D, JET, J-TEXT, KSTAR), spherical tori (MAST, NSTX) and a reversed field pinch (EXTRAP-T2R). Furthermore, the phase of interchange modes was controlled in the LHD helical device. These results share a common interpretation in terms of torques acting on the mode. Based on this interpretation, it is predicted that control-coil currents will be sufficient to control the phase of locking in ITER. This will be possible both with the internal coils and with the external error-field-correction coils, and might have promising consequences for disruption avoidance (by aiding the electron cyclotron current drive stabilization of locked modes), as well as for spatially distributing heat loads during disruptions.

\textsuperscript{1}This work was supported by the US Department of Energy under DE-SC0008520, DE-FC-02-04ER54698 and AC-02-09CH11466.

NP8.00023 Observing the Coupling of the Toroidal Plasma Rotation Due to $m/n=2/1$ and $m/n=3/2$ Neoclassical Tearing Modes by Uncorrected $n=2$ Error Field in DIII-D\textsuperscript{1}, M. OKABAYASHI, B.J. TOBIAS, Princeton Plasma Physics Laboratory, E.J. STRAIT, R.J. LA HAYE, C. PAZ-SOLDAN, General Atomics, D. SHIRAKI, Oak Ridge National Laboratory, J.M. HANSON, Columbia U. — Injection of electromagnetic torque by tearing mode rotation control feedback can sustain rotation of the 2/1 Neoclassical Tearing Modes by Uncorrected n=2 Error Field in DIII-D. Observation of the coupling of the toroidal plasma rotation due to $m/n=2/1$ and $m/n=3/2$ neoclassical tearing modes by uncorrected $n=2$ error field in DIII-D reveals the existence of locked modes (LMs) and the ratio of disruptive LMs to all LMs. Furthermore, the phase of interchange modes was controlled in the LHD helical device. These results share a common interpretation in terms of torques acting on the mode. Based on this interpretation, it is predicted that control-coil currents will be sufficient to control the phase of locking in ITER. This will be possible both with the internal coils and with the external error-field-correction coils, and might have promising consequences for disruption avoidance (by aiding the electron cyclotron current drive stabilization of locked modes), as well as for spatially distributing heat loads during disruptions.

\textsuperscript{1}This work was supported by the US Department of Energy under DE-AC02-99CH11466, DE-FC02-04ER54698, DE-AC05-00OR22725, and DE-FG02-04ER54761.
NP8.00024 Physics-model-based Modeling and Control of the Toroidal Rotation Profile for DIII-D
W. WEHNER, E. SCHUSTER, Lehigh U., M.L. WALKER, D.A. HUMPHREYS, General Atomics — A model suitable for control purposes, a so-called “control-oriented” model, requires only the dominant underlying physics that is relevant for control design. A control-oriented model of the toroidal rotation profile evolution for DIII-D has been derived from a simplified version of the first-principles-based momentum diffusion equation combined with scenario-specific models of the momentum sources. For DIII-D, four momentum sources are available for consideration: the non-axisymmetric field coils; which provide rotation damping; the co-current on-axis neutral beam injectors (NBI); the co-current off-axis NBI; and the counter-current on-axis NBI. These four sources allow not only control of the bulk plasma rotation, but also control of the profile shape. Optimal state feedback with integral action has been designed from the model and demonstrated in simulation to regulate the rotation profile around a desired target shape.

1 Supported by the US Department of Energy under DE-SC0001334, DE-SC0010661 and DE-FC02-04ER54698.

NP8.00025 TGLF Analysis of ITG-TEM Transitions in DIII-D Plasmas
X. WANG, S. MORDJUCK, College of William and Mary, G.M. STAEBLER, General Atomics, O. MENEGHINI, ORAU — TGLF [1] calculations show that, when adding electron cyclotron heating, DIII-D H-mode plasmas can transit from the ion temperature gradient (ITG) to trapped electron mode (TEM) domain around mid-radius. With different turbulence scale-lengths as well as opposite drift direction, ITG/TEM plasmas have different transport features, and thus lead to different density and rotation profiles. Detailed TGLF sensitivity analysis shows that the trapped electron mode’s growth-rate is more sensitive to electron temperature gradient than the density gradient. Furthermore, by varying the input torque from co-IP to counter-IP through neutral beams, the ITG/TEM reversing radial location changes. We compare three parameters: density fluctuations, linear instability growth-rates, and ExB shearing rates in these discharges. We show that, for co- and counter-beam discharges, the ExB shearing rate becomes comparable or even larger than the growth-rate in the plasma edge. However, under balanced beam injection, the growth-rate is always larger than the shearing rate.


NP8.00026 Gyrokinetics with Advanced Collision Operators
E.A. BELLJ, J. CANDY, General Atomics — For gyrokinetic studies in the pedestal region, collisions are expected to play a more critical role than in the core and there is concern that more advanced collision operators, as well as numerical methods optimized for the strong collisionality regime, are needed. For this purpose, a new gyrokinetic solver CGYRO has been developed for precise studies of high collisionality regimes. Building on GYRO and NEO, CGYRO uses the NEO pitch angle and energy velocity-space coordinate system to optimize the accuracy of the collision dynamics, particularly for multi-species collisions and including energy diffusion. With implementation of the reduced Hirschman-Sigmar collision operator with full cross-species coupling, CGYRO recovers linear ITG growth rates and the collisional GAM test at moderate collision frequency. Methods to improve the behavior in the collisionless regime, particularly for the trapped/passing particle boundary physics for kinetic electrons, are studied. Extensions to advanced model operators with finite-k corrections, e.g., the Sugama operator [1], and the impact of high collisionality on linear gyrokinetic stability in the edge are explored.


NP8.00027 A Combined Phase Contrast Imaging-Interferometer System for the Detection of Multiscale Electron Density Fluctuations
E.M. DAVIS, J.C. ROST, M. PORKOLAB, A. MARINONI, Massachusetts Institute of Technology — ITER and next-step devices will have harsh neutron environment and limited port space, severely restricting many crucial plasma diagnostics. As such, it is essential that we develop robust diagnostics with minimal access restrictions, small port requirements, and high spatiotemporal bandwidths. DIII-D’s Phase Contrast Imaging (PCI) system is a model of such a burning plasma diagnostic, using a 10.6 µm laser to measure \( \tilde{\rho} \). To eliminate PCI’s low-k cutoff, we have designed and are constructing a traditional interferometer along the existing PCI beam path, extending the minimum detectable \( k \) to 0 cm\(^{-1}\). The combined PCI-interferometer uses a single 10.6 µm beam, two interference schemes, and two detectors to make the relevant measurements. In addition to diagnostic proof-of-principle, the combined PCI-interferometer’s improved bandwidth will aid model validation and allow measurement of low and high \( k \) MHD modes. Initial results will be discussed.

1 Work supported by the US DOE under DE-FG02-94ER54325, DE-FC02-04ER54698, DE-FC02-99ER54512, and NNSA SSGF.

NP8.00028 Modeling Tokamak Transport with Neural-Network Based Models
O. MENEGHINI, Oak Ridge Associated Universities, C. LUNA, Arizona State University, J. PENNA, Massachusetts Institute of Technology, S.P. SMITH, L.L. LAO, General Atomics — This work uses neural networks (NNs) as a means to extract information from the massive volume of aggregated data that are available either from experiments or from simulation databases, and distill an accurate transport model for the heat, particle, and momentum transport fluxes as a function of local dimensionless plasma parameters [1]. The resulting model has been benchmarked with over 4000 DIII-D plasmas in different regimes, and it is able to capture the experimental behavior inside of \( p < 0.95 \) with average error \(<2\%\) for all transport channels. The NN model was embedded into the ONETWO transport code and is now being used to develop time-dependent scenarios in support of DIII-D operations. The simulated temperature, density and rotation profiles closely match the experimental measurements, and a stiff response of the heat fluxes has been observed in the model for increasing source power. The numerical efficiency of the NN approach makes it ideal for real time plasma control and scenario preparation for current experiments and for ITER.


NP8.00029 Inclusion of Relativistic Broadening for ECE-\( T_e \) Mapping in DIII-D
M.E. AUSTIN, M.W. BROOKMAN, University of Texas at Austin — Recent increased demands on electron cyclotron emission (ECE)-derived electron temperature (\( T_e \)) measurement accuracy in DIII-D have lead to a re-examination of calibration and analysis methods. In particular, a new technique using sawtooth oscillations to assess ECE-\( T_e \) overlap in the core shows that the inclusion of relativistic broadening for the ECE channel positions is crucial to obtain accurate gradients in the central region of the plasma, even for \( T_e(0) \) values less than 4 keV. A calculation of ECE-\( T_e \) postion shifts \( \delta R \) for the range of DIII-D operating parameters find that the \( \delta R \) corrections range from 0.5 cm for \( T_e \sim 2 \) keV to more than 2 cm for \( T_e \sim 8 \) keV. Two methods for inclusion of the relativistic shifts in DIII-D \( T_e \) profiles are compared, a slower full numerical calculation of absorption and emission profiles versus a faster analytical formula.

1 Work supported in part by the US Department of Energy under DE-FG03-07ER54415, DE-FG02-93ER54197 and DE-FC02-04ER54698.
NP8.00030 Modeling and Analysis for Tearing Mode Stability in DIII-D Hybrid Discharges

KYUNGJIN KIM, Seoul National U./Oak Ridge National Laboratory, J.M. PARK, M. MURAKAMI, Oak Ridge National Laboratory, R.I. LA HAYE, General Atomics, YONG-SU NA, Seoul National U., DIII-D TEAM — Plasma rotation in DIII-D hybrid scenario plasmas is found to change the stability of tearing modes (TM) in a profound manner. It is important to understand the onset threshold and the evolution of TMs for developing a high-performance steady-state fusion reactor. The modified Rutherford equation (MRE) estimates the growth rate of an island and is used to analyze the TM stability. The change in TM stability was investigated in hybrid plasmas with various conditions including rotation, normalized beta, q profile, and so on. The measured island width is larger in low qtor cases and increased as plasma rotation was reduced. The island width calculated by MRE with TM stability index $\Delta'$ assumed from its poloidal mode number, -$m/r$, showed a good agreement during high rotation, but could not be matched to the experimental island width at lower rotation. Simulations of TMs using resistive MHD codes such as NIMROD and PEST3 will also be presented and compared with experiments to determine the possibility for predicting TM onset by $\Delta'$ calculation.

1Work supported in part by the US DOE under DE-AC05-00OR22725 and DE-FC02-04ER45698.

NP8.00031 Classical m/n=2/1 Tearing Mode Stability Based on Initial Island Growth Rate of Neoclassical Tearing Modes in DIII-D ITER Baseline Scenario Discharges

R.J. LA HAYE, G.L. JACKSON, T.C. LUCE, GA, O. MENEGHINI, ORISE, K.E.J. OLOFFSSON, F. TURCO, Columbia U., W.M. SOLOMON, PPPL — Deleterious m/n=2/1 tearing modes appear in some slowly evolving ITER baseline scenario DIII-D discharges. The destabilization is here interpreted as due to an initially positive (destabilizing) classical tearing index. Examples of 2/1 tearing occurring after at least 3 seconds into discharges are analyzed. Island width evolution is evaluated by the Mirnov magnetic probe array using the motional Stark effect EFIT equilibrium reconstructions and is calibrated by the electron cyclotron emission (ECE) diagnostic. The magnetics analysis code EigSpec is used to sort out multiple modes and determine at which the m/n=2/1 mode begins to grow. The classical stability index is determined from the modified Rutherford equation (MRE) by taking the helically perturbed bootstrap components (including both curvature and small island effects) and subtracting from the initial normalized island growth rate. The data is well described by the imbalance of the sum of the destabilizing classical tearing and the helically perturbed bootstrap current terms with the sum of the stabilizing curvature and “ion polarization” effects. Comparison of the empirically determined classical index will be made with that from the linear stability code PEST3 using kinetic EFITs from experiment.

1This work supported by the US DOE under DE-FC02-04ER45698 and 1DE-FG02-04ER54761, DF-AC02-09CH11466.

NP8.00032 Development and Testing of EFIT 3D Equilibrium Reconstruction Capability

L.L. LAO, N.M. FERRARO, E.J. STRAIT, A.D. TURNBULL, General Atomics, J.D. KING, Oak Ridge Institute for Science Education — Recent development and testing of EFIT capability to reconstruct tokamak 3D perturbed equilibrium are described. The 3D extension is based on an expansion of the MHD equations to account for the 3D effects. EFIT uses the cylindrical coordinate system and can include magnetic island and stochastic effects. Several linearization schemes are being explored to improve the EFIT 3D perturbed solutions. Algorithms are also being developed to allow EFIT to reconstruct 3D perturbed equilibria directly making use of plasma response to 3D perturbations from the MARS or M3D-C1 MHD codes. Other efforts include testing of the new EFIT 3D capability using simulated magnetic data based on response calculations from MARS and M3D-C1, and performing detailed benchmarking calculations against other 3D codes such as VMEC/V3FIT. Reconstruction examples using EFIT and the new DIII-D 3D magnetic measurements to reconstruct 3D perturbed experimental equilibria using well-diagnosed discharges from DIII-D error field, RWM, and RMP experiments will be presented.

1Work supported by the US DOE under DE-FC02-04ER54698 and DE-FC02-95ER54309.

NP8.00033 Status and System Performance for the DIII-D ECH System

M. CENGERH, J. LOHR, Y.A. GORELOV, D. PONCE, R. PRATER, C.P. MOELLER, General Atomics — The electron cyclotron heating (ECH) capabilities on DIII-D are being steadily updated, leading to increased experimental flexibility and high reliability of the system. A 110 GHz depressed collector gyrotron in the 0.5 MW class was installed and is being tested and conditioned to longer pulse length. A second depressed collector gyrotron is operational in addition to the four 110 GHz, 1 MW gyrotrons. A new design depressed collector gyrotron in the 1.5 MW class, operating at 117.5 GHz, is expected to be installed during 2015 following rework to address a high voltage standoff problem. This tube will operate in the TE20,9 mode and has achieved 1.8 MW for short pulses during factory testing. The individual power generated at the gyrotrons and the power injected into the tokamak are measured on a shot-to-shot basis for the present year, with calibration based on the measured linearity between the injected power and the gyrotron cavity loading. The individual average injected powers into the plasma are between 520 and 760 kW. The line transmission coefficient including the waveguide line and the MOU is between -1.04 dB and -1.43 dB.

1Work supported by the US Department of Energy DE-FC02-04ER45698.

NP8.00034 High Speed Scanning of the ECH RF beams on DIII-D

J. LOHR, M. CENGERH, Y.A. GORELOV, S. NORAKY, D. PONCE, A.S. WELANDER, General Atomics, R.A. ELLIS, E. KOLEMEN, Princeton Plasma Physics Laboratory — The ECH launchers on the DIII-D tokamak have been modified for rapid poloidal sweeping of the rf beams using high speed dc motors and magnetic position encoders. This enables the system to perform such tasks as responding to the need to suppress growing tearing modes on different flux surfaces, modifying sawtooth oscillations and altering the current density profile. The mechanical capability is backed by real time motional Stark effect ECH equilibrium calculations, magnetic spectra analysis by NEWSPEC, fast ray tracing using TORBEAM (checked by TORAY) and real time $n_e$ and $T_e$ profiles from Thomson scattering. The poloidal scan can cover the full 40$^\circ$ range across the plasma upper half plane in about 100 ms and provide position accuracy for the rf deposition of approximately 2 mm at the plasma center for a beam with 10 cm diameter at the -10 dB contour. The entire capability is orchestrated from the Plasma Control System, which can also modulate the gyrotron outputs as required.

1Work supported by the US Department of Energy DE-FC02-04ER54698 and DE-AC02-09CH11466.

NP8.00035 Analysis and Alignment of a Gyrotron RF Beam on the DIII-D ECH System

Y.A. GORELOV, J. LOHR, A. TORREZAN, J.P. ANDERSON, D. PONCE, M. CENGERH, General Atomics — The DIII-D ECH transmission line installation comprises seven runs of up to 80 meters of 31.75 mm diameter waveguide, with transmission efficiencies from 69% to 79%. The efficiency depends on the purity of the HE$_{1,1}$ mode in the waveguide. The Gaussian rf beam from a gyrotron is converted to the HE$_{1,1}$ waveguide mode with a single focusing mirror in the matching optics unit (MOU) that places a waist, $w_0 = 19$ mm, at the input of the waveguide. At tilt angles $\theta$ of less than two degrees and small offsets $\Delta$ of less than 3 mm, the mode conversion from a pure HE$_{1,1}$ mode increases as $\theta^2$ and $\Delta^2$ respectively. The rf beam from the newest gyrotron was recorded in free space propagation at 10 cm intervals from the gyrotron window using an infrared camera. These data were used for phase retrieval calculations to optimize the design of the focusing mirror in the MOU. The mirror position was then set to align the rf beam with the waveguide axis. The measurement was repeated for the rf beam radiated from a short length of waveguide and the HE$_{1,1}$ content was 87%. This is slightly low compared to the measurements of the other waveguides.

1Work supported by the US DOE under DE-FC02-04ER54698.
NP8.00036 Finding Evidence for Scattering of ECRH Power by Density Blobs\textsuperscript{1}, M.W. BROOKMAN, M.E. AUSTIN, K.W. GENTLE, W.L. ROWAN, University of Texas at Austin — Thermal transport studies using electron cyclotron heating (ECH) have measured anomalous effects consistent with narrow deposition profiles expected for the DIII-D gyrotrons. Recent theoretical work suggests that density blobs in the edge are capable of scattering and frequency shifting ECH power and broadening the deposition [1]. Knowledge of the heating profile is necessary for understanding thermal transport and mode suppression, as well as searching for density blob. Deposition profiles of modulated ECH (MECH) pulses from DIII-D gyrotrons are derived from 2nd harmonic X-mode electron cyclotron emission (ECE) measurements using the University of Texas 40 channel heterodyne radiometer. The uncertainties and resolution limits of this measurement are explored in both time and frequency domain analysis. The ability of the ECE system to resolve broadening effects from density bubbles is examined and measured deposition profiles are compared to previous derivations.

\textsuperscript{1}Work supported by the US Department of Energy under DE-FG02-07ER54917, DE-FG02-04ER54698.

NP8.00037 Near Real-Time Gyrotron Data Streaming and Data Acquisition with ns Resolution on the DIII-D ECH System\textsuperscript{1}, A.C. TORREZAN, D. PONCE, Y.A. GORELOV, M. CENGHER, J. LOHR, General Dynamics — As part of the expansion and upgrade of the electron cyclotron heating (ECH) system on DIII-D, a new data acquisition setup has been implemented to acquire and display waveform data from all gyrotrons in near real time with high time resolution. The data acquisition for each gyrotron system is based on a fast digitizer with 8 channels running at 2 MS/s/channel and a resolution of 14 bits. This enables the operator to monitor all gyrotron-relevant variables as well as fast diagnostic signals such as window arcs. The data are transferred to a local computer through a 132 MB/s PCI bus, and then are streamed to the ECH operator and to a local network attached storage using 1 GB Ethernet links. The data are displayed to the ECH operator by means of a graphical user interface developed in LabVIEW, replacing physicaloscopes. Acquired gyrotron data are accessible at DIII-D through a local database (PTDATA) connected to the ECH data acquisition system by an Ethernet line, a configuration that eliminates the need for legacy CAMAC hardware in the data link.

\textsuperscript{1}Work supported by the US Department of Energy under DE-FG02-04ER54698.

NP8.00038 The ITER Plasma Control System Simulation Platform\textsuperscript{1}, D.A. HUMPHREYS, M.L. WALKER, A.S. WELANDER, General Dynamics, A. AMBROSINO, G. TOMMASI, M. MATTIE, CREATE, G. NEU, C. RAPSON, G.R. RAUPP, W.M. TREUTTERER, ITER-Garching, A. WINTER, ITER IO — Design of the ITER plasma control system (PCS) will require extensive simulation to evaluate both candidate architecture and algorithms. The ITER Plasma Control System Simulation Platform (PCSSP) is a specialized simulation environment currently under development to satisfy the demanding requirements of this design process. The PCSSP supports control-level models of systems relevant to ITER plasma control, including key plasma responses, and provides very high flexibility in selection of these models for a given simulation purpose. This flexibility enables higher fidelity models to be used to focus on particular control loops, for example. The PCSSP also supports modeling and simulation of exceptions (off-normal and fault events), as well as PCS algorithms and policies for handling these exceptions. We describe the present implementation and status of PCSSP, including modules simulating axisymmetric MHD, basic kinetics, and tearing mode physics, along with corresponding controller and exception handling modules.

\textsuperscript{1}Supported by ITER/CT/6000000037.

NP8.00039 Using the TokSys Modeling and Simulation Environment to Design, Test and Implement Plasma Control Algorithms on DIII-D\textsuperscript{1}, A.W. HYATT, A.S. WELANDER, N.W. EIDIETIS, M.J. LANCTOT, D.A. HUMPHREYS, General Dynamics — The DIII-D tokamak has 18 independent poloidal field (PF) shaping coils and an independent Ohmic transformer coil system. This gives great plasma shaping flexibility and freedom but requires a complex control capability that imposes some form of constraint so that a given plasma shape and specification leads to uniquely determined PF shaping currents. One such constraint used is to connect all PF coils in parallel to a common bus, forcing the sum of those PF current to be zero. This constraint has many benefits, but also leads to instability where adjacent PF coils of opposite current can mutually increase, leading to Ohm shaped distortion when using the standard shape control algorithms. We will give examples of improved control algorithms that were extensively tested using the TokSys simulation suite available at DIII-D and then successfully implemented in practice on DIII-D. In one case using TokSys simulations to develop a control solution for a long sought plasma equilibrium saved several days of expensive tokamak operation time.

\textsuperscript{1}Work supported by the US Department of Energy under DE-FG02-04ER54698.

NP8.00040 GPU-Based Optimal Control Techniques for Resistive Wall Mode Control on DIII-D\textsuperscript{1}, M. CLEMENT, University of California San Diego, G.A. NAVRATIL, J.M. HANSON, Columbia University, E.J. STRAIT, General Dynamics — The DIII-D tokamak can excite strong, locked or nearly locked kink modes whose rotation frequencies do not evolve quickly and are slow compared to their growth rates. To control such modes, DIII-D plans to implement a Graphical Processing Unit (GPU) based feedback control system in a low-latency architecture based on system developed on the HBT-EP tokamak [1]. Up to 128 local magnetic sensors will be used to extrapolate the state of the rotating kink mode, which will be used by the feedback algorithm to calculate the required currents for the internal and/or external control coils. Offline techniques for resolving the mode structure of the resistive wall mode (RWM) will be presented and compared along with the proposed GPU implementation scheme and potential real-time estimation algorithms for RWM feedback.

\textsuperscript{1}Supported by ITER/CT/6000000037.

NP8.00041 Optimization of the Current Ramp-up Phase in DIII-D via Physics-model-based Control of Plasma Safety Factor Profile Dynamics\textsuperscript{1}, J.E. BARTON, W.P. WEHNER, E. SCHUSTER, Lehigh University, T.C. LUCE, G.L. JACKSON, J.R. FERRON, D.A. HUMPHREYS, A.W. HYATT, General Dynamics — Simulations and experimental results in DIII-D are presented to demonstrate the potential of physics-model-based control of the plasma safety factor profile to improve the reproducibility of plasma startup conditions by achieving a specified target profile at the end of the current ramp-up. Three different profiles $q_{\text{min}}$ of 1.3, 1.65, 2.1 and $q_{\text{max}}$ of 4.4, 5.0, 6.2, respectively were specified as targets. A feedforward + feedback scheme is utilized to control the $q$ profile and is constructed by embedding a nonlinear, physics-based model of the $q$ profile dynamics into the control design process. A unique characteristic of the feedforward trajectories obtained by solving the optimization problem is the regulation of the plasma current ramp-up rate to achieve the target $q$ profiles. The feedback controller is employed to add robustness to the control scheme and account for drifts due to external plasma disturbances.

\textsuperscript{1}Supported by the US Department of Energy under DE-SC0001334, DE-SC0010661 and DE-FC02-04ER54698.
NP8.00042 Observed linkage between ELM occurrence times and the phase of full flux loop signals in JET plasmas1, R.O. DENDY, CCFE Culham, S.C. CHAPMAN, CFSA Warwick U., T.N. TODD, CCFE Culham, N.W. WATKINS, MPP-UKS Dresden, A.J. WEBSTER, CCFE Culham, F. CALDERON, CFSA Warwick U., J. MORRIS, CCFE Culham, JET EFDA CONTRIBUTORS TEAM — We have identified (S Chapman, R Dendy et al, POP 21 062302 (2014)) a phase relation between the occurrence times of edge localized modes (ELMs) in H-mode plasmas in the Joint European Torus (JET), and the voltage in full flux toroidal loops in the divertor region. The ELMs are observed in Be II emission at the divertor, and arise from intrinsic ELMing, with no external control applied. We relate ELM occurrence times from the Be II signal to the time-evolving phase of full flux loop signals, which provide global measurements proportional to the voltage induced by changes in poloidal magnetic flux. Each ELM produces a rapid initial pulse in the full flux loop signals. The arrival time of the next ELM, relative to this pulse, is in two categories: (a) prompt ELMs, directly paced by the initial response in the flux loop signals; and (b) all other ELMs, which occur after the decay of the initial response of the full flux loop signals. The times at which ELMs in category (b) occur, relative to the first ELM of the pair, cluster at times when the instantaneous phase of the full flux loop signal is close to the distribution of times at the time of the first ELM. This may contribute to the distribution of inter-ELM time intervals reported by A Webster, R Dendy et al, PPCF 56 075017 (2014).

1Supported by U.S. DOE Grant DE-FG02-86ER553222.

NP8.00043 Gyrokinetic Analysis of ASDEX-Upgrade Inter-ELM Pedestal Profile Evolution. DAVID HATCH, Institute for Fusion Studies, University of Texas at Austin, M.G. DUNNE, H. DOERK, F. JENKO, D. TOLD, E. WOLFROUM, E. VIEZZER, Max Planck Institute for Plasma Physics, THE ASDEX-UPGRADE TEAM — The gyrokinetic GENE code is used to study Inter-ELM H-mode pedestal profile evolution on the ASDEX Upgrade Tokamak. Four main instabilities are observed during various inter-ELM phases—density gradient driven drift waves (DWs), microturbulent modes (MTMs), kinetic ballooning modes (KBMs), and electron temperature gradient (ETG) modes. We focus in detail on three time points: (a) an early time point during which the radial electric field profile has not recovered and low k_y DWs are the sole instability, (b) an intermediate phase during which the electron temperature gradient is fixed at a critical value, but the KBM limit has not been fully reached, and (c) the phase immediately preceding the ELM, during which the profiles are near or above the KBM limit. The properties of the dominant microinstabilities are generally consistent with the profile evolution. Complementary nonlinear simulations will also be presented.

NP8.00044 Disruption avoidance through active magnetic feedback in tokamak plasmas. ROBERTO PACCAGNELLA, PAOLO ZANCA, VADIM YANOBSKY, CLAUDIO FINOTTI, GABRIELE MANDUCHI, CHIARA PIRON, LORELLA CARRARO, PAOLO FRANZ. Consorzio RFX, RFX TEAM — Disruptions avoidance and mitigation is a fundamental need for a fusion relevant tokamak. In this paper a new experimental approach for disruption avoidance using active magnetic feedback is presented. This scheme has been implemented and tested on the RFX-mod device operating as a circular tokamak. RFX-mod has a very complete system designed for active mode control that has been proved successful for the stabilization of the Resistive Wall Modes (RWMs). In particular the current driven 2/1 mode, unstable when the edge safety factor, q_e, is around (or even less than) 2, has been shown to be fully and robustly stabilized. However, at values of q_e (q_e > 3), the control of the tearing 2/1 mode has been proved difficult. These results suggested the idea to prevent disruptions by suddenly lowering q_e to values around 2 where the tearing 2/1 is converted to a RW. Contrary to the universally accepted idea that the tokamaks should disrupt at low q_e, we demonstrate that in presence of a well designed active control system, tokamak plasmas can be driven to low q_e actively stabilized states avoiding plasma disruption with practically no loss of the plasma internal energy.

NP8.00045 HBT-EP Program: Active MHD Mode Dynamics & Control1. G.A. NAVRATIL, S. ANGELINI, J. BIALEK, P.J. BYRNE, A.J. COLE, B.A. DEBONO, P.E. HUGHES, J.P. LEVESQUE, M.E. MAUEL, Q. PENG, D.J. RHODES, C.C. STOAFER, Columbia University, C.J. HANSEN, Univ of Washington — The HBT-EP active mode control research program aims to: (i) quantify external kink dynamics and multimode response to applied magnetic perturbations, (ii) understand the relationship between control coil configuration, conducting and ferritic wall effects, and active feedback control, and (iii) explore advanced feedback algorithms. Biorthogonal decomposition is used to observe multiple simultaneous resistive wall modes (RWM). Improved visualization of MHD kink mode structure is achieved using a tangential fast camera viewing visible light emission that augments magnetic probe data. A 512 core GPU-based low latency (14µs) MIMO control system uses 96 inputs and 64 outputs for Adaptive Control of RWMs. An in-vessel adjustable ferritic wall was used to study ferritic RWMs with enhanced MHD response. A biased electrode in the plasma was used to control the rotation of long-wavelength kink instabilities can be strongly modified. When the probe is biased to apply a torque in the direction of the edge of the plasma, the rotation of long-wavelength kink instabilities can be strongly modified. When the probe is biased to apply a torque in the direction of the edge of the plasma, the rotation of long-wavelength kink instabilities can be strongly modified.

1Supported by U.S. DOE Grant DE-FG02-86ER553222.

NP8.00046 Study of Kink Stability during Large Changes of Mode Rotation Induced by a Biased Probe1. CHRIS STOAFER, Q. PENG, J.P. LEVESQUE, M.E. MAUEL, G.A. NAVRATIL, Columbia University — A bias probe has been installed the High Beta Tokamak – Extended Pulse (HBT-EP) for studying MHD mode rotation and stability. By applying a voltage to the probe inserted into the edge of the plasma, the rotation of long-wavelength kink instabilities can be strongly modified. When the probe is biased to apply a torque in the direction of natural MHD mode rotation (7 - 10 kHz), the mode rotation can double. When the probe is biased in the opposite direction, wall-stabilized kinks can either stop rotating or be forced to counter-rotate in the ion drift direction. A time-varying bias can be applied to the probe with a 5 kW amplifier, which induces a time-varying mode rotation. An active controller can also be used to generate a bias voltage as a function of time. In this case, signals are generated through an active GPU-based digital feedback system, and this allows for MHD stability studies under the highly desirable condition of feedback controlled MHD mode rotation. Plasma rotation is measured with a Mach probe, and MHD mode rotation is measured by analyzing magnetic sensors on HBT-EP. Observations of plasma stability with HBT-EP's adjustable wall are reported for a wide range of mode rotation rates.

1Supported by U.S. DOE Grant DE-FG02-86ER553222.

NP8.00047 Initial Ferritic Wall Mode studies on HBT-EP1. PAUL HUGHES, J. BIALEK, A. BOOZER, M.E. MAUEL, J.P. LEVESQUE, G.A. NAVRATIL, Columbia Univ — Low-activation ferritic steels are leading material candidates for use in next-generation fusion development experiments such as a prospective US component test facility and DEMO [1]. Understanding the interaction of plasmas with a ferromagnetic wall will provide crucial physics for these experiments. Although the ferritic wall mode (FWM) was seen in a linear machine [2], the ferritic steel was observed to be compatible with high-performance operation in JFT-2M [3]. Using its high-resolution magnetic diagnostics and adjustable wall segments, HBT-EP now operates successfully with a high-permeability (µ ≈ 8) tilled ferritic first wall and is exploring the dynamics and stability of kink modes interacting with the ferritic tiles. In this poster, we report the first studies of the evolution of naturally rotating modes, increased plasma response to phase-flip resonant magnetic perturbations (RMPs) [4], and enhanced plasma disruption as wall configuration is adjusted from stainless wall to ferritic wall configuration.

1Supported by U.S. DOE Grant DE-FG02-86ER553222.
NP8.00048 Investigation of Multi-Mode MHD Behavior in Shaped HBT-EP Discharges\textsuperscript{1} , PATRICK BYRNE, J.P. LEVESQUE, M.E. MAUEL, Q. PENG, D.J. RHODES, P.E. HUGHES, G.A. NAVRATIL, Columbia University — We report on investigations into the effect on multimode MHD of a newly installed poloidal field (PF) coil. The coil will allow the circular, limited HBT-EP to follow the main thrust of research towards a fusion reactor, which has been directed toward plasmas that are shaped and diverted. The coil shapes the high field side of the plasma up to and including imposing a PF null, while retaining compatibility with existing diagnostics and control systems. Multimode dynamics have been detected in naturally-rotating kink modes and during the response to 3D resonant magnetic perturbations\textsuperscript{2}. Shaping changes both the resonant helical characteristics of MHD instabilities and the plasma response to external excitation and active control. Calculations using the TokaMac and DCON code\textsuperscript{3} have predicted that the coupling between the two least stable MHD kink modes would be reduced when edge $q^*$ is near resonance. The RMP response, mode structure, and multi-mode content of diverted plasmas are compared to limited states. Preliminary results show shaping changes the relative strengths of the $n = 1$ and $n = 2$ modes.

\textsuperscript{1}Supported by DOE Grant DE-FG02-86ER53222.
\textsuperscript{2}Levesque, et al., Nucl Fusion 53, 073037 (2013).

NP8.00049 Advanced feedback control of wall modes using active rotation control on HBT-EP\textsuperscript{1} , QIAN PENG, JEFF LEVESQUE, CHRIS STOAFAER, DOV RHODES, PAUL HUDGES, PATRIC BYRNE, MICHAEL MAUEL, GERALD NAVRATIL, Columbia Univ — The HBT-EP tokamak can excite strong, saturated kink modes whose growth\textsuperscript{2} and rotation frequencies evolve on a millisecond timescale. To control such modes, HBT-EP uses a GPU-based feedback system in a low latency architecture\textsuperscript{3} . When feedback is applied, the mode amplitude changes but the rotation frequency also changes quickly. The product of the latency, 20\mu s, and the mode frequency, around 8 kHz, is 0.16. This adds difficulty to robust feedback control even with a low latency controller\textsuperscript{4}. To overcome this challenge, we have included active control of the bias voltage applied on an edge probe into the feedback loop. The bias voltage applied on the edge probe enables us to influence the rotation of the modes in real-time. The variation in geometry of the system, where we observe that the detected mode amplitude has a phase dependency, is also taken into consideration in the algorithm design. In addition, HBT-EP can vary the wall configuration and includes ferritic wall effects. The feedback algorithm is tested on all cases and the performance will be reported.

\textsuperscript{1}Supported by U.S. DOE Grant DE-FG02-86ER53222.
\textsuperscript{3}Rath, et al., Nucl Fusion 53, 073052 (2013).

NP8.00050 Modeling Error-Field Response of the Resistive Wall Mode\textsuperscript{1} , DOV RHODES, A.J. COLE, G.A. NAVRATIL, J. BIALEK, A.H. BOOZER, Columbia University, R. FITZPATRICK, University of Texas at Austin, J.P. LEVESQUE, M.E. MAUEL, Q. PENG, Columbia University — Stability of the resistive wall mode (RWM) is sensitive to error-fields as small as $10^{-4}$ [1]. Error-fields introduced by slight coil misalignments can induce localized resonant torques generated by shielding currents in a resistive plasma, as well as a global non-resonant torque created by symmetry-breaking deformations of the magnetic surfaces. The latter effect, termed necoclastic toroidal viscosity (NTV), is of particular interest as tokamak plasmas become hotter and less collisional. Both torques contribute to rotation damping which tends to non-linearly destabilize the RWM. Fitzpatrick’s 2010\textsuperscript{1} quasi-linear sharp-boundary model of the multi-mode plasma response includes the non-ideal effect of resonant torques. We present an extended model including NTV to study the effect of error-field driven torques and plasma shaping on the evolution of the RWM. The model will be formulated to provide input for Bialak’s VALEN code [2], which calculates RWM stability in the presence of a realistic conducting wall geometry. A better understanding of the plasma response to error-fields will facilitate more effective design of feedback control systems in a tokamak.

\textsuperscript{1}Fitzpatrick, Phys. Plasmas 17, 112502 (2010).
\textsuperscript{2}J. Bialek, Phys. Plasmas 8, 2170 (2001).

NP8.00051 MEASUREMENT AND DIAGNOSTIC TECHNIQUES

NP8.00052 Fast, Deep-Record-Length, Fiber-Coupled Photodiode Imaging Array for Plasma Diagnostics\textsuperscript{1} , SAMUEL BROCKINGTON, ANDREW CASE, F. DOUGLAS WITHERSPOON, HyperV Technologies Corp — HyperV Technologies has been developing an imaging diagnostic comprised of an array of fast, low-cost, long-record-length, fiber-optically-coupled photodiode channels to investigate plasma dynamics and other fast, bright events. By coupling an imaging fiber bundle to a bank of amplified photodiode channels, imagers and streak imagers of 100 to 1000 pixels can be constructed. By interfacing analog photodiode systems directly to commercial analog-to-digital converters and modern memory chips, a prototype 100 pixel array with an extremely deep record length (128k points at 20 Msamples/sec) and 10 bit pixel resolution has already been achieved. HyperV now seeks to extend these techniques to construct a prototype 1000 Pixel framing camera with up to 100 Msamples/sec rate and 10 to 12 bit depth. Preliminary experimental results as well as Phase 2 plans will be discussed. Work supported by USDoe Phase 2 SBIR Grant DE-SC0009492.

NP8.00053 In-situ Testing of the EHT High Gain and Frequency Ultra-Stable Integrators\textsuperscript{1} , KENNETH MILLER, TIMOTHY ZIEMBA, JAMES PRAGER, ILIA SLOBODOV, DAN LOTZ, Eagle Harbor Technologies, Inc. — Eagle Harbor Technologies (EHT) has developed a long-pulse integrator that exceeds the ITER specification for integration error and pulse duration. During the Phase I program, EHT improved the RPPL short-pulse integrators, added a fast digital reset, and demonstrated that the new integrators exceed the ITER integration error and pulse duration requirements. In Phase II, EHT developed Field Programmable Gate Array (FPGA) software that allows for integrator control and real-time signal digitization and processing. In the second year of Phase II, the EHT integrator will be tested at a validation platform experiment (HIT-SI) and tokamak (DIII-D). In the Phase IIb program, EHT will continue development of the EHT integrator to reduce overall cost per channel. EHT will test lower cost components, move to surface mount components, and add an onboard Field Programmable Gate Array and data acquisition to produce a stand-alone system with lower cost per channel and increased the channel density. EHT will test the Phase IIb integrator at a validation platform experiment (HIT-SI) and tokamak (DIII-D).

\textsuperscript{1}Work supported by the DOE under contract number (DE-SC0006281).

NP8.00054 Real-time EFIT data reconstruction based on neural network in KSTAR, SEHYUN KWAK, Department of Nuclear and Quantum Engineering, KAIST, Daejeon, Korea, YOUNGMU JEON, National Fusion Research Institute, Daejeon, Korea, YOUNG-CHUL GHIM, Department of Nuclear and Quantum Engineering, KAIST, Daejeon, Korea — Real-time EFIT data can be obtained using a neural network method. A non-linear mapping between diagnostic signals and shaping parameters of plasma equilibrium can be established by the neural network, particularly with the multilayer perceptron. The neural network is utilized to attain real-time EFIT data for Korea Superconducting Tokamak for Advanced Research (KSTAR). We collect and process existing datasets of measured data and EFIT data to train and test the neural network. Parameter scans such as the numbers of hidden layers and hidden units were performed in order to find the optimal condition. EFIT data from the neural network was compared with both offline EFIT and real-time EFIT data. Finally, we discuss advantages of using neural network reconstructed EFIT data for real time plasma control.
NP8.00055 Generating synthetic 3D density fluctuation data to verify two-point measurement of parallel correlation length. JAEWOOK KIM, YOUNG-CHUL GHIM, Department of Nuclear and Quantum Engineering, KAIST, Daejeon 305-701, Republic of Korea, NUCLEAR FUSION AND PLASMA LAB TEAM — A BES (beam emission spectroscopy) system and an MIR (Microwave Imaging Reflectometer) system installed in KSTAR measure 2D (radial and poloidal) density fluctuations at two different toroidal locations. This gives a possibility of measuring the parallel correlation length of ion-scale turbulence in KSTAR. Due to lack of measurement points in toroidal direction and shorter separation distance between the diagnostics compared to an expected parallel correlation length, it is necessary to confirm whether a conventional statistical method, i.e., using a cross-correlation function, is valid for measuring the parallel correlation length. For this reason, we generated synthetic 3D density fluctuation data following Gaussian random field in a toroidal coordinate system that mimic real density fluctuation data. We measure the correlation length of the synthetic data by fitting a Gaussian function to the cross-correlation function. We observe that there is disagreement between the measured and actual correlation lengths, and the degree of disagreement is a function of at least, correlation length, correlation time and advection velocity of synthetic data. We identify the cause of disagreement and propose an appropriate method to measure correct correlation length.

NP8.00056 A parallelized Python based Multi-Point Thomson Scattering analysis in NSTX-U. JARED MILLER, Northeastern University, AHMED DIALLO, BENOIT LEBLANC, Princeton Plasma Physics Laboratory — Multi-Point Thomson Scattering (MPTS) is a reliable and accurate method for the determination of temperature, density, and pressure of a magnetically confined plasma. Nd:YAG (1064 nm) lasers are fired into the plasma with a frequency of 60 Hz, and the light is Doppler shifted by Thomson scattering. Polychromators on the midplane of the tokamak pick up the light at various radii/scattering angles, and the avalanche photodiode’s voltages are added to an MDSplus tree for later analysis. This project ports and optimizes the prior serial IDL MPTS code into a well-documented Python package that runs in parallel. Since there are 30 polychromators in the current NSTX setup (12 more will be added when NSTX-U is completed), using parallelism offers vast savings in performance. NumPy and SciPy further accelerate numerical calculations and matrix operations. Matplotlib and PyQt make an intuitive GUI with plots of the output, and MultiProcessing parallelizes the computationally intensive calculations. The Python package was designed with portability and flexibility in mind so it can be adapted for use in any polychromator-based MPTS system.

NP8.00057 An Alternative Optical Concept for Electron Cyclotron Emission Imaging (ECEI). JASON LIU, UC Berkeley, JUNE-EOK LEE, Postech University, MANFRED BITTER, PPPL, BURKHARD PLAUM, Stuttgart University, WOOCHANG LEE, HYEON PARK, Unist University, GUNSU YUN, Postech University, WALTER KASPAREK, Stuttgart University, UC BERKELEY TEAM, PPPL TEAM, POSTECH UNIV., UNIST UNIV. COLLABORATION, STUTTGART UNIVERSITY TEAM — The implementation of advanced ECEI systems on tokamak experiments has revolutionized the diagnostic of MHD activities and improved our understanding of instabilities, which lead to disruptions. It is therefore desirable to have an ECEI system on ITER. However, present ECEI systems require large access ports and employ cumbersome optical components that have, up to now, precluded the implementation of such an ECEI system on ITER. This poster describes an alternative optical ECEI concept that utilizes a single spherical mirror as the primary optical component and exploits the astigmatism of such a mirror to produce an image of the radiating plasma with one-dimensional spatial resolution on the detector. Since this alternative approach would only require a thin slit as the viewing port to the plasma, it would make the implementation of an ECEI system on ITER feasible. Experimental results from laboratory characterization of this optical system are presented and compared to numerically simulated results. Possible approaches to implementing this ECEI system on ITER are also discussed.

1 We gratefully acknowledge the support of this work by the US Department of Energy Contract No. DE-AC02-09CH11466 and Korean NRF Contract No. 20120005920.

NP8.00058 Probing Runaway Electrons with Nanoparticle Plasma Jet. I.N. BOGATU, J.R. THOMPSON, S.A. GALKIN, J.S. KIM, FAR-TECH, Inc. — The injection of C60/C nanoparticle plasma jet (NPPJ) into tokamak plasma during a major disruption has the potential to probe the runaway electrons (REs) during different phases of their dynamics and diagnose them through spectroscopy of C ions visible/UV lines. A C60/C NPPJ of ~ 75 mg, high-density (~10^23 m^-3), hyper-velocity (~4 km/s), and uniquely fast response-to-delivery time (~1 ms) has been demonstrated on a test bed. It can rapidly and deeply deliver enough mass to increase electron density to ~2.4x10^21 m^-3, ~60 times larger than typical DIII-D pre-disruption value. We will present the results of our investigations on: 1) C60 fragmentation and gradual release of C atoms along C60 NPPJ penetration path through the RE energy-residual cold plasma, 2) estimation of photon emissivity coefficient for the lines of the C ions, and 3) simulation of C60/C PJ penetration to the RE beam location in equivalent conditions to the characteristic ~ 1 T B-field of DIII-D. The capabilities of this injection technique provide a unique possibility in understanding and controlling the RE beam, which is a critical problem for ITER.

2 Work supported by US DOE DE-SC0011864 grant

NP8.00059 A method of diagnosing magnetized plasmas using Raman scattering. MINSUP HUR, MYUNGHOON CHO, YOUNGKUK KIM, Ulsan NaI Inst of Sci & Tech — We propose a method to diagnose a magnetized plasma using Raman scattering. It is found from the X-mode dispersion relation that the frequency of the backward scattered wave is downshifted by an amount of upper hybrid frequency, while that of the forward scattered wave merely depends on the magnetic field. Such a spectral difference is used to measure simultaneously the plasma density and magnetic field of magnetized plasmas. The idea was verified by a series of 1D PIC simulations, where we used the directional field splitting method to obtain accurate peak position of the scattered waves’ frequencies. Theoretical expectation of the frequency shift and the growth rate gives a possibility to applying diagnostics of Tokamak.

1 plasma diagnostics

NP8.00060 Analysis of Tangential Camera Views of Tokamak Plasmas. W.H. MEYER, M.E. FENSTER-MACHER, LLNL, M. GROTH, Aalto University — Commercial digital video cameras are increasingly being employed as sensor and digitizer for fusion plasma diagnostics. Here we describe some of our recent work to significantly improve tomographic analysis of tangential viewing camera data in toroidal geometry. Fiducial images obtained during vents are used to produce direct linear transformation matrices for each diagnostic camera and determine an accurate camera position and viewport. A tokamak solid model for rendering is used between vents to check camera alignment or when hardware fiducial images are unavailable. The rendering provides camera pixel distance of integration, vessel impact position, and angle of incidence. Reflection characterization is also performed using this solid model. After determining the camera geometry parameters, a response matrix is calculated for toroidally symmetric solution grids. We apply standard SPS to the back projection problem for filtered visible light cameras. Forward projections are utilized for theory code validation and visualization. Poloidal IR profiles are extracted from tangential viewing IR camera data using surface parameters determined from solid model rendering. We present examples of each of these applications.

2 This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
NP8.00061 In-situ measurement of low Z coating thickness on metal substrates, A.L. ROQUEMORE, M. JAWORSKI, C.H. SKINNER, J. MILLER, Princeton Plasma Physics Laboratory — The surface composition of plasma facing components in magnetic fusion devices critically affects plasma performance but is difficult to measure in situ. We have used a compact assembly of an annular solid state detector and alpha particle source to employ Rutherford backscattering (RBS) to measure the thickness of a coating of low Z material on a heavier substrate in as little as 2 hours per location. RBS of energetic particles is typically used as a technique to measure near surface concentrations of high Z atoms in a substrate comprised mainly of lighter atoms. We have demonstrated its utility to determine the thickness of a coating of a low Z material on a heavier substrate in a short time. With a moveable probe, this technique could be used to provide an in situ thickness measurement of the Be, Li, B, and C coatings on metal tiles in 2 hours per location. A test stand was used to determine the range of low-Z thicknesses that can be measured on Mo tiles. The detector and electronics were calibrated by detecting the 5.423 MeV alpha particles emitted from a thin, 1 nCi, 241Am source. This enabled the energy spectrum emitted from the thicker 0.1 mCi source to be measured (4.24 MeV centroid and 0.62 MeV FWHM) and the energy loss of the alpha particles in the low Z coating to be determined. A Monte Carlo program was used to investigate effects of the large energy spread of the thick 0.1 mCi source and of the detailed geometrical setup.

1 Work supported by U.S.D.O.E. Contract No. DE-AC02-09CH11466

NP8.00062 Determination of the Relative Two-photon Absorption Cross-section Between Xenon and Hydrogen, DREW ELLIOTT, EARL SCIME, DUSTIN MCCARREN, ROBERT VANDERVORT, MARK SODERHOLM, West Virginia University — Two-photon Absorption Laser Induced Fluorescence (TALIF) is a non-perturbative method for measuring the density and temperature of neutral hydrogen in a fusion plasma. Calibration of a TALIF system, for absolute density measurements, requires a measurement of a known density of particles under controlled conditions. Since hydrogen is diatomic, hydrogen TALIF system calibration requires measurements of target cold monatomic gas with a two-photon transition from the ground state and fluorescence decay at accessible energies. Here we present single-sided TALIF (angular momentum change of 2) measurements of a new transition in xenon with absorption and emission wavelengths nearly identical to those of the hydrogen TALIF sequence (the n = 3 to n = 2 emission in hydrogen is at 656.27 nm whereas it is at 655.99 nm in xenon). The xenon calibration approach provides the first opportunity for absolute calibration of Doppler-free (angular momentum change of 0) hydrogen TALIF. We first measure the relative TALIF absorption cross section between xenon and krypton and then use the known cross section ratio between the krypton and hydrogen transitions to calculate the relative xenon-hydrogen cross section. Single isotope xenon samples are used to remove the confounding factors of isotopic and hyperfine splitting.

NP8.00063 Development of Low Pressure High Density Plasmas on the Helicon Plasma Experiment (HPX), ROYCE JAMES, PHILLIP AZZARI, PAUL CRILLY, OMAR DUKE-TINSON, JACKSON KARAMA, RICHARD PAOLINO, CARTER SCHLANK, JUSTIN SHERMAN, US Coast Guard Academy — The small Helicon Plasma Experiment (HPX) at the Coast Guard Academy Plasma Lab (CGAPL), continues to progress toward utilizing the reputed high densities (10cm$^{-3}$ and higher) at low pressure, (0.1 T) [1] of helicons, for eventual high temperature and density diagnostic development in future laboratory investigations. HPX is designed to create repeatedly stable plasmas induced by an RF frequency in the 10 to 70 MHz range. We employ a 400 to 1000 Gauss electromagnet that promotes energy conservation in the plasma via external energy production in the magnetic field facilitated by decreased inertial effects, in order to reach the Helicon Mode. HPX is completing construction of triple and mach particle probes, magnetic probes, and is designing a single point 300 W Thompson Scattering system backed by a 32-channel Data Acquisition (DAQ) system capable 12 bits of sampling precision at 2 MS/s for HPX plasma property investigations. Progress on the development of the RF coupling system, Helicon Mode development, magnetic coils, and observations from the optical, particle, and electromagnetic scattering diagnostics will be reported.


1 Supported by U.S. DEPS Grant [HEL-JTO] PRWJFY13

NP8.00064 Status of motional Stark effect and Zeeman effect diagnostics for KSTAR, JINSEOK KO, JINIL CHUNG, Natl Fusion Res Inst, MAARTEN DE BOCK, ITER Organization, THE KSTAR TEAM — The motional Stark effect (MSE) diagnostic system is under development aiming at commissioning in 2015. The design and fabrication of the polarization preserving front optics has been complete, including the multi-layer dielectric coated mirror and beam splitter, the latter being required to split the incident light into that above 600 nm for MSE and a minimum distortion against tilting have been procured. Both the analog lock-in and the post-processing numerical Fourier transform will be exploited. Including the multi-layer dielectric coated mirror and beam splitter, the latter being required to split the incident light into that above 600 nm for MSE and a minimum distortion against tilting have been procured. Both the analog lock-in and the post-processing numerical Fourier transform will be exploited. The Li-beam based Zeeman effect (ZE) diagnostic system is under development aiming at commissioning in 2015. The design and fabrication of the polarization preserving front optics has been complete, including the multi-layer dielectric coated mirror and beam splitter, the latter being required to split the incident light into that above 600 nm for MSE and a minimum distortion against tilting have been procured. Both the analog lock-in and the post-processing numerical Fourier transform will be exploited. The design and fabrication of the polarization preserving front optics has been complete, including the multi-layer dielectric coated mirror and beam splitter, the latter being required to split the incident light into that above 600 nm for MSE and a minimum distortion against tilting have been procured. Both the analog lock-in and the post-processing numerical Fourier transform will be exploited.

NP8.00065 LOW TEMPERATURE PLASMAS; PRODUCTION, IONIZATION KINETICS AND SHEATHS

NP8.00066 Temporally and Spatially Resolved Electron Density Measurements of an Air Breakdown Plasma Using a 1.4 MW, 110 GHz Gyrotron, SAMUEL SCHAUB, JASON HUMMELT, WILLIAM GUSS, MICHAEL SHAPIRO, RICHARD TEMKIN, Massachusetts Inst of Tech-MIT — A megawatt-class, 110 GHz gyrotron was used to produce a linearly polarized, quasioptical beam in 3 µs pulses. Using a lens, the beam was focused to a 3.2 mm spot size, producing a peak electric field of 57 kV/cm, after transmission losses. This electric field was great enough to produce a breakdown plasma in air at pressures ranging from a few Torr up to atmospheric pressure. The resulting breakdown plasma spontaneously forms a two-dimensional array of filaments, oriented parallel to the polarization of the beam, that propagate toward the microwave source. In our latest experiments, a needlepoint initiator has been introduced at the focal point of the beam, creating highly reproducible plasma arrays. Taking advantage of this reproducibility, the dynamics of the array formation and propagation were captured using a 2 ns fast gating intensified CCD camera (ICCD). The ICCD was combined with a two-wavelength laser interferometer, operating at 532 and 635 nm, to make spatially and temporally resolved electron density measurements of the plasma array. Abel inversion techniques were applied to the resulting line integrated data resulting in local measurements of electron density.

1 This work was supported by an AFOSR grant on the Basic Physics of Distributed Plasma Discharges.
NP8.00067 Time-Resolved High-Spatial-Resolution Measurements of Underwater Laser Ionization and Filamentation\textsuperscript{1} \quad TED JONES, MIKE HELLE, DMITRI KAGANOVICH, ANTONIO TING, JOE PENANO, BAHMAN HAFIZI, Plasma Physics Div., Naval Research Laboratory, Washington, DC, YU-HSIN CHEN, Research Support Instruments, Lanham, MD — Intense underwater laser propagation, filamentation, and ionization are being investigated at NRL for applications including laser-guided discharges, advanced micromachining, and low-frequency laser acoustic generation. Time-resolved spectroscopy of intense underwater propagation and filamentation reveal strong Stimulated molecular Raman Scattering with ps temporal structure and frequency chirp. In addition, fs-time-resolution perpendicular shadowgraph images of ns underwater laser ionization reveal gas microbubble generation throughout the pump beam path. These microbubbles form in ps timescales with remarkably uniform initial diameters of few-microns. Simulations using the HELCAP 4D nonlinear laser propagation code accurately predict measured filament fluence profiles and propagation, but also indicate complex, time-dependent and axially non-uniform plasma behavior. Results from recent experiments and simulations will be presented.

\textsuperscript{1}This work is supported by NRL Base Funds.

NP8.00068 Amplification of 126 nm femtosecond seed pulses in optical-field-induced Ar plasma filamentation, SHOICHI KUBODERA, NAQYUKI DESHIMARU, MASANORI KAKU, MASHIKIO KATTO, University of Miyazaki — We have observed amplification of femtosecond (fs) VUV coherent seed beam at 126 nm by utilizing an optical-field-induced ionization (OFI) high-pressure Ar plasma filamentation. We have produced a low-temperature and high-density Ar plasma filamentation inside a high-pressure Ar cell by irradiating a high-intensity laser with an intensity of approximately $10^{14}$ Wcm\textsuperscript{-2}. Argon excimer molecules (Ar\textsubscript{2}\textsuperscript{+}) as an amplifier medium were produced inside the high-pressure cell and were used to amplify a weak VUV ultrashort seed pulse at 126 nm, which was generated by harmonic generation of another short pulse infrared laser at 882 nm. We have measured the amplification characteristics and the OFI plasma diagnostics by utilizing the fs VUV pulses at 126 and 882 nm, respectively. The maximum optical gain value of 1.1 cm\textsuperscript{-1} was observed. Temporal behaviors of the plasma temperature and density in the nano-second time scale indicated a high-density and low-temperature plasma produced by the OFI. These plasma behaviors were utilized to reproduce the optical amplification characteristics with our OFI excimer simulation code.

NP8.00069 RF Discharge Equilibrium, Transport, and Afterglow Radiation and Density Peaks in a Pre-Ionization Source for the Caltech MHD-Driven Jet Experiment, VERNON CHAPLIN, PAUL BELLAN, Caltech — A novel pulsed battery-powered RF plasma source has been developed for pre-ionization in the Caltech MHD-driven jet experiment, enabling the formation of lower mass, faster jets than was possible with neutral gas breakdown alone. Results of jet experiments relevant to astrophysical and fusion plasmas will be presented, along with characteristics of the custom 3 kW, 13.56 MHz RF amplifier and detailed studies of the argon RF plasma properties. The discharge conditions as a function of power input and axial magnetic field were monitored with Langmuir probes and optical spectroscopy; comparison of the data with a global discharge model indicated that the source was operating in a primarily inductively coupled mode with peak $n_e > 3 \times 10^{19}$ m\textsuperscript{-3}. A 1D transport model has been developed to quantitatively explain the expansion of the RF plasma into the jet experiment chamber. The plasma transitioned from an ionizing to recombining phase during the course of the experiment, causing fast camera images to be a poor indicator of the density distribution. The optical brightness in the afterglow was proportional to the gas pressure and exceeded the main discharge brightness above 500 mTorr, and the downstream ion density also increased after power turn-off, likely due to metastable-metastable ionization.

NP8.00070 Measurement of CO\textsubscript{2} laser absorption by tin plasma emanating extreme ultraviolet light for photo-lithography\textsuperscript{1}, HIRAKU MATSUKUMA, KENSUKE YOSHIDA, TATSUYA HOSODA, AKIFUMI YOGO, SHINSUKE FUJIOKA, KATSUNOBU NISHIHARA, Osaka University, ATSUSHI SUNAHARA, TOSHIHIRO SOMEKAWA, Institute of Laser Technology, HIROAKI NISHIMURA, Osaka University — Laser-driven tin plasma has been studied as a light source of extreme ultraviolet (EUV) at 13.5 nm (+/- 1% in-band width) for the next-generation semiconductor manufacturing. By using CO\textsubscript{2} laser as a driver, high conversion efficiency (CE) has been attained in previous works by optimizing optical thickness for EUV radiation. Radiation hydrodynamic simulation predicts, however, that absorption coefficient for CO\textsubscript{2} laser is as high as 50% for a tin plasma generated with a single laser pulse mainly due to short plasma scale. The relatively low absorption is a crucial problem for efficient generation of EUV light. In order to solve this problem and to increase the energy absorption, a double pulse method has been proposed where plasma scale length is extended by pre-pulse irradiation. Therefore, it is important to measure CO\textsubscript{2} laser absorption rate precisely in order to optimize plasma conditions. For this purpose we designed an integrating sphere for CO\textsubscript{2} laser. Laser absorption was measured for tin plasmas generated under various conditions including target geometries. We will show experimental results and discuss on guidelines for getting higher CE.

\textsuperscript{1}This study has been partly supported by Strategic Innovation Program for Energy Conservation Technologies in 2013 from New Energy and Industrial Technology Development Organization (NEDO) of Japan.

NP8.00071 Development of a volume production type hydrogen negative ion source by using sheet plasma, SATOKI MATSUMOTO, TAKAAKI IJIMA, AKIRA TONEGAWA, Tokai Univ, KOHNOUSUKE SATO, Chubu Electric Power Co. Inc., KAZUTAKA KAMAMURA, Tokai Univ — Stationary production of negative ions is important to play an essential role in Neutral beam injection (NBI). Cesium seeded Surface-production of negative ion sources are used for NBI. However, Cesium seeded surface- production of negative ion sources are not desirable from the point of view of operating steady state ion sources. We carried out the volume production of negative ion sources by volume-production in hydrogen sheet plasma. Production of hydrogen negative ions through volume processes needs both high energy electron region and low energy electron region. The sheet plasma is suitable for the production of negative ions, because the electron temperature in the central region of the plasma as high as 10 – 15eV, whereas in the periphery of the plasma, a low temperature of a few eV of obtained. The hydrogen negative ion density was detected using an omegatron mass analyzer, while the electron density and temperature were measured using a Langmuir probe. Negative ions current extracted from the grid are measured by Faraday-cup.

NP8.00072 Microwave Assisted Helicon Source Plasma, JOHN MCKEE, ROBERT VANDERVORT, MARK SODERHOLM, DUSTIN MCCARREN, EARL SCIME, West Virginia University — Helicon plasma sources are an efficient method by which plasmas of relatively high densities can be produced. However, the temperature of these plasmas is comparatively low. Electron temperatures are often only a few eV, with ion temperatures being a factor of ten below that. These temperatures are too low to study ion behavior in lighter noble gases, such as helium, using laser induced fluorescence (LIF) schemes as the energy difference between the ion ground state and excited levels is typically tens of eV. To bridge this energy divide, a 1.2 kW source of 2.45 GHz microwaves is used in addition to the normal rf helicon source. Through electron cyclotron resonance (ECR) heating, the electron temperature is raised and low lying ion energy states are populated. Here we present spectroscopic measurements of microwave assisted helium plasmas.
related to plasma instabilities? The current and azimuthal flow profiles of the jets are tailored by biasing the electrodes at different potentials. High-speed effect of current and flow profiles on the collimation and stability of jets to address the questions: why are jets collimated and long? How are jet irregularities of magnetized helical flows in plasma jets provides boundary conditions and dimensionless numbers relevant to astrophysical jets. The goal is to observe the VON DER LINDEN, SETTHIVOINE YOU, University of Washington — A triple electrode planar plasma gun (MOCHI LabJet) designed to study the dynamics suggests that destabilizing magnetic energy can be converted into stabilizing shear flows at two-fluid spatial scales of reconstructing 3D ion flow fields. Time-resolved measurements will determine if magnetic helicity is converted into ion kinetic helicity as predicted by the theory of canonical helicity transport. The theory suggests that fundamental tubes of magnetic flux with helical flows (canonical flux tubes) could be stabilized to large aspect-ratios by converting helical magnetic pitch into helical shear flows.

NP8.00074 The MOCHI LabJet Experiment1. SETTHIVOINE YOU, JENS VON DER LINDEN, KEON VEREEN, ERIC SANDER LAVINE, EVAN CARROLL, ALEX CARD, MANUEL AZUARA ROSALES, MORGAN QUNILEY, University of Washington — The MOCHI LabJet experiment aims to simulate a magnetically driven jet launched by an accretion disk in the laboratory. The design uses three concentric planar electrodes linked by a vacuum magnetic field to drive azimuthal and axial shear flows in a jet configuration. Azimuthally symmetric gas sources reduce any anchoring effects on azimuthal rotation of the plasma. Two pulse-forming networks bias the electrodes to control the radial electric field profile and the azimuthal shear rotation profile. The dynamics of plasma jets are observed with 3D high-resolution magnetic probe arrays and computed vector tomography of ion Doppler spectroscopy. Vector tomography is capable of reconstructing 3D ion flow fields. Time-resolved measurements will determine if magnetic helicity is converted into helical magnetic pitch into helical shear flows. This work is supported by US DOE Grant DE-SC0010340.

NP8.00075 Optically Isolated Control of the MOCHI LabJet High Power Pulsed Plasma Experiment1, EVAN CARROLL, MORGAN QUNILEY, JENS VON DER LINDEN, SETTHIVOINE YOU, University of Washington — The MOCHI LabJet experiment designed to investigate the dynamics of astrophysical jets at the University of Washington, requires high energy pulsed power supplies for plasma generation and sustainment. Two 600 µF, 10 kV DC, pulse forming, power supplies have been specifically developed for this application. For safe and convenient user operation, the power supplies are controlled remotely with optical isolation. Three input voltage signals are required for relay actuation, adjusting bank charging voltage, and to fire the experiment: long duration DC signals, long duration user adjustable DC signals and fast trigger pulses with < 1 µs rise times. These voltage signals are generated from National Instruments timing cards via LabVIEW and are converted to optical signals by coupling photodiodes with custom electronic circuits. At the experiment, the optical signals are converted back to usable voltage signals using custom circuits. These custom circuits and experimental set-up are presented. This work is supported by US DOE grant DE-SC0010340.

NP8.00076 Dynamics of Laboratory Astrophysical Jets with Magnetized Helical Flows1, JENS VON DER LINDEN, SETTHIVOINE YOU, University of Washington — A triple electrode planar plasma gun (MOCHI LabJet) designed to study the dynamics of magnetized helical flows in plasma jets provides boundary conditions and dimensionless numbers relevant to astrophysical jets. The goal is to observe the effect of current and flow profiles on the collimation and stability of jets to address the questions: why are jets collimated and long? How are jet irregularities related to plasma instabilities? The current and azimuthal flow profiles of the jets are tailored by biasing the electrodes at different potentials. High-speed camera images, high-resolution B probe measurements, and 3D vector tomography of plasma flows will map a stability space for varying current and flow profiles. An analytical stability space is derived with Newcomb’s variational analysis applied to collimated magnetic flux tubes with skin and core currents. Two numerical stability spaces are also computed by integrating the Euler-Lagrange equation and applying a shooting method to the ideal MHD eigenvalue problem. The eigenvalue problem is generalized to include azimuthal flows and computed with a monotonicity condition [1] for minimizing the required scanning of the complex eigenvalue space.


This work was sponsored in part by the US DOE Grant DE-SC0010340.

NP8.00077 High-Resolution B Dot Probe for Measuring 3D Magnetic Fields in the MOCHI LabJet Experiment1, MANUEL AZUARA ROSALES, JENS VON DER LINDEN, SETTHIVOINE YOU, University of Washington — The MOCHI Labjet experiment will use a triple electrode planar plasma gun to explore canonical helicity transport in laboratory astrophysical jets. Canonical helicity transport suggests that destabilizing magnetic energy can be converted into stabilizing shear flows at two-fluid spatial scales $i_c \sim \pi B_i c / \nu_p$. A high-resolution $B$ probe array, capable of measuring magnetic field dynamics at length and time scales important to canonical helicity transport is being built. The probe array consists of three tridents, made of 5.13 mm OD and 4.32 mm ID stainless steel tubes of 102 cm length, enclosing a total of 1215 commercial inductor chips with a three axis spatial resolution of 11 mm. The average value for the effective NA of each inductor chip is $1.21 \times 10^{-4}$ m². The probe array lays in a plane perpendicular to the jet, and is axially translatable. This work is supported by US DOE Grant DE-SC0010340.

NP8.00078 Optical diagnostics in the MOCHI LabJet experiment, ALEXANDER CARD, KEON VEREEN, CHRIS CRETEL, SETTHIVOINE YOU, Univ of Washington — The MOCHI LabJet experiment is designed to observe the dynamics of canonical flux tubes and measure the conversion of magnetic helicity into ion flow helicity. In addition to magnetic probes capable of measuring 3D magnetic fields, Ion Doppler spectroscopy will reconstruct 3D flow field from computed vector tomography of line-integrated ion Doppler measurements. About 500 collimated lines-of-sight are distributed into 64 viewpoints regularly arranged around the 1.4m diameter spherical vacuum chamber. The custom fiber-bundles are arranged into a 2D array and coupled to a 1m focal length Czerny-Turner monochromator with custom matching optics. The spectral light is recorded with a dual-frame 1024x1024 intensified CCD camera with a 2 µs phosphor decay time capable of taking two measurements in a single plasma shot. A Mach-Zehnder HeNe interferometer with unequal path lengths is also under construction for line-integrated plasma density measurements. This work is supported by US DOE Grant DE-SC0010340.
NP8.0079 Investigating the Dynamics of Canonical Flux Tubes in Jet Geometry¹, ERIC LAVINE, SETTHIVOINE YOU, University of Washington — Highly collimated plasma jets are frequently observed at galactic, stellar, and laboratory scales. Some models suppose these jets are magnetohydrodynamically-driven magnetic flux tubes filled with flowing plasma, but they do not agree on a collimation process. Some evidence supporting a universal MHD pumping mechanism has been obtained from planar electrode experiments with aspect ratios of ∼1:0.1; however, these jets are subject to kink instabilities beyond a certain length and are unable to replicate the remarkable aspect ratios (10-1000:1) seen in astrophysical systems. Other models propose these jets are flowing Z-pinch plasmas and experiments that use stabilizing shear flows have achieved aspect ratios of ∼30:1, but are line tied at both ends. Can both collimation and stabilization mechanisms work together to produce long jets without kink instabilities and only one end tied to the central object? This question is evaluated from the point of view of canonical flux tubes and canonical helicity transport, indicating that jets can become long and collimated due to a combination of strong helical shear flows and conversion of magnetic helicity into kinetic helicity. The MOCHI LabJet experiment is designed to study this in the laboratory.

¹Supported by US DoE Early Career Grant DE-SC00010340

NP8.0080 A Plasma Tweezer Concept to De-spin an Asteroid, KEON VEREEN, IMAN DATTA, SETTHIVOINE YOU, University of Washington — The Plasma Tweezer is a new concept for controlled de-spinning and deflection of space bodies without mechanical contact. The method shoots plasma jets or beams at the target from a pair of plasma thrusters located at the end of each lever arm of a “tweezer” structure. The main spacecraft body is at the fulcrum point of the tweezer and the target is located between the thrusters. This arrangement cancels out the impulse of two plasma jets on the spacecraft and applies forces on opposite sides of the target. Careful timing and orientation of the jets can then provide the necessary forces to despin and redirect the target. This concept is more efficient than the Ion Beam Shepherd method [Bombardelli C, Pelaez J, “Ion Beam Shepherd for Asteroid Deflection,” J. Guid. Control Dyn. 34(3) 595-601] because it does not require a secondary thruster to cancel momentum and can benefit from angular momentum stored in the spacecraft’s initial spin stabilization.

NP8.0081 Injection of a coaxial-gun-produced magnetized plasma into a background helicon plasma, YUE ZHANG, ALAN LYNN, MARK GILMORE, Univ of New Mexico, SCOTT HSU, Los Alamos National Laboratory — A compact coaxial plasma gun is employed for experimental investigation of plasma bubble relaxation into a lower density background plasma. Experiments are being conducted in the linear device HelCat at UNM. The gun is powered by a 120-uF ignitron-switched capacitor bank, which is operated in a range of 5 to 10kV and 100 kA. Multiple diagnostics are employed to investigate the plasma relaxation process. Magnetized argon plasma bubbles with velocities 1.2Cs, densities 10²⁰ m⁻³ and electron temperature 13eV have been achieved. The background helicon plasma has density 10¹³ m⁻³, magnetic field from 200 to 500 Gauss and electron temperature 1eV. Several distinct operational regimes with qualitatively different dynamics are identified by fast CCD camera images. Additionally a B-dot probe array has been employed to measure the spatial toroidal and poloidal magnetic flux evolution to identify plasma bubble configurations. Experimental data and analysis will be presented.

NP8.0082 Correlating Metastable-Atom Density, Reduced Electric Field, and Electron Energy Distribution in the Early Stages of a 1-Torr Ar Discharge¹, S.H. NOGAMI, J.B. FRANEK, M.E. KOEPKE, V.I. DEMIDOV, West Virginia University, E.V. BARNAT, Sandia National Laboratories — Measurements of electron density, metastable-atom density, and reduced electric field are used to approximate reaction rates [1] for electron-atom collision excitation in a 1-Torr positive column of Ar plasma. This allows us to relate the observed 420.1nm to 419.8nm line-intensity ratio to plasma parameters by invoking a plausible assumption regarding the shape of the electron energy distribution function (EEDF) throughout the discharge [1]. We show that these reaction rates agree well with experimental observations in the late stages of the pulse and we address discrepancies in the initial and transient phases of the discharge. We examine three assumptions made in the model to see if they are violated in any stage of the discharge: (1) The stepwise excitation from the 1s4 and 1s2 resonant states is negligible; (2) The numerical model designed for a 5-Torr plasma is applicable to a 1000-mTorr plasma; and (3) The EEDF is bi-Maxwellian and is modified only slightly due to the presence of electrons or metastable-atoms. We conclude that diagnostic signatures for electron density, metastable-atom density, and reduced electric field can be quantitatively interpreted by this correlation at all stages of the discharge.


¹Work supported by DOE grant DE-SC0001939.

NP8.0083 Atomic modeling and spectral analysis of the Auburn Linear Experiment for Instability Studies (ALEXIS)¹, N. IVAN ARNOLD, ED THOMAS, STUART LOCH, CONNOR BALLANCE, Auburn University — Performing spectroscopic measurements of emission lines in relatively cold laboratory plasmas is challenging because the plasma is often neutral-dominated and is not in thermal equilibrium. However, these types of plasma do offer a unique opportunity for benchmarking the finer details of atomic physics, helping researchers gain a better understanding of fundamental atomic processes in plasmas. In this presentation, we report on recent modifications to ALEXIS intended to allow for a more complete test of the atomic model.

¹This project is supported with funding from NASA and the Department of Energy.

NP8.0084 Systematic Effects in Laser-Induced Fluorescence Measurements of Ion Density and Temperature Caused by Optical Pumping¹, THOMAS LANGIN, TREVOR STRICKLER, PATRICK MCMULLEN, THOMAS KILLIAN, Rice University — Ultracold neutral plasmas of strontium are generated by photoionizing laser-cooled atoms. The plasma evolution is probed by laser induced fluorescence (LIF) via the 5s²S₁/₂-5p²P₁/₂ ion transition. Spectra are obtained by recording LIF intensity at varying laser detunings. The ion temperature, T, is then measured by fitting a Voigt profile to obtain the Doppler width. However, for linearly (circularly) polarized light, 5p²P₁/₂ ions have a 7% (33%) chance of decaying to the dark metastable 5d³D₃/₂ state (dark opposite spin state). Near resonance, where ions are more likely to scatter multiple photons during the LIF process, the observed signal will be depressed due to optical pumping. This causes an artificial broadening in the spectra and thus models suppose these effects are flowing Z-pinch plasmas and experiments that use stabilizing shear flows have achieved aspect ratios of ∼30:1, but are line tied at both ends. Can both collimation and stabilization mechanisms work together to produce long jets without kink instabilities and only one end tied to the central object? This question is evaluated from the point of view of canonical flux tubes and canonical helicity transport, indicating that jets can become long and collimated due to a combination of strong helical shear flows and conversion of magnetic helicity into kinetic helicity. The MOCHI LabJet experiment is designed to study this in the laboratory.

¹This work was supported by the National Science Foundation and the Department of Energy (PHY-0714603), the Air Force Office of Scientific Research (FA9550-12-1-0267), the Department of Defense (NDSEG Fellowship), and Shell.
NP8.00085 Periodic Evolution of a Xe I Population in an Oscillatory Discharge: Comparison between Time-Synchronized Laser-Induced-Fluorescence Measurements and A Dynamic Collisional-Radiative Model1. ANDREANNA FABRIS, CHRISS V. YOUNG, MARK A. CAPPELLI, Stanford Univ, PLASMA PHYSICS LABORATORY, Stanford, CA, USA — We study the evolution of the Xe I (6s(^1)S_2) — 6p(^3)P_2 (834.68 nm) transition lineshape in a plasma discharge oscillating at 60 Hz using time-synchronized laser induced fluorescence (LIF) measurements and a collisional-radiative model. Two different time-synchronized LIF techniques based on phase sensitive detection of the fluorescence signal are applied, yielding consistent results. The maximum observed peak fluorescence intensity occurs at low values of the discharge current, although the peak intensity drops to zero at zero discharge current. The peak intensity also decreases at the discharge current maximum. A dynamic collisional-radiative model of the weakly ionized xenon discharge is also implemented, based on a set of rate equations. The proper electron impact cross-sections and radiative decay rates are identified from the literature and used to compute accurate rate coefficients with the Boltzmann solver Bolsig+, including the time-varying electric field. The time evolution of the probing excited state density predicted by the model shows good agreement with the experimental measurements.2

1 This work is sponsored by the U.S. Air Force Office of Scientific Research with Dr. Mitat Birkan as program manager. CVY acknowledges support from the DOE NNSA Stewardship Science Graduate Fellowship under Contract DE-FC52-08NA28752.

NP8.00086 Ion velocity distribution function measurements in a dual-frequency rf sheath.1. NATHANIEL MOORE, WALTER GEKELMAN, PATRICK PRIBYL, UCLA Department of Physics, YITING ZHANG, MARK KUSHNER, Electrical Engineering and Computer Science, U. Michigan — Ion dynamics are investigated in a dual-frequency rf sheath above a 300 mm diameter biased silicon wafer in an industrial inductively coupled (440 kHz, 500 W) plasma etch tool. Ion velocity distribution (IVD) function measurements in the argon plasma are taken using laser induced fluorescence (LIF). Planar sheets of laser light enter the chamber both parallel and perpendicular to the surface of the wafer in order to measure both parallel and perpendicular IVDs at thousands of spatial positions. A fast (30 ns exposure) CCD camera measures the resulting fluorescence with a spatial resolution of 0.4 mm. The dual-frequency bias on the wafer is comprised of a 2 MHz low frequency (LF) bias and an adjustable 10-20 MHz high frequency (HF) bias. The bias voltages may be switched on and off (f_LF up to 1 kHz, duty cycle 10-90%). Several different bias and timing combinations were tested. Ion energy distribution function and ion flux measurements for each case are compared. For the LF case (no HF), the IVD was found to be uniform to within 5% across the wafer. IVDs at a function of phase of the LF bias were also measured. The LF experimental results are compared with simulations specifically designed for this particular plasma tool.

1 Work supported by the NSF and DOE.

NP8.00087 Particle-in-Cell simulation of secondary electron emission effects in a trench geometry. Y. NISHIMURA, C.W. HUANG, Y.C. CHEN, T.L. LIN, Institute of Space and Plasma Sciences, National Cheng Kung University — A Particle-in-cell simulation code is developed to investigate interaction between plasma and material surfaces in a one dimensional geometry and a two dimensional trench geometry. Both the electron and ion dynamics are incorporated. In the presence of secondary electron emission, the sheath potential can disappear. Repeatedly reflecting electron beam components can drive kinetic instabilities. Asymmetric effects of the reflecting wall conditions as well as Coulomb collisional effects are incorporated into the numerical simulation. This work is supported by National Science Council of Taiwan, NSC 100-2112-M-006-021-MY3 and NSC 103-2112-M-006-021-MY3.

NP8.00088 PIC Simulation of RF Plasma Sheath Formation and Initial Validation of Optical Diagnostics using HPC Resources1. CASEY ICENHOUR, ASHE EXUM, North Carolina State University, ELLIJA MARTIN, DAVID GREEN, Oak Ridge National Laboratory, DAVID SMITH, Tech-X Corporation, STEVEN SHANNON, North Carolina State University — The coupling of experiment and simulation to elucidate near field physics above ICRF antennas presents challenges on both the experimental and computational side. In order to analyze this region, a new optical diagnostic utilizing active and passive spectroscopy is used to determine the structure of the electric fields within the sheath region. Parallel and perpendicular magnetic fields with respect to the sheath electric field have been presented. This work focuses on the validation of these measurements utilizing the Particle-in-Cell (PIC) simulation method in conjunction with High Performance Computing (HPC) resources on the Titan supercomputer at Oak Ridge National Laboratory (ORNL). Plasma parameters of interest include electron density, electron temperature, plasma potentials, and RF plasma sheath voltages and thicknesses. The plasma is modeled utilizing the VSIM plasma simulation tool, developed by the Tech-X Corporation. The implementation used here is a two-dimensional electromagnetic model of the experimental setup. The overall goal of this study is to develop models for complex RF plasma systems and to help outline the physics of RF sheath formation and subsequent power loss on ICRF antennas in systems such as ITER.

1 This work is carried out with the support of Oak Ridge National Laboratory and the Tech-X Corporation.

NP8.00089 An Experiment to Investigate Ion-Ion Two-Stream Instabilities in the Presheath. RYAN T. HOOD, SCOTT D. BAAERUD, FREDERICK N. SKIFF, ROBERT L. MERLINO, University of Iowa — An experiment has been constructed to investigate ion-ion two-stream instabilities and their effect on ion flow velocities near sheaths. The device is a multidipole hot filament discharge operated in a mixture of argon and xenon. An emissive probe will be used to measure the electrostatic potential and laser induced fluorescence (LIF) will be used to measure the ion velocity distributions throughout the presheath of a negatively biased electrode. Optical tagging and LIF will be used to measure fluctuations in the ion distribution functions in an effort to search for evidence of ion-ion two-stream instability. This is thought to be responsible for anomalous friction causing a merging of ions toward a common Bohm speed near the sheath edge. The results of measurements of the basic plasma parameters will be presented as well as a detailed description of the LIF system.

NP8.00090 Expansion into vacuum of a plasma with a two-temperatures electron distribution function. ABDOURAHMANE DIAWE, New Mexico Consortium, CENTRE DE PHYSIQUE THEORIQUE- INTERACTION LASER PLASMA TEAM, U. MONTPELLIER, UFR Physique — Recent developments in laser-plasma ion acceleration has renewed interest in plasma expansion into vacuum theory. This phenomenon is usually described by simple 1-D model using the acceleration of ions under the isothermal or adiabatic pressure of hot electrons. However, the electron energy spectra obtained when a short pulse laser interacts with a solid target is generally composed of two temperatures electrons: a hot electrons population (with low density) and a cold electrons population (with a higher density). We will give an overview of a plasma expansion into a vacuum with a two-temperature electron distribution function. Characteristics (amplitude, microscopic structure) of the rarefaction shock which occurs in the plasma when the hot- to the cold-electron temperature ratio is larger than 5 + √2 are investigated using a semi-infinite plasma. Asymptotic expressions of the quantities of the flow are established in the limit of large temperature ratios. Spatial structures of the ion and electron densities and velocities are presented, together with the prediction of the maximum ion velocity. A second illustration corresponds to the expansion of a thin-film into a vacuum with a two- temperature electron distribution function.

NP8.00091 VAN ALLEN 100 —
NP8.00092 Onset of reconnection in the near magnetotail: PIC simulations, YI-HSIN LIU, NASA-GSFC, JOACHIM BIRN, SSI, WILLIAM DAUGHTON, LANL, MICHAEL HESSE, NASA-GSFC, KARL SCHINDLER, Ruhr-University, Bochum — Using 2.5-dimensional particle-in-cell (PIC) simulations of magnetotail dynamics, we investigate the onset of reconnection in realistic tail configurations. Reconnection onset is preceded by a driven phase, during which magnetic flux is added to the tail at the high-latitude boundaries, followed by a relaxation phase, during which the configuration continues to respond to the driving. We found a clear distinction between stable and unstable cases, dependent on the deformation amplitude and ion/electron mass ratio. The threshold appears consistent with electron tearing. The evolution prior to onset as well as the evolution of stable cases, are largely independent of the mass ratio, governed by the integral entropy conservation as imposed in MHD. This suggests that ballooning instability in the tail should not be expected prior to the onset of tearing and reconnection. The onset time and other onset properties depend on the mass ratio, consistent with expectations for electron tearing. At onset, we found electron anisotropies $T_\perp/T_\parallel = 1.1 - 1.3$, raising growth rates and wave numbers. Our simulations have provided a quantitative onset criterion that is easily evaluated in MHD simulations, provided the spatial resolution is sufficient.\footnote{Liu et al. submitted to JGR}

NP8.00093 Whistler Anisotropy Instabilities as the Source of Banded Chorus: Van Allen Probes Observations and Particle-in-Cell Simulations, S. PETER GARY, Space Science Institute, XIANGRONG FU, MISA M. COWEE, REINHARD H. FRIEDEL, HERBERT O. FUNSTEN, Los Alamos National Laboratory, GEORGE B. HOSPODARSKY, CRAIG KLETZING, WILLIAM KURTH, University of Iowa, BRIAN A. LARSEN, Los Alamos National Laboratory, KAIFUN LIU, Auburn University, ELIZABETH A. MACDONALD, NASA/Goddard Space Flight Center, KYUNGUK MIN, Auburn University, GEOFFREY D. REEVES, RUTH M. SKOUG, DAN WINSKE, Los Alamos National Laboratory — Magnetospheric banded chorus events are enhanced whistler waves with frequencies $\omega \sim \Omega_e/2$. Here two-dimensional particle-in-cell simulations in a magnetized, homogeneous, collisionless plasma test the hypothesis that banded chorus is due to the whistler anisotropy instability excited by two distinct, anisotropic electron components. The electron densities and temperatures are derived from HOPE instrument measurements on the Van Allen Probes A satellite during a banded chorus event on 1 November 2013. Observations show a three-component electron model consisting of a dense, cold (a few tens of eV) population, a less dense, warm (a few hundred eV) anisotropic population, and a still less dense, hot (a few keV) anisotropic population. Simulations show that the warm component drives quasi-electrostatic upper-band chorus, and the hot component drives electromagnetic lower-band chorus; the gap near $\Omega_e/2$ follows from growth of the two distinct instabilities.

NP8.00094 An Experimental Concept for Probing Nonlinear Radiation Belt Physics\footnote{Supported by the Naval Research Laboratory Base Funds}, BILL AMATUCCI, GURU GANGULI, CHRIS CRABTREE, MANISH MITHAIWALA, CARL SIEFRING, ERIK TEJERO, Plasma Physics Division, Naval Research Laboratory — The SMART sounding rocket is designed to probe the nonlinear response of a known ionospheric stimulus. High-speed neutral barium atoms generated by a shaped charge explosion perpendicular to the magnetic field in the ionosphere form a ring velocity distribution of photo-ionized Ba+ that will generate lower hybrid waves. Induced nonlinear scattering of lower hybrid waves into whistler/magnetosonic waves has been theoretically predicted, confirmed by simulations, and observed in the lab. The effects of nonlinear scattering on wave evolution and whistler escape to the radiation belts have been studied and observable signatures quantified. The fraction of the neutral target kinetic energy converted into waves is estimated at 10-12%. SMART will carry a Ba release module and an instrumented daughter section with vector wave magnetic and electric field sensors, Langmuir probes and energetic particle detectors to determine wave spectra in the source region and detect precipitated particles. The Van Allen Probes can detect the propagation of the scattered whistlers and their effects in the radiation belts. By measuring the radiation belt whistler energy density, SMART will confirm the nonlinear scattering process and the connection to weak turbulence.

NP8.00095 PIC simulations of whistler wave generation using plasma conditions from the RAM-SCB model, YIQUN YU, LEI ZHAO, LANL, BO PENG, KTH, GIAN LUCA DELZANNO, VANIA JORDANOVA, LANL, STEFANO MARKIDIS, KTH — Wave-particle interactions play an important role in the Earth’s inner magnetospheric dynamics. We study the whistler wave generation with an implicit particle-in-cell code (iPIC3D) within unstable equatorial regions identified by the kinetic ring current model RAM-SCB. During storm time, RAM-SCB shows that hot electrons on the dayside demonstrate high temperature anisotropy and are unstable to whistler wave excitation. By using plasma parameters from RAM-SCB, we carry out iPIC3D simulations assuming a bi-Maxwellian distribution for electrons. We find that with an electron temperature anisotropy of 4, electron density of $6 \times 10^{11} \text{ cm}^{-3}$, and parallel temperature of $1 \text{ keV}$ on the dayside around $\omega_L \sim 5.5$, whistler waves are rapidly excited and propagate along the background magnetic field. Comparisons with linear theory show good agreement. The electron velocity distribution is significantly changed after wave generation, with smaller anisotropy due to the pitch-angle scattering. Furthermore, test particles are tracked in the whistler wave environment and the pitch-angle diffusion coefficient is extracted. The coefficient generally agrees with quasi-linear theory prediction with slight deviation even when the wave amplitude is as large as 5% of the background magnetic field.

NP8.00096 Bounce averaged diffusion coefficients in a physics based magnetic field geometry from RAM-SCB, LEI ZHAO, YIQUN YU, GIAN LUCA DELZANNO, VANIA K. JORDANOVA, Los Alamos National Laboratory — In this we explore wave-particle interaction in the radiation belt. By applying quasilinear theory, we obtain the particle diffusion coefficients in both pitch angle and energy for different configurations of the Earth’s magnetic field. We consider the Earth’s magnetic dipole field as a reference, and compare the results against 3D non-dipole field configurations corresponding to quiet and stormy conditions. The latter are obtained with RAM-SCB, a code that models the Earth’s ring current and provide a realistic modeling of the Earth’s magnetic field. The bounce averaged electron pitch angle diffusion coefficients are calculated for each magnetic field configuration. The equatorial pitch angle, wave frequency and spectral distribution of whistler waves are shown to affect the bounce averaged diffusion coefficients. In addition, wave-particle resonance is significantly influenced by the magnetic field configuration: in storm conditions, diffusion is strongly reduced for some equatorial pitch angles.

NP8.00097 Wave-particle interactions in the radiation belts: effect of wave spectra, DIMITRIS VASSILIADIS, MATTIAS TORNQUIST, MARK KOEPKE, West Virginia University — Particle acceleration in Earth’s radiation belts is often explain in terms of radial diffusion theory. Some of the most important contributions to diffusive transport are stochastic as well as resonant interactions with low-frequency (Alfvén/magnetosonic) waves. While spectra of such waves are traditionally assumed to be broadband and spectrally white, a number of recent studies [Rae et al., 2012; Ozeki et al., 2012] indicate that the spectra of ground geomagnetic pulsations are significantly more complex. We examine power-law spectra in particle simulations in a realistic magnetospheric field configuration and report on their effect on the transport and energization of the pre-storm electron population.

NP8.00098 LPI SHORT PULSE & BEAMS —
NP8.00099 Analysis of ionization with intense laser radiation1, BAHMAN HAFIZI, DANIEL GORDON, Naval Research Laboratory, JOHN PALASTRO, Icarus Research Inc, MICHAEL HELLE, Naval Research Laboratory — Laser-plasma experiments routinely rely on field ionization for plasma formation. While several analyses of non-relativistic ionization have been carried out [1], they often fail to reproduce experimental observations [2]. Moreover for large laser intensities or for high-Z atoms relativistic effects become important. We have undertaken a numerical study of ionization processes employing three-dimensional, time dependent, deBroglie/Compton wavelength-resolved, parallel algorithms for the Schrödinger and Klein-Gordon equations [3]. Along with the numerical analysis we have performed analytic modeling, employing the Schrödinger, Klein-Gordon and Dirac equations. Results of the analysis and numerical studies will be presented. In particular we discuss ionization of hydrogen-like Xe, the momentum distribution of ejected electrons and the related Bohmian trajectories.

1Supported by Naval Research Laboratory Base Program and Department of Energy.

NP8.00100 Enhancing Bremsstrahlung Radiation using Front Surface Target Structures1, SHENG JIANG, ANDREW KRYGIER, DOUGLASS SCHUMACHER, RICHARD FREEMAN, KRAMER AKLI, The Ohio State University — X-ray or γ-ray sources generated by laser solid interactions have many potential applications in different fields including X-ray radiography, pair production and photonuclear physics. Recent studies with 3D PIC modeling have shown that large scale front surface target structures can significantly increase the energy and narrow the angular distribution of hot electrons compared to that for a regular flat target [1]. These characteristics of electrons are crucial for further Bremsstrahlung production using a high-Z converter target. The corresponding Bremsstrahlung radiation covers a wide energy range and can be as high as 100 MeV. By performing the Monte-Carlo simulations we find that the peak γ-ray brightness is 6.0×10^{19} s^{-1}mm^{-2}mrad^{-2} at 10MeV and 1.4×10^{19} s^{-1}mm^{-2}mrad^{-2} at 100MeV (0.1% bandwidth), which is comparable to other tunable γ-ray sources. The brightness for high energy γ-rays (>50MeV) is one or few orders of magnitude higher using the structured target than the flat target. Simulation and preliminary experimental results will be presented.

1This work is supported by AFOSR Young Investigator Program and NNSA with computing time from the Ohio Supercomputer Center.

NP8.00101 Guiding of high-energy electrons in high-intensity-laser interactions with wire targets through surface wave excitation, A. MAKIMCHUK, P. BELANCOURT, P. KORDELL, M.J.-E. MANUEL, L. WILLINGALE, A.G. THOMAS, R.P. DRAKE, K. KRUSHELNICK, University of Michigan, A. BRANTOV, V.YU. BYCHENKOV, Lebedev Physics Institute, Moscow, Russia — Experiments investigating the interaction of an ultra-short pulse laser (intensity of up to 2×10^{19} W/cm^2) with thin metal wires of different diameter, length and conductivity at different angles of incidence were performed. The generation of a highly collimated electron beam with a charge of several nC, electron energies in the range of 1-7 MeV and efficiency of few percents were demonstrated. The beam was confined and guided along a thinnest wire of 15 microns wide and 1.4*10^{-2} mm at 10 MeV and 1.4*10^{-2} mm at 100 MeV (0.1% bandwidth), which is comparable to other tunable γ-ray sources. The brightness for high energy γ-rays (>50 MeV) is one or few orders of magnitude higher than that of the structured target. Simulation and preliminary experimental results will be presented.

NP8.00102 Recent High-Intensity Experiments at the Trident Laser1, JAMES COBBLE, SASIKUMAR PALANIYAPPAN, CORT GAUTIER, YONGHO HUANG, Los Alamos National Laboratory — With near-diffraction-limited irradiance of 2×10^{20} W/cm^2 on target and prelate contrast better than 10^{-10}, we have accessed the regime of relativistic transparency (RT) at the Trident Laser. The goal was to access electron debris emitted from the target rear surface with phase-contrast imaging (PCI) and current density measurements (hence, the total electron current). Companion simulations show whether the experiments are in the target-normal-sheath-acceleration mode or in the RT regime. The super laser contrast allows us to shoot targets as thin as 50 nm. PCI at 527 nm is temporally resolved to 600 fs. It has shown the evolution of electron behavior over tens of ps, including thermal electrons accompanying the ion jet, accelerated to many tens of MeV earlier in time. Faraday-cup measurements indicate the transfer of many microC of charge during the laser drive. As a ride-along experiment using a gas Cherenkov detector (GCD), we have detected gamma rays of energy >5 MeV. This radiation has a prompt component and a lesser source, driven by accelerated ions, that is time resolved by the GCD. The ion time of flight is compared to Thomson parabola data. Electron energy spectra are also collected.

1This work is supported by US DOE/NNSA, performed at LANL, operated by LANS LLC under contract DE-AC52-06NA25396.

NP8.00103 Self-focusing instability of stochastic laser pulses1, VLADIMIR MALKIN, NATHANIEL FISCH, Princeton University — The propagation of coherent laser pulses through plasmas and other focusing Kerr-like media is known to be limited by the transverse filamentation instability, or so-called, critical power of self-focusing. It appears, however, that the self-focusing instability threshold for stochastic laser pulses might be much higher than for coherent laser pulses. Furthermore, the instability of over-threshold stochastic pulses might develop much slower than the instability of coherent pulses of the same intensity. These effects might be used advantageously to suppress the transverse filamentation instability of amplified pulses in ultra-powerful plasma-based backward Raman amplifiers.

1Work supported by HDTRA1-11-1-0037, by NSF PHY-1202162, and by the NNSA SSAA DE274-FG52-08NA28553.

NP8.00104 Generation of lower harmonic radiation by a strong laser plasma interaction with asymmetrically bundled carbon nanotubes1, TOSHIHIRO TAGUCHI, MASASHIKO INOUE, Setsunan University, THOMAS ANTONSEN, University of Maryland — We have investigated a generation of low frequency radiation by an interaction between a strong laser field and nano particles, such as clusters or carbon nanotubes (CNTs), using PIC simulations. As known well, a single mode laser irradiation is not enough to generate the lower harmonics and the second harmonic laser must be added. The main reason of this problem is that the single mode laser can only induce odd harmonic oscillations on electrons. The odd harmonic generation is due to the symmetric shape of the targets, spherically for clusters and cylindrically for CNTs. The symmetric ion structure produces a symmetric electrostatic potential in a target and the potential exerts an antisymmetric forces on electrons. This is why only the odd harmonics are generated by the monochromatic laser. This indicates that the possibility of the even harmonic excitation exists when the potential structure is not symmetric. Since carbon nanotubes are synthesized on metal catalysts, the shape of the bundled CNTs can be changed by the shape of the catalysts. We performed PIC simulations of laser plasma interaction with a carbon nanotube of a shape like an egg. As a result, we found that even modes are generated as well as odd modes and lower harmonic oscillation is also excited.

1This work was supported by a Grant-in-Aid for Scientific Research (C), 24540543.
NP.00.1005 Spot sizes of laser accelerated protons in thin multi-ion foils\textsuperscript{1}, TUNG-CHANG LIU, XI SHAO, CHUAN-SHENG LIU, University of Maryland, College Park, BENGT ELIASSON, Strathclyde University, JYHYPENG WANG, Academia Sinica, SHIH-HUNG CHEN, National Central University — We present a numerical study of the effect of the laser spot size of a circularly polarized laser beam on the energy of quasi-monoenergetic protons in laser proton acceleration using a thin carbon-hydrogen foil. The used proton acceleration scheme is a combination of laser radiation pressure and shielded Coulomb repulsion due to the carbon ions. We observe that the spot size plays a crucial role in determining the efficiency of proton acceleration. Using a laser pulse with fixed input energy and pulse length impinging on a carbon-hydrogen foil, a laser beam with smaller spot sizes can generate higher energy but fewer quasi-monoenergetic protons. We studied the scaling of the proton energy with respect to the laser spot size and obtained an optimal spot size for maximum proton energy flux. In particular, we provided a theoretical model interpreting the acceleration mechanism for non-penetration cases and the calculated optimal spot size agreed well with the 2D PIC simulation results. Using the optimal spot size, we can generate an 80 MeV quasi-monoenergetic proton beam containing more than 10\textsuperscript{10} protons using a laser beam with power 250 TW and energy 10 J and a target of thickness 0.15 wavelength and 49 critical density made of 90\% carbon and 10\% hydrogen.

\textsuperscript{1}This work was supported by US DoE grant DESC0008381.

NP.00.1006 Mass Limited Target Effects on Proton Acceleration with Femtosecond Laser Plasma Interactions, CALVIN ZULICK, A. RAYMOND, A. MCKELVEY, L. WILLINGALE, V. CHVYKOV, A. MAKSIMCHUK, A.G.R. THOMAS, V. YANOFSKY, K. KRUSHELNICK, University of Michigan — Experiments at the HERCULES laser facility have been performed to study the effect of reduced mass targets on proton acceleration through the use of foil, grid, and wire targets in femtosecond laser plasma interactions. The target thickness was held approximately constant at 12.5 \(\mu\)m, while the lateral extent of the target was varied. The electron current density was measured with an imaging Cu \(K\alpha\) crystal. Higher current densities were observed as the target mass was reduced which corresponded to an increase in the temperature of the accelerated proton beam. As the target thickness was increased, the electron current density was reduced. The results indicate that mass-limited targets can be used to accelerate protons to high energies. 

NP.00.1017 Plasma generation in mass-limited water targets, JUNGMOO HAH, KIRK LIBERTY, JOHN NEES, KARL KRUSHELNICK, ALEXANDER THOMAS, Univ of Michigan - Ann Arbor — One major problem associated with high repetition-rate laser experiments is obtaining a suitable target for each shot, while maintaining shot-to-shot spatial stability. For high repetition-rate laser experiments with solid targets, rotating stage is usually used for moving a target point, which causes stability and size problems. To solve these problems, some researchers have tried to replace solid targets with a rotating stage with liquid targets, and a tungsten needle to make continuous and stable water droplets with a diameter of \(\sim 2 \mu\)m. These mass-limited water droplets act as a target for some advantages. First, heat dissipation is blocked, so the target is entirely heated. Second, effective spatial contrast is improved by reducing the interaction between lower intensity spatial wings of the beam and a single-micron target. Third, at the relativistic laser intensities, a smaller target allows for higher electron densities at the target's back surface, which enhances field's strength for ion acceleration. For these advantages, it is understood that mass plasma generation processes. Therefore, we investigate the processes by irradiating fs laser pulses to mass-limited droplets and these interactions are captured by CCD.
NP8.00111 X-Ray Imaging of Ultrafast Magnetic Reconnection Driven by Relativistic Electrons. ANTHONY RAYMOND, ANDREW MCKELVEY, CALVIN ZULICK, ANATOLY MAKSIMCHUK, ALEXANDER THOMAS, LOUISE WILLINGLE, VLADIMIR CHVYKOV, VICTOR JANOVSKY, KARL KRUSENLICK, CUOS, University of Michigan — Magnetic reconnection events driven by relativistic electrons are observed between two high intensity laser/plasma interaction sites. The two laser focuses were on average 20 µm FWHM containing 50TW of power each, delivered with a split f/3 paraboloid onto copper foil targets at a focused intensity of 4x10^{18} W/cm². A spherically bent k-alpha X-ray Bragg crystal was utilized to image the interactions, and by motorizing one half of the paraboloid vertically the focal separation was varied between 0-200 µm. While these k-alpha images demonstrated a ring structure surrounding a single focus (due to electrons returning from vacuum to the rear of the target surface), splitting the focuses revealed the rings of either spot interacting and enhancing between the focuses, evidencing magnetic reconnection driven by the relativistic electron currents. Imaging the transversely propagating electrons with a filtered LANEX screen demonstrated relativistic currents with spatial nonuniformities potentially directly originating from reconnection events, and varying target geometries were used to investigate the resulting effects on the spatial electron profiles. At present PIC simulations are being conducted to better understand and attempt to reproduce the measured electron outflow dynamics.

1Currently at: ELI Attosecond Light Pulse Source

NP8.00112 Quasi-Monoenergetic Dense and Uniform Electron Bunch Generation from Laser Driven Double-Layer Thin Films. C. WANG, R. ROYCROFT, E. MCCARY, A. MEADOWS, J. BLAKENEY, K. SERRATTO, D. KUK, C. CHESTER, L. GAO, Center for High Energy Density Science, University of Texas, Austin, H. FU, X.Q. YAN, State Key Laboratory of Nuclear Physics and Technology, Peking University, J. SCHREIBER, Fakultat fur Physik, Ludwig-Maximilians-University, I. POMERANTZ, A. BERNSTEIN, H. QUEVEDO, D. DYER, E. GAUL, T. DITMIRE, Center for High Energy Density Science, University of Texas, Austin, D.C. GAUTIER, J. FERNANDEZ, Los Alamos National Laboratory, B.M. HEGELICH, Center for High Energy Density Science, University of Texas, Austin — We demonstrate that dense, uniform quasi-monoenergetic relativistic electron bunches can be generated from the interaction of a high-intensity laser pulse with a double-layer thin film target. The first layer of the target is a freestanding, nanometer-scale, diamond-like carbon production layer. The second layer is a thin plastic reflection layer which reflects the drive-laser pulse, but allows electrons to pass through. Although a single electron bunch is generated from the second layer alone, by adding it behind the first layer we obtained a quasi-monoenergetic bunch along the laser axis, 35 times denser than a bunch from the single layer target. Comparing the angular distribution of the electron spectra from a double-layer target with that of a single-layer target, we observed an increase of the electron cutoff energy at larger angles, which improves the uniformity of created electron bunches.

NP8.00113 Energy Loss of High Intensity Focused Proton Beams Penetrating Metal Foils1, C. MCGUFFEY, B. QIAO, J. KIM, F.N. BEG, UC San Diego, M.S. WEI, M. EVANS, P. FITZSIMMONS, R.B. STEPHENS, General Atomics, S.N. CHEN, J. FUCHS, LULI, P.M. NILSON, D. CANNING, M. MASTROMONTE, LLE, U Rochester, M.E. FOORD, LLNL — Shortpulse-laser-driven intense ion beams are applicable for applications in probing and creating high energy density plasmas. Such a beam isochorically heats and rapidly ionizes any target it enters into warm dense matter with uncertain transport and stopping properties. Here we present experimental measurements taken with the 1.25kJ, 10ps OMEGA EP BL shortpulse laser of the proton and carbon spectra after passing through metal foils. The laser irradiated spherically curved C targets with intensity 4x10^{18} W/cm², producing proton beams with 3 MeV slope temperature and a sharp low energy cutoff at 5 MeV which has not been observed on lower energy, shorter pulse intense lasers. The beam either diverged freely or was focused to estimated 10^{16} p+ /cm² by a surrounding structure before entering the metal foils (Al or Au and a Cu tracer layer). The proton and ion spectra were altered by the foil depending on material and whether or not the beam was focused. Transverse proton radiography probed the target with ps temporal and 10 micron spatial resolution, indicating an electrostatic field on the foil may also have affected the beam. We present supported particle-in-cell simulations of the beam generation and transport to the foils.

1This work was supported by the DOE/NNSA National Laser User Facility program, Contract DE-SC0001265.

NP8.00114 Stochastic heating of electrons by intense laser radiation in the presence of electrostatic potential well1, SERGEI KRASHENINNIKOV, UCSD — Previous model used for the study of synergistic effects of electrostatic potential well and laser radiation where electric field in electrostatic potential was slowing down electrons moving in the direction of the laser field propagation, is extended for the opposite case, where electric field of the well is accelerating electrons moving in the direction of the laser field propagation. It was found that in both cases the rate of stochastic heating of energetic electrons remains virtually the same.

1This work was supported by the USDOE Grant DE-NA0001858 at UCSD and grant 14.Y26.31.008 of the MES of the Russian Federation at MEPhI.

NP8.00115 Fast ion distribution in the presence of flow1, SETH DAVIDOVITS, NATHANIEL FISCH, Princeton University — Experiments and simulations in multiple ICF related configurations have observed signs of bulk flow near stagnation. These configurations include both laser driven implosions such as at the NIF, as well as Z-Pinches. We investigate the possibilities for enhancement or depletion of fast ion tails in simplified flow models, with an eye towards applicability to ICF experiments. Small effects on the tail populations may substantially affect fusion output, as the fast ions in these tails have much larger fusion cross sections than thermal ions and make up the majority of fusion production for typical ICF temperatures. While in collisional plasma the bulk of the distribution function is driven toward Maxwellian in a few collision times, the high velocity tails can take much longer to form. Furthermore, the long mean free paths of the fast ions means they may sample differing regions of flow, while thermal particles only sample the local flow.

1This work was supported by DOE through contracts DE-AC02-09CH1-1466 and 67350-9960 (Prime # DOE DE-NA0001836). Seth Davidovits would like to acknowledge support of the DOE-CSGF program under grant DE-FG02-97ER25308.

NP8.00116 Electron Transport and Related Nonequilibrium Distribution Functions in Large Scale ICF Plasma. W. ROZMUS, Univ of Alberta, AB, Canada, T. CHAPMAN, LLNL, A.V. BRANTOV, Lebedev Phys. Institute, Moscow, Russia, B. WINJUM, UCLA, CA, USA, R. BERGER, LLNL, CA, USA, S. BRUNNER, Ecole Polytechnique, Lausanne, Switzerland, V. YU. BYCHENKO, Lebedev Phys. Institute, Moscow, Russia, A. TABLEMAN, UCLA, CA, USA — Using the Vlasov-Fokker-Fokker-Planck (VFP) code OSUHN [M. Tzoufras et al. Phys. Plasmas 20, 056303 (2013)] and higher order perturbative solutions to the VFP equation, we have studied electron distribution functions (EDF) in inhomogeneous and hot hohlraum plasmas of relevant to the current ICF experiments. For these inhomogeneous ICF plasmas characterized by with the temperature and density gradients consistent with the high flux model [M.D. Rosen, et al., HEDP 7, 180 (2011)], nonequilibrium EDF often display unphysical properties related to first and second order derivatives at larger velocities. These EDF strongly modify the linear plasma response, including Landau damping of Langmuir waves, electrostatic fluctuation levels, and instability gain coefficients. We have found that Langmuir waves propagating in the direction of the heat flow have increased Landau damping compared to damping calculated from a Maxwellian EDF, while Langmuir waves propagating in the direction of the temperature gradients are far less damped as compared to damping calculated from the Maxwellian EDF. These effects have been discussed in the context of stimulated Raman scattering, Langmuir decay instability and Thomson scattering experiments.
NP8.00117 Revisiting hot electron generation in ignition-scale hohlraums1, WILLIAM KRUER, CLIFF THOMAS, DAVID STROZZI, NATHAN MEEZAN, OTTO LANDEN, HARRY ROBEY, Lawrence Livermore National Laboratory — Recent work invoking hot electron preheat in NIC ignition experiments is motivating a fresh look at hot electron generation in ignition-scale hohlraums. Various mechanisms for high energy electron generation are considered, with particular attention to their time dependence and the potential role of the two plasmon decay instability in the main laser pulse. The energy at risk calculations are updated to include the effects of cross beam energy transfer on the time-dependent energy and intensity of the inner beams as well as improvements in the calculated plasma conditions. The generation of hot electrons by the Raman-scattered light driving the two plasmon decay instability and the effect of the Weibel instability on the propagation of the hot electrons are also briefly considered. Uncertainties in interpreting the energy in hot electrons from hard x-ray measurements and techniques to reduce hot electron generation are discussed.

1This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract DE-AC52-07NA27344.


NP8.00118 Laser backscatter damage risk assessments of NIF Target Experiments, R.K. KIRKWOOD, D.J. STROZZI, P.A. MICHEL, D.A. CALLAHAN, B. RAYMOND, G. GURURANGAN, B.J. MACGOWAN, LLNL, NIF TEAM — The National Ignition Facility (NIF) performs target experiments of many types. Laser power and target configurations and materials vary between experiments; in many cases the variation is incremental from a previously fielded experiment but can also involve a major change that represents a new operating regime for laser plasma interactions with a large plasma. A review methodology has been established to assess the potential risk of damage to the facility optics from scattered light for all proposed experiments. This process uses a defined set of rules and criteria to efficiently assess the risks of each proposed experiment. This assessment allows rapid approval of most experiments and identifies others that need more detailed analysis and/or modifications to their design to produce acceptable risk. The methodology uses comparisons to an extensive data base of existing experiments and some simple rules to extend beyond the parameters for which we have data. This poster will describe our assessment methodology and data sets that provide the experimental basis.

NP8.00119 The Langmuir Decay Instability and Stimulated Raman Scattering in ICF-Relevant Plasmas1, B.J. WINJUM, A. TABLEMAN, F.S. TSUNG, W.B. MORI, UCLA — Kinetic simulations of stimulated Raman scattering (SRS) in ICF-relevant plasmas with long-scale-length density gradients have shown that SRS can grow strongly when the laser propagates above that density for which \( k_D \approx 0.30 \), where \( k \) is the wavenumber of the daughter electron plasma wave and \( \lambda_D \) is the electron Debye length. Simulations and experiments have shown that SRS saturation is dominated by kinetic effects for \( k_D \gg 0.30 \) and the Langmuir decay instability (LDI) for \( k_D < 0.30 \), but few kinetic simulations of SRS have explicitly explored the role of LDI in this regime or the transition in SRS behavior across this \( k_D \) boundary. Here we present one- and two-dimensional PIC simulations of LDI in the midst of SRS dynamics for both single-laser-speckles as well as for lasers propagating up long-scale-length density gradients covering a range of \( k_D \). We show the effect of LDI on SRS reflectivity and hot electron generation for variable \( Z_{Te}/T_i \) and \( k_D \), as well as the effect of LDI on the spatio-temporal behavior of electron plasma wave packets generated by SRS.

1Supported by DOE Grant Nos. DE-NA0001833 and DE-FG02-04ER54789, NSF Grant No. ACI-1339893, and UCLA’s IDRE; simulations performed on the UCLA Hoffman2 and Dawson2 clusters, NERSC’s Edison, and NCSA’s Bluewaters.

NP8.00120 Simulations of 3D LPI’s relevant to IFE using the PIC code OSIRIS, F.S. TSUNG, W.B. MORI, B.J. WINJUM, UCLA — We will study three dimensional effects of laser plasma instabilities, including backward raman scattering, the high frequency hybrid instability, and the two plasmon instability using OSIRIS in 3D Cartesian geometry and cylindrical 2D OSIRIS with azimuthal mode decompositions. With our new capabilities we hope to demonstrate that we are capable of studying single speckle physics relevant to IFE in an efficient manner.

NP8.00121 Three-Dimensional Full-Beam Simulation of Ultrashort Laser Pulse Amplification by Brillouin Backscattering in the Strong Coupling Regime, KATHLEEN WEICHMAN, RICHARD BERGER, THOMAS CHAPMAN, STEVEN LANGER, Lawrence Livermore National Laboratory, Livermore, CA 94551, USA, CATERINA RICONDA, Laboratoire pour l’Utilisation des Lasers Intenses/Université Pierre et Marie Curie, 75005 Paris, France — Laser amplification by stimulated Brillouin scattering (SBS) has been previously proposed as a method of achieving high intensity sub-picosecond laser pulses. The 3D fluid simulation code pF3D is used to simulate the SBS interaction of the energy electron generation are considered, with particular attention to their time dependence and the potential role of the two plasmon decay instability in the main laser pulse. The energy at risk calculations are updated to include the effects of cross beam energy transfer on the time-dependent energy and intensity of the inner beams as well as improvements in the calculated plasma conditions. The generation of hot electrons by the Raman-scattered light driving the two plasmon decay instability and the effect of the Weibel instability on the propagation of the hot electrons are also briefly considered. Uncertainties in interpreting the energy in hot electrons from hard x-ray measurements and techniques to reduce hot electron generation 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 and partly funded by the Laboratory Research and Development Program at LLNL under project tracking code 12-ERD-061.

1Supported by DOE Grant Nos. DE-NA0001833 and DE-AC52-07NA27344.


3L. Lancia et al., Oral presentation at the 44th annual Anomalous Absorption Conference, Estes Park, 2014.

NP8.00122 Hohlraum Modeling of Hybrid Shock Ignition Target, E.S. DODD, J.A. BAUMGAERTEL, E.N. LOOMIS, Los Alamos Natl Lab — Hybrid Shock Ignition (HSI) combines a hohlraum driven capsule with a directly driven shock for heating. Unlike standard Shock Ignition, the capsule is imploled with X-rays from a laser driven hohlraum to compress the fuel, which is too cold to ignite. However, as in Shock Ignition, the compressed fuel is subsequently heated to ignition temperatures with a directly-driven shock. The use of indirect and direct drive in the same target necessitates complex beam geometry, and thus HSI is being pursued with spherical hohlraums. More importantly for the NIF, the beam repointing required for polar direct drive will not be needed for the implosion phase with this target. Spherical hohlraums have been fielded previously at the Omega laser as a part of the Tetrahedral Hohlraum Campaign. They were originally proposed as an alternative to cylindrical hohlraums to achieve highly symmetric radiation drive. The new HSI hohlraums will require six laser entrance holes in hexahedral symmetry to accommodate all beams. This presentation will show radiation-hydrodynamic calculations of the current hexahedral Omega hohlraum design, as well as benchmark calculations of the old tetrahedral targets.


3Supported under the U. S. DOE by the Los Alamos National Security, LLC under contract DE-AC52-06NA25396. LA-UR-14-24945.
NP8.00123 Capsule Design for Hybrid Shock Ignition1. J.A. BAUMGAERTEL, E.S. DODD, E.N. LOOMIS, Los Alamos National Laboratory — Hybrid Shock-Ignition (HSI) is an alternate fusion energy concept that combines indirect drive and shock ignition schemes in order to access new regimes in National Ignition Facility (NIF) hohlraum physics. Building off of tetrahedral hohlraum experiments [1] at the OMEGA laser facility, we have preliminary designs for spherical hohlraums that combine symmetrically arranged laser entrance holes for indirect-drive beams (to initially compress the capsule) and holes for direct-drive beams to drive a strong ignitor shock (to further compress and ignite the fuel). A LANL Eulerian hydrodynamic code is being used to find optimal laser drive, hohlraum, and capsule specifications, via criteria such as implosion symmetry, implosion time, and neutron yield. At first, drive will be modeled using a radiation source to mimic the hohlraum drive, and later, ignitor beams will be added. Initial capsule designs will be presented for experiments to develop the HSI platform on the sub-ignition scale OMEGA laser facility in FY15.


1Supported under the U. S. Department of Energy by the Los Alamos National Security, LLC under contract DE-AC52-06NA25396. LA-UR-14-25071

NP8.00124 Shocks waves in high power laser plasma interactions . R. BINGHAM, STFC Rutherford Appleton Laboratory, Didcot, UK and University of Strathclyde, Glasgow, UK. R.A. CAIRNS, University of St Andrews, Fife, UK, P.A. NORREYS, University of Oxford, Oxford, UK and STFC Rutherford Appleton Laboratory, Didcot, UK, R. TRINES, STFC Rutherford Appleton Laboratory, Didcot, UK. — Some recent experiments on the interaction of high power lasers with plasmas have shown evidence of shock like structures with very high electric fields existing over very short distances. In inertial confinement fusion capsules the existence of fields of more than $10^{11}$ V/m over distances of the order of 10-100 nm have been observed. In other experiments with intense lasers interacting with over dense plasmas high energy proton beams with small energy spread are observed. We propose a theory to describe laminar ion sound structures in a collisionless plasma. Reflection of a small fraction of the upstream ions converts the well-known ion acoustic soliton into a structure with a steep potential gradient upstream and with downstream oscillations. The strong electric field is also responsible for separation in the shocked region in a deuterium, tritium mix, while accelerating the deuterium and tritium ions at the shock front. The possibility of using these accelerated ions to heat the fuel in a fast ignition scheme will be discussed.

NP8.00125 Fast Ignition by Photon-Pressure Accelerated Ion Beam. TOMOYUKI JOHZAKI, Graduate School of Engineering, Hiroshima University, YASUKIHO SENTOKU, University of Nevada, Reno, ATSUSHI SUNAHARA, Institute for Laser Technology, TAKAMASA MORIKAWA, TAKUMA ENDO, Graduate School of Engineering, Hiroshima University — For enhancing the core heating efficiency in fast ignition, the ion beam generated by radiative pressure acceleration with circularly-polarized ultra-intense laser pulse is used as a core heating driver. In the present study, on the basis of the integrated simulations (PIC simulations for beam generation and Fokker-Planck simulations for core heating) and demonstrated the potential probability for C6+ beam driven fast ignition. From the coupled transport and hydro simulations, it is found that the beam particle (C6+) energy of 100 ~ 200 MeV minimizes the beam energy required for ignition and the beam duration of ~ 1 ps is suitable for ignition in terms of beam generation and core heating. From 2D PIC simulations for ion beam generation it is found that fast ion beam with ion energy of 210 MeV is obtained when the carbon target with the ion density of 90 ncr (ncr is the laser critical density) is irradiated with the CP laser with the intensity of 6x10^{22} W/cm^2. In this case, 12% energy conversion efficiency of laser to ion beam is obtained. If assuming the laser spot of 24 micron diameter and pulse duration of 700fs, the required laser energy for beam generation is ~190 kJ and the resultant beam energy of 23 kJ, which satisfy the beam condition required for ignition.

NP8.00126 Unique capabilities for ICF and HEDP research with the KrF laser 1. STEPHEN OBENSCHAIN, JASON BATES, LOP-YUNG CHAN, MAX KARASIK, DAVID KEHNE, JOHN SETHIAN, VICTOR SERLIN, JAMES WEAVER, US Naval Research Laboratory, JAECHUL OH, Research Support Instruments, BRUCE JENKINS, Berkeley Research Associates Inc., ROBERT LEHMBERG, Research Support Instruments, FRANK HEGENER, STEPHEN TERRELL, Commonwealth Technology, YEFIM AGLITSKIY, Leidos, ANDREW SCHMITT, US Naval Research Laboratory — The krypton-fluorine (KrF) laser has unique characteristics that allow parametric studies of LPI. These features include short wavelength (248 nm), large bandwidth (~2-3 THz), beam smoothing by induced spatial incoherence (ISI), and full aperture focal spot zooming during the laser pulse. The KrF laser facility allows easy implementation of focal zooming where the laser radial profile is varied during the laser pulse. The capability for near continuous zooming with KrF would be valuable towards minimizing the effects of cross beam energy transport (CBET) in directly driven capsule implosions. The broad bandwidth ISI beam smoothing that is utilized with the KrF laser facility may further inhibit certain laser plasma instability. In this presentation we will summarize our current understanding of laser target interaction with the KrF laser and the benefits it provides for ICF and certain HEDP experiments. Status and progress in high-energy KrF laser technology will also be discussed.

1Work supported by the Department of Energy, NNSA

NP8.00127 Progress in LPI Experiments at the NikeLaser 1. J. WEAVER, D. KEHNE, S. OBENSCHAIN, A. SCHMITT, V. SERLIN, (NRL), J. OH, R. LEHMBERG, (RSI), F. TSUNG, (UCLA), P. MCKENTY, (LLE), J. SEELY, (BRA) — The experimental program at the Nike laser facility at NRL is studying laser plasma instabilities (LPI) in the quarter critical region and cross-beam energy transport (CBET). The Nike krypton-fluorine (KrF) laser has unique characteristics that allow parametric studies of LPI. These features include short wavelength (248 nm), large bandwidth (~2-3 THz), beam smoothing by induced spatial incoherence (ISI), and full aperture focal spot zooming during the laser pulse. The Nike laser also has a unique beam geometry that combines two radially separated beam arrays (145° in azimuth) with close beam-beam spacing (as low as 3.5°) within the main drive array. Particularly relevant for the CBET studies, recent campaigns have demonstrated the capability to alter the laser bandwidth by a factor of ~10 as well as shifts in the peak laser wavelength. An extensive LPI diagnostic suite is available for observation of stimulated Raman scattering, two-plasmon decay, stimulated Brillouin scattering, the parametric decay instability, and hard x-ray emission due to hot electrons. An overview of the observations of scattered laser light made during the previous studies of instabilities in the quarter critical region will be presented. Ongoing analysis of observed LPI emission from rotated targets will also be included. Plans for upcoming experiments related to quarter critical instabilities and CBET will be discussed.

1Work supported by DoE/NNSA.

NP8.00128 Presheath and boundary effects on helicon discharge equilibria1. CORY JACKSON, University of Wisconsin - Madison, M. UMAIR SIDDQUI, West Virginia University, JUSTIN KIM, NOAH HERSHKOWITZ, University of Wisconsin - Madison — Two distinct discharge equilibria are observed in a 500 W argon helicon plasma with uniform magnetic fields of 900 G at neutral pressures between 3 and 4 mTorr. Both modes exhibit localized populations of relatively hot electrons. For one discharge equilibria a downstream density peak is observed, similar to observations by other authors [Chen et al., Plasma Sources Sci. Technol. 5, 173 (1996)]. For the other mode the hot electrons are confined by a localized potential structure and no density peaks are observed. The determination of the discharge mode and the location of the potential structure and hot electron population is modulated by the position of the downstream conducting boundary and the length of its presheath.

1Work supported by U.S. DOE Grant No. DE-FG02-97ER54437
Wednesday, October 29, 2014 9:30AM - 10:18AM –
Session NM10 Mini-Conference: Nonlinear Effects in Geospace Plasmas I  Salon FGH - Evgeny Mishin,
Air Force Research Laboratory

9:30AM NM10.00001 Interaction of High Frequency Electromagnetic Waves with Vortex Density Structures: Comparison of Analytical and LSP Simulation Results\(^1\), V. SOTNIKOV, T. KIM, Air Force Research Laboratory, Wright Patterson AFB, OH 45433, J. LUNDBERG, Riverside Research, Beavercreek, OH 45431, I. PARASCHIV, University of Nevada at Reno, NV 89523, T. A. MEHLHORN, Naval Research Laboratory, Washington, DC 20375 — Interchange or flute type density irregularities in magnetized plasma are associated with Rayleigh-Taylor type instability. In particular, we are interested in the generation of low frequency plasma density irregularities in the form of flute type vortex density structures and interaction of high frequency electromagnetic waves used for surveillance and communication with such structures. These types of density irregularities play an important role in refraction and scattering of high frequency electromagnetic signals propagating in the earth ionosphere, in high energy density physics (HEDP), and in many other applications. We will present PIC simulation results of EM scattering on vortex type density structures using the LSP code and compare them with analytical results. Two cases will be analyzed. In the first case electromagnetic wave scattering will take place in the ionospheric plasma. In the second case laser probing in a high-beta Z-pinch plasma will be presented.

\(^1\)This work was supported by the Air Force Research laboratory, the Air Force Office of Scientific Research, the Naval Research Laboratory and NNSA/DOE grant no. DE-FC52-06NA27616 at the University of Nevada at Reno.

9:42AM NM10.00002 Are the Electromagnetic Whistlers Associated with Magnetotail Reconnection Driven by Temperature Anisotropy or by Electron Phase Space Holes?\(^2\), MARTIN V. GOLDMAN, DAVID L. NEWMAN, Univ of Colorado - Boulder, JONATHAN EASTWOOD, Imperial College, London, UK, GIOVANNI LAPENTA, KU, Leuven, Belgium — Kinetic simulations of magnetotail reconnection and theoretical analysis have recently been used to show that bipolar fields associated with electron phase space holes on separatrices near an x-point can efficiently emit electromagnetic whistler waves [Goldman, et al., Phys. Rev. Lett. 112, 145002 (2014)]. It is shown here from the same simulation at later times that hole emission of whistlers also occurs near the pile-up front (dipolarization front) associated with magnetotail reconnection. In addition, a more general kinetic theory analysis of Čerenkov emission of whistlers by holes is performed which includes electron temperature anisotropy and enables the comparison of Čerenkov emission of whistlers by holes with whistler instability due to temperature anisotropy in regions where both anisotropy and holes are present. Observations of whistlers and holes near dipolarization fronts [e.g., Deng, et al., J. Geophys. Res. 115, A09225 (2010)] are discussed in the context of these studies.

\(^2\)Research supported by NASA

9:54AM NM10.00003 A Quantitative Kinetic Theory of Meteor Plasma Formation\(^3\), YAKOV DIMANT, MEERS OPPENHEIM, Boston Univ — Every second millions of small meteoroids hit the Earth from space, the vast majority too small to observe visually. Radars easily detect the plasma they generate and use the data they gather to characterize the meteoroids and the atmosphere in which they disintegrate. These diagnostics requires a detailed quantitative understanding of the formation of the meteor plasma and how it interacts with the Earth’s atmosphere. Meteoroids become detectable to radars after they heat due to collisions with atmospheric molecules sufficiently that they begin to sublimate. The sublaminated material then collides into atmospheric molecules and forms plasma around and behind the meteoroid. Reflection of radar pulses from the plasma around the descending meteoroid produces a localized signal called a head echo. This research applies kinetic theory to show that the meteoroid plasma develops over a length-scale close to the ion mean free path with a non-Maxwellian velocity distribution. This analytical model will serve as a basis for quantitative interpretation of the head echo radar measurements, the ionization efficiency (called the Beta parameter), and should help us calculate meteoroid and atmosphere parameters from radar head-echo observations.

\(^3\)Work supported by NSF Grant AGS-124482.

10:06AM NM10.00004 Turbulent Plasmaspheric Boundary Layer: Observables and Consequences\(^1\), EVGENY MISHIN, Air Force Research Laboratory — In situ satellite observations reveal strong lower hybrid/fast magnetosonic turbulence and broadband hiss-like VLF waves in the substorm subsauroral geospace at and earthward of the electron plasmasheet boundary. These coincide with subauroral ion drifts/polarization streams (SAID/SAPS) in the plasmasphere and topside ionosphere. SAID/SAPS appear in ~10 min after the substorm onset consistent with the fast propagation of substorm injection fronts. The SAID channel follows the dispersionless cutoff of the energetic electron flux at the plasmapause. This indicates that the cold plasma maintains charge neutrality within the channel, thereby short-circuiting the injected plasma jet (injection fronts over the plasmasphere. Plasma turbulence leads to the circuit resistivity and magnetic diffusion as well as significant electron heating and acceleration. As a result, a turbulent boundary layer forms between the inner edge of the electron plasmasheet and plasmasphere. The SAID/SAPS-related VLF emissions appear to constitute a distinctive subset of substorm/storm-related VLF activity in the region co-located with freshly injected energetic ions inside the plasmasphere. Significant pitch-angle diffusion coefficients suggest that substorm SAID/SAPS-related VLF waves could be responsible for the alteration of the outer radiation belt boundary during (sub)storms.

\(^1\)Supported by the Air Force Office of Scientific Research.
2:00PM PI1.00001 Higher Velocity High-Foot Implosions on the National Ignition Facility Laser*, DEBRA CALLAHAN, Lawrence Livermore National Lab — After the end of the National Ignition Campaign on the National Ignition Facility (NIF) laser, we began a campaign to test capsule performance using a modified laser pulse-shape that delivers higher power early in the pulse (“high foot”) [1, 2, 4]. This pulse-shape trades one-dimensional performance (peak compression) for increased hydrodynamic stability. The focus of the experiments this year has been to improve performance by increasing the implosion velocity using higher laser power/energy, depleted uranium hohlraums, and thinner capsules. While the mix of ablator material into the hotspot has been low for all of these implosions, the challenge has been to keep the implosion shape under control. As the peak laser power is increased, the plasma density in the hohlraum is increased – making it more and more challenging for the inner cone beams to reach the midplane of the hohlraum and resulting in an oblate implosion. Depleted uranium hohlraums have higher albedo than Au hohlraums, which leads to additional drive and improved implosion shape. Thinner ablators increase the velocity by reducing the amount of payload; thinner ablators also put less mass into the hohlraum which results in improved inner beam propagation. These techniques have allowed us to push the capsule to higher and higher velocity. In parallel with this effort, we are exploring other hohlraums such as the rugby shaped hohlraum to allow us to push these implosions further. This talk will summarize the progress of the high foot campaign in terms of both capsule and hohlraum performance.

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


2:30PM PI1.00002 Three-dimensional simulations of NIF implosions: insight into experimental observations†, BRIAN SPEARS, Lawrence Livermore National Lab — We have developed new three-dimensional (3D) radiation hydrodynamics simulation capabilities for NIF implosions to help explain trends in experimental observations. Simulation advances include full Monte Carlo particle transport for nuclear burn and diagnostics processes, resolution of lower-energy DE neutrons, and updated mesh management to allow large, low-mode spherical harmonic perturbations. We have also further advanced our 3D post-processing to generate simulated diagnostics, including time-integrated neutron images, detailed neutron spectra from instrument lines of sight, low-resolution neutron spectra covering the full sphere, and time-resolved x-ray imaging with enhanced spectral resolution. The advanced simulations and the resultant simulated diagnostics reproduce many surprising aspects of the NIF experimental trends. Puzzles that may be explained include longer burn durations, large and strongly direction-dependent ion temperatures as inferred from neutron spectra, large neutron-weighted bulk velocities, and large differences between DD- and DT-inferred temperatures. The improved simulations have allowed the development of controlled NIF experiments designed to test our capabilities to accurately model the impact of 3D shape perturbations on cryogenic layered implosions and surrogate gas-filled symcaps. LLNL-ABS-654616.

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

3:00PM PI1.00003 Validating Hydrodynamic Growth in National Ignition Facility Implosions*, J. LUC PETERSON, Lawrence Livermore National Laboratory — The hydrodynamic growth of capsule imperfections can threaten the success of inertial confinement fusion implosions. Therefore, it is important to design implosions that are robust to hydrodynamic instabilities. However, the numerical simulation of interacting Rayleigh-Taylor and Richtmyer-Meshkov growth in these implosions is sensitive to modeling uncertainties such as radiation drive and material equations of state, the effects of which are especially apparent at high mode number (small perturbation wavelength) and high convergence ratio (small capsule radius). A series of validation experiments were conducted at the National Ignition Facility to test the ability to model hydrodynamic growth in spherically converging ignition-relevant implosions. These experiments on the Hydro-Growth Radiography platform [1] constituted direct measurements of the growth of pre-imposed imperfections up to Legendre mode 160 and a convergence ratio of greater than four using two different laser drives: a “low-foot” drive used during the National Ignition Campaign [2] and a larger adiabat “high-foot” drive that is modeled to be relatively more robust to ablation front hydrodynamic growth [3]. We will discuss these experiments and how their results compare to numerical simulations and analytic theories of hydrodynamic growth, as well as their implications for the modeling of future designs.

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


3:30PM PI1.00004 Near-vacuum hohlraums for driving fusion implosions with high density carbon ablators†, LAURA BERZAK HOPKINS, Lawrence Livermore National Laboratory — Achieving ignition requires reaching fast implosion velocities, which pulses the need for a highly efficient hohlraum to drive direct-drive inertial confinement fusion implosions. Gas-filled hohlraums are typically utilized due to the pulse length (15-20 ns) needed to drive plastic (CH) capsules. With the recent use of 3x denser high-density carbon (HDC) capsules, ignition pulses can be less than 10 ns in duration, providing the opportunity to utilize near-vacuum hohlraums (NVH) to drive ignition-relevant implosions on the National Ignition Facility (NIF) with minimal laser-plasma instabilities which complicate standard gas-filled hohlraums. Initial NVH implosions on the NIF have demonstrated coupling efficiency significantly higher than observed in gas-filled hohlraums — backscatter losses less than 2% and virtually no suprathermal electron generation. A major design challenge for the NVH is symmetry control. Without tamping gas, the hohlraum wall quickly expands filling the volume with cold plasma. However, results to-date indicate that the inner-cone beams propagate freely to the hohlraum wall for at least 6.5 ns. With minimal predicted cross-beam power transfer, this propagation enables symmetry control via dynamic beam phasing – time-dependent direct adjustment of the inner- and outer-cone laser pulses. A series of experiments with an HDC ablator and NVH culminated in a 6 ns, 1.2 MJ cryogenic DT layered implosion yielding 1.8 x 10^{15} neutrons—significantly higher yield than any CH implosion at comparable energy. This implosion reached an ignition-relevant velocity – 350 km/s – with no observed ablator mix in the hot spot. Recent experiments have explored two-shock designs in a larger, 6.72 mm hohlraum, and upcoming experiments will incrementally extend the pulse duration toward a 9 ns long, three-shock ignition design.

†Prepared by LLNL under Contract DE-AC52-07NA27344.
RICCARDO TOMMASINI, Lawrence Livermore National Laboratory, USA — Implosion efficiency depends on keeping the in-flight ablator and fuel as close as possible to spherical at all times while maintaining the required implosion velocity and in-flight aspect ratio. Asymmetries and areal density non-uniformities seeded by time-dependent drive variations and target imperfections grow in time as the capsule implodes, with growth rates that are amplified by instabilities. One way to diagnose them is by imaging the self-emission from the implosion core. However, this technique, besides only providing direct information of the shape of the hot emission region at final assembly, presents complications due to competition between emission gradients and reabsorption.

Time-resolved radiographic imaging, being insensitive to this effect, is therefore an important tool for diagnosing the ablator and the shell in inertial confinement fusion (ICF) implosions. Experiments aimed at measuring the density, areal density and areal density asymmetries of the shell in ICF implosions have been performed using two different radiographic techniques on the National Ignition Facility. We will report the results from both 1D and 2D geometries using slit and pinhole imaging coupled to area backfilling and as close as 150 ps to peak compression. We will focus in particular on comparisons of the in-flight shell thicknesses and ablative front length scales between low- and high-adiabat implosions, and the perturbations on areal density seeded both by time dependent drive asymmetries and by the membranes used to hold the capsule within the hohlraum in indirect drive ICF targets.

1This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

4:30PM PI1.00006 Studying shock dynamics and in-flight $\rho R$ asymmetries in NIF implosions using proton spectroscopy. ALEX ZYLSTRA, MIT — Ignition-scale, indirect-drive implosions of CH capsules filled with D$^3$He gas have been studied with proton spectroscopy at the NIF. Spectral measurements of D$^3$He protons produced at the shock-bang time provide information about the shock dynamics and in-flight characteristics of these implosions. The observed energy downshift of the D$^3$He-proton spectra are interpreted with a self-consistent 1-D model to infer $\rho R$, shell $R_{\text{sh}}$, and yield at this time. The observed $\rho R$ at shock-bang time is substantially higher for implosions where the laser drive is on until near the compression-bang time (“short-coast”) than in the long-coast implosions ($\sim$800ps) than in the short-coast implosions ($<400$ps). These differences are determined from the D$^3$He proton spectra and in-flight x-ray radiography data, and it is found to contradict radiation-hydrodynamic simulations, which predict a 700 – 800ps temporal difference independent of coasting time. A large variation in the shock proton yield is also observed in the dataset, which is interpreted with a Guderley shock model and found to correspond to $\sim2\times$ variation in incipient hot-spot adiabat caused by shock heating. This variation may affect the compressibility of NIF implosions. Finally, data from multiple proton spectrometers placed at the pole and equator reveal large $\rho R$ asymmetries, which are interpreted as mode-2 polar or azimuthal asymmetries. At the shock-bang time (CR $\sim 3 – 5$), asymmetry amplitudes $>10\%$ are routinely observed. Compared to compression-bang time x-ray self-emission symmetry, no apparent asymmetry-amplitude growth is observed, which is in contradiction to several growth models. This is attributed to a lack of correspondence between shell and hot-spot symmetry at peak compression, as discussed in recent computational studies [R.H.H. Scott et al., Phys. Rev. Lett. 110, 075001 (2013)].

1This was performed in collaboration with the NIF team and was supported in part by the U.S. DOE, LLNL and LLE.

Wednesday, October 29, 2014 2:00PM - 3:00PM –
Session PT2 Tutorial: Magnetohydrodynamic Turbulence: Observation and Experiment
Bissonet - Eric Blackman, University of Rochester

2:00PM PT2.00001 Magnetohydrodynamic Turbulence: Observation and Experiment. MICHAEL BROWN, Swarthmore College — Turbulence has been studied in laboratory plasmas for decades. Magnetic and electrostatic turbulence fluctuations have been implicated in degraded confinement in fusion devices so understanding turbulent transport is critical for those devices. Magnetic turbulence in laboratory plasmas has received less attention. Internal magnetic measurements in fusion plasmas are difficult. In addition, the externally applied magnetic field in most laboratory plasmas has a strong effect on the character of the turbulence (particularly parallel and perpendicular to the applied field). The solar wind is the best studied turbulent MHD plasma. There have been some recent advances in solar measurements using multiple satellites and high bandwidth instruments. We will review some recent observations in solar turbulent transport as well as measurements of magnetic turbulence in laboratory plasmas. We will discuss the analysis techniques common to both, such as correlation functions, structure functions, and spectra. Finally, we will describe a new turbulent plasma source with several unique features called the MHD plasma wind tunnel. First, the MHD wind tunnel configuration has no applied magnetic field and has no net axial magnetic flux. Second, the plasma flow speed is on the order of the local sound speed ($M = 1$), so flow energy is comparable to thermal energy. Third, the plasma $\beta$ (ratio of thermal to magnetic pressure) is of order unity so thermal energy is comparable to magnetic energy. We will present some initial results from the SSX MHD wind tunnel, including a recent observation of turbulent intermittency.

1Work supported by DOE OFES and NSF CMSO.

Wednesday, October 29, 2014 2:00PM - 5:00PM –
Session PO3 C-Mod and ASDEX Upgrade Tokamaks
Salaon D - Francesca Turco, Columbia University

2:00PM PO3.00001 Overview of Recent Alcator C-Mod Results. EARL MARMAR, MIT. ALCATOR C-MOD TEAM — Alcator C-Mod research currently emphasizes RF heating, current and flow drive, divertor/PMI issues, non-ELMing pedestal regimes with enhanced confinement, and disruption mitigation/runaway dynamics. Stability analysis of I-mode pedestals shows pressures well below the peeling-ballooning limit, as well as expected kinetic ballooning mode thresholds, consistent with the lack of ELMs. Results with the magnetic field aligned ICRF antenna show reductions in high-Z metallic impurities. Implementation of novel “mirror-probe” electronics has enabled simultaneous measurements of $T_e$, $n_e$ and $\phi$ with $\pm 1\,\mu$s time response using a single probe tip, revealing important properties of the Quasi-Coherent-Mode (QCM) which regulates edge particle transport in EDA H-mode. An Accelerator-based In-situ Material Surveillanc diagnostic has been deployed, providing the first between-shot measurements of surface evolution of the all-metal wall. We have observed suppression of boundary turbulence and $T_e$ improvement using LHRF into high-density H-modes, with H-factor increases up to 30%. Upgrades which are ready for construction and near installation on C-Mod include: an off-midplane LH launcher to test theories of improved current drive at high density and an actively heated (900 K) tungsten DEMO-like outer divertor. We are proposing a new facility, ADX, based on Alcator technology, to access advanced magnetic topologies to solve the divertor PMI problem, combined with high-field launch LHCD and ICRF to extend the tokamak to steady-state with reactor relevant tools.

1Supported by USDOE.
2:12PM PO3.00002 I-mode access and transitions in an expanded operating space on Alcator C-Mod1, J.R. WALK, J.W. HUGHES, M.A. CHILENSKI, M. GREENWALD, N.T. HOWARD, MIT Plasma Science and Fusion Center, M.L. REINKE, University of York, J. RICE, A.E. WHITE, MIT Plasma Science and Fusion Center, Y. MARZOUK, MIT Department of Aeronautics and Astronautics — Understanding and actuating impurity transport is of particular interest for future machines because of the concern that core accumulation of heavy impurities will lead to radiative collapse and higher disruptivity. This problem is expected to be especially pronounced at low collisionality, where a strong peak of the electron density profile has previously been observed (Greenwald et al. 2007, Nucl. Fusion 47, L26). To investigate this issue several experiments have been performed in Alcator C-Mod to measure the behavior of mid-Z (Ar, Ca) and high-Z (Mo, W) impurities in H-mode plasmas of varying collisionality (2 < n_e T_e < 40). These plasmas are of particular interest to this problem because they are entirely RF heated and lack core particle sources. Impurities are injected using laser blow-off or gas injection and the evolution of the impurity density profile is constrained with an X-ray imaging crystal spectrometer. These diagnostics combined with analysis using STRAHL allows detailed study of the transport. Furthermore, analysis of the background n_e, T_e profiles is conducted using advanced techniques including Gaussian process regression. An outline of this analysis scheme will be presented and recent results obtained from its application will be shown.

1Supported by DOE award DE-FC02-99ER54512.

2:24PM PO3.00003 Stability and ELM Characterization in I-Mode Pedestals1,2, E.M. EDLUND, E. FREDRICKSON, Princeton Plasma Physics Laboratory, C. FIORE, C. GAO, J.E. RICE, A.E. WHITE, MIT Plasma Science and Fusion Center, J. RICE, M. GREENWALD, A. HUBBARD, J. HUGHES, J. IBRY, Y. LIN, E. MARMAR, R. MUMGAARD, MIT/PSFC, S. SCOTT, PPL, J. TERRY, J. WALK, A. WHITE, D. WHYTE, S. WOLFE, S. WUKITCH, MIT/PSFC — Core impurity transport has been investigated for a variety of confinement regimes in C-Mod plasmas from x-ray emission following laser blow-off injection of medium and high Z materials, avoiding the need for externally-applied ELM suppression. However, under certain conditions small, intermittent ELM-like events are seen. These events exhibit a range of phenomena in terms of edge and pedestal behavior, particularly for the ELM trigger - the majority of events are synchronized with the sawtooth heat pulse reaching the edge. The stationary pedestal structure is stable against peeling-ballooning MHD as calculated by ELITE in all cases, necessitating treatment of transient pedestal modification to characterize these events. We characterize these ELM events in terms of edge behavior, particularly the modification of the temperature pedestal, edge turbulence and fluctuations, and peeling-ballooning MHD stability.

1Supported by USDoE award DE-FC02-99ER54512.

2:36PM PO3.00004 Core Impurity Transport in C-Mod L-, I- and H-mode Plasmas1, J. RICE, M. REINKE, C. GAO, N. HOWARD, M. CHILENSKI, MIT/PSFC, P.B. SNYDER, GA, A.E. HUBBARD, J.L. TERRY, A.E. WHITE, D.G. WHYTE, S.G. BAEK, MIT/PSFC, I. CZIEGLER, UCSD CMTFO, E. EDLUND, PPL — The I-mode is a novel high-confinement regime explored on Alcator C-Mod, notable for its formation of an H-mode-like temperature pedestal without the accompanying density pedestal, maintaining L-mode particle confinement. I-mode exhibits a number of desirable properties for a reactor regime: among them, it naturally lacks large ELMs, avoiding the need for externally-applied ELM suppression. This work is supported by USDoE award DE-FC02-99ER54512.

2:48PM PO3.00005 Comparison of sawtooth heat pulses across confinement regimes in Alcator C-Mod plasmas, E.M. EDLUND, E. FREDRICKSON, Princeton Plasma Physics Laboratory, C. FIORE, C. GAO, J.E. RICE, A.E. WHITE, S.J. WUKITCH, Massachusetts Institute of Technology, M. BROOKMAN, W. ROWAN, University of Texas at Austin, N.T. HOWARD, Oak Ridge Institute for Science and Education, AND ALCATOR C-MOD TEAM — Prior studies of heat pulses from sawteeth in TFTR and DIII-D experiments found that the thermal conductivities derived from heat pulses (χ^hp) are increased by a factor of a few to an order of magnitude over the thermal conductivities derived from power balance (χ^pb) and suggest a strong dependence of χ on the local temperature gradient [1]. This may have important consequences for turbulence modeling that ignores the role of sawteeth by using profiles representative of the mean. In this study, we investigate Alcator C-MoD experiments and apply methods similar to those used in ref. [1] to model the evolution of heat pulses propagating outward from the core. Calculations of thermal conductivities derived from sawtooth heat pulses will be presented as a function of density and confinement regime and compared with those derived from power balance. This work is supported by USDoE awards DE-FC02-99ER54512, DE-FC02-09CH11466 and DE-FG03-96ER-54373.


3:00PM PO3.00006 Collisionality dependence of impurity transport in Alcator C-Mod H-modes1, M.A. CHILENSKI, M. GREENWALD, N.T. HOWARD, MIT Plasma Science and Fusion Center, M.L. REINKE, University of York, J. RICE, A.E. WHITE, MIT Plasma Science and Fusion Center, Y. MARZOUK, MIT Department of Aeronautics and Astronautics — Understanding and actuating impurity transport is of particular interest for future machines because of the concern that core accumulation of heavy impurities will lead to radiative collapse and higher disruptivity. This problem is expected to be especially pronounced at low collisionality, where a strong peak of the electron density profile has previously been observed (Greenwald et al. 2007, Nucl. Fusion 47, L26). To investigate this issue several experiments have been performed in Alcator C-Mod to measure the behavior of mid-Z (Ar, Ca) and high-Z (Mo, W) impurities in H-mode plasmas of varying collisionality (2 < n_e T_e < 40). These plasmas are of particular interest to this problem because they are entirely RF heated and lack core particle sources. Impurities are injected using laser blow-off or gas injection and the evolution of the impurity density profile is constrained with an X-ray imaging crystal spectrometer. These diagnostics combined with analysis using STRAHL allows detailed study of the transport. Furthermore, analysis of the background n_e, T_e profiles is conducted using advanced techniques including Gaussian process regression. An outline of this analysis scheme will be presented and recent results obtained from its application will be shown.

1Supported by USDoE award DE-FC02-99ER54512.
3:12PM PO3.00007 The Effects of Dilution on Turbulence and Transport in C-Mod Ohmic Plasmas and Comparisons With Gyrokinetic Simulations1, PAUL ENNEVEER, MIKLOS PORKOLAB, JOHN RICE, J. CHRIS ROST, EVAN DAVIS, DARIN ERNST, CATHERINE FOIRE, AMANDA HUBBARD, JERRY HUGHES, JIM TERRY, MIT, NAO TO TSUJI, University of Tokyo, JEFF CANDY, GARY STAEBLER, General Atomics, MATTHEW REINKE, University of York, AND ALCATOR C-MOD TEAM — Main ion dilution had been predicted by gyrokinetic simulations to decrease the turbulent ion thermal transport in C-Mod ohmic plasmas in the radial range of r/a = 0.4-0.8 [1]. This predicted effect was tested with a set of experiments on C-Mod where ohmic plasmas across the LOC (linear ohmic) -SOC (saturated ohmic) transition density were seeded with Nitrogen to dilute them. The seeding decreased the ion energy diffusivity and increased the electron density at which the toroidal rotation reversed direction. Experiments were also performed by injecting Ar to increase Zeff without significant dilution to separate the two effects. GYRO, TGRY, and TGLF simulations were performed on nitrogen seeded discharges and it was found that the simulations using experimental profiles agreed with the electron heat flux, but over-predict the ion flux. To get agreement between simulated and experimental ion flux, the experimental ion temperature profiles had to be flattened slightly but within experimental error.

1Work supported by US DOE awards DE-FG02-94ER54235 and DE-FG02-99-ER54512.

3:24PM PO3.00008 Validation study of gyrokinetic simulation (GYRO) near the edge in Alcator C-Mod ohmic discharges1, C. SUNG, A. WHITE, N. HOWARD, PSFC, MIT, D. MIKKELSEN, PPPPL, C. HOLLAND, UCSD, J. RICE, PSFC, MIT, M. REINKE, University of York, C. GAO, P. ENNEVER, M. PORKOLAB, PSFC, MIT, R. CHURCHILL, PPPPL, C. THEILER, EPFL, J. WALK, J. HUGHES, A. HUBBARD, M. GREENWALD, PSFC, MIT — A validation study of local gyrokinetic simulations (GYRO [J. Candy and R. E. Waltz, J. Comput. Phys. 186, 545 (2003)]) near the edge region (r/a ~ 0.85) has been performed for two C-Mod ohmic discharges, namely one that is in the Linear Ohmic Confinement (LOC) regime and the other one in the Saturated Ohmic Confinement (SOC) regime. Comparing the simulated heat fluxes and synthetic \( T_e \) fluctuations with the experiments, it is found that GYRO can reproduce the ion heat flux and the \( T_e \) fluctuation level measured by the Correlation ECE (CECE) diagnostic within their uncertainties, while the simulated electron heat flux is under-predicted. Furthermore, the synthetic \( T_e \) spectral shape is not matched with the measured spectrum in both LOC/SOC discharges. We have also performed global simulations to consider the interaction of turbulence within the sampling volume of the CECE diagnostic, enabling us to evaluate the importance of global simulations in applying a synthetic CECE diagnostic in this study. The LOC/SOC transition physics will be also explored.

1Research supported by USDoE awards DE-SC0006419, DE-FG02-99ER54512.

3:36PM PO3.00009 Assessment of parallel ion heat flux in the SOL of Alcator C-Mod with implications for heat-flux limiters1, D. BRUNNER, B. LABOMBARD, M. CHURCHILL, J. HUGHES, B. LIPSCHULTZ, R. OCHOUKOV, C. THEILER, J. WALK, D. WHYTE, MIT PSFC, T. Rognlien, I. C. Faust, G. M. Wallace, S. G. Baek, D. Brunner, B. Labombard, R. R. Parker, A. E. Hubbard, B. L. Labombard, M. Porkolab, J. Takase, T. Shinya, University of Tokyo, R. Vieira, N. Mucic, MIT — A systematic assessment of parallel ion heat flux in the Alcator C-Mod scrape-off layer is performed, revealing the role of kinetic effects. Experimental upstream ion-to-electron temperature ratios, as measured with charge exchange recombination spectroscopy and a reciprocating Langmuir probe near the separatrix, are compared to a simplified 1D, two-fluid model (benchmarked with UEDGE). At high collisionality with the divertor plasma nearly detached, the measured temperature ratio (\( \sim 2 \)) is matched by the fluid model. At low collisionality with the divertor sheath limited, the measured ratio (\( \sim 4 \)) is under-predicted by 2, suggesting that kinetic corrections are needed. Heat flux limiters are often used to approximate kinetic effects in fluid models; a coefficient of 0.21 for the free streaming heat flux is typical, informed by kinetic and fluid simulation comparisons. Using this correction brings modeled and measured temperature ratios into agreement at low and high collisionalities. This verifies the role of kinetic effects on ion heat transport and supports the coefficient of 0.21 as a first approximation. However, a more precise empirical prescription for heat flux limiter coefficients will require a more thorough examination of boundary ion temperature, both up- and downstream.

1Work is supported by US-DOE awards DE-FG02-99-ER54512.

3:48PM PO3.00010 Spectral measurements of lower hybrid waves in the high-density multi-pass regime of Alcator C-Mod1, J. H. WALK, D. WHYTE, MIT PSFC, T. Rognlien, I. C. Faust, G. M. Wallace, S. G. Baek, D. Brunner, B. Labombard, R. R. Parker, A. E. Hubbard, B. L. Labombard, M. Porkolab, MIT, Y. Takase, T. Shinya, University of Tokyo, R. Vieira, N. Mucic, MIT — Spectral measurements of lower hybrid waves have been performed on the diverted Alcator C-Mod tokamak by an aim of identifying the root cause of the observed anomalous loss of LH current drive efficiency in the high-density multi-pass regime. A recent experiment conducted in the reversed-field configuration confirms the previously observed magnetic-configuration dependent parametric decay instability (PDI) in the forward-field configuration at \( n_e \approx 1.1 \times 10^{20} \text{ m}^{-2} \), suggesting edge/scrape-off-layer plasma are playing an important role in determining the PDI onset. As the plasma density is raised towards \( n_e \approx 1.5 \times 10^{20} \text{ m}^{-2} \), decay spectra are observed to be dominated by PDI that are excited at the low-field-side (LFS) of the tokamak, regardless of magnetic-configuration types. While the quantification of pump depletion due to PDI needs further investigations, the measured pump peak power at the high-field-side is observed to maintain its strength up to \( n_e \approx 1.5 \times 10^{20} \text{ m}^{-2} \), indicating multi-pass propagations of LH waves. This also implies that strong single-pass Landau absorption could help recover the expected current drive efficiency. A set of LH magnetic probes is being designed to further examine how much the launched parallel wavenumber spectrum is affected by nonlinear effects on the first pass from the launcher to the plasma at the LFS.

1Supported by DOE award DE-FG02-99ER54512.

4:00PM PO3.00011 Power balance of Lower Hybrid Current Drive in the SOL of High Density Plasmas on Alcator C-Mod Tokamak1, I.C. Faust, G.M. Wallace, S.G. Baek, D. Brunner, B. Labombard, R.R. Parker, Y. Lin, S. Shiraia, J.L. Terry, D.G. Whyte, MIT PSFC, ALCATOR C-MOD TEAM — Lower Hybrid Current Drive (LHCD) on Alcator C-Mod exhibits low efficiency for densities \( n_e > 1 \times 10^{20} \text{ m}^{-3} \) for diverted discharges. Emissivity profiles of Hydrogenic Ly\(_\alpha\) and H\(_\alpha\) show significant changes during the application of LH wave as high density, along with enhanced parametric decay instability (PDI) and the generation of thermoemeric scrape-off-layer (SOL) currents. A corresponding reduction in X-ray emission from fast electrons in the confined plasma suggest damping of the LH waves in the SOL. A wide-viewing, absolutely-calibrated Hydrogen Ly\(_\alpha\) camera was installed to characterize fast timescale (~ 0.1 ms) poloidal dynamics of SOL during the application of LHCD. Analyses and results will be shown characterizing the absolute power deposition LHCD as it relates to various plasma null configurations. Ly\(_\alpha\) emission is also correlated to various experimental parameters such as SOL electron density and temperature profiles and Lower Hybrid input power in order to elucidate possible damping mechanisms.

1Work is supported by US-DOE awards DE-FG02-99ER54512.
4:12PM PO3.00012 Modeling of pedestal and core radiation in nitrogen seeded H-modes at ASDEX Upgrade — LIVIA CASALI, EMILIANO FABLE, RALPH DUX, MATTHIAS BERNERT, FRANCOIS RYTER, Max-Planck-Institut für Plasmaphysik, Garching, Germany, ASDEX UPGRADE TEAM — This work presents the time dependent modeling of the radiation and impurities in the presence of ELMs using the ASTRA transport code coupled to the impurity and radiation code STRAHL. The modeling focuses on the nitrogen seeded discharges of ASDEX Upgrade which exploits the high radiation scenario necessary for next step devices. ASDEX Upgrade has a full tungsten wall and therefore the impurities considered in the model are N and W. The modeling results highlight the importance of non coronal effects induced by transport for low-Z impurities in the pedestal, while tungsten radiation is not affected by transport. Diffusive and convective ELM models are investigated and a comparison between the modeled and the measured radiation suggests a dominant diffusive contribution in the ELM crash. The different values of the neoclassical pinch for N and W result in different reactions to the ELM frequencies and explain the fact that a sufficiently high ELM frequency is required to prevent W accumulation in the confined region.

4:24PM PO3.00013 Fast-ion transport and NBI current drive in ASDEX Upgrade — BENEDIKT GEIGER, MARKUS WEILAND, ALEXANDER MLYNEK, MIKE DUNNE, RALPH DUX, RAINER FISCHER, JOERG HOBIRK, CHRISTIAN HOFPF, MATTHIAS REICH, DAVID RITTICH, FRANCOIS RYTER, PHILIP SCHNEIDER, GIOVANNI TARDINI, Max-Planck Institute for Plasmasphysik, Garching, Germany, ASDEX UPGRADE TEAM — This work presents the time dependent modeling of the radiation and impurities in the presence of ELMs using the ASTRA transport code coupled to the impurity and radiation code STRAHL. The modeling focuses on the nitrogen seeded discharges of ASDEX Upgrade which exploits the high radiation scenario necessary for next step devices. ASDEX Upgrade has a full tungsten wall and therefore the impurities considered in the model are N and W. The modeling results highlight the importance of non coronal effects induced by transport for low-Z impurities in the pedestal, while tungsten radiation is not affected by transport. Diffusive and convective ELM models are investigated and a comparison between the modeled and the measured radiation suggests a dominant diffusive contribution in the ELM crash. The different values of the neoclassical pinch for N and W result in different reactions to the ELM frequencies and explain the fact that a sufficiently high ELM frequency is required to prevent W accumulation in the confined region.

4:36PM PO3.00014 Measurement of plasma response to 3D fields at high-$\beta$ in ASDEX Upgrade — P. PIOVESAN, Consorzio RFX, V. IGOCINE, IPP, A. KIRK, CCIFE, M. MARASCHEK, IPP, L. MARRELLI, Consorzio RFX, W. SUTTROP, IPP, D. YADKYIN, Chalmers U., M. CAVEDON, IPP, I.G. CLASSEN, DIFFER, A. GUDE, M. REICH, E. VIEZER, E. WOLFRUM, IPP, ASDEX UPGRADE TEAM — The response of 3D fields to plasma configurations is essential in fusion devices because these suprathermal particles are responsible for plasma heating, current drive and can, if poorly confined, damage surrounding walls. The degradation of the fast-ion confinement caused by large and small scale instabilities must consequently be investigated. In the ASDEX Upgrade tokamak, fast ions are generated by neutral beam injection (NBI) and their slowing down distribution can be studied using FIDA spectroscopy, neutral particle analyzers and neutron detectors. Neoclassical fast-ion transport is observed by these measurements in MHD-quiescent discharges with relatively weak heating power (less than 5 MW). The presence of sawtooth instabilities, in contrast, yields a strong internal fast-ion redistribution that can be modeled very well when assuming full reconnection of the helical magnetic field. The fast-ion current drive efficiency has been studied in discharges with up to 10 MW of heating power in which on-axis and off-axis NBI were exchanged. The radial shape of the fast-ion population, generated by the different NBIs, changes as predicted and a corresponding modification of the current profile is measured.

4:48PM PO3.00015 Slow conversion of ideal MHD perturbations into a tearing mode after a sawtooth crash — VALENTIN IGOCINE, ANJA GUDE, SYBILLE GÜNTER, KARL LACKNER, QINGQUAN YU, LAURA BARRERA ORTE, Max Planck Institute for Plasma Physics, Garching, Germany, ANTON BOGOMOLOV, IVO CLASSEN, FOM-Institute DIFFER, Dutch Institute for Fundamental Energy Research, 3430 BE Nieuwegein, The Netherlands, BERNHARD KRIESCHE, IPP, H. X. VU, U. of California, San Diego — The localization of the two-plasmon–decay (TPD) instability to specific angular regions of the quarter-critical surface in spherical implosion experiments on ASDEX Upgrade has been demonstrated through the imaging of both half- and three-halves harmonic emission. Sawteeth typically provide the strongest magnetic perturbations and are able to trigger the modes at the smallest normalized beta values. We have investigated the mechanism of the seed island formation by sawteeth in much detail. Careful analysis of electron cyclotron emission, magnetic probes and Soft X-ray measurements directly after the crash reveals the existence of an ideal (2,1) magnetic perturbation at the q=2 surface directly after the crash. This ideal perturbation converts into a tearing mode on a timescale much longer than the sawtooth crash time.

Wednesday, October 29, 2014 2:00PM - 5:00PM — Session PO4 Laser Plasma Interactions — Salon E - Denise Hinkel, Lawrence Livermore National Laboratory

2:00PM PO4.00001 An Investigation of Two-Plasmon–Decay Localization in Spherical Implosion Experiments on OMEGA — J.F. MYATT, J. SHAW, J. ZHANG, A.V. MAXIMOV, R.W. SHORT, W. SEKA, D.H. EDGELL, Laboratory for Laser Energetics, U. of Rochester, D.F. DUBOIS, LANL and Lodestar Research, D.A. RUSSELL, Lodestar Research, H.X. VU, U. of California, San Diego — The localization of the two-plasmon–decay (TPD) instability to specific angular regions of the quarter-critical surface in spherical implosion experiments on OMEGA has been demonstrated through the imaging of both half- and three-halves harmonic emission. Localization is possible because TPD is a multiband instability and different angular locations on the quarter-critical surface are driven by beams whose incident angles and intensities vary. The degree of localization has been quantified through a series of numerical calculations that were performed with a 3-D nonlinear Zakharov model of TPD. Based on these results, estimates for localized electron plasma temperature excursions over a single discharge have been obtained and compared with those inferred from experiment. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


2 D. H. Edgell et al., this conference.

2:12PM PO4.00002 Spatial Variation of Two-Plasmon–Decay Laser–Plasma Interactions Found in 3/2 $\omega$ Target Images — D.H. EDGELL, I.V. IGUMENSHCHEV, D.T. MICHEL, J.F. MYATT, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester — The Thomson-scattering system (TSS) on OMEGA has recorded images of 3/2$\omega$ light emitted from implosions. The 3/2$\omega$ light results from Thomson scattering of the drive beams off electron plasma waves (EPW’s) driven by the two-plasmon-decay (TPD) laser–plasma interaction at the quarter-critical surface. The images indicate that the 3/2$\omega$ emission is not uniform over the surface. The images show distinct patterns that change as the drive beam profile is varied. The fraction of laser energy converted to hot electrons has been shown to empirically scale with the TPD multibeam common-wave gain (CWG) during implosions on OMEGA. A hydrodynamic post-processor code calculates the CWG, including the effects of cross-beam energy exchange on the laser intensity and $k$ vectors of the EPW’s driven at the quarter-critical surface. The 3/2$\omega$ light Thomson scattered off these EPW’s and collected is modeled and compared to the observed images. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

Plasma Waves Driven by Multiple Laser Beams
R.K. FOLETT, R.J. HENCHEN, S.X. HU, J. KATZ, D.T. MICHEL,
J.F. MYATT, H. WEN, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester — Thomson scattering is used to probe electron plasma waves (EPW’s) driven by the common-wave two-plasmon–decay (TPD) instability near the quarter-critical density. Between two and five laser beams (λ ≈ 351 nm) illuminated planar CH targets with 300-μm-diam (FWHM) laser spots with overlapped intensities ∼ 10^{15} W/cm^2. A 263-nm Thomson-scattering beam was used to probe densities ranging from 0.2 to 0.25 n_c while k matching the TPD common wave. The Thomson-scattering spectra show two spectral peaks consistent with scattering from forward-scattered TPD common wave EPW’s and Langmuir decay of backscattered TPD waves. Broad TPD driven spectral features were observed in an alternate scattering configuration probing EPW k vectors that do not lie along a TPD maximum-growth hyperbola, consistent with TPD k-space saturation. Experimental results are compared to ZAK3D simulations. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

Absolute and Convective Two-Plasmon Decay Driven by Multiple Laser Beams
R.W. SHORT, J.F. MYATT, J. ZHANG, W. SEKA, Laboratory for Laser Energetics, U. of Rochester — Analysis of two-plasmon decay (TPD) driven by multiple laser beams indicates that the linear phase of the instability is dominated by an absolute instability that most strongly drives plasma waves with small wave numbers; this is consistent with Zakharov simulations. Two types of absolute mode are found in the small-k region, with the dominant mode depending on the relative angles between the beams. Thresholds decrease with increasing angle of incidence. Although the analysis presented here is linear, observations indicate that the absolute mode persists well into the nonlinear regime. Representative results for the absolute TPD threshold as a function of beam geometry and polarization will be presented, and the consequences for direct-drive experiments discussed. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

Particle-in-cell Modeling of Laser–Plasma Interactions in Three Dimensions
H. WEN, A.V. MAXIMOV, R. YAN, J. LI, C. REN, J.F. MYATT, Laboratory for Laser Energetics, U. of Rochester — In the direct-drive method of inertial confinement fusion, the laser–plasma interactions (LPI’s) near quarter-critical density are very important for laser absorption and fast-electron generation. Three-dimensional simulations with the particle-in-cell (PIC) code OSIRIS have allowed us to study different parametric instabilities including two-plasmon decay, stimulated Raman scattering, and stimulated Brillouin scattering. These instabilities may coexist and interact in the region near quarter-critical density. The spectra of forward-going and backward-going scattered light and fast electrons in two-dimensional and three-dimensional PIC simulations have been studied. Characteristics of LPI driven by a plane-wave laser and by an incoherent laser beam are compared. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

Self-Consistent Calculation of Half-Harmonics Emission Generated by the Two-Plasmon–Decay Instability
J. ZHANG, J.F. MYATT, A.V. MAXIMOV, R.W. SHORT, Laboratory for Laser Energetics, U. of Rochester, D.F. DUBOIS, LANL and Lodestar Research, D.A. RUSSELL, Lodestar Research, H.X. VU, U. California, San Diego — Half-harmonics emission can be used as an effective diagnostic tool for the two-plasmon–decay (TPD) instability. However, interpretation of the half-harmonics spectrum is difficult because of its complicated generation mechanism. We have developed a code that can calculate half-harmonics emission self-consistently with the TPD instability. The results would be useful to interpret experimental data and help design experiments. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

Two-plasmon decay instabilities in a plasma with ion density fluctuations
JUN LI, CHUANG REN, RUI YAN, Laboratory for Laser Energetics, University of Rochester — Previous study found that the two-plasmon decay (TPD) modes in the low density region were important to hot electron generation in direct-drive inertial confinement fusion [R. Yan et al., Phys.Rev.Lett 108, 175002 (2012)]. These modes were linked to ion density fluctuations and formed the first stage for electron acceleration due to their low phase velocities. Here we investigate the excitation mechanism of these modes by studying linear and fast growth of TPD instabilities in a plasma with ion density modulations under parameters relevant to OMEGA experiments using LTS [R. Yan et al., Phys.Plasmas 17, 052701 (2010)] fluid simulations. It is found that when a sinusoidal static ion density modulation is added to the linear plasma density profile, the otherwise convective TPD modes become absolute with a growth rate much higher than the convective growth rate without the ion density modulation. An analytical theory is also developed to understand these results. This may explain why in Particle-in-Cell simulations these modes were only found in the nonlinear stage when ion density fluctuations were present.

Boosting the performance of Brillouin amplification via reduction of parasitic Raman scattering and filamentation
R. TRINES, R. BINGHAM, P.A. NORREYS, STFC Rutherford Appleton Laboratory, Didcot, UK, E.P. ALVES, R.A. FONSECA, L.O. SILVA, Instituto Superior Tecnico, Lisbon, UK, K.A. HUMPHREY, University of Strathclyde, Glasgow, UK, F. FIUZA, LNL, R.A. CAIRNS, University of St. Andrews, Fife, UK — Brillouin amplification of laser pulses in plasma is a promising scheme to produce picosecond pulses of petawatt power, as it is more robust than Raman amplification. However, parasitic instabilities spoil the quality of the amplified pulse: Raman backscattering affects the contrast ratio, filamentation ruins the pulse envelope and Raman forward scattering spoils the pulse’s coherence and causes the amplification to saturate. Through analytic theory and simulations, we have identified a novel parameter window where the performance of Brillouin amplification is maximized and the highest pulse powers are reached while the deleterious influence of parasitic instabilities is strongly reduced. The respective merits of using plasma densities either above or below the quarter-critical density will be discussed.
3:36PM PO4.00009 Laser-Plasma Instabilities by Avoiding the Strong Ion Landau Damping Limit: The Central Role of Statistical, Ultrafast, Nonlinear Optical Laser Techniques (SUNOL)\(^1\).

BEDROS AFEYAN, Polymath Research Inc., STEFAN HÜLLER, Centre de Physique Theorique, Ecole Polytechnique, FR, DAVID MONTGOMERY, Los Alamos National Laboratory, JOHN MOODY, Lawrence Livermore National Laboratory, DUSTIN FROULA, Laboratory for Laser Energetics, JAMES HAMMER, OGGIE JONES, PETER AMENDT, Lawrence Livermore National Laboratory — In mid-Z and high-Z plasmas, it is possible to control crossed beam energy transfer (CBET) and subsequently occurring single or multiple beam instabilities such as Stimulated Raman Scattering (SRS) by novel means. These new techniques are inoperative when the ion acoustic waves are in their strong damping limit, such as occurs in low Z plasmas with comparable electron and ion temperatures. For mid-Z plasmas, such as Z = 10, and near the Mach 1 surface, the strong coupling regime (SCR) can be exploited for LPI mitigation. While at higher Z values, it is thermal filamentation in conjunction with nonlocal heat transport that are useful to exploit. In both these settings, the strategy is to induce laser hot spot intensity dependent, and thus spatially dependent, frequency shifts to the ion acoustic waves in the transient response of wave–wave interactions. The latter is achieved by the on-off nature of spike trains of uneven duration and delay, STUD pulses. The least taxing use of STUD pulses is to modulate the beams at the 10 ps time scale and to choose which crossing beams are overlapping in time and which are not.

\(^1\)Work supported by a grant from the DOE NNSA-OFES joint program on HEDP

3:48PM PO4.00010 Laser plasma interaction in rugby-shaped hohlraums, P.-E. MASSON-LABORDE, F. PHILIPPE, V. TASSIN, M.-C. MONTEIL, P. GAUTHIER, A. CASNER, S. DEPIERREUX, P. SEYTOR, D. TETYCHENNE, P. LOISEAU, P. FREYMERIE, CEA DAM DIF — Rugby-shaped-hohlraum has proven to give high performance compared to a classical similar-diameter cylinder hohlraum. Due to this performance, this hohlraum has been chosen as baseline ignition target for the Laser MegaJoule (LMJ). Many experiments have therefore been performed during the last years on the Omega laser facility in order to study in details the rugby hohlraum. In this talk, we will discuss the interpretation of these experiments from the point of view of the laser plasma instability problem. Experimental comparisons have been done between rugby, cylinder and elliptical shape rugby hohlraums and we will discuss how the geometry differences will affect the evolution of laser plasma instabilities (LPI). The efficiency of laser smoothing techniques on these instabilities will also be discussed as well as gas filling effect. The experimental results will be compared with FCI2 hydro radiative calculations and linear postprocessing with Piranah. Experimental Raman and Brillouin spectrum, from which we can infer the location of the parametric instabilities, will be compared to simulated ones, and will give the possibility to compare LPI between the different hohlraum geometries.

4:00PM PO4.00011 Multibeam Laser–Plasma Interactions Lead to Localized Interaction Regions, W. SEKA, W. THEOBALD, J.F. MYATT, R.W. SHORT, R.E. BAHR, Laboratory for Laser Energetics, U. of Rochester, R. NORA, R. BETTI, Laboratory for Laser Energetics and Fusion Science Center, U. of Rochester — Spherical high-intensity laser–plasma interaction experiments on Omega with and without smoothing by spectral dispersion show evidence of stimulated Brillouin and Raman scattering and two-plasmon decay in the corona at or below \(\tau_c/4\). The multibeam nature of the interaction and its symmetry requirements automatically lead to localized interaction regions that may influence energy deposition and drive uniformity. The localized nature of these processes manifests itself in scattered-light images and spectra in various wavelength regimes. We will present experimental evidence for these processes supported by hydrodynamic and laser–plasma interaction simulations. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.

4:12PM PO4.00012 Cross-Beam Energy Transfer Driven by Incoherent Laser Beams with Colors, A.V. MAXIMOV, J.F. MYATT, R.W. SHORT, I.V. IGUMENSHCHEV, W. SEKA, Laboratory for Laser Energetics, U. of Rochester — Recently, the effect of cross-beam energy transfer (CBET) has become one of the most important challenges for the effective coupling of laser energy to the target in inertial confinement fusion (ICF) (see, e.g., Ref. 1). CBET is based on competition and/or self-mixed Brillouin scattering (SBS) driven by multiple crossing laser beams in the regime of moderate SBS amplification gains, and is consequently sensitive to the frequency characteristics of the laser beams driving the ICF targets: smoothing by spectral dispersion or frequency shifts between the beams (colors). Different from reduced ray-type models used in large-scale hydrodynamic simulations with CBET\(^2\)\(^{,}\), we have developed a laser–plasma interaction (LPI)-type model of CBET that is capable of capturing the effects of laser speckles and the non-paraxial propagation of multiple laser beams\(^3\). The LPI-type CBET model has been applied to the interaction between incoherent laser beams with different colors and the differences from the ray-type CBET model have been shown. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.


4:24PM PO4.00013 Manipulation of the polarization of intense laser beams via optical wave mixing in plasmas\(^4\), PIERRE MICHEL, LAURENT DIVOL, DAVID TURNBULL, JOHN MOODY, Lawrence Livermore National Laboratory — When intense laser beams overlap in plasmas, the refractive index modulation created by the beat wave via the ponderomotive force can lead to optical wave mixing phenomena reminiscent of those used in crystals and photorefractive materials. Using a vector analysis, we present a full analytical description of the modification of the polarization state of laser beams crossing at arbitrary angles in a plasma. We show that plasmas can be used to provide full control of the polarization state of a laser beam, and give simple analytical estimates and practical considerations for the design of novel photonics devices such as plasma polarizers and plasma waveplates.

\(^3\)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.

4:36PM PO4.00014 The numerical study of Stimulated Raman and Brillouin Scattering in multiple laser beams, CHUNYANG ZHENG, LIANG HAO, Institute of Applied Physics and Computational Mathematics, Beijing — Two dimensional simulations of multi-beam laser-plasma interactions have been performed in the 2D particle-in-cell (PIC) code. The Raman or Brillouin amplification and competition between them in the presence of strong cross beam energy transfer are discussed. We observe that the total backward scattering level can be significantly enhanced or reduced by varying the wavelength separations among the interaction beams. The effects of particle trapping and side scattering which are responsible for the nonlinear saturation of SRS or SBS are also analyzed.
and find by comparing the codes with a simple particle pusher that the particle pusher error dominates the results. We derive the constraint imposed by use of motion, decreasing with increasing $\alpha$

Focusing on a laser field, comparing the codes PSC and LSP. We find an unexpectedly small timestep is required for both codes to resolve the classical electron

Facility, STFC, GUANGYE CHEN, Los Alamos National Laboratory — We present a study of particle-in-cell simulation error in modeling a free electron in an

ion beam formation and neutron production. Results will be present on the predicted effects of different anode configurations. This work performed under the

are advanced through the final pinch phase using an adaptive variable time-step to capture the fs and sub-mm scales of the kinetic instabilities involved in the

performed using a new hybrid fluid-to-kinetic model transitioning from a fluid description to a fully kinetic PIC description during the run-in phase. Simulations

focus (DPF) Z-pinches with deuterium gas fill are compact devices capable of producing $10^{12}$ neutrons per shot but past predictive models of large-scale DPF

have not included kinetic effects such as ion beam formation or anomalous resistivity. We report on progress of developing a predictive DPF model by extending our 2D axisymmetric collisional kinetic particle-in-cell (PIC) simulations to the 1 MJ, 2 MA Gemini DPF using the PIC code LSP. These new simulations incorporate electrodes, an external pulsed-power driver circuit, and model the plasma from insulator lift-off through the pinch phase. The simulations were performed using a new hybrid fluid-to-kinetic model transitioning from a fluid description to a fully kinetic PIC description during the run-in phase. Simulations are advanced through the final pinch phase using an adaptive variable time-step to capture the fs and sub-mm scales of the kinetic instabilities involved in the ion beam formation and neutron production. Results will be present on the predicted effects of different anode configurations. 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 supported by the Laboratory Directed Research and Development Program (11-ERD-063) and the Computing Grand Challenge program at LLNL. This work supported by Office of Defense Nuclear Nonproliferation Research and Development within U.S. Department of Energy’s National Nuclear Security Administration.

2:24PM PO5.00003 Intensity-dependent criteria for PIC simulations of relativistic electrons in a laser field. GINEVRA E. COCHRAN, The Ohio State University, Department of Physics, ALEXEY V. AREFIEV, University of Texas at Austin, Institute for Fusion Studies, DOUGLASS W. SCHUMACHER, The Ohio State University, Department of Physics, A.P.L. ROBINSON, Central Laser Facility, STFC, GUANGYE CHEN, Los Alamos National Laboratory — We present a study of particle-in-cell simulation error in modeling a free electron in an ultraintense laser field, comparing the codes PSC and LSP. We find an unexpectedly small timestep is required for both codes to resolve the classical electron motion, decreasing with increasing $\alpha$, the normalized vector potential. We consider grid dispersion, the field solver, and the particle pusher as sources of error, and find by comparing the codes with a simple particle pusher that the particle pusher error dominates the results. We derive the constraint imposed by use of the relativistic Boris particle pusher on the timestep and find that it must decrease inversely as $\alpha$. We find the particle pusher error accumulates on the small trajectory segments where the gamma-factor is approximately unity and the laser fields are strong, and present a sub-cycled version of the simple particle pusher code which reduces error. This work was supported in part by an allocation of computing time from the Ohio Supercomputer Center. This work was supported by U.S. Department of Energy Contract Nos. DE-FC52-06NA26262 and DE-FG02-04ER54742, and National Nuclear Security Administration Contract No. DE-FC52-08NA28512.

2:36PM PO5.00004 Numerical stability of pseudo-spectral PIC code generalizations1. BRENDAN B. GODFREY, University of Maryland, JEAN-LUC VAY, Lawrence Berkeley National Laboratory — Laser Plasma Accelerator (LPA) particle-in-cell (PIC) simulations are computationally demanding, because they require beam transport over times and distances long compared with the natural scales of the acceleration mechanism and because they are prone to numerical instabilities. To provide greater flexibility in LPA PIC simulations, we have generalized the Pseudo-Spectral Time Domain (PSTD) algorithm to accommodate arbitrary order spatial derivative approximations and substantially longer time steps. Here, we show that, by extending approaches developed by us for other PIC algorithms, numerical Cherenkov instabilities can be suppressed for the generalized PSTD algorithm. We also illustrate the relationships between the generalized PSTD and other PIC algorithms, such as Finite Difference Time Domain (FDTD) and Pseudo-Spectral Analytical Time Domain (PSATD) algorithms. Background information can be found at http://hifweb.lbl.gov/public/BLAST/Godfrey/.

Work supported in part by DOE under contract DE-AC02-05CH11231

Wednesday, October 29, 2014 2:00PM - 4:36PM –
Session PO5 Numerical Simulation Methods
Galerie 2 - Greg Moses, University of Wisconsin-Madison

2:00PM PO5.00001 Relativistic Modeling Capabilities in PERSEUS Extended MHD Simulation Code for HED Plasmas1. NATHANIEL HAMLIN, CHARLES SEYLER, Cornell University — We discuss the incorporation of relativistic modeling capabilities into the PERSEUS extended MHD simulation code for high-energy-density (HED) plasmas, and present the latest simulation results. The use of fully relativistic equations enables the model to remain self-consistent in simulations of such relativistic phenomena as hybrid X-pinches and laser-plasma interactions. A major challenge of a relativistic fluid implementation is the recovery of primitive variables (density, velocity, pressure) from conserved quantities at each time step of a simulation. This recovery, which reduces to straightforward algebra in non-relativistic simulations, becomes more complicated when the equations are made relativistic, and has thus far been a major impediment to two-fluid simulations of relativistic HED plasmas. By suitable formulation of the relativistic generalized Ohm’s law as an evolution equation, we have reduced the central part of the primitive variable recovery problem to a straightforward algebraic computation, which enables efficient and accurate relativistic two-fluid simulations. Our code recovers expected non-relativistic results and reveals new physics in the relativistic regime.

1Work supported by the National Nuclear Security Administration stewardship sciences academic program under Department of Energy cooperative agreement DE-NA0001836

2:12PM PO5.00002 Particle-In-Cell Modeling For MJ Dense Plasma Focus with Varied Anode Shape . A. LINK, C. HALVORSON, A. SCHMIDT, LLNL, E.C. HAGEN, NSTEC, D. ROSE, D. WELCH, Voss Scientific — Megajoule scale dense plasma focus (DPF) Z-pinches with deuterium gas fill are compact devices capable of producing $10^{12}$ neutrons per shot but past predictive models of large-scale DPF
2:48PM PO5.00005 Macroparticle merging algorithm for PIC, MARIJA VRANIC, THOMAS GRISMAIER, JOANA L. MARTINS, GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de, RICARDO A. FONSECA, DCTI/ISCTE Instituto Universitário de Lisboa, 1649-026 Lisbon, Portugal, LUIS O. SILVA, GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de — With the development of large supercomputers (>1000000 cores), the complexity of the problems we are able to simulate with particle-in-cell (PIC) codes has increased substantially. However, localized density spikes can introduce load imbalance where a small fraction of cores is occupied, while the others remain idle. An additional challenge lies in self-consistent modeling of QED effects at ultra-high laser intensities ($I > 10^{21}$ W/cm$^2$), where the number of pairs produced sometimes grows exponentially and may reach beyond the maximum number of particles that each processor can handle. We can overcome this by resampling the 6D phase space: the macroparticles can be merged into fewer particles with higher particle weights. Existing merging scheme [1] preserves the total charge, but not the particle distribution. Here we present a novel particle-merging [2] algorithm that preserves the energy, momentum and charge locally and thereby minimizes the potential influence to the relevant physics. Through examples of classical plasma physics and more extreme scenarios, we show that the physics is not altered but we obtain an immense increase in performance.


3:00PM PO5.00006 First PIC simulations modeling the interaction of ultra-intense lasers with sub-micron, liquid crystal targets, MATTHEW MCMAHON, PATRICK POOLE, CHRISTOPHER WILLIS, DAVID ANDERECK, DOUGLASS SCHUMACHER, The Ohio State University — We recently introduced liquid crystal films as on-demand, variable thickness (50 – 5000 nanometers), low cost targets for intense laser experiments [POP 21, 063109 (2014)]. Here we present the first particle-in-cell (PIC) simulations of short pulse laser excitation of liquid crystal targets treating Scarlet (OSU) class lasers using the PIC code LSP. In order to accurately model the target evolution, a low starting temperature and field ionization model are employed. This is essential as large starting temperatures, often used to achieve large Debye lengths, lead to expansion of the target causing significant reduction of the target density before the laser pulse can interact. We also present an investigation of the modification of laser pulses by very thin targets. This work was supported by the DARPA PULSE program through a grant from ARMDEC, by the US Department of Energy under Contract No. DE-NA0001976, and allocations of computing time from the Ohio Supercomputing Center.

3:12PM PO5.00007 Fourier Planck theory for energetic electron deposition in laser fusion, WALLACE MANHEIMER, DENIS COLOMBANT, Retired — We have developed a Fokker Planck model to calculate the transport and deposition of energetic electrons, produced for instance by the two plasmon decay instability at the quantum critical surface [1]. In steady state, the Fokker Planck equation reduces to a single universal equation in energy and space, an equation which appears to be quite simple, but which has a rather unconventional boundary condition. The equation is equally valid in planar and spherical geometry, and it depends on only a single parameter, the charge state Z. Hence one can solve for a universal solution, valid for each Z. An asymptotic solution to this fourier Planck instability is also presented, which allows the heating of the main plasma to be calculated from a simple analytical expression. A more accurate solution in terms of a Bessel function expansion will also be presented. From this, one obtains a heating rate which can be simply incorporated into fluid simulations.


3:24PM PO5.00008 Nonlocal electron transport: comparison with the SNB model and results for implosion runs, DENIS COLOMBANT, Berkeley Research Associates, Beltsville, MD, WALLACE MANHEIMER, RSI, Lanham MD, ANDREW J. SCHMITT, Plasma Physics Division, Naval Research Laboratory — Two main models have been proposed for nonlocal transport: the SNB model and ours, the velocity dependent Krook (VDK) model. Although these models are based on similar basic equations, they differ in some aspects. A comparison between the two models was published last year[1] followed this year by implosion calculations using the SNB model only[2]. Our model has since then been updated numerically and runs much faster than our previous one and is now comparable to SNB in running time. We have run some of the same test problems as Marocchino et al., and we have also made some implosion runs for shock ignition targets. We have also updated our code to make it easier to change the electron collision frequencies when needed. Most of the results we have obtained are quite different from Marocchino’s, in particular from his version of our model. We present these results and discuss them in some detail.

[1] Work supported by DoE/NNSA.

3:36PM PO5.00009 Direct Comparison of Full-Scale Vlasov-Fokker-Planck and Classical Modeling of Megagauss Magnetic Field Generation in Plasma Near Hohlraum Walls From Nanosecond Laser Pulses, ARCHIS JOGLEKAR, ALEXANDER THOMAS, Univ of Michigan - Ann Arbor, MARTIN READ, ROBERT KINGHAM, Imperial College — Here, we present 2D numerical modeling of near critical density plasma using a fully implicit Vlasov-Fokker-Planck (VFP) code, IMPACTA, with the addition of a ray tracing package. In certain situations, such as at the critical surface at the walls of a hohlraum, magnetic fields are generated through the crossed temperature and electron density gradients. Modeling shows 0.3 MG fields and the strong heating also results in magnetization of the plasma up to $\gamma \sim 0.5$. In the case without magnetic field generation, the heat flows from the laser heating region are isotropic. Including magnetic fields causes the heat flow to form jets along the wall due to the Rigbi-Leduc effect. The heating of the wall region causes steep temperature gradients. This serves as a positive feedback mechanism for the field generation rate resulting in nearly twice the amount of field generated in comparison to the case without magnetic fields over 1 ns. The heat conduction, field generation, and the calculation of other transport quantities, is performed ab-initio due to the nature of the VFP equation set. In order to determine the importance of the kinetic effects from IMPACTA, we perform direct comparison with a classical (Braginskii) transport code with hydrodynamic motion (CTC+)

1 The authors would like to acknowledge DOE Grant #DESC0010621 and Advanced Research Computing, UM-AA.

4:46PM PO5.00010 A Numerical Study of the Two and Three Dimensional Richtmyer Meshkov Instability, YE ZHOU, LLNL, BEN THORNBER, Univ. of Sydney — The Richtmyer-Meshkov instability occurs as shock waves pass through a perturbed material interface. This paper presents a series of large-eddy-simulations of the two dimensional turbulent RM instability and compares the results to the fully three dimensional simulations conducted by Thornber et al. There are two aims to this paper, the first is to explore the number of independent realisations which are required to give a statistically converged solution for a two dimensional flow field, in a similar vein to that undertaken by Clark. The second aim is to elucidate the key differences in flow physics between the two dimensional and three dimensional Richtmyer-Meshkov instabilities, particularly their asymptotic self-similar regime. Earlier publications on the Rayleigh Taylor instability imply that lower mixing, larger structures, and more rapid late time growth are expected. The full paper will detail the statistical convergence of the 2D simulations a function of ensemble number and grid resolution, and ensemble averaged growth rates, mixing parameters, turbulent kinetic energy and spectra compared to the equivalent parameters from 3D mixing simulations.
4:00PM PO5.00011 Thermodynamic modeling of uncertainties in NIF ICF implosions due to underlying microphysics models\(^1\). JIM GAFFNEY, PAUL SPRINGER, GILBERT COLLINS, Lawrence Livermore National Laboratory — Design and analysis calculations for ICF implosions rely on a large number of physics models, which are extremely difficult to test in isolation. As a result, models are often run in regimes where physical models contain significant uncertainties. While efforts have been made to design ignition targets that are robust to physics uncertainties, the use of full-scale hydrodynamic simulations limit these studies to sparse, low dimensional grids. More lightweight models, while much simpler, have proven very useful in analyzing and understand experimental ICF data and play an essential role in moving the field forward. We will describe a thermodynamic hot spot model that includes all physical models, along with variations that are consistent with the expected uncertainties, that is fast and lightweight enough to perform studies consisting of a million simulation points or more. We will present results from a large number of calculations and discuss the use of these data in understanding experimental results, with particular emphasis on underlying microphysics models.

\(^1\)Supported by U.S. DOE under Contract No. DE-AC02-09CH11466

Wednesday, October 29, 2014 2:00PM - 4:48PM —
Session PO7 Low Temperature Plasmas: Diagnostics, Surfaces, Applications and Thrusters
Galerie 6 - John Foster, University of Michigan

2:00PM PO7.00001 ABSTRACT WITHDRAWN

4:12PM PO5.00012 Enhanced NLTE Atomic Kinetics Modeling Capabilities in HYDRA\(^1\). MEHUL V. PATEL, HOWARD A. SCOTT, MICHAEL M. MARINAK, Lawrence Livermore National Laboratory — In radiation hydrodynamics modeling of ICF targets, an NLTE treatment of atomic kinetics is necessary for modeling high-Z hohlraum wall materials, high-Z dopants mixed in the central gas hotspot, and is potentially needed for accurate modeling of outer layers of the capsule ablator. Over the past several years, the NLTE DCA atomic physics capabilities in the 3D ICF radiation hydrodynamics code HYDRA have been significantly enhanced. The underlying atomic models have been improved, additional kinetics options including the ability to run DCA in cells with dynamic mixing of species have been added, and the computational costs have been significantly reduced using OpenMP threading. To illustrate the improved capabilities, we will show higher fidelity results from simulations of ICF hohlraum energetics, laser irradiated sphere experiments, and ICF capsule implosions.

\(^1\)Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-656773

4:24PM PO5.00013 Variational integration for ideal MHD with built-in advection equations\(^1\). YAO ZHOU, HONG QIN, JOSHUA BURBY, AMITAVA BHAT TACHARJEE, Princeton Plasma Phys Lab — Newcomb’s Lagrangian for ideal MHD in Lagrangian labeling is discretized using discrete exterior calculus. Variational integrators for ideal MHD are derived thereafter. Besides being symplectic and momentum preserving, the schemes inherit built-in advection equations from Newcomb’s formulation, and therefore mitigate numerical resistivity significantly. We implement the method in 2D and show that it does not suffer from numerical reconnection when singular current sheets are present. We then apply it to studying the dynamics of the ideal coalescence instability with multiple islands. The relaxed equilibrium state with embedded current sheets is obtained numerically.

\(^1\)Prepared by LLNL under Contract DE-AC52-07NA27544

2:12PM PO7.00002 The effect of ambipolar electric fields on the electron heating in capacitive RF plasmas, JULIAN SCHULZE, West Virginia University, ZOLTAN DONKO, ARANKA DERZSI, IHIR KOROLOV, Hungarian Academy of Sciences, EDMUND SCHUENGEL, West Virginia University — We investigate the electron heating dynamics in argon and helium capacitively coupled RF discharges driven at 13.56 MHz by Particle in Cell simulations and by an analytical model. Electrons are found to be heated by strong ambipolar electric fields outside the sheath during the phase of sheath expansion in addition to classical sheath expansion heating. Moreover, we find that electrons reflected multiple times from the expanding sheath edge within one RF period are the primary sources of ionization. In fact a synergistic combination of different heating events is required to sustain the plasma. The ambipolar electric field outside the sheath is found to be time modulated due to a time modulation of the electron mean energy caused by the presence of sheath expansion heating only during one half of the RF period at a given electrode. This time modulation results in more heating than cooling on time average. If an electric field reversal is present during sheath collapse, this time modulation will be enhanced. This ambipolar electron heating is found to represent an important heating mechanism, which should be included in models of capacitive RF plasmas.

2:24PM PO7.00003 Investigation of self-excited plasma series resonance oscillations in multi-frequency capacitive discharges, EDMUND SCHUENGEL, JULIAN SCHULZE, Department of Physics, West Virginia University, IHOR KOROLOV, ARANKA DERZSI, ZOLTAN DONKO, Institute for Solid State Physics and Optics, Wigner Research Centre for Physics, Hungarian Academy of Sciences, Budapest, Hungary — The self-excitation of plasma series resonance (PSR) oscillations is a dominant feature in the current of asymmetric capacitively coupled radio-frequency discharges. The asymmetry can be caused by an asymmetry of the chamber geometry and/or that of the applied voltage waveform. We study the self-excitation of the PSR in a geometrically symmetric, electrically asymmetric capacitive argon discharge using PIC/MCC simulations, as well as an analytical model. The results show that increasing the number of subsequent harmonics in the driving voltage waveform enhances the asymmetry and, therefore, leads to a significant increase of the current amplitude of higher harmonics, which are generated due to the nonlinearities of the sheaths. These high-frequency resonance oscillations between the capacitive sheaths and the inductive plasma bulk can only be reproduced correctly by the analytical model, if the cubic sheath charge - voltage relation and the temporal modulation of the bulk length and electron density within the RF period are taken into account. Furthermore, we demonstrate that the nonlinear electron resonance heating (NERH) associated with the presence of PSR oscillations significantly contributes to the total electron heating and causes a spatial asymmetry of the ionization.

2:36PM PO7.00004 Formation and dynamics of striations in an annular inductive plasma, NICOLAS PLIHN, VICTOR DESANGLES, Laboratoire de Physique, ENS Lyon & CNRS, Lyon, France, PASCAL CHABERT, Laboratoire de Physique des Plasmas, Ec Polytechnique & CNRS, Palaiseau, France — We present an experimental characterization of the dynamics of a low pressure, radio-frequency inductively coupled plasma with an internal coil (resulting in an annular geometry) as described in [1]. At low pressure, the resulting plasma equilibrium is axisymmetric. We show that the cylindrical symmetry of the system is broken at sufficiently high pressure (above 20 mTorr) and low coupled power. In these non-axisymmetric configurations, striations occur along the azimuthal direction. The number of plasma lobes (or striations) increases as pressure increases (from 2 to 7 lobes as pressure increases from 50 to 2500 mTorr). Both stationary and rotating lobes have been observed. The transition between the axisymmetric and non-axisymmetric configurations is shown to be subcritical, resulting in bistability. The transitions between non-axisymmetric configurations with various numbers of lobes are supercritical. High-speed imaging of the emitted light and time-resolved Langmuir probe measurements allow to precisely characterize the dynamics of the lobes, as well as the transitions between configurations.

3:00PM PO7.00006 Investigation of possible sheath disappearance near a electrode biased at the plasma potential

— It is well established that when an electrode is biased negative with respect to the plasma potential, an ion sheath forms and when it is biased positive with respect to the plasma potential, an electron sheath forms that the electrode is small (Aplate/Achamber < (me/Mi)1/2) [1]. However, when a small electrode is biased at the plasma potential, it is unknown whether an ion sheath, an electron sheath or no sheath will form. Movable small (3-5cm diameter) plates biased at the plasma potential are immersed in a filament discharge in a multi-dipole chamber. Plasma potential and IVDs near the plate are measured to determine whether an ion sheath, an electron sheath or no sheath formed. Ion velocities are determined by Laser-Induced Fluorescence, the electron temperature and electron density are measured by a planar Langmuir probe and the plasma potential is measured by an emissive probe.


3:12PM PO7.00007 Direct measurements of ion dynamics in magnetic presheaths

— The supersonic acceleration occurring at the plasma-material interface in presence of an oblique magnetic field is analyzed performing kinetic-kinetic particle-in-cell simulations (kinetic ions, kinetic electrons), comprising the effect of collisions. The energy-angle distribution functions of both ions and electrons are obtained at several locations from the bulk quasi-neutral plasma to the wall, in order to show how the plasma kinetics changes during the acceleration across the presheath up to the material wall. We highlight how collisional processes affect the structure of the sheath and presheath and modify the energy-angle distributions at the material wall. We present the scaling factor of the average ion and electron energy and peak pitch angle at the wall as a function of the bulk plasma conditions, for use in the correlation of fluid plasma models to material models.

3:24PM PO7.00008 Ion and Electron Energy-Angle Distribution Functions at the Material Wall in Magnetized Plasmas

— The supersonic acceleration occurring at the plasma-material interface in presence of an oblique magnetic field is analyzed performing kinetic-kinetic particle-in-cell simulations (kinetic ions, kinetic electrons), comprising the effect of collisions. The energy-angle distribution functions of both ions and electrons are obtained at several locations from the bulk quasi-neutral plasma to the wall, in order to show how the plasma kinetics changes during the acceleration across the presheath up to the material wall. We highlight how collisional processes affect the structure of the sheath and presheath and modify the energy-angle distributions at the material wall. We present the scaling factor of the average ion and electron energy and peak pitch angle at the wall as a function of the bulk plasma conditions, for use in the correlation of fluid plasma models to material models.

3:36PM PO7.00009 Erosion due to ion sputtering in absence of Debye Sheath at Divertor plates: PIC simulation

— The supersonic acceleration occurring at the plasma-material interface in presence of an oblique magnetic field is analyzed performing kinetic-kinetic particle-in-cell simulations (kinetic ions, kinetic electrons), comprising the effect of collisions. The energy-angle distribution functions of both ions and electrons are obtained at several locations from the bulk quasi-neutral plasma to the wall, in order to show how the plasma kinetics changes during the acceleration across the presheath up to the material wall. We highlight how collisional processes affect the structure of the sheath and presheath and modify the energy-angle distributions at the material wall. We present the scaling factor of the average ion and electron energy and peak pitch angle at the wall as a function of the bulk plasma conditions, for use in the correlation of fluid plasma models to material models.

4:00PM PO7.00011 Simulation of Nanofilm Formation in Low-Temperature Plasmas

— The supersonic acceleration occurring at the plasma-material interface in presence of an oblique magnetic field is analyzed performing kinetic-kinetic particle-in-cell simulations (kinetic ions, kinetic electrons), comprising the effect of collisions. The energy-angle distribution functions of both ions and electrons are obtained at several locations from the bulk quasi-neutral plasma to the wall, in order to show how the plasma kinetics changes during the acceleration across the presheath up to the material wall. We highlight how collisional processes affect the structure of the sheath and presheath and modify the energy-angle distributions at the material wall. We present the scaling factor of the average ion and electron energy and peak pitch angle at the wall as a function of the bulk plasma conditions, for use in the correlation of fluid plasma models to material models.
Integrated data analysis (IDA) tools are under development to maximize information in MST's advanced diagnostic set. Special emphasis is given to (1) ohmic heating with minimal external magnetization, (2) predictive capability in toroidal confinement physics, and (3) basic plasma physics is summarized. Dissipation replaces the Ohmic heating term in the electron energy equation. We will present the general results of this analysis, as well as initial results obtained using this approach. An external electron source is utilized to neutralize the ion beam, preventing the spacecraft from charging up negatively. Hall thrusters also accelerate ions electrostatically, but the electrons are held back not by grids but by a magnetic field. A cool electron source is needed here also. Helicon thrusters eject neutral plasma, and the ions are given a kick in an external “double layer,” which forms as a sheath in free space. We have miniaturized a helicon thruster by using a permanent magnet over a small discharge tube. The ejected plasma is measured with a retarding-field ion analyzer. At low pressures, the RFID peaks around 27eV and can be increased by biasing the top plate, thus achieving a reasonable specific impulse.

A Simple Model of Cross-Field Diffusion in Hall Thrusters based on Turbulence Energy Cascade . MARK A. CAPPELLI, EUNSUN CHA, Stanford Univ, EDUARDO FERNANDEZ, Eckerd College — We present a Hall plasma thruster model based on turbulence energy cascade to smaller scales characterized by the electrons gyro-radius. We employ arguments originally developed for viscous energy dissipation in turbulent fluid mechanics with the assumption that the electron scattering rate is expected to scale as the strain-rate in the electron fluid, and that the size of the largest turbulent eddies scale as the electron gyro-radius and local drift velocity. Using this framework, expressions are derived for the entropy production rate which can be used in an independent entropy transport equation from which the transport coefficient can be derived. Alternatively, if one assumes that the main source of energy dissipation is turbulent energy cascade, then the energy dissipation replaces the Ohmic heating term in the electron energy equation. We will present the general results of this analysis, as well as initial results obtained from 2-D hybrid simulations that incorporate this model and its variants.

A permanent-magnet helicon thruster . FRANCIS F. CHEN, UCLA — Gridded ion thrusters are the classical method for propelling spacecraft to their designed orbital velocities. These thrusters generate electrons with a thermionic cathode and accelerate them with positive grids, creating a plasma. Ions are extracted from the plasma and accelerated with another grid and ejected from the spacecraft to propel it. An external electron source is used to neutralize the ion beam, preventing the spacecraft from charging up negatively. Hall thrusters also accelerate ions electrostatically, but the electrons are held back not by grids but by a magnetic field. A cool electron source is needed here also. Helicon thrusters eject neutral plasma, and the ions are given a kick in an external “double layer,” which forms as a sheath in free space. We have miniaturized a helicon thruster by using a permanent magnet over a small discharge tube. The ejected plasma is measured with a retarding-field ion analyzer. At low pressures, the RFID peaks around 27eV and can be increased by biasing the top plate, thus achieving a reasonable specific impulse.

A Simple Model of Cross-Field Diffusion in Hall Thrusters based on Turbulence Energy Cascade. We present a Hall plasma thruster model based on turbulence energy cascade to smaller scales characterized by the electrons gyro-radius. We employ arguments originally developed for viscous energy dissipation in turbulent fluid mechanics with the assumption that the electron scattering rate is expected to scale as the strain-rate in the electron fluid, and that the size of the largest turbulent eddies scale as the electron gyro-radius and local drift velocity. Using this framework, expressions are derived for the entropy production rate which can be used in an independent entropy transport equation from which the transport coefficient can be derived. Alternatively, if one assumes that the main source of energy dissipation is turbulent energy cascade, then the energy dissipation replaces the Ohmic heating term in the electron energy equation. We will present the general results of this analysis, as well as initial results obtained from 2-D hybrid simulations that incorporate this model and its variants.
PP8.00005 Fast ion beta limit measurements by collimated neutron detection in the MST. WILLIAM CAPECCHI, JAY ANDERSON, SCOTT EILERMAN, JON KOLINER, JOSH REUSCH, University of Wisconsin, Madison, LIANG LIN, UCLA, DEYONG LIU, UC Irvine — Fast ion orbits in the reversed field pinch (RFP) magnetic configuration are well ordered and have low orbit loss, even considering the stochasticity of the magnetic field generated by multiple tearing modes. Purely classical TRANSP modeling of a 1MW tangentially injected hydrogen neutral beam in MST deuterium plasmas predicts a core-localized fast ion density that can be up to 25% of the electron density and a fast ion beta of many times the local thermal beta. However, neutral particle analysis of an NBI-driven mode (presumably driven by a fast ion pressure gradient) shows transport of core-localized fast ions and a saturated fast ion density. The TRANSP modeling is presumed valid until the onset of the beam driven mode and gives an initial estimate of the volume-averaged fast ion beta of 1-2% (local core value up to 10%). A collimated neutron detector for fusion product profile measurements is in development to determine the energy and spatial distribution of fast ions, the design of which is informed by recent neutron moderation measurements with polyethylene. Characterization of both the local and global fast ion beta will be done for deuterium beam injection into deuterium plasmas for comparison to TRANSP predictions. Work supported by US DOE.

PP8.00006 Characterization of an ultra-low-frequency beam-driven instability in the RFP. E. PARKE, J.K. ANDERSON, D.J. DEN HARTOG, S. EILERMAN, J.J. KOLINER, S. MUNARETTO, M.D. NORNBERG, J.A. REUSCH, University of Wisconsin-Madison — Decoupling of fast ions from the magnetic field in the reversed-field pinch allows neutral beam injection (NBI) on MST to achieve large fast ion populations that drive a rich variety of instabilities. A bursting instability near the plasma rotation frequency has recently been observed under appropriate conditions. Plasma flow measurements show that the instability propagates at ~7 kHz in the plasma reference frame. This mode also participates in energetic particle mode avalanches to drive significant fast ion transport; a neutral particle analyzer measures reduction of signal at the beam energy by almost 30%. During a burst the tearing mode amplitudes and rotation velocities increase. Bulk-ion heating of approximately 10 eV is also observed, which may be indicative of a reconnection event. Correlated electron temperature fluctuations exhibit a core-peak structure with an amplitude of 10-15 eV and which depends sensitively on reversal parameter. The correlated electron temperature fluctuations indicate that this mode is electromagnetic in nature. We offer a qualitative comparison to expectations for fishbones, beta-induced Alfvén eigenmodes, and reconnection which highlights the need for greater theoretical support for energetic particle effects in the RFP.

PP8.00007 Investigation of fast-ion instabilities and tearing-mode reduction during neutral beam injection in a reversed field pinch. L. LIN, W.X. DING, D.L. BROWER, UCLA, J.K. ANDERSON, W. CAPECCHI, S. EILERMAN, J.J. KOLINER, M.D. NORNBERG, J. REUSCH, J.S. SARFF, UW-Madison, D. LIU, UC-Irvine — Neutral beam injection into the MST-RFP is observed to drive instabilities that induce fast-ion transport and quench the fast-ion density below classical predictions. These instabilities are detected for both super- and sub-Alfvénic fast ions, indicating that free energy arises from the real space gradient. As plasma current and fast-ion species are changed, the mode number of the dominant instability varies to maintain the wave-particle resonance condition. The dominant instability also exhibits a dependence on fast-ion velocity. As v increases, the mode frequency linearly increases and the spatial asymmetry of associated density fluctuations becomes more pronounced. These features link the observed instabilities to continuum modes destabilized by strong drive. In addition to driving instabilities, fast ions are observed to affect intrinsic tearing modes. For certain plasma scenarios, fast ions reduce the core-resonant tearing mode amplitude by 60% while enhancing the kinetic dynamo arising from coherent interactions between density and radial magnetic fluctuations. This implies the potential importance of kinetic dynamo in the tearing mode suppression. Tearing modes can also impact fast-ion redistribution as suggested by edge-resonant tearing mode triggering of a chirping fast-ion mode.

PP8.00008 Alfvén Modes in the MST Revised Field Pinch. MENG LI, BORIS BREIZMAN, LINJIN ZHENG, Institute for Fusion Studies, The University of Texas at Austin, LIANG LIN, WEIXING DING, DAVID BROWER, University of California Los Angeles — This work presents a theoretical and computational analysis of core-localized energetic particle driven modes observed near the magnetic axis in MST [L. Lin, W. Ding, D.L. Brower, et al., Phys. Plasmas 20, 030701 (2013)]. Using the measured safety factor and plasma pressure profiles as input, the linear ideal MHD code AEGIS [L. J. Zheng and M. Kotschenreuther, J. Comp. Phys. 211, 748 (2006)] reveals Alfvénic modes close to the measured frequencies. The AEGIS results together with a reduced analytical model demonstrate that the modes are essentially cylindrical and dominated by a single poloidal component (m = 1). The calculated modes are localized in the plasma core where the magnetic shear is weak and continuum damping is minimal. Detailed analysis establishes constraints on the safety factor and pressure profile under which two modes can exist simultaneously as seen in experiment.

PP8.00009 Feasibility study of off-axis NBI in the Reversed Field Pinch. J.K. ANDERSON, W. CAPECCHI, J. KIM, J.J. KOLINER, M.D. NORNBERG, J.A. REUSCH, University of Wisconsin, L. LIN, UCLA — The reversed field pinch is a unique and complementary magnetic configuration for the study of energetic ion driven instabilities and their effects. EP-driven modes (destabilized by fast ion spatial gradients) have been discovered in MST with use of 1 MW tangentially-oriented neutral beam injection (NBI). More widely ranging studies of EP modes would be possible in MST with control of the fast ion density profile: the tangential NBI can only generate a core-localized, high pitch fast ion population. Here we present an initial physics study on the feasibility of off-axis NBI in the RFP. Simple deposition calculations suggest a flexible mounting system on a single large port allows localized placement of the fast ion source over a significant radial range (r/a ≳ 0.1). TRANSP/ NUBEAM calculations are used with a subset of MST equilibria to predict classical behavior of fast ions in these injection geometries. Ion orbit tracing through the tearing-mode-induced turbulent magnetic field is performed with RIO to evaluate the behavior of fast ions at mid-radius. Expected fast ion density profiles and implications on mode stability are presented for a variety of MST discharges.

PP8.00010 An Update on the Retarding Potential Grid System for a Neutral Particle Analyzer. EPHEM D. MEZOLIN, JAMES B. TITUS, Florida A&M University, JAY K. ANDERSON, JOSH A. REUSCH, University of Wisconsin - Madison — The ion energy distribution in a magnetically confined plasma can be inferred from the neutral particles that escape the plasma. On the Madison Symmetric Torus (MST), deuterium neutrals are measured in the energy range 0.34 to 45 keV by the Florida A&M University compact neutral particle analyzer (CNPA) and the MST advanced neutral particle analyzer (ANPA). The CNPA energy range covers the bulk ions from the thermal to the beginning of the fast-ion tail (0.34 to 5.2 keV) with high energy resolution (25 channels) while the ANPA covers the vast majority of the fast-ion tail distribution (up to 45 keV) with low energy resolution (10 channels). MST has gained a wealth of information about the fast-ion distribution, but much more information could be gleaned from a higher energy resolution analyzer over the fast-ion tail. Retarding potential analyzers have been used on spacecraft for decades to measure ion distributions in extraterrestrial atmospheres by slowing down charged particles before they reach the detectors. Recent work has been done to design and implement a retarding potential between the vacuum chamber of MST and the CNPA to be able to use the CNPA’s high energy resolution over any 5 keV range between 0 and 35 keV. An update of the construction and implementation of the retarding potential grid system will be presented.
PP8.00011 Preliminary MHD Validation Studies on MST\textsuperscript{1}. C.M. JACOBSON, A.F. ALMAGRI, K.J. MCCOLLAM, J.A. REUSCH, J.P. SAUPPE, J.C. TRIANA, University of Wisconsin-Madison — Quantitative validation of visco-resistive MHD models using MST takes advantage of its well-diagnosed, standard RFP plasmas. These plasmas are largely governed by MHD relaxation activity, so that a broad range of validation metrics can be evaluated. Nonlinear simulations using the single-fluid MHD code DEBS at Lundquist number $S = 4 \times 10^6$ produced equilibrium relaxation cycles in qualitative agreement with experiment, but magnetic fluctuation amplitudes were at least twice as large as in experiment. The extended-MHD code NIMROD was used previously at $S = 8 \times 10^4$, which is below MST’s operational lower limit of $S \geq 5 \times 10^5$. The predicted $b$ from NIMROD was about half as large for a two-fluid case as for a single-fluid, suggesting that a two-fluid model may be necessary for quantitative agreement with experiment. Comparisons of linear and nonlinear DEBS and NIMROD runs at low $S$ are presented, focusing on how their different numerical algorithms affect their performance. Experimental equilibrium and fluctuation measurements at low $S$ from an insertable magnetic probe are compared with simulation results. Future scaling studies of $b$ as a function of $S$ are planned using NIMROD at low $S$ complemented by DEBS at higher $S$.

\textsuperscript{1}This work is supported by the US DOE and NSF.

PP8.00012 Using IDA to Understand Electron Temperature Structures in High Temperature Discharges in the Madison Symmetric Torus\textsuperscript{1}. L.M. REUSCH, M.E. GALANTE, D.J. DEN HARTOG, Univ of Wisconsin, Madison, F. FRANZ, Consorzio RFX, EURATOM-ENEA Association, Italy, J.R. JOHNSON, M.B. MCGARRY, H.D. STEPHENS\textsuperscript{2}, Univ of Wisconsin, Madison — The Madison Symmetric Torus (MST) Reversed-Field Pinch is equipped with two independent electron temperature (Te) diagnostics: Thomson scattering (TS) and double-filter soft x-ray (SXR). Both diagnostics are able to measure Te at a rate up to 25 kHz and are in good qualitative agreement in the hot plasma core, where Te > 1 keV. We are able to combine information from both TS and SXR diagnostics along with prior physics knowledge using integrated data analysis techniques (IDA) [R. Fischer and A. Dinklage, Rev. Sci. Instrum. 75, 4237 (2004)] to improve the precision and utility of Te measurements on MST. Using IDA, there is a factor of 4 improvement in the uncertainty of all temperature measurements. We have also implemented a Markov Chain Monte Carlo analysis for analyzing the various temperature structures that MST is capable of sustaining. We have compared emissivity maps and flux surface reconstructions to the electron temperatures from several discharges to characterize the phenomenology of temperature structures in high temperature plasmas in MST.

\textsuperscript{1}Work supported by US DOE and NSF.

\textsuperscript{2}now at Pierce College Fort Steilacoom

PP8.00013 Determination of $Z_{\text{eff}}$ in MST Plasmas through Integrated Data Analysis, MATTHEW GALANTE, LISA REUSCH, DANIEL DEN HARTOG, University of Wisconsin-Madison, PAOLO FRANZ, Consorzio-RFX, JAY JOHNSON, MEGHAN MCGARRY, University of Wisconsin-Madison, HILLARY STEPHENS, Pierce College Fort Steilacoom — On most plasma science experiments, a maximum of 10 independent diagnostics is used to combine measurements to provide a single result for a plasma parameter. These measurements are typically subject to large uncertainties and are measured at a limited spatial resolution. MST’s current 41 diagnostics enable measurements to be taken at a wide range of spatial resolutions and with uncertainties that are lower than in many other experiments. For example, the purity (>99.8%) of the beryllium foils used to block visible light and to select the SXR energy range can produce significant changes in the data by altering the transmission function. In addition, the detailed geometry of the SXR detectors (silicon photodiodes) must be taken into account, including any difference in material composition such as the presence of oxides, front windows and frames, etc., to avoid misinterpretation of the data. All of these effects can be accommodated by using IDA, there is a factor of 4 improvement in the uncertainty of all temperature measurements. We have also implemented a Markov Chain Monte Carlo analysis for analyzing the various temperature structures that MST is capable of sustaining. We have compared emissivity maps and flux surface reconstructions to the electron temperatures from several discharges to characterize the phenomenology of temperature structures in high temperature plasmas in MST.

PP8.00014 Improvements in SXR and Te Measurements on MST\textsuperscript{1}. J.A. GOETZ, M.B. MCGARRY, University of Wisconsin - Madison, P. FRANZ, Consorzio RFX - Padova, D.J. DEN HARTOG, J. JOHNSON, University of Wisconsin - Madison — A diagnostic that uses soft-x-ray (SXR) emission to provide both tomographically reconstructed x-ray emissivity and double-foil electron temperature from either brightness or emissivity has been in use on MST. Analysis of the data from this system has revealed several effects that were not accounted for in past diagnostics. For example, the purity (>99.8%) of the beryllium foils used to block visible light and to select the SXR energy range can produce significant changes in the data by altering the transmission function. In addition, the detailed geometry of the SXR detectors (silicon photodiodes) must be taken into account, including any difference in material composition such as the presence of oxides, front windows and frames, etc., to avoid misinterpretation of the data. All of these effects have been studied and will be presented in this work. Modifications of the diagnostic have been implemented in order to decrease the impact of these features on the measurements and have led to improved measurements and a validation of the results from the diagnostic. Time-resolved SXR emissivity and full radial profiles of electron temperature have been analyzed. In particular, high current improved confinement discharges often exhibit enhanced emission from island structures, both rotating and locked. Analysis has been concentrated on the correlation of SXR structures with temperature profiles in locked plasmas.

\textsuperscript{1}Work supported by USDoE.

PP8.00015 Statistical Analysis of Thomson Scattering Measurements for High-Frequency Temperature Fluctuations\textsuperscript{1}. LUCAS MORTON, DANIEL DEN HARTOG, ELI PARKE, JAMES DUFF, UW-Madison, LIANG LIN, UCLLA — The MST Thomson Scattering (TS) Diagnostic is used to study electron temperature (Te) fluctuations at frequencies ($<300$kHz) higher than those of global core-resonant tearing modes ($m = 1$, $n = 5-8$). Each of the twin TS lasers can fire 4-5 pulses at repetition rate of 12.5 kHz. Adjusting the time delay between the lasers (as low as 1 $\mu$s) allows probing of high-frequency (up to 1 MHz) fluctuations by autocorrelating the resulting Te measurements. This technique’s effectiveness is demonstrated by comparing its results to those of tearing-mode-correlation studies. In 400 kHz standard MST discharges, the dominant tearing modes have associated Te fluctuations of up to 25 +/- 5 eV in the core. The TS autocorrelation measures total fluctuations of 42 +/- 5 eV, indicating that tearing comprises much of the core Te fluctuations. With improved laser alignment, we investigate 400 kHz improved confinement (PPCD) plasmas where global tearing activity is reduced and electrostatic turbulence may dominate electron thermal transport and fluctuation power. We also find no significant Te fluctuation ($<5$ eV) correlated with edge-localized density fluctuations seen by the FIR interferometer in 200kHz PPCD plasmas.

\textsuperscript{1}This work supported by the US DOE and NSF.
PP8.00016 Probing the limits on beta and density in the RFP $^1$. B.E. CHAPMAN, K.J. CASPARY, J.K. ANDERSON, W. CAPECCHI, D.J. DEN HARTOG, S.T. LIMBACH, L.A. MORTON, S.P. OLIVA, E. PARKE, J.S. SARFF, W.C. YOUNG, UW-Madison, D.L. BROWER, W.X. DING, J.R. DUFF, L. LIN, UCLA, S.K. COMBS, ORNL — RFP-record values of total beta and normalized density have been achieved in MST plasmas with inductive current profile control combined with pellet and neutral beam injection. Total beta reaches 28% and appears to be limited by transport. The density has thus far reached $2.0n_{\text{Greenwald}}$, limited only by the size of pellet that can be ablated inside the MST plasma. Current profile control is used routinely in MST to reduce current-gradient-driven tearing fluctuations and stochastic transport. Beta is thereby increased but is well below pressure-related stability limits due to a concomitant reduction in $P_{\text{Ohmic}}$. With edge-deposited fueling based on gas puffing, the density is also necessarily low, typically at or below $0.2n_{\text{Greenwald}}$, in order to avoid edge-resonant instability. With direct pellet fueling of the plasma core, a substantially larger density is possible, and this leads to a substantially larger $P_{\text{Ohmic}}$ and beta. NBI further augments beta with modest heating and a population of 25 keV fast ions. The beta limit is probed with a three-fold variation in $P_{\text{Ohmic}}$ brought about with a density scan. Magnetic fluctuations increase with density, likely leading to increased transport and the observed saturation of beta.

$^1$Work supported by U.S.D.O.E.

PP8.00017 Ion energy transport in MST $^1$. Z.A. XING, D.J. DEN HARTOG, S. KUMAR, M.D. NORNBERG, J.S. SARFF, Univ of Wisconsin, Madison, J.B. TITUS, Florida A&M University — The mechanisms governing ion energy transport must be identified and quantified in order to further understand non-collisional ion heating in the RFP. In improved confinement (PPCD) plasmas in MST, non-collisional ion heating appears to be small, making these the ideal baseline plasmas in which to investigate ion energy transport. Previous work has demonstrated that impurity ion particle transport is classical in PPCD plasmas. Characterizing both particle and energy transport in PPCD plasmas will serve as a first step in understanding the transition to strong non-collisional ion heating and stochastic transport in standard RFP plasmas. The energy transport model now being developed accounts for collisional equilibration between species, classical convective and conductive energy transport, and energy loss due to charge exchange collisions. This model uses MSTfit to provide equilibrium magnetic geometry, and a modified STRAHL code for particle profile and transport modeling. Previous measurements from sub-optimal PPCD plasmas with residual magnetic fluctuations are being analyzed with this model to examine the possible transition to stochastic transport.

$^1$This work is supported by the U.S. DOE and NSF. STRAHL is provided by Ralph Dux of the Max-Planck-Institut fur Plasmaphysik.

PP8.00018 Nonlinear gyrokinetic simulations of improved confinement RFP plasmas $^1$. DANIEL CARMODY, M.J. PUESCHEL, J.K. ANDERSON, P.W. TERRY, University of Wisconsin - Madison — The reversed field pinch (RFP), a device dominated by the global tearing modes in standard modes of operation, has been able to achieve reduced transport and increased energy confinement time through the use of pulsed poloidal current drive (PPCD), a current profile control technique. To evaluate the potential contributions of microinstabilities to transport fluxes in the PPCD regime of the Madison Symmetric Torus, we use the gyrokinetic code GENIC and experimental profile data. Linear results from 200 kA and 500 kA PPCD discharges show the dominant instabilities to be an ion temperature gradient mode and a density-gradient-driven trapped electron mode, respectively. Nonlinear simulations of the 500 kA case show strong zonal flow activity that results in a significant Dimits-like shift, with a nonlinear threshold about a factor of three larger than the linear critical value. We find magnetic shear to play an important role in determining the nonlinear saturation levels, with lower shear resulting in the reduction of zonal flow shearing rate and the enhancement of linear growth rates. The nonlinear threshold occurs at roughly the experimental value, suggesting that microturbulent processes may be an important factor in determining experimental transport levels.

$^1$Work supported by US DOE Grant No. DE-FG02-85ER53212.

PP8.00019 Measurement of high-frequency, small scale density fluctuations in improved confinement RFP plasmas. J.R. DUFF, B.E. CHAPMAN, J.S. SARFF, D. CARMODY, P.W. TERRY, D.J. DEN HARTOG, L.A. MORTON, UW-Madison, L. LIN, W.X. DING, D.L. BROWER, UCLA, MST TEAM — In standard MST RFP plasmas, core transport is governed by magnetic fluctuations associated with global tearing modes. Using pulsed parallel current drive, tearing is significantly reduced and smaller-scale fluctuations are likely important to electron particle and heat transport for these improved confinement plasmas. On MST, an 11-chord FIR laser-based interferometry diagnostic, with $\sim 8$ cm chord spacing, is used to measure electron density fluctuations with wavenumbers $k \approx 1-2$ cm$^{-1}$. An upgrade underway will allow resolution up to $k \approx 15$ cm$^{-1}$. A fast magnetic coil array is employed for magnetic fluctuations. High-frequency ($<50$ kHz) small-scale ($n\approx15$) density and magnetic fluctuations have been observed in the edge plasma, where density and temperature gradients are largest. These fluctuations are distinct from tearing and have amplitudes that correlate with the density gradient and electron beta. The MST is well suited to explore beta scaling given the large dynamic range (9-26%) found in the device. Correlation of the measured density fluctuations with plasma parameters in high beta plasmas will serve to identify the drive and contribute to validation of gyrokinetic codes. Work supported by DOE and NSF.

PP8.00020 Investigation of density and potential fluctuations measured in the interior of improved confinement RFP plasmas $^1$. P.J. FIMOGNARI, D.R. DEMERS, Xanito Technologies, LLC, Madison, WI, D. CARMODY, P.W. TERRY, University of Wisconsin, Madison, WI — The Heavy Ion Beam Probe (HIBP) is uniquely capable of simultaneously measuring density and potential fluctuations in the plasma core. Characterizing the amplitudes, wavelengths, and cross phases of these quantities is necessary for validation efforts. During improved confinement (IC) periods in the Madison Symmetric Torus (MST) Reversed Field Pinch (RFP), HIBP measurements indicate density and potential fluctuations are broadband with most power below 100 kHz; the cross phase varies with radius and frequency. Gyrokinetic simulations of MST experimental discharges, focusing on microinstabilities during IC periods, suggest ITG and TEM are the predominant linear instabilities; profiles of various parameters are key to the growth or stability of these modes. Comparison of these simulations to interior fluctuation profiles is made possible by using the HIBP along with equilibrium temperature and density gradients. Measurements of fluctuations have been acquired with the HIBP at multiple radial locations inside the MST reversal surface; analysis of these and other relevant experimentally measured quantities will be presented.

$^1$This work is supported by US DoE award no. DE-SC0006077.

PP8.00021 3D Equilibrium Reconstruction with Internal Measurements on Madison Symmetric Torus. J.J. KOLINER, B.E. CHAPMAN, J.S. SARFF, J.K. ANDERSON, S. MUNARETTO, W. CAPECCHI, UW-Madison, L. LIN, UCLA, J.D. HANSON, M.R. CIANCIOSA, Auburn U. — Plasmas in the MST reversed field pinch (RFP) bifurcate to a helical equilibrium, forming a single helical axis (SHAx) at high plasma current ($I_p \approx 500$ kA) and low density ($n_e \approx 0.5 \times 10^{19} \text{ m}^{-3}$). In order to understand the physics of confinement and self-organization in SHAx, 3D equilibrium reconstruction is needed. The V3FIT equilibrium reconstruction code is applied using measurements from the 11-chord interferometer-polarimeter, 22-point Thomson scattering system, 4-camera soft x-ray probes, and magnetic. Equilibria have been generated using a fixed plasma boundary with no external currents. Model signals fit well to observed signals, $\chi^2 \approx 1$, and the zero crossing of line-averaged $n_e B_0$ from Faraday rotation is matched by the model. External magnetics are shown to be an inadequate equilibrium constraint with the VMEC model, due to possible shear in the poloidal phase of the helical structure, as well as strong contribution to the edge magnetic field from currents in the conducting shell. To address this shortcoming, a filament current model has been created to simulate the conducting shell with many external currents for a free plasma boundary. Axisymmetric equilibria have been reconstructed using the filament model and compared to solutions obtained with the MSTFIT axisymmetric equilibrium reconstruction code. The filament model has been extended to allow reconstruction of helical equilibria. Supported by DOE.
PP8.0022 Dynamics of helical states in MST
STEVEN MUNARETTO, University of Wisconsin-Madison, N. PINNELL, D. BROWER, The University of California at Los Angeles, B.E. CHAPMAN, D.J. DEN HARTOG, W.X. DING, J. DUSS, University of Wisconsin-Madison, P. FRANZ, Consorzio RFX, J.A. GOETZ, D. HOLLY, L. LIN, K.J. MCCOLLAM, M. MCGARRY, L. MORTON, M.D. NORNBERG, E. PARKE, J.S. SARFF, University of Wisconsin-Madison — The thermal and the magnetic dynamics of quasi-single-helicity (QSH) plasmas evolve independently during the formation and sustainment of the core helical structure. At higher plasma current (and Lundquist number) MST plasmas transition from an axisymmetric multi-helicity state to a QSH state characterized by strong toroidal mode and reduced secondary mode amplitudes. Plasmas in the QSH state tend to wall-lock, often in an orientation that is unfavorable for optimized measurements of the 3D structure using MST’s advanced diagnostics. Recently a technique to control the locking position through an applied resonant magnetic perturbation has been developed. Using this technique it is possible to adjust the 3D phase more optimally for specific diagnostics, to study the dynamics of the QSH structure and thermal features. The multi-chord FIR interferometer shows the presence of a density structure for the duration of the QSH state. Measurements of the time evolution of the electron temperature profile using the Thomson Scattering diagnostic reveal that the transition to QSH allows the presence of a 3D thermal structure, but this structure is intermittent. Understanding the mechanism(s) driving these dynamics is the goal of this work. Work supported by the US DOE and NSF.

PP8.0023 Diagnosing 50kV hydrogen neutral beam characteristics
M.D. NORNBERG, J.K. ANDERSON, D.J. DEN HARTOG, S. MUNARETTO, S. OLIVA, University of Wisconsin-Madison, D. CRAIG, Wheaton College — The 50 kV hydrogen diagnostic neutral beam on MST facilitates charge-exchange spectroscopy measurements of impurity ions and core-localized magnetic field measurements through the motional Stark effect. Interpretation of these measurements requires good knowledge of the beam energy components and divergence. The characteristics of this neutral beam are now time dependent and sub-optimal for sufficient signal-to-noise discrimination in spectroscopic measurements. In particular, the 1/3 energy component is comparable to the primary energy component at the beginning of the beam pulse and the beam current is not steady. Design considerations for test stand diagnostics including Doppler-shift spectroscopy to quantitatively molecular and impurity species, optical beam profile measurements with filtering to address outgassing and impurity sources, and calorimetry are presented. The test stand will facilitate optimization of the beam fueling, current, and voltage to restore the beam operation to specification. Of particular concern are reliable formation of an arc in the ion source, plasma temperature, outgassing, and neutralization.

1This work is supported by the Department of Energy.

PP8.0024 Electron Bernstein Wave Studies in MST
ANDREW SELTZMAN, JAY ANDERSON, CARY FOREST, PAUL NONN, MARK THOMAS, University of Wisconsin-Madison — The overdense condition in an RFP prevents electromagnetic waves from propagating past the edge, however use of the electron Bernstein wave (EBW) has the potential to heat and drive current in the plasma. A 450kw RF source that generates 2ms pulses at 5.55GHz and an antenna system with suitable power handling capability has been constructed. The design and implementation of a suitable launch structure is challenging in the RFP for several reasons. It is necessarily a low-field-side launch due to the magnetic field geometry, the close-fitting conducting shell requires a minimum port hole size, the port hole leads to local magnetic field perturbation that affects the resonance condition, and there is a very small vacuum gap between the shell and plasma leading to substantial antenna-plasma interaction. Testing of an EBW waveform antenna system for use in heating experiments is underway. A multi-chord soft x-ray camera and spectrum analyzer connected to a receiving probe antenna are used to look for evidence of electron heating and coupling effects. Power handling tests on the antenna are used to determine the maximum tests on the antenna are used to determine the maximum signal-to-noise discriminability in spectroscopic measurements. Work supported by USDOE.

1Work supported by USDOE.

PP8.0025 First Assessment of the MST Plasma Wall Interaction
RYAN NORVAL, JOHN GOETZ, DANIEL DEN HARTOG, OLIVER SCHMITZ, University of Wisconsin-Madison — Studies of RFP plasma-wall interaction (PWI) have been rather limited. To rectify this, a new program of studying the plasma wall interaction on MST is being developed. An endoscope camera setup is used to study neutral recycling and impurity production at the poloidal limiter structure of MST, a known area of PWI due to field errors and protective tiles. Initial measurements show a strong dependence of the plasma wall interaction at MST on the magnetic mode structure and 3D equilibrium. The results show that the main interaction domain is shifted from the inboard limiter to the outboard limiter with increasing plasma current. Also, operation in the single helical axis state results in a very strong localization of the plasma wall interaction. The camera provides a temporal resolution of up to 1 kHz. Light from the 400 nm to 1100 nm can be collected by the camera. Enhanced light may then be filtered in order to identify different impurity species. The experimental data will be compared to modeling of the magnetic field structure in order to connect the magnetic topology to the plasma equilibrium features. Work Supported by DOE and NSF.

PP8.0026 Studies of X-ray Spectroscopy in Improved Confinement Plasmas on MST
J.D. LEE, A.F. ALMAGRI, J.K. ANDERSON, B.E. CHAPMAN, J.S. SARFF, Physics Department, University of Wisconsin-Madison, R.W. HARVEY, CompX, COMPX COLLABORATION — The X-ray spectroscopy diagnostic on MST consists of six SXR detectors and six HXR detectors capable of measuring photons in the energy range 3–25 keV and 10–60 keV, respectively. The detectors are installed on chords ranging from r/a = 0.87 inboard to r/a = 0.84 outboard. X-ray measurements have been made in MST improved confinement plasmas, PPCD, with plasma current of 400 kA, electron density of 0.6x10^{14} m^{-3}, and electron temperature of 1200 eV. A simple model for Zeff yields a central value around 4 for these plasma conditions. The measured X-ray spectra are also consistent with the temperature measured by Thomson Scattering. At the end of the improved confinement period we observe the X-ray emission at energy above 6 keV to decay faster than at the lower energies, suggestive of reemerging stochastic transport. At this event, the x-ray flux increases at all energies for a few microseconds following by a rapid decrease. Measured spectra will be used to constrain radial profiles for Zeff and radial diffusion, D_r, by comparison with the Bremsstrahlung spectra calculated from CQL3D, a Fokker-Planck solver. Presently CQL3D cannot account for the recombination spectra, which are present in the measured x-ray emission.

1Work supported by US DoE.

PP8.0027 Investigation of Electron Energization During Magnetic Reconnection Events in MST
AMI M. DUBOIS, J.D. LEE, A.F. ALMAGRI, B. CHAPMAN, D.J. DEN HARTOG, J.A. GOETZ, K. MCCOLLAM, M. NORNBERG, J.S. SARFF, Univ of Wisconsin-Madison, Madison — Magnetic reconnection plays an important role in particle transport and energization in space, astrophysical, and laboratory plasmas. Strong ion heating and energetic ion tail formation are observed in MST plasmas at the time of reconnection events, but Thomson scattering measurements indicate a slight drop in the electron temperature. This drop is probably the result of an increase in stochastic thermal transport. A large reconnection event usually terminates PPCD. At this event, with the temperature measured by Thomson Scattering. A Fast X-Ray (FXR) detector, capable of measuring photon energies between 1 and 20 keV with a shaping time of 20 ns, has been installed on MST to measure x-ray spectra and calculate electron energy distributions. Distributions at tens of microsecond intervals around reconnection events will be compared to determine if a tail population of electrons is generated.

This work is supported by DOE and NSF.
PP8.00028 Burst Electron Heating Measured with High-Repetition-Rate Thomson Scattering on the MST Reversed-Field Pinch. WILLIAM YOUNG, L.A. MORTON, E. PARKE, D.J. DEN HARTOG, Univ of Wisconsin, Madison, CMSO, MST TEAM — Improved operation of a high-repetition-rate laser allows MST Thomson scattering measurements at rates up to 200 kHz. The new laser will be applied to improving electron temperature measurements during spontaneous periods of improved confinement with RFP plasmas, where ensemble data shows a 4% increase in electron temperature during bursts of magnetic activity associated with edge-resonant m=0 modes. This heating is concurrent with a reduction of core parallel current and magnetic energy, then followed by an inward propagating cold pulse consistent with previous SXR data. The Thomson scattering diagnostic uses a 1064 nm high-repetition-rate laser currently employing a Nd:YVO₄ oscillator, four Nd:YAG amplifier stages, and a final Nd:glass amplifier. This laser can operate under a variety of modes while maintaining 1.5 J pulse energies necessary for Thomson scattering, including 4 ms long bursts at 10 kHz pulsing rate, ten bursts of 15 pulse at 75 kHz, or bursts of 5 pulses at 200 kHz.

PP8.00029 Effects of m = 0 mode suppression on m = 1 magnetic and velocity fluctuations in the RFP. D. CRAIG, Wheaton College (IL), D.J. DEN HARTOG, University of Wisconsin - Madison, D. MARTIN, Wheaton College (IL), M.R. NORMBERG, J.A. REUSCH, J. TRIANA, University of Wisconsin - Madison, MST TEAM — Poloidal mode number m = 0 present but the velocity fluctuations are lower and have a different phase with respect to the magnetic field fluctuation. We have reproduced the experiment in nonlinear resistive MHD simulations with the DEBS code. In the code, removal of the reversal surface reduces m = 0 modes but not as strongly as in the experiment. The m = 1 magnetic fluctuations in the code are of similar amplitude with and without the reversal surface but the velocity fluctuations are reduced without m=0 present. The phase between v and b does not change significantly in the code in contrast to the experiment. Addition of the mean flow profile by the magnetic fluctuations (an effect not included in the code) may be responsible for the difference in phase observed in the experiment. This work has been supported by the USDOE and NSF.

PP8.00030 Using Temperature Fluctuation Measurements for Equilibrium Reconstruction and Dynamo Measurement. D.J. DEN HARTOG, E. PARKE, J.K. ANDERSON, C.A. JOHNSON, Department of Physics, University of Wisconsin–Madison — The high-repetition-rate Thomson scattering system on MST, in combination with advanced Bayesian statistical methods, enables determination of tearing-mode-correlated temperature fluctuations as small as a few percent of the equilibrium temperature. Tearing mode rational surface locations are determined from the characteristic phase flip observed in temperature fluctuation structures, providing a strong constraint for equilibrium reconstruction. Recent experiments in neutral beam heated plasmas indicate an inward shift of the n = 1, m = 6 rational surface of approximately 1 cm relative to non-beam heated plasmas. The measured shift of the rational surface enables diagnosis of current redistribution and safety factor modification due to the fast ion population. Additionally, from the phase of correlated temperature fluctuations, the product \(<δT_e δb_θ>\) is determined. This term is part of \(<δp_δb_θ>\), the divergence of which is often called the kinetic dynamo. The kinetic dynamo depends on an imbalance of the radial transport of field-aligned current. Previous measurements of the density fluctuation term \(<δn_δb_θ>\) suggest that the kinetic dynamo plays a role in the RFP dynamo process. These measurements of temperature-fluctuation-driven current transport indicate that both terms are needed for a complete picture of the kinetic dynamo.

PP8.00031 Density Fluctuation Induced Kinetic Dynamo and Tearing Mode Nonlinear Saturation in the MST Reversed Field Pinch. WEIXING DING, LIANG LIN, University of California, Los Angeles, J.R. DUFF, University of Wisconsin, Madison, D.L. BROWER, University of California, Los Angeles, J.S. SARFF, University of Wisconsin, Madison — In the MST reversed field pinch (RFP), the evolution of core tearing mode nonlinear evolution is partially determined by the electron current density profile along with nonlinear interactions among multiple tearing modes. Density fluctuations driven by intrinsic magnetic perturbations are usually large, approximately 1%, in RFP plasmas. These density fluctuations can modify the current density profile via the kinetic dynamo effect, defined as the correlated product of parallel electron pressure and radial magnetic field fluctuations, which alters the temporal dynamics of tearing modes in MST. A component of the kinetic dynamo originating from the correlated product of density and radial magnetic fluctuations has been measured using a high-speed, low phase noise polarimetry-interferometry diagnostic. Between sawtooth crashes it is found that the measured kinetic dynamo has finite amplitude that generates an anti-dynamo in the plasma core, which would tend to flatten the current density profile. These measurements suggest that density fluctuations passively driven by magnetic fluctuations can actively alter tearing modes via fluctuation-induced current transport. Work supported by US DOE and NSF.

PP8.00032 Extended Measurements of Current-Momentum Relaxation in the Madison Symmetric Torus. J.C. TRIANA, A.F. ALMAGRI, J.S. SARFF, J.P. SAUPPE, C.R. SOVINEC, University of Wisconsin - Madison — Direct measurements of the turbulent emf and stresses associated with tearing-induced fluctuations in MST reveal coupled current and momentum relaxation in the RFP. These forces were previously measured in the edge of MST plasmas (ξ > 0.85), showing that the Hall \(\frac{1}{2} (\vec{v} \times \vec{b})\) and MHD \((\vec{v} \times \vec{b})\) terms are both large but dominate Ohm’s law at different radii. A robust deep-insertion probe has been developed to measure the radial profile of the Hall term to \(ξ > 0.45\) in 200 kA plasmas. The modal composition of the emf/stress is inferred using pseudospectral (cross-correlation) analysis with the spectrum measured with a toroidal magnetic array at the plasma surface. Extended MST measurements with parameters comparable to the experiment have been performed using NIMROD, revealing intricate behavior of the Hall dynamo profile across the plasma radius. The extended profile measurements using the deep-insertion probe allow more complete comparisons with computational predictions and provide constraints for future simulations. The DEBS (single fluid MHD) code is also used to compare results for different plasma models.

PP8.00033 Dissipation Range of Anisotropic Magnetic Fluctuations in MST plasmas. JAMES B. TITUS, Florida A&M University, ABDULGADER F. ALMAGRI, PAUL W. TERRY, JOHN S. SARFF, University of Wisconsin - Madison, EPHREM D. MEZONLIN, Florida A&M University — Previous measurements of broadband magnetic fluctuations in the Madison Symmetric Torus (MST) 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. The non-classical dissipation feature may be indicative of the powerful non-collisional ion heating observed in MST plasmas. We report new measurements with increased spatial resolution, by decreasing the distance between coils (4 mm) and increasing the number of coils (7) in each direction. Initial analysis shows similar anisotropic behavior for larger values of k but with a modest difference in the spectral characteristics. In particular, the exponential falloff appears to weaken at shorter wavelengths, suggesting strong dissipation occurs over an intermediate range of scales somewhat larger than the ion gyroradius. Also, the power spectrum is much steeper at small scales during pulsed poloidal current drive and non-reversed plasmas, where tearing instability and/or non-linear coupling is reduced.

Work supported by DOE and NSF.
PP8.00034 Electromagnetic energy transport in RFP magnetic relaxation , K.J. MCCOLLAM, D.J. THUECKS, D.R. STONE, J.K. ANDERSON, D.J. DEN HARTOG, J. DUFF, J. KO, S. KUMAR, E. PARKE, UW-Madison, L. LIN, D.L. BROWER, W.X. DING, UCL. — In an RFP driven by steady toroidal induction, tearing modes responsible for magnetic relaxation redistribute electromagnetic energy throughout the plasma, generating the net EMF that regulates the equilibrium profile. In M. experiments, insertable edge probes measure local fluctuations in electric and magnetic fields, from which fluctuation-average Poynting flux is derived. This outwards directed flux is maximal during discrete “sawtooth” magnetic relaxation events and is a significant fraction (a few 10s of percent) of the total input inductive power when averaged over time. Spatially, the flux is maximum at the reversal surface and decreases outside, indicating that transported energy is deposited at the plasma edge. These results are similar to expectations from a simple model of an incompressible fluid plasma with a resistive boundary and consistent with estimates of global power balance from time-resolved equilibrium reconstructions. This work was supported by the US DOE and NSF.

PP8.00035 NIMROD Extended MHD Simulations of Reversed-Field Pinch Relaxation Dynamics , JOSHUA SAUPPE, CARL SOVINEC, JOHN SARFF, JOSEPH TRIANA, University of Wisconsin-Madison — The nonlinear evolution and relaxation dynamics of an initially non-reversed twofluid plasma in cylindrical geometry is investigated using the NIMROD code. The initial relaxation event brings the plasma to the characteristic reversed-field state. There is significant magnetic activity with MHD and Hall dynamos working together to relax the parallel current profile while the fluctuation-induced Lorentz force drives plasma flows. Subsequent events have considerably less magnetic activity and often have opposing MHD and Hall dynamos. The direction of the driven flows in these events differs from the initial event, and is consistent with experimental observations on the MST RFP. The nonlinear mode coupling during relaxation events is investigated, and the presence of the Hall dynamo is found to significantly alter the spectral power flow. Synthetical diagnostics are used to compare simulation results to experimental measurements of Hall dynamo mode structure with laser Faraday rotation and magnetic probes. At modest Lundquist number the time-scales of relaxation and drive are well-separated and the simulations are compared to two-fluid relaxation theories. Generalized two-fluid helicities are well-conserved relative to magnetic energy over the simulated relaxation events.

Work supported by U.S. DoE and NSF.

PP8.00036 Effect of parallel electron heat transport on drift and drift-tearing modes in RFP plasmas , V.V. MIRNOW, C.C. HEGNA, J.P. SAUPPE, C.R. SOVINEC, Univ of Wisconsin, Madison — Linear numerical simulations were performed for plasma slab with cold ions and hot electrons in a doubly periodic box bounded by two perfectly conducting walls. Within this model, configurations with magnetic shear are unstable to current-driven drift-tearing instability. Additionally, there is an unstable pressure-gradient driven mode that is largely electrostatic in nature, suggestive of a resistive-drift type instability. The simultaneous presence of linear drift-like and tearing instabilities was observed using both two fluid extended modeling with NIMROD and analytical methods. The primary motivation for these studies is to understand the electrostatic transport thought to be present in Madison Symmetric Torus RFP experiments. Our previous analytical studies were performed either in the limit of infinitely large parallel electron heat conduction or in the pure adiabatic regime with an isentropic equilibrium. We report now on a general model with arbitrary equilibrium and finite parallel thermal conduction. Drift mode stability is sensitive to the ratio of density and temperature gradient scales and the instability exists even for pure transverse perturbations. Preliminary analytical results confirm some reduction of the drift-tearing mode growth rate caused by finite electron thermal conduction, consistent with previous works. Results of NIMROD simulations for different regimes of the electron thermal conduction are reported as well.

The work is supported by the U. S. DOE and NSF.

PP8.00037 3D MHD modeling of fusion plasmas with the PIXIE3D and SpeCyCyl codes , D. BONFIGLIO, S. CAPPELLO, M. VERANDA, Consorzio RFX, Italy, L. CHACÓN, LANL, NM, D.F. ESCANDE, Aix-Marseille Université, CNRS, France — Recent advancements in nonlinear 3D MHD modeling of fusion plasmas with the PIXIE3D and SpeCyCyl codes are reported. The fundamental mathematical correctness of the two codes was proven by a nonlinear cross-benchmark study [1]. The codes have then been used to model the three main configurations for magnetic confinement, namely tokamak, stellarator and reversed-field pinch (RFP) plasmas. Qualitative agreement with respect to experimental observations in the RFX-mod device operated as both RFP and tokamak has been demonstrated by taking advantage of numerical features such as the possibility of applying 3D external magnetic perturbations [2]. More recently, 3D magnetic perturbations have also been used to obtain stellarator fields. The toroidal coupling between MHD modes (as provided by PIXIE3D in toroidal geometry) affects both the MHD dynamics and the magnetic topology. In addition, PIXIE3D solves the heat transport equation with self-consistent coupling between resistivity (afflicting Ohmic heating) and temperature. The use of this feature will be discussed, with particular attention to the RFP case.


PP8.00038 A new technique for effective core fueling and density control in RFX-mod , GIANLUCA DE MASII, FULVIO AURIEMMA, ROBERTO CAVAZZANA, EMILIO MARTINES, GIANLUCA SPIZZO, Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaieria Venete SpA) — High current plasmas in the RFX-mod Reversed Field Pinch device can be presently sustained either operating at low density (ne/nG ≲ 0.3, being nG the Greenwald density) or transiently at high density by pellet injection. Discharges at ne/nG > 0.3 are difficult to sustain due to the high ohmic power required and a confinement properties downgrading. In these regimes, the transport mechanism results in a hollow density profile preventing an effective core fueling. A different behavior is observed in Ultra-low q configuration (q ≳ 1 ≳ 0), in which the increased particle diffusivity produces flat density profiles and makes easier neutral particle penetration. In this contribution we show the main results of a new method to produce a more effective core fueling based on the previous empirical observations. The idea was to produce during the discharges narrow time windows with q ≳ 1 ≳ 0 values and, during this phase, to apply a strong gas puffing. This experimental condition is found to allow an increased particles core penetration. From the operational point of view, a lower input power was needed to sustain the discharges with similar core density. A deeper analysis through the ASTRA code will highlight the relation between transport properties and magnetic topology.

PP8.00039 Neutron and Gamma-ray Detection in Reversed-Field Pinch Deuterium Plasmas in the RFX-mod Device , MATTEO ZUIN, Consorzio RFX, Corso Stati Uniti 4, Padova, LUCA STEVANATO, Dipartimento di Fisica ed Astronomia dell’Università di Padova, Via Marzolo 8, Padova, Italy, EMLIO MARTINES, WINDER GONZALES, ROBERTO CAVAZZANA, Consorzio RFX, Corso Stati Uniti 4, Padova, DAVIDE CESTER, Dipartimento di Fisica ed Astronomia dell'Università di Padova, Via Marzolo 8, Padova, Italy, G. NBBIA, INFN Sezione di Padova, Via Marzolo 8, Padova, Italy, LASZLO SAJO-BOHUS, Universidad Simon Bolivar, Caracas 1080A, Venezuela, GIUSEPPE VIESTI, Dipartimento di Fisica ed Astronomia dell’Università di Padova, Via Marzolo 8, Padova, Italy — An experimental analysis of neutron and gamma-ray fluxes exiting purely ohmically heated plasmas in reversed-field pinch (RFP) configuration is presented. The diagnostic system, installed in the RFX-mod, is made of 2 spectillators (EI-301 liquid and NaI(Tl)) coupled to flat-panel photomultipliers, which can be operated under magnetic fields. The production of neutrons and gamma rays in Deuterium plasmas is found to be strongly dependent on the Ohmic input power, with a threshold value of about 1.2MA in terms of plasma current level, below which low levels of gamma rays and almost no neutrons are detected. Neutron and gamma production is characterized by a bursty behavior, correlated to the spontaneous magnetic reconnection events, occurring almost cyclically in the RFP plasmas. The role of ion heating and particle acceleration during such events is discussed.
PP8.00040 Magnetic topology change induced by reconnection events in RFP plasmas, BARBARA MOMIC, EMILIO MARTINEZ, PAOLO INNONCENNE, RITA LORENZINI, CRISTINA REA, PAOLO ZANCA, MATTEO ZUIN, Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA) Corso Stati Uniti 4 - 35127 Padova (Italy) — Magnetic reconnection is a phenomena observed in various plasmas across the Universe, where a conversion of magnetic to kinetic energy of plasma particles is consequent to a change in the global magnetic topology. In laboratory plasma magnetic reconnections are associated to relaxation processes, like sawtooth crashes in Tokamak dynamics and the so-called dynamo effect in Reversed Field Pinches (RFPs). In this work we propose the study of magnetic crashes in RFP dynamics, where the recursive transition from a more ordered helical state to a chaotic one is associated with rapid magnetic reconnection events. More into details, we propose to analyse RFX-mod discharges reconstructing the magnetic topology in the whole plasma volume at fixed time snapshots. Times are chosen in a window around the crashes, and the magnetic topology is reconstructed by using the solutions of a Newcomb-type equation, solved consistently with experimental boundary conditions. New boundary conditions are given by internal magnetic measurements coming from the ISIS probe system, in order to detect high frequency dynamics. Poincaré plots are used as a tool for the visualization of magnetic topology changes.

PP8.00041 Fast growing instabilities and non-linear saturated states in hybrid tokamak and RFP plasmas, DANIELE BRUNETTI, JONATHAN GRAVES, WILFRED COOPER, EPFL-CRPP, DAVID TERRANOVA, Consorzio RFX euratom ENEA, CHRISTER WAHLBERG, Department of Astronomy and Space Physics, EURATOM/VR Fusion Association — The stability of large scale m=1 helical displacements of tokamak and RFP plasmas with reversed shear are investigated using the 3D equilibrium code VMEC/ANIMEC and the non-linear initial value stability code XTOR. The non-linear growth rate and the saturated states obtained with XTOR are compared to VMEC/ANIMEC calculations, and with analytic predictions. For conditions where the magnetic shear is allowed to become small over a large portion of the plasma, resistive sidesbands coupled to a core kink-like mode exhibit extremely fast growth. The sensitivity of the dependence of the growth rate upon the Lundquist number to two-fluid effects has been examined analytically and also numerically with the XTOR code. It is found that these additional non-MHD effects tend to moderately reduce the growth rate of resistive modes. A family of modes are obtained, including modes with novel scaling on Lundquist number, some of which rotate in the electron diamagnetic direction, and others in the ion diamagnetic direction. In ideal and resistive numerical simulations, qualitative agreement has been found between XTOR and analytical predictions in absence of non-MHD effect.

PP8.00042 Evaluation of time evolution of 3-D Structure in RELAX RFP with SXR Imaging Technique, AKIO SANPEI, SADAO MASAMUNE, KANAE NISHIMURA, RYOTA UEBA, GO ISHI, RYOSUKE KODERA, YOSUKE AOKI, HARUHIKU HIMURA, Kyoto Inst of Tech, SATOSHI OHDACHI, NAOKI MIZUGUCHI, TSUYOSHI AKIYAMA, National Institute for Fusion Science — In a low-α RFP machine RELAX (R = 0.51 m/a = 0.25 m (A = 2)), a quasi-periodic transition to quasi-single helicity (QSH) state has been observed. During the QSH state, the fluctuation power concentrates in the dominant m = 1/n = 4 mode, and a (toroidally rotating) 3-D helical structure has been observed with radial array of magnetic probes. We have applied a high-speed (10-microsecond time resolution) dual soft-X (SXR) imaging diagnostic system to take SXR images from tangential and vertical directions simultaneously to observe 3-D dynamic structures of the SXR emissivity. The magnetic field topology for the QSH RFP phase in RELAX plasmas are identified with obtained dual SXR images and results of external magnetic measurements. Recently, we have developed a two-dimensional electron temperature diagnostic system for thermal structure studies. The system consists of a SXR camera with two pin-holes for two-kinds of absorber foils, combined with a high-speed camera. We have succeeded in distinguishing Te image in QSH from that in multi-helicity (MH) RFP states. The most recent results using above techniques will be presented, together with discussion on possible reconstruction methods from 3-D imaging.

PP8.00043 Reversed Field Pinch Dynamics in Toroidal and Cylindrical Geometries1, JORGE A. MORALES, WOUTER J.T. BOS, LMFA, CNRS, Ecole Centrale de Lyon, France, KAI SCHNEIDER, M2P-CNRS, Aix-Marseille University, Marseille, France, DAVID C. MONTGOMERY, Department of Physics and Astronomy, Dartmouth College, NH, USA — The effect of the curvature of the imposed magnetic field on Reversed Field Pinch dynamics is investigated by comparing the flow of a magnetofluid in a torus with aspect ratio 1.83, with the flow in a periodic cylinder. It is found that an axisymmetric toroidal mode is always present in the toroidal, but absent in the cylindrical configuration. In particular, in contrast to the cylinder, the toroidal case presents a double poloidal recirculation cell with a shear localized at the plasma edge. Quasi-single-helicity states are found to be more persistent in toroidal than in periodic cylinder geometry.

1This work was supported by the contract SIcO-MHD (ANR-Blanc 2011-045), computing time was supplied by IDRIS, project 22206.

PP8.00044 NSTX AND OTHER SPHERICAL TORI —

PP8.00045 Overview of NSTX Facility Upgrades Status and Research Plans1, MASAYUKI ONO, Princeton Plasma Phys Lab, NSTX-U TEAM — NSTX is undergoing a major device upgrade as well as an addition of a second more tangential Neutral Beam Injection (NBI) heating and current drive system. NSTX upgrade will double the toroidal field from 0.5 T to 1 T, the plasma current from 1 MA to 2 MA, the NBI heating and current drive power from 7 MW to 14 MW, and increase the peak field plasma pulse length from 1 sec to 7 sec. More tangential NBI injection (CHI), and this also permits high currents to pass through the CS for baking. Other conditioning techniques are required to further reduce the dominant impurities, which are expected to be carbon and oxygen. Boronization will first be performed, where helium glow discharge cleaning (GDC) is followed by GDC with a mixture of 95% helium and 5% deuterated trimethyl boron (TMB), and another period of helium GDC. This is to be compared with lithiumization, where lithium vapor is evaporated directly on PFC surfaces. The effectiveness of both conditioning techniques has been inferred from plasma measurements subsequent to their application, but the link between them and actual PFC conditions has not been made. The new Materials Analysis and Particle Probe (MAPP) is intended to do this with in situ analysis of PFC samples exposed to NSTX-U plasmas.

1This work supported by DoE Contract No. DE-AC02-09CH11466 and DE-SC0010717.
PP8.00047 Status and Plans for Transient CHI and MGI Experiments on NSTX-U  
R. Raman, T.R. Jarboe, B.A. Nelson, Univ. of Washington, D. Mueller, F. Ebrahimi, G. Taylor, S.C. Jardin, PPPL — Results from NSTX Transient Coaxial Helicity Injection (CHI) experiments have demonstrated generation of 300kA start-up currents, and when these discharges were coupled to induction they attained 1MA of plasma current consuming 65% of the inductive flux of standard inductive-only discharges in NSTX. The NSTX-U device will have numerous improvements to enhance transient CHI capability. TSC simulations have been used to guide the choice of NSTX-U coil currents for initial CHI operations in FY14, which show more than a doubling of the CHI current generation potential in NSTX-U. The NIMROD code has been used to understand basic physics trends, which are consistent with scaling relations that have been used to guide the CHI design on NSTX and NSTX-U. In support of ITER disruption mitigation studies, an ITER-type MGI valve has been designed, built and tested, including in the presence of externally imposed magnetic fields. FY14 research on NSTX-U will use three of these valves positioned at different poloidal locations to study the MGI gas assimilation efficiency. This work is supported by U.S. DOE Contracts: DE-AC02-09CH11466, DE-FG02-99ER54519 AM08, and DE-SC0006757.

PP8.00048 Plasma injection and evolution in CHI simulations of NSTX1  
E.B. Hooper, Lawrence Livermore Natl Lab, C.R. Sovinec, University of Wisconsin, R. Raman, University of Washington — Simulations of co-injection of helicity and plasma into a low density plasma in NSTX are compared with experiment, extending previous simulations that assumed helicity injection into a constant density plasma [1, 2]. The background plasma response is minimized by density-dependent artificial radiation. Helicity and plasma flow from the slot at the ExB velocity due to the applied voltage. A simple model of impurity radiation from the injected plasma improves agreement with the temperature during experimental plasma buildup and following flux closure after injection [3]. The simulations also explore the effect of impurity concentration near the bottom plate where impurities are generated at the footprints of the currents associated with the injection. As in previous simulations [4], non-axisymmetric flows and currents are generated during injection but have little impact on the final closed-flux configuration.

1 Work performed under the auspices of the U.S. Department of Energy under contract DE-AC52-07NA27344 at LLNL.

PP8.00049 Magnetic Field Measurements in NSTX-U with the MSE-LIF Diagnostic1  
Fred Levinton, Nova Photonics, Inc., Jill Foley, Twinleaf LLC, Darrell Dicicco, David Cylinder, Hannah La Fleur, Howard Yuh, Nova Photonics, Inc. — The motional Stark effect with laser-induced fluorescence diagnostic (MSE-LIF) was installed on NSTX during the 2011 run year. The MSE-LIF will enable radially resolved measurements of the magnetic field pitch angle and magnitude, both of which can be used to constrain plasma equilibrium reconstructions. A diagnostic neutral beam with low axial energy spread, low divergence, and high reliability has been developed. It operates routinely at 35 kV and 40 mA. A laser has been developed with high power (∼10 W) and optimal linewidth matched to the energy spread of the neutral beam (∼6 GHz). The laser wavelength is near 651 nm for a match to the Doppler-shifted Balmer-alpha transition in the beam neutrals. The unique high-power, moderate linewidth laser system utilizes a 18 emitter diode laser bar and feedback from a volume Bragg grating for line width narrowing. A magnetic shield protects the ion source from the NSTX stray fields. Initial data in a gas-filled torus and low magnetic fields was taken on NSTX. Several improvements have been made to the system during the NSTX upgrade, including adding more spatial channels and several laser improvements.

1 Supported by USDOE Grant No. DE-FG02-01ER54516.

PP8.00050 Preparing Plasma Control and Digital Coil Protection for NSTX-U  
P. Gerhardt, K. Erickson, D.A. Gates, R. Kaita, D. Mueller, PPPL, S.A. SABBAGH, Columbia University, T. STEVENSON, P. TITUS, W. QUE, PPPL — Compared to NSTX, NSTX-U will have twice the toroidal field (Bp ∼ 0.5T → 1.0T) and plasma current (Ip ∼ 1MA → 2MA). These increases in capability have mandated a new digital coil protection system (DCPS). This software computes forces, stresses, and coil heating in real time, and brings down the coil power supplies in a controlled manner when the forces, heating and currents exceed limits; the algorithms and their numerical implementation will be described. The algorithms have been run on the legacy NSTX database of discharges, motivating a reexamination of some limit values and identification of the plasma control behaviors that lead to large forces and stresses. These and other changes in the conversion to NSTX-U have motivated improvements to the plasma control system (PCS) algorithms. The preliminary design of an architecture for a automated discharge termination system will be presented, motivated by the desire to reduce large current transients during disruptions, thereby reducing stresses and avoiding DCPS faults. Other improvements to the plasma control system include the automation of the TF current rampdown, improvements to the gas delivery algorithms, and the addition of many more flux loops and magnetic pickup (Mirov) sensors for real time equilibrium reconstruction. This work was sponsored by the U.S. Department of Energy.

PP8.00051 First-Principles-Driven Optimal Control of the Current Profile in NSTX-U  
Zeki Ilhan, Justin Barton, William Wehner, Eugenio Schuster, Lehigh University, David Gates, Stefan Gerhardt, Egemen Kolemen, Jonathan Menard, PPPL — Regulation in time of the toroidal current profile is one of the main challenges toward the realization of the next-step operational goals for NSTX-U. A nonlinear, control-oriented, physics-based model describing the temporal evolution of the current profile is obtained by combining the magnetic diffusion equation with empirical correlations obtained at NSTX-U for the electron density, electron temperature, and non-inductive current drives. In this work, the proposed model is embedded into the control design process to synthesize a time-variant, linear-quadratic-integral, optimal controller capable of regulating the safety factor profile around a desired target profile while rejecting disturbances. Neutral beam injectors and the total plasma current are used as actuators to shape the current profile. The effectiveness of the proposed controller in regulating the safety factor profile in NSTX-U is demonstrated via closed-loop predictive simulations carried out in PTRANSP.

1 Supported by PPPL.

PP8.00052 A framework for control simulations using the TRANSP code1  
Mark D. Boyer, Princeton Plasma Physics Laboratory, ORISE, Rob Andre, David Gates, Stefan Gerhardt, Princeton Plasma Physics Laboratory, IMene Goumiri, Princeton University, Jon Menard, Princeton Plasma Physics Laboratory — The high-performance operational goals of present-day and future tokamaks will require development of advanced feedback control algorithms. Though reduced models are often used for initial designs, it is important to study the performance of control schemes with integrated models prior to experimental implementation. To this end, a flexible framework for closed loop simulations within the TRANSP code is being developed. The framework exploits many of the predictive capabilities of TRANSP and provides a means for performing control calculations based on user-supplied data (controller matrices, target waveforms, etc.). These calculations, along with the acquisition of “real-time” measurements and manipulation of TRANSP internal variables based on actuator requests, are implemented through a hook that allows custom run-specific code to be inserted into the standard TRANSP source code. As part of the framework, a module has been created to constrain the thermal stored energy in TRANSP using a confinement scaling expression. Progress towards feedback control of the current profile on NSTX-U will be presented to demonstrate the framework.

1 Supported in part by an appointment to the U.S. Department of Energy Fusion Energy Postdoctoral Research Program administered by the Oak Ridge Institute for Science and Education.
PP8.00053 Modeling and control of plasma rotation for NSTX using Neoclassical Toroidal Viscosity (NTV) and Neutral Beam Injection (NBI) — IMENE GOUIMI, CLARENCE ROWLEY, Princeton Univ, STEVEN SABBAGH, Columbia Univ, DAVIN GATES, STEFAN GERHARDT, PPPL — A model-based system to control plasma rotation in a magnetically confined toroidal fusion device is developed to maintain plasma stability for long pulse operation. This research uses experimental measurements from the National Spherical Torus Experiment (NSTX) and is aimed to control plasma rotation by using momentum from injected neutral beams and viscosity generated by three-dimensional applied magnetic fields as actuators. Based on the data driven model obtained, a feedback controller is designed to theoretically sustain the toroidal momentum of the plasma in a stable fashion and to achieve desired plasma rotation profiles. On going work includes extending this method to NSTX Upgrade which has more complete radial coverage of the neutral beams momentum sources which enable simultaneous control of plasma stored energy (Beta control).

PP8.00054 Modeling of fully non-inductive startup and ramp-up towards development of advanced scenarios in NSTX-U1 — FRANCESC POLI, ROBERT ANDRE, NICOLA BERTELLI, STEFAN GERHARDT, CHARLES KESSEL, PPPL, ROGER RAMAN, Univ. Washington, GARY TAYLOR, PPPL — The National Spherical Torus eXperiment Upgrade (NSTX-U) will operate at maximum axial toroidal field of 1T, maximum plasma current Ip of 2MA, and pulse length up to 5 seconds. Three additional neutral beam injection (NBI) sources, with tangency radii of 110-130cm, will provide significant off-axis current drive. Time-dependent free-boundary TRANSP/ISOLVER simulations have self-consistently modelled fully non-inductive (NI) Ip ramp-up. Non-solenoidal startup with Coaxial Helicity Injection (CHI), simulated with TSC, provides the initial plasma condition for the simulations. RF waves are injected to prepare target plasmas where NBI can be used with minimal power/particle losses. 1MW of Electron Cyclotron (EC) power can rapidly heat CHI plasmas up to 1keV, and 4MW of High Harmonics Fast Wave power can drive 350kA. With 10MW of NBI, NI Ip ramp up to 900kA is possible in 2.5s. In this paper we discuss how the time of the NBI sources and the NBI source energy affect the profile evolution and access to advanced target scenarios in NSTX-U. These simulations provide a reference operational space for RI ramp-up experiments during the first two years of operation of NSTX-U, as well as guidance for the EC accessibility and use for optimization in non-solenoidal startup experiments.

PP8.00055 Experimental Observation of High-k Turbulence Evolution across L-H Transition in NSTX — Y. REN, R.E. BELL, PPPL, D.R. SMITH, UW-Madison, S.J. ZWEBEN, W. GUTTENFELDER, S.M. KAYE, B.P. LEBLANC, E. MAZZUCATO, PPPL, K.C. LEE, NFRI, C.W. DOMIER, UC-Davis, L. SHAO, ASIPP, H. YUH, Nova Photonics — It is well accepted that L-H transition is due to suppression of edge turbulence and thus forming Edge Transport Barrier (ETB). While suppression of low-k (ion-scale) turbulence across L-H transition was widely reported, here we report high-k turbulence evolution across L-H transition in NSTX for the first time. The high-k turbulence at r/a=0.7-0.8 was measured using a microwave scattering system with the ETB located at r/a > 0.9. An intermittent phase for the high-k turbulence is observed after the L-H transition with gradual decrease in the overall turbulence spectral power and intermittent periods (about 0.5-1 ms) of minimum high-k turbulence. A phase of minimum high-k turbulence is observed following the intermittent phase, and the high-k turbulence suppression is found to occur only at lower wavenumbers, namely k⊥≤9-10. The suppression is found to be consistent with the decrease in maximum ETG linear growth rate from gyrokinetic stability analysis. However, the observed intermittency cannot be explained by the linear analysis. Low-k turbulence, measured by Beam Emission Spectroscopy and Gas Puff Imaging, shows similar temporal behavior as the measured high-k turbulence.

PP8.00056 Studying high-k turbulence with microwave scattering in NSTX1 — J. RUIZ, PSFC, MIT, Cambridge, MA 02139, USA, Y. REN, PPPL, Princeton, NJ 08543, USA, A.E. WHITE, PSFC, MIT, Cambridge, MA 02139, USA, W. GUTTENFELDER, S.M. KAYE, B.P. LEBLANC, E. MAZZUCATO, PPPL, Princeton, NJ 08543, USA, K.C. LEE, NFRI, Daejeon, 305-806, Korea, C.W. DOMIER, UC-Davis, Davis, CA 95616, USA, D.R. SMITH, U. Wisconsin-Madison, Madison, WI 53706, USA, H. YUH, Nova Photonics, Inc., Princeton, NJ 08540, USA, PSFC, MIT, CAMBRIDGE, MA 02139, USA TEAM, PPPL, PRINCETON, NJ 08543, USA TEAM — Understanding electron thermal transport is important for achieving predictive capability for the performance of future fusion devices such as ITER. In NSTX, electron thermal transport is found to dominate energy loss. Numerical simulations and experiments have shown that electron temperature gradient (ETG) turbulence on the electron gyro-scale, k⊥pe ≤ 1, can be responsible for anomalous electron thermal transport in NSTX. Electron scale (high-k) turbulence with k⊥pe ≤ 0.6 was measured with a high-k microwave scattering system in NSTX. Enhanced high-k fluctuations have been previously observed when electron ETG exceeds critical gradient, and are affected by ExB shear flows, reverse magnetic shear, electron density gradient and electron collisionality. A description of the NSTX high-k scattering diagnostic will be presented, as well as the effect of magnetic field curvature and turbulence anisotropy on the spatial localization and k-resolution. Analysis of high-k turbulence measurements during plasma current ramp-down in a set of NSTX H-mode plasmas will also be presented.

1Work supported by US DOE.

PP8.00057 Core electron thermal transport in NSTX due to orbit stochastization by high frequency Alfvén eigenmodes1 — N.A. CROCKER, UCLA, E. BELOVA, E.D. FREDRICKSON, N.N. GORELENKOV, PPPL, K. TRITZ, JHU, W.A. PEEBLES, S. KUBOTA, UCLA, R.E. BELL, A. DIALLO, B.P. LEBLANC, J.E. MENARD, R.B. WHITE, PPPL, H. YUH, Nova Photonics — Progress is reported in understanding the role of high frequency Alfvén eigenmodes (AE) in anomalously high electron thermal transport in the core of high performance, beam-heated NSTX plasmas. Compressional (CAE) and global (GAE) AE modes have been hypothesized to cause the transport by stochastization of electron guiding-center drift orbits. Results reported here, arrived at via new measurements of CAE and GAE δψ, coupled with the guiding-center code ORBIT, support this. The measurements are also compared to eigenmodes from the initial value code HYM—which simulates an MHD plasma coupled to fully kinetic fast-ions. Reflectometer measurements are inverted using a synthetic diagnostic to obtain δψ. The measurements show that the CAEs peak in the core, while the GAEs peak in the edge. Simulation also shows edge peaking for the GAEs, but with notable differences in structure. The differences will be examined with HYM to elucidate the importance of effects such as coupling of shear and compressional Alfvén waves. The measured modes are used in ORBIT simulations to model the effects on electron orbits and the resulting transport is compared with that inferred from the experimental power balance calculated with TRANSP.

1US DOE Contracts DE-SC0011810, DE-FG02-99ER54527 and DE-AC02-09CH11466.
Reduced model prediction of electron temperature profiles in microtearing-dominated NSTX plasmas

WANG, Princeton University Plasma Physics Lab., S. ETHERY, Y. YEN, S. KAYE, J. CHEN, PPPL, ZIP, UCSD, E. STARTSEV, PPPL — Nonlinear global gyrokinetic simulations critical for addressing highly distinct turbulence and transport physics in spherical tokamaks (ST) such as NSTX have led to new insights. The drift wave Kelvin-Helmholtz instability, driven by strong shear flow, was found to be unstable in NSTX L-mode plasmas. The mode is characterized by finite $k_r$ and broader $k_θ$ than for the ITG mode. While the strong rotation shear leads to a reduction in the lowest-k turbulence, the remaining low-k fluctuations can produce a significant ion thermal transport comparable to experimental levels in the outer core region. Low-k fluctuations in L-mode also produce significant toroidal momentum flux, including a large anti-gradient residual stress mainly due to zonal flow shear induced symmetry breaking. Another new, important turbulence source identified in NSTX is the dissipative trapped electron mode (DTEM), which is believed to play little role in the core of conventional tokamaks. The drift wave Kelvin-Helmholtz instability is the potential redistribution of fast-ions by higher frequency Alfvénic instabilities. Analysis indicates that utilizing reconstructed total pressure and rotation profiles as opposed to using modeled/predicted fast-ion pressure and angular momentum profiles from TRANSP in the limit of zero anomalous fast-ion diffusion can yield better agreement between measured and predicted stability characteristics — consistent with apparent redistribution of fast-ions. Reconstruction methodologies and associated stability implications will be discussed.

Identification of new turbulence contributions to plasma transport in NSTX

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Variations in Edge and SOL Turbulence in NSTX

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Direct Comparison of GPI and BES measurements of Edge Fluctuations in NSTX

This work was partly supported by US-DoE contract DE-AC02-09CH11466.

Experimental Study of Kink-like Modes in NSTX Plasmas

This work is supported by U.S. DOE Contract DE-AC02-09CH11466.

Equilibrium reconstruction including kinetic effects and impact on MHD stability interpretation

This work is supported by U.S. DOE Contract DE-AC02-09CH11466.
PP8.00064 Kinetic resistive wall mode stability evaluation and physics insight application in NSTX1, J. BERKERY, S. SABBAGH, Columbia U., R. BETTI, U. of Rochester, R. BELL, A. DIALLO, S. GERHARDT, B. LEBLANC, J. MENARD, M. PODESTA, PPPL — Research on the National Spherical Torus Experiment (NSTX) has studied the stability of resistive wall modes (RWMs) in high-beta fusion plasmas for disruption avoidance. Stabilizing mechanisms for RWMs have been identified as the transfer of energy from the mode to thermal particles through rotational resonances and the effect of energetic particles to resist distortion of the magnetic field lines. These kinetic effects have been implemented in the M3Sk code and results have compared favorably with NSTX experiments including prediction of the marginal stability point and agreement with the trends of low-frequency MHD spectroscopy experiments. Further improvement of the already close agreement of M3Sk to experimental results is being pursued by comparison to a large database of NSTX discharges and implementation of additional physics in the code, including rotational effects on the fluid stability and the effect of pressure anisotropy. An ITPA MHD Stability Group joint analysis task verified several kinetic RWM codes, including M3Sk, and generally good agreement between the codes was achieved. A new disruption avoidance algorithm in NSTX-Upgrade will utilize the knowledge gained by kinetic stability physics insight, calculation, and comparison with experiment.

1This research was supported by the U.S. Department of Energy under contracts DE-FG02-99ER54524, DE-AC02-09CH11466, and DE-FG02-93ER54215.

PP8.00065 Effect of Externally Applied Perturbation Fields on Alfvénic MHD Activity in the NSTX Tokamak1, ALESSANDRO BORTOLON, University of Tennessee, Knoxville — Observations from NSTX demonstrate that externally applied magnetic perturbations (MP) can alter the dynamic of beam driven Alfvén modes. Bursting Global Alfvén Eigenmodes (GAE, n=7-9, 400-700 kHz) respond to pulses of static n=3 fields (∂B/∂t ~ 0.01 at the plasma edge) reducing mode amplitude, bursting period and frequency sweep by a factor of 2-3 [Bortolon et al., Phys. Rev. Letters, Vol. 110 (2013) 265008]. Similar MP attenuate the amplitude of continuous Toroidal Alfvén Eigenmodes (TAE, n=2-3, 50-90 kHz). Calculations of the perturbed beam-ion distribution function, considering MP from ideal or resistive plasma response, confirm an enhanced fast-ion transport consistent with a reduced drive for the GAE. At the same time, MP can also affect the Alfvén stability by altering the structure of Alfvén continua through modification of the kinetic profiles or introducing toroidal coupling as result of the broken axisymmetry. Computations of the n=2 Alfvén continuum for NSTX equilibria with n=3 MP show strong modification of the TAE continuum near the plasma edge, where coupling between n=2 and n=5 continuum modes reduces the gap, providing an additional damping for TAE modes extending in this region.

1DOE contracts No. DE-FG02-06ER54867, DE-AC02-09CH11466.

PP8.00066 Time-series classification of ELMs on NSTX with machine learning analysis1, DAVID SMITH, R. FONCK, G. MCKEE, Univ of Wisconsin, Madison, NSTX TEAM — The linear peeling-ballooning model can describe onset conditions for edge-localized modes (ELMs), but understanding saturation mechanisms and transport dynamics requires nonlinear models and experimental validation. Here, we examine time-series data of ELM bursts on NSTX to identify representative ELM groups with similar evolution characteristics. We apply hierarchical cluster analysis, an unsupervised machine learning technique popular in genomics, to beam emission spectroscopy (BES) measurements of ELM bursts. The application of cluster analysis to time-series data requires metrics to quantify the similarity or dissimilarity among time-series data. We find that both correlation and dynamic time warping similarity metrics reveal 2 groups of ELM events: fast, non-oscillatory ELMs (≈ 200 micro-s) and slow, oscillatory ELMs (≈ 1 ms). We also report on progress with wavelet-based similarity metrics. The identification of representative ELM groups with cluster analysis can establish validation scenarios for simulations, facilitate the automatic identification of ELMs in data, prepare ELM measurements for subsequent supervised machine learning analysis, and, more broadly, demonstrate the applicability of machine learning analysis to fusion plasma data.

1Supported by US Dept. of Energy grant no. DE-SC0001288.

PP8.00067 Pedestal Structure Evolution between ELMs for Different Lithium Wall Conditioning on NSTX1, QIAN TENG, AHMED DIALLO, TRAVIS GRAY, RAJESH MAINGI, BENOIT LEBLANC, Princeton Plasma Physics Lab — Understanding the evolution of the pedestal structure is important to develop predictive capabilities of fusion power for future devices. A detailed analysis of electron pressure, density and temperature profiles measured on H-mode discharges on NSTX is performed to investigate the dynamics of pedestal parameters between ELMs. [Discharges with lithium wall conditioning of 50mg, 150mg and 300mg.] This work is an extension from previous pedestal structure investigations [1]. The result shows that almost all the pedestal parameters, the width and height of pressure, density and temperature monotonously increase between ELMs while density height increases and sometimes saturates at the last 30% of an ELM cycle, and the density width decreases monotonously. The dependence of pedestal parameters on plasma current and neutral beam injection power is investigated. The pedestal width scaling with poloidal beta will also be performed and compared with previous works. The impact of lithium wall conditioning on pedestal height and width dynamics will be reported.

1This work is supported by the US DOE under DE-AC02-09CH11466.

PP8.00068 The 3D Structure of Flux Tubes That Admit Flute Instability in the Scrape-Off-Layer (SOL) of Tokamaks1, HIRONORI TAKAHASHI, Princeton Plasma Physics Laboratory — A severe reduction in size down to an ion gyro-radius scale, commonly known as “squeezing,” in a lateral dimension of the cross section of a flux tube is traditionally thought to inhibit the occurrence of the flute instability in the Scrape-off-Layer of a diverted tokamak by isolating the main volume of the flux tube from its ends at electrically conducting target plates. A study reported here in the 3D flux tube structure reveals the absence of squeezing for a flux tube that is sufficiently large in its toroidal extent (small toroidal harmonic number n) and located in a layer of low field-line shear around the “sweet spot” (about mid-way between the primary and secondary separatrices). The low-shear layer does not hence inhibit the flute instability through the squeezing mechanism, and may thus restore the flute instability, among the most virulent in the magnetized plasma, to the ranks of candidate electrostatic instabilities thought to underlie the turbulence in the SOL in tokamaks. Variations along the flux tube of geometrical characteristics including the cross section will be calculated to develop criteria for the absence of squeezing.

1Supported in part by the US DOE under DE-AC02-09CH11466.
PP8.00069 Characterization of inter-ELM impurity transport following 3D-field-triggered ELMs in NSTX 1. FILIPPO SCOTTI, V.A. SOUKHANOVSKIĬ, LLNL, R.E. BELL, PPPL, J.M. CANIK, ORNL, A. DIALLO, B.P. LEBLANC, M. PODESTA 2, PPPL. — The response of electron temperature and density profiles to edge localized modes (ELMs) triggered by 3D fields and the inter-ELM impurity transport are studied in NSTX H-mode discharges. 3D magnetic perturbations (n = 3) were used in lithium-conditioned ELM-free H-mode discharges to trigger ELMs (fELM = 10-62.5 Hz) and mitigate core impurity buildup [Canik PRL 2010]. For 10 Hz triggering, impurity flushing was observed for ψN > 0.5 following the ELM crash, with up to a 30% drop in carbon density at the pedestal top and comparable effects on the Ti, ne, Ti, ψ profile. The increase in the triggered ELM frequency progressively reduced the total carbon inventory, affecting profiles at inner radii. Carbon transport during and following the ELM crash is modeled using the impurity transport code MIST. Transient perturbations to the steady state particle diffusivity D and convective velocity v are applied to simulate the effect of the ELM on the carbon density evolution. An inward (convective) transport perturbation for ψ > 0.5 and an outward (diffusive and/or convective) transport perturbation for ψN > 0.5 are needed to reproduce the carbon density profile temporal evolution. While the equilibrium v/D ratio is inferred from the steady state carbon density profiles, the profile recovery following the ELM crash is used to estimate absolute values of the transport coefficients.

1Work supported by U.S. DOE Contracts: DE-AC02-09CH11466, DE-AC52-07NA27344, DE-AC05-000R22725.

PP8.00070 Midplane Neutral Density Profiles in NSTX 1. D.P. STOTLER, PPPL, F. SCOTTI, LLNL, R.E. BELL, B.P. LEBLANC, PPPL, R. RAMAN, U.Wash. — A procedure for using the Degas 2 Monte Carlo neutral transport code to infer neutral density profiles from the Balmer-β emission data recorded by a tangential camera was proposed previously and is examined in more detail here. The simulations track the penetration of an ad hoc neutral gas source at the vacuum vessel wall; the associated light emission seen by the camera is obtained via a synthetic diagnostic. The resulting radial emission profiles compare well with the measured ones, with the ratio of the profile peaks providing scaling factors for the neutral source strength and all output quantities. The procedure yields absolute radial profiles of deuterium atoms and molecules at the NSTX midplane. We will first show that the modeled camera image and density profiles are insensitive to variations in the spatial distribution of the neutral source. The procedure will then be applied to data from a variety of different NSTX operating regimes. A detailed uncertainty and error analysis will also be presented.

1This work supported by US DOE contracts DE-AC02-09CH11466, DE-AC52-07NA27344, and DE-SC0006757.

PP8.00071 Effects of TAE Avalanches on the neutral beam driven current profile and fast ion loss in NSTX and NSTX-U plasmas 1. DOUGLASS DARROW, PPPL, ALESSANDRO BORTOLON, Univ. Tenn. Knoxville, NEAL CROCKER, UCLA, ERIC FREDRICKSON, NIKOLAI GORELENKOVA, MARINA GORELENKOVA, GERRIT KRAMER, PPPL, SHIGEYUKI KUBOTA, UCLA, MARIO PODESTA, ROSCO WHITE, PPPL. — Strong bursts of TAEs with multiple n numbers present, termed TAE avalanches, are observed in NSTX plasmas, including early in the discharge, when the plasma current is being ramped up. These avalanches cause radial redistribution, slowing down, and loss of beam ions from the plasma. Losses are often particularly pronounced during these events. All of these changes in the beam ion distribution can affect the beam driven current profile. Measurements and modeling of the beam ion population and driven currents in NSTX, using the ORBIT and SPIRAL codes will be compared, including the effects of avalanches and associated MHD activity during the current ramp up phase. In addition, since NSTX-U will utilize additional neutral beams with different orientations from the set on NSTX, modeling of the effects of avalanches on the distribution of beam ions and associated beam driven current from the new beam lines will also be discussed.

1This work supported by US DoE contract DE-AC02-09CH11466.

PP8.00072 The Effect of Different Fast-ion Instabilities on the Fast-ion Profile 1. E. RUSKOV, W. HEIDBRINK, D. LIU, UC Irvine, E. FREDRICKSON, A. BORTOLON, PPPL. — Fast-ion driven instabilities in NSTX take many forms, including steady, bursting, and avalanching toroidal Alfvén eigenmodes (TAE), avalanching global AEs, energetic particle modes (EPM), long-lived modes (LLM) and abrupt large-amplitude events (ALE). The occurrence or absence of these modes on Mirnov signals correlates with the ratio of fast-ion to Alfven speed and the ratio of fast-ion to thermal pressure [1]. The drop in neutron rate at these events correlates differently with mode amplitude for the different types of events [1]. In this study, we expand this database to investigate the correlation of vertical fast-ion D-alpha (FIDA) data with the different types of MHD. The measured profiles are compared with classically-predicted profiles.


PP8.00073 TRANSP modeling of NB current drive including MHD effects 1. M. PODESTA, M. GORELENKOVA, R.B. WHITE, PPPL. — Simulations using a newly developed physics-based fast ion transport model are used to understand and quantify MHD effects on neutral beam (NB) current drive efficiency. NSTX results confirm that toroidal Alfvén eigenmodes (TAEs) and kink-like instabilities can cause substantial decrease in the central NB-driven current and modify its radial profile. Quantitative analysis is performed through a new model, developed for the TRANSP code, which computes EP transport in phase space to account for resonant wave-particle interactions. Simulations show that so-called TAE avalanches can cause decrements of up to 30% in the core NB-driven current, and even larger (relative) changes toward the plasma edge. Perturbations of the current profile persist over a considerable fraction of the slowing down time, with a recovery rate set by the NB injection rate. In contrast to ad-hoc diffusive models previously available in TRANSP, the new model captures the feature that TAEs mainly affect fast ions with large parallel velocity, i.e. the most effective in driving current, leaving other portions of the fast ion distribution nearly unperturbed.

1DOE contract No. DE-AC02-09CH11466.

PP8.00074 Validation of critical gradient model for fast ion relaxation in NSTX 1. JEFF LESTZ, NIKOLAI GORELENKOVA, MARIO PODESTA, Princeton Plasma Physics Laboratory. — Confinement of energetic particles (EP) is essential to optimize performance of present day tokamaks and future fusion devices. With superalfvenic velocities, EP interact resonantly with Toroidal Alfvén Eigenmodes (TAEs), resulting in enhanced radial transport and particle loss. A reduced quasi-linear “critical gradient model” (CGM) has been developed by Ghantous to account for this interaction, and was previously validated against DIII-D demonstrating surprising agreement [1]. The CGM uses linear instability theory to calculate the fast ion pressure gradient corresponding to marginal TAE stability. Integration of this gradient determines the relaxed fast ion profile and losses. This work focuses on applying the CGM to an NSTX plasma, using neutral beam injection for its validation. Through confinement studies were done with the help of TRANSP code in order to infer the EP radial diffusion rates consistent with the plasma performance in experiments. The analysis found typical radial diffusion of ~ 1 m²/s, with a transient peak value of ~ 8 m²/s. As a relatively fast code, the CGM can be used for predictive modelling of EP profiles in future devices such as ITER.

PP8.00075 3D halo neutral simulations in TRANSP code and application to NPA diagnostic on NSTX. M. V. GORELENKOVA, S.S. MEDLEY, PPPL, Princeton University — The TRANSP-based NPA simulations made up to 2014 were not accurate since they did not handle halo neutrals properly. The halo neutrals were volume averaged both poloidally and toroidally. However estimates show that halo neutrals remain in the vicinity of the neutral beam footprint and because of multi-generations they have comparable density as primary beam neutrals. To address this inconsistency a 3D halo neutral module has been developed and implemented for the analysis in TRANSP code. The 3D halo neutral model uses a “beam-in-a-box” model that encompasses both injected beam neutrals and resulting halo neutrals. Upon deposition by charge exchange, subsets of the full, one-half and one-third beam energy components produce thermal halo neutrals that are tracked through successive halo neutral generations until an ionization event occurs or a descendant halo exits the box. The Neutral Particle Analyzer (NPA) simulator in TRANSP is applied to NSTX discharges to study the effect of 3D halo neutrals on temporal evolution of NPA flux and the shape of energy spectra of fast particles.

PP8.00076 Benchmark of 3D halo neutral simulation in TRANSP and FIDASIM and application to projected neutral-beam-heated NSTX-U plasmas. D. LIU, UC Irvine, S.S. MEDLEY, M.V. GORELENKOVA, PPPL, W.W. HEIDBRINK, L. STAGNER, UC Irvine — A cloud of halo neutrals is created in the vicinity of beam footprint during the neutral beam injection and the halo neutral density can be comparable with beam neutral density. Proper modeling of halo neutrals is critical to correctly interpret neutral particle analyzers (NPA) and fast ion D-alpha (FIDA) signals since these signals strongly depend on local beam and halo neutral density. A 3D halo neutral model has been recently developed and implemented inside TRANSP code. The 3D halo neutral code uses a “beam-in-a-box” model that encompasses both injected beam neutrals and resulting halo neutrals. Upon deposition by charge exchange, a subset of the full, one-half and one-third beam energy components produce thermal halo neutrals that are tracked through successive halo neutral generations until an ionization event occurs or a descendant halo exits the box. A benchmark between 3D halo neutral model in TRANSP and in FIDA/NPA synthetic diagnostic code FIDASIM is carried out. Detailed comparison of halo neutral density profiles from two codes will be shown. The NPA and FIDA simulations with and without 3D halos are applied to projections of plasma performance for the National Spherical Torus Experiment Upgrade (NSTX-U) and the effects of halo neutral density on NPA and FIDA signal amplitude and profile will be presented.

PP8.00077 Upgrades to the NSTX SOL reflectometer to study plasma-antenna coupling and RF-edge interactions. CORNWALL LAU, JOHN B. WILGEN, JOHN B. CAUGMAN, GREG R. HANSON, Oak Ridge National Laboratory, JOEL HOSEA, RORY PERKINS, Princeton Plasma Physics Laboratory, PHIL RYAN, Oak Ridge National Laboratory, GARY TAYLOR, Princeton Plasma Physics Laboratory — The goal of the Oak Ridge National Laboratory (ORNL) scrape-off-layer (SOL) reflectometer is to measure the density profiles and fluctuations in front of the HHFW antenna on NSTX-U to help understand plasma-antenna coupling and RF-edge interactions, such as profile modifications due to field-aligned power losses and/or parametric decay instabilities. Originally designed for NSTX conditions, the reflectometer is being upgraded to operate at the increased magnetic fields of NSTX-U. General upgrades will be discussed. Most importantly, due to the doubling of the magnetic field for NSTX-U, the use of the current 6-27 GHz X-mode R cutoff on NSTX needs to be reconsidered. If only the X-mode R-cutoff is used, the operating frequencies will need to be modified, requiring significant hardware modifications to both the electronics and reflectometer launchers. It will be shown that the frequencies will not need to be modified for NSTX-U operation if both X-mode L and R cutoffs are measured. The measured SOL density profiles are intended to be used as inputs into RF simulation codes, and one such simulation using COMSOL multiphysics is being developed to understand the electric fields in front of the antenna for cold plasma conditions. Progress on the COMSOL simulation will be reported.

PP8.00078 Benchmark of ICRF codes in mid and high harmonic regimes in view of NSTX-U operation. NICOLA BERTELLI, C.K. PHILLIPS, E.J. VALEO, PPRL, R. BILATO, M. BRAMBILLA, IPP-Garching, E.F. JAEGGER, XCEL Engineering, P.T. BONOLI, PSFC-MIT — NSTX-Upgrade (NSTX-U) is presently scheduled to operate at the beginning of 2015 with toroidal magnetic fields (BT) up to 1 T, nearly twice the value used in the experiments on NSTX, and with NBI power up to 10 MW. The doubling of BT while retaining the 30 MHz rf source frequency moves the heating regime from the high harmonic fast wave (HHFW) regime (up to 5th harmonic) used in NSTX to the mid harmonic fast wave (MHFW) regime (up to 5th harmonic). Both the MHFW regime and the doubling of the NBI power can strongly affect the power absorption partitioning. In fact, the thermal and fast ions absorption can significantly increase [Bertelli et al AIP Conf. Proc. 1580, (2014) 310]. Thus, it is crucial to have an accurate evaluation of the power absorbed by fast and thermal ions for experimental analysis. Detailed benchmarking comparisons between the full wave codes TORIC v.5 [Brambilla, PPCF 44, (2002) 2423], TORIC v.6 [Bilato et al, NF 51, (2011) 103034], AORSA [Jaeger et al, PoP 8, 1573 (2001)], and the ray tracing code GENRAY [Smirnov et al, Bull. Am. Phys. Soc. 39, 1626 (1994)] have been performed. Finally, numerical predictions on NSTX-U are discussed for different scenarios.

PP8.00079 Comparison of NSTX FIDA, Charge Exchange, and Neutron Fluxes with Calculated Signals Based on CQL3D-FOW Distribution Functions1. R.W. HARVEY, YU.V. PETROV, J.E. KINSEY, CompX, D. LIU, W.W. HEIDBRINK, UC Irvine, G. TAYLOR, Princeton Plasma Physics Lab, P.T. BONOLI, Mass. Inst. of Technology — Ion distribution function calculations with CQL3D [1] have been substantially advanced through implementation of guiding-center-orbit-based Fokker-Planck Coefficients [2]. The resulting finite-orbit-width (FOW) calculations are carried out with a fast CQL3D-Hybrid-FOW option, and in a slower but neoclassically complete (except no vorticity) CQL3D-FOW option. Good comparison between time-dependent Fast Ion Diagnostic FIDA [3], NPA, and neutron signals resulting from neutral beam injection (NBI) and high harmonic fast wave (HHFW) power injected into the NSTX spherical tokamak have been simulated with the CQL3D-Hybrid-FOW, using only the FOW effects on QL diffusion, and particle losses, direct and CX. Comparisons are also made with recent CQL3D-FOW results [2], as well as with the original FIDA calculation code [3,4] and a recent fortran version [5].

1Supported by the U.S. DOE Contract DE-AC02-09CH11466.

2Supported by USDOE grants SC0006614, ER54744, and ER44649.
PP8.00080 Numerical optimization of perturbative coils for tokamaks, Samuel Lazerson, Jong-Kyu Park, Nikolas Logan, Princeton Plasma Phys Lab, Allen Boozer, Columbia University, NSTX-U research team — Numerical optimization of coils which apply three dimensional (3D) perturbative fields to tokamaks is presented. The application of perturbative 3D magnetic fields in tokamaks is now commonplace for control of error fields, resistive wall modes, resonant field drive, and neoclassical toroidal viscosity (NTV) torques. The design of such systems has focused on control of toroidal mode number, with coil shapes based on simple window-pane designs. In this work, a numerical optimization suite based on the STELLOPT 3D equilibrium optimization code is presented. The new code, IPECOPT, replaces the VMEC equilibrium code with the IPEC perturbed equilibrium code, and targets NTV torque by coupling to the PENT code. Fixed boundary optimizations of the 3D fields for the NSTX-Li experiment are underway. Initial results suggest NTV torques can be driven by normal field spectrums which are not pitch-resonant with the magnetic field lines. Work has focused on driving core torques with $n = 1$ and edge torques with $n = 3$ fields. Optimizations of the coil currents for the planned NSTX-U NCC coils highlight the code’s free boundary capability.

1This manuscript has been authored by Princeton University under Contract Number DE-AC02-09CH11466 with the U.S. Department of Energy.

PP8.00081 Suppressed gross erosion of high-temperature lithium films under high-flux deuterium bombardment, Tyler Abrams, M.A. Jaworski, R. Kaita, A.M. Capece, J.H. Nichols, D.P. Stotler, PPPL, J.P. Roszell, Princeton U., G. De Temmerman, M.A. Van den Berg, H.J. Van der Meiden, T.W. Morgan, FOM-DIFFER — Liquid lithium is an attractive plasma facing component (PFC) for a fusion reactor because it improves confinement and protects the underlying substrate from high heat fluxes. However some previous studies have implied the maximum Li temperature permitted on such devices may be unacceptably low. Recently thin (<1 µm) and thick (~500 µm) Li films on TZM molybdenum substrates were studied in the Magnum-PSI linear plasma device with ion fluxes $>10^{24}$ m$^{-2}$ s$^{-1}$ and Li surface temperatures $<800$°C. Measured Li erosion yields under neon plasma bombardment were similar to previous studies on low-flux devices, but erosion under deuterium bombardment was significantly suppressed. This motivated development of a mixed-material Li-D surface model incorporating D diffusion in Li, preferential sputtering, and LiD chemistry. This model is coupled to the adatom-evaporation equation for thermally-enhanced sputtering and the Langmuir law evaporation equation to obtain realistic predictions of temperature-dependent erosion rates. This model is found to predict the correct functional dependence of the mixed-material Li-D erosion rate vs. temperature in these discharges. Further investigations via molecular dynamics (MD) simulations and surface science experiments will also be presented.

2This work supported by US DOE contract DE-AC02-09CH11466.

PP8.00082 Advances in global mixed-material surface evolution modeling for NSTX-U, J.H. Nichols, M.A. Jaworski, R. Kaita, T. Abrams, D.P. Stotler, PPPL, K. Schmid, IPP Garching — NSTX-U will initially operate with graphite walls, periodically coated with thin lithium films to improve plasma performance. Prior experiments with Li evaporation on NSTX suggest that poloidally inhomogenous mixed-material C/Li surfaces will evolve over the course of the campaign due to wall material migration during plasma operation. Understanding the depletion and accumulation of Li in different parts of the machine is a key component of optimizing the Li conditioning process. To that end, the WallDYN global mixed-material surface evolution model [K. Schmid et al., J. Nucl. Mater. 415, S284-S288 (2011)] has been applied to the NSTX-U geometry. The WallDYN model couples local erosion and deposition processes with plasma impurity transport in a non-iterative, self-consistent manner that maintains overall material balance. For this work, a simplified C/Li mixed-material erosion model is generated by parameterizing sputter and reflection yield calculations from TRIM-like codes. The sensitivity of global lithium migration rates to various model parameters will be examined. A qualitative comparison will be made between the WallDYN model and post-campaign Li coverage measurements from NSTX.

1Work supported by US DOE contract DE-AC02-09CH11466.

PP8.00083 Overview of results from the Lithium Tokamak Experiment (LTX), R. Majeski, R. Bell, D. Boyle, A. Capece, A. Diallo, E. Granstedt, C.M. Jacobson, R. Kaita, B. Koel, T. Kozub, B. Leblanc, M. Lucia, R. Maingi, E. Merino, J. Schmitt, D. Stotler, G. Tchilingarian, PPPL, T.M. Biewer, T.K. Gray, ORNL, S. Kubota, W.A. Peebles, UCLA, P. Beiersdorfer, LLNL, K. Tritz, JHU, J.P. Allain, F. Bedoya, UIUC — LTX is a low aspect ratio tokamak with a heated liner or shell, which covers 80 percent of the plasma surface area (4 square meters). In 2014, a new approach to wall coatings was developed. The shells are now preheated to 300°C, and previously applied lithium coatings are allowed to oxidize. An electron beam system is then used to evaporate lithium from a pool of liquid at the bottom of the lower shell. The plasma surface area (4 square meters). In 2014, a new approach to wall coatings was developed. The shells are now preheated to 300°C, and previously applied lithium coatings are allowed to oxidize. An electron beam system is then used to evaporate lithium from a pool of liquid at the bottom of the lower shell. The e-beam system produces a 50 – 100 nm coating of liquefied lithium in a few minutes, which is then seen to grow in thickness over the course of the campaign. Work supported by US DOE contracts DE-AC02-09CH11466 and DE-AC52-07NA27344. With thick Li coatings on TZM molybdenum substrates were studied in the Magnum-PSI linear plasma device with ion fluxes $>10^{24}$ m$^{-2}$ s$^{-1}$ and Li surface temperatures $<800$°C. Measured Li erosion yields under neon plasma bombardment were similar to previous studies on low-flux devices, but erosion under deuterium bombardment was significantly suppressed. This motivated development of a mixed-material Li-D surface model incorporating D diffusion in Li, preferential sputtering, and LiD chemistry. This model is coupled to the adatom-evaporation equation for thermally-enhanced sputtering and the Langmuir law evaporation equation to obtain realistic predictions of temperature-dependent erosion rates. This model is found to predict the correct functional dependence of the mixed-material Li-D erosion rate vs. temperature in these discharges. Further investigations via molecular dynamics (MD) simulations and surface science experiments will also be presented.

PP8.00084 Diagnostic Overview of the Lithium Tokamak Experiment (LTX), T.K. Gray, T.M. Biewer, J.M. Canik, ORNL, R.E. Bell, D.P. Boyle, A. Diallo, E. Granstedt, C.M. Jacobson, R. Kaita, T. Kozub, B. Leblanc, M. Lucia, R. Maingi, E. Merino, R. Majeski, J.C. Schmitt, PPPL, S. Kubota, W.A. Peebles, UCLA, P. Beiersdorfer, J.H.T. Clementson, A.G. Mclean, K. Widmann, LLNL, K. Tritz, JHU, J.P. Allain, F. Bedoya, UIUC — LTX is a low aspect ratio tokamak with a heated liner or shell, which covers 80 percent of the plasma surface area (4 square meters). In 2014, a new approach to wall coatings was developed. The shells are now preheated to 300°C, and previously applied lithium coatings are allowed to oxidize. An electron beam system is then used to evaporate lithium from a pool of liquid at the bottom of the lower shell. The e-beam system produces a 50 – 100 nm coating of liquefied lithium in <5 minutes. Compared to previous results with helium-dispersed coatings, discharges using the new approach have strongly reduced impurities, especially oxygen. Magnetic analysis indicates that confinement in LTX Ohmic discharges is now well as a summary of results.

1Supported by US DOE contracts DE-AC02-09CH11466 and DE-AC52-07NA27344.

PP8.00085 Diagnostic Overview of the Lithium Tokamak Experiment (LTX), T.K. Gray, T.M. Biewer, J.M. Canik, ORNL, R.E. Bell, D.P. Boyle, A. Diallo, E. Granstedt, C.M. Jacobson, R. Kaita, T. Kozub, B. Leblanc, M. Lucia, R. Maingi, E. Merino, R. Majeski, J.C. Schmitt, PPPL, S. Kubota, W.A. Peebles, UCLA, P. Beiersdorfer, J.H.T. Clementson, A.G. Mclean, K. Widmann, LLNL, K. Tritz, JHU, J.P. Allain, F. Bedoya, UIUC — The Lithium Tokamak Experiment (LTX) is a low aspect ratio tokamak with a conformal low re-cycling first wall. The first wall is comprised of four stainless steel-lined copper shells, heatable to 300°C, onto which lithium is evaporated. The magnetic diagnostic suite has recently been upgraded to be more compatible with high temperatures and the lithium environment. A Thomson scattering system with new edge channels measures radial profiles of ne and Te. While Doppler spectroscopy is used to measure the ion temperature and speed of carbon and lithium impurities. Two 20 AXUV-diode arrays, 1 filtered for Ly-alpha and the other for bolometry, provide full radial coverage at the toroidal midplane, while a XUV spectrometer provides measurements of core impurities. The Materials Analysis and Particle Probe (MAPP) provided crucial information about the surface condition of the plasma-facing wall between shots. Measurements of the edge plasma are accomplished with filterscopes, visible spectrometers, Langmuir probes and a fast framing, filtered tangential camera.

2This work was supported by DoE Contracts DE-AC05-00OR22725, DE-AC52-07NA27344 and DE-AC02-09CH11466.
PP8.00085 Enhanced Alignment Techniques for the Thomson Scattering Diagnostic on the Lithium Tokamak eXperiment (LTX)1. ENRIQUE MERINO, TOM KOZUB, DENNIS BOYLE, MATTHEW LUCIA, RICHARD MAJESKI, ROBERT KAITA, JOHN C. SCHMITT, BENOIT LEBLANC, AHMED DIALLO, Princeton Plasma Physics Laboratory (PPPL), C.M. JACOBSON, University of Wisconsin-Madison. — The Thomson Scattering (TS) System in LTX is used to measure electron temperature and density profiles of core and edge plasmas. In view of TS measurements showing low signal-to-noise and high stray light, numerous improvements were performed in recent months. These will allow for better measurements. Due to the nature of LTX’s lithium coated walls, a particular challenge was presented by alignment procedures which required insertion and precise positioning of equipment in the vacuum vessel without breaking vacuum. To overcome these difficulties, the laser flight tubes were removed and an alignment probe setup placed along the beam line on a differentially pumped assembly. The probe was then driven into the vacuum vessel and back-illumination of the viewing optics on it allowed for alignment and spatial calibration. Other upgrades included better bracling of flight tubes and viewing optics as well as a redesigned beam dump. An overview of these improvements will be presented.

1Supported by US DOE contracts DE-AC02-09CH11466 and DE-AC52-07NA27344.

PP8.00086 Estimates of the Electron Density Profile on LTX Using FMCW Reflectometry and mm-Wave Interferometry2. W.A. PEEBLES, S. KUBOTA, X.V. NGUYEN, UCLA, T. HOLOMAN, R. KAITA, T. KOZUB, D. LABRIGE, J.C. SCHMITT, R. MAJESKI, PPPL — An FMCW (frequency-modulated continuous-wave) reflectometer has been installed on the Lithium Tokamak Experiment (LTX) for electron density profile and fluctuation measurements. This diagnostic consists of two channels using bistatic antennas with a combined frequency coverage of 13.5–33 GHz, which corresponds to electron density measurements in the range of 0.2–1.3×10¹¹ cm⁻³ (in O-mode). Initial measurements will utilize O-mode polarization, which will require modeling of the plasma edge. Reflections from the center stack (d水泥etry above the peak cutoff frequency), as well as line density measurements from a 296 GHz interferometer (single-chord, radial midplane), will provide constraints for the profile reconstruction/estimate. Typical chord-averaged line densities on LTX range from 2–6×10¹⁰ cm⁻³, which correspond to peak densities of 0.6–1.8×10¹¹ cm⁻³ assuming a parabolic shape. If available, EFIT/LRDIFIT results will provide additional constraints, as well as the possibility of utilizing data from measurements with X-mode or dual-mode (simultaneous O- and X-mode) polarization.

2Supported by U.S. DoE Grants DE-FG02-99ER54527 and DE-AC02-09CH11466.

PP8.00087 Impurities in the Lithium Tokamak Experiment1. D.P. BOYLE, R.E. BELL, R. KAITA, R. MAJESKI, PPPL, T.M. BIEWER, T.K. GRAY, ORNL, K. TRITZ, JHU, K. WIDMANN, LLNL — The Lithium Tokamak Experiment (LTX) is designed to study the low-recycling regime through the use of close-fitting, lithium-coated, heatable shell quadrants surrounding the plasma volume. Lithium coatings can getter and bury impurities, but they can also become covered by impurity compounds. Liquefied coatings can both dissolve impurity compounds and bring them to the surface, while sputtering and evaporation rates increase strongly with temperature. Here, we use spectroscopic measurements to assess the effects of varying wall conditions on plasma impurities, mainly Li, C, and O. A passive Doppler spectroscopy system measures toroidal and poloidal impurity profiles using fixed-wavelength and variable-wavelength visible spectrometers. In addition, survey and high-resolution extreme ultraviolet spectrometers detect emission from higher charge states. Preliminary results show that fresh Li coatings generally reduced C and O emission. C emission decreased sharply following the first solid Li coatings. Inverted toroidal profiles in a discharge with solid Li coatings show peaked Li III emissivity and temperature profiles. Recently, experiments with fresh liquid coatings led to especially strong O reduction. Results from these and additional experiments will be presented.

1Supported by US DOE contracts DE-AC02-09CH11466 and DE-AC05-00OR22725.

PP8.00088 Examining the temperature behavior of stainless steel surfaces exposed to hydrogen plasmas in the Lithium Tokamak eXperiment (LTX)1. FELIPE BEDOYA, JEAN PAUL ALLAIN, Univ of Illinois - Urbana, ROBERT KAITA, MATTHEW LUCIA, DENIS ST-ONGE, ROBERT ELLIS, RICHARD MAJESKI, Princeton Plasma Physics Laboratory — The Materials Analysis Particle Probe (MAPP) is an in-situ diagnostic designed to characterize plasma-facing components (PFCs) in tokamak devices. MAPP is installed in LTX at Princeton Plasma Physics Laboratory. MAPP’s capabilities include remotely operated XPS acquisition and temperature control of four samples. The recent addition of a focused ion beam allows XPS depth profiling analysis. Recent published results show an apparent correlation between hydrogen retention and temperature of Li coated stainless steel (SS) PFCs exposed to plasmas like those of LTX. According to XPS data, the retention of hydrogen by the coated surfaces decreases at about 180 °C. In the present study MAPP will be used to study the oxidation of Li coatings as a function of time and temperature of the walls when Li coatings are applied. Experiments in the ion-surface interaction experiment (IIAX) varying the hydrogen fluence on the SS samples will be also performed. Conclusions resulting from this study will be key to explain the PFC temperature-dependent variation of plasma performance observed in LTX.

1This work was supported by U.S. DOE contracts DE-AC02-09CH11466, DE-AC52-07NA27344 and DE-SCO010717.

PP8.00089 Dependence of LTX plasma performance on surface conditions as investigated by the Materials Analysis and Particle Probe1. M. LUCIA, R. KAITA, R. MAJESKI, D.P. BOYLE, M.A. JAWORSKI, J.C. SCHMITT, D.A. ST. ONGE, PPPL, F. BEDOYA, J.P. ALLAIN, UIUC — The Lithium Tokamak Experiment (LTX) is a spherical torus magnetic confinement device designed to accommodate solid or liquid lithium as the primary plasma-facing component (PFC). Results are presented from the implementation on LTX of the Materials Analysis and Particle Probe (MAPP), a compact in vacuo surface science diagnostic. With MAPP’s in situ analysis techniques of x-ray photoelectron spectroscopy (XPS) and thermal desorption spectroscopy (TDS), evolution of the PFC surface chemistry in LTX is studied as a function of varied hydrogen plasma exposure, surface temperature, and lithium coating. Performance of LTX plasma discharges depends on the composition and temperature of the PFCs in a strong and complex fashion. This work attempts to relate LTX plasma performance to the surface conditions as determined by XPS and TDS with MAPP. As proxies for the LTX PFCs, MAPP samples are exposed to both lithium evaporations and plasma discharges inside LTX. Metrics of LTX plasma performance include energy confinement time, plasma temperature and density profiles, and state of impurity species. Single Langmuir probes on MAPP and triple Langmuir probes throughout LTX are also used to relate LTX edge plasma parameters to MAPP results.

1This work was supported by U.S. DOE contracts DE-AC02-09CH11466, DE-AC52-07NA27344, and DE-SC0010717, as well as by a NSF GRFP fellowship under grant DGE-0646086.
PP8.00090 Thermal Desorption Spectroscopy of plasma-facing components with the Materials Analysis and Particle Probe1. D.A. ST-ONGE, R. KAITA, M. LUCIA, R. ELLIS, P.PPL, J.P. ALLAIN, F. BEDOYA, U. Illinois — The Material Analysis and Particle Probe (MAPP) is an in-vacuo diagnostic device for studying surface-plasma interactions on plasma facing components (PFC) in fusion devices. This diagnostic allows four samples to be exposed simultaneously and analyzed individually in situ. The supercenter is the location at which an X-ray source, an ion source, a residual gas analyser and an electron-energy analyzer all focus. Samples in this position are interchanged by rotation of the probe head using an eight-position Geneva drive. Currently the remote automation of the probe head is being developed using LabVIEW instruments, which shall monitor and control the rotational position of the samples. One technique to analyse samples used here is through thermal desorption spectroscopy (TDS), where a sample is heated sufficiently to release adsorbed molecules from the surface. To ensure samples are analysed individually, they must be thermally isolated. We will study the thermal isolation between samples using the Lithium Tokamak Experiment (LTX), which is a spherical torus designed to study lithium-based PFCs. Preliminary TDS experiments on stainless-steel samples with a range from 20°C to 800°C and a ramp of 2°C/s will be performed on LTX plasmas.

1This work was supported by U.S. DOE contracts DE-AC02-06CH11466, DE-AC52-07NA27344, and DE-SC0001071, as well as by an NSERC PGS-D scholarship.

PP8.00091 Initiatives in Non-Solenoidal Startup and H-mode Physics at Near-Unity A1, M.W. BONGARD, J.L. BARR, M.G. BURKE, R.J. FONCK, E.T. HINSON, B.T. LEWICKI, J.M. PERRY, A.J. REDD, D.J. SCHLOSSBERG, K.E. THOME, G.R. WINZ, University of Wisconsin-Madison — Research on the A ∼ 1 Pegasus ST is advancing the physics of non-solenoidal tokamak startup and the H-mode confinement regime. Local helicity injection (LHI) uses current sources in the plasma edge to initiate and drive Iϕ via DC helicity injection, subject to constraints from helicity conservation and Taylor relaxation. To date, Iϕ ∼ 0.18 MA has been initiated with |Iinj| ∼ 6 kA. A predictive 0-D power balance model of LHI Iϕ(t) evolution matches present discharges with strong PF induction. It projects Iϕ ∼ 0.3 MA operation in Pegasus will achieve the LHI-dominated physics regime expected for 1 MA NSTX-U startup. Ohmic H-mode plasmas are routinely attained, due to the low Pθ, at the low Bτ of A ∼ 1 plasmas. However, both limited and favorable τB/N SN plasmas have Pθ ∼ 11 times higher than expected from high-A scalings. They have improved τco (H95% ∼ 1) and a quiescent V Pedestal edge localized modes (ELMs). Unique V Ped(t) measurements through a single Type I ELM show a complex, multimodal pedestal collapse and filamentation. A proposed Pegasus-U initiative will upgrade the centerstack assembly and LHI injector systems, increasing Bτ to 1 T, Ohmic Vτ by ×6, and pulse length to 100 ms at A = 1.2. This allows the physics and technology of LHI to be validated at NSTX-U relevant parameters, supports studies of nonlinear ELM dynamics, and will test high-Bτ tokamak stability.

1Work supported by US DOE grant DE-FG02-96ER54375.

PP8.00092 Magnetics and Power System Upgrades for the Pegasus-U Experiment1, R.C. PRESTON, M.W. BONGARD, R.J. FONCK, B.T. LEWICKI, University of Wisconsin-Madison — To support the missions of developing local helicity injection startup and exploiting advanced tokamak physics studies at near unity aspect ratio, the proposed Pegasus-U will include expanded magnetic systems and associated power supplies. A new centerstack increases the toroidal field seven times to 1 T and the volt-seconds by a factor of six while maintaining operation at an aspect ratio of 1.2. The poloidal field magnet system is expanded to support improved shape control and robust double- or single null divertor operation at the full plasma current of 0.3 MA. An integrated digital control system based on Field Programmable Gate Arrays (FPGAs) provides active feedback control of all magnet currents. Implementation of the FPGAs is achieved with modular noise reducing electronics. The digital feedback controllers replace the existing analog systems and switch multiplexing technology. This will reduce noise sensitivity and allow the operational Ohmic power supply voltage to increase from 2100 V to its maximum capacity of 2400 V. The feedback controller replacement also allows frequency control for "freewheeling"—stopping the switching for a short interval and allowing the current to coast. The FPGAs assist in optimizing pulse length by having programmable switching events to minimize energy losses. They also allow for more efficient switching topologies that provide improved stored energy utilization, and support increasing the pulse length from 25 ms to 50–100 ms.

1Work supported by US DOE grant DE-FG02-96ER54375.

PP8.00093 Predictions for Non-Solenoidal Startup in Pegasus with Lower Divertor Helicity Injectors1. J.M. PERRY, J.L. BARR, M.W. BONGARD, R.J. FONCK, B.T. LEWICKI, University of Wisconsin-Madison — Non-solenoidal startup in Pegasus has focused on using arrays of local helicity injectors situated on the outboard midplane to leverage PF induction. In contrast, injector assemblies located in the lower divertor region can provide improved performance. Higher toroidal field at the injector increases the helicity injection rate, providing a higher effective loop voltage. Poloidal flux expansion in the divertor region will increase the Taylor relaxation current limit. Radial position control requirements are lessened, as plasma expansion naturally couples to injectors in the divertor region. Advances in cathode design and plasma-facing guard rings allow operation at bias voltages over 1.5 kV, three times higher than previously available. This results in increased effective loop voltage and reduced impurity generation. Operation of helicity injectors in the high field side elevates the current requirements for relaxation to a tokamak-like state, but these are met through the improved injector design and increased control over the poloidal field structure via the addition of new coil sets. These advances, combined with the relocation of the injectors to the divertor region, will allow access to the operational regime where helicity injection current drive, rather than the poloidal induction, dominates the discharge—a prerequisite for scaling to larger devices. Initial estimates indicate that plasma currents of 0.25–0.30 MA are attainable at full toroidal field with 4 injectors of 2 cm² each and 8 kA total injected current.

1Work supported by US DOE grant DE-FG02-96ER54375.

PP8.00094 Physics of Intense Electron Current Sources for Helicity Injection1, E.T. HINSON, J.L. BARR, M.W. BONGARD, M.G. BURKE, R.J. FONCK, B.T. LEWICKI, J.M. PERRY, A.J. REDD, G.R. WINZ, University of Wisconsin-Madison — DC helicity injection (HI) for non-solenoidal ST startup requires sources of current at the tokamak edge. Since the rate of HI scales with injection voltage, understanding of the physics setting injector impedance is necessary for a predictive model of the HI rate and subsequent growth of Iϕ. In Pegasus, arc plasma sources are used for current injection. They operate immersed in tokamak edge plasma, and are biased at ∼1–2 kV with respect to the vessel to draw current densities J ∼ 1 kA/cm² from an arc plasma cathode. Prior to tokamak formation, impedance data manifests two regimes, one at low current (< 1 kA) with I ∼ V²/2, and a higher current where I ∼ V¹/² holds. The impedance in the I ∼ V³/² regime is consistent with an electrostatic double layer. Current in the I ∼ V¹/² regime is linear in arc gas fueling rate, suggesting a space-charge limit set by nelec. In the presence of tokamak plasmas, voltage oscillations of the order 100s of volts are measured during MHD relaxation activation. These fluctuations occur at the characteristic frequencies of the n = 1 and n = 0 MHD activity observed on magnetic probes, and are suggestive of dynamic activity found in HI simulations in NIMROD. Advanced injector design techniques have allowed higher voltage operation. These include staged shielding to prevent external arcing, and shaped cathodes, which minimize the onset and material damage due to cathode spot formation.

1Work supported by US DOE grant DE-FG02-96ER54375.
PP8.00095 Anomalous Ion Heating, Intrinsic and Induced Rotation in the Pegasus Toroidal Experiment

The Pegasus toroidal experiment at the University of Wisconsin-Madison initiates plasma discharges through either standard, MHD-stable inductive current drive or non-solenoidal local helicity injection. It is observed that anomalous ion heating has been observed, with \( T_i \approx 800 \text{ eV} \) at the end of the helicity injection phase. The ion heating is hypothesized to be a result of large-scale magnetic reconnection activity, with a strong reconnection activity providing a rich environment to study ion dynamics. During LHI discharges, a significant amount of anomalous ion heating has been observed, with \( T_i \approx 800 \text{ eV} \) but \( T_e < 100 \text{ eV} \). The ion heating is hypothesized to be a result of large-scale magnetic reconnection activity. The amount of heating scales with increasing fluctuation amplitude of the dominant, edge localized, mode. Chordal \( T_i \) spatial profiles indicate centrally peaked temperatures, suggesting a region of good confinement with the plasma core surrounded by a stochastic region. LHI plasmas are observed to rotate, perhaps due to an inward radial current generated by the stochasticity of the plasma edge by the injected current streams. Rotation shear is currently used as a combination of high-field side fueling and Ohmic current drive. This regime shows a significant increase in rotation shear compared to L-mode plasmas. In addition, these plasmas have been observed to rotate in the counter-\( I_p \) direction without any external momentum sources. The intrinsic rotation direction is consistent with predictions from the saturated Ohmic confinement regime.

1 Work supported by US DOE grant DE-FG02-96ER54375.

PP8.00096 Initial Thomson Scattering Surveying of Local Helicity Injection and Ohmic Plasmas at the Pegasus Toroidal Experiment

A multipoint Thomson scattering diagnostic has recently been installed on the Pegasus ST. The system utilizes a frequency-doubled Nd:YAG laser, spectrometers with volume phase holographic gratings, and a gated, intensified CCD camera. It provides measurements of \( T_e \) and \( n_e \) at 8 spatial locations for each spectrometer once per discharge. It is observed that the multi-aperture and beam dump system has been implemented to mitigate interference from stray light. This system has provided initial measurements in the core region of plasmas initiated by local helicity injection (LHI), as well as conventional Ohmic L- and H-mode discharges. Multi-shot averages of low-density \( (n_e \sim 3 \times 10^{19} \text{ m}^{-3}) \), \( I_p \sim 0.1 \text{ MA LHI discharges show central } T_e \sim 75 \text{ eV} \) at the end of the helicity injection phase. \( I_p \sim 0.13 \text{ MA Ohmic plasmas at moderate densities } (n_e \sim 2 \times 10^{19} \text{ m}^{-3}) \) have core \( T_e \sim 150 \text{ eV} \) in L-mode. Generally, these plasmas do not reach transport equilibrium in the short 25 ms pulse length available. After an L-H transition, strong spectral broadening indicates increasing \( T_e \), to values above the range of the present spectrometer system with a high-dispersion VPH grating. Near-term system upgrades will focus on deploying a second spectrometer, with a lower-dispersion grating capable of measuring the 0.1–1.0 keV range. The second spectrometer system will also increase the available number of spatial channels, enabling study of H-mode pedestal structure.

1 Work supported by US DOE grant DE-FG02-96ER54375.

PP8.00097 Probe Measurements in the H-mode Pedestal Region in the Pegasus Toroidal Experiment

Measurements of electric field fluctuations in magnetic confinement experiments are desired for validating turbulence and transport models. A new diagnostic to measure \( E_r(r,t) \) fluctuations is in development on the Pegasus Toroidal Experiment. The approach is based on neutral beam emission spectroscopy using a high-throughput, high-resolution spectrometer to resolve fluctuations in wavelength separation between components of the motional Stark effect spectrum. Fluctuations at mid-minor-radius, normalized to an estimated MSE field, are estimated to be \( \delta E/E_{\text{MSE}} \approx 10^{-3} \). In order to resolve fluctuations at turbulent time scales \( (f_k \nu_k \approx 500 \text{ kHz}) \), beam and spectrometer designs minimize broadening and maximize signal-to-noise ratio. The diagnostic employs a Fabry-Perot spectrometer with étendue-matched collection optics and low noise detectors. The interferometer spacing is varied across the face of the etalon to mitigate geometric Doppler broadening. An 80 keV \( \text{IP} \) beam from PBX-M with a divergence \( \Omega < 0.5 \text{ degrees} \) is being refurbished for this project. The beam includes a new ion source to maximize full energy species fraction and is designed to provide \( \approx 2 \text{ cm spatial resolution} \) and \( 50 \text{ ms of } 6 \text{ mA/cm}^2 \text{ current density} \) at the focal plane. Successful development and demonstration on Pegasus will guide future deployment on larger fusion facilities.

1 Work supported by US DOE grant DE-FG02-96ER54375.

PP8.00098 Progress Toward a Technique for Measuring Electric Field Fluctuations in Tokamak Core Plasmas

Measurements of electric field fluctuations in magnetic confinement experiments are desired for validating turbulence and transport models. A new diagnostic to measure \( E_r(r,t) \) fluctuations is in development on the Pegasus Toroidal Experiment. The approach is based on neutral beam emission spectroscopy using a high-throughput, high-resolution spectrometer to resolve fluctuations in wavelength separation between components of the motional Stark effect spectrum. Fluctuations at mid-minor-radius, normalized to an estimated MSE field, are estimated to be \( \delta E/E_{\text{MSE}} \approx 10^{-3} \). In order to resolve fluctuations at turbulent time scales \( (f_k \nu_k \approx 500 \text{ kHz}) \), beam and spectrometer designs minimize broadening and maximize signal-to-noise ratio. The diagnostic employs a Fabry-Perot spectrometer with étendue-matched collection optics and low noise detectors. The interferometer spacing is varied across the face of the etalon to mitigate geometric Doppler broadening. An 80 keV \( \text{IP} \) beam from PBX-M with a divergence \( \Omega < 0.5 \text{ degrees} \) is being refurbished for this project. The beam includes a new ion source to maximize full energy species fraction and is designed to provide \( \approx 2 \text{ cm spatial resolution} \) and \( 50 \text{ ms of } 6 \text{ mA/cm}^2 \text{ current density} \) at the focal plane. Successful development and demonstration on Pegasus will guide future deployment on larger fusion facilities.

1 Work supported by US DOE grant DE-FG02-89ER53296.

PP8.00099 Error field minimization strategies towards MAST Upgrade operation

In fusion devices, the presence of magnetic error fields (EF) leads to toroidal asymmetries in the magnetic field. Even small EFs of the order of \( B_r \approx 10^{-4} \) can have detrimental effect on plasma operations, since they can induce locked mode formation and thus plasma termination. In the MAST spherical tokamak, intrinsic EFs have been identified as limiting low density experiments and have been compensated using error field correction coils. In building MAST Upgrade device, a careful design, manufacture and installation of axisymmetric coils has been adopted to reduce the EF amplitude to the lowest possible value. In the present work, passive and active control strategies for EF correction are presented. The passive control concerns the optimization of the fine-scale coil alignment in order to minimize the n=1 EF amplitude. Such studies require high accuracy magnetic measurements and associated 3D modelling. A model-based optimization approach has been adopted to identify the right shift and tilt in the coil position which allow for the n=1 EF correction. However, inevitably residual EFs will be present and active control algorithms will need to be implemented in the plasma control system to compensate them. Such control schemes will be discussed.

1 Work supported by the RCUK Energy Programme and European Union’s Horizon 2020 research and innovation programme under grant agreement number 210130335.
In addition to simulation results, initial attempts to measure high frequency fluctuations (f ≤ ω Debye) in the electron diffusion region which acts to broaden the layer. Anomalous resistivity is also generated by the turbulence and significantly modifies the force balance.

Using 3D, fully explicit kinetic simulations with a realistic and unprecedentedly large separation between the Debye length and the electron skin depth, we show that fully kinetic simulations do not agree with experimental observations on the size of the electron diffusion region, implying a different reconnection mechanism.

With controlling plasmas in the TS-4 ST experiment and in MHD/PIC simulation. In the TS-4, the plasmoid ejection from the core ST plasma, which is a standard operation of dynamic divertor, was demonstrated for the first time. Using this experimental data as background condition, the confinement of the heat flux from the core plasma in the plasmoid is indicated through orbit calculation. In addition, physical pictures of the heat flux transport from the SOL region to the plasmoid will be studied in detail by 2-dimensional collisionless particle simulations in the rectangular coordinate. Since the strong guide field exists the region where the plasmoid is formed and transported, field-aligned motion is important for understanding the heat flux transport from the SOL region to the plasmoid both for ions and electrons.

This work is supported by DOE Contract No. DE-AC0209CH11466 and NASA program for the MMS mission under the grant No. NNH11AQ45I.

**PP8.00101 Experimental and numerical studies of dynamic divertor with plasmoid**. SHIZUO INOUE, YASUSHI ONO, YASUHIRO KAMINOU, University of Tokyo, RITOKU HORIUCCI, National Institute for Fusion Science — Novel dynamic divertor operation with controlling plasmas has been studied in TS-4 ST experiment and in MHD/PIC simulation. In the TS-4, the plasmoid ejection from the core ST plasma, which is a standard operation of dynamic divertor, was demonstrated for the first time. Using this experimental data as background condition, the confinement of the heat flux from the core plasma in the plasmoid is indicated through orbit calculation. In addition, physical pictures of the heat flux transport from the SOL region to the plasmoid will be studied in detail by 2-dimensional collisionless particle simulations in the rectangular coordinate. Since the strong guide field exists the region where the plasmoid is formed and transported, field-aligned motion is important for understanding the heat flux transport from the SOL region to the plasmoid both for ions and electrons.

This work is supported by Grants-in-aid for Scientific Research (S24226020), NIFS Collaboration Research Program (NIFS12KUTR081), and the Collaborative Research Program of Research Institute for Applied Mechanics, Kyushu University.

**PP8.00102 Conceptual Design of a Small Aspect Ratio Tokamak of Variable Configuration**. JULIO HERRERA-VELAZQUEZ, ISMAEL ARROYO-DIAZ, DOMENICA CORONA-RIVERA, Instituto de Ciencias nucleares, UNAM, ESTEBAN CHAVEZ-ALARCÓN, Instituto Nacional de Investigaciones Nucleares — We show the preliminary work being done in order to propose a mid-term project for a Mexican nuclear fusion programme, with the necessary flexibility to produce original results. The purpose is to study the feasibility of a medium size, low aspect ratio tokamak, with the capability of actively controlling the shape and position of the plasma column. Its objective would be to explore the necessary operational conditions for high β and high bootstrap current. The 3D-MAPTOR code is used in order to estimate the magnetic field surfaces behaviour. The TEMEX tokamak would consist in a stainless-steel toroidal vacuum chamber with semi-rectangular cross section, with external toroidal and poloidal field coils. The central post would include the central solenoid, as well as inner control coils. The toroidal magnetic field is produced by 10 rectangular coils, made out of 40 turns of water cooled copper conductor. Six poloidal field coils have been included, distributed in two groups of three, one on the upper, and another one on the lower side of the torus.

**PP8.00103 MAGNETIC RECONNECTION**

**PP8.00104 Dual Species Trapping by RF Field Structure**. NATHANIEL HICKS, University of Alaska Anchorage — A computational particle-in-cell study is performed in which the effects of RF trapping of a light species and consequent effects on accompanying heavier species in bulk plasma are explored. Electrode structures such as the RF quadrupole are simulated in 2-D, and parameters such as relative charge-to-mass ratios of the light and heavy species are investigated. Scaling to electron trapping and trapping dependences on species temperatures and RF parameters are investigated as well. The RF plasma sheath for this configuration is a topic of particular interest.

**PP8.00105 Anomalous resistivity due to high-frequency waves at the X-line during magnetic reconnection**. J. JARA-ALMONTE, H. JI, PPPL, W. DAUGHTON, LANL, V. ROYTHERSTHEYN, ScibeQuest, M. YAMADA, J. YOO, W. FOX, PPPL — One major consequence of magnetic reconnection is the efficient transfer of energy from magnetic fields to plasma particles. During collisionless reconnection, the decoupling of the field from the plasma is known to occur only within the localized ion and electron diffusion regions, however predictions from fully kinetic simulations do not agree with experimental observations on the size of the electron diffusion region, implying a different reconnection mechanism. Using 3D, fully explicit kinetic simulations with a realistic and unprecedentedly large separation between the Debye length and the electron skin depth, we show that high frequency electrostatic waves (ω ≫ ω Debye) can exist within the electron diffusion region. These waves generate small-scale turbulence within the electron diffusion region which acts to broaden the layer. Anomalous resistivity is also generated by the turbulence and significantly modifies the force balance. In addition to simulation results, initial attempts to measure high frequency fluctuations (f ≤ 1 GHz) in the Magnetic Reconnection Experiment (MRX) will be presented.

**PP8.00106 Studies of electron energization during magnetic reconnection in a laboratory plasma**. JONGSOO YOO, MASAHIK YAMADA, HANTAO JI, JONATHAN JARA-ALMONTE, BYUNGEUN NA, CLAYTON E. MYERS, WILLIAM FOX, Princeton Plasma Physics Laboratory — Bulk electron heating and energetic electron generation during magnetic reconnection are studied in the Magnetic Reconnection Experiment (MRX). Analysis of the measured 2-D electron temperature profile shows that electrons are heated non-classically near the electron diffusion region. Electron heating is observed over the broad downstream region during anti-parallel reconnection without a significant density asymmetry across the current sheet. Classical Ohmic heating accounts for about 20% of the required heating power. When there is a strong density asymmetry across the current sheet, the electron temperature profile changes such that the electron temperature is highest near the low-density-side separatrix where strong density gradients and electromagnetic fluctuations in the lower hybrid frequency range are also observed. These laboratory measurements agree with space observations at the dayside magnetopause. Possible mechanisms for bulk electron heating are discussed. Recent diagnostic developments, including 2-D EUV imaging and electron energy analyzer, for measurements of energetic electron generation are presented.
PP8.00107 Laboratory evidence that line-tied tension forces can suppress loss-of-equilibrium flux rope eruptions in the solar corona. C.E. MYERS, M. YAMADA, E. BELOVA, H. JI, J. YOO, W. FOX, J. JARA-ALMONTE, L. GAO, Princeton Plasma Physics Laboratory — Loss-of-equilibrium mechanisms such as the ideal torus instability [Kliem & Török, Phys. Rev. Lett. 96, 255002 (2006)] are predicted to drive arch flux ropes in the solar corona to erupt. In recent line-tied flux rope experiments conducted in the Magnetic Reconnection Experiment (MRX), however, we find that quasi-statically driven flux ropes remain confined well beyond the predicted torus instability threshold. In order to understand this behavior, in situ measurements from a 300 channel 2D magnetic probe array are used to comprehensively analyze the force balance between the external (vacuum) and internal (plasma-generated) magnetic fields. We find that the line-tied tension force—a force that is not included in the basic torus instability theory—plays a major role in preventing eruptions. The dependence of this tension force on various vacuum field and flux rope parameters will be discussed.

PP8.00108 Development of phosphor imaging diagnostics for particle energization and field line mapping studies in MRX. W. FOX, S.J. ZWEBEN, J. YOO, J. JARA-ALMONTE, C. MYERS, M. YAMADA, H. JI, Princeton Plasma Physics Laboratory — The energization of particles by magnetic reconnection is one of its most important roles in space and astrophysical plasmas. We present results from phosphor-screen imaging diagnostics for the Magnetic Reconnection Experiment, developed to measure the location and timing of particle energization by magnetic reconnection and to map field lines. Phosphor-based imaging diagnostics have previously been used to study plasma dynamics in non-neutral plasmas and low-temperature linear machines [1]. In MRX, movable, phosphor-coated probes are scanned across the current sheet, and phosphor emission is imaged on a fast camera acquiring at typically 500 frames/sec. Optical filters isolate the phosphor emission from line emission in the plasma. The energy sensitivity of the probe is determined by the characteristics of the phosphor and bias of the probe with respect to the plasma. We also present the development of an e-beam diagnostic to directly map the magnetic field line structure and possibly to measure the parallel electric field and/or cross-field electron transport. A modulated electron beam from a hot tungsten filament will be detected downstream by Langmuir probes and the phosphor imager.


PP8.00109 FLARE (Facility for Laboratory Reconnection Experiments): A Major Next-Step for Laboratory Studies of Magnetic Reconnection. H. JI, A. BHATTACHARJEE, S. PRAGER, Princeton U., S. BALE, UC-Berkeley, T. CARTER, N. CROCKER, UCLA, J. DRAKE, U. Maryland, J. EGEDAL, J. WALLACE, U. Wisconsin, E. BELOVA, R. ELLIS, W. FOX, P. HEITZENROEDER, M. KALISH, J. JARA-ALMONTE, C. MYERS, W. QUE, Y. REN, P. TITUS, M. YAMADA, J. YOO, PPO, W. DAUGHTON, LANL — A new intermediate-scale plasma experiment, called the Facility for Laboratory Reconnection Experiments or FLARE, is under construction at Princeton as a joint project by five universities and two national labs to study magnetic reconnection in regimes directly relevant to space, solar, astrophysical, and fusion plasmas. The currently existing small-scale experiments have been focusing on the single X-line reconnection process in plasmas either with small effective sizes or at low Lundquist numbers, but both of which are typically very large in natural and fusion plasmas. The design of the FLARE device is motivated to provide experimental access to the new regimes involving multiple X-lines at large effective sizes and high Lundquist numbers. The motivating major physics questions, the construction status, and the planned collaborative research will be discussed.

PP8.00110 Experimental Study of a Linear/Non-Linear Flux Rope. TIMOTHY DEAHAAS, WALTER GEKELMAN, BART VAN COMPENORLLE, Univ of California - Los Angeles — Flux Ropes are magnetic structures of helical field lines, accompanied by spiraling currents. Commonly observed on the solar surface extending into the solar atmosphere, flux ropes are naturally occurring and have been observed by satellites in the near earth and laboratory environments. In this experiment, a single flux rope (r = 2.5 cm, dz = 1100 cm) was formed in the cylindrical, magnetized plasma of the Large Plasma Device (L = 200 cm, r = 30 cm, n_e = 10^{12} cm^{-3}, T_e = 4 eV, He). The flux rope was generated via a DC discharge between a cathode and anode. This fixes the rope at its source while allowing it to freely move about the anode. At large currents (I > B_oπr^2/2da), the flux rope becomes helical in structure and oscillates about a central axis. Under varying Alfvén speeds and injection current, the transition of the flux rope from stable to kink-unstable was examined. As it becomes non-linear, oscillations in the magnetic field shift from sinusoidal to Sawtooth-like. The frequency, mode number, and plasma parameters are motivated by a new laboratory experiment on the Large Plasma Device at UCLA. For sufficiently long systems, we demonstrate that tearing instability have largely focused on 1D equilibria with periodic boundary conditions, current sheets in nature have a finite spatial extent and are embedded within a larger open system. In many applications, the field boundary conditions are line-tied as in the case of flux ropes on the dayside magnetopause where the ionosphere acts as a conducting surface. To assess the applicability of existing linear tearing theory to these more realistic configurations, we consider a series of 3D kinetic simulations of force-free current layers with line-tied boundary conditions for the fields and open boundaries for the particles. The geometry and plasma parameters are motivated by a new laboratory experiment on the Large Plasma Device at UCLA. For sufficiently long systems, we demonstrate that key aspects of the theory remain valid. New diagnostics are employed to characterize the nonlinear reconnection rate and the structure of the magnetic field.
PP8.00113 Blasting current sheets into flux ropes using laser plasmas\textsuperscript{1} . S. VINCENA, W. GEKELMAN, J. BONDE, UCLA Department of Physics and Astronomy — In plasmas, current sheets have been shown to break apart into three-dimensional flux ropes via turbulent magnetic reconnection\textsuperscript{[1]}. Such events occur naturally anywhere from the sun to planetary magnetospheres. In nature, the onset of the breakup is random, but in this experiment it is seeded at a chosen time and location—allowing study of the dynamics in a repeatable laboratory experiment. In the Large Plasma Device (LPD), current sheets are created using a LaB\textsubscript{6} cathode, with $T_e = 200\text{eV}$, $n \approx 1 \times 10^{12}\text{cm}^{-3}$, yielding cross-field dimensions $\Delta = 0.9\text{c}/\omega_{pi}$ and $w = 3.8c/\omega_{pe}$ for a H plasma, and a Lundquist number $S = 8 \times 10^{13}$. The synchronization of the breakup from current sheet to flux ropes is achieved by the cross-field injection of a laser ablation plasma, whose lifetime is less than an ion cyclotron period. The system dynamics are explored using magnetic and emissive probes (providing total E) along with spectral measurements before and after the breakup.

\textsuperscript{1} Work is performed at the Basic Plasma Science Facility and funded by the US DoE and NSF.

PP8.00114 Nonlinear analysis of explosive growth of collisionless magnetic reconnection in the presence of the effect of finite electron temperature\textsuperscript{1} . MAKOTO HIROTA, YUJI HATTORI, Tohoku University — Explosive behavior of collisionless magnetic reconnection is investigated by analyzing a two-fluid model that includes the effects of the electron inertia and the electron temperature (or compressibility). By micromixing both the electron skin depth $d_e$ and the ion sound gyroradius $\rho_s$ such that $\rho_s = d_e < 0.01L$ (where $L$ is the system size), a direct numerical simulation is performed to enlarge strongly nonlinear regime of a collisionless tearing instability. The nonlinear evolution is shown to be explosive when the inverse of the tearing index $1/\Delta^2$ is smaller than $\rho_s = d_e$, whereas the maximum reconnection speed at the fully reconnected state does not significantly depend on the size of $\rho_s = d_e$. The singular current-vortex sheets are generated in the form of the X shape [Cafaro et al. Phys. Rev. Lett 80, 4430 (1998)]. In the explosive phase, the expansion of this X shape as well as the magnetic island occurs locally near the reconnection point. By taking an approach similarly to the asymptotic matching, the dynamics of the current-vortex sheets is analyzed and the explosive reconnection speed is estimated theoretically.

\textsuperscript{1} This work is supported by JSPS Grant-in-Aid for Young Scientists(B) (No. 25800308).

PP8.00115 Impulsive Magnetic Reconnection by Acceleration of Ejecting Plasmoid Motion . Y. ONO, C.Z. CHENG, Y. HAYASHI, A. KUWADA, H. TANABE, K. KADOWAKI. University of Tokyo — We show for the first time in laboratory merging experiments, the ejection of plasmoid from current sheet as a major driving mechanism for impulsively fast magnetic reconnection. The high inflow of plasma (and thus magnetic flux) and low current-sheet resistivity cause flux pile-up initially, which is followed by rapid growth of plasmoid in the current sheet. When the flux pileup exceeds a critical level, the plasmoid is ejected from the squeezed current sheet area. The reconnection rate is slow during the flux pileup stage, but becomes drastically fast during the ejection, indicating impulsive reconnection. The reconnection electric field and effective resistivity in the current sheet reach their peak values when the acceleration rate of plasmoid motion peaks. This clear relationship indicates that the acceleration of plasmoid ejection is a major fast reconnection mechanism. The present experimental result explains the simultaneous occurrence of plasmoid acceleration rate and enhanced magnetic reconnection observed during the impulsive phase of solar flares.

PP8.00116 Electron Heating Characteristics of Magnetic Reconnection in UTST Merging Tokamak Experiment . XUEHAN GUO, TAKAMICHI SUGAWARA, MICHIAKI INOMOTO, YASUSHI ONO, The University of Tokyo. UTST TEAM — Localized electron heating from 10eV to 30eV was documented around the X-point during strong guide field (typically $B_t \sim 15B_p$) magnetic reconnection in the UTST tokamak merging experiment. We developed a novel two-dimensional Thomson scattering measurement system by sliding radially the whole 1D system that can measure an axial profile of electron temperature and density in a single discharge. The high electron temperature area was found to have a round shape with radius of 2cm, in sharp contrast with high current density area. This scale length 2cm is close to the orbit amplitude of an ion meandering motion 1.5-2cm but 3 times longer than the ion gyroradius 0.6cm. The electron heating power is about 12MW/m\textsuperscript{2} which is an order of magnitude larger than heating power calculated from the Spitzer resistivity. The increment in electron thermal energy is about 2.2J, which is about 15% of the dissipated magnetic energy of 14 J measured by 2D magnetic probe array. This conversion ratio in the strong guide field magnetic reconnection is higher than that in the weak guide field (typically $B_t \sim 5B_p$) experiment in MAST and TS-3 devices, suggesting that the electrons are accelerated toroidally toroidally by reconnection electric field and thermalized around X-point.

PP8.00117 Floating Potential Measurement for High Field Guide Field Magnetic Reconnection in the UTST Tokamak Merging Experiment . KOTARO YAMASAKI, SHIZUO INOUE, the University of Tokyo, SHUJI KAMIO, National Institute for Fusion Science, TAKENORI WATANABE, ANQI WANG, XUEHAN GUO, HIROKI ISHIKAWA, TOMOHIKO USHIKI, HIROKI NAKAMATA, TAKUMICHI SUGAWARA, KEITA MATSUYAMA, NAOTO KAWAKAMI, the University of Tokyo, TAKUMA YAMADA, Kyusyu University, MICHIAKI INOMOTO, the University of Tokyo, FRANK CHENG, National Cheng Kung University, YASUSHI ONO, the University of Tokyo — Langmuir probe measurements revealed a clear quadrapole structure of floating potential around the X-point in the UTST tokamak merging experiment. We developed a novel two-dimensional Thomson scattering measurement system by sliding radially the whole 1D system that can measure an axial profile of electron temperature and density in a single discharge. The high electron temperature area was found to have a round shape with radius of 2cm, in sharp contrast with high current density area. This scale length 2cm is close to the orbit amplitude of an ion meandering motion 1.5-2cm but 3 times longer than the ion gyroradius 0.6cm. The electron heating power is about 12MW/m\textsuperscript{2} which is an order of magnitude larger than heating power calculated from the Spitzer resistivity. The increment in electron thermal energy is about 2.2J, which is about 15% of the dissipated magnetic energy of 14 J measured by 2D magnetic probe array. This conversion ratio in the strong guide field magnetic reconnection is higher than that in the weak guide field (typically $B_t \sim 5B_p$) experiment in MAST and TS-3 devices, suggesting that the electrons are accelerated toroidally toroidally by reconnection electric field and thermalized around X-point.

PP8.00118 Impulsive magnetic reconnection induced by electromagnetic fluctuations during guide field magnetic reconnection experiment . AKIHIRO KUWAHATA, RYOMA YANAI, MICHIAKI INOMOTO, HIROSHI TANABE, YASUSHI ONO. The University of Tokyo — Impulsive reconnection was observed subsequently to the occurrence of large-amplitude monochromatic electromagnetic fluctuations, which were generated inside the diffusion region during magnetic reconnection in the presence of a guide field ($B_g / B_t > 1$, where $B_g$ and $B_t$ are the guide field and reconnection field, respectively), in TS-3 plasma merging experiment. The fluctuations satisfy the dispersion relations of kinetic Alfvén wave (KAW). We found a positive correlation between the amplitude of fluctuations and the enhancement of reconnection rate. Ion heating was also observed after the waves propagated to the downstream region, but the wave’s Poynting flux was not large enough to balance with the observed ion heating power. The integrated scenario in guide field reconnection for impulsive fast reconnection is: (1) energetic electrons are produced by parallel acceleration during initial slow reconnection phase, (2) the fast electrons drive instabilities to excite KAW-like fluctuations inside the diffusion region, and then (3) these waves modify the local current sheet structure to trigger the impulsive fast reconnection. Although the waves do not account for the energy gain itself, they play roles to rapidly release magnetic energy.

PP8.00119 Ion Heating Characteristics of Merging/Reconnection Startup in MAST Spherical Tokamak Experiment. HIROSHI TANABE, Univ. Tokyo, TAKUMA YAMADA, Kyushu Univ., TAKENORI WATANABE, KEII GI, AKIHIRO KUWAHATA, KAZUTAKE KADOWAKI, YASUHIRO KAMINOYU, HIDEYA KOIKE, KENTO NISHIDA, SUGURU IMANAKA, HARUKI YAMANAKA, Univ. Tokyo, SETTHIVOINE YOU, Univ. Washington, BRENDAN CROWLEY, General Atomics, NEIL CONWAY, RORY SCANNEL, CCFE, MIKHAIL GRYAZNEVICH, Tokamak Solutions, MICHIAKI INOMOTO, YASUSHI ONO, Univ. Tokyo — The high power reconnection heating has been investigated in MAST ST (spherical tokamak) merging startup experiment using a new 32-chords ion Doppler tomography diagnostics with optimized spatial resolution for the current sheet. The magnetic reconnection is observed to heat mostly ions in the downstream by the outflow and to heat electrons inside the current sheet. However, the high $T_e$ area is highly localized at the X-point probably due to the X-line acceleration of electrons. Finally both $T_i$ and $T_e$ profiles are observed to form triple-peak structures after the ion-electron energy relaxation time $\tau_{rec}$. The guide field does not affect ion heating under high guide field condition $B_t > 3B_{rec}$, while it increases significantly the localized electron heating at the X point. The increment of ion temperature reaches $\sim 200$eV in TS-3 and over $\sim 1$keV in MAST, as predicted in the $B_{rec}$ (reconnecting field energy) scaling of reconnection heating. This scaling is also observed in the $B_{rec}$ merging startup scenario for spherical tokamak.

PP8.00120 A new coronal mass ejection experiment by use of PF and CS coils in TS-4 ST/CT device. KAZUTAKE KADOWAKI, AKINORI SATO, MICHIAKI INOMOTO, YASUSHI ONO, University of Tokyo — A novel simulation experiment of coronal mass ejection (CME) has been performed using two PF coils, two fluxcores and a center solenoid coil in TS-4 merging device. The operation is described as follows. A fluxcore is used to form a spheromak that has a certain amount of linked flux with the center solenoid coil. Then, we turn on the out PF coil current parallel to that of spheromak to let the spheromak expand in radial direction like a rising plasmoid/filament. This motion causes the linked flux of spheromak to reconnect, transforming the linked flux into the private flux. The reconnection is observed to accelerate the plasmoid to $\sim 20$ km/s about 20% of the Alfvén velocity. The size of current sheet (L $\sim 10$cm, $\delta$ $\sim 4$cm) and time scale (30µs) of reconnection are almost equal to those of the conventional tokamak merging experiment. This operation similar to the CME model is useful to study the CME mechanism under varied linked flux, acceleration and boundary conditions. It is also noted that this experiment with free plasmoid ejection has no density/flux pileup unlike the conventional non-steady reconnection/merging.

PP8.00121 Three-Dimensional Turbulent Reconnection Induced by the Plasmoid Instability. YI-MIN HUANG, Princeton University, AMITAVA BHATTACHARJEE, Department of Astrophysical Sciences, Princeton University — It has been established that the Sweet-Parker current layer in high Lundquist number ($S$) reconnection is unstable to the super-Alfvénic plasmoid instability. Past two-dimensional (2D) magnetohydrodynamic simulations have demonstrated that the plasmoid instability leads to a new regime where the Sweet-Parker current layer changes into a chain of plasmoids connected by secondary current sheets, and the averaged reconnection rate becomes nearly independent of $S$. In a three-dimensional (3D) configuration with a guide field, the additional degree of freedom allows plasmoid instabilities to grow at oblique angles [Baalrud et al. Phys. Plasmas 19, 022101 (2012)] and develop complex dynamics of flux ropes, which may be viewed as a self-generated turbulent state. In our 3D simulations, kinematic and magnetic energy fluctuations are observed to form cigar-shaped eddies elongated along the direction of local magnetic field, which is a signature of anisotropic MHD turbulence. Additionally, the energy fluctuation spectra are found to satisfy power laws in the inertial range. The characteristics of this self-generated turbulent reconnection are compared with corresponding 2D simulations of the same configuration, as well as turbulent reconnection driven by an external forcing.

PP8.00122 Scaling of Hall Reconnection in the Coalescence Problem in Large Systems. JONATHAN NG, AMITAVA BHATTACHARJEE, YI-MIN HUANG, PPPL and Center for Heliospheric Physics — As collisionless reconnection modeling of most space plasmas with realistic parameters is beyond the capability of today’s simulations, due to the separation between global and kinetic length scales, it is important to establish scaling relations in model problems so as to extrapolate to realistic scales. Large scale particle-in-cell (PIC) simulations of island coalescence have shown that the time averaged reconnection rate scales like $\sqrt{d_i'/\lambda}$, where $\lambda$ is the system size, while the maximum rate remains constant [1]. This differs from an earlier claim that reconnection rate is independent of system size [2] and predictions of fluid simulations and theory [3,4] that the maximum rate scales like $d_i'/\lambda$. We perform Hall MHD simulations with the same geometry to study this discrepancy. We find that when the scale separation between the current sheet width and ion skin depth is large enough, the maximum reconnection rate is constant and the average rate decreases weakly as system size increases, in contrast to the PIC results. The differences between PIC and fluid results are discussed.


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PP8.00123 Superthermal electron energization in magnetic reconnection exhausts. JAN EGEDAL, UW-Madison, WILLIAM DAUGHTON, LANL — Using a kinetic simulation of magnetic reconnection it was recently shown that magnetic-field-aligned electric fields ($E_{||}$) can be present over large spatial scales in reconnection exhausts [1]. Here we document how the electron confinement provided in part by the structure in $E_{||}$ allows sustained energization by perpendicular electric fields ($E_{\perp}$). The energization is a consequence of the confined electrons’ bounce motion, that includes so-called curvature and gradient-B drifts aligned with the reconnection electric field. The level of energization is proportional to the initial particle energy and is therefore enhanced by the initial energy boost of the acceleration potential $\epsilon\Phi = e\int_{x_l}^{x_r} E_{\perp} dl$, acquired by electrons entering the region. The mechanism is effective in an extended region of the reconnection exhaust allowing for the generation of super-thermal electrons in reconnection scenarios including only a single x-line. An expression for the phase-space distribution of the super-thermal electrons is derived, providing an accurate match to the kinetic simulation results.


*Supported by DOE, NSF and NASA.*
PP8.00124 Demonstration of anisotropic fluid closure capturing the kinetic structure of magnetic reconnection\(^1\). OBIOMA OHIK, MIT, JAN EGEDAL, UW-Madison, VYACHESLAV LUKIN, NRL, WILLIAM DAUGHTON, LANL — Weakly-collisonal magnetic reconnection, a process linked to solar flares, coronal mass ejections, and magnetic substorms, has been widely studied through fluid and kinetic simulations. While two-fluid models often reproduce the fast reconnection rate of kinetic simulations, significant differences are observed in the structure of the reconnection regions\(^1\). Recently, new equations of state that accurately account for the development of anisotropic electron pressure due to the electric and magnetic trapping of electrons have been developed\(^1\). Using these equations of state, guide-field fluid simulations have been shown to reproduce the detailed reconnection region observed in kinetic simulations\(^3\). Implementing this two-fluid simulation using the HiFi framework\(^4\), we study the force balance of the electron layers in guide-field reconnection and derive scaling laws for the heating observed in these layers.

1 Supported by DOE, NSF and NASA

PP8.00125 In situ evidence of new magnetotail reconnection regime with embedded current layers and anisotropic exhaust electrons\(^1\). JOHN BOGUSKI, JAN EGEDAL, UW-Madison, WILLIAM DAUGHTON, LANL — Using kinetic simulations a new regime of magnetic reconnection has been discovered in parameter ranges similar to those found in the Earth’s magnetotail\(^1\). The regime is closely related to the dynamics of magnetized trapped electrons causing strong electron pressure anisotropy which reaches the firehose condition and has the ability to drive current layers in the reconnection exhaust\(^2\). As part of an endeavor to conclusively verify the existence of the new reconnection regime in Earth’s magnetotail, a systematic analysis of the 2002-08-28 reconnection event first identified by A.L. Borg\(^3\) is performed. In particular we assess the pressure anisotropy, the satisfaction of the firehose condition, and the agreement of pressure measurements to those predicted from theory. The analysis of this event and comparison to simulation results document the importance of the new regime to reconnection in the Earth magnetosphere.

1 Supported by DOE, NSF and NASA

PP8.00126 Asymmetric Reconnection in the Terrestrial Reconnection EXPERiment \(^1\), JOSEPH OLSON, JAN EGEDAL, CARY FOREST, JOHN WALLACE, University of Wisconsin-Madison, TREX TEAM, MPDX TEAM — The Terrestrial Reconnection EXPERiment (TREX) is a new and versatile addition to the Wisconsin Plasma Astrophysics Laboratory (WIPAL) at the University of Wisconsin-Madison. TREX is optimized for the study of kinetic reconnection in various regimes and to provide the first laboratory evidence in support of a new model describing the dynamics of trapped electrons and correlating pressure anisotropy. The initial configuration implemented in TREX is specially designed to study asymmetric reconnection scenarios. These are particularly relevant to the dayside magnetopause in which the plasma beta of the solar wind and of the magnetosphere can differ by factors of 100-1000. The configuration utilizes the Helmholtz coils to produce a static, uniform magnetic field up to 275 G through the 3 m spherical vacuum vessel. Plasma is produced on a 10 s rep rate while two internal coils are pulsed, creating an opposing magnetic field to induce reconnection with asymmetric high and low beta inflows. A Langmuir and Bdot probe array is swept in between pulses to build up the magnetic profiles in the reconnection region. Preliminary data from these initial runs will be presented.

PP8.00127 Quasi-separatrix layer diagnostics and electron force balance in line-tied systems\(^1\). ZACHARY BILLEY, ELLEN ZWEIBEL, University of Wisconsin-Madison, JOHN FINN, WILLIAM DAUGHTON, Los Alamos National Laboratory — Magnetic reconnection plays a key role in processes such as coronal mass ejections, solar/stellar dynamics, planetary magnetospheres and accretion disk flares. Magnetic reconnection may be influenced by the line-tied boundary conditions in these systems. For example, magnetic field lines that enter and exit a stellar surface are fixed to the surface at the timescales which coronal magnetic reconnection events take place. In some systems, temperatures may be high enough and densities low enough that collisionless effects play the dominant role. Motivated by this, we investigate collisionless magnetic reconnection in line tied geometry with a series of fully kinetic particle-in-cell simulations of varying lengths. To understand the reconnection physics, we employ field line integrated reconnection diagnostic\(^2\) to examine the formation of quasi-separatrix layer\(^2\) and their association with the integrated parallel electric field. In addition, we examine the electron force balance along field lines to identify the nature of non-ideal behavior in the reconnection region and its connection to magnetic topology.

1 Finn et al., Plasma Physics and Controlled Fusion 56, 064013, 2014

PP8.00128 A fluid theory of fast low-beta magnetic reconnection\(^1\), ADAM STANIAR, ANDREI SIMAKOV, LUIS CHACON, WILLIAM DAUGHTON, Los Alamos Natl Lab — Low-beta reconnection, where the magnetic field is dominated by a strong out-of-plane component, is important in laboratory magnetic confinement devices, the solar corona, and other magnetically dominated astrophysical environments. Despite the importance of these applications, reconnection in this regime remains poorly understood. It has been suggested that fast dispersive waves are responsible for the fast timescales of reconnection in both the high-beta and low-beta regimes. However, recent kinetic simulations have demonstrated that reconnection rates remain fast, even without such waves. Here we show from fluid simulations that rates are fast in cases with and without fast dispersive waves. We present a fluid theory of the dissipation region, which predicts the functional form of the dissipation region thickness, length, upstream magnetic field, and reconnection rate in both cases. These results are benchmarked against fluid simulations with strict control of dissipation, and comparisons are made with kinetic simulations.

PP8.00129 Influence of Line-Tied Boundary Conditions on the Development of Magnetic Reconnection in Force-Free Current Layers\(^1\). CİHAN AKÇAY, WILLIAM DAUGHTON, ADAM STANIAR, Los Alamos National Laboratory, VYACHESLAV LUKIN, Naval Research Laboratory — The evolution of plasmas in magnetically dominated low-\(\beta\) regimes often leads to the formation of nearly force-free current sheets where magnetic reconnection may be triggered by the tearing instability. In this study, we examine the influence of line-tied boundary conditions on the onset and development of three-dimensional magnetic reconnection in force-free layers. To better understand the physics, we perform cross-comparisons between fully kinetic VPIC simulations and two-fluid HiFi simulations. We focus on a range of guide fields \(B_g = (1 - 10)B_0\) relevant to both space and laboratory plasmas, and compare the evolution between systems with line-tied and periodic boundary conditions.
PP8.00130 Developments of Electromagnetic Particle Simulation Code for Magnetic Reconnection Researches in Open System PASMO and Visualization Library VISMO. H. OHTANI, R. HORIUCHI, M. NUNAMI, S. USAMI, NIFS, N. OHNO, U.Hyogo — As the capabilities of computers are improved, the sizes of simulations become greater and greater. In this situation, we have some big issues. One of them is how to develop an efficient simulation code, and another is how to visualize the large data by the simulation. In order to investigate magnetic reconnection from the microscopic viewpoint, we develop a three-dimensional electromagnetic PIC code in an open system (PASMO) [1]. For performing the code on a distributed memory and multi-processor computer system with a distributed parallel algorithm, we decompose three-dimensionally the simulation domain, and introduce the charge conservation scheme to exclude the global calculation, such as Poisson solver with FFT. In the visualization of the simulation data, we develop an in-situ visualization library VISMO [2] for the PIC simulation to carry out the visualization in tandem with the simulation on the same computers. The simulation code with VISMO generates image files instead of raw data. We will discuss the performance of the new PASMO and the simulation results visualized by VISMO on the magnetic reconnection.

1Supported by a Grant-in-Aid for Scientific Research from JSPS (Grant No.23340182) and General Coordinated Research at NIFS (NIFS14KNSS046, NIFS13KNXN260 and NIFS13KNTS024).

PP8.00131 Magnetic islands and energy conversion process in collisionless driven reconnection, RITOKU HORIUCHI, SHUNSUKE USAMI, HIROAKI OHTANI, National Institute for Fusion Science — Relationship between magnetic islands and energy conversion process in collisionless driven reconnection is investigated by means of electromagnetic particle simulation in an open system. By controlling an external driving field imposed at the upstream boundary, we realized two different kinds of solutions in the time evolution of a reconnection system starting from the same initial condition, i.e., the first is a solution with no magnetic islands in the current sheet, and the second is a solution with many islands in it. The energy conversion rate in the second solution is found to be much higher than that in the first solution. This suggests that magnetic islands play a key role in the energy conversion process of collisionless reconnection. The energy conversion rate from the EM field to plasmas decreases as a guide field is intensified. However, its rate to ions is always twice that of to electrons, regardless of whether a guide magnetic field and/or magnetic islands exist. It is also found that the energy conversion from the EM field to ions is dominantly caused by the in-plane electric field, while the conversion to electrons is by the out-of-plane electric field.

PP8.00132 “Complex Reconnecting” Modes and Critical Direction of their Propagation*, P. BURATTI, ENEA, B. COPPI, MIT, G. PUCELLA, ENEA — Experiments in weakly collisional plasma regimes (e.g. neutral beam heated plasmas in the H-regime [1]), measuring the Doppler shift associated with the plasma local rotation [1], have shown that the direction of the propagation of the observed reconnected structures in the frame with \( E_r = 0 \) is in the direction of the ion diamagnetic velocity. This is contrary to the direction of the phase velocity of the “drift-tearing” modes found originally in the Ref. [2]. Consequently, the theory of “Complex Reconnecting” Modes has been developed that include the effects finite ion gyro radius, finite ion transverse viscosity, finite longitudinal electron pressure and magnetic diffusion coefficient. Thus modes are found with very low values of the growth rate, a phase velocity about equal the ion diamagnetic velocity that is consistent with recent experimental observations, and widths of the reconnection layer larger than the ion gyro radius. Another option involves assuming the presence of a plasma inductivity [3] in the electron momentum conservation equation. *Sponsored in part by the US Department of Energy.


PP8.00133 Electron Temperature Fluctuations Associated with High Temperature Reconnecting Modes*, B. BASU, B. COPPI, P. MONTAG — Experimental observations [1] and theoretical considerations [2] indicate that, in high temperature plasmas, the value of the perpendicular electron thermal conductivity is relatively large and its effects can compete with those of the parallel thermal conductivity in the theory of reconnecting modes. These effects are taken into account in the relevant expression for the electron thermal energy balance equation. Then the equations for high temperature reconnecting modes are derived and solved showing how limited the applicability of the linearized theory of drift tearing modes [3] is to explain current experimental observations. Electrostatic modes that can be excited in the presence of resistivity gradients [4] are also investigated. When the electron drift wave frequency becomes important, no radially localized unstable mode of this kind can be found with or without the combined effects of trapped electrons and weak collisionality. *Sponsored in part by U.S. DOE.


PP8.00134 Plasma Relaxation Dynamics Moderated by Current Sheets, ROBERT DEWAR1, Australian National University, AMITAVA BHATTACHARJEE, Princeton Plasma Physics Laboratory, ZENSHO YOSHIDA, University of Tokyo — Ideal magnetohydrodynamics (IMHD) is strongly constrained by an infinite number of microscopic constraints expressing mass, entropy and magnetic flux conservation in each infinitesimal fluid element, the latter preventing magnetic reconnection. By contrast, in the Taylor-relaxed equilibrium model all these constraints are relaxed save for global magnetic flux and helicity. A Lagrangian is presented that leads to a new variational formulation of magnetized fluid dynamics, relaxed MHD (RxMHD), all static solutions of which are Taylor equilibrium states. By postulating that some long-lived macroscopic current sheets can act as barriers to relaxation [1], separating the plasma into multiple relaxation regions, a further generalization, multi-relaxed MHD (MRxMHD), is developed. These concepts are illustrated using a simple two-region slab model similar to that proposed by Hahm and Kulsrud—the formation of an initial shielding current sheet after perturbation by boundary rippling is calculated using MRxMHD and the final island state, after the current sheet has relaxed through a reconnection sequence [2], is calculated using RxMHD.

1Supported by Australian Research Council grant DP110102881.

[1] Z Yoshida & RL Dewar, J Phys A 45 365502 (2012);
PP8.00135 Kinetic Alfvén waves in three-dimensional magnetic reconnection , JI LIANG, School of Physics and Optoelectronic Technology, Dalian University of Technology, Dalian 116024, China, YU LIN, XUEYI WANG, Department of Physics, Auburn University, Auburn, AL, USA — Ion kinetic structure of magnetic reconnection in a current sheet is investigated with a 3-D hybrid code for cases with various X-line lengths and guide fields. It is found that kinetic Alfvén waves (KAWs) are generated in the reconnection. In the cases in which the X-line is so long to extend through the entire domain, quasi 2-D configurations are present. For a current sheet with a zero guide field, the KAWs are found near the separatrices, whereas in the cases with a finite guide field, the KAWs are not found near the separatrices. The KAWs are generated from the X-line. The X-line has a finite length $L_x$ with $\xi \sim 10 L_x$ and $d_i$ being the ion inertial length, the wave perturbations are of a highly 3-D nature. Waves with a dominant $k_{G1} \sim 1$ are found propagating outward along magnetic field lines from the reconnection region with a slightly super-Alfvénic velocity. The structure, polarization relations, and damping of KAWs are examined. The dependence of wave propagation on $B_G/B_{G0}$ is also investigated, where $B_{G0}$ is the antiparallel magnetic field component. The critical length of X-line for the generation of 3-D like structures is found to be $\zeta \lesssim 30 d_i$.

PP8.00136 Magnetic island evolution in sheared flows for stellarator fields, JULIO MARTINELL, Instituto de Ciencias Nucleares, UNAM, DANIEL LOPEZ-BRUNA, Laboratorio Nacional de Fusion, CIEMAT — It has been evidenced that the magnetic islands associated to low-order rational magnetic surfaces in stellarators play an important role in the dynamics and transport properties. In particular, in the TJ-II heliac there is clear evidence of the appearance of transport barriers near the position of rational surfaces that may lead to an L-H transition or to an oscillatory behavior. Low-frequency magnetic activity has also been detected, that indicates variations in the properties of the magnetic islands. In order to explain the observations, we study the evolution of magnetic islands in the 3D geometry of stellarators starting from the vacuum islands due to error fields. The nonlinear equation for the island width is considered with the inclusion of the polarization current which depends on the EXB velocity profiles around the island; this has a destabilizing contribution. Additionally, the electromagnetic torque acting on the islands produced by the currents in the rational surface are computed, which turns out to be proportional to the island width. The results indicate that shear flow produces island growth and when a given width is exceeded the torque gives rise to island rotation in the frame where $E=0$. This leads to reduction of the flow shear and transport barrier vanishing.

PP8.00137 On the energy conversion and particle acceleration during magnetic reconnection , XIAOCAN LI, Univ of Alabama - Huntsville, FAN GUO, HUI LI, BILL DAUGHTON, YI-HSIN LIU, Los Alamos National Lab, GANG LI, Univ of Alabama - Huntsville — Using two-dimensional particle-in-cell (PIC) kinetic simulations and magnetohydrodynamic (MHD) simulations, we study energy conversion and particle energization during magnetic reconnection. In the PIC simulations that solve collisionless Vlasov-Maxwell equations, pressure anisotropy develops naturally, and it gets stronger with a stronger guide field. The particle acceleration and energy conversion through particle curvature drift, gradient drift, magnetization current, and parallel electric field are compared. We find that their contributions change with guide field. The results are explained in a drift kinetic approximation, where electric current is associated with pressure anisotropy. This explanation is further verified using high-Lundquist-number MHD simulations of magnetic reconnection, where plasma pressure is assumed to be isotropic. This work demonstrates the importance of considering anisotropic velocity distribution in particle acceleration during magnetic reconnection.

PP8.00138 Nonlinear Diamagnetic Stabilization of Double Tearing Modes in Cylindrical MHD Simulations , STEPHEN ABBOTT, KAI GERMASCHEWSKI, Univ of New Hampshire — Double tearing modes (DTMs) may occur in reversed-shear tokamak configurations if two nearby rational surfaces couple and begin reconnecting. During the DTM's nonlinear evolution it can enter an "explosive" growth phase leading to complete reconnection, making it a possible driver for off-axis sawtooth crashes. Motivated by similarities between this behavior and that of the $m = 1$ kink-tearing mode in conventional tokamaks we investigate diamagnetic drifts as a possible DTM stabilization mechanism. We extend our previous linear studies of an $m = 2$, $n = 1$ DTM in cylindrical geometry to the fully nonlinear regime using the MHD code MRC-3D. A pressure gradient similar to observed ITB profiles is used, together with Hall physics, to introduce $\omega_e$ effects. We find the diamagnetic drifts can have a stabilizing effect on the nonlinear DTM through a combination of large scale differential rotation and mechanisms local to the reconnection layer. MRC-3D is an extended MHD code based on the libMRC computational framework. It supports nonuniform grids in curvilinear coordinates with parallel implicit and explicit time integration.

PP8.00139 Crossed Flux Tube Experiment (CroFT), MAGNUS HAW, PAUL BELLAN, Caltech — Magnetic flux tubes are a fundamental feature of solar coronal loops and astrophysical jets, as well as fusion devices, such as tokamaks and spheromaks. These flux tubes are subject to magnetohydrodynamic forces, expanding, undergoing kink instabilities, and magnetically reconnecting. The CroFT experiment arranges for two flux tubes to cross over each other in a variety of geometries (rotating candelabra) with separate control/power supplies for each flux tube. The experiment aims to study the dynamics and interaction of thesearched, plasma-filled flux tubes, specifically the magnetic reconnection that occurs at the crossover point and how this is affected by loop geometry. Initial observations indicate these flux tubes magnetically reconnect with each other as predicted: two equally sized loops reconnect to form a single loop, whereas large elongated loops reconnect in a way that is dependent on the parallel electric fields of both tubes are parallel. If the flux tubes are formed adjacent, rather than crossing over each other, they do not merge. It has also been observed that flux tubes of different species generate protrusions/jets not seen in single-species pairs. Additional non-optical diagnostics (voltage, current) are still being built.

PP8.00140 Circularly polarized Magnetic Field of Whistler Wave during Fast Magnetic Reconnection , XUANG ZHAI, PAKORN WONGWAITAYAKORNKUL, PAUL BELLAN, Caltech, BELLAN GROUP TEAM — Obliquely propagating whistler waves are expected to have circularly polarized magnetic components [1] and to be associated with fast magnetic reconnection. In the Caltech plasma jet experiment, a current-carrying collimated jet is created from the merging of eight plasma-filled flux ropes. Fast magnetic reconnection occurs during the merging process. When the current-carrying jet undergoes fast kink instability, a lateral Rayleigh-Taylor instability occurs on the jet surface and induces another fast magnetic reconnection event [2]. A capacitive coupling probe placed near the jet has measured fast electric field fluctuations at 15MHz which is in the whistler regime for this plasma. A 3D fast Bdot probe with good electrostatic rejection has been specifically designed to measure the 3D magnetic components of the whistler wave. Preliminary results have revealed a 3D 15 MHz magnetic fluctuation. Work is underway to increase the sensitivity of the induction probe and also to reduce electrostatic pickup. With the improved probe, the polarization property of the magnetic component of the whistler wave is expected to be resolved if it exists.


1Support provided by DOE, NSF
interstellar neutral atoms are ionized by the solar wind or UV. Their initial speed in the plasma frame is equal to the solar wind speed. Specific application examples will be drawn from laboratory controlled fusion experiments, the general approach is applicable to space and astrophysical plasmas.

is a non-perturbative treatment of the tail ions where the ion Knudsen number approaches or surpasses order unity. This can be sharply contrasted with the flow, and temperature. Here we describe a hybrid model for coupling such constrained kinetic calculation to global plasma fluid models. The key ingredient as the fusion reactivity in controlled fusion, the ion heat flux, and in the case of a tokamak, the ion bootstrap current. Evaluating the deviation from a local mean-free-path plasma of superthermal power-law spectra observed during quiet solar wind conditions. of superthermal ions traversing multiple contracting and reconnecting inertial-scale quasi-2D flux ropes in the supersonic slow solar wind. A steady-state solution merging, and of heating of ions and electrons in the vicinity. We will present a new statistical transport theory designed to model the acceleration and transport of inertial-scale flux ropes that intermittently reconnect. Solar wind observations indicate that the statistical properties of the turbulence agree well with the MHD turbulence simulations, while particle simulations stress how ions can be efficiently accelerated to produce power law spectra when traversing multiple flux ropes.

PP.00141 3-D Gyrokinetic Electron and Fully Kinetic Ion Simulation of Current Sheet Instabilities. ZHENYU WANG, YU LIN, XUEYI WANG, Auburn University, KURT TUMMEL, University of California at Irvine, LIU CHEN, Zhejiang University — Instability of a Harris current sheet is investigated using a 3-D linearized (f,k) electromagnetic gyrokinetic electron and fully kinetic ion (GeFi) particle simulation code. The equilibrium magnetic field consists of an asymptotic anti-parallel component \( B_{za} \) and a guide field \( B_G \), with the current sheet normal in the z direction. The simulation is performed for cases with a broad range of \( B_G \). The eigenmode structure, real frequency, and the growth rate of instabilities are calculated as a function of wave numbers \( k_x \) and \( k_y \). In the cases with a small \( k_y B_G \), tearing mode is found to dominate, with peak growth rate at \( k_x L = 0.5-0.5 \), where \( L \) is the half-width of the current sheet. On the other hand, in the cases with a small \( k_y B_G \leq 0.1 \), there exist two unstable modes: a quasi-electrostatic mode at the current sheet edge with wave number \( 0.3 \leq k_y B_G < 0.6 \) and frequency around the lower-hybrid frequency \( \omega_{LH} \) and an electromagnetic mode with \( k_y B_G \leq 0.2 \) at the sheet center under a guide field \( B_G/B_{za} = 0.1 \). The transition from the tearing-like instability to the \( k_y \)-dominant instabilities is presented by scanning through the \((k_x, k_y)\) space. The complete 3-D profile of instabilities

PP.00142 3D Gyrokinetic Theory of Electromagnetic Lower-Hybrid Drift Instabilities in a Harris Current Sheet with Guide Field\(^1\), KURT TUMMEL, University of California, Irvine, LIU CHEN, University of California, Irvine and Zhejiang University, CHINA; ZHENYU WANG, Auburn University — Electromagnetic fluctuations in the lower-hybrid drift(LHD) frequency range have been observed in current sheets in the magnetosphere, magnetopause, and laboratory plasmas. In theory and simulations, the lower hybrid drift instabilities typically dominate the linear phase of current sheet dynamics, appearing as quasi-electrostatic, edge-localized, electron-scale waves that propagate nearly perpendicular to the magnetic field. In current sheets with strong drift velocities, fluctuations in the LHD frequency range are observed near the current sheet center, with longer wavelengths and stronger magnetic fluctuations than conventional LHDs. Analyses of these modes have used fluid theory or the local approximation to handle the electron response. We have adopted a gyrokinetic-electron, unmagnetized kinetic-ion model to study the electromagnetic effects in a 3D nonlocal analysis of an ion-scale Harris current sheet with a guide field. Both numerical and analytical results will be presented and compared with those of direct simulations.

\(^{1}\)Supported by US NSF, US DOE and NSFC Grants.

Wednesday, October 29, 2014 2:00PM - 4:45PM – Session PM9 Mini-Conference: Nonthermal Ions in Space and Laboratory Plasmas Salon ABC - Nikolai Pogorelov, University of Alabama in Huntsville

2:00PM PM9.00001 A tutorial on neutral beam injection into tokamaks\(^1\), W.W. HEIDBRINK, UC Irvine — Neutral beam injection heats most magnetic fusion experiments. A typical source injects 2 MW of 80 keV deuterons. Deposition is governed by electron impact ionization and charge exchange with thermal ions. A “halo” cloud of thermal neutrals surrounds the “footprint” of injected neutrals. After ionizing, the energetic ions are confined by the magnetic field, eventually forming an axisymmetric fast-ion population. Fast ions that orbit through the beam footprint sometimes reneutralize. Escaping neutrals and light emitted by reneutralized fast ions is used to diagnose the fast-ion population. The initial beam deposition and halo cloud are also measured optically.

\(^{1}\)Work supported by the US Department of Energy

2:15PM PM9.00002 Superthermal Ion Transport and Acceleration in Multiple Contracting and Reconnecting Inertial-scale Flux Ropes in the Solar Wind. JAKOBUS LE ROUX, GARY ZANK, GARY WEBB, University of Alabama in Huntsville — MHD turbulence simulations with a strong large-scale magnetic field show that the turbulence is filled with quasi-2D inertial-scale flux ropes that intermittently reconnect. Solar wind observations indicate that the statistical properties of the turbulence agree well with the MHD turbulence simulations, while particle simulations stress how ions can be efficiently accelerated to produce power law spectra when traversing multiple flux ropes. Recent observations show the presence of different size inertial-scale magnetic islands in the slow solar wind near the heliospheric current sheet, evidence of island merging, and of heating of ions and electrons in the vicinity. We will present a new statistical transport theory designed to model the acceleration and transport of superthermal ions traversing multiple reconnecting and reconnecting inertial-scale quasi-2D flux ropes in the supersonic slow solar wind. A steady-state solution for the accelerated particle spectrum in a radially expanding solar wind will be discussed, showing that the theory potentially can explain naturally the existence of superthermal power-law spectra observed during quiet solar wind conditions.

2:30PM PM9.00003 A hybrid model for computing nonthermal ion distributions in a long mean-free-path plasma\(^1\), XIANZHU TANG, CHRIS MCDEVITT, ZEHUA GUO, Los Alamos National Laboratory, HERB BERK, University of Texas at Austin — Non-thermal ions, especially the suprathermal ones, are known to make a dominant contribution to a number of important physics such as the fusion reactivity in controlled fusion, the ion heat flux, and in the case of a tokamak, the ion bootstrap current. Evaluating the deviation from a local Maxwellian distribution of these non-thermal ions can be a challenging task in the context of a global plasma fluid model that evolves the plasma density, flow, and temperature. Here we describe a hybrid model for coupling such constrained kinetic calculation to global plasma fluid models. The key ingredient is a non-perturbative treatment of the tail ions where the ion Knudsen number approaches or surpasses order unity. This can be sharply constrained with the standard Chapman-Enskog approach which relies on a perturbative treatment that is frequently invalidated. The accuracy of our coupling scheme is controlled by the precision of the non-perturbative kinetic model to perturbative solutions in both configuration space and velocity space. Although our specific application examples will be drawn from laboratory controlled fusion experiments, the general approach is applicable to space and astrophysical plasmas as well.

\(^{1}\)Work supported by DOE

2:45PM PM9.00004 Acceleration of pickup ions by intermittent compressive plasma waves in interplanetary space\(^1\), MING ZHANG, Florida Institute of Technology — Pickup ions are created in interplanetary space when penetrated by interstellar neutral atoms are ionized by the solar wind or UV. Their initial speed in the plasma frame is equal to the solar wind speed \( V_{sw} \) and they are the dominant supra-thermal population. Their distribution function is basically flat below \( V_{sw} \), and is often accompanied by a power-law high-energy tail that sometimes can extend much above \( V_{sw} \). More interestingly, power-law slope index is often very close to -5. Fisk and Gloeckler (2008, ApJ, v686, p1466) suggested this spectrum is produced by stochastic acceleration in compressive plasma turbulence or waves. We have studied the behaviors of particle acceleration by compressive wave trains. It is found that the waves can efficiently accelerate pickup ions with an exponential increase of pressure. This pressure may moderate the wave amplitude, so that the system eventually establishes equilibrium. At the point, a \( p^{-5} \) distribution is automatically fulfilled by balancing the effect of acceleration with any particle loss mechanisms. This situation is more easily achieved with intensive intermittent compressive waves that only occupy a limited volume of space. We hope these phenomena will be verified in laboratory plasma experiments.

\(^{1}\)Supported by DOE Grant DE-SC0008721
Air Force Research Laboratory

3:00PM PM9.00005 The coupling between pick-up ions and energetic neutral atoms in the heliosphere. JACOB HEERIKHIUSEN, ERIC ZIRNSTEIN, GARY ZANK, NIKOLAI POGORELOV, University of Alabama in Huntsville — The expansion of the solar wind into the interstellar medium creates the heliosphere. While the ionized components of the solar wind and interstellar medium don’t mix, neutrals from interstellar space enter the heliosphere where they may experience charge-exchange collisions with ions. The charge-exchange process creates a new non-thermal ion known as a pick-up ion. Such ions tend to experience different dynamic processes at the solar wind termination shock, or indeed any other shocks, and hence give rise to a broad non-thermal population of ions in the heliosheath. Charge-exchange of non-thermal ions gives rise to a population of energetic neutrals which, in turn form a seed population for pick-up ions in the interstellar medium near the heliosphere. In this talk we discuss the coupling of various pick-up ion and energetic neutral populations throughout the heliospheric interface and present our latest simulation results.

3:15PM PM9.00006 Observations of Interstellar Pickup Ions and their Suprathermal Tails in Interplanetary Space and in the Heliosheath. GEORGE GLOECKLER, LEN FISK, University of Michigan — Since the invention of space-borne time-of-flight mass spectrometers in the late 1990s, distribution functions of singly charged interstellar pickup ions, produced primarily by charge exchange with the solar wind and by photoionization of the interstellar neutral gas, have been observed from 1 to ∼ 5 AU in interplanetary space. Here we summarize observed characteristics of pickup ion spectra (primarily of He and He) as well as of the pickup ion tails that are readily produced in Local Acceleration Regions in space, both at 1 AU and in the heliosheath, and briefly discuss the most likely mechanisms for producing interstellar pickup ions as well as their tails that in the heliosheath extend to high (∼ 10 MeV/nuc) energies.

3:40PM PM9.00007 Kappa distributions: Founding statistical mechanics in space plasmas. GEORGE LIVADIOTIS, Southwest Res Inst — Space plasmas are collisionless systems out of thermal equilibrium described by a single type or a more complex combination of kappa distributions. These distributions have recently received impetus, as they provide efficient modeling for observed distributions in numerous space plasmas throughout the heliosphere. Moreover, theoretical developments showed the connection of kappa distributions with non-extensive statistical mechanics, an unambiguous generalization of the classical Boltzmann-Gibbs statistics, revealing the robust physical meaning of temperature, pressure, and other thermodynamic parameters. The kappa distributions and the proven tools of non-extensive statistical mechanics have been successfully applied to a variety of space plasmas throughout the heliosphere, from the inner heliosphere, e.g., the solar wind and planetary magnetospheres, to the outer heliosphere, e.g., the inner heliosheath and beyond. These analyses led to the determination of the thermodynamic variables and the understanding of the underpinning physical processes of these plasmas, as well as to more fundamental findings, such as the new quantization constant that characterizes collisionless space plasmas.

3:55PM PM9.00008 Non-thermal plasmas in fusion tokamak edge. C.S. CHANG, Princeton Plasma Physics Laboratory — Nonthermal plasma is an important part of the tokamak edge physics, if not dominant, and makes the fluid or thermal equilibrium physics to be limited. The non-thermal plasma in the edge region is generated by plasma loss along open magnetic field lines, wall-recycled neutral particles, sputtered impurity particles, orbit loss cone in the velocity space and strong plasma turbulence. They affect the edge plasma confinement through modification of electric field, parallel heat loss, plasma flow, and turbulence transport. Various generation mechanisms of the non-thermal plasmas, their dynamics, and their effect on the plasma transport will be discussed in detail using simulation results from the plasma kinetic code XGC in realistic diverted edge geometry.

4:15PM PM9.00009 Modeling Non-thermal Ions in the Heliosphere1. NIKOLAI POGORELOV, MATTHEW BEDFORD, Department of Space Science and CSPAR, University of Alabama in Huntsville, IGOR KRYUKOV2, CSPAR, University of Alabama in Huntsville, GARY ZANK, Department of Space Science and CSPAR, University of Alabama in Huntsville — Interactions of flows of partially ionized, magnetized plasma are frequently accompanied by the presence of both thermal and non-thermal components in the ion distribution function. If a non-thermal component of ions is formed due to charge exchange and collisions between the thermal ions and neutrals, it experiences the action of magnetic field, its distribution function is isotropized, and it soon acquires the bulk velocity of the ambient plasma without being thermodynamically equilibrated. This situation, e.g., takes place in the outer heliosphere — a part of the solar plasma region beyond the solar system whose properties are determined by the solar wind (SW) interaction with the local interstellar medium (LISM). We describe a new physical model of the SW flow suitable for description of the SW–LISM interaction involving thermal and nonthermal ion components. This approach is incorporated into a suite of computer codes developed at the University of Alabama in Huntsville (MS-FLUKSS, Multi-Scale FLUid-Kinetic Simulation Suite). We compare results of our modeling with direct measurements made by the fleet of NASA’s near-Earth spacecraft and Voyagers providing data from the SW region beyond the heliospheric termination shock and the helopause.

1Supported, in part, by DOE grant DE-SC0008721
2Also at the Institute for Problems in Mechanics, NAS

4:30PM PM9.00010 Knudsen and inverse Knudsen layer effect on tail ion distribution and fusion reactivity in inertial confinement fusion targets. C.J. MCDEVITT, X-Z TANG, Z. GUO, Los Alamos National Laboratory, H.L. BERK, University of Texas, Austin — A series of reduced models are used to study the fast ion tail in the vicinity of a transition layer between plasmas at disparate temperatures and densities, which is typical of the gas-pusher interface in inertial confinement fusion targets. Emphasis is placed on utilizing progressively more comprehensive models in order to identify the essential physics for computing the fast ion tail at energies comparable to the Gamow peak. The resulting fast ion tail distribution is subsequently used to compute the fusion reactivity as a function of collisionality and temperature. It is found that while the fast ion distribution can be significantly depleted in the hot spot, leading to a reduction of the fusion reactivity in this region, a surplus of fast ions is present in the neighboring cold region. The presence of this fast ion surplus in the neighboring cold region is shown to lead to a partial recovery of the fusion yield lost in the hot spot.

Wednesday, October 29, 2014 2:00PM - 2:48PM –
Session PM10 Mini-Conference: Nonlinear Effects in Geospace Plasmas II Salon FGH - Evgeny Mishin, Air Force Research Laboratory
2:00PM PM10.00001 Demonstration of anisotropic fluid closure capturing the kinetic structure of magnetic reconnection1, OBIOMA EGEDAL, MIT, JAN EGEDAL, UW-Madison, VYACHESLAV LUKIN, NRL, WILLIAM DAUGHTON, LANL — Weakly-collisional magnetic reconnection, a process linked to solar flares, coronal mass ejections, and magnetic substorms, has been widely studied through fluid and kinetic simulations. While two-fluid models often reproduce the fast reconnection rate of kinetic simulations, significant differences are observed in the structure of the reconnection regions [1]. Recently, new equations of state that accurately account for the development of anisotropic electron pressure due to the electric and magnetic trapping of electrons have been developed [2]. Using these equations of state, guide-field fluid simulations have been shown to reproduce the detailed reconnection region observed in kinetic simulations [3]. Implementing this two-fluid simulation using the HiFi framework [4], we study the force balance of the electron layers in guide-field reconnection and derive scaling laws for the heating observed in these layers.


1Supported by DOE, NSF and NASA

2:12PM PM10.00002 In situ evidence of new magnetotail reconnection regime with embedded current layers and anisotropic exhaust electrons1, JOHN BOGUSKI, JAN EGEDAL, UW-Madison, WILLIAM DAUGHTON, LANL — Using kinetic simulations a new regime of magnetic reconnection has been discovered in parameter ranges similar to those found in the Earth’s magnetotail [1]. The regime is closely related to the dynamics of magnetized trapped electrons causing strong electron pressure anisotropy which reaches the firehose condition and has the ability to drive current layers in the reconnection exhaust [2]. As part of an endeavor to conclusively verify the existence of the new reconnection regime in Earth’s magnetotail, a systematic analysis of the 2002-08-28 reconnection event first identified by A.L. Borg [3] is performed. In particular we assess the pressure anisotropy, the satisfaction of the firehose condition, and the agreement of pressure measurements to those predicted from theory. The analysis of this event and comparison to simulation results document the importance of the new regime to reconnection in the Earth magnetospher.


1Supported by DOE, NSF and NASA

2:24PM PM10.00003 Unifying the Parker and the Turbulence Models of Solar Coronal Heating1, C.S. NG, T.J. DENNIS, University of Alaska Fairbanks — We present results from a series of three-dimensional simulations investigating heating in coronal loops of various lengths, based on the equations of reduced magnetohydrodynamics, following up on our recent simulations of the Parker model of coronal heating [Ng et al., Astrophys. J. 747 109, 2012]. We study the time-averaged energy dissipation rate ($\langle W \rangle$) as a function of the length of the loop $L$. We confirm that in the limit of small $L$ ($L \ll V_A \tau_c$, where $V_A$ is the Alfvén speed based on the parallel magnetic field and $\tau_c$ is the correlation time of the random photospheric motions), $\langle W \rangle$ agrees well with the scaling derived from the Parker model. In the other limit of $L \gg V_A \tau_c$, we show that $\langle W \rangle$ is given by the photospheric Poynting flux required to launch Alfvén waves. In the intermediate range of $L \sim V_A \tau_c$, $\langle W \rangle$ is well described by a scaling based on the Kolmogorov turbulence energy cascade, rather than the Iroshnikov-Kraichnan cascade. We also show that $\langle W \rangle$ can be modeled by combining the Parker heating and the Alfvén wave launching power for all range of $L$.

1This work is supported by a National Science Foundation grant AGS-0962477.

2:36PM PM10.00004 Nonlinear Plasma Experiments in Geospace with Gigawatts of RF Power at HAARP , J.P. SHEERIN, N. RAYYAN, Eastern Michigan Univ., B.J. WATKINS, W.A. BRISTOW, U. Alaska-Fairbanks, P.A. BERNHARDT, NRL — The HAARP phased-array HF transmitter at Gakona, AK delivers up to 3.6 GW (ERP) of HF power in the range of 2.8 – 10 MHz to the ionosphere with millisecond pointing, power modulation, and frequency agility. HAARP’s unique features have enabled the conduct of a number of nonlinear plasma experiments in the interaction region of overdense ionospheric plasma including stimulated electromagnetic emissions (SEE), artificial aurora, artificial ionization layers, VLF wave-particle interactions in the magnetosphere, strong Langmuir turbulence (SLT) and suprathermal electron acceleration. Diagnostics include the Modular UHF Ionospheric Radar (MUIR) sited at HAARP, the SuperDARN-Kodiak HF radar, spacecraft radio beacons, HF receivers to record stimulated electromagnetic emissions (SEE) and telescopes and cameras for optical emissions. We report on short timescale ponderomotive overshoot effects, artificial field-aligned irregularities (AFAl), the aspect angle dependence of the intensity of the plasma line, and suprathermal electrons. Applications are made to the study and control of irregularities affecting spacecraft communication and navigation systems.

Wednesday, October 29, 2014 5:15PM - 6:15PM – Session RE1 DPP Business Meeting  
Galerie 2 - Mark Koepke, West Virginia University

5:15PM RE1.00001 DPP Business Meeting

Wednesday, October 29, 2014 6:30PM - 10:00PM – Session RE2 DPP Reception and Banquet  
Carondolet - Mark Koepke, West Virginia University

6:30PM RE2.00001 DPP Reception —.

7:30PM RE2.00002 DPP Banquet and Talk , ERIC DONOVAN, University of Calgary, Canada —.

Wednesday, October 29, 2014 3:00PM - 5:00PM – Session QI2 Particle Beams and Waves  
Bissonet - Chuang Ren, University of Rochester
3:00PM Q12.00001 Analytical methods for describing charged particle dynamics in general focusing lattices using generalized Courant-Snyder theory. HONG QIN, Princeton University and University of Science and Technology of China — The dynamics of charged particles in general linear focusing lattices is analyzed using a generalized Courant-Snyder (CS) theory, which extends the original CS theory for one degree of freedom to higher dimensions. The general focusing lattices are allowed to include quadrupole, skew-quadrupole, solenoidal, and dipole components, as well as variation of beam energy and torsion of the fiducial orbit. The scalar envelope function is generalized into an envelope matrix, and the scalar envelope equation, also known as the Ermakov-Milne-Pinney equation in quantum mechanics, is generalized to an envelope matrix equation. The phase advance is generalized into a 4D symplectic rotation, or an U(2) element. Other components of the original CS theory, such as the CS invariant, transfer matrix, and Twiss functions all have their counterparts in the generalized theory with remarkably similar expressions. The gauge group of the generalized theory is analyzed. If the gauge freedom is fixed with a desired symmetry, the generalized CS parametrization assumes the form of the modified Iwasawa decomposition, whose importance in phase space quantum mechanics and optics has been recently realized. It is shown that the spectral and structural stability properties of a general focusing lattice are uniquely determined by the generalized phase advance. For structural stability, the generalized CS theory developed enables application of the Krein-Moser theory to significantly simplify the theoretical and numerical analysis. The generalized CS theory provides an effective tool to study the coupled dynamics of high-intensity charged particle beams and to discover more optimized lattice designs in the larger parameter space of general focusing lattices.

1Research supported by the U.S. Department of Energy.

3:30PM Q12.00002 Optical control of electron trapping: Generation of comb-like electron beams for tunable, pulsed, multi-color radiation sources. SERGE KALMYKOV, University of Nebraska - Lincoln — All-optical control over the electron phase space in laser-plasma accelerators enables production of “designer” electron beams that can be optimized for specific applications. GeV-scale acceleration with sub-100 TW (rather than PW) laser pulses, at repetition rates orders-of-magnitude higher than permitted by existing PW facilities, in a few-mm (rather than cm) length plasma, requires maintaining an accelerating gradient as high as 10 GV/cm. This, in turn, dictates acceleration in the blowout regime in a dense plasma (~10^19 cm^-3). These highly dispersive plasmas rapidly transform the drive pulse into a relativistic optical shock, causing the plasma wake field (electron density bubble) to constantly expand, trapping background electrons, greatly degrading beam quality. We show that these effects can be overcome using a high-bandwidth driver (over 1/2 the carrier frequency) with a negative frequency chirp. Temporally advancing higher frequencies (thus compensating for the plasma-induced nonlinear frequency red-shift) and propagating the pulse in a plasma channel (to suppress diffraction of its leading edge) delays pulse self-steepening through electron dephasing and extends the dephasing length. As a result, continuous injection is suppressed and electron energy is boosted to the GeV level. In addition, periodic self-injection in the channel produces a sequence of femtosecond-length, quasi-monoenergetic bunches. The number of these spectral components, their charge, energy, and energy separation can be controlled by varying the channel radius and length, whereas accumulation of the noise (viz. continuously injected charge) is prevented by the negative chirp of the driver. This level of control is hard to achieve with conventional accelerator techniques. It is demonstrated that these clean, polychromatic, comb-like beams can drive high-brightness, tunable, multi-color gamma-ray sources.

3Work is supported by the US DOE Grant DE-SC0008382 and NSF Grant PHY-1104683.

4:00PM Q12.00003 Multi-dimensional Vlasov Simulations and Modeling of Trapped-Electron Sideband and Filamentation Instabilities of Non-Linear Electron Plasma Waves. RICHARD BERGER, Lawrence Livermore National Laboratory — Vlasov simulations of large amplitude electron plasma waves (EPWs), which play an essential role in laser-driven relevant plasmas, have been carried out in 1D and 2D and compared with theoretical models [1]. The electrons trapped in the wave troughs are shown to be well described by an “adiabatic” description with a corresponding frequency shift of the EPW [2]. Trapped particles play an essential role in the mechanisms underlying sideband instabilities that may affect the EPW, in particular longitudinal instabilities of trapped particle instability (TPI) type, as well as transverse instabilities of kinetic filamentation type. A systematic study of the spectrum of linearly unstable modes in 1D and 2D systems, including their growth rates and wavevectors, has been completed by scanning the amplitude and wavenumber of the initial wave. Simulation results for the TPI are successfully compared with Kruezer’s reduced model [3] and are also analyzed for the development of the “negative mass instability” [4]. In the non-linear phase, both the TPI and filamentation instabilities are self-sustained due to a rapid decay of the field energy, and the spectrum of linearly unstable modes is reduced to a small number of “damped” modes. These are reached in conjunction with the development of significant regions in phase space where trajectories of particles, resonant with the initial wave, become chaotic.


3This 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 Laboratory Research and Development Program at LLNL under project tracking code 12-ERD

4:30PM Q12.00004 Diocotron Mode Damping from a Flux through the Critical Layer. C. FRED DRISCOLL, University of California, San Diego — Experiments and theory characterize a novel type of spatial Landau damping of diocotron modes which is algebraic rather than exponential in time; this damping is caused by flux of particles through the wave/rotation critical layer. These oblique diocotron (drift) modes with azimuthal mode numbers m_φ = 1, 2,... are dominant features in the dynamics of non-neutral plasmas in cylindrical and toroidal traps; and they are directly analogous to Kelvin waves on 2D fluid vortices. Spatial Landau damping is the resonant interaction between a mode at frequency f_m and the plasma rotation f_0(r), at the Kelvin radius R_k, where f_m = m_φ f_0(R_k). This is mathematically analogous to velocity-space Landau damping with f_k = kv/2π. Experimentally, diocotron modes on pure electron plasma exhibit exponential Landau damping when the initial plasma density is non-zero at R_k. Here, we demonstrate that a steady outward flux of particles through R_k causes diocotron modes to damp algebraically to zero amplitude, as D(t) = D_0 - γ_m t. The outward flux is controlled and measured experimentally, and the damping rates γ_m are proportional to the flux. In general, any weak non-ideal process which causes outward flow may cause this damping. Analytics and simulations have developed a simple model of this damping, treating the transfer of canonical angular momentum from the mode to particles transiting the nonlinear trapping region at R_k. The model qualitatively agrees with experiments for m_φ = 1, but nominally predicts a discrepant algebraic exponent for m_φ = 2, perhaps due to the amplitude dependence of the trapping structure. Overall, this novel flux-driven damping is determined by the present magnitudes of the wave and outward flux, in contrast to the Landau analysis of phase mixing of the initial density.

1Supported by NSF/DOE Partnership grants PHY-0903877 and DE-SC0002451.


Resonant Field Amplification Experiments

Dr. T. J. Murphy, and S. J. Gilbert.

I wish to acknowledge the many collaborators who contributed to our work in this area, in particular M. Leventhal, A. Passner, R. G. Greaves, J. R. Danielson, T. J. Murphy, and S. J. Gilbert.

1 Atomic physics aspects of our work are supported by the NSF, grant PHY 10-68023. Other aspects of this work have been supported by AT&T Bell Laboratories, ONR, the DOE/NSF Plasma Partnership, and DTRA.

Thursday, October 30, 2014 8:00AM - 9:00AM —
Session SR1 James Clerk Maxwell Prize Address: Antimatter Plasmas in the Laboratory Aca-dia/Bissonet - Phillip Sprangle, Naval Research Laboratory and University of Maryland

8:00AM SR1.00001 Antimatter Plasmas in the Laboratory1, CLIFFORD M. SURKO, Physics Department, University of California, San Diego — The focus of this talk is the creation and uses of nonrelativistic positron plasmas and beams. Key plasma physics drivers for this research will be described, centered on techniques to create and manipulate antimatter plasmas and gases; and outstanding challenges will be discussed. Areas of progress and future promise will be described, including the formation and study of antihydrogen (stable neutral antimatter): positron binding to ordinary matter; and efforts to study the electron-positron many-body system in both the quantum and classical regimes, Bose-condensed gases of positronium atoms (Ps BEC) and classical electron-positron (“pair”) plasmas.

1 Supported by the US DOE under DE-AC02-09CH11466 & DE-FC02-04ER54698.
11:00AM T11.00004 Experimental Tests of Linear and Nonlinear 3D Equilibrium Models in DIII-D* J.D. KING, Oak Ridge Institute for Science and Education — A major upgrade to the DIII-D magnetic diagnostics has been used to show that linear ideal MHD captures the key features of plasma response to 3D fields over a wide range of conditions, while a nonlinear model disagrees with observations. New measurements on the low and high field sides of the torus allow detailed comparisons with “synthetic diagnostic” predictions of several MHD models, in plasmas with edge safety factor \(q_{95}\) and plasma pressure \(\beta\) spanning the range expected for ITER’s baseline scenario. Model comparisons with DIII-D data confirm that the linear ideal MHD code MARSF-3 provides a quantitative description of the plasma response to applied fields with toroidal mode numbers \(n=1\) and \(n=3\). Similarly, good experimental agreement is seen for the linearized two-fluid MSDC-1 code and ideal MHD IPEC code. In contrast, the \(n=1\) plasma response predicted by the nonlinear 3D equilibrium code VMEC is found to disagree with measurement in both amplitude (by a factor of 3 or more) and qualitative structure – perhaps related to VMEC’s strong sensitivity to the current density near the plasma edge. The measured plasma response to \(n=3\) perturbations is characterized by strong variations in amplitude at the high field side as the edge safety factor is varied, in good qualitative agreement with ideal MHD predictions of resonant behavior as rational surfaces reach the edge \(q_{95} = m/3\). However, the resonance at \(q_{95} = 11/3\) appears significantly weaker than the others, which suggests the presence of non-ideal effects – possibly loss of screening currents and formation of islands. This observation may shed new light on the physics of the suppression of edge localized modes (ELMs) by \(n=3\) magnetic perturbations, which in DIII-D occurs most easily with \(q_{95}\) near 11/3.

The success of ideal, linear MHD models, as well as the understanding of the limits of their validity (e.g. edge resonances, and the well-known role of kinetic effects in high \(\beta\) plasmas), will be important in predicting the response of future burning plasmas to small 3D perturbations.

*Supported by the US DOE under DAE-AC05-00OR23100 and DE-FG02-04ER54698.

11:30AM T11.00005 Observing the plasma response to applied non-axisymmetric fields in the presence of an adjustable ferritic wall** JEFFREY LEVESQUE, Columbia University — We report high-resolution detection of the time-evolving, three-dimensional (3D) plasma response to applied non-axisymmetric magnetic fields in a tokamak with an adjustable ferromagnetic wall and with a variably-shaped equilibrium. Ferritic tiles (5mm thick, saturated \(\mu/\mu_0 \sim 8\)) have been added to the plasma-facing side of half of the in-vessel movable wall segments in the High Beta Tokamak – Extended Pulse (HBT-EP) device in order to explore Ferromagnetic Resistive Wall Mode (FRWM) stability.

Low-activation ferritic steels are a candidate for structural components of a fusion reactor, and these controlled experiments examine MHD stability of plasmas with nearby ferromagnetic material. Plasma-wall separation for alternating ferritic and non-ferritic wall segments can be adjusted between discharges without opening the vacuum vessel. Amplification of applied resonant fields is observed to increase when the ferromagnetic wall is close to plasma surface instead of the standard stainless steel wall. Experiments with rapidly rotating external kink modes show wall stabilization despite the presence of the close ferritic wall \((b/a \sim 1.07)\), extending previous observations in JFT-2M. Plasmas are observed to have reduced wall stabilization when a biased electrode is used to slow the mode rotation. Resonant fields are also applied while the plasma evolves from circular limited cross-sections to shaped, single-null cross-sections in order to study the effects of shaping on multimode interactions. Multimode activity in diverted and limited plasmas is compared with DCON predictions.

**Supported by U.S. DOE Grant DE-FG02-86ER55222.

12:00PM T11.00006 Observations of Transitions Between Nested and Braided Magnetic Island in DIII-D and LHD† K. IDA, National Institute for Fusion Science — Measurements of modulated heat pulse propagation in DIII-D have revealed the existence of self-regulated oscillations in the radial energy transport that are indicative of bifurcations in the structure of a q = 2 magnetic island. Strong screening of the heat pulse is seen in one state followed by weak screening later in the discharge. The magnetic island with strong screening is interpreted as having a narrow stochastic region near X-point with nested flux surfaces occupying most of the island (a completely nested island), where very slow heat pulse propagation suggests a reduction of transport. Weak screening of heat pulse suggests a wide stochastic region near the X-point and a small region of nested flux surfaces inside the island (partially braided magnetic island). The reduction of heat transport observed inside magnetic island has recently been reported both in helical and tokamak plasmas (1:2). In the LHD experiment, there are two patterns of heat pulse propagation observed in the flat temperature region. One is a bi-directional slow heat pulse propagation and the other is a fast heat pulse propagation. This bifurcation in the heat pulse propagation is consistent with a topological transition between a nested magnetic island and a completely braided magnetic island in LHD and is consistent with the DIII-D measurement.

In the DIII-D experiments, the radial heat transport is either enhanced or reduced depending on the state of the island, because the radial transport is reduced inside the X-point region. These results demonstrate that the structure of magnetic islands can spontaneously transition during a discharge and modulate the local energy transport inside magnetic island by at least a factor of three.

†Supported in part by the US DOE under DE-FC02-04ER54698, DE-FG03-97ER54415 and DE-AC05-00OR22725.

Thursday, October 30, 2014 9:30AM - 12:30PM – Session T12 1CF and Z-pinch Physics

Bissonet - Patrick McKenty, University of Rochester

9:30AM T12.00001 Rosenbluth Award: First observations of Rayleigh-Taylor-induced magnetic fields in laser-produced plasmas using x rays and protons MARIO MANUEL, University of Michigan - Ann Arbor — Recent experiments [Manuel, PRL 108 (2012)] demonstrated the existence of self-generated B-fields from the Rayleigh-Taylor (RT) instability in laser-produced plasmas, as originally predicted by Mima et al. [Mima PRL 41 (1978)]. Misaligned density and temperature gradients caused by RT growth (ablatively driven targets generate B-fields in the plasma through the Biermann battery source). X-ray and proton radiography diagnosed areal-density and B-field perturbations in laser-irradiated targets with seeded sinusoidal surface perturbations. Inferred B-field strengths indicated ratios of thermal to magnetic pressures \(\beta\) near the ablation surface of \(10^{-6}\), suggesting no magnetic effects on ablative RT during the linear growth phase. However, the magnitude of this self-generated field increases with the perturbation height [Srinivasan, PRL 108 (2012)] and can affect morphology in the nonlinear regime. The detailed structure of highly nonlinear RT spikes is important to understand the inner wall expansion of hohlraums in indirect-drive inertial fusion and in multiple astrophysical systems, including the explosion phase of core-collapse supernovae and formation of planetary nebulae. Numerical calculations investigating the magnetic effects on nonlinear RT-spike evolution under conditions similar to previous measurements will be covered and implications discussed.

Support for this work was provided by NASA through Einstein Postdoctoral Fellowship grant number PF3-140111 awarded by the Chandra X-ray Center, which is operated by the Astrophysical Observatory for NASA under contract NAS8-03060. This work is funded by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasma under grant number DE-NA0001840. Previous work described here was supported in part by NLUF (DE-NA0000877), FSC/UR (415023-G), DoE (DE-FG52-09NA29553), LLE (414090-G), and LLNL (B580243).
10:00AM TI2.00002 Kinetic Effects in Inertial Confinement Fusion\textsuperscript{3}. GRIGORY KAGAN, Los Alamos National Lab — Sharp background gradients, inevitably introduced during ICF implosion, are likely responsible for the discrepancy between the predictions of the standard single-fluid rad-hydro codes and the experimental observations. On the one hand, these gradients drive the inter-ion-species transport, so the fuel composition no longer remains constant, unlike what the single-fluid codes assume. On the other hand, once the background scale is comparable to the mean free path, a fluid description becomes invalid. This point takes on special significance for the particle's energy. The distribution function of energetic ions may therefore be far from Maxwellian, even if thermal ions are nearly equilibrated. Ironically, it is these energetic, or tail, ions that are supposed to fuse at the onset of ignition. A combination of studies has been conducted to clarify the role of such kinetic effects on ICF performance. First, transport formalism applicable to multi-component plasmas has been developed. In particular, a novel “electro-diffusion” mechanism of the ion species separation has been shown to exist. Equally important, in drastic contrast to the classical case of the neutral gas mixture, thermo-diffusion is predicted to be comparable to, or even much larger than, baro-diffusion. By employing the effective potential theory this formalism has then been generalized to the case of a moderately coupled plasma with multiple ion species, making it applicable to the problem of mix at the shell/fuel interface in ICF implosion. Second, distribution function for the energetic ions has been found from first principles and the fusion reactivity reduction has been calculated for hot-spot relevant conditions. A technique for approximate evaluation of the distribution function has been identified. This finding suggests a path to effectively introducing the tail modification effects into mainline rad-hydro codes, while being in good agreement with the first principle based solution.

\textsuperscript{3}This work was partially supported by the Laboratory Directed Research and Development (LDRD) program of LANL.

10:30AM TI2.00003 Impact of First-Principles Property Calculations of Warm-Dense Deuterium/Tritium on Inertial Confinement Fusion Target Designs, S.X. HU, Laboratory for Laser Energetics, U. of Rochester — Accurate knowledge of the properties of warm dense deuterium/tritium (DT) is essential to reliably design inertial confinement fusion (ICF) implosions. In the warm-dense-matter regime, routinely accessed by low-adiabat ICF implosions, strong-coupling and degeneracy effects play an important role in determining plasma properties. Using first-principles methods of both path-integral Monte Carlo and quantum molecular-dynamics (QMD), we have performed systematic investigation of the equation of state\textsuperscript{2}, thermal conductivity\textsuperscript{3}, and opacity\textsuperscript{4} for DT over a wide range of densities and temperatures. These first-principles properties have been incorporated into our hydrocodes. When compared to hydro simulations using standard plasma models, significant differences in 1-D target performance have been identified for simulations of DT implosions. For low-adiabat (\(\alpha \leq 2\)) DT plasma conditions, the QMD-predicted opacities are 10 to 100\times higher than predicted by the cold-opacity-patched astrophysical opacity table. The thermal conductivity could be \(3 \times 10\times\) larger than the Lee–More model prediction. These enhancements can modify the shell adiabat and shock dynamics in lower-\(\alpha\) ICF implosions, which could lead to \(\sim 40\%\) variations in peak density and neutron yield. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

11:00AM TI2.00004 Reaction-in-Flight Neutrons and the Stopping Power in Cryogenic NIF Capsules, ANNA HAYES, Los Alamos National Laboratory — Recent experiments in cryogenic DT capsules at the National Ignition Facility (NIF) observed high-energy reaction-in-flight (RIF) neutrons via threshold (>15 MeV) neutron reactions on thulium foils. This represents the first measurements of RIF neutrons in inertial confinement fusion plasmas. RIF neutrons are produced by a two-step process. In the first step, a primary 14.1 MeV DT neutron knocks a triton or deuterion up to a spectrum of energies from 0 to more than 10 MeV. In the second step, the energetic knocked-on ion undergoes a DT reaction with a thermal ion, producing a neutron above the primary 14 MeV peak. Transport and energy loss of the knock-on ions inducing the RIF reactions directly affect the RIF production rate, and RIF measurements can be used to determine the stopping power for charged particles in the plasma. Here we present the formalism for extracting the stopping power from the measured RIF signals. We find that the stopping power extracted from these measurements is consistent with a strongly coupled quantum degenerate plasma for the high-density cold fuel surrounding the hotspot of the compressed capsule. These RIF measurements represent the first determination of stopping powers in strongly coupled plasmas.

11:30AM TI2.00005 Highly nonlinear ablative Rayleigh-Taylor experiments on the National Ignition Facility, ALEXIS CASNER, CEA, DAM, DIF, F-91297 Arpajon Cedex, France — Cryogenic indirect-drive implosions on NIF have evidenced that the ablative Rayleigh-Taylor Instability (RTI) is an important driver of hot spot mix \cite{CASNER2013}. This motivates the switch to a higher adiabat implosion design \cite{KAGAN2014}. Recent tests in physical regimes not encountered in ICF will help to build a better understanding of hydrodynamic instabilities. Under the NIF Discovery Science program, indirect drive experiments were performed to study the ablative RTI in transition from weakly nonlinear to highly nonlinear regime \cite{CASNER2012}. The unique capabilities of the NIF are harnessed to accelerate planar samples over much larger distances (~2 mm) and longer time periods (~10 ns) than previously achieved. The existence of a turbulent-like regime at ablation front is in fact not precluded by theory. This question is crucial for laboratory astrophysics and supernova of type Ia explosions based on the analogy between the flame front and the ablation front. A modulated package is accelerated by a 180 eV radiative temperature plateau created by a room temperature gas-filled platform irradiated by 64 NIF beams. Simultaneous trajectory and RTI growth measurements are performed. We present measurements made for various two-dimensional patterns (single-mode and broadband multimode modulations) and compare our results with weakly nonlinear analytical theory and FC12 hydrocode simulations. The dependence of RTI growth on initial conditions and ablative stabilization is emphasized, as well as the possibility of measuring RTI bubble-merger for the first time in indirect-drive. In collaboration with D. Martinez, V.A. Smalyuk, B. Remington (LLNL), L. Masse, S. Liberatore, P. Loiseau (CEA).

\begin{thebibliography}{9}
\bibitem{HURRICANE2014} O.A. Hurricane et al., Nature 506, 343 (2014).
\end{thebibliography}
12:00PM Ti2.00006 Dynamic plasma-wall modeling of ELMy H-mode plasmas, A. PIGAROV, UCSD, S. KRASHENINNIKOV, USCD, E. HOLLMANN, UCSD, T. ROGNIEN, LLNL, E. UNTERBERG, ORNL, C. LASNIER, LLNL — We discuss UEDGE-MB-W version of the 2-D transport code, which incorporates the Macro-Blob (MB) approach to simulate ELMy plasma dynamics and various dynamic models for hydrogen inventory in the first wall (W). Results of time-dependent coupled simulations in various sequences of type-I ELMy with UEDGE-MB-W are presented. The temporal evolution of deuterium inventories of the pedestal plasma and wall and the calculated rates of particle deposition into wall during ELMy and of wall outgassing between ELMy are in agreement with experimental data on graphite-wall tokamaks. The fraction of pedestal particle losses deposited into the wall during ELMy is studied found to vary from 20 to 80% depending on the sizes and frequencies of ELMy. Modeling results for discharge exhibiting the transition from small to giant type-I ELMy due to NBI decrease are analyzed, demonstrating the dominant role of wall outgassing in pedestal density built-up. Dynamic deposition/release equilibrium attained in the saturated wall in a sequence of ELMy and the roles of different PSI processes in generating gas release are analyzed. The role of transient events in formation of detached divertor plasma is studied. The dynamics of such plasma is modeled and ionization/recombination/radiation deposition/release equilibrium attained in the saturated wall in a sequence of ELMs and the roles of different PSI processes in generating gas release are analyzed. The temporal evolution of deuterium inventories of the pedestal plasma and wall and the calculated rates of particle deposition into wall during ELMs and of wall outgassing between ELMy are in agreement with experimental data on graphite-wall tokamaks. 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10:30AM TO3.00006 Tungsten and molybdenum transport studies in the TEXTOR tokamak. ARMIN WECKMANN, PER PETERSSON, PETTER STROEM, MARÈK RUBEL, Royal Institute of Technology, Stockholm, Sweden. JAN COENEN, ARKADI KRETER, PETER WIENHOLD, IEK-4, Forschungszentrum Juelich, Germany — Understanding the transport of high-Z metals in tokamaks is important for magnetic controlled fusion devices. Two separate experiments aiming at the determination of tungsten and molybdenum migration were performed in the TEXTOR tokamak by means of controlled injection of volatile compounds:WF$_6$ and MoF$_6$. Nitrogen-15 tracer was also seeded for plasma edge cooling. Spectroscopy measurements were done for edge and core plasma. The experiments done on the last day before the shut-downs were followed by comprehensive analyses of plasma facing components (PFC), test limiters and collector probes. Surface studies with ion and electron spectroscopy techniques enabled mapping of the metal content both in toroidal and poloidal position in the whole torus. The material balance and the global and local deposition patterns were determined. The results explain gradual migration of high-Z metals by prompt re-deposition and re-erosion processes. The differences between W and Mo will be addressed. Data on He and N-15 retention will also be presented.

10:42AM TO3.00007 Fluence Resolved Growth of Nanostructured Tungsten “Fuzz”. PETER FIFLIS, DAVIDE CURRELI, DAVID RUZIC, Univ of Illinois - Urbana. — Growth of nanostructures on the surface of tungsten plasma facing components is anticipated in the next generation of experimental fusion reactors. Determining the mechanisms underlying tungsten fuzz growth is an important step towards mitigation of fuzz formation. Nanostructured tungsten was produced on ohmically heated tungsten wires in a helicon plasma source (maximum flux of 2.5e21 m$^{-2}$s$^{-1}$), asymmetry in the setup allows for investigation of temperature and flux effects in a single sample. An effort at elucidating the mechanism of formation was made by inspecting SEM micrographs of the nanostructured tungsten at successive fluence steps of helium ions up to 1e27 m$^{-2}$. To create these micrographs a single tungsten sample was exposed to the plasma, removed and inspected with an SEM, and replaced into the plasma. The tungsten surface was marked in several locations so that each micrograph is centered within 200 nm of each previous micrograph. Pitting of the surface (dia. 20 ± 10 nm, fl. 5+/-2e25 m$^{-2}$) followed by surface roughening (9+/-2e25 m$^{-2}$) and finally tendril formation (30+/10 nm, 2+/-1e26 m$^{-2}$) is observed.

10:54AM TO3.00008 Flux threshold of He-ion-beam induced nano-fuzz growth on hot tungsten below and above the displacement damage threshold energy. HUSSEIN HIJAZI, MARK E. BANNISTER, CHAD M. PARISH, HARRY M. MEYER III, FRED W. MEYER, Oak Ridge National Laboratory — Measurements of nano-fuzz growth on linear plasma devices have shown that below the displacement damage energy threshold, a minimum He-ion flux is required for nano-fuzz formation. We report comparative measurements of nano-fuzz flux thresholds below and above the displacement damage energy threshold using well characterized He ion beams at the ORNL MIRF. He-ion-beam flux distributions were optimized and measured at 218 and 2000 eV prior to ion beam impact on W coupons heated to about 1000 deg. C. After exposure times ranging from 4200 to 7200 seconds, the beam spots were examined by SEM over a 0.5 mm x 0.5 mm grid, which was spatially correlated to the measured flux distributions. In this manner, we were able to obtain, in a single ion beam exposure, the flux dependence of the observed surface morphology changes at each of the two energies. At 218 eV, for fluxes below 1.5x10$^{15}$/cm$^2$/s, ordered surface structures are observed, with great grain-to-grain variability, together with blisters and pinholes, while above this flux value, individual grain characteristics disappear, and nano-fuzz growth is observed. At 2 keV, very similar surface morphologies are observed, but the flux threshold for nano-fuzz formation has almost doubled, to 2.5 - 3x10$^{16}$/cm$^2$/s. Possible reasons for this increase will be discussed.

1Research sponsored by the LDRD Program of ORNL, managed by UT Battelle, LLC, for the US DOE

11:06AM TO3.00009 Creation of deuterium protective layer below the tungsten surface. PREDRAG KRSTIC, Stony Brook University, IGOR KAGANOVICH, EDWARD STARTSEV, Princeton Plasma Physics Laboratory — By cumulative irradiation of both pre-damaged and virgin surfaces of monocrystal tungsten by deuterium atoms of impact energy of few tens of eV, we simulate by classical molecular dynamics the creation of a deuterium protective layer. The depth and width of the layer depend on the deuterium impact energy and the diffusion rate of deuterium in tungsten, the latter being influenced by the tungsten temperature and damage. Found simulation results are in concert with the experimental results, found recently in DIFFER [1].


1Support of the PPPL LDRD project acknowledged.

11:18AM TO3.00010 Simulation of tungsten dust impact on ITER-like plasma edge. R.D. SMIRNOV, S.I. KRASHENINNIKOV, A.YU. PIGAROV, UCSD, T.D. ROGNLIEN, LLNL — The large stationary or intermittent particle and heat fluxes in future fusion devices, such as ITER, can damage plasma-facing components leading to production of metallic dust and droplets. Transport and ablation of such dust devices, such as ITER, can damage plasma-facing components leading to production of metallic dust and droplets. Transport and ablation of such dust in the next generation of experimental fusion reactors. Understanding the transport of high-Z metals in tokamaks is important for electromagnetic fusion devices. Two separate experiments aiming at the determination of tungsten and molybdenum migration were performed in the TEXTOR tokamak by means of controlled injection of volatile compounds:WF$_6$ and MoF$_6$. Nitrogen-15 tracer was also seeded for plasma edge cooling. Spectroscopy measurements were done for edge and core plasma. The experiments done on the last day before the shut-downs were followed by comprehensive analyses of plasma facing components (PFC), test limiters and collector probes. Surface studies with ion and electron spectroscopy techniques enabled mapping of the metal content both in toroidal and poloidal position in the whole torus. The material balance and the global and local deposition patterns were determined. The results explain gradual migration of high-Z metals by prompt re-deposition and re-erosion processes. The differences between W and Mo will be addressed. Data on He and N-15 retention will also be presented.

11:30AM TO3.00011 Lithium-Metal Infused Trenches: Progress toward a Divertor Solution. D.N. RUZIC, P. FIFLIS, M. CHRISTENSON, M. SZOTT, W. XU, S. JUNG, Univ of Illinois - Urbana, T.W. MORGAN, Dutch Institute for Fundamental Energy Research (FOM - DIFFER), K. KALATHIPARAMBIL, Univ of Illinois - Urbana. The application of liquid metal, especially liquid lithium, as a plasma facing component (PFC) has the capacity to offer a strong alternative to solid PFCs by reducing damage concerns and enhancing plasma performance. The Liquid-Metal Infused Trenches (LiMIT) concept is a liquid metal divertor alternative which employs thermoelectric current from either plasma or external heating in tandem with the toroidal field to self-propel liquid lithium through a series of trenches. LiMIT has been tested in several devices, namely HT-7, the IUUC SLIDE and TELS facilities and Magnum PSI at heat fluxes of up to 3 MW/m$^{-2}$. Results of these experiments, including velocity and temperature measurements, power handling considerations, and preliminary vapor shielding results will be discussed, focusing on the 117 shots performed at Magnum scanning magnetic fields and heat fluxes up to ~ 0.3 T and 3 MW/m$^{-2}$. Concerns over tritium retention and MHD droplet ejection will additionally be addressed. LiMIT has also been proposed to function as a limiter on the EAST moveable limiter arm and tests have been performed with a prototype module inclined at various angles.

Data on He and N-15 retention will also be presented.
11:42AM TO3.00012 Effect of Energetic Plasma Flux on Flowing Liquid Lithium Surfaces1, KISHOR KALATHIPARAMBIL, SOONWOOK JUNG, MICHAEL CHRISTENSON, PETER FIFLIS, WENYU XU, MATHEW SZOTT, DAVID RUIZIC, CPMI, Department of Nuclear, Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign — An operational liquid lithium system with steady state flow driven by thermo-electric magneto-hydrodynamic force and capable of constantly refreshing the plasma exposed surface have been demonstrated at U of I [1]. To evaluate the system performance in reactor relevant conditions, specifically to understand the effect of disruptive plasma events on the performance of the liquid metal PFCs, the setup was integrated to a pulsed plasma generator. A coaxial plasma generator drives the plasma towards a theta pinch which preferentially heats the ions, simulating ELM like flux, and the plasma is further guided towards the target chamber which houses the flowing liquid system. The effect of the incident flux is examined using diagnostic tools including triple Langmuir probe, calorimeter, rogowski coils, Ion energy analyzers, and fast frame spectral image acquisition with specific optical filters. The plasma have been well characterized and a density of \( \sim 10^{21} \text{ m}^{-3} \), with electron temperature \( \sim 10 - 20 \text{ eV} \) is measured, and final plasma velocities of 34 – 74 kms \(^{-1} \) have been observed. Calorimetric measurements using planar molybdenum targets indicate a maximum plasma energy (with 6 kV plasma gun and 20 kV theta pinch) of 0.08 MJ m\(^{-2} \) with plasma divergence effects resulting in marginal reduction of 40 \pm 23 \text{ J} \) in plasma energy. Further results from the other diagnostic tools, using the flowing lithium targets and the planar targets coated with lithium will be presented. [1] D. N. Ruzic et. al, Nuc. Fusion 52 102002 (2011)

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1 DOE DE-SC0008587

11:54AM TO3.00013 HIDRA: A new device for PFC and PMI development, DANIEL ANDRUCZYK, DAVID N. RUIZIC, JEAN PAUL ALLAIN, DAVIDE CURRELI, University of Illinois Urbana - Champaign, HIDRA TEAM — A toroidal plasma device is being constructed at the University of Illinois dedicated in part as a toroidal liquid-metal PFC technology test bench. The Hybrid Illinois stellarator/tokamak Device for Research and Applications (HIDRA) is a medium sized classical stellarator (previously WEGA, IPP Greifswald) with, \( R = 0.72 \text{ m} \), \( a = 0.19 \text{ m} \), \( B < 0.5 \text{ T} \) and will be able to reach \( T_e = 10-50 \text{ eV} \), \( n_i = 10^{17} - 10^{19} \text{ m}^{-3} \) with plasmas running up to several minutes. A critical knowledge gap for liquid-metal PFCs is their integration and performance in asymmetric confinement fusion environments. HIDRA will be used to evaluate technologies such as TEMHD driven flows for the first wall, help address key questions including whether a full toroidal liquid-metal loop can operate in a toroidal machine, test low recycling regimes and whether D can be removed and recycled easily. Also, UIUC’s experience with in-situ diagnostics will open up new opportunities for innovative Material Application Testing (HIDRA-MAT).

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Thursday, October 30, 2014 9:30AM - 12:06PM — Session TO4 Compression and Burn III — Salon E - Bruce Remington, Lawrence Livermore National Laboratory

9:30AM TO4.00001 Time-Resolved Imaging of Cryogenic Target X-Ray Emission at Peak Compression on OMEGA — F.I. MARSHALL, J.A. DELETTREZ, R. EPSSTEIN, V.N. GONCHAROV, D.T. MICHEL, T.C. SANGSTER, C. STOECKL, Laboratory for Laser Energetics, U. of Rochester — This talk will describe the measurements of cryogenic target region size and time history inferred from the combination of a high-speed x-ray framing camera and two time-integrating x-ray microscopes. The high-speed framing camera infers the time of peak stagnation from pinhole images taken at 30-ps time intervals with 30-ps frame times and with \( \sim 15 \mu \text{m} \) resolution. The two Kirkpatrick–Baez-type x-ray microscopes have spatial resolutions of \( \sim 5 \mu \text{m} \) and \( \sim 7 \mu \text{m} \) respectively, and are currently time integrating. The inferred x-ray core size and emission time interval will be compared to the measured neutron emission time and to simulations of the experiments. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

9:42AM TO4.00002 Correlations of Multiple Ion-Temperature Measurements with Shot Parameters in DT Cryogenic Implosions on OMEGA — V.YU. GLEBOV, C.J. FORREST, T.C. SANGSTER, C. STOECKL, Laboratory for Laser Energetics, U. of Rochester — Several neutron time-of-flight (nTOF) detectors installed at different lines of sight (LOS) are used to measure neutron-averaged ion temperature in direct-drive DT implosions on the OMEGA laser. The measurement precision of the ion temperature in different LOS for ambient targets is less than 4\% rms. In DT cryogenic implosions, however, the ratio of the ion temperature measured in different LOS can vary by a factor of 2. Correlations of the ion-temperature difference with parameters such as target offset, beam power balance, and phase plates in DT cryogenic implosions on OMEGA will be presented. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

9:54AM TO4.00003 Ultraviolet Thomson Scattering from Direct-Drive Coronal Plasmas in Multilayer Targets — R.J. HENCHEN, V.N. GONCHAROV, D.T. MICHEL, R.K. FOLLETT, J. KATZ, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester — Several neutron time-of-flight (nTOF) detectors installed at different lines of sight (LOS) are used to measure neutron-averaged ion temperature in direct-drive DT implosions on the OMEGA laser. The measurement precision of the ion temperature in different LOS for ambient targets is less than 4\% rms. In DT cryogenic implosions, however, the ratio of the ion temperature measured in different LOS can vary by a factor of 2. Correlations of the ion-temperature difference with parameters such as target offset, beam power balance, and phase plates in DT cryogenic implosions on OMEGA will be presented. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

10:06AM TO4.00004 Fast-Electron Temperature Measurements in Laser Irradiation at 10\(^{14}\) W/cm\(^2\), A.A. SOLODOV, B. YAAKOBI, J.F. MYATT, C. STOECKL, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester — The temperature \( T \) of the fast electrons in planar-target irradiation using 2-ns UV pulses at 10\(^{14}\) W/cm\(^2\) was measured on the OMEGA EP laser using the bremsstrahlung radiation (hard x-ray (HXR)) and the \( K_{\alpha} \) radiation from high-Z signature layers. The HXR was measured by a nine-channel filter spectrometer [hard x-ray image plate (HXIP)]. Two types of experiments used the \( K_{\alpha} \) radiation. The first used a thick Mo (or Ag) target and the ratio of \( K_{\alpha} \) emitted toward the front and the back of the target, measured and simulated by a Monte Carlo (MC) code. The ratio decreases with increasing \( T \) (since \( K_{\alpha} \) is emitted deeper in the foil and therefore absorbed less on the way back out). The second type used a target composed of five consecutive-Z layers (Nb, Mo, Rh, Pd, Ag) and \( K_{\alpha} \) lines emitted from the back (highest-Z), measured and simulated by the MC code. For higher temperatures, the \( K_{\alpha} \) energy decreases more slowly with \( Z \). All of these measurements agree with each other. However, a three-channel scintillation photomultiplier system systematically yields higher temperatures. This indicates a higher-energy radiation component that is not detected by the HXIP because of the sharp drop in image plate (IP) sensitivity. Extending the HXIP detection to higher energies (using \( K_{\beta} \) fluorescence, for which the IP sensitivity is higher) is planned. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award DE-NA0001944.
10:18AM TO4.00005 Measurements of charged-particle stopping around the Bragg peak in OMEGA ICF plasmas, J. FRENJE, C.K. LI, F. SEGUIN, A. ZYLSTRA, R. PETRASSO, MIT, P. GRABOWSKI, UCI, R. MANCINI, UNR, S. REGAN, J. DELETTREZ, V. GLEBOV, T. SANGSTER, LLNL — We report on measurements of charged-particle stopping around the Bragg peak in plasmas relevant to Inertial Confinement Fusion (ICF). The energy loss of DD-tritons, DD-protons, D3He-alphas and D3He-protons, which are ideal particles for validating approximations to the ion-electron collision operator, have been measured in D4He gas-filled imploding plasmas. These experiments are relevant to alpha-particle transport and heating in hot-spot ignition experiments. As the DD and D3He fusion products span a large range of velocities, these measurements represent the first detailed experimental study of charged-particle stopping, ranging from linear low-velocity stopping, through the Bragg peak, to high-velocity stopping. The results are contrasted to commonly used theories, including the Brown–Preston–Singleton and Li–Petrasso formalisms. The data is also used to rule out theories that neglect quantum diffusion and dynamic screening. This work was supported in part by the US DOE, NLUF, LLNL and GA.

10:30AM TO4.00006 Observation of variations in the T+T neutron spectrum with varying center-of-mass energy, M. GATU JOHNSON, J.A. FRENJE, A. ZYLSTRA, M.J. ROSENBERG, H.G. RINDERKNECHT, J.A. FRENJE, F.H. SEGUIN, R.D. PETRASSO, MIT, S.X. HU, R. BETTI, T.C. SANGSTER, LLE, P.A. AMENDT, C. BELLEI, S.C. WILKS, LLNL, N.M. HOFFMAN, LANL, A. NIKROO, GA — Time-gated, proton radiography provides direct measurements of radial electric fields and their temporal evolution in directly-driven capsule implosions. The experimental data indicate that such fields are associated with a spherically converging shock inside an imploding capsule. The implications are simulated with the 2D hydrodynamic code DRACO. Several related mechanisms for generating such fields are discussed. The measurements provide physical insight into the structure, strength and dynamics of spherically converging shocks and have important implications for ICF implosion physics. This work was supported in part by the U.S. DOE, NLUF, LLNL and LLE.

10:42AM TO4.00007 Electric Fields Associated with Spherically Converging Shocks in Directly-Driven OMEGA Implosions, C.K. LI, A. ZYLSTRA, M.J. ROSENBERG, H.G. RINDERKNECHT, J.A. FRENJE, F.H. SEGUIN, R.D. PETRASSO, MIT, S.X. HU, R. BETTI, T.C. SANGSTER, LLE, P.A. AMENDT, C. BELLEI, S.C. WILKS, LLNL, N.M. HOFFMAN, LANL, A. NIKROO, GA — Time-gated, proton radiography provides direct measurements of radial electric fields and their temporal evolution in directly-driven capsule implosions. The experimental data indicate that such fields are associated with a spherically converging shock inside an imploding capsule. The implications are simulated with the 2D hydrodynamic code DRACO. Several related mechanisms for generating such fields are discussed. The measurements provide physical insight into the structure, strength and dynamics of spherically converging shocks and have important implications for ICF implosion physics. This work was supported in part by the U.S. DOE, NLUF, LLNL and LLE.

10:54AM TO4.00008 Studies of 3He+3He, T+3He, and p+D nuclear reactions relevant to stellar or Big-Bang Nucleosynthesis using ICF plasmas at OMEGA, ALEX ZYLSTRA, MARIA GATU JOHNSON, JOHAN FRENJE, CHIKANG LI, FREDRICK SEGUIN, HONG SIO, MICHAEL ROSENBERG, HANS RINDERKNECHT, RICHARD PETRASSO, MIT, HANS HERRMANN, YONG HO KIM, GERRY HALE, LANL, DENNIS MCNABB, DAN SAYRE, JESSE PINO, LLNL, CARL BRUNE, Ohio University, ANDY BACHER, Indiana University, CHAD FORREST, VLADIMIR GLEBOV, CHRISTIAN STOECKL, ROGER JANEZIC, CRAIG SANGSTER, LLE — The 3He+3He, T+3He, and p+D reactions directly relevant to Stellar or Big-Bang Nucleogenesis (BBN) have been studied at the OMEGA laser facility using high-temperature low-density ‘exploding pusher’ implosions. The advantage of using these plasmas is that they better mimic astrophysical systems than cold-target accelerator experiments. Measured proton spectra from the 3He+3He reaction are used to constrain nuclear R-matrix modeling. The resulting T+3He γ-ray data rule out an anomalously-high 6Li production during BBN as the high observed values in primordial material. The proton spectrum from the T+3He reaction is also being used to constrain the R-matrix model. Recent experiments have probed the p+D reaction for the first time in a plasma; this reaction is relevant to energy production in protostars, brown dwarfs and at higher CM energies to BBN.

1 This work was partially supported by the US DOE, NLUF, LLE, and GA.

11:06AM TO4.00009 Increased shell entropy as an explanation for observed decreased shell areal densities in OMEGA implosions, NELSON HOFFMAN, HANS HERRMANN, YONGHO KIM, Los Alamos National Laboratory — A reduced ion-kinetic (RIK) model used in hydrodynamic simulations has had some success in explaining time- and space-averaged observables characterizing the fusion fuel in hot low-density ICF capsule implosions driven by 1-ns 60-beam laser pulses at OMEGA [Rosenberg et al., Phys. Rev. Lett. 112, 185001 (2014); Rinderknecht et al., Phys. Plasmas 21, 056311 (2014); Hoffman et al., in preparation]. But observables characterizing the capsule shell, e.g., the areal density of 12C in a plastic shell, have proved harder to explain. Recently we have found that assuming the shell has higher entropy than expected in a 1D laser-driven RIK simulation allows an explanation of the observed values of 12C areal density, and its dependence on initial shell thickness in a set of DT-filled plastic capsules. If, for example, a 15-µm CH shell implodes on an adiabat two to three times higher than predicted in a typical unmodified RIK simulation, the calculated burn-averaged shell areal density decreases from ~ 80 mg/cm² in the unmodified simulation to the observed value of ~ 25 mg/cm². We discuss possible mechanisms that could lead to increased entropy in such implosions.

1 Research supported by U.S. Department of Energy under contract DE-AC52-06NA25396

11:18AM TO4.00010 Predictions of secondary reactions, areal densities and hot-spot radii for Omega capsule implosions, M.J. SCHMITT, H.W. HERRMANN, Y.H. KIM, N.S. KRASHENNIKIKOVA, Los Alamos Natl Lab, S.M. SEPKE, Lawrence Livermore Natl Lab — The radial density profile of an imploding capsule at the time of fusion burn is an important factor in determining the characteristics of the imploded shell and the conditions in the hot burning core. We have simulated a set of deuteron-filled Hoppe glass (SiO2) capsule implosions using Hydra and predicted the fraction of secondary protons (4He+D→p[14.7MeV]+4He) and neutrons (T+D→n[14.1MeV]+4He) that are generated. The importance of using the downshift of secondary reaction protons for diagnosing capsule areal density is well known. We show how the conversion efficiency changes with variations to the capsule gas fill. A strong correlation between the downshift of the secondary protons with respect to the areal density of the shell, i.e. the γ factor, at the time of peak burn is predicted. Predictions for primary and secondary yield variations for alternate gas fills including binary mixtures of H2, D2, 3He and 4He also will be shown. Synthetic self-emission diagnosis of the implosion trajectory will be compared to the radial temperature profile to assess the accuracy of hot spot measurement at the time of nuclear burn. The variation in the temporal burn profile, including the variation of three burn peak components will be discussed.

1 Supported by the US DOE/NNSA, performed in part at LANL, operated by LANS LLC under contract number DE-AC52-06NA25396.
11:30AM TO4.00011 Inferring multiple ion temperatures and fluid velocities from neutron spectra, BRIAN APPELBE, JEREMY CHITTENDEN, Imperial College London — Thermal broadening of the DD and DT neutron spectra is a common method for measuring ion temperature. However, recent work has shown that bulk motion of the fuel in ICF capsule implosions can also have a broadening effect on the emitted spectra. This can lead to errors in ion temperature estimates. In this presentation we show that, in addition, the neutron spectra emitted by non-igniting ICF plasmas are not dominated by a single ion temperature or velocity but are the superposition of component spectra produced by regions of the plasma with a wide variation of densities, temperatures and fluid velocities. In order to identify the different component spectra, it is necessary to analyze the overall shape of the spectra and not just the width. We develop a Maximum Likelihood Estimator (MLE) algorithm for analyzing the emitted spectra which allows us to identify multiple temperatures and fluid velocities and the relative density of these components. The algorithm works by finding a best fit to the emitted spectra for a specified number of components. It allows us to estimate the range of temperatures and fluid velocities which make significant contributions to the neutron spectra and estimate the peak temperatures achieved in the experiment. The algorithm is tested using 3D simulations of imploding capsules.

11:42AM TO4.00012 On thermonuclear ignition criterion at the National Ignition Facility, BAOLIAN CHENG, THOMAS KWAN, YI-MING WANG, STEVEN BATHA, Los Alamos National Laboratory — A novel analytical model [1] for thermonuclear burn (TN) in inertial confinement fusion capsules is derived from fundamental physics principles and is found to be consistent with available experimental data. Based on the model, we obtained a general thermonuclear ignition criterion in terms of the areal density and temperature of the hot fuel. This newly derived TN ignition threshold and its alternative forms explicitly show the minimum requirements of the hot fuel pressure, mass, areal density, and burn fraction for achieving ignition. Comparison of our criterion with existing theories, simulations, and the National Ignition Facility (NIF) experimental data show that our ignition threshold is more stringent than those in existing literature and that our results are consistent and compare well with the NIF experimental data. Model applications to various inertial confinement fusion capsules and differences between our model and others are discussed.


11:54AM TO4.00013 Applying the minimal energy scaling law to NIF data, YI-MING WANG, BAOLIAN CHENG, THOMAS KWAN, STEVEN BATHA, Los Alamos Natl Lab — The minimal energy implosion-scaling model [1] was recently developed to characterize the physical properties of the hot spot in terms of the peak implosion energy. In this model, the hot spot energy, volume, pressure, mass, and areal density at the stagnation time are uniquely determined by the peak implosion velocity, the equation of state and the adiabat of the pusher and the DT fuel (cold and hot) at the peak implosion time. In this work, we apply this model to a number of published low-foot and high-foot experiments performed at the National Ignition Facility. Our model analysis is in good agreement with the experimental data when a high adiabat is assumed for both low and high foot experiments. Implications of the results are discussed. 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.

10:06AM TO5.00004 X-ray Absorption Near-Edge Spectroscopy (XANES) of Warm Dense Silicon Dioxide. 

KYLE ENGELHORN, LBNL; BYOUNG-ICK CHO, Gwangju Institute of Science and Technology; BEN BARBREL, UC Berkeley; VANINA RECOULES, CEA; DAM, DIF; STEPHANE MAZEVET, LUTH Observatoire; DENISE KROL, UC Davis; ROGER FALCONE, UC Berkeley; PHIL HEIMANN, SLAC — The electronic structure of warm dense silicon dioxide has been investigated by X-ray Absorption Near-Edge Spectroscopy (XANES). An ultrafast optical laser pulse isochorically heats a thin sample. The measured XANES spectra are compared with simulations generated by molecular dynamics and density functional theory. Three new features are observed: a peak below the band gap, absorption within the band gap and a broadening of the absorption edge. From comparison with the calculations, the peak below the band gap provides a measurement of the electron temperature while the spectral features above the O K-edge constrain the ion temperature. Further, the absorption within the gap presents evidence for broken Si-O bonds. The XANES is interpreted as that of a non-equilibrium liquid.

10:18AM TO5.00005 Pump-probe studies of radiation induced defects and formation of warm dense matter with pulsed ion beams1 , T. SCHENKEL, A. PERSAUD, H. GUJ, P.A. SEIDL, W.L. WALDRON, LBNL, Berkeley, CA; E.P. GILSON, I.D. KAGANOVICH, R.C. DAVIDSON, PPPL, Princeton, NJ; A. FRIEDMAN, J.J. BARNARD, LLNL, Livermore, CA; A.M. MINIOR, LBNL and UC Berkeley — We report results from the 2nd generation Neutralized Drift Compression Experiment at Berkeley Lab. NDCX-II is a pulsed, linear induction accelerator designed to drive thin foils to warm dense matter (WDM) states with peak temperatures of ~ 1 eV using intense, short pulses of 1.2 MeV lithium ions [1]. Tunability of the ion beam enables pump-probe studies of radiation effects in solids as a function of excitation density, from isolated collision cascades to the onset of phase-transitions and WDM. Ion channeling is an in situ diagnostic of damage evolution during ion pulses with a sensitivity of <0.1% displacements per atom [2]. We will report results from damage evolution studies in thin silicon crystals with Li+ and K+ beams. Detection of channeled ion tracks lattice disorder evolution with a resolution of ~ 1 ns using fast current measurements. We will discuss pump-probe experiments with pulsed ion beams and the development of diagnostics for WDM and multi-scale (ms to fs) access to the materials physics of collision cascades e.g. in fusion reactor materials.

[1] W.L. Waldron, et al., NIM A733,226(2014);

1 Work performed under auspices of the US DOE under contract no. DE-AC02-05CH11231.

10:30AM TO5.00006 Pseudo-atom molecular dynamics for warm dense plasma mixtures. CHARLES STARRETT, JEROME DALIGAUT, DIDIER SAUMON, Los Alamos National Laboratory — We have developed a new method for calculating the thermodynamics of warm dense mixtures. It combines an average atom-like approach to calculate the electronic structure of one “pseudo-atom” with classical molecular dynamics (MD) for the ionic structure. The result is a model in which both electronic and ionic structures of a plasma can be calculated rapidly and the resulting thermodynamics agree excellently with the much more expensive ab initio DFT-MD methods. We will present an outline of the new method and comparisons with DFT-MD for the ion-ionic structure and the thermodynamics.

10:42AM TO5.00007 Understanding Generalized Coulomb Logarithms1 , PAUL GRABOWSKI, University of California, Irvine — The Coulomb logarithm is ubiquitous in plasma physics. For ideal classical plasmas, physically motivated simple formulas suffice, but in warm dense matter, low temperature, or high-density plasmas, these simple prescriptions break down. Recent work [P. Grabowski et al., Phys. Rev. Lett. 111, 215002 (2013)] used classical molecular dynamics to understand how strong correlation should be treated in the electron-ion collision operator of a uniform electron gas. In this talk, I will quantify quantum and inhomogeneous corrections to this operator and present simple Coulomb logarithm formulas that are fit to calculations using convergent kinetic theories.

1 This work was funded by the Laboratory Directed Research and Development Program at LLNL under project tracking code 12-SI-005.

10:54AM TO5.00008 Coupling Strength and Coupling Parameters in One-Component Plasmas1 , TORBEN OTT, MICHAEL BONITZ, University of Kiel, LIAM STANTON, Lawrence Livermore National Laboratory, MICHAEL MURILLO, Los Alamos National Laboratory — Strong correlations in plasmas are a subject of continuing interest in many experiments. How to quantify the degree of correlations in systems with varying charge state, temperature and screening length is, however, a question of some debate. In this contribution, we propose a one-to-one mapping between the structural properties of a one-component plasma and its coupling strength. This allows one to assess the degree of correlation without knowledge of the charge state or temperature. We furthermore define an effective coupling parameter for screened Coulomb systems which allows one to compare systems with different screening lengths to one another and Coulomb systems.

1 Supported by SFB-TR24 (A7).
11:06AM TO5.00009 Ab initio thermodynamic quantities of the strongly degenerate electron gas from Configuration Path Integral Monte-Carlo simulations. 

MICHAEL BONITZ*, TIM SCHOOF, SIMON GROTH, Institute for Theoretical Physics and Astrophysics, CAU Kiel — Thermodynamic properties of the homogeneous electron gas (HEG) at finite temperatures are of high importance for many systems, including dense quantum plasmas, warm dense matter or plasmas in the interior of compact stars. Recently, Restricted Path Integral Monte-Carlo data for low to moderate densities \( r_s = \sqrt{\rho/a_0} \geq 1 \) have been presented [1], while the high-density regime was not accessible due to the Fermion sign problem. We here apply the recently developed Configuration PIMC (CPIMC) method [2,3] to the HEG at high densities \( r_s \lesssim 0.5 \) and low to moderate temperatures \( \Theta = k_B T/E_F \leq 1 \). We demonstrate that CPIMC allows for efficient ab-initio equilibrium calculations of thermodynamic properties of highly degenerate, moderately coupled electrons. It is based on the representation of the N-particle density operator in a basis of antisymmetrized N-particle states \([2]\) and does not suffer from the Fermion sign problem in the non-interacting limit.


11:18AM TO5.00010 Current status of the HED instrument design at the European XFEL for studying plasma physics. 

M. NAKATSUTSUMI, European XFEL, GmbH, K. APPEL, I. THORPE, G. PRIEBE, European XFEL, A. PELKA, T. COWAN, HZDR, TH. TSCHENTSCHER, European XFEL — The High Energy Density Physics (HED) instrument at the European XFEL will provide an unique platform to investigate the interaction of high-energy lasers with solid targets (3 - 24 keV range) and the capability to generate matter under extreme conditions of pressure, temperature or electric field using high energy optical lasers (100 TW Ti-Sapphire and 100 J/ns diode-pumped laser) or pulsed magnets (30 T). Scientific applications will be studies of matter occurring inside exoplanets, of new extreme-pressure phases and solid-density plasmas, and of structural phase transitions of complex solids in high magnetic fields. Following the delivery of the technical design documents, the HED instrument is presently completed with the goal of first x-ray beam in spring 2017. User operation shall start at the end of 2017. The talk includes a presentation of the current HED instrument design as well as the results from specific experiment requirements, which will be discussed.

11:30AM TO5.00011 The LCLS Matter under Extreme Conditions Instrument. 

PHILIP HEIMANN, HAE. JA LEE, BOB NAGLER, ERIC GALTIER, EDUARDO GRANADOS, BRICE ARNOLD, ZHOU XING, SLAC National Accelerator Laboratory — The LCLS MEC instrument is comprised of x-ray optics and diagnostics, a large target chamber and nanosecond and femtosecond laser systems. The x-ray focusing is accomplished by Be lenses. An upgrade of the femtosecond laser system is underway first to an energy of 1 J and then to 7 J. Diagnostics include forward and backward scattering x-ray spectrometers, a VISAR interferometer and area detectors for x-ray diffraction. A multiplexing method, to provide beamtime at two instruments, has been developed by translating a mirror. Examples of scanning, diffraction and imaging experiments at MEC will be presented.

11:42AM TO5.00012 X-ray scattering measurements of magnesium at the transition from the condensed matter to the warm dense matter regime. 

LUKE FLETCHER, SLAC National Accelerator Laboratory, ART PAK, TAMMY MA, TILO DOPPNER, BENJAMIN BACHMANN, SEBASTIEN LEPAPE, ULF ZASTRAU, BOB NAGLER, HAEJA LEE, ERIC GALETIER, MAXENCE GAUTHIER, ELISEO GAMBOA, MICHAEL MACDONALD, MINGSHENG WEI, ZHIJIAN CHEN, MIAOZHEN MO, BENJAMIN BARBREI, DOMINIK KRAUS, ROGER FALCONE, JERRY HASTINGS, SIEGFRIED GLENZER, HED science collaboration — Direct measurements of the strength in the ionic structure factor at various scattering angles is important for accurate first-principle calculations of material properties in the high pressure and temperature phase. In this study, spectrally resolved XRTS measurements in combination with proof-of-principle, single shot 2D angularly resolved x-ray scattering measurements of changes in the solid-state structure and the ion-ion correlation peak for both single and double (counter-propagating) shocks have been observed in Mg foils. The 527 nm, 2 GW laser system available at the MEC station of the LCLS facility has been used to compress magnesium foils using laser-driven shocks. In our study, 25_m and 50_m thick Mg targets were compressed 2x and 3x the solid density respectively using 3 ns pulses with a total laser energy of 6 J per beam. A drive intensity of 4x10^14 W/cm^2 on each irradiated surface was used to generate high pressure shock waves in the sample while 8 keV x-rays from the LCLS were used to probe the compressed targets for both single and double shocked geometries.

11:54AM TO5.00013 Free-electron x-ray laser measurements of collisional-damped plasmons in isochorically heated warm dense matter. 

PHILIP SPERRLING, HAE-JA LEE, ELISEO GAMBOA, SLAC National Accelerator Laboratory, HEIDI REINHOLZ, GERS ROEPKE, Institut fuer Physik, Universitat Rostock, Rostock, Germany, ULF ZASTRAU, Institut fuer Optik und Quantenelektronik, Friedrich-Schiller-Universitat, Jena, Germany, LUKE FLETCHER, SIEGFRIED GLENZER, SLAC National Accelerator Laboratory — Collisional-damped plasmons were obtained in highly-spectrally resolved measurements of isochorically heated solid aluminum for the first time. The determination of electron-electron and strong electron-ion collisions. 8 keV x-rays from the Linac Coherent Light Source have been focused to micrometer diameter focal spots heating solid aluminum foils to temperatures up to 7 eV. The forward scattering spectra show plasmons that directly determine the density and temperature from the plasmon frequency shift and from the detailed balance relation indicating a warm dense matter state with large ion coupling parameters of up to 30. These experiments show a non-quadratic plasmon dispersion relation shifted to lower plasmon energy shifts at wave numbers of 0.5Å < k < 2Å. Not predictable by dispersion relations arising from the Gross-Born relation and the Born-Mermin approximation. Therefore, the measured collisional-damped plasmons indicate collisions beyond the Born approximation and have been described successfully by taking into account electron-electron collisions as well as strong electron-ion collisions. In this talk, we will discuss the first measurement of strong collisions affecting strong collisions in the electron-ion collision model and conductivity.

12:06PM TO5.00014 Investigation of the melting of shock compressed Iron with XANES technique at LCLS. 

A. RAVASIO, M. HARLAND, A. DENOEDU, A. BENUZZI-MOUNAIX, M. KOENIG, T. VINCI, LULI, France, S. MAZEYET, R. MUSELLA, LUTH, France, F. GUYOT, IMPMC, France, G. MORARD, IMPMC, France, F. DORCHIES, C. FOURMENT, J. GAUDIN, CELIA, France, Y. FENG, D. ZHU, H.J. LEE, B. NAGLER, E.C. GALTIER, LCLS, USA, N. OZAKI, K. MIYANISHI, Osaka University, Japan, S. TOLEIKIS, FLASH, Germany, J. BOUCHET, V. RECOULES, CEA, France, M. NAKATSUTSUMI, European XFEL, Germany, U. ZASTRAU, Univ. of Jena, Germany — X-ray Absorption Near Edge Spectroscopy is a powerful technique of both the electronic structure and the atomic short-range order in various media, from molecules to condensed matter. In a recent experiment performed at LCLS-MEC, we have applied this technique to study the melting of Iron under shock compression. An accurate knowledge of its properties at high pressures and at extreme temperatures is indeed crucial for geophysics and planetary science. In particular, detailed information on melting curves and solid phases are required to anchor Earth’s thermal profile and assess the solid or liquid nature of exoplanets’ cores. Here we will present the obtained results and discuss how XANES data unambiguously evidenced the melting of iron on the high pressure Hugoniott.
12:18PM TO5.00015 Electron dynamics in WDM with x-ray pump/x-ray probe at LCLS. BENJAMIN BARBREL, ROGER FALCONE, Uvic of California - Berkeley, PHIL HEIMANN, SIEGFRIED GLENZER, SLAC, ALESSANDRA RAVASIO, LULI, ERIC GALTIER, SLAC, KYLE ENGELHORN, LBL, HYUN-KYUNG CHUNG, AIEA, GIULIO MONACO, Univ. Trento, ALISON SAUNDERS, Univ of California - Berkeley, LUKE FLETCHER, JEROME HASTINGS, SLAC, ULF ZASTRAU, Jena, MAC MACDONALD, WILL SCHUMAKER, MAXENCE GAUTIER, HAE JA LEE, BOB NAGLER, ELISEO GAMBOA, SLAC — Recent machine developments at LCLS have led to the capability for the FEL to deliver two x-ray pulses separated both in time and photon energy. This enables x-ray pump/x-ray probe experiments to be performed to study the ultrafast dynamics of electrons in warm dense matter (WDM) plasmas. Such experiments open a window over the first tens of femtoseconds of the time evolution of non-equilibrium electron distribution in dense plasmas. We recently conducted an LCLS-MEC experiment in which thin metallic foils where irradiated with two x-ray pulses. The first x-ray pulse isochorically heats up the material, and the second x-ray probe the electrons properties of the sample in the first 100fs of its evolution via x-ray Thomson scattering. In this presentation I will discuss the first results of these experiments as well as the potential of x-ray pump/x-ray probe experiments for WDM science.

Thursday, October 30, 2014 9:30AM - 12:30PM — Session TO6 Radiation Sources, Particle Beams, and Positron Production Galerie 3 - Zulfikar Najmudin, Imperial College, UK

9:30AM TO6.00001 X-ray radiation from a laser-wakefield accelerator in the self-modulated regime1, FELICIE ALBERT, BRADLEY POLLOCK, JOHN RUBY, MICKAEL KLEM, ARTHUR PAK, FREDERICO FIUZA, JOSEPH RALPH, JOHN MOODY, Lawrence Livermore National Laboratory, JESSICA SHAW, NUNO LEMOS, KEN MARSH, CHRIS CLAYTON, CHAN JOSHI, UCL, BENJAMIN GALLOWAY, JILA, WILLIAM SCHUMAKER, SIEGFRIED GLENZER, SLAC. We will present recent experiments performed using the Titan laser (150 J, 1 ps) at the Jupiter Laser Facility, LLNL. When a 0.5 - 1 ps laser pulse with an intensity approaching 10^20 W/cm^2 is focused on a gas target (electron density 10^{19} cm^{-3}), electrons can be accelerated via the self-modulated laser wakefield (SMLWF) regime. [1] Electrons are accelerated by the plasma wave created in the wake of the light pulse, whereas in DLAs, electrons are accelerated from the interaction of the laser field with the focusing force of the plasma channel. In our experiments, the SMLWF mechanism dominates, (< 10^{20} W/cm^2), and the transmitted laser spectrum exhibits intense Raman satellites which measured shifts depend on the electron plasma density. The high charge, ~ 100 MeV electrons measured in our experiments are also a source of bright multi-kV x-ray beams of interest of future high energy density science applications.

1This work was performed under the auspices of the U.S. Department of Energy under contract DE-AC52-07NA27344, and supported by the LDRD Program tracking code 13-LW-076.

9:42AM TO6.00002 Ultra-bright X-rays using Plasma Wigglers1, JIMMY HOLLOWAY, University College London, PETER NORREYS, University of Oxford / STFC Rutherford Appleton Laboratory, RICCARDO BARTOLINI, University of Oxford / Diamond Light Source, ROBERT BINGHAM, University of Strathclyde / STFC Rutherford Appleton Laboratory, RICHARD WALKER, Diamond Light Source / University of Oxford, MATTHEW WING, University College London — Fourth generation light sources have advanced many fields of the natural sciences by providing extraordinary reductions in X-ray pulse lengths and increases in brightness. In this paper, we will present a novel numerical study, showing that existing third generation synchrotron light sources can produce X-ray pulses with equally unique properties, by undulating their electron beams within plasma wakefields. We have conducted a full scale two dimensional particle-in-cell study that shows that by micro-bunching a realistic electron beam longitudinally generates an X-ray pulse of comparable brightness to fourth generation free electron laser sources is possible. The production mechanism ensures the pulses are radially polarized on creation. We also demonstrate that the micro-bunched electron beam is also an effective wakefield driver, one that provides in itself another potential new cost-effective route to a reliable intense X-ray source.

1This work has been supported by the STFC and EPSRC.

9:54AM TO6.00003 Multi-GeV electron beam and high brightness betatron x-ray generation in recent Texas Petawatt laser-driven plasma accelerator experiments, XIAOMING WANG, RAFAL ZGADZAJ, NEIL FAZEL, ZHENGYAN LI, XI ZHANG, WATSON HENDERSON, YEN-YU CHANG, RICK KORZEKWA, H.-E. TSAI, HERNAN QUEVEDO, GILLISS DYER, ERHARD GAUL, M. PAUL MARTINEZ, AARON BERNSTEIN, MICHAEL DONOVAN, VLADIMIR KHUDIK, GENNADY SHVETS, TODD DITMIRE, MICHAEL DOWNER, University of Texas at Austin — Compact laser-plasma accelerators (LPAs) driven by petawatt (PW) lasers have produced highly collimated, quasi-monoenergetic multi-GeV electron bunches with ~ 100 pC charge [1], which are promising sources of ultrafast x-rays. Here we report three recent advances in PW-LPA performance brought about by optimizing the focal volume of the Texas PW laser with a unique mirror. First, we accelerated electrons up to 3 GeV with hundreds of pC over 1GeV and ~0.5 mrad divergence. Second, we significantly improved shot-to-shot reproducibility (90% shots > 1GeV, 10% >2GeV). Third, by introducing a double-peaked laser focus, creating a “double bubble” that subsequently merged [2], we significantly increased electron charge (0.5 nC) above 1 GeV, while producing brighter (10^{22} photon/mm^2/ rad/0.1% ), higher (up to 30keV) betatron x-rays, characterized by a multi-metal filter pack and phase-contrast imaging. We observe evidence of dimuon production [3] by irradiating a high-Z target with this high-bright, GeV electron beam. [1] Wang et al., Nature Commun. 4, 1988 (2013); [2] Kim et al., Phys. Rev. Lett. 11, 165002 (2013). [3] Titov et al., Phys. Rev.-ST AB 12, 111301 (2009).

10:06AM TO6.00004 High-brightness, high-energy radiation generation from non-linear Thomson scattering of laser wakefield accelerated electrons, W. SCHUMAKER1, Z. ZHAO, A.G.R. THOMAS, K. KRUSHELNICK, University of Michigan, G. SARRI, D. CORVAN, M. ZEPF, Queen’s University of Belfast, J. COLE, S. MANGLES, Z. NAJMUDIN, Imperial College London — To date, all-optical sources of high-energy ( > MeV) photons have only been reported in the linear (α_0 < 1) regime of Thomson scattering using laser wakefield acceleration (LWFA). We present novel results of high-brightness, high-energy photons generated via non-linear Thomson scattering using the two-beam Astra-Gemini laser facility. With one 300 TW beam, electrons were first accelerated to 500 MeV energies inside gas cells through the process of LWFA. A second 300 TW laser pulse focused to α_0 ≈ 2 was subsequently scattered off these electrons, resulting in a highly directional, small source size, and short pulse beam of photons with >10 MeV energies. The photon beam was propagated through a low-Z converter and produced Compton-scattered photons that were spectrally measured by magnetic deflection and correlated with the incident photons. The measured photon yield at 15 MeV was 2 x 10^{10} photons/MeV and, when coupled with the small source size, divergence, and pulse duration, results in a record peak brightness of 2 x 10^{19} photons/s/mm^2/ mrad^2/0.1% bandwidth at 15 MeV photon energy.

1Current Affiliation: Stanford University/SLAC National Accelerator Laboratory
10:18AM TO6.00005 Compton Backscattered X-rays from Self-Generated Laser Wiggler in a Laser Wakefield Accelerator†, ANTONIO TING, DMITRI KAGANOVIĆ, BAHMAN HAFIZI, Naval Research Lab, JOHN PALASTRO, Icarus Research, Inc., MICHAEL HELLE, DANIEL GORDON, Naval Research Lab, YU-HSIN CHEN, RSI, Inc., JOHN SEELEY, Artep Inc. — A unique Compton backscattering configuration for generating monochromatic, short pulse, and potentially coherent x-rays in a Laser Wakefield Accelerator (LWFA) is being studied at the Naval Research Laboratory. Reflection mechanisms such as stimulated scattering and shock-created density gradients in a plasma can generate the required backward-travelling laser pulse directly from the same laser pulse used in the LWFA, i.e., the high energy electron beam and the counter-propagating photon beam are both self-generated by an ultrashort laser pulse in plasma. The automatic alignment of the counter-propagating electrons and photons together with the extended interaction distance and tightly guided beam sizes in a LWFA can lead to a high-gain situation for the Doppler upshifted forward propagating x-rays. Possibilities for exponential gain to achieve coherent generation of the x-rays are under investigation. Theoretical, numerical, and preliminary experimental results will be presented.

†This work is supported by DOE and NRL 6.1 funding

10:30AM TO6.00006 Ring-Shaped Distributions of Monoenergetic Electron Beams Generated via Density Discontinuities in a Two-Stage Gas Cell, ZHEN ZHAO, KEEGAN BEHM, BIXUE HOU, VLADIMIR CHVYKOV, ANATOLY MAKSIMCHUK, VICTOR YANOVSKY, ALEXANDER THOMAS, KARL KRUSHELNICK, University of Michigan — Using two-stage gas cells for laser wakefield acceleration experiments, we measure clear ring-shaped angular distributions of monoenergetic electron beams. These “halo”-like structures are observed both on an on-axis and a magnet spectrometer imaging system. Initial assessment of the beam-halos suggests that they are most consistently generated in a gas cell where opposing flows create a type of density discontinuity between the stages. Generating such well-defined angular distributions of mono-energetic electrons may be useful for plasma-based X-ray sources.

10:42AM TO6.00007 X-ray Emission Characteristics of Ultra-High Energy Density Relativistic Plasmas Created by Ultrafast Laser Irradiation of Nanowire Arrays†, R.C. HOLLINGER, C. BARGSTEN, V.N. SHLYAPTSEV, Colorado State University, A. PUKHOV, Heinrich-Heine-Universität Düsseldorf, M.A. PURVIS, A. TOWNSEND, D. KEISS, Y. WANG, S. WANG, A. PRIETO, J.J. ROCCCA, Colorado State University — Irradiation of ordered nanowire arrays with high contrast femtosecond laser pulses of relativistic intensity creates volumetrically heated near solid density plasmas characterized by multi-Kev temperatures and extreme degrees of ionization. The large hydrodynamic-to-radiative lifetime ratio of these plasmas results in very efficient X-ray generation. Au nanowire array plasmas irradiated at 1 x 10^21 W/cm^2 are measured to convert ~ 5 percent of the laser energy into hv>0.9 KeV X-rays, and >1 x 10^-4 into hv>9 KeV photons, creating bright picosecond X-ray sources. The angular distribution of the higher energy photons is measured to change from isotropic into annular as the intensity increases, while softer X-ray emission (hv >1 KeV) remains isotropic and nearly unchanged. Model simulations suggest the unexpected annular distribution of the hard X-rays might result from bremsstrahlung of fast electrons confined in a high aspect ratio near solid density plasma in which the electron-ion collision mean free-path is of the order of the plasma thickness.

†Work supported by the U.S. Department of Energy, Fusion Energy Sciences and the Defense Threat Reduction Agency grant HDTRA-1-10-1-0079. A.P was supported by of DFG-funded project TR18.

10:54AM TO6.00008 Volumetric Heating of Ultra-High Energy Density Relativistic Plasmas by Ultrafast Laser Irradiation of Aligned Nanowire Arrays†, CLAYTON BARGSTEN, REED HOLLINGER, VYACHESLAV SHLYAPTSEV, Colorado State University, ALEXANDER PUKHOV, Heinrich-Heine-Universität Düsseldorf, DAVID KEISS, AMANDA TOWNSEND, YONG WANG, SHOUJUN WANG, AMY PRIETO, JORGE ROCCCA, Colorado State University — We have demonstrated the volumetric heating of near-solid density plasmas to keV temperatures by ultra-high contrast femtosecond laser irradiation of arrays of vertically aligned nanowires with an average density up to 30% solid density. X-ray spectra show that irradiation of Ni and Au nanowire arrays with laser pulses of relativistic intensities ionizes plasma volumes several micrometers in depth to the He-like and Co-like (Au 52+) stages respectively. The penetration depth of the heat into the nanowire array was measured monitoring He-like Co lines from irradiated arrays in which the nanowires are composed of a Co segment buried under a selected length of Ni. The measurement shows the ionization reaches He-like Co for depth of up to 5 μm within the target. This volumetric plasma heating approach creates a new laboratory plasma regime in which extreme plasma parameters can be accessed with table-top lasers. Scaling to higher laser intensities promises to create plasmas with temperatures and pressures approaching those in the center of the sun.

†Work supported by the U.S. Department of Energy, Fusion Energy Sciences and the Defense Threat Reduction Agency grant HDTRA-1-10-1-0079. A.P was supported by of DFG-funded project TR18.

10:06AM TO6.00009 Characterizing relativistic petawatt-laser-generated particle beams on Orion, MATTHEW HILL, PETER ALLAN, COLIN BROWN, RAY EDWARDS, EDWARD GUMBRELL, DAVID HOARTY, LAUREN HOBBS, STEVEN JAMES, Plasma Physics, AWE, Aldermaston, UK, HUI CHEN, ANDY HAZI, EDWARD MARLEY, RONNIE SHEPHERD, JACKSON WILLIAMS, Physics Division, Lawrence Livermore National Laboratory, CA, USA — The Orion laser facility at AWE has been used to irradiate a variety of metal and plastic targets with up to 600 J of 1.054-um laser light at pulse lengths ranging from 0.5 ps to 8 ps and intensities above 10^{21} W/cm^2. The particle beams produced from these targets include considerable numbers of relativistic electrons (up to 250 MeV) as well as positrons, protons and heavy ions (up to 60 MeV). Magnetic spectrometers, radiographic film stacks and a Thomson parabola suggest strong shear field acceleration of both positrons and ions, as well as very hot electron distributions (T_e >18 MeV) indicating efficient laser-plasma coupling at high intensities. Simultaneous proton radiography and heating have been accomplished on metal foils and foams, showing promise for diagnosing short-pulse laser-plasma interactions as well as fields within extended target objects. We report on the latest progress in charged particle diagnostics systems and experimental platforms on the Orion facility. Supporting work performed at LLNL under the auspices of the U.S. DoE under contract DE-AC52-07NA27344.
11:18AM TO6.00010 Optical Guiding and Electron Acceleration in Programmably Modulated Plasma Waveguides, GEORGE HINE, ANDREW GOERS, JENNIFER ELLE, LINUS FEDER, HOWARD MILCHBERG, Institute for Research in Electronics and Applied Physics, University of Maryland, College Park. — We demonstrate the guiding of relativistically intense laser pulses through programmably structured plasma waveguides. The structure of the waveguide is dictated electronically using a Spatial Light Modulator (SLM). The waveguides are generated by sending a radially patterned intense laser pulse through an axicon in a clustered gas medium, efficiently ionizing and heating a column of plasma which expands to form an optical guiding structure. Intensity modulations at the line focus produce density modulations as the waveguide evolves. Perturbing of the intense laser pulse is achieved using the SLM in an interferometric configuration. This SLM patterning technique allows for in situ sculpting of waveguides with arbitrary density structures. Density ramps are generated for electron injection, and periodic structures are formed to quasi-phase-matched laser wakefield acceleration and direct laser acceleration.

This work is supported by the DoE and DTRA.

11:30AM TO6.00011 Positron Production Using a Laser-Wakefield Electron Source, G. JACKSON WILLIAMS, Lawrence Livermore National Laboratory and UC Davis, Dept of Applied Science, FELICIE ALBERT, HUI CHEN, Lawrence Livermore National Laboratory, JAEBUM PARK, Lawrence Livermore National Laboratory and UC Davis, Dept of Applied Science, BRADLEY POLLOCK, Lawrence Livermore National Laboratory — Laser-driven Cherenkov wake schemes build on the same principle, with only a minor reduction in resolution and applicable range. We were able to characterize the angular distribution of the gamma-rays as a Gaussian cone with a Full-Width-at-Half-Maximum (FWHM) of 35 degrees. The laser (10-ps) laser. The beam is then collimated into an electron–positron spectrometer by an 8-T magnetic field produced with a small (12-mm-diam) coil powered by (TPW), and refinements have been made to the simulation to help design future experiments. In addition, this simulation was used in the design and calibration of Au and Pt targets. The general results of these simulations have been validated in experiments conducted from 2011 to 2013 on the Texas Petawatt Laser (TPW), and refinements have been made to the simulation to help design future experiments. In addition, this simulation was used in the design and calibration of spectrometers used in these experiments. In particular, we have designed and deployed a Forward Compton Electron Spectrometer (FCES) which is more compact and cost-effective than previous instruments. With the reduction in resolution and applicable range, we were able to characterize the angular distribution of the gamma-rays as a Gaussian cone with a Full-Width-at-Half-Maximum (FWHM) of 35 degrees. The laser-to-gamma-ray-energy yield was around 2%. The gamma-ray spectra fit a two-temperature model, with mean temperatures of 2.1 MeV at low energies (up to 5 MeV) and a mean temperature of 6 MeV at high energies (above 10 MeV). In the future, we hope to explore the astrophysical implications of these systems.

11:42AM TO6.00012 Monte-Carlo Simulations of the Creation of High Energy Gamma Rays and Electron/Positron Pairs and Experiments on the Texas Petawatt Laser, ALEXANDER HENDERSON, EDISON LIANG, PABLO YEPES, Rice University, GILLISS DYER, NATHAN RILEY, KRISTINA SERRATTO, University of Texas at Austin. — High intensity (>10^{18} W/cm^2) lasers incident on high-Z, solid targets produce a large number of high-energy electrons, which in turn produce gamma-rays and electron-positron pairs. We have used GEANT4 Monte-Carlo simulation to characterize the production of these particles in and their passage through thick (>1 mm) Au and Pt targets. The general results of these simulations have been validated in experiments conducted from 2011 to 2013 on the Texas Petawatt Laser (TPW), and refinements have been made to the simulation to help design future experiments. In addition, this simulation was used in the design and development of spectrometers used in these experiments. In particular, we have designed and deployed a Forward Compton Electron Spectrometer (FCES) which is more compact and cost-effective than previous instruments. With the reduction in resolution and applicable range, we were able to characterize the angular distribution of the gamma-rays as a Gaussian cone with a Full-Width-at-Half-Maximum (FWHM) of 35 degrees. The laser-to-gamma-ray-energy yield was around 2%. The gamma-ray spectra fit a two-temperature model, with mean temperatures of 2.1 MeV at low energies (up to 5 MeV) and a mean temperature of 6 MeV at high energies (above 10 MeV). In the future, we hope to explore the astrophysical implications of these systems.

12:06PM TO6.00014 Generation of a Strong Terahertz Radiation by Counter-Propagating Laser Pulses in a Magnetized Plasma, MIN SUP HUR, MYUNG-HOON CHO, YOUNG-KUK KIM, UNIST. — A novel scheme of terahertz emission from a laser-plasma system was studied by theory and PIC simulations. In this new scheme, two counter-propagating laser pulses collide in a magnetized plasma. The strong ponderomotive force of the colliding pulses induces longitudinal current, which again is partially converted to a transverse one via the external magnetic field. This current actually plays the role radiating antenna. Since the ponderomotive force of the colliding pulses is generally much stronger than that from the single pulse, the intensity of the terahertz emission from the suggested scheme can be enhanced by tens of times from the single-pulse scheme. Theoretically it was found that the terahertz amplitude scales with the P-square of the driving pulse instead of just P. More than that, an interesting physics of the electric field diffusion near the cutoff was observed in the simulations and fully described theoretically. One direct result of such a driven-diffusion of the electric field is the growth of the central field, leading to increased terahertz emission with the plasma density gradient.

12:18PM TO6.00015 Liquid crystals as on-demand, variable thickness targets for intense laser applications, PATRICK L. POOLE, C. DAVID ANDERECK, DOUGLASS W. SCHUMACHER, The Ohio State University. — Laser-based ion acceleration is currently studied for its applications to advanced imaging and cancer therapy, among others. Targets for these and other high-intensity laser experiments are often small metallic foils with few to sub-micron thicknesses, where the thickness determines the physics of the dominant acceleration mechanism. We have developed liquid crystal films that preserve the planar target geometry advantageous to ion acceleration schemes while providing on-demand thickness variation between 50 and 5000 nm. This thickness control is obtained in part by varying the temperature at which films are formed, which governs the phase (and hence molecular ordering) of the liquid crystal material. Liquid crystals typically have vapor pressures well below the 10^{-6} Torr operating pressures of intense laser target chambers, and films formed in air maintain their thickness during chamber evacuation. Additionally, the minute volume that comprises each film makes the cost of each target well below one cent, in stark contrast to many standard solid targets. We will discuss the details of liquid crystal film control and formation, as well as characterization experiments performed at the Scarlet laser facility.

This work was performed with support from DARPA and NNSA.
Magnetic reconnection in a magnetized high-energy-density plasma is characterized by measuring the dynamics of the plasma density and magnetic field between two counter-propagating and colliding plasma flows. The density and magnetic field were profiled using the \(4\omega\) angular filter refractometry and fast proton deflectometry diagnostics, respectively. The plasma flows are created by irradiating oppositely placed plastic targets with 1.8-KJ, 2-ns laser beams on the OMEGA EP Laser System. The two plumes are magnetized by an externally controlled magnetic field with an \(x\)-type null point geometry with \(B = 0\) at the midplane and \(B = 8\) T at the targets. The interaction region is pre-filled with a low-density background plasma. The counterflowing super-Alfvénic plasma plumes sweep up and compress the magnetic field and the background plasma into a pair of magnetized ribbons, which collide, stagnate, and reconnect at the midplane, allowing for the first detailed observation of a stretched current sheet in laser-driven reconnection experiments. The measurements are in good agreement with first-principles particle-in-cell simulations. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944 and NIFL Grant DE-SC0008655.

\(3\)This work was supported by NNSA under Corporate Agreement No. DE-FC52-08NA28302 and Grant No. DE-NA0002205; by DOE under Grant No. DE-FC02-04ER54789; and by NSF under Grant No. PHY-1314734.
The scaling of reconnection rate in relativistic collisionless magnetic reconnection, YI-HSIN LIU, NASA-GSFC, WILLIAM DAUGHTON, FAN GUO, HUI LI, LANL, MICHAEL HESSE, NASA-GSFC. — Relativistic reconnection is suggested to play a crucial role in the energy release and non-thermal particle acceleration in pulsed winds, gamma-ray burst and astrophysical jets from active galactic nuclei or black holes. While there has been significant progress in understanding the particle spectrum generated during reconnection, the scaling of the reconnection in relativistic regimes remains unclear. Several numerical studies suggest that the reconnection rate is only enhanced mildly from \( \sim 0.1 \) in the non-relativistic regime up to \( \sim 0.3 \) in the strongly relativistic regime, which appears to be consistent with the prediction of Lyubarsky[1]. In this work, first-principle fully kinetic simulations are systematically conducted to explore this issue. In particular, scaling-studies of reconnection rate as function of various parameters, such as the magnetization parameter, upstream pressure and guide field, are performed. Relativistic Ohm’s law is analyzed to identify the mechanism of flux-breaking. Theoretical models are derived and compared against the observed scaling.


10:42AM TOP.00007 How robust is the Fermi acceleration in magnetic reconnection? FAN GUO, HUI LI, WILLIAM DAUGHTON, Los Alamos Natl Lab, XIAOCAN LI, University of Alabama in Huntsville, YI-HSIN LIU, Los Alamos Natl Lab. — Previous kinetic simulations (Guo et al. 2014) have found that magnetic reconnection in relativistic plasmas is highly efficient at accelerating particles through a first-order Fermi process resulting from the curvature drift of particles in the direction of the electric field induced by the relativistic flows. This abstract will focus on understanding how robust the mechanism is in magnetic reconnection. We will discuss this mechanism in large 2D systems with very long simulation time and 3D systems where flux tubes are not well defined. We will also discuss the influence of anisotropy and collision to the mechanism.

10:54AM TOP.00008 Dynamics of the current sheet during driven guide-field reconnection. OLAFL GRULKE, HANNES BOHLIN, DUSAN MILOJEVIC, KIAN RAHRBAINIA, ILYA SHESTERIKOV, ADRIAN VON STECHOW, MPI for Plasma Physics. — A key issue in the spatiotemporal evolution of magnetic reconnection is the geometry and dynamics of the current sheet, which forms in response to the inductive electric field around the X-point. This paper presents experimental investigations of the current sheet during driven reconnection in the cylindrical experiment VINETA.II. Due to the superimposed homogeneous axial guide magnetic field it is observed that the current sheet thickness varies along the X-line due to magnetic mapping effects. Consequently the reconnection rate is a function of axial position. Within the current sheet electromagnetic fluctuations are observed. The fluctuation amplitude correlates with the local current density and has a similar spatial profile as the current sheet. The fluctuations are coherent with nearly isotropic correlation lengths on the order of the electron skin depth. Power spectra display a power law decrease with a breaking slope at the lower hybrid frequency.

11:06AM TOP.00009 Enhanced Magnetic Reconnection By Drift-Wave Instabilities M.J. PUESCHEL, P.W. TERRY, University of Wisconsin-Madison, D. TOLD, Max Planck Institute for Plasma Physics. — A physical process is presented by which magnetic reconnection may be accelerated far beyond the rates usually achievable by tearing modes. The growth rates of reconnection processes are normally regulated by current gradients, whereas micro-scale instabilities in fusion devices tend to be driven by pressure gradients. Through gyrokinetic simulations, the interplay of these mechanisms and its potential consequences for reconnection physics are studied. As in [M.J. Pueschel et al., Phys. Plasmas 18, 112102 (2011)], current sheets are used to drive reconnection, with background density or temperature gradients added independently. If sufficiently large, these gradients may excite a novel, drift-wave-type instability — described here in some detail — that relies fundamentally on parallel magnetic fluctuations. In particular, it is able to couple to the tearing mode via the Vlasov nonlinearity. In this case, the tearing mode starts to grow at the rate of the drift wave, independently of its own drive. Applying this mechanism to the solar corona, it is found that for pressure gradient length scales below 200 km, such gradient-enhanced tearing may be expected to exceed the usual reconnection rate.

11:18AM TOP.00010 Re-assessing how much parallel and perpendicular electric fields accelerate electrons during magnetic reconnection. NAOKI BESSHO, LI-JEN CHEN, KAI GERMASCHEWSKI, The University of New Hampshire, AMITAVA BHATTACHARYEE, Princeton Plasma Physics Laboratory, Princeton University. — By means of 2-D PIC simulations applicable to reconnection in the Earth’s magnetotail, we show that the parallel electric field accelerates electrons only up to 40 keV, and further acceleration above that energy in fact comes from the perpendicular electric field, which can explain observations of energetic electrons with energies greater than 100 keV. We show that the parallel potential, which is the integral of the parallel electric field along the field line, is proportional to \( \omega_{pe}/\Omega \), and also to \( n_e/n_0 \). We also show that \( \omega_{pe}/\Omega \) is the ratio of the plasma frequency to the electron cyclotron frequency, and \( n_e/n_0 \) is the ratio of the lobe density to the density of the current sheet. Applying the parameters in the Earth’s magnetotail to the above relations, we demonstrate that the parallel potential is not more than 40 keV. In addition to pitch angle scattering from the parallel to the perpendicular velocity for electron beams along magnetic field, which was suggested in previous studies, energetic electrons accelerated by the perpendicular electric field experience pitch angle scattering from the perpendicular to the parallel velocity, which can isotropize the plasma in the exhaust.

11:30AM TOP.00011 Fundamental limitation of a two-dimensional description of magnetic reconnection MARIE-CHRISTINE FIRPO, LPP, CNRS - Ecole Polytechnique. — For magnetic reconnection to be possible, the electrons have at some point to “get free from magnetic slavery,” according to von Steiger’s formulation [1]. Stochasticity may be considered as one possible ingredient through Fermi process resulting from the curvature drift of particles in the direction of the electric field induced by the relativistic flows. Observations of energetic electrons with energies greater than 100 keV. We show that the parallel potential, which is the integral of the parallel electric field along the field line, is proportional to \( \omega_{pe}/\Omega \), and also to \( n_e/n_0 \). We also show that \( \omega_{pe}/\Omega \) is the ratio of the plasma frequency to the electron cyclotron frequency, and \( n_e/n_0 \) is the ratio of the lobe density to the density of the current sheet. Applying the parameters in the Earth’s magnetotail to the above relations, we demonstrate that the parallel potential is not more than 40 keV. In addition to pitch angle scattering from the parallel to the perpendicular velocity for electron beams along magnetic field, which was suggested in previous studies, energetic electrons accelerated by the perpendicular electric field experience pitch angle scattering from the perpendicular to the parallel velocity, which can isotropize the plasma in the exhaust.


11:42AM TOP.00012 Non-linear Tearing of 3D Null Point Current Sheets PETER WYPER, GSFC, DAVID PONTIN, Dundee University. — The manner in which the rate of magnetic reconnection scales with the Lundquist number in realistic three dimensional (3D) geometries is still an unsolved problem. It has been demonstrated that in 2D rapid non-linear tearing allows the reconnection rate to become almost independent of the Lundquist number (the “plasmoid instability!”). Here we present the first study of an analogous instability in a fully 3D geometry, defined by a magnetic null point. The 3D null current layer is found to be susceptible to an analogous instability, but is marginally more stable than an equivalent 2D Sweet-Parker-like layer. Tearing of the sheet creates a thin boundary layer around the separatrix surface where efficient mixing of flux between the two topological domains occurs as the flux rope structures created during the tearing process evolve. This leads to a substantial increase in the rate of reconnection between the two domains.
11:54AM TO7.00013 Global stability versus diffusion region micro-physics in flare reconnection during CME formation1, VYACHESLAV S. LUKIN, ED LEE, MARK G. LINTON, Naval Research Laboratory — A model of coronal mass ejection (CME) initiation and flare magnetic reconnection is implemented within the HiFi framework with different combinations of initial conditions governing the magnetic equilibrium and gravitational stratification of the atmosphere. The model’s sensitivity to the initial conditions and reconnection micro-physics is then investigated by a systematic parameter study. We find that the initial equilibrium, which includes a pre-existing magnetic flux rope located above a magnetic X-point, can be unstable to the X-point collapse due to wave accumulation there. However, introduction of an overall guide field allows small-amplitude waves to pass through the X-point and stabilize the equilibrium. Simulations of magnetic flux emergence via photospheric boundary driving demonstrate the impact of the guide field on the dynamics of resulting eruptions. In particular, we find that the rate of flare reconnection and the speed of the CME can be determined by the magnitude of the guide field irrespective of the micro-physics of magnetic reconnection. In a stratified atmosphere, we also identify a novel mechanism for producing quasi-periodic behavior at the flare reconnection site as a possible explanation of similar phenomena observed in solar and stellar flares.  

1This work was supported by NASA SR&T and ONR 6.1.

12:06PM TO7.00014 The Onset of Ion Heating During Magnetic Reconnection with a Strong Guide Field, JAMES DRAKE, MICHAEL SWISDAK, University of Maryland — The onset of the acceleration of ions during magnetic reconnection in the limit of a strong guide field is explored via PIC simulations that self-consistently follow the motions of protons and α particles. Heating parallel to the local field is strongly reduced compared with the anti-parallel reconnection. The dominant heating of thermal ions results from pickup behavior during entry into reconnection exhausts and produces heating perpendicular rather than parallel to the local field. Pickup behavior requires that the ion transit time across the boundary (with a transverse scale of order ρi) be short compared with the cyclotron period. This translates into a threshold in the strength of reconnecting field that favors the heating of ions with high mass-to-charge. A simulation with a broad initial current layer causes the amplitude of the reconnecting field upstream of the dissipation region to increase with time and a sharp onset of perpendicular heating when the pickup threshold is crossed. A comparison of the time variation of the parallel and perpendicular heating with that predicted establishes the scaling of ion heating with ambient parameters both below and above the pickup threshold. The relevance to observations in the solar corona is discussed.

9:30AM - 9:30AM — Session TP8 Poster Session VII: C-MOD Tokamak; Divertors; Boundary / Edge Physics; Heating and Current Drive: Turbulence, Transport and Astrophysical Plasmas Preservation Hall -

TP8.00001 C-MOD TOKAMAK; DIVERTORS; BOUNDARY / EDGE PHYSICS; HEATING AND CURRENT DRIVE —

TP8.00002 ADX: a high field, high power density, Advanced Divertor test eXperiment1, R. VIEIRA, B. LABOMBARD, E. MARMAR, J. IRBY, S. SHIRAIWA, J. TERRY, G. WALLACE, D.G. WHYTE, S. WOLFE, S. WUKITCH, MIT PSFC, FOR THE ADX TEAM — The MIT PSFC and collaborators are proposing an advanced divertor experiment (ADX) — a tokamak specifically designed to address critical gaps in the world fusion research program on the pathway to FNSF/Demo. This high field (6.5 tesla, 1.5 MA), high power density (P/S ∼ 1.5 MW/m²) facility would utilize Alcator magnet technology to test innovative divertor concepts for next-step DT fusion devices (FNSF, DEMO) at reactor-level boundary plasma pressures and parallel heat flux densities while producing high performance core plasma conditions. The experimental platform would also test advanced lower hybrid current drive (LHCD) and ion-cyclotron range of frequency (ICRF) actuators and wave physics at the plasma densities and magnetic field strengths of a DEMO, with the unique ability to deploy launcher structures both on the low-magnetic-field side and the high-field side — a location where energetic plasma-material interactions can be controlled and wave physics is most favorable for efficient current drive, heating and flow drive. This innovative experiment would perform plasma science and technology R&D necessary to inform the conceptual development and accelerate the readiness-for-deployment of FNSF/Demo — in a timely manner, on a cost-effective research platform.

1Supported by DE-FG02-99ER54512.

TP8.00003 Optimizing LHCD launcher using poloidal steering on Alcator C-Mod and ADX, P. BONOLI, B. LABOMBARD, R. PARKER, S. SHIRAIWA, G. WALLACE, S. WUKITCH, R. LECCACORVI, R. VIEIRA, PSFC, MIT, ALCATOR C-MOD TEAM — The poloidal location of the lower hybrid current drive (LHCD) launcher has a strong influence on the trajectory and absorption of the LH wave (poloidal steering). The physics design of an advanced off-midplane launcher (LH3) for Alcator C-Mod exploits this characteristic. By shifting the launcher from the mid-plane by 25cm, it is predicted to realize strong (>80%) single pass absorption localized at about r/a = 0.7 in conjunction with the mid-plane (LH2) antenna. While LH3 is a proposal to overcome the LH density limit and to provide a unique opportunity to validate LHCD simulation codes under reactor-like conditions, poloidal steering can be used more extensively by launching waves from the high field side (HFS). On ADX, the LHCD launcher is proposed to be located on the HFS. Better accessibility due to higher magnetic field allows for using lower N/ri, which results in higher current drive efficiency. Also a more quiescent edge plasma may reduce the effect of N/ri shifts due to scattering from density fluctuations. LHCD simulations for target plasmas expected on ADX, optimization of poloidal steering, and RF simulation of high field side launcher will be presented. This work supported by USDOE awards DE-FG02-99ER54512 and DE-AC02-09CH11466.

TP8.00004 ICRF Actuator Development for Alcator C-Mod and ADX1, W.M. BECK, S.J. WUKITCH, P. KOERT, B. LABOMBARD, Y. LIN, R. VIEIRA, J. TERRY, MIT PSFC, AND ALCATOR C-MOD TEAM — Future fusion reactors will present more severe constraints on ion cyclotron range of frequency (ICRF) actuators than ITER or present day experiments. One challenge to ICRF utilization is its interaction with the edge plasma, particularly impurity contamination and enhanced localized heat loads. Another is maintaining high coupled power through plasma variations, with high power density and antenna materials compatible with a nuclear environment. The RF plasma edge interaction is thought to be linked to RF electric fields parallel to the magnetic field, E||. Experiments comparing a field aligned (FA), minimized integrated E||, and a toroidally aligned (TA) antenna have demonstrated the FA antenna has significantly reduced impurity contamination and antenna impurity source compared to the TA antennas. The FA antenna also shows load tolerance we speculate to be a result of reduced slow wave coupling between straps and reduced RF induced heat flux. Latest results and analysis will be presented including further optimization that can be realized by locating the antenna to the high field side due to the inherent impurity screening observed in near double null configuration.

1Supported by US DOE award DE-FG02-99ER54512.
TP8.00005 ARC: A compact, high-field, disassemblable fusion nuclear science facility and demonstration power plant.

Brandon Sorbom, MIT, Justin Ball, MIT, Oxford, Timothy Palmer, Franco Mangiarotti, Jennifer Sierchio, Paul Bonoli, Caleb Kaster, Derek Sutherland, Harold Barnard, Christian Haakonsen, Jon Goh, Choongki Sung, Dennis Whyte, MIT — The Affordable, Robust, Compact (ARC) reactor conceptual design aims to reduce the size, cost, and complexity of a combined Fusion Nuclear Science Facility (FNSF) and demonstration fusion pilot power plant. ARC is a 270 MWe tokamak reactor with a major radius of 3.3 m, a minor radius of 1.1 m, and an on-axis magnetic field of 9.2 T. ARC has Rare Earth Barium Copper Oxide (REBCO) superconducting toroidal field coils with joints to allow disassembly, allowing for removal and replacement of the vacuum vessel as a single component. Inboard-launched current drive of 25 MW LHRF power and 13.6 MW ICRF power is used to provide a robust, steady state core plasma far from disruptive limits. ARC uses an all-liquid blanket, consisting of low pressure, slowly flowing Fluorine Lithium Beryllium (FLiBe) molten salt. The liquid blanket acts as a working fluid, coolant, and tritium breeder, and minimizes the solid material that can become activated. The large temperature range over which FLiBe is liquid permits blanket operation at 800-900 K with single phase fluid cooling and allows use of a high-efficiency Brayton cycle for electricity production in the secondary coolant loop.

TP8.00006 Upgraded PMI diagnostic capabilities using Accelerator-based In-situ Materials Surveillance (AIMS) on Alcator C-Mod.

Leigh Kessler, Harold Barnard, Zachary Hartwig, Brandon Sorbom, Richard Lanza, David Terry, Rui Vieira, Dennis Whyte, Massachusetts Institute of Technology — The AIMS diagnostic was developed to rapidly and non-invasively characterize in-situ material interactions (PMI) in a tokamak. Recent improvements are described which significantly expand this measurement capability on Alcator C-Mod. The detection time at each wall location is reduced from about 10 min to 30 s, via improved hardware and detection geometry. Detectors are in an augmented re-entrant tube to maximize the solid angle between detectors and diagnostic locations. Spatial range is expanded by using beam dynamics simulation to design upgraded B-field powers supplies to provide maximal poloidal access, including a ~ 20 m toroidal range in the divertor. Measurement accuracy is improved with angular and energy resolved cross section measurements obtained using a separate 0.9 MeV deuteron ion accelerator. Future improvements include the installation of recessed scintillator tiles as beam targets for calibration of the diagnostic. Additionally, implanted depth marker tiles will enable AIMS to observe the in-situ erosion and deposition of high-Z plasma-facing materials. This work is supported by U.S. DOE Grant No. DE-FG02-94ER54423 and Cooperative Agreement No. DE-FC02-99ER54512.

TP8.00007 The influence of divertor geometry on access to high confinement regimes on the Alcator C-MOD tokamak.

J.W. Hughes, B. Labombard, A. Hubbard, E. Marmar, J. Terry, J. Rice, J. Walk, D. Whyte, MIT, PSFC, Y. Ma, ITER Organization, I. Cziegler, UCSD, E. Edlund, PPL, C. Theiler, EPFL — The placement of X-point and strike points in a diverted tokamak can have a remarkable impact on properties of the divertor, including thermal and particle confinement. The distinctive divertor of Alcator C-MOD allows us to demonstrate these effects experimentally, as we vary equilibrium shaping to obtain substantial variation of divertor leg length, field line attack angle and divertor baffling. In response to these changes, we observe differences in both L-mode confinement and access to high-confinement regimes (i.e. ELMy H-mode and I-mode). With the ion grad-B drift directed toward the divertor, scanning the strike point can induce ~ 2x reductions in H-mode power threshold, and can produce a window for I-mode operation with H98 > 1. Recent experiments seek to explore these effects using improved diagnostics, and to extend them to the case with ion grad-B drift directed away from the divertor.

1Supported by USDoE award DE-FC02-99ER54512.

TP8.00008 Scalings of nonlinear transfer processes in the edge plasma and their connection to turbulence and the appearance of a higher-frequency (about 200 to 400 kHz) fluctuation, dubbed the “weakly-coherent mode” (WCM). The WCM is well characterized experimentally, with density and temperature fluctuations visible on multiple diagnostics. First analysis of C-MOD I-mode pedestals with the BOUT++ code was presented. The magnetic equilibrium is generated using the kinetic EFIT with measured pressure profile and the calculated bootstrap current from the Sauter model. The linear simulations are carried out using fits to measured plasma density and electron temperature profiles, assuming that electron and ion temperature are equal Te = Ti. The electric field is determined by the force balance relation assuming no net equilibrium flow. The preliminary simulation results show that there is no peeling-ballooning mode instability, consistent with earlier ELITE analysis. When turning off the parallel electron pressure gradient term in Ohm’s law in 6-field two-fluid model, the linear growth rate is small, indicating that the drift-Alfven instability is dominant. The linear and nonlinear simulation results with experimentally measured Er profile will also be presented.

TP8.00009 First analysis of I-mode pedestals with the BOUT++ code.

Zixi Liu, ASIPP, Xueqiao Xu, LNL, Xiang Gao, ASIPP, A.E. Hubbard, Jerry Hughes, PSFC, T.Y. Xia, ASIPP, J.R. Walk, C. Theiler, PSFC, Tao Zhang, J.G. Li, ASIPP, East Team, LNL Collaboration, PSFC Collaboration — Edge turbulence in I-mode is characterized by a strong reduction of mid-frequency turbulence and the appearance of a higher-frequency (about 200 to 400 kHz) fluctuation, dubbed the “weakly-coherent mode” (WCM). The WCM is well characterized experimentally, with density and temperature fluctuations visible on multiple diagnostics. First analysis of C-MOD I-mode pedestals with the BOUT++ code will be presented. The magnetic equilibrium is generated using the kinetic EFIT with measured pressure profile and the calculated bootstrap current from the Sauter model. The linear simulations are carried out using fits to measured plasma density and electron temperature profiles, assuming that electron and ion temperature are equal Te = Ti. The electric field is determined by the force balance relation assuming no net equilibrium flow. The preliminary simulation results show that there is no peeling-ballooning mode instability, consistent with earlier ELITE analysis. When turning off the parallel electron pressure gradient term in Ohm’s law in 6-field two-fluid model, the linear growth rate is small, indicating that the drift-Alfven instability is dominant. The linear and nonlinear simulation results with experimentally measured Er profile will also be presented.

TP8.00010 Light impurity transport in I-mode in Alcator C-MOD.

W.L. Rowan, I.O. Bespamyatnov, D.R. Hatch, W.L. Horton, K.T. Liao, IFS, The University of Texas at Austin — The I-mode hallmarks are H-mode-like electron temperature pedestal and energy confinement simultaneous with L-mode-like density pedestal and particle confinement. The I-mode is observed over a wide range of plasma parameters and is robust. As might be expected from the particle confinement observation, accumulation of naturally-occurring impurities is reduced compared to H-mode. Heavy impurity measurements confirm the observation of L-mode-like particle confinement. In the results reported here for light impurities, I-mode impurity profiles are compared with both H- and L-mode profiles for helium and boron with an emphasis on core confinement. We search for the dependence of the impurity density gradient on the equilibrium density and temperature scale length, the Zeff the collisionality, as well as on total radiation loss, stored energy, and global confinement. The results allow comparisons among discharge modes, as well as comparison to other devices, and turbulence predictions. The data analysis is compared with gyrokinetic simulations using the GENE code.

1Supported by USDoE award DE-FG03-96ER54373.
TP8.00011 Validation of spectral MSE for Alcator C-Mod and ITER1

I.O. BESPAMYATNOV, W.L. ROWAN, IFS, The University of Texas at Austin, R.T. MUMGAARD, R.S. GRANETZ, MIT-PSFC, S.D. SCOTT, PPPL, F. LEVINTON, H. YUH, Nova Photonics, Inc.

The MSE spectrum was measured on C-Mod with sufficient accuracy to infer the spectral shifts and relative spectral intensities of the MSE full-energy pi and sigma components. The results were successfully used to benchmark new predictions. (I. O. Bespamyatnov, Nucl. Fusion 53 (12), 123010 (2013)). MSE optics, spectrometer, beam timing, plasma/gas density and magnetic field were optimized. Spectral resolution was improved by 50% over 2012 results by decreasing the spectrometer slits and the aperture of the MSE optics. Spectral fitting analysis was developed and optimized for local diagnostic equipment and plasma conditions. The spectral MSE approach, one based on line ratios and the other based on line shifts, can be compared to MIE polariometry which provides reliable pitch angle measurement for C-Mod. The results of these experiments are reported here and applicability both to C-Mod and ITER is discussed. Based on these results, additional hardware improvements are proposed.

1Supported by USDoE awards DE-FG03-96ER54373, DE-FCO0-99ER54512, DE-AC02-09CH11466.

TP8.00012 Design and construction of a multi-spectral MSE system for Alcator C-Mod, ROBERT T. MUMGAARD, MIT PSFC, STEVEN D. SCOTT, PPPL — Extensive studies of polarized inside the Alcator C-mod tokamak have identified the sources of partially polarized light which contaminates the Motional Stark Effect (MSE) measurement. A multi-spectral MSE approach has been developed utilizing a narrow-bandpass, interference-filter-based polychromator which measures the polarization simultaneously at multiple wavelengths on the same viewing sightline. This allows the MSE polarized background to be wavelength interpolated in real time using off-MSE wavelengths. A 10 sightline, 4-wavelength, high throughput imaging polychromator system was designed, based on experience from a successful prototype. This system incorporates advances in high transmission (>90%) narrow bandpass filters, filter temperature tuning and avalanche photodiode detectors. In addition to enabling a factor of 5-10x improvement in background reduction, the MSE system was designed, based on experience from a successful prototype. This system incorporates advances in high transmission (>90%) narrow bandpass filters, filter temperature tuning and avalanche photodiode detectors. In addition to enabling a factor of 5-10x improvement in background reduction, this system was designed, based on experience from a successful prototype. This system incorporates advances in high transmission (>90%) narrow bandpass filters, filter temperature tuning and avalanche photodiode detectors. In addition to enabling a factor of 5-10x improvement in background reduction, the MSE system is designed to be remotely operable and largely device independent. Initially, it will be deployed on C-Mod to enable MSE measurements in Advanced-Tokamak plasmas under development there. This work is supported by USDoE awards DE-FCO0-99ER54512 and DE-AC02-09CH11466.

TP8.00013 Comparison of techniques for determining structure velocities in Gas-Puff Imaging data1, J.M. SIERCIOOH, A.E. WHITE, J.L. TERRY, MIT PSFC, I. CZIEGLER, USCD, S.J. ZWEBEN, PPPL — The Gas Puff Imaging (GPI) diagnostic on Alcator C-Mod has been previously in numerous studies involving code validation, GAMs and zonal flows, and turbulent blob dynamics. Different methods of analyzing GPI data for turbulent structure velocities are presented, including Fourier analysis, time delay estimation, and pattern tracking. Representative implementations of these methods are explained and their results are compared on the same GPI data to reveal both agreements and discrepancies in measured velocities. We have developed a code for producing synthetic sequences of images that mimic features of the actual GPI images but move the images' structures at known velocities. This allows quantitative analysis of the analysis methods and reveals their strengths and weaknesses. We have found that the methods agree when the structures move in the same direction but disagree when there is significant dispersion or structures appearing to move in opposite directions. Comments on the appropriate use of each of method, as well as some important physics involving multi-scale/field dispersion, will be explained.

1Supported by USDoE award DE-FCO0-99ER54512 and NSF GRFP.

TP8.00014 Understanding the Role of Electron-Scale Turbulence in the Core of Alcator C-Mod Using Multi-Scale Gyrokinetic Simulation1, N.T. HOWARD, ORISE, C. HOLLAND, USCD, A.E. WHITE, M. GREENWALD, MIT-PSFC, J. CANDY, General Atomics — First-of-a-kind, nonlinear gyrokinetic simulations that capture both the ion and electron spatio-temporal scales were performed in the core (r/a = 0.6) of Alcator C-Mod, ITG and TEM dominated. These simulations demonstrated the coexistence of ion- and electron-scale turbulence, an enhancement of ion-scale turbulence, and an ion-scale turbulence. These simulations, performed using the GYRO code, capture ion and electron-scale turbulence up to kl = 4.8 with realistic electron mass (m/0.01(m/0.01))5 = 60.0), allowing for the first quantitative comparison of multi-scale simulations with experiment. Electron-scale turbulence plays a significant, even dominant, role in the core of a standard ITG and TEM dominated L-mode discharges, driving experimentally-relevant levels of electron heat flux in the form of radially elongated ETG "streamers" that coexist, ion-scale turbulent eddies. The implications of these results for transport models are discussed.

1Supported by USDoE award DE-FCO0-99ER54512.

TP8.00015 Investigating electromagnetic effects on core transport in Alcator C-Mod H-mode discharges, W. GUTENFELDER, PPPL, N.T. HOWARD, ORISE, J. IRBY, PSFC, MIT, F.M. POLI, PPPL, A.E. WHITE, PSFC, MIT, W.F. BERGERSON, Lincoln Labs, MIT, D.L. BROWER, W.X. DING, UCLA, C.E. KESSEL, PPPL, C. SUNG, S.M. WOLFE, P. XU, PSFC, MIT — Understanding the importance of electromagnetic effects on core turbulence and transport is being pursued at Alcator C-Mod, especially for higher performance H-mode plasmas at increasing beta. Previously reported measurements from a line-integrated polarmeter diagnostic reveal broadband, high frequency fluctuations [1]. The presence of these features, absent in core and edge density fluctuation measurements from phase contrast imaging, suggest they may be related to fluctuations in the magnetic field. Such features were observed in a number of H-mode plasmas over a range of normalized beta (βN ~ 1.2) and Greenwald fraction (fGW ~ 0.45-0.85). To investigate the possible influence of electromagnetic effects on core transport and turbulence, gyrokinetic simulations are used to predict microinstabilities of these discharges, the corresponding relative amplitude of the magnetic fluctuations in comparison to density fluctuations, and the sensitivity of these predictions to variations in beta. Results of both linear and nonlinear simulations and their comparison with transport and turbulence measurements will be presented. This work is supported by US DOE contracts DE-AC02-09CH11466 and DE-FCO0-99ER54512.


TP8.00016 Gyrokinetic Simulations of Impurity Seeded C-Mod Ohmic Plasmas1, MIKLOS PORKOLAB, PAUL ENNEVER, JOHN RICE, J. CHRIS ROST, EVAN DAVIS, DARIN ERNST, CATHERINE FIORE, AMANDA HUBBARD, JERRY HUGHES, JIM TERRY, MIT, NAOTO TSUJII, University of Tokyo, JEFF CANDY, GARY STAEBLER, General Atomics, MATTHEW REINKE, University of York, AND ALCATOR C-MOD TEAM — Ohmic plasmas on C-Mod were seeded with nitrogen to study the impact of dilution in the LOC (linear ohmic) and SOC (saturated ohmic) regimes [1]. The seeding decreased ion diffusivity and caused the rotation to reverse in certain cases. TGLF, TGYRO, and global gyro simulations were performed on these plasmas, simulating both transport and the density fluctuations. TGYRO simulations using TGLF showed that the ion temperature profile only needed slight modification to get agreement with the heat flux, and the electron temperature profile needed no modification. However, when these TGYRO modified profiles were simulated with global GYRO the ion and electron fluxes were much lower than the experimental measurements and the TGLF simulated fluxes. The average of these TGYRO and experimental profiles gave ion fluxes that agreed with the experimental fluxes, and the density fluctuations agreed with PCI measurements. The electron flux from GYRO is below experimental levels, and since these plasmas have little TEM turbulence, current ETG simulations are being performed to make up the difference. Results will be presented.

1Work supported by US DOE awards DE-FG02-94-ER54235 and DE-FG02-99-ER54512.
TP8.00017 ICRF Induced Argon Pumpout in H-D Plasmas at Alcator C-Mod

S. Cao, J.E. Rice, MIT-PSFC, M.L. Reinke, University of York, Y. Lin, S.J. Wukitch, E.S. Marmar, MIT-PSFC, and Alcator C-Mod Team — Argon pumpout during ICRF experiments in H-D plasmas is observed at Alcator C-Mod. This pumpout happens only when 1) the H/D ratio is relatively high ($n_{H}/n_{D}$ ≈ 35–65%), at which level the H-D mode conversion layer is close to the Ar(I+2) 2nd harmonic resonance layer, and 2) the ICRF power is above 0.4 MW. At Alcator C-Mod the 80 MHz ICRF is launched from the low-field side, different from the TFR tokamak where the pumpout effect was first reported. The directly measured Ar(I+2) and Ar(I+) emissivity profiles show that the pumpout happens in all plasma regions for several argon charge states. A scan of H/D ratio shows that the pumpout effect is maximized at $n_{H}/n_{D}$ = 42 ± 5%, at which about 80% of argon is pumped out within 50 ms. It is yet to be understood whether the resonant effect or the peripheral/edge effect dominates the pumpout process. Preliminary simulation shows that the pure edge effect cannot fully reproduce the fast response of the core emissivity in the experiments. More analyses will be performed using the time-evolving impurity transport code STRAHL.

supported by USDoE award DE-FC02-99ER54512.

TP8.00018 Extending the Capabilities of the Shoelace Antenna on Alcator C-Mod

T. Golfinopoulos, B. Labombard, R.R. Parker, W. Burke, E.M. Davis, R. Granetz, M. Greenwald, J.W. Hughes, J.H. Irby, R. Lecacorvi, E.S. Marmar, W. Parkin, M. Porkolab, J.L. Terry, R.F. Vieira, S.M. Wolfe, S. Wukitch, MIT, Alcator C-Mod Team — The mission of the Shoelace antenna is to couple to short-wavelength edge fluctuations in order to study their properties, possibly open-ended and closed-loop control, and to exploit these fluctuations to actively drive transport. The antenna matches both perpendicular wave number and frequency to two such fluctuations: the Weakly- and Quasi-Coherent modes, which regulate transport across the plasma boundary in high-performance, ELM-free, steady-state regimes. In initial operation, the antenna induced a drift-wave-like edge mode [Golfinopoulos Phys. Plasmas '14], but no measurements were available to assess resultant transport. Here, we present two upgrades to the system. The antenna’s pitch angle was adjusted such that, when field-aligned, the antenna maps to the Mirror Langmuir Probe [Labombard Phys. Plasmas '14], providing detailed fluctuation, profile, and transport measurements. In addition, antenna power has been quadrupled to ≥ 6 kW, increasing driven mode amplitude and reach up the pedestal.

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

TP8.00019 Locked-mode avoidance and recovery without external momentum input

L. Delgado-Aparicio, D.A. Gates, PPL, S. Wolfe, J.E. Rice, C. Gao, S. Wukitch, M. Greenwald, J. Hughes, E. Marmar, MIT-PSFC, S. Scott, PPL — Error-field-induced locked-modes (LMs) have been studied in C-Mod at ITER toroidal fields without NBI fueling and momentum input. The use of ICRF heating in synch with the error-field ramp-up resulted in a successful delay of the mode-onset when $P_{ICR}$ > 1 MW and a transition into H-mode when $P_{ICR} > 2$ MW. The recovery experiments consisted in applying ICRF power during the LM non-rotating phase successfully unlocking the core plasma. The “induced” toroidal rotation was in the counter-current direction, restoring the direction and magnitude of the toroidal flow before the LM formation, but contrary to the expected Rice-scaling in the co-current direction. However, the LM occurs near the LOC/SOC transition where rotation reversals are commonly observed. Once LM is turned off, the core plasma “locks” at later times depending on the evolution of $n_{e}$ and $V_{f}$. This work was performed under US DoE contracts including DE-FC02-99ER54512 and others at MIT and DE-AC02-09CH11466 at PPL.

TP8.00020 Amplitude modulation of lower hybrid waves for transport control

G.M. Wallace, S.G. Bae, I.C. Faust, T. Golfinopoulos, B.L. Labombard, R.T. Mumgaard, R.R. Parker, S.D. Scott, S. Shiraiwa, J.L. Terry, MIT-PSFC — Steady, high-power lower hybrid (LH) waves have been shown to alter transport characteristics in the edge and pedestal regions of EDA H-modes on Alcator C-Mod [J. Hughes et al, Nucl. Fus., 2010]. The modifications of the pedestal are particularly striking in high-density H-modes [J. Terry, this conference], perhaps through interaction with the transport-regulating edge Quasi-Coherent Mode (QCM), since it is strongly affected by the injection of LH waves. The transport effect of a QCM precurs Simple Spitzer model is used to estimate the residual inductively-driven current which scales the pre-LH current by the ratio of the loop voltage to the pre-LH current, correcting also for the change in conductivity. The current-drive efficiency is defined as $\eta = P_{LH} / V_{LH}$ During LHCD, a simple Spitzer model is used to estimate the residual inductively-driven current which scales the pre-LH current by the ratio of the loop voltage to the pre-LH current, correcting also for the change in conductivity. The current-drive efficiency is defined as $\eta = P_{LH} / V_{LH}$ $\eta = 0.065 + 0.40 \times I_{p}$ [MA], reaching a value of $\eta = 0.47$ at $I_{p} = 1.02$ MA. A positive but weaker correlation between $\eta$ and $\eta$ does not explain the $\eta$ dependence on $I_{p}$. Preliminary GENRAY/CQL3D simulations at $I_{p} = 1.0$ MA predict 900 kW of driven current versus 1000 kA observed. Comparons of $\eta$ to numerical simulations over a wide parameter range will be discussed.

This work supported by DoE awards DE-FC02-99ER54512 and DE-AC02-09CH11466.

TP8.00021 Scaling of Global LHCD Efficiency in Alcator C-Mod

S. Scott, PPL, P. Bonoli, R. Mumgaard, S. Shiraiwa, G. Wallace, D. Whytne, MIT-PSFC — A database of global current-drive efficiency by Lower Hybrid waves has been assembled covering nine years of C-Mod operation. Plasma conditions were averaged over 50 ms time slices during equilibrated current-profile time periods, excluding transient events such as Prad spikes. The database comprises 1980 time slices spanning $PLH < 1.1$ MW, $n_{e} = 1.5-2.3$, $I_{p} = 0.3-1.0$ MA, $\omega_{p} = 0.35-1.5 e^{20}$. Nine percent of the data points are approximately non-inductive ($\Delta V_{H} / V_{H} > 0.9$), while 17 percent experience low m, n MHD that degrades the LHCD efficiency. During LHCD, a simple Spitzer model is used to estimate the residual inductively-driven current which scales the pre-LH current by the ratio of the loop voltage to the pre-LH loop voltage, correcting also for the change in conductivity. The current-drive efficiency is defined as $\eta = P_{LH} / V_{LH}$ $\eta = 0.065 + 0.40 \times I_{p}$ [MA], reaching a value of $\eta = 0.47$ at $I_{p} = 1.02$ MA. A positive but weaker correlation between $\eta$ and $\eta$ does not explain the $\eta$ dependence on $I_{p}$. Preliminary GENRAY/CQL3D simulations at $I_{p} = 1.0$ MA predict 900 kW of driven current versus 1000 kA observed. Comparons of $\eta$ to numerical simulations over a wide parameter range will be discussed.

1Work supported by DoE awards DE-FC02-99ER54512 and DE-AC02-09CH11466.

TP8.00022 "nScope: python based scientific workbench with visualization tool for MDSplus data

S. Shiraiwa, PSFC, MIT — nScope [1] is a python based scientific data analysis and visualization tool constructed on wxPython and Matplotlib. Although it is designed to be a generic tool, the primary motivation for developing the new software is 1) to provide an updated tool to browse MDSplus [2] data, with functionalities beyond dwscope and jScope [3, and 2) to provide a universal interface to construct interface tools to perform computer simulation and modeling for Alcator C-Mod. It provides many features to visualize MDSplus data during tokamak experiments including overplotting different signals and discharges, various plot types (line, contour, image, etc.), in-panel data analysis using python scripts, and publication quality graphics generation. Additionally, the logic to produce multi-panel plots is designed to be backward compatible with dwscope, enabling smooth migration for dwscope users. nScope uses multithreading to reduce data transfer latency, and its object-oriented design makes it easy to modify and expand while the open source nature allows portability. A built-in tree data browser allows a user to approach the data structure both from a GUI and a script, enabling relatively complex data analysis workflow to be built quickly. As an example, an IDL-based interface to perform GENRAY/CQL3D simulations was ported on nScope, thus allowing LHCD simulation to be run between shot using C-Mod experimental profiles. This workflow is being used to generate a large database to develop a LHCD actuator model for the plasma control system. [1]http://piscope.psfc.mit.edu [2]http://www.mdsplus.org. Supported by USDoE award DE-FC02-99ER54512.
TP8.00023 Documenting scientific workflow: the metadata, provenance and ontology project1, MARTIN GREENWALD, J. STILLERMAN, J. WRIGHT, MIT - PSFC, G. ABLA, R. CHANTHAVONG, D. SCHISSEL, General Atomics, A. ROMOSAN, A. SHOSHANI, LBNL — Careful management of data, its creation and transformation (provenance) and associated metadata is a critical part of any scientific enterprise. Traditionally this was the role of the lab notebook, but the digital era has resulted instead in the fragmentation of data, processing and annotation. This paper describes an ongoing multi-institutional project aimed at remedying this problem by developing tools to automate documentation of scientific workflows and associated information. Data and all processes that create or modify that data are represented mathematically as a directed acyclic graph, providing explicit information about the relationships between elements with all elements having globally unique and persistent IDs. The export of data, for publication, presentation or external databases would be recorded, allowing traceability in either direction — answering the questions “Where was this data used?” or “Where did the data in this figure come from.” Namespace management is provided through a well structured “ontology,” which can be customized for any particular community or application.  

1Supported by DOE contract DE-SC0008736.

TP8.00024 Towards a Lithium Radiative / Vapor-Box Divertor1, ROBERT GOLDSTON, Princeton Plasma Physics Laboratory, MARIUS CONSTANTIN, Yale University, MICHAEL JAWORSKI, Princeton Plasma Physics Laboratory, RACHEL MYERS, Princeton University, MASAYUKI ONO, JACOB SCHWARTZ, Princeton Plasma Physics Laboratory, FILIPPO SCOTTI, Lawrence Livermore National Laboratory, ZHAONAN QU, Princeton University — Recent research has indicated that the peak perpendicular heat flux on reactor divertor targets will be hundreds of MW/m² in the absence of dissipation and/or spatial spreading. Thus we are attracted to both enhanced radiative cooling and continuous vapor shielding. Lithium particle lifetimes < 100 micro-sec enhance radiation efficiency at T <10 eV, while lithium charge-exchange with neutral hydrogen may enhance radiative efficiency for T >10 eV and nH/nL >0.1. We are examining if the latter mechanism plays a role in the narrowing of the heat-flux footprint in lithiated NSTX discharges. In parallel we are investigating the possibility of immersing a reactor divertor leg in a channel of lithium vapor. If we approximate the vapor channel as in local equilibrium with lithium-wetted walls ranging from 300°C at the entrance point to 950°C 10m downstream in the parallel direction, we find that the vapor can both balance reactor levels of upstream plasma pressure and stop energetic ions and electrons with energies up to at least 25 keV, as might be produced in ELMs. Each 10 l/sec of lithium evaporated deep in the channel and recondensed in cooler regions spreads 100 MW over a much wider area than the original strike point.

1This work supported by US DOE contract DE-AC09-06CH11466

TP8.00025 Classification of magnetic configurations for the cloverleaf divertor, D.D. RYUTOV, M.V. UMANSKY, LLNL — The cloverleaf divertor [D.D. Ryutov, M.V. Umansky, Phys. Plas., 20, 092509, 2013] is based on magnetic configuration with the third-order poloidal field null. If the currents in the divertor coils are somewhat different from those required for the generation of the third-order null, the latter splits into three closely-spaced first-order nulls. One can move these nulls around by changing the currents in the divertor coils. A large variety of configurations can be created. In this study we provide general topological classification of all configurations possible in the case of the coils situated at sufficiently large distance from the nulls. It turns out that these configurations can be identified by a single dimensionless parameter, analogously to what has been done for the snowflake divertor [D.D. Ryutov, M.A. Makowski, M.V. Umansky, PPCF, 52, 105001, 2010]. In addition to this general classification, we evaluate the length scales of the field variation in each of the three nulls, as well as connection lengths and local magnetic shear for a variety of configurations. Work performed for U.S. DOE by LLNL under Contract DE-AC52-07NA27344.

TP8.00026 Modifying COGENT to Study Snowflake Divertors1, R.H. COHEN, CompX, M. DORF, M. DORR, D.D. RYUTOV, LLNL — The snowflake divertor concept entails modifying the poloidal field system of a tokamak to produce a 2nd-order null in magnetic-field strength in place of the conventional 1st-order null x point within the equilibrium magnetic-field separatrix. It more effectively spreads the divertor heat load and offers a number of other advantages. We describe plans to modify the COGENT edge kinetic code to study snowflake divertors. COGENT employs mapped multi-block grid technology to handle the geometric complexity of the conventional divertor configuration. To simulate snowflake divertors, the number of grid blocks is increased from 8 to 12, consistent with the modified topology of the exact snowflake configuration. We examine the applicability of the modified structure to study configurations that are not exactly snowflakes, the so-called “snowflake-plus” and “snowflake-minus” configurations. Initial applications of the modified code will be assessment of collisionless orbit dynamics and neoclassical transport.

1Work performed for U.S.DOE by LLNL under contract DE-AC52-07NA27344 and by CompX under sub-contract from LLNL.

TP8.00027 Modeling of ion orbit loss and intrinsic toroidal rotation with the COGENT code1, M. DORF, M. DORR, Lawrence Livermore National Laboratory, R. COHEN, CompX, T. ROGLNLIEN, J. HITTINGER, Lawrence Livermore National Laboratory — We discuss recent advances in cross-separatrix neoclassical transport simulations with COGENT, a continuum gyro-kinetic code being developed by the Edge Simulation Laboratory (ESL) collaboration. The COGENT code models the axisymmetric transport properties of edge plasmas including the effects of nonlinear (Fokker-Planck) collisions and a self-consistent electrostatic potential. Our recent work has focused on studies of ion orbit loss and the associated toroidal rotation driven by this mechanism. The results of the COGENT simulations are discussed and analyzed for the parameters of the DIII-D experiment.

1Work performed for USDOE at LLNL under contract DE-AC52-07NA27344

TP8.00028 PIC Simulation of plasma detachment1, SEJII ISHIGURO, National Institute for Fusion Science, THEERASARN PIANPANIT, The Graduate University for Advanced Studies (Sokendai), HIROKI HASEGAWA, RYUTARO KANNO, National Institute for Fusion Science — The detached plasma, which is caused by gas puffing, has been proposed and it is the most promising way to reduce the heat load to the divertor plate of fusion oriented devices. Dynamical and kinetic behavior of the detached plasma is unresolved. So we are developing particle-in-cell simulation model with atomic processes such as line radiation, ionization, charge-exchange collision and recombination. As a first step, we have performed PIC simulation with Monte Carlo collisions, where spatial and velocity space distributions of charged particles, self-consistent electric field, and atomic processes such as ionization and charge exchange are included. Temperature decrease and density increase in front of the target is observed and electric potential structure along the axis is created.

1This work is performed with the support and under the auspices of NIFS Collaboration Research programs[NIFS14KNNX279 and 8 NIFS13KNS038] and the Research Cooperation Program on Hierarchy and Holism in Natural Sciences at the NINS.
TP8.00029 Seeking Stable Detachment Scenarios of Advanced X-Divertors with SOLPS 5.1, BRENT COVELE, PRASHANT VALANJIU, MIKE KOTSCHENREUTHER, SWADESH MAHAJAN, UT-Austin Institute for Fusion Studies, JOHN CANIK, Oak Ridge National Laboratory, HUTCH NEILSON, CHARLES KESSEL, Princeton Plasma Physics Laboratory, BRIAN LABOMBARD, STEPHEN WOLFE, MIT Plasma Science & Fusion Center — A broad investigation into new magnetic equilibria for several tokamaks (C-Mod, NSTX-Upgradable, K-DEMO, and a Fusion Nuclear Science Facility) using the CORSICA code has revealed a host of advanced X-Divertors (XD) feasible on existing and planned PF coil sets. Because of their flaring flux tubes and higher Divertor Index ($D_{IXD} > 1$), XDAs may open regimes of stable divertor detachment without negatively impacting H-Mode confinement, something which has not been experimentally achievable with a standard divertor ($D_{IXD} = 1$). To investigate stable X-Divertor detachment, 2D transport modeling is performed using the SOLPS 5.1 code suite. Sophisticated neutral physics modeling in the Eirene 2008 code, including neutral-neutral interactions, is required to accurately model the evolution of detachment. Initial results show steep, steady-state parallel electron temperature gradients near the divertor targets, as well as a reduction in the target heat fluxes. This is indicative of an arrestment of the detachment front near the targets, as predicted by the Divertor Index.

TP8.00030 Direct Measurement of the First Wall Recycling Coefficient on RFX-mod, ROBERTO CAVAZZANA, MATTEO AGOSTINI, LORELLA CARRARO, PAOLO INNOCENTE, LIONELLO MARRELLI, PAOLO SCARIN, GIANLUCA SPIZZO, MONICA SPOLARE, NICOLA VIANELLO, MATTEO ZUIN, Consorzio RFX (CNR, ENEA, INFN, Universita' di Padova, Acciaieria Venete SpA) — A diagnostic for the direct measurement of the Deuterium particle fluxes and the recycling coefficient $\Gamma = \Gamma_{in}/\Gamma_{out}$ at the first wall has been recently installed on RFX-mod. The system is composed by a set of combined diagnostics. Two sets of Langmuir probes (LP) are mounted on a movable graphite tile; one is configured as a triple probe (measuring $T_e, n_e$, while the other set uses two floating potential for the measurement of the electric field and plasma flow velocity transverse components. The two LP sets can also be combined as a Mach probe for estimation of the parallel flow velocity, allowing the separation between the convective and the turbulent contributions. A set of spectroscopic measurements (calibrated D$_e$, C-II and Li-I emissions), a single point thermal infrared sensor and a fast camera in the visible range aimed at the graphite tile, are used to evaluate the particle influx and the response of the graphite sample at different plasma conditions. The intent is to determine the behavior of the asymmetry of the recycling coefficient due to the geometry of the magnetic field. Furthermore it will be possible to establish the role of the particle source in the density accumulation effect induced by magnetic islands present at the edge.

TP8.00031 Fundamental study on separation of fuel and impurity particles by using divertor simulator TPD-Sheet IV, TAKAFUMI MAEKAWA, TAKAAKI IJIIMA, TAKUYA HASE, AKIRA TONEGAWA, Tokai Univ, KOHNSUKE SATO, Chube Electric Power Co.Inc., KAZUTAKA KAWAMURA, Tokai Univ — The pumping of helium ash has become important for the control in the SOL/divertor plasma because of the helium ash makes dilution of the fuel density and makes decreases the core plasma temperature. The selective removal of helium ash using by ion cyclotron resonance (ICR) method has been studied in a linear divertor simulator, TPD-Sheet IV. We have demonstrated the ICR method of the helium or helium/hydrogen sheet plasma by the RF electrodes of two parallel plates, sandwiching the plasma. Measurements of the ion temperature in the plasma were carried out a fast scanning Faraday cup. In addition, the ion densities in the plasma were measured by an omegatron mass analyzer and the neutral densities of resonant ions were measured by a quadrupole mass analyzer. As a result, the ion densities of heated ion decrease with increasing the RF power. It is found that the selective removal of the helium ions in the sheet plasma is successful by ICR method.

TP8.00032 Impact of the Pedestal Plasma Density on ELM Dynamics and Energy Loss Scaling, X.Q. XU, LLNL, J.F. MA, UT Austin, G.Q. LI, CASIPP, BOUT++ COLLABORATION — The latest BOUT++ studies show an emerging understanding of ELM dynamics and the consistent collisionality scaling of ELM energy losses with ITPA multi-tokamak database. A series of BOUT++ simulations are conducted to investigate the scaling characteristics of the ELM energy losses vs collisionality via a density scan, while keeping the plasma cross-sectional shape, total stored energy, total plasma current, pressure profiles fixed. The neoclassical collisionality at peak gradient position increases by a factor of 3262 from 0.0019 to 6.197. The critical trend of linear simulations emerges as a transition from ballooning-dominated states at high collisionality to peeling-dominated states at low collisionality with decreasing density. Nonlinear BOUT++ simulations show a two-stage process of ELM crash evolution of (i) initial bursts of pressure ballooning and toroidal rotation and (ii) rapid transition to peeling dominated propagation. This simulated void propagation stirs the top of pedestal plasma and yields an increasing ELM size with decreasing collisionality after a series of micro-bursts. The pedestal plasma density plays a major role in determining the ELM energy loss through its effect on the edge bootstrap current and ion diamagnetic stabilization.

TP8.00033 Studies of impact of plasma shaping on edge localized modes with a nonlinear code BOUT++, G.Q. LI, Institute of Plasma Physics, CAS, X.Q. XU, Lawrence Livermore National Laboratory, P.B. SNYDER, A.D. TURNBULL, General Atomics, T.Y. XIA, Institute of Plasma Physics, CAS — The plasma shaping has important effects on the edge localized modes (ELMs). In this work, with the 3-field BOUT++ code, we study the impact of the plasma shaping on the ELMs. Three kinds of typical plasma shapes are studied: circular (cmm), elongated (dmm) and shaped with X-point (meudas). Our calculations show that the shaped plasma and the X-point geometry have stabilizing effect on the ELMs. For linear ideal MHD calculation we benchmark BOUT++ results with ELITE and GATO codes. Then we study the role of non-ideal effects such as resistivity on the ELMs for the X-point geometry. Also the nonlinear calculations are carried out to study the impact of plasma shape on the ELM size.

TP8.00034 Development of test particle module for impurity generation and transport in BOUT++ framework, XIAOTAO XIAO, CASIPP, LLNL, XUEQIAO XU, LLNL — Developing the test particle module in BOUT++ framework is the first step to enhance its capability to simulate impurity generation and transport in edge plasmas, which potentially can be extended to efficiently simulate both turbulence and neoclassical physics in realistic geometry. The motion of impurity charged particles are governed by guiding-center (GC) equations in the presence of turbulent electromagnetic fields. The GC equations are the well-known Hamiltonian guiding center equation given by Littlejohn, Boozer, White and others. The Fourth-order Runge-Kutta algorithm is used to advance the GC equations in time. In order easily to couple with BOUT++ fluid module, the same 3-field BOUT++ framework is used, while the direct measurement of the Deuterium particle fluxes and the recycling coefficient $\Gamma = \Gamma_{in}/\Gamma_{out}$ is performed using the SOLPS 5.1 code suite.
TP8.00035 Simulations of particle and heat fluxes to divertor targets of ELMy H-mode in DIII-D and EAST1, T.Y. XIA, Institute of Plasma Physics, CAS, XUEQIAO XU, Lawrence Livermore National Lab, TIANYANG XIA, Institute of Plasma Physics, CAS — Here we report on the BOUT++ simulation results for the mitigating impact of rectified RF sheath potential on the peeling-balloonning modes. The limiter and the RF wave antenna are placed at the outer middle plane in the scrape-off-layer (SOL) in shift-circle geometry. The external shear flow is induced by the limiter and the RF wave. Besides this, the sheath boundary conditions are imposed on the perturbed potential and parallel current. From the three-field simulations [1], it is found that the energy loss is suppressed by the external shear flow in the nonlinear phase. The external shear flow due to the RF wave leads to a broad turbulence spectrum. The wider spectrum leads to a weaker turbulence transport and results in a smaller energy loss. The perturbed electric potential and the parallel current near the sheath region are also suppressed locally due to the sheath boundary condition. Based on this work, this effect of limiter will also be applied in six-field which includes more physics effects [2]. The effect of sheath boundary conditions on the thermal conductivities and heat flux will be studied.

1This work was performed under the auspices of the U.S. DoE by LLNL under Contract DE-AC52-07NA27344 and is supported by the NMCFSP of China under Contracts No. 2011GB107001 and National ITER plans Program of China No. 2011GB105003.

TP8.00036 Mitigating impact of rectified RF sheath potential on the ELMs1, BIN GUIL Institute of Plasma Physics Chinese Academy of Sciences, XUEQIAO XU, Lawrence Livermore National Lab, TIANYANG XIA, Institute of Plasma Physics, CAS — Here we report on the BOUT++ simulation results for the mitigating impact of rectified RF sheath potential on the peeling-balloonning modes. The limiter and the RF wave antenna are placed at the outer middle plane in the scrape-off-layer (SOL) in shift-circle geometry. The external shear flow is induced by the limiter and the RF wave. Besides this, the sheath boundary conditions are imposed on the perturbed potential and parallel current. From the three-field simulations [1], it is found that the energy loss is suppressed by the external shear flow in the nonlinear phase. The external shear flow due to the RF wave leads to a broad turbulence spectrum. The wider spectrum leads to a weaker turbulence transport and results in a smaller energy loss. The perturbed electric potential and the parallel current near the sheath region are also suppressed locally due to the sheath boundary condition. Based on this work, this effect of limiter will also be applied in six-field which includes more physics effects [2]. The effect of sheath boundary conditions on the thermal conductivities and heat flux will be studied.

1This work was performed for USDOE by LLNL under DE-AC52-07NA27344, LLNL LDHD project 12-ERD-022 and the China Natural Science Foundation under Contract No.10721505, LLNL-ABS-657008.

TP8.00037 Couple an ICRF core spectral solver to and edge FEM code1, JOHN WRIGHT, SYUNICHI SHIRAIWA, MIT - PSFC, RF - SCIDAC TEAM — The finite element method (FEM) and the spectral approaches to simulation of ion cyclotron (IC) waves in toroidal plasmas each have strengths and weaknesses. For example, the spectral approach (eg TORIC) has a natural algebraic representation of the parallel wavenumber and hence the wave dispersion but does not easily represent complex geometries outside the last closed flux surface, whereas the FEM approach (eg LHEAF) naturally represents arbitrary geometries but does not easily represent thermal corrections to the plasma dispersion. The two domains: thermal core in flux surface and cold edge plasma may be combined in such a way that each approach is used where it works naturally. Among the possible ways of doing this, we demonstrate the method of mode matching. This method provides an easy way of combining the two linear systems without significant modifications to the separate codes. We will present proof of principal cases and initial applications to minority heating.

1Supported by DoE Contract Nos. DE-FC02-01ER54648.

TP8.00038 Iterative addition of perpendicular kinetic effects to finite-difference simulation of radio-frequency heating1, DAVID GREEN, Oak Ridge National Lab, LEE BERRY, XCEL Engineering, RF-SCIDAC COLLABORATION — In previous work we have demonstrated [1] the iterative addition of parallel kinetic effects to finite-difference frequency-domain simulation of radio-frequency (RF) wave propagation in fusion relevant plasmas. Such iterative addition in configuration space bypasses several of the difficulties with traditional spectral methods for kinetic RF simulation when applied to problems that exhibit non-periodic geometries. Furthermore, the direct numerical integration of particle trajectories in real magnetic field geometries removes violations of the stationary phase approximation inherent in the spectral approach [1]. Here we extend this approach to include perpendicular kinetics.

1This 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-AC05-00OR22725.

TP8.00039 Modeling RF-induced Plasma-Surface Interactions with VSim1, THOMAS G. JENKINS, DAVID N. SMITHE, ALEXEI Y. PANKIN, CHRISTINE M. ROARK, PETER H. STOLTZ, SEAN C.-D. ZHOU, SCOTT E. KRUGER, Tech-X Corporation — An overview of ongoing enhancements to the Plasma Discharge (PD) module of Tech-X’s VSim software tool is presented. A sub-grid kinetic sheath model, developed for the accurate computation of sheath potentials near metal and dielectric-coated walls, enables the physical effects of DC and RF sheath dynamics to be included in macroscopic-scale plasma simulations that need not explicitly resolve sheath scale lengths. Sheath potential evolution, together with particle behavior near the sheath (e.g. sputtering), can thus be simulated in complex, experimentally relevant geometries. Simulations of RF sheath-enhanced impurity production near surfaces of the C-Mod field-aligned ICRF antenna are presented to illustrate the model; impurity mitigation techniques are also explored. Model extensions to capture the physics of secondary electron emission and of multispecies plasmas are summarized, together with a discussion of improved tools for plasma chemistry and IEDF/EEFD visualization and modeling. The latter tools are also highly relevant for commercial plasma processing applications. Ultimately, we aim to establish VSimPD as a robust, efficient computational tool for modeling fusion and industrial plasma processes.

Supported by U.S. DoE SBIR Phase 1/II Award DE-SC0009501.
TP8.00040 Validation Studies of the Finite Orbit Width version of the CQL3D code1, YU.V. PETROV, R.W. HARVEY, CompX — The Finite-Orbit-Width (FOW) version of the CQL3D bounce-averaged Fokker-Planck (FP) code [1] has been further developed and tested. The neoclassical radial transport appears naturally in this version by averaging the local collision coefficients along guiding center orbits, with a proper transformation matrix from local (R,Z) coordinates to the midplane computational coordinates, where the FP equation is solved. In a similar way, the local quasilinear rf diffusion terms give rise to additional radial transport of orbits. The main challenge is the internal boundary conditions (IBC) which add many elements into the matrix of coefficients for the solution of FPE on the computational grid, effectively making it a non-banded matrix (but still sparse).

Steady state runs have been achieved at NERSC supercomputers in typically 10 time steps. Validation tests are performed for NSTX conditions, but using different scaling factors of equilibrium magnetic field, from 0.5 to 8.0. The bootstrap current calculations for ions show a reasonable agreement of current density profiles with Sauter et al. model equations [2] which are based on 1st order expansion, although the magnitudes of currents may differ by up to 30%.

1Supported by USDOE grants SC0006614, ER54744, and ER44649.

TP8.00041 RF sheaths for arbitrary B field angles1, DANIEL D’IPPOLITO, JAMES MYRA, Lodestar Research Corporation — RF sheaths occur in tokamaks when ICRF waves encounter conducting boundaries and accelerate electrons out of the plasma. Sheath effects reduce the efficiency of ICRF heating, cause RF-specific impurity influxes from the edge plasma, and increase the plasma-facing component damage. The rf sheath potential is sensitive to the angle between the B field and the wall, the ion mobility and the ion magnetization. [J.R. Myra et al., Nucl. Fusion 30, 845 (1990)]. Here, we obtain a numerical solution of the non-neutral rf sheath and magnetic pre-sheath equations (for arbitrary values of these parameters) and attempt to infer the parametric dependencies of the Child-Langmuir law. This extends previous work [D.A. D’ippolito and J.R. Myra, APS-DPP Meeting, 2013] on the magnetized, immobile ion regime. An important question is how the rf sheath voltage distributes itself between sheath and pre-sheath for various B field angles. This will show how generally previous estimates of the rf sheath voltage and capacitance were reasonable, and to improve the RF sheath BC.

1Work supported by US DOE grants DE-FG02-05ER54823 and DE-FG02-97ER54392.

TP8.00042 Plasma-Based Electrical Transformers and Electrostatic Current Drive in Tokamaks, RICHARD NEBEL, W. GIBSON, K. MOSER, D.C. BARNES, L.L. GLASCOCK, Tibbar Technologies, J.M. FINN, J. DUNN, Los Alamos National Laboratory — Recent nonlinear simulations shown that it is possible to drive current in tokamaks with app-located helical electrostatic fields. These electrostatic studies have uncovered a new nonlinear MHD relaxation principle. This new principle states that if helical electrostatic fields are applied to a plasma, it tries to relax to a state where the magnetic field aligns parallel with the electrodes. If an m=1, n=1 driving electrostatic field is applied at the boundary, the plasma tries to relax to a state where q ∼ 1 everywhere even if no loop voltage is applied to the plasma. It is possible to operate a tokamak steady-state without applying a loop voltage. At Tibbar Technologies we are primarily interested in using this new MHD relaxation principle to build DC-DC electrical transformers. This technology is important for High Voltage DC electrical transmission. We have now demonstrated this new physics in a linear device in the laboratory. The plasma tries to align the magnetic fields parallel to the electrodes, as the theory predicts. It also doesn’t matter which electrode is positive and which is negative, which is also consistent with the theory. Finally, changing the direction of the magnetic field in the solenoid also changes the direction of the current flow in the secondary of the transformer. Efficiencies of 50%-60% are regularly observed.

TP8.00043 Suprathermal electron dynamics and hard X-ray tomography in TCV, JOSEF KAMLEITNER, STEFANO CODA, École Polytechnique Fédérale de Lausanne (EPFL) - Centre de Recherches en Physique des Plasmas (CRPP), CH-1015 Lausanne, Switzerland, JOAN DECKER, CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France — Theoretically predicted toroidal and poloidal emission asymmetries are observed by energy-resolved hard X-ray (HXRS) observations in tokamaks. These bremsstrahlung measurements, in conjunction with Fokker-Planck modeling and synthetic diagnostics [2], characterize the suprathermal electron distribution during electron cyclotron resonance heating and current drive (ECRH, ECCD). The dynamics and the transport of suprathermal electrons in real and velocity space are studied, also with respect to quasilinear effects in EC wave absorption. Further new results are presented concerning the interaction of fast electrons with magnetohydrodynamics (MHD) instabilities, especially the m/n=1/1 internal kink, and including runaway electron creation and transport.

1Supported by DoE, GA No. 633053, and HNPTFR.

TP8.00044 Experimental Study of RF Sheaths due to Shear Alfvén Waves in the LAPD, MICHAEL MARTIN, WALTER GEEKELMAN, BART VAN COMPENHELLE, PATRICK PRIEBL, TROY CARTER, UCLA, Dept. of Physics and Astronomy — Ion cyclotron resonance heating (ICRH) is an important tool in current fusion heating experiments and will be an essential part of heating power in ITER. Radio frequency (RF) sheaths in the near-field (at the antenna) and in the far-field (e.g. the divertor region) form during ICRH and may cause deleterious effects, such as destruction of wall materials and plasma impurity generation. In this study a shear Alfvén wave is launched from an antenna in the LAPD bulk plasma (n_e ∼ 10^12 cm^-3, T_e ∼ 5 eV, B_0 = 1.8 kG, diameter = 60 cm, length = 18 m) and forms an RF sheath on a limiter plate. Plasma potential rectification is observed with an emissive probe in the bulk plasma only on field lines connected to the limiter. The largest enhancement occurs inside the current channel of the Alfvén wave. Plasma potential measurements at various axial distances from the limiter show the rectification decreases with distance. 2-D maps of plasma potential as well as $\tilde{E} = -\nabla \Phi$ will be presented. The scaling of sheath potential with wave power and plasma parameters will also be shown.

TP8.00045 Scattering of radio frequency waves by density fluctuations1, A.K. RAM, PSFC-MIT, K. HIZANIDIS, NTUA, EURÓfusión, Greece — The scattering of radio frequency waves by density fluctuations in magnetized fusion plasmas is studied using two different techniques. For coherent fluctuations, such as blobs in the edge region, we use a full-wave model for which the theory is similar to that for Mie scattering of electromagnetic waves by dielectric objects [1]. The blobs are considered to be either spherical or cylindrical with their axes aligned along the magnetic field. For incoherent planar fluctuations, which can be either in the core of the plasma or in the edge region, we use the Kirchhoff approach in tandem with Huygen’s principle. The anisotropy induced by the magnetic field is such that the propagation characteristics and the polarization of the wave modes depend on the polar angle with respect to the direction of the magnetic field. An incident plane wave is not only scattered by the coherent and incoherent fluctuations, but also couples power to a different plasma wave. The scattered spectrum is affected by the size of the fluctuations, the frequency, and the direction of propagation of the incident wave. We present the two theoretical models along with numerical results on the spectral characteristics of the scattered waves.

1Supported by DoE, GA No. 633053, and HNPTFR.
TP8.00046 Effects of lower hybrid waves on temperature gradient driven drift-modes in tokamaks: Momentum and impurity transport, SALIL DAS, Prince Georges Community College, Maryland, USA, HOGUN JHANG, RAGHVENDRA SINGH, WCI Center for Fusion Theory, National Fusion Research Institute (NRFI), 305-333, Daegon, Korea, HANS NORDMAN, Department of Earth and Space Sciences, Chalmers University of Technology, Goteborg-412 96, Sweden — An important goal in tokamak fusion research is the evaluation of the effects of intrinsic rotation on transport barrier formation, determination of momentum pinch velocity and its theoretical basis, and, the significant effect of impurities on tokamak performance by their contribution to radiation losses and plasma dilution resulting in lower fusion power. We use the four-wave parametric process to study these effects involving a fluid model for ion-temperature-gradient and trapped-electron mode driven turbulence in the presence of radio frequency fields in the lower hybrid (LH) range of frequencies. Explicit expressions for the non-linear growth rate and the associated ion thermal conductivity and effective impurity diffusivity are derived. Parametric coupling of the pump and the sidebands exert a ponderomotive force on electrons, modifying the eigenfrequency of the drift waves and influencing the turbulence strength and the turbulent transport properties. The effects of the rf fields on the momentum and impurity transport coefficients are evaluated for key parameters like rf power, temperature gradients, and magnetic shear.

1Turbulent Particle transport in Magnetized Plasmas: Garbet et al, PRL, 91, 3, 2003

TP8.00047 Parallel heat flux and flow acceleration in open field line plasmas with magnetic trapping, ZEHUA GUO, XIANZHU TANG, CHRIS MCDEVITT, Los Alamos Natl Lab — Various simulations and experimental observations have suggested the importance of kinetic effects, such as particle orbital losses, the anisotropy of distribution functions, and the long mean-free-path of superthermal particles, in the tokamak edge region. The magnetic field strength modulation in a tokamak scrape-off layer (SOL) provides both flux expansion next to the divertor plates and magnetic trapping in a large portion of the SOL. In this work, the effects of magnetic trapping and a marginal collisionality on parallel heat flux and parallel flow acceleration are examined. The various transport mechanisms are captured by kinetic simulations in a simple but representative mirror-expander geometry. The observed parallel flow acceleration is interpreted and elucidated with a modified Chew-Goldberger-Low (CGL) model that retains temperature anisotropy and finite collisionality. We will also show that the use of sheath-boundary-condition in modelling tokamak SOL to be problematic since it simply prohibits the flow transition from subsonic to supersonic at the mirror throat far away from the divertor.

TP8.00048 Kinetic applications of the ArbiTER eigenvalue code, D.A. BAVER, J.R. MYRA, Lodestar Research Corporation, M.V. UMANSKY, Lawrence Livermore National Laboratory — ArbiTER is a flexible eigenvalue code designed for linear fluid or kinetic plasma models with various dimensionalities and topologies. This flexibility derives from the use of specialized equation and topology parsers, which permit run-time specification of a particular linearized physics model, geometry, and grid connectivity, which in turn determine how a particular equation set will be discretized. The resulting matrix form of the problem is then solved using the SLEPC [1] eigensolver package, and can be solved either as a generalized eigenvalue problem, or as a matrix solve in the case of source-driven problems. While the ArbiTER code and its predecessor 2DX have demonstrated significant utility in tokamak edge fluid problems due to their inherent flexibility, the primary aim of its development is to solve kinetic eigenvalue problems. To address this goal, we present first results from implementation of a gyrokinetic model in slab geometry. These results are compared to known solutions for limiting cases.

1http://www.grycap.upv.es/slepc/

TP8.00049 Kinetic stability analysis on electromagnetic filamentary structure, WONJAE LEE, SERGEI KRASHENINNIKOV, Univ of California - San Diego — A coherent radial transport of filamentary structures in SOL region is important for its characteristics that can increase unwanted high fluxes to plasma facing components. In the course of propagation in radial direction, the coherency of the filaments is significantly limited by electrostatic resistive drift instability (Angus et al., 2012). Considering higher plasma pressure, which would have more large impact in heat fluxes, electromagnetic effects will reduce the growth rate of the drift wave instability and increase the instabilities from electron inertial effects. According to a linear stability analysis on equations with fluid approximation, the maximum growth rate of the instability from the electron inertia is higher than that of drift-Alfven wave instability in high beta filaments such as ELMs. However, the analysis on the high beta filaments requires kinetic approach, since the decreased collisionality will make the fluid approximation broken. Therefore, the kinetic analysis will be presented for the electromagnetic effects on the dynamics of filamentary structures.

1Work supported by the U.S. DOE grant DE-SC0006562.

TP8.00050 Particle Simulation of the Blob Propagation in Non-Uniform Plasmas, HIROKI HASEGAWA, SEIJI ISHIHITO, National Institute for Fusion Science — The kinetic dynamics on blob propagation in non-uniform plasmas have been studied with a three dimensional electrostatic plasma particle simulation code. In our previous studies, we assumed that grad-B is uniform in the toroidal and poloidal directions. In scrape-off layer (SOL) plasmas of real magnetic confinement devices, however, the direction of grad-B is different between the inside and the outside of torus. In this study, we have investigated the blob kinetic dynamics in the system where grad-B is spatially non-uniform. We observe different potential and particle flow structures from those shown in our previous studies. Thus, it is found that propagation properties of blobs in non-uniform grad-B plasmas are also distinct. These properties depend on the initial blob location in the toroidal directions. We will also discuss the application of this study to pellet dynamics.

1Supported by NIFS Collaboration Research programs (NIFS13KNSS008 and NIFS14KNXN279) and a Grant-in-Aid for Scientific Research from Japan Society for the Promotion of Science (KAKENHI 23740411).

TP8.00051 Turbulent transport regimes and the SOL heat flux width, J.R. MYRA, D.A. D’IPPOLITO, D.A. RUSSELL, Lodestar Research Corp. — Understanding the responsible mechanisms and resulting scaling of the scrape-off layer (SOL) heat flux width is important for predicting viable operating regimes in future tokamaks, and for seeking possible mitigation schemes. Simulation and theory results using reduced edge SOL turbulence models have produced SOL widths and heat fluxes in agreement with experiment in many cases. In this work, we attempt to qualitatively and conceptually understand various regimes of edge/SOL turbulence and the role of turbulent transport in establishing the SOL heat flux width. Relevant considerations include the type and spectral characteristics of underlying instabilities, the location of the gradient drive relative to the SOL, the nonlinear saturation mechanism, and the parallel heat transport regime. Recent SOLT turbulence code results are employed to understand the roles of these considerations and to develop analytical scalings. This work is supported by US DOE grant DE-FG02-07ER55392.

1Work supported by US DOE grant DE-FG02-97ER55392.
TP8.00052 Modeling of Weakly Collisional Parallel Electron Transport for Edge Plasma Simulations

M. V. UMANSKY, A. M. DIMITS, I. JOSEPH, LLNL; J. T. OMOTANI, Culham Labs, T. D. RÖGNLIEN, LLNL — The parallel electron heat transport in a weakly collisional regime can be represented in the framework of the Landau-fluid (LF) model [1]. Practical implementation of LF-based transport models has become possible due to the recent invention of an efficient non-spectral method for the non-local closure operators [2]. Here the implementation of a LF based model for the parallel plasma transport is described, and applications to realistic divertor simulations are discussed.

1Work performed for U.S. DoE by LLNL under Contract DE-AC52-07NA27344.


TP8.00053 Calculation of plasma dielectric response in inhomogeneous magnetic field near electron cyclotron resonance

Y. SHIMA, Plasma Research Center, University of Tsukuba, GAMMA 10 TEAM — Effective ICRF heating creates high ion-temperature plasma of several keV temperature. For this purpose, we need to develop a nonlinear toroidal particle code to study the radio frequency wave heating and current drive in fusion plasmas. Implementation of an LF-based model for the parallel plasma transport in the UEDGE code is described, and applications to realistic divertor simulations are discussed.

Alfven wave becomes unstable overcoming ion-cyclotron damping and so-called Alfven-ion-cyclotron (AIC) wave is spontaneously excited. Density fluctuations and the diamagnetism display apparent effects of such nonlinear couplings on the global energy confinement of GAMMA 10. This is partly supported by a Grant-in-Aid for Scientific Research from JSPS, Japan (No. 25400531) and by the bidirectional collaborative research programme of the National Institute for Fusion Science, Japan (NIFS14KUGM0097).

TP8.00054 Iterative Methods to Solve Linear RF Fields in Hot Plasma

ANIMESH KULEY, JIAN BAO, ZHIHONG LIN, University of California Irvine — RF particle simulation has been developed in this work to provide a first-principles tool for studying the RF nonlinear interactions with plasmas. In this model, ions are considered as fully kinetic particles using the Vlasov equation and electrons are treated as guiding centers using the drift kinetic equation. This model has been implemented in a global gyrokinetic toroidal code GTC with realistic electron-to-ion mass ratio in cylindrical geometry and verified the linear physics of ion plasma oscillation, ion Bernstein wave, lower hybrid wave and electron cyclotron resonance waves. Numerical modeling of RF fields in hot magnetized nonuniform plasma requires calculation of nonlocal conductivity kernel describing the dielectric response of such plasma to the RF field. In many cases, the conductivity kernel is a localized function near the test point which significantly simplifies numerical solution of the full wave 3-D problem. Preliminary results of feasibility analysis of numerical calculation of the conductivity kernel in a 3-D hot nonuniform magnetized plasma in the electron cyclotron frequency range will be reported. This case is relevant to modeling of ECRH in ITER. The kernel is calculated by integrating the linearized Vlasov equation along the unperturbed particle’s orbits. Particle’s orbits in the nonuniform equilibrium magnetic field are calculated numerically by one of the Runge–Kutta methods. RF electric field is interpolated on a specified grid on which the conductivity kernel is discretized. The resulting integrals in the particle’s initial velocity and time are then calculated numerically. Different approaches of the integration are tested in this feasibility analysis.

1Work is supported by the U.S. DOE SBIR program.

TP8.00055 Fully kinetic particle simulation of radio frequency waves in toroidal geometry

SVIDZINSKI, EVSTATI EVSTATIEV, VLADIMIR SVIDZINSKI, ANDY SPENCER, SERGEI GALKIN, FAR-TECH, Inc — Most magnetic plasma confinement devices use radio frequency (RF) waves for current drive and/or heating. Numerical modeling of RF fields is an important part of performance analysis of such devices and a predictive tool aiding design and development of future devices. Prior attempts at this modeling have mostly used direct solvers to solve the formulated linear equations. Full wave modeling of RF fields in hot plasma with 3D nonuniformities is mostly prohibited, with memory demands of a direct solver placing a significant limitation on spatial resolution. Iterative methods can significantly increase spatial resolution. We explore the feasibility of using iterative methods in 3D full wave modeling. The linear wave equation is formulated using two approaches: for cold plasmas the local cold plasma dielectric tensor is used (resolving resonances by particle collisions), while for hot plasmas the conductivity kernel (which includes a nonlocal dielectric response) is calculated by integrating along test particle orbits. The wave equation is discretized using a finite difference approach. The initial guess is important in iterative methods, and we examine different initial guesses including the solution to the cold plasma wave equation.

1Work is supported by the U.S. DOE SBIR program.

TP8.00056 On the nonlinear couplings among ICRF waves observed in GAMMA 10

R. IKEZOE, M. ICHIMURA, T. OKADA, M. HIRATA, T. YOKOYAMA, Y. IWAMOTO, S. SUMIDA, K. TAKEYAMA, S. JANG, T. OI, M. YOSHIAKU, J. KOHAGURA, Y. SHIMA, Plasma Research Center, University of Tsukuba, GAMMA 10 TEAM — Effective ICRF heating creates high ion-temperature plasma of several keV temperature. Density fluctuations associated with AIC waves and ICRF waves for heating have been recently measured by using reflectometers on GAMMA 10. The measured fluctuations show fruitful wave-wave couplings more clearly than magnetic fluctuations measured by pick-up coils at the plasma periphery. The signals showing the axially transported energetic-ion flux and the diamagnetism display apparent effects of such nonlinear couplings on the global energy confinement of GAMMA 10. Bispectral analysis is applied to the density fluctuations and the detailed characteristics of the nonlinear couplings occurring among the AIC waves and ICRF waves for heating in GAMMA 10 are presented.

1This work is partly supported by a Grant-in-Aid for Scientific Research from JSPS, Japan (No. 25400531) and by the bidirectional collaborative research programme of the National Institute for Fusion Science, Japan (NIFS14KUGM0097).

TP8.00057 TURBULENCE, TRANSPORT AND ASTROPHYSICAL PLASMAS —
TP8.00058 Global transition from drift wave dominated regimes to multi-instability plasma dynamics and simultaneous formation of a radial transport barrier in helicon plasma. SAIKAT CHAKRABORTY THAKUR, LANG CUI, JORDAN GOSELIN, PAYAM VAEZ, CHRIS HOLLAND, GEORGE TYNAN, UC San Diego — Recent studies in CSDX reported a sharp global transition in the plasma dynamics during the route to turbulence [1]. For B < 140 mT, the plasma is dominated by density gradient driven drift waves [DW]. For B > 140 mT, a new global equilibrium is achieved with simultaneous existence of three radially separated plasma instabilities: coherent Rayleigh Taylor [RT] modes at the center, DW at the density gradient and turbulent, shear driven Kelvin-Helmholtz [KH] instabilities at the edge. Only the RT modes rotate in the ion diamagnetic drift direction. The radial particle flux is directed outward for small radii and inward for large radii, forming a radial particle transport barrier leading to stiff profiles and increased core density. Simultaneously the core Ar-II light emission increases (x 10) forming a very bright blue core. The radial extent of the inner RT mode and the blue core coincides with the radial location of the particle transport barrier. This equilibrium with simultaneous RT-DW-KH instabilities shows very rich plasma dynamics including intermittency, blob formation and propagation, inward particle flux against density gradients etc. We report detailed studies of azimuthal momentum balance and time resolved dynamics leading to the transition using Langmuir probes, fast imaging, spectroscopy, laser induced fluorescence etc.


TP8.00059 Heavy Impurity Entrainment in the Parallel Flows of CSDX. JORDAN GOSELIN, SAIKAT THAKUR, GEORGE TYNAN, Univ of California - San Diego — The lifetime of the plasma facing components (PFCs) in a tokamak, governed primarily by material erosion and redeposition, has been identified as a crucial research topic. While some work has been done that shows evidence of the entrainment of impurities in linear machines and in tokamaks, detailed controlled studies of entrainment in plasma flows are harder to come by. Recently, experiments in CSDX have shown increasing parallel ion velocity positively correlated with increasing magnetic field. In an effort to study the effects of the background flow on impurity transport, a laser blow off apparatus was installed on the Controlled Shear Decorelation eXperiment (a 3m long helicon source operated plasma machine). Results are shown for parallel entrainment of Bismuth impurities in a relatively light background Ar plasma (5.2 mass ratio).

TP8.00060 Influence of Parallel Dynamics and Electron Temperature Fluctuations on Collisional Drift-Wave Simulations of CSDX. PAYAM VAEZ, CHRISTOPHER HOLLAND, GEORGE TYNAN, SAIKAT CHAKRABORTY THAKUR, CHRISTIAN BRANDT, Univ of California - San Diego — Previous 2D numerical simulations of collisional drift-wave turbulence in the linear Controlled Shear Decorelation Experiment (CSDX) device were unable to reproduce experimental observations at magnetic fields above 1.4 kG at either the quantitative or qualitative level. Experimental observations [1] suggest that dynamics of previously neglected ion parallel velocity and associated parallel shear-flow driven instabilities become important at the higher fields. In this poster, we present comparisons of new 3D simulations performed with the BOUT++ framework [2] which include parallel ion velocity dynamics, as well as self-consistent electron temperature fluctuations, to the CSDX observations at multiple magnetic field strengths. We compare the simulated scalings of density and potential fluctuation spectra with magnetic field, as well as radial particle flux and Reynolds stress to 2D results and experimental observations. The comparisons are made using synthetic probe and fast camera diagnostics that incorporate both the electron density and temperature dynamics.


TP8.00061 Up-Gradient Particle Flux driven by Nonlinear Flow-to-Fluctuation Energy Transfer. LANG CUI, GEORGE TYNAN, PATRICK DIAMOND, SAIKAT THAKUR, CHRISTIAN BRANDT, University of California, San Diego — We report a fluctuation-driven particle flux that transports particles up the mean density gradient when density-gradient driven collisional drift waves generate a sufficiently strong radially sheared azimuthal zonal flow in a cylindrical magnetized plasma. Time-domain and bispectral Fourier domain analysis shows that at the peak of the shear layer, where the particle flux is outward, the turbulent stress acts to nonlinearly reinforce the shear flow. Between the peak of the shear layer and the maximum density gradient, the zonal flow nonlinearly drives fluctuations which give rise to an up-gradient particle flux carried mostly by blobs (holes) that move up (down) the gradient, resulting in a steepening of the mean density gradient. The observations show that spatially separated multiple free-energy sources can drive non-diffusive up-gradient transport that affects global plasma equilibrium. Possible links to toroidal confinement and space plasma systems are discussed.

TP8.00062 Waves and instabilities in high β, warm ion plasmas in LAPD. TROY CARTER, SETH DORFMAN, GIOVANNI ROSSI, DANIEL GUCIE, WALTER GELKMAN, UCLA, KRIS KLEIN, U. New Hampshire, GREG HOWES, U. Iowa — The Large Plasma Device (LAPD) has been upgraded with a second LaB₆ cathode plasma source that permits the creation of higher density (∼ 3 x 10¹³ cm⁻³), higher temperature (T_e ∼ 12 eV), warm ion (T_i ∼ 6 eV) plasmas. Along with increased magnetic field, significant increases in plasma β can be achieved with this new source (e.g. at B = 100 G, β ∼ 1). These new plasma conditions permit a range of new experimental opportunities on LAPD including: linear and nonlinear studies of Alfven waves in warm ion, high β plasmas; pressure-gradient driven instabilities in increased β plasmas and electromagnetic modifications to turbulence and transport; instabilities driven by ion temperature anisotropies (e.g. firehose and mirror instabilities). The characteristics of the new plasma will be presented along with a discussion of these new research areas.

TP8.00063 Turbulence and transport in high density, increased β LAPD plasmas. GIOVANNI ROSSI, TROY CARTER, DANNY GUCIE, Univ of California - Los Angeles — A new LaB₆ cathode plasma source has recently been deployed on the Large Plasma Device (LAPD), allowing for the production of significantly higher plasma density (nₑ ∼ 3 x 10¹³ cm⁻³) and temperature (T_e ∼ 12 eV and T_i ∼ 6 eV). This source produces a smaller core plasma (~20cm diameter) that can be embedded in the lower temperature, lower density standard LAPD plasma (~60 cm diameter, 10¹² cm⁻³, T_e ∼ 5 eV, T_i ∼ 1 eV). We will present first results from experiments exploring the nature of turbulence and transport produced by this high density core plasma. In contrast to the edge of the standard LAPD plasma, coherent fluctuations are observed in the edge of the high density core plasma. These coherent modes are dominant at low field (~400 G) with a transition to a more broadband spectrum at higher fields (~1 kG). The combination of increased density and temperature reduced in the field in LAPD lead to significant increases in plasma β (in fact β ∼ 1 can be achieved for B ∼ 100 G). As the field is lowered, the strength of correlated magnetic fluctuations increases substantially.

TP8.00064 Scaling of Turbulence and Transport with pᵣ in LAPD. DANIEL GUCIE, TROY CARTER, GIOVANNI ROSSI, University of California Los Angeles — The plasma column size of the Large Plasma Device (LAPD) is varied in order to investigate the variation of turbulence and transport with pᵣ = pₑ / a. The data set includes plasmas produced by the standard BaO plasma source (straight field plasma radius a 30cm) as well as the new higher density, higher temperature LaB₆ plasma source (straight field plasma radius a 10cm). The size of the plasma column is scaled in order to observe a Bohm to Gyro-Bohm diffusion transition. The main plasma column magnetic field is held fixed while the field in the cathode region is changed in order to map the cathode to different plasma column scales in the main chamber. Past experiments in the LAPD have shown a change in the observed diffusion but no transition to Gyro-Bohm diffusion. Results will be presented from an ongoing campaign to push the LAPD into the Gyro-Bohm diffusion regime.
TP8.00065 A Procedure to Predict the Subcritical Turbulent Onset Criterion Applied to a Modified Hasegawa-Wakatani Model  
BRETT FRIEDMAN, LLNL, TROY CARTER, UCLA — Linear eigenmode analysis is often used to predict whether a plasma or fluid system will be turbulent, but it fails for systems which have highly non-orthogonal linear eigenvectors [1]. In fact, such systems may become turbulent despite having no unstable linear eigenvectors at all (subcritical turbulence). For about a century, researchers have attempted to predict critical parameters that mark the onset of subcritical turbulence with little success. Using recently-developed intuition regarding the role of non-orthogonal linear eigenvectors in subcritical turbulent sustainment, we have developed a method to calculate turbulent growth rates, which can be used to predict the onset of subcritical turbulence. We apply our procedure to 2D and 3D versions of the Hasegawa-Wakatani (HW) model [2], showing good agreement with nonlinear simulation results. We also use a modified version of the 3D HW model [3], which is subject to subcritical turbulence, in order to test our method in predicting the subcritical turbulent onset.


TP8.00066 Fast Ion Transport by Magnetic Flux Ropes  
ADAM PREIWISCH, WILLIAM HEIDBRINK, HEINRICH BOEHMER, ROGER McWILLIAMS, University of California, Irvine, TROY CARTER, WALTER GEKELMAN, SHREEKRISHNA TRIPATHI, BART COMPERNOLLE, STEVEN VINCENZA, University of California, Los Angeles — Energetic Lithium test ions (500 \leq E_{\text{fast}} / T_i \leq 1000) are launched in a Helium plasma in the presence of current-produced magnetic flux ropes at the upgraded Large Plasma Device (LAPD) at UCLA. Perturbing flux ropes are introduced via a hot, biased LaB6 cathode in the main chamber[1] Ion beam broadening up to fifty percent above background levels is observed in the radial direction after passing through the flux rope region (T_{\text{e,max}} \sim 7eV, B_{\perp} \sim 7G, \Delta V=160V). Density, temperature, and magnetic fluctuation profiles are also obtained. A noise model has been developed to assess the quality of ion signals during the flux rope discharge period. The enhancement to transport may be a result of increased Coulomb scattering, magnetic fluctuations, or electric fields. Further analysis to determine the primary mechanism is ongoing.


TP8.00067 MHD turbulence analyses in the plasma wind-tunnel of the Swarthmore Spheronmak Experiment  
D.A. SCHAEFFNER, A. WAN, E.R. HUDSON, P.J. WECK, M.R. BROWN, Swarthmore College, V.S. LUKIN, Naval Research Laboratory — An MHD plasma module has been developed for use in the wind-tunnel of the Swarthmore Spheronmak Experiment (SSX) provides a test bed for studying magnetic turbulence in the laboratory. Results show favorable statistical comparisons to solar wind and magnetosphere turbulence. Analysis of temporal and spatial magnetic fluctuations shows power-law spectra, intermittency and variance anisotropy. Magnetic spectra have indices steeper than Kolmogorov theory and feature a steepening consistent with the onset of dissipation at ion inertial length scales. Comparisons of frequency and wavenumber spectra constructed from multi-channel probes are made to investigate the validity of the Taylor Hypothesis. Intermittency analysis shows increasing kurtosis of PDFs of magnetic field increments with decreasing time scale and increasing magnetic helicity. Taylor microscale is determined through radial correlation length analysis and the magnetic Reynolds number calculation compares well to the value computed using resistivity. Results compare well to Hall-MHD simulations generated using the HiFi framework. Simulations are used to explore the wave mode content through correlations of density and parallel magnetic field. Finally, permutation entropy analysis of SSX is presented.

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TP8.00068 Overview of Recent Results on Turbulence and Flows Under Biasing in a Magnetized Linear Plasma  
M. GILMORE, T.R. DESJARDINS, University of New Mexico, D. FISHER, Dartmouth College, J.M. REYHOLDS BARREDO, Universidad Carlos III de Madrid — Ongoing experiments on the effects of flow shear on electrostatic turbulence in the presence of electrode biasing are being conducted in helicon plasmas in the linear HelCat (Helicon-Cathode) device. It is found that changes in flow shear, affected by electrode biasing through $\mathbf{E} \times \mathbf{B}$ rotation, can strongly affect fluctuation dynamics, including fully suppressing the fluctuations or inducing chaos. Parameters such as $B$-field, gas fill pressure, and RF source power also strongly affect fluctuation dynamics. In some cases, multiple modes (resistive drift, rotation-driven interchange and/or Kelvin-Helmholtz) are present, and interact nonlinearly. It is found that neutral particle profiles are hollow, and that neutrals may exert significant $\mathbf{F}_r \times \mathbf{B}$ torque on the plasma column through collisions. At high positive electrode bias, a large amplitude, global instability, identified as the potential relaxation instability is observed. Here, an overview of recent experimental results, as well as linear stability analysis using an eigenmode solver, are presented. Additionally, preliminary results from global nonlinear three fluid (electron, ion, neutral) results are discussed.

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TP8.00069 Observation of the Early Transition from Slab to mixed Slab-Toroidal ETG Turbulence  
ABED BALBAKY, VLADIMIR SOKOLOV, AMIYA K. SEN, Columbia University — Parametric studies of the transition between the slab branch of electron temperature gradient (ETG) mode and the mixed slab-toroidal branch of the ETG mode in CLM are reported. CLM was operated in a mirror machine configuration with a cell length of 500 cm, and a mirror ratio of 1-2. For typical CLM parameters and a mode localized at $r=2$ cm this provides a range for inverse radius of curvature $R_c^{-1}$ between 0 and .006 cm$^{-1}$. Under normal conditions theory predicts transition between slab and toroidal modes would occur when the parameter $k_{||} R_c / 2 k_{\perp} \rho \sim 1$ [1]. Recent experiments have obtained an experimental scaling of mode amplitude and frequency as a function of $R_c^{-1}$. They indicate that even for much more modest levels of $k_{||} R_c / 2 k_{\perp} \rho \sim 1$, there are substantial increases in saturated mode, up to 5 times larger than the pure slab mode. Changes in real frequency in the mode are generally small, on the order of < 5%.


This research was supported by the Department of Electrical Engineering of Columbia University.
TP8.00070 Measurement of Electron Thermal Transport Induced by ETG Modes in the Transition from the Slab to the Toroidal Branch of Mode1, VLADIMIR SOKOLOV, ABED BALBAKY, AMIYA K. SEN, Columbia University — Transition from the slab to the toroidal branch of the electron temperature gradient (ETG) mode has been successfully achieved in a basic experiment in Columbia Linear Machine CLM [1]. The measurement of the radial electron thermal conductivity shows its increase with transition from slab to the toroidal ETG mode. A miniature triple probe was used for these measurements [2] and the value of thermal conductivity is found to be about $2 \sim 12$ m$^2$/s. The corresponding gyrobohm diffusion coefficient $\chi_{\perp e} \sim 2 \sim 4$ m$^2$/s. A similar result of the transport measurement was obtained by using a novel diagnostic system.


1This research was supported by the Department of Electrical Engineering of Columbia University

TP8.00071 On Zonal Flow Formation in Plasmas and Fluids: Probing the Drift-Rossby Analogy, M.J. BURIN, CSU San Marcos, CMTFO, G.R. TYNAN, UCSD, CMTFO, H. JI, Princeton University, CMTFO, E. EDLUND, E. GILSON, PPPL, P. DANG, Princeton University, R. EZETA, University of Twente — A well-recognized isomorphism exists between the equations describing drift waves within magnetized plasmas and Rossby waves on rotating planets. Both systems also exhibit large-scale zonal flows that arise due to nonlinear energy transfer from smaller, turbulent motions. While such energy transfer has been recently characterized in plasmas (via Reynolds’ stresses), similar data from geophysically relevant flows has been lacking. We report on a new experimental effort to characterize large-scale flow generation within a laboratory fluid. Results are discussed with the aim of better quantifying the analogy.

TP8.00072 Turbulence and transport in a 3D magnetic boundary, MATTEO AGOSTINI, LORELLA CARRARO, GIOVANNI CIACCIO, GIANLUCA DE MASI, CRISTINA REA, PAOLO SCARIN, GIANLUCA SPIZZO, MONICA SPOLAORE, NICOLA VIANELLO, Consorzio RFX — In present fusion devices the interaction between 3D magnetic field, edge kinetic properties and turbulence is a crucial issue; not only in intrinsically 3D configurations such as the stellarators, but also in tokamaks, where magnetic perturbations are applied to control ELMs and plasma wall interaction. In the RFX-mod reversed field pinch the spontaneous development at high plasma current of a helical magnetic state displays strong analogies with the aforementioned configurations. At the edge the presence of a stochastic layer and magnetic islands with a well-defined helical symmetry leads to a helical pattern of flow, pressure gradients and turbulent fluctuations: larger fluctuations and shorter correlation lengths are observed near the X-point of the magnetic island, where also a flow slowing-down occurs. Aim of this work is to study the effect of edge turbulence on particle transport in a 3D magnetic boundary, characterizing the properties of the edge blobs along the helical deformation. The magnetic topology also modifies kinetic properties, with higher pressure gradients observed close to the O-point of the island. The measurement of the time evolution of pressure gradient and blob characteristics, can clarify the mutual relation between these two quantities.

TP8.00073 Experimental Study on an Intermediate Plasma in the HYPER-II Device1, KENICHIRO TERASAKA, FUMIYA KAWAZU, KANSHI FURUTA, RIKU NAKANO, Kyushu University, SHINJI YOSHIMURA, National Institute for Fusion Science, MASAYOSHI Y. TANAKA, Kyushu University — Recently, the onset of azimuthal plasma rotation and the saturation of acceleration along the magnetic field line have been observed in an inhomogeneous magnetic field (HYPER-II). These interesting results are considered to be the unique in an intermediate plasma, which consists of magnetized electrons and unmagnetized ions, and are clearly different from that of well-known magnetized plasmas. However, the flow structure formation of intermediate plasma has not been well understood so far, since there are a few experiments. In order to study the flow structure generated in the intermediate plasma, we have started a new experiment using the HYPER-II device at Kyushu Univ., Japan. The HYPER-II device has a large volume chamber, in which an intermediate plasma in a magnetic field intensity of the order of 10 gauss is produced. We have especially interested in the effect of plasma rotation in the magnetized region on the flow structure of intermediate plasma. For this purpose, we have developed a set of coaxial electrodes to control the plasma rotation. In the poster session, we will present the characteristic feature of the HYPER-II device: performance of HYPER-II, diagnostic methods including the preliminary results.

1This work was supported by JSPS KAKENHI Grant Number 25800306 (Grant-in-Aid for Young Scientists B).

TP8.00074 Investigation of the Scattering of Electromagnetic Signals from Low Frequency Turbulence1, ERIK TEJERO, Naval Research Lab, LON ENLOE, US Air Force Academy, VLADIMIR SOTNIKOV, Air Force Research Lab, CHRIS CRABTREE, Naval Research Lab, ERIC GILLMAN, NRC-NRL Postdoctoral Fellow, BILL AMATUCCI, GURU GANGULI, Naval Research Lab — The linear Electron-Ion Hybrid (EIH) instability was previously predicted to explain the observation of waves in applications from the plasma sheet boundary layer to laser produced plasmas. PIC simulations have shown that a key feature of the nonlinear evolution of the EIH mode is that it leads to the formation of coherent, closed potential contours in the fluctuating electrostatic potential. We have expanded the theory to include collisional plasmas for applications to plasmas surrounding a hypersonic vehicle. In this collisional plasma, strongly sheared transverse flows can exist due to the relative motion of the vehicle and the surrounding atmosphere. If the scale size of these sheared flows is sufficiently small, they can give rise to the EIH instability. We are study whether the resulting lower hybrid turbulence can impede communication to and from a hypersonic vehicle. Experiments conducted in the Space Physics Simulation Chamber have demonstrated the existence of this instability in the linear phase in a collisional environment and have begun examining the nonlinear evolution of the instability. Results from laboratory experiments and theory on the generation of the EIH instability in a collisional plasma environment and microwave scattering will be presented.

1This work is supported by AFOSR and the NRL base program.

TP8.00075 Stability criteria for MHD equilibrium configurations with flows: a Hamiltonian approach1, P.J. MORRISON, The University of Texas at Austin, T. ANDREUSSI, F. PEGORARO, Alta Space Pisa, Italy — Stability criteria for equilibrium MHD configurations with flows can be obtained by exploiting the Hamiltonian structure of the magnetohydrodynamics (MHD) equations by referring to three different kinds of energy principles. Following up on previous work [Phys. Plasmas 19, 052102 (2012); 20, 092104 (2013)] we compare the Lagrangian, Eulerian, and Dynamically Accessible stability criteria of a simple set of MHD equilibria. These criteria differ because of the different constraints that are imposed on the variations of the equilibrium quantities in the stability analyses. We illustrate these constraints along with the corresponding stability criteria for cylindrical magnetized plasma configurations with flows.

1PJM supported by the U.S. Dept. of Energy Contract # DE-FG05-80ET-53088
TP8.00076 General Framework for statistical tracer analysis as a diagnostic for turbulent transport in gyrokinetic codes. JOSE-MIGUEL REYNOLDS-BARREDO, JORGE ALBERTO ALCÜGN, RAUL SANCHEZ, VICTOR TRIBALDOS, Universidad Carlos III de Madrid, DAVID NEWMAN, University of Alaska Fairbanks — It has been known for a long time that tracers can be useful tools to characterize the nature of transport. On the other side, several state-of-the-art gyrokinetic codes exist (GENE, GYSELA, UCAN...) that offer us a rich variety of turbulent data to analyze, that belongs to regimes of interest for the nuclear fusion program. Advancing tracers in these codes is not easy. It would be best if they could be advanced in parallel with the turbulence. However, gyrokinetic runs are very expensive and one cannot afford to repeat runs to relocate tracer particles in another location, or to repeat their initialization. For that reason, it is better to develop an independent tool that can read the turbulence information from the gyrokinetic runs stored in file and then generate new tracer particles in time and space as needed to carry out as many tracer runs as the desired. In this contribution, we present such a framework. It has been developed in FORTRAN90 and accepts input from all the aforementioned codes, including both the electrostatic potential and the magnetic field configurations. Tracers can be advected considering either of the following effects: ExB drifts, magnetic drifts, parallel motion, etc. Preliminary effects of the use of the tool with several GK codes will be presented.

TP8.00077 Coherent Structures and Reconnection in Collisionless Turbulence. VADIM ROYTER-SHTEYN, Space Science Institute and Sci4bquest, Inc, HOMA KARIMABADI, Sci4bquest, Inc — The sub-proton range of collisionless turbulence has attracted considerable attention in the last decades due to its role in the dissipation of cascading energy and increased availability of high-quality measurements capable of constraining the relevant models. Coherent structures, such as current sheets, have long been considered important sites for the dissipation of energy. However, a self-consistent treatment of their formation and of the relevant collisionless dissipation mechanisms has only become possible recently. Here we discuss several examples from recent kinetic simulations of turbulence focusing on the role of current sheets and magnetic reconnection. In the 3D fully kinetic simulations with initial conditions relevant to solar wind turbulence, current sheets form over a large range of scales and are shown to be sites of increased energy transfer between fluctuating fields and particles. Moreover, depending on the initial conditions and the type of driving, other types of coherent structures are possible, such as magnetic holes. 2D and 3D global hybrid simulations of the interaction between solar wind and planetary magnetospheres demonstrate inherent connections between collisionless shocks, turbulence, and magnetic reconnection. Specifically, the interaction of foreshock turbulence driven by reflected ions with the shock itself leads to a variety of fascinating phenomena in the magnetosheath, seeding both small-scale turbulence and large-scale global perturbations.

TP8.00078 Large Eddy Simulations of 2D Lattice Boltzmann MHD Turbulence. CHRISTOPHER FLINT, GEORGE VAHALA, William & Mary, LINDA VAHALA, Old Dominion University, MIN SOE, Rogers State University — Dellar’s LBM of 2D incompressible MHD introduced both a velocity and magnetic distribution functions. As a result div \( B = 0 \) is automatically enforced through the trace of an antisymmetric perturbed tensor. We have extended this algorithm to 3D MHD turbulence, with excellent parallelization to many thousands of cores. In LES of MHD turbulence, only the subgrid modes are modeled for using some ad hoc closure scheme. In the Smagorinsky model, the filtered Reynolds stress is modeled by mean field gradient terms. Recently, Ansumali et al. have developed a LES for Navier-Stokes turbulence by filtering the underlying mesoscopic LB. The filtered LB equations are then solved with the standard closure schemes. A Smagorinsky LES with no ad hoc closure is developed and its subgrid terms contribute at the transport time scales. This forces a relationship between the filter width and the Knudsen number. Here we extend these ideas to MHD turbulence and achieve closures under the simple assumption that the subgrid terms affect the evolution on the transport time scale. These ideas will first be tested on the flow of 2D jets in a magnetic field. The DNS data base is being generated from a multiple relaxation time (MRT) model for both the velocity and magnetic fields. 

TP8.00079 Characterizing transport with local perturbations and Lagrangian trajectories in two-dimensional plasma turbulence. DOUGLAS OGATA, DAVID NEWMAN, University of Alaska Fairbanks, RAUL SANCHEZ, JOSE-MIGUEL REYNOLDS-BARREDO, Universidad Carlos III — Perturbative experiments such as pellet injections, gas puffs, heat pulses have been used to investigate the transport characteristics in hot plasmas where probes are not suitable. However, the addition of too large a perturbation can alter the local transport characteristics making it a poor measure of the underlying transport. This work attempts to evaluate both the impact of different sized local perturbations on transport characteristics and the evolution of that perturbation as a measure of transport within a general non-diffusive transport framework. This is done by comparing the evolution of the local perturbation profile and the advection of a passive scalar with the transport characteristics extracted from the Lagrangian trajectories in a two-dimensional electrostatic plasma fluid turbulence model. This work presents the methodology and preliminary comparisons between the trajectories analysis and the evolution of a profile perturbation in order to find experimentally feasible observables to characterize the transport dynamics. 

TP8.00080 Wave-Kinetic Simulations of Lower-Hybrid Turbulence driven by Velocity Ring Instabilities1. GURU GANGULI, CHRIS CRABTREE, Naval Research Laboratory, LEONID RUDAKOV, Icarus Research Inc., MANISH MITHAIWALA, Naval Research Laboratory — We develop numerical solutions to the wave-kinetic equation in a periodic box including the effects of nonlinear (NL) scattering of Lower-hybrid waves giving the evolution of the wave-spectra in wavenumber space. Simultaneously we solve the particle diffusion equation of both the background plasma particles and the ring ions, due to both linear and nonlinear Landau resonances. At initial times for cold ring ions, an electrostatic beam mode is excited, while the kinetic mode is stable. As the instability progresses the ring ions heat, the beam mode is stabilized, and the kinetic mode destabilized. When the amplitude of the waves becomes sufficient the lower-hybrid waves are scattered (by either nearly unmagnetized ions or magnetized electrons) into electromagnetic magnetosonic waves [Ganguli et al 2010]. The effect of NL scattering is to limit the amplitude of the waves, slowing down the quasilinear relaxation time and ultimately allowing more energy from the ring to be liberated into waves [Mithaiwala et al. 2011]. The effects of convection out of the instability region are modeled, additionally limiting the amplitude of the waves, allowing further energy to be liberated from the ring [Scales et al., 2012]. Results are compared to recent 3D PIC simulations [Winske and Daughton 2012].

1This work is supported by the Naval Research Laboratory base program.

TP8.00081 Investigation of magnetic field generation by non-Gaussian, non-Markovian velocity fluctuations using meshless, Lagrangian numerical schemes. RAUL SANCHEZ, Univ Carlos III De Madrid, DAVID NEWMAN, University of Alaska at Fairbanks — Turbulent velocity fields can generate perturbations of the electric current and magnetic field that, under certain conditions, may generate an average, large-scale magnetic field. Such generation is important to understand the behavior of stars, planetary and laboratory plasmas. This generation is typically modeled by assuming near-Gaussian, random velocity fluctuations. This simplification allows to express the effective electromotive force in Faraday’s law in terms of a piece proportional to the large-scale magnetic field itself (the \( \alpha \) term) and another proportional to its curl (the \( \beta \) term) assuming certain symmetry conditions are met. Physically, the \( \alpha \) term is a measure of the mean helicity of the flow and drives the dynamo process. In a previous contribution, we examined theoretically what consequences would follow from assuming instead Levy-distributed, Lagrangianly-correlated velocity fields, that have been recently identified as of relevance in regimes of near-marginal turbulence or in the presence of a strong, stable sheared flow. Here, we will discuss and extend these results numerically by implementing the kinematic dynamo equation using a Lagrangian, meshless numerical method inspired by the SPH schemes frequently used in hydrodynamics.
TP8.00082 Electromagnetic corrections to the zonal flow residual1, ISTVAN PUSZTAI, Chalmers Univ. Technol., and MIT PSFC, PETER J. Catto, MIT PSFC, FELIX I. ParrA, Oxford Univ., Phys. Dept. — The axisymmetric zonal flow residual calculation in tokamak plasmas is generalized to include electromagnetic perturbations. Instead of imposing magnetic perturbations externally, we formulate and solve a description retaining the fully self-consistent temporal and spatial perturbations in the electric and magnetic fields. Simple expressions for the electrostatic, shear and compressional magnetic residual responses derived provide a fully electromagnetic test of the zonal flow residual in gyrokinetic codes. We find that at $\beta = 0.1$ the most easily testable quantity is the compressional magnetic perturbation generated by the density perturbation corresponding to the zonal flow potential, while at small values of $\beta$, the electrostatic and shear magnetic responses to an initial compressional magnetic perturbation can also be detected. Without collisions any initial magnetic perturbation remain completely undamped.

1Supported by US Department of Energy grant at DE-FG02-91ER-54109 at MIT. IP is supported by the International Postdoc grant of Vetenskapsradet.

TP8.00083 Theoretical Issues on the Spontaneous Rotation of Axisymmetric Plasmas*, T. ZHOU, B. COPPI, MIT — An extensive series of experiments have confirmed that the observed phenomenon of "spontaneous rotation" in axisymmetric plasmas is connected to the excitation of relevant collective modes [1] and, consequently, both to the confinement properties of the concerned plasmas, when referring to electrostatic modes, and to the magnetic reconnection processes associated with the excitation of electromagnetic modes [2]. Internal localized modes [2] can extract angular momentum from the plasma column from which they grow while, the background plasma has to recoil in the direction opposite to that of mode phase velocity. In the case of a set of plasma drift modes, the loss of their angular momentum can be connected to the directed particle ejection to the surrounding medium. The recoil angular momentum is then redistributed inside the plasma column mainly by a process that includes [1] the contribution of an effective viscous diffusion and of an inward (pinch) angular momentum flux that is connected, for instance, to ETG or ITG driven modes. *US DOE partly sponsored.

TP8.00084 Hamiltonian gyro-averaged area preserving map models of finite Larmor radius effects on ExB chaotic transport , JULIO FONSECA, University of Sao Paulo, Brazil, DIEGO DEL-CASTILLO-NEGRETE, Oak Ridge National Laboratory, IBERE CALDAS, University of Sao Paulo, Brazil — Area preserving maps have been extensively used to model 2-dimensional chaotic transport in plasmas and fluids. Here we focus on three types of area preserving maps describing ExB chaotic transport in magnetized plasmas with zonal flows perturbed by electrostatic drift waves. We include finite Larmor radius (FLR) effects by gyro-averaging the corresponding Hamiltonians of the maps. The Hamiltonians have frequencies with monotonic and non-monotonic profiles. In the limit of zero Larmor radius, the monotonic frequency map reduces to the standard Chirikov-Taylor map, and, in the case of non-monotonic frequency, the map reduces to the standard non-twist map. We show that FLR leads to chaos suppression, modifies the stability of fixed points, and changes the robustness of transport barriers. FLR effects also modify the phase space topology and give rise to bifurcations of the zonal flow ExB velocity profile. Dynamical systems methods based on recurrence time statistics are used to quantify the dependence on the Larmor radius of the threshold for the destruction of transport barriers.

TP8.00085 Partial barriers to heat transport in monotonic-q and reversed shear 3-dimensional chaotic magnetic fields, DIEGO DEL-CASTILLO-NEGRETE, Oak Ridge National Laboratory, DANIEL BLAVEZSKI, Institute for Mechanical Systems ETH Zurich, Switzerland — The quantitative understanding of the role of magnetic field stochasticity on transport in 3-D configurations is of paramount importance for understanding the confinement properties of fusion plasmas. Problems of interest include the control of ELMs by RMPs and the assessment of heat fluxes at the divertor. In this contribution we present numerical solutions of the time dependent parallel heat transport equation describing transport of heat pulses in 3-D chaotic magnetic fields. To overcome the limitations of standard approaches, we use a Lagrangian-Green’s function (LG) method that allows the efficient and accurate integration of the anisotropic heat transport equation with local and non-local parallel heat flux closures in integrable and chaotic B-fields. The results provide conclusive evidence that even in the absence of flux surfaces, chaotic magnetic field configurations exhibit partial barriers to heat transport. In particular, high-order islands and remnants of destroyed flux surfaces (Cantor) act as partial “leaky” barriers that slow down or even stop the inward propagation of heat pulses. The magnetic field connection length, $<l_B>$, exhibits a strong gradient where the partial barriers form, and it reaches a plateau whose value determines the “porosity” of the barrier. Heat pulses are shown to slow down considerably in the shear reversal region and, as a result, the time delay of the temperature response in chaotic reversed shear configurations is about an order of magnitude larger than the delay time in monotonic-q profiles.

TP8.00086 Simulating MHD/Fluid type electromagnetic modes in the total-f gyrokinetic code XGC1, J. LANG, S.-H. KU, C.-S. CHANG, PPPL, Y. CHEN, S.E. PARKER, U. of Colorado at Boulder — For a more complete description of the MHD/Fluid type modes activities including ELMs and neoclassical tearing modes, their interaction with the kinetic neoclassical and microturbulence dynamics needs to be simulated together. Evolution of the background profile should also be captured self-consistently. We report recent development activity of the MHD/fluid modes capability in the total-f gyrokinetic codes in the limit of small delta-B. Verification of the Alfven wave modes, low-n tearing modes, and transition from ITG to KBM modes will be presented. Plan for further development will be discussed. Important implication of the new development to the XGC1 program and fusion physics will also be discussed.

TP8.00087 Energy Dissipation in Electromagnetic Microturbulence, G.G. WHELAN, M.J. PUESCHEL, P.W. TERRY, University of Wisconsin-Madison — Typically, almost all roots of the gyrokinetic plasma dispersion relation are damped modes. Through nonlinear transfer, often involving coupling with zonal flows, these modes receive energy from unstable modes. This has significant consequences and in cases the effects from mode coupling are even the dominant contributions for the saturation physics of plasma turbulence. Using the gyrokinetic code GENE, we track the nonlinear-flows generated by a single wave number by making use of both proper orthogonal decomposition and linear eigenmode representation. Expanding on previous, electrostatic work [K.D. Makwana et al., Phys. Rev. Lett. 112, 095002 (2014)], we investigate how finite-beta physics affect zonal flow coupling, as well as the cumulative effects of zonal modes and frequency profiles. In particular: how effective zonal flows are in facilitating energy transfer to stable modes, the energy dissipation by stable modes in the drive range and the possible contributions by resonant effects respectively. In this context, consequences for the understanding of electromagnetic stabilization of ion-temperature-gradient-driven turbulence are detailed.

TP8.00088 Gyrokinetic Simulation of Microturbulent Saturation at Finite $\beta$, P.W. TERRY, M.J. PUESCHEL, D. CARMODY, G.G. WHELAN, University of Wisconsin-Madison — Saturation and zonal flow physics for microturbulence is investigated for tokamaks and the RFP using gyrokinetic computation to understand scalings with respect magnetic shear and $\beta$. Modeling an MST discharge shows that the critical instability gradient for TEM is higher than the tokamak threshold by the aspect ratio $(R/a)$. This factor is rooted in the shorter magnetic field scale length of the RFP. Nonlinear simulations show strong zonal flows and a large Dimsit shift exceeding the tokamak shift by a factor of order $(R/a)$. The non zonal transition (NZT), a critical $\beta$ for which zonal flows are disabled by flute-induced charge loss is also considered. The critical $\beta$ occurs when the radial displacement of a magnetic field line over a half connection length is equal to the radial correlation length. These quantities scale with the connection length and magnetic drift length entering the instability threshold and quasilinear diffusivities, making the RFP critical $\beta$ for NZT higher than the tokamak value by $(R/a)^{1.5}$ times tokamak $\beta$. These results are consistent with magnetic shear and $q$ dependence in the kinetic ballooning threshold, indicating that $\beta$ effects will only arise at high $\beta$ relative to typical RFP operation.
TP8.00089 Passive advection in a collisionless plasma, ANJOR KANEKAR, Univ of Maryland-College Park, ALEXANDER SCHIEKOHIN, University of Oxford, GREG HAMMETT, Plasma Physics Laboratory, Princeton University, WILLIAM DORLAND, Univ of Maryland-College Park, NUNO LOUREIRO, IPFN, Instituto Superior Tecnico, Universidade de Lisboa — We consider a simple kinetic model for the evolution of the particle distribution function in a magnetized turbulent plasma that includes both phase mixing (Landau damping) and advection by a stochastic velocity field: a “kinetic passive scalar” in the Batchelor regime. The advection due to stochastic velocity field allows for a stochastic version of the plasma echo by coupling the “phase-mixing” and the “un-phase-mixing” components of the free energy. We have developed a new analytical framework to diagnose the efficiency of such coupling. We have also developed a new GPU code named Gandalf that solves this kinetic model numerically. In this poster, we shall present numerical and analytical results related to this work.

TP8.00090 Self-Consistent evolution of radial electric field in a low flow ordered drift kinetic system, W. SENGUPTA, A.B. HASSAM, T.M. ANTONSEN, University Of Maryland College Park — We present a closed set of low collisionality drift kinetic equations which are full-f, nonlinear, with arbitrary geometry, electromagnetic with arbitrary beta, with ExB flow of order the diamagnetic flow, and with time variations ordered as second order in gyro-radius expansion. Our equations can be applied to the tokamak edge including evolution of the profiles. As has been pointed out by Parra et al [1-2], we show that in order to self-consistently evolve the radial electric field, second order terms need to be retained. The complete set involves evolution of f, the magnetic field, and the ExB flow. We shall compare our drift kinetic system with the Gyrokinetic system developed by Calvo-Parra [2]. We shall also discuss the effects of the higher order corrections on the Rosenbluth-Hinton residual Zonal flows.


1Work Supported by DOE.

TP8.00091 Compression of spinning plasma, VASILY GEYKO, NATHANIEL FISCH, Princeton University — Adiabatic compression of a spinning plasma in cylindrical geometry is studied in thermodynamical limit. Compared to spinning neutral gas, additional electrostatic energy of charge separation yields to increased heat capacity for both axial and longitudinal compressions. Radial compression of plasma with external axial magnetic field is also considered. The obtained results can be used as thermodynamical estimations for z-pinch compression.

TP8.00092 Modeling magnetospheres of spinning black holes, ALEX FORD, BRETT KEENAN, MIKHAIL MEDVEDEV, University of Kansas — We numerically model the magnetospheres of spinning (Kerr) black holes (BHs) and the production of relativistic jets in active Galactic Nuclei, quasars and micro-quasars, blazars, etc. There is a lore that Kerr BHs in an external magnetic field form force-free magnetospheres, whose structure is believed to determine how relativistic jets are launched and how the BH energy is extracted, e.g., via Blandford-Znajek mechanism. The key assumption for the force-free condition is the presence of plasma with the density being above the Goldreich-Julian density. Unlike NSs which can in principle supply electrons from the surface, plasma around BHs must be generated in situ via a pair cascade. Here we we present numerical modeling of the “gap” region, where cascade can occur. We explore the conditions of the plasma generation, without which AGN, quasar/blazar and other jets cannot exist.

1Supported by grant DOE grant DE-FG02-07ER54940 and NSF grant AST-1209665.

TP8.00093 “Pseudo-cyclotron” radiation and transport of non-relativistic particles in inhomogeneous sub-Larmor-scale electro-magnetic fields, BRETT KEENAN, ALEX FORD, MIKHAIL MEDVEDEV, University of Kansas — Plasma turbulence in some astrophysical objects (e.g., weakly magnetized collisionless shocks in GRBs and SN) has small-scale electro-magnetic field fluctuations. We study spectral characteristics of radiation produced by particles moving in such turbulence and relate it to transport properties (diffusion) of these particles. It was shown earlier that relativistic particles produce jitter radiation, which spectral characteristics are markedly different from synchrotron radiation. Here we study radiation produced by non-relativistic particles. Unlike radiation in homogeneous field, which spectrum consists of a single cyclotron harmonic, radiation in the sub-Larmor-scale turbulence reflects statistical properties of the underlying magnetic field. We present both analytical estimates and results of ab initio numerical simulations. We also show that particle propagation in such turbulence is diffusive and evaluate the diffusion coefficient. We demonstrate that the diffusion coefficient correlates with some spectral parameters. These results can be very valuable for remote diagnostics of laboratory and astrophysical plasmas.

1Supported by grant DOE grant DE-FG02-07ER54940 and NSF grant AST-1209665.

TP8.00094 Shear-Driven Dynamo Waves in Fully Nonlinear Regime, PEERA PONGKITIWANICHAKUL, FAUSTO CATTANEO, Univ of Chicago, GIUSEPPINA NIGRO, University of Calabria, Italy — Dynamo action is often invoked to explain the origin of magnetic fields in astrophysics. Often, the generated magnetic fields are organized on spatial and temporal scales much larger than that of the underlying turbulence. This process of large-scale dynamo action is well understood when the magnetic Reynolds number is small or moderate, but not as clear when the magnetic Reynolds number becomes large. In this regime, the fluctuations control the operation of the dynamo obscuring the large-scale behavior. Recently, Tobias and Cattaneo (2013) developed a dynamo model involving strongly helical flows and large scale shear that could generate well organized large-scale magnetic fields in the form of a traveling dynamo waves. Their model, however, was only kinematic, and did not include the back reaction of the Lorentz force on the flow. Here, we have undertaken a systematic extension of their work to the fully nonlinear regime. Helical turbulence, and large scale shear are produced self-consistently by prescribing body forces that, in the kinematic regime replicate the original velocity used by Tobias & Cattaneo. I will present results in the nonlinear regime for different magnetic Prandtl numbers and show different cases of large-scale organization.

TP8.00095 Towards an Analytical Model of Differential Rotation in the Solar Convection Zone, LEE GUNDERSON, AMITAVA BHATTACHARJEE, Princeton Plasma Physics Laboratory — The Solar Convection Zone (SCZ) is a region of turbulent convection in a rotating stratified plasma. Helioseismology and numerical models have provided mean flow profiles of this region, showing characteristic differential zonal rotation and meridional circulation (Thompson et al. 2003). Numerical simulations have reproduced these profiles, including in the hydrodynamic limit (Fan and Fang 2014). However, the theoretical underpinnings are still being debated. Balbus (2009) proposed the following ansatz: the isentropic and isotropical contours coincide. Indeed, with this assumption, the resulting solutions to the thermal wind equation gave profiles of remarkable similarity to observations. We have developed a Grad-Shafranov treatment of axisymmetric equilibrium in the hydrodynamic case, however the result suggests that entropy should be a function of angular momentum, which give profiles that are not characteristic of the SCZ. We attempt to improve on this formulation by introducing a mean-field model of the Reynolds stress and testing Balbus’ ansatz, and will report on the progress towards an analytical model of differential rotation in the SCZ.
TP8.00096 Nonmodal growth and the magnetorotational dynamo instability1. JONATHAN SQUIRE, AMITAVA BHATTACHARJEE, Princeton University — Unravelling the important dynamo processes in magnetized rotating shear flows remains fundamental in understanding turbulent transport in astrophysical disks. We consider the dynamo of the magnetorotational instability (MRI) in its simplest possible form, studying the unstratified shearing box without a mean magnetic field. Despite the lack of spectral instability, sustained turbulence and dynamo is possible in this system, with the non-normality of the linear operator playing an important role. An analysis of the MRI from this non-normal perspective has proved enlightening, illustrating that the fastest growing non-axisymmetric disturbances are very different from the eigenmodes, invariably resembling waves shearing with the background flow (shear waves). With the goal of understanding the core dynamo process, we evolve an statistical ensemble of shear waves in a quasi-linear version of the shearing box system. Among the most interesting ideas resulting from this approach is the existence of a mean field dynamo instability of homogenous background turbulence. The instability saturates at levels consistent with fully nonlinear turbulence simulations and depends strongly on magnetic Prandtl number.

1This work was supported by Max Planck/Princeton Center for Plasma Physics and U.S. DOE (DE-AC02- 09CH11466).

TP8.00097 MRI Turbulence at High Reynolds Numbers, JUSTIN WALKER, STANISLAV BOLDYREV, University of Wisconsin-Madison, GEOFFROY LESUR, Institut de Planetologie et d’ Astrophysique de Grenoble (IPAG) — The properties of magnetic turbulence driven by the magnetorotational instability (MRI) are studied at large Reynolds numbers by simulation. The results are compared with previous published results at lower Reynolds number and with forced magnetohydrodynamic (MHD) turbulence. Preliminary results suggest that spectra exhibit a power law within a short inertial range, and similarities and differences with the inertial range in MHD turbulence are established.

TP8.00098 Towards kinetic simulation of MRI using GPU1, T. TATSUNO, Univ Electro-Communications, W. DORLAND, A. KANEKAR, Univ Maryland — Graphics processor Units (GPUs) are nowadays widely used in fluid and MHD simulations. Due to their fast computation and memory access, they enable us to make large simulations on a desktop that used to be only accessible by a large supercomputer. So far, however, there are not many attempts to make kinetic simulations on GPU. In this work, we will try to develop a kinetic simulation code on GPU. We plan to apply the developing kinetic simulation code to analyze magnetorotational instability (MRI). It is shown by the fluid analyses with some kinetic effects included in the model [1, 2] that the pressure anisotropy brings an important effect on the accretion rate. However, the results depend on the free parameters in the terms for kinetic effects. Thus evaluation using kinetic simulation is desired for quantitative estimate.


1This work is supported in part by JSPS KAKENHI Grant Number 24540533.

TP8.00099 ABSTRACT WITHDRAWN —

TP8.00100 Particle In Cell Codes on Highly Parallel Architectures, ADAM TABLEMAN, UCLA Department of Physics — We describe strategies and examples of Particle-In-Cell Codes running on Nvidia GPU and Intel Phi architectures. This includes basic implementations in skeletons code and full-scale applications in 1D, 2D, and 3D codes in astrophysics. Both the similarities and differences between Intel’s and Nvidia’s hardware will be examined. Work supported by grants NSF ACI 1339893, DOE DE SC 000849, DOE DE SC 0008316, DOE DE NA 0001833, and DOE DE FC02 04ER 54780.

TP8.00101 Particle-in-Cell Simulations of Driven Solar Wind Turbulence, JASON TENBARGE, JAMES JUNO, University of Maryland — Turbulence is a ubiquitous phenomenon in space and astrophysical plasmas and is responsible for mediating the transfer of large scale electromagnetic energy to small scales where the energy is eventually damped onto the particles. Solar wind observations suggest that the turbulence is dominated by low frequency Alfvénic fluctuations, which approximately follow the predictions of critical balance. We present results from the first driven, three-dimensional particle-in-cell simulations of Alfvénic turbulence spanning inertial to electron kinetic scales. The simulations are driven to a statistically steady state with an oscillating Langevin antenna intended to mimic turbulent energy cascaded from scales larger than the simulation domain. Since a primary focus of the turbulence community is energy dissipation and one of the dominant mechanisms is likely Landau damping, a parameter scan in wavelength, plasma beta, and particle number is presented to determine the computational requirements of particle-in-cell simulations to accurately capture the Landau damping of Alfvén waves.

TP8.00102 Gyrokinetic Study of Intermittency in Interstellar Turbulence, G. LAU, P.W. TERRY, M.J. PUESCHEL, University of Wisconsin, Madison — The temporal broadening of pulsar signals from scintillation is dependent on the distance to the pulsar, but the exact scaling cannot be recovered from electron density fluctuations that follow Gaussian statistics - Lévy statistics are required [5, 6]. We investigate the possibility that interstellar turbulence produces Lévy statistics in electron density fluctuations, focusing on the intermittency associated with current filaments and sheets in decaying gyrokinetic turbulence at ion gyroradius scales. It has been shown that the proper distributions arise in a 2D fluid model for kinetic Alfvén turbulence [P. W. Terry and K. W. Smith, Astrophys. J. 665, 402 (2007)]. Using the GENE code, we continue this work by confirming that gyrokinetics returns similar results. We then extend to 3D and show the effects of collisions on the emerging structures.

TP8.00103 A new method of driving turbulence in particle-in-cell simulations, JAMES JUNO, JASON TENBARGE, MARC SWISDAK, WILLIAM DORLAND, University of Maryland — We present a novel approach for driving turbulence in particle-in-cell (PIC) simulations with the implementation of an oscillating Langevin antenna which drives \( A_\parallel \) across the domain. The antenna obtains its name from its similarity to the Langlevin equation for Brownian motion and allows us to more realistically model the injection of energy from scales larger than the simulation domain so we can simulate a more computationally feasible subrange of the turbulent cascade. Oftentimes, PIC simulations are driven from a single point, or from the edge of the simulation domain; however, the Langevin antenna works like a body force, driving the plasma from all points in space. Furthermore, studies of turbulence with PIC are often decaying, but with the antenna, we can model steady state conditions. Thus, we can create a more physically motivated simulation of the turbulent evolution from large scales to small scales and better understand the dissipation of turbulence in systems such as the solar wind. Though we focus on driving low frequency Alfvén waves, the flexibility of the antenna allows for driving any range of frequencies. Comparisons to linear theory and fully non-linear gyrokinetic simulations are presented as validation of our method.
TP8.00104 Parametric Antenna Concept for Efficient Very Low Frequency (VLF) Wave Excitation. T. KIM, V. SOTNIKOV, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433, E. MISHIN, Air Force Research Laboratory, Kirtland AFB, NM 87117, T. GENONI, D. ROSE, Voss Scientific Inc, Albuquerque, NM 87107 — Concept of a parametric antenna in the ionospheric plasma is analyzed. Such antennas are capable of exciting electromagnetic radiation fields, specifically the creation of whistler waves generated at the very low frequency (VLF) range, which are also capable of propagating large distances away from the source region. The mechanism of whistler wave generation is considered a parametric interaction of quasi-electrostatic low oblique resonance (LOR) oscillations excited by conventional antenna. The transformation of LOR waves on quasi-neutral density perturbations in the near field of an antenna gives rise to whistler waves on combination frequencies. Amplitude of these waves can considerably exceed the amplitude of whistler waves directly excited by a loop. Simulation to demonstrate excitation and spatial structure of VLF waves excited by a loop antenna using a PIC code LSP will be presented as well.

Work supported by the Air Force Research Laboratory.

TP8.00105 Nonlinear simulation of the whistler wave excited by the energetic particles. GE WANG, GUOYONG FU, Princeton Plasma Physics Laboratory — The energetic particle induced whistler waves are widely observed in the magnetosphere and fusion related devices. We report the nonlinear delta f-PIC simulation of the oblique whistler wave in the homogeneous background magnetic field, where the longitudinal electric field is observed to be important and the whistler wave deviates from the circular polarization. A nonlinear resonance plays an important role on the damping mechanisms at the half electron cyclotron frequency, which helps to transfer the whistler wave energy into the thermal energy of background particles. We also explore the possibility of the frequency chirps when the cyclotron resonance and Landau resonance coexist, where the hole and clump generated in the phase space will provide a candidate for the whistler chorus in the magnetosphere.

TP8.00106 Effects of Induced Scattering of Lower-Hybrid Waves by Plasma Particles on the Lifespan of Plasma-sheet Turbulence. MANISH MITHAIWALA, Naval Research Laboratory, LEONID RUDAKOV, Icarus Research Inc., GURUDAS GANGULI, CHRIS CRABTREE, Naval Research Laboratory — The portion of broadband electrostatic turbulence in the plasma sheet consisting of lower-hybrid waves is thought to be generated by proton-ring distributions [1]. However it remains a mystery why these ring distributions are so long lived. The possibility that induced non-linear scattering of lower-hybrid waves from plasma electrons to longer wavelengths has been considered as a saturation mechanism for these instabilities, which saturate the wave amplitude at very low levels, allowing the ion-ring distributions to be long-lived. This was demonstrated theoretically, as well as in 3D simulations [2, 3]. A comparison of the electric field fluctuation amplitude at two different values of plasma beta confirms that the saturation amplitude depends on temperature. This is consistent with nonlinear scattering by particles being the dominant nonlinearity rather than three-wave interaction. Though it has been shown previously that it is inappropriate to treat the nonlinear scattering of lower-hybrid waves only in the electrostatic limit, the suggested electromagnetic generalizations only included changes to the nonlinear charge density. Thus a self-consistent treatment that includes both a nonlinear charge and current density is shown to be necessary [4].


This work is supported by NRL Base Funds.

TP8.00107 Gyrokinetic simulations of kink modes in astrophysical jets. JOSEPH MCCLENAGHAN, University of California, Irvine, KEN FOWLER, University of California, Berkeley, HUI LI, Los Alamos National Lab, ZHICHONG LIN, University of California, Irvine — With the prediction that powerful astrophysical jets that are formed around supermassive black holes maintain collimation by presence of a self generated magnetic field, linear MHD theory predicts that these magnetically confined jet plasmas would be unstable to kink modes. Kink modes have been studied extensively in tokamak experiments, theory, and MHD simulations, however, their dynamical evolution can depend on the nonlinear coupling of multiple physical processes. In this work, we have applied the gyrokinetic Toroidal Code (GTC) to study internal kink modes in a proposed jet equilibrium. Linear stability properties suggest that kink modes in astrophysical jets are nonlinearly unstable with reasonable agreement to MHD. Nonlinear saturation amplitude and continued evolution of kink modes are examined to better understand how the jet can remain collimated in the presence of these modes without being disrupted. We also look at the generation of a mean parallel electric field by the nonlinear evolution of internal kink modes and the potential implication of this field on particle acceleration in jets.

TP8.00108 Small-Scale Irregularities in Equatorial Spread-F. YAKOV DIMANT, MEERS OPPENHEIM, Boston Univ — Equatorial Spread-F is a spectacular plasma phenomenon that reshapes the nighttime ionosphere and disrupts GPS navigation and radio communication. Current computer models simulate the evolution of large-scale spread-F phenomena (1000km-to-kilometer), but they do not explain what causes the meter-scale irregularities observed by radars and space-borne instruments. Our recent particle-in-cell (PIC) simulations of weakly collisional plasma have demonstrated that large-scale plasma density gradients and related electric fields may drive local plasma instabilities, although only for a limited set of parameters. Motivated by these PIC simulations, we have revisited the linear theory of this instability, employing a novel and sophisticated eigenmode analysis. This method identified eigenmode wave structures in regions having strong plasma density gradients. These wave structures are not linearly unstable, but are not damped either. This means that small-scale fluctuations provided by an external source (e.g., by a nonlinear spectral cascade from longer-wavelength spread-F turbulence) can be resonantly amplified and may explain radar observations without invoking linear instability.

1Work supported by NASA LWS Grant 10-LWSRT10-0078.

TP8.00109 Development and Validation of a Critical Gradient Energetic Particle Driven Alfvén Eigenmode Transport Model for DIII-D Tilted Neutral Beam Experiments. R.E. WALTZ, General Atomics, E.M. BASS, UCSD — Recent experiments on DIII-D with tilted neutral beam injection (NBI), which significantly vary the beam energetic particle (EP) source profiles, have provided strong evidence that unstable Alfvén eigenmodes (AE) drive stiff EP transport at a critical EP density gradient [1]. We hope to identify the critical gradient with the condition that the maximum local AE growth rate falls to the local ion temperature gradient (ITG) trapped electron mode (TEM) rate at the same low toroidal mode number. This condition was supported by early nonlinear local gyro simulations [2] and more is more optimistic than stiff EP transport at the AE marginal stability gradient used in a recent ITER projection of AE driven alpha confinement losses [3]. The AE and ITG/TEM growth rates are from gyro with comparison of Maxwellian and slowing down beam-like EP distributions.


Work supported by the US Department of Energy under DE-FG02-95ER54309 and DE-FC02-08ER54977.
2:00PM UI1.00001 Rotating structures and vortices in low temperature plasmas, JEAN-PIERRE BOEUF, LAPLACE, University of Toulouse, France — Rotating structures are present in a number of low temperature EXB devices such as Hall thrusters, magnetrons, Penning discharges etc. . Some aspects of the physics of these rotating instabilities are specific to low temperature plasmas because of the relatively large collisionality, the role of ionization, and the fact that ions are often non-magnetized. On the basis of fully kinetic simulations (Particle-In-Cell Monte Carlo Collisions) we describe the formation of a rotating instability associated with an ionization front (“rotating spoke”) [1] and driven by a cross-field current in a self-sustained cylindrical magnetron discharge at gas pressure on the order of 1 Pa. The rotating spoke is a strong double layer (electrostatic sheath) moving towards the higher potential region at a velocity close to the critical ionization velocity, a concept proposed by Alfven in the context of the formation of the solar system. The mechanisms of cross-field electron transport induced by this instability are analyzed. At lower pressure (<0.01 Pa) the plasma of a magnetron discharge is non-neutral and the simulations predict the formation of electron vortices rotating in the azimuthal direction and resulting from the diocotron instability. The properties of these vortices are specific since they form in a self-sustained discharge where ionization (and losses at the ends of the plasma column) play an essential role in contrast with the electron vortices in pure electron plasmas [2]. We discuss and analyze the mechanisms leading to the generation, dynamics and merging of these self-sustained electron vortices, and to the periodic ejection of fast electrons at the column ends (consistent with previous experimental observations).


2:00PM UI1.00002 Effects of Anomalous Electron Cross-Field Transport in a Low Temperature Magnetized Plasma1, YEVGENY RAITSES2, Princeton Plasma Phys Lab — The application of the magnetic field in a low pressure plasma can cause a spatial separation of low and high energy electrons. This so-called magnetic filter effect is used for many plasma applications, including ion and neutral beam sources, plasma processing of semiconductors and nanomaterials, and plasma thrusters. In spite of successful practical applications, the magnetic filter effect is not well understood. In this work, we explore this effect by characterizing the electron and ion energy distribution functions in a plasma column with crossed electric and magnetic fields. Experimental results revealed a strong dependence of spatial variations of plasma properties on the gas pressure. For xenon and argon gases, below ~ 1 mtorr, the increase of the magnetic field leads to a more uniform profile of the electron temperature. This surprising result is due to anomalously high electron cross-field transport that causes mixing of hot and cold electrons. High-speed imaging and probe measurements revealed a coherent structure rotating in E cross B direction with frequency of a few kHz. Theory and simulations describing this rotating structure has been developed and points to ionization and electrostatic instabilities as their possible cause [1,2]. Similar to spoke oscillations reported for Hall thrusters [2,3], this rotating structure conducts the large fraction of the cross-field current. The use of segmented electrodes with an electrical feedback control is shown to mitigate these oscillations [3].


3:00PM UI1.00003 Electric discharge microplasmas generated in highly fluctuating fluids: Characteristics and application to the synthesis of molecular diamond1, SVEN STAUSS, Department of Advanced Materials Science, The University of Tokyo — Plasma-based fabrication of novel nanomaterials and nanostructures is paramount for the development of next-generation electronic devices and for green energy applications. In particular, controlling the interactions between plasmas and materials interfaces, and the plasma fluctuations are crucial for further development of plasma-based processes and bottom-up growth of nanomaterials. Discharge microplasmas generated in supercritical fluids represent a special class of high-performance plasma sources, where fluctuations on the molecular scale influence the discharge properties and the possible bottom-up growth of nanomaterials. In the first part of the talk, we will discuss an anomalous growth of microplasmas generated near the critical point, a local decrease in the breakdown voltage, which has been observed for both molecular and monatomic gases. This anomalous behavior is suggested to be caused by the concomitant decrease of the ionization potential due to the formation of clusters near the critical point, and the formation of extended electron mean free paths induced by the high-density fluctuation near the critical point. We will also show that when generating microplasma discharges close to the critical point, that the high-density fluctuation of the supercritical fluid persists. In the second part of the presentation, we will first introduce the basic properties of diamondoids and their potential for application in many different fields - biotechnology, medicine, opto- and nano-electronics - before discussing their synthesis by microplasmas generated inside both conventional batch-type and continuous flow reactors, using the smallest diamondoid, adamantane, as a precursor and seed. Finally we show that one possible growth mechanism of larger diamondoids from smaller ones consists in the repeated abstraction of hydrogen terminations and the addition of methyl radicals.

1Supported financially in part by Grant No. 2376088 and Grant No. 21110002 from the Ministry of Education, Culture, Sports, Science and Technology of Japan
4:00PM UI1.00005 Coupling effects of driving frequencies on the electron heating in electronegative capacitive dual-frequency plasmas

JULIAN SCHULZE, West Virginia University — The coupling of the driving frequencies represents a serious limitation of the control of process relevant plasma parameters in low-pressure electronegative capacitive discharges excited by two significantly different frequencies. Here, we investigate the interaction of the low-frequency (LF) and high-frequency (HF) driving sources in electronegative capacitive radio frequency discharges by Particle-in-Cell/Monte Carlo Collisions (PIC/MCC) simulations. Such discharges can operate in the drift-ambipolar (DA) mode [1], where the ionization is dominated by electrons accelerated (i) by a strong drift field in the plasma bulk due to the low dc conductivity resulting from the depleted electron density and (ii) by an ambipolar field at the sheath edges caused by local maxima of the electron density in the electrostatic edge region of the discharge. The PIC/MCC simulations reveal frequency coupling mechanisms, different from those characteristic of electropositive discharges, due to the presence of the DA electron heating mode [2]. These mechanisms affect the electron heating (i) in the plasma bulk due to constructive/destructive interaction of drift electric fields originating from the HF and LF sources and (ii) at the collapsing sheath edge due to ambipolar electric fields influenced by the LF voltage amplitude via a modification of the sheath width. We analyze the effect of these phenomena on the discharge operation and plasma parameters.


4:30PM UI1.00006 Controlling the dynamics of electrons and ions in large area capacitive radio frequency plasmas via the Electrical Asymmetry Effect

EDMUND SCHUENGEL, Department of Physics, West Virginia University, Morgantown, WV 26506, USA — The processing of large area surfaces in capacitive radio-frequency plasmas is a crucial step in the manufacturing of various high-technological products. To optimize these discharges for applications, understanding and controlling the dynamics of electrons and ions is vitally important. A recently proposed method of controlling these dynamics is based on the Electrical Asymmetry Effect (EAE) [1]: By driving the capacitive discharge with a dual-frequency voltage waveform composed of two consecutive harmonics, the symmetry of the discharge can be varied by tuning the relative phase. In this experimental study, the EAE is tested in hydrogen diluted silane discharges. The electron dynamics visualized by Phase Resolved Optical Emission Spectroscopy depends on the electrical asymmetry, the heating mode, and the presence of dust particles agglomerating in the plasma volume [2,4]. In particular, a transition from the α-mode (heating by sheath expansion and field reversal) to the Ω-mode (heating by drift field in the bulk) is observed. The ion dynamics are strongly affected by the sheaths electric fields, which can be controlled via the EAE: Separate control of the flux and mean energy of ions onto the electrodes is possible via the EAE [1,3]. Furthermore, investigations of the spatially resolved ion flux in the electromagnetic regime, i.e. using higher driving frequencies, reveal that the ion flux profile is controllable via the phase, as well, allowing for a significant improvement of the uniformity [4]. Thus, it is demonstrated that the EAE is a powerful tool to control the properties of large area capacitive discharges in the volume and at the surfaces in various ways.


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former affiliation: Institute for Plasma and Atomic Physics, Ruhr-University Bochum, Germany

Thursday, October 30, 2014 2:00PM - 3:00PM –
Session UT2 Tutorial: 3D Toroidal Physics
Bissonet - Saskia Mordjick, College of William and Mary

2:00PM UT2.00001 3D toroidal physics: testing the boundaries of symmetry breaking
DON SPONG, Oak Ridge National Laboratory — Toroidal symmetry is an important concept for plasma confinement; it allows the existence of nested flux surface MHD equilibria and conserved invariants for particle motion. However, perfect symmetry is unachievable in realistic toroidal plasma devices. For example, tokamaks have toroidal ripple due to discrete field coils, optimized stellators do not achieve exact quasi-symmetry, the plasma itself continually seeks lower energy states through helical 3D deformations, and reactors will likely have non-uniform distributions of ferritic steel near the plasma. Also, some level of designed-in 3D magnetic field structure is now anticipated for most concepts in order to lead to a stable, steady-state fusion reactor. Such planned 3D field structures can take many forms, ranging from tokamaks with weak 3D ELM-suppression fields to stellators with more dominant 3D field structures. There is considerable interest in the development of unified physics models for the full range of 3D effects. Ultimately, the questions of how much symmetry breaking can be tolerated and how to optimize its design must be addressed for all fusion concepts. Fortunately, significant progress is underway in theory, computation and plasma diagnostics on many issues such as magnetic surface quality, plasma screening vs. amplification of 3D perturbations, 3D transport, influence on edge pedestal structures, MHD stability effects, modification of fast ion-driven instabilities, prediction of energetic particle heat loads on plasma-facing materials, effects of 3D fields on turbulence, and magnetic coil design. A closely coupled program of simulation, experimental validation, and design optimization is required to determine what forms and amplitudes of 3D shaping and symmetry breaking will be compatible with future fusion reactors. The development of models to address 3D physics and progress in these areas will be described.

This work is supported both by the US Department of Energy under Contract DE-AC05-00OR22725 with UT-Battelle, LLC and under the US DOE SciDAC GSEP Center

Thursday, October 30, 2014 2:00PM - 5:00PM –
Session UO3 Research in Support of ITER
Salon D - Francesca Poli, Princeton Plasma Physics Laboratory

2:00PM UO3.00001 Time-resolved kinetic modelling of ELM-induced tungsten influx in ITER
STEVEN LISGO, ITER Organization, JAMES HARRISON, CCCF, MARTIN KOČAN, RICHARD PITTS, ITER Organization, STEFFEN POTZEL, IPP Garching, DETLEV REITER, FZJ, PETER STANGEBY, GA — High performance operation in ITER (Q ~ 10) will require tungsten (W) core concentrations below ~ 10^{-5}. The steady-state influx of W from the strike-points will be nominal since only detached plasmas can satisfy the engineering heat-flux limit of 10 MW m^{-2}, but high energy particles reaching the target plates during Edge-Localized Modes (ELMs) will exceed the W sputtering threshold. Given the very low W concentration limit for the core, operational planning requires that the production and transport of W in the boundary plasma be assessed for controlled ELMs and infrequent natural Type-I ELMs, and in the absence and presence of resonant magnetic perturbations (RMPs). ELM simulations with the SOLPS plasma fluid code were recently performed, where prompt redeposition was found to reduce the W influx by more than an order of magnitude [D. Coster et al, 40th EPS, 2014]. The present study employs the OSM-EIRENE-DIVIMP code package, which utilizes an empirical fluid model to describe the bulk plasma evolution and W is treated kinetically. Model benchmarks against experimental data are presented. RMPs will be addressed in future work. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.
2:12PM UO3.00002 Revisited ELM divertor heat load scaling to ITER with JET and ASDEX Upgrade data
THOMAS EICH, BERNHARD SIEGLIN, ALBRECHT HERRMANN, Max-Planck-Institute for Plasma Physics, GUY MATTHEWS, MARC BEURSKENS, CCFE, ALBERTO LOARTE, Iter Organization, ASDEX UPGRADE TEAM, JET-EFDA COLLABORATION — The divertor heat load due to type-I ELMs is a major concern for ITER. Both the suppression of ELM losses and the scaling of ELM induced heat loads is hence a major research topic at the various operating tokamaks. The ELM energy density was calculated by assuming a relative ELM loss in ITER of few percent and a moderate broadening of the wetted area. The absolute numbers entering the scaling are the stored energy and the inter-ELM wetted area. Though it was shown both by DIII-D and JET that the ELM wetted area increases with the ELM loss energy, a scaling providing a quantitative estimate remained elusive. Recent attempts revisiting data from JET operation with carbon PFCs and with ITER-like-wall show an approximately linear dependence of ELM energy density with the pedestal top electron pressure. An attempt to scale the ELM energy density to ITER with pedestal pressure has the advantage that it directly utilizes measurements from Thomson-Scattering and infra-red thermography. However, it requires well diagnosed target heat load data for a wide scan in pedestal pressure. Currently this attempt is applied to data from ASDEX Upgrade to establish a multi-machine scaling.

2:24PM UO3.00003 Power Deposition on the DIII-D Inner Wall Limiter
P.C. STANGEBY, C.K. TSUI, J.D. ELDER, University of Toronto, C.J. LASNIER, A.G. MCLEAN, LLNL, A.W. LEONARD, GA, J.A. BOEDO, D.L. RUDAKOV, UCSD, M. KOCAN, R.A. PITTS, ITER — Power deposition on the inner wall limiter (IWL) of DIII-D was measured by infrared (IR) thermography and calculated from plasma profiles measured by an inner column Swing-Probe for 6 ohmic discharges. In some cases clear evidence was found for a narrow feature with $\lambda_{short} \sim $ ion poloidal gyro-radius near a few mm, and of strength $q_{HL}/q_{IL}$ between 0.5 and a factor of 5, where $q_{HL}$ is the parallel power flux density. The objective of the experiment was to check the assumptions made in defining the shape of the ITER IWL, in particular to see if the radial gradient of $q_{HL}$ increases near the last closed flux surface on DIII-D in agreement with observations in other tokamaks [JET, COMPASS, TCV, C-Mo]. On the basis of the results from the IWL experiments done on the 5 tokamaks, ITER decided in April 2014 to re-design the limiter shape to accommodate a narrow power feature.

2:36PM UO3.00004 X-Divertors on ITER - with no hardware changes
PRASHANT VALANJU, BRENT COVELE, MIKE KOTSCHENREUTHER, SWADESH MAHAJAN, Institute for Fusion Studies, UT Austin, CHARLES KESSEL, Princeton Plasma Physics Lab — Using CORSICA, we have discovered that X-Divertor (XD) equilibria are possible on ITER — without any extra PF coils inside the TF coils, and with no changes to ITER’s poloidal field (PF) coil set, divertor cassette, strike points, or first wall. Starting from the Standard Divertor (SD), a sequence of XD configurations (with increasing flux expansions at the divertor plate) can be made by reprogramming ITER PF coil currents while keeping them all under their design limits (Lackner and Zohm have shown this to be impossible for Snowflakes). The strike point is held fixed, so no changes in the divertor or pumping hardware will be needed. The main plasma shape is kept very close to the SD case, so no hardware changes to the main chamber will be needed. Time-dependent ITER-XD operational scenarios are being checked using TSC. This opens the possibility that many XDs could be tested and used to assist in high-power operation on ITER. Because of the toroidally segmented ITER divertor plates, strongly detached operation may be critical for making use of the largest XD flux expansion possible. The flux flaring in XD is expected to increase the stability of detachment, so that H-mode confinement is not affected. Detachment stability is being examined with SOLPS.

3:00PM UO3.00005 High resolution scrape-off layer profile measurements in limited and diverted plasmas in C-Mo — investigation of heat flux channel width physics
B. LABOMBARD, J.L. TERRY, D. BRUNNER, MIT PSFC, E. ELDUND, PPPL, T. GOLFINOPoulos, J.W. HUGHES, MIT PSFC, C. THEILER, CRPP Lausanne, J. WALK, S. WOLFE, D. WHYTE, MIT PSFC — Narrow scrape-off layer (SOL) heat flux channel widths ($\lambda_n$) are seen on many tokamaks, both in inner-wall limited (IWL) and divertor discharges. These observations have important consequences for ITER and reactors, impacting the design of inner limiter tiles for heat load during startup and pushing the limits of divertor plate operation and control. A dominant $\sim 1/\sqrt{p}$ scaling for $\lambda_n$ is seen in a wide range of cases (IWL, H-mode and L-mode diverted [at low density]), suggestive of a poloidal ion gyroradius effect. It is troubling that $\lambda_n$ does not appear to scale with major radius — a challenge for reactors. The latter observation contrasts with H-mode pedestal widths that increase with machine size, implying that the physics that sets the local gradient scale lengths in pedestal and SOL may be different. We have recently implemented a scanning “Mirror Langmuir Probe” diagnostic on C-Mo with the idea of exploring this critical interface with very high resolution. Narrow $\lambda_n$ “features” in IWL discharges have been mapped out in detail, exhibiting a $\sim 1/\sqrt{p}$ scaling with some evidence of a break-in-slope feature at the LCS. We will report on these findings and on L and H-mode experiments in progress, in which divertor conditions are varied (low recycling, high-recycling, detached).

3:06PM UO3.00006 Perspectives on the Final Design Review process from the US ITER DRGA team
T. M. BIEWER, C.C. KLEPPER, W. DEVAN, V. GRAVES, C. MARCUS, Oak Ridge National Laboratory, P. ANDREW, ITER International Organization, D.W. JOHNSON, Princeton Plasma Physics Laboratory — Among the ITER procurements awarded to the US ITER Domestic Agency, and subsequently to the ORNL Fusion & Materials for Nuclear Systems Division, is the design and fabrication of the Diagnostic Residual Gas Analyzer (DRGA) system. The DRGA system reached the Final Design Review (FDR) in July 2014, and is the first US-credited diagnostic system to achieve this milestone. The design effort has focused on the vacuum and mechanical interface of the DRGA gas sampling tube with the ITER vacuum vessel and cryostat. In addition to technical issues needed to negotiate the mechanical interface, a significant number of procedural issues at US ITER and the ITER IO were encountered to navigate the DRGA project to this milestone. The process has been beneficial to both the DRGA project, and in-turn to US ITER, by illuminating the procedures in practice. This presentation will highlight some of the issues encountered and relay perspectives for designing hardware for ITER.

3:12PM UO3.00007 Control of Plasma Stored Energy for Burn Control Using DIII-D In-Vessel Coils
R.J. HAWRYLUK, B.A. GRIESSON, E. KOLEMEN, R. NAZIKIAN, W.M. SOLOMON, Princeton Plasma Physics Laboratory, N.W. EIDITIS, A.W. HYATT, C. PAZ-SOLDAN, General Atomic, S. WOLFE, Massachusetts Institute of Technology — A new approach has been experimentally demonstrated to control the stored energy by applying a non-axisymmetric magnetic field using the DIII-D in-vessel coils to modify the energy confinement time. In relatively low collisionality DIII-D discharges, the application of non-axisymmetric magnetic fields results in a decrease in confinement time and density pumpout. Control of the stored energy was demonstrated by the application of non-axisymmetric fields while using gas puffing to compensate the density pumpout in the pedestal. Since the fusion power in a power plant operating at high $Q_{DD}$ can be related to the plasma stored energy and hence, is a strong function of the energy confinement time, the application of non-axisymmetric fields may be an effective technique to adjust the fusion power in a power plant.

This work was supported by the US Department of Energy under DE-AC02-09CH11466 and by TACC at UT Austin.

Work was supported by the US Department of Energy under DE-AC02-04ER54917 and DE-AC02-04ER54917.
3:24PM UO3.00008 Extending the Physics Basis of ITER Baseline Scenario Stability to Zero Input Torque1. C. PAZ-SOLDAN, T.C. LUCE, A.M. GAROFALO, G.L. JACKSON, R.J. LA HAYE, General Atomics, J.M. HANSON, K.E.J. OLOFSSON, F. TURCO, Columbia U., B.A. GRIESON, W.M. SOLOMON, Princeton Plasma Physics Laboratory — DIII-D operation at ITER baseline scenario parameters (safety factor $\sim 3$, normalized $\beta \sim 2$, low input torque) is challenging due to the destabilization of $m/n=2/1$ or $3/2$ tearing modes that rapidly lead to a loss of H-mode confinement and potential disruption. Despite proximity to stability limits, stationary operation at ITER-equivalent levels of input torque has been achieved with improved correction of DIII-D intrinsic error fields used to remove magnetic braking torques in combination with steady gas flows and pulsed 3D fields used to pace edge-localized mode (ELM) activity. Operation with zero input torque remains elusive. In this regime, ELMs are more difficult to control and toroidal rotation more difficult to sustain. Additionally, the confinement H-factor is found to decrease significantly from large to zero torque, regardless of heating mix. These results indicate that ITER baseline scenario extrapolations derived from discharges with large input torque are likely to be optimistic.

1Work supported by the US Department of Energy under DE-FC02-04ER54698, DE-FG02-04ER54761 and DE-AC52-07NA27344.

3:36PM UO3.00009 Steady-state ELM-suppressed H-modes from KSTAR to ITER and beyond1. YONGKYOON IN, J.G. KWAK, Natl Fusion Res Inst, THE KSTAR TEAM — Long-pulse, steady-state high-performance plasma is not only an important mission in KSTAR, but also directly relevant to ITER. While demonstrating the pulse-length of more than 20 sec H-mode flat-top in 2013, KSTAR has been exploring various means to achieve and sustain steady-state, ELM-suppressed/mitigated H-modes using versatile in-vessel control coils (IVCC), ECCD/ECH, and/or SMBI. In particular, taking advantage of the versatile 3-rows of IVCC, KSTAR accomplished both $n=1$ and $n=2$ RMP-driven, ELM-suppressed regimes that lasted up to 4 sec so far (limited by the discharge pulse length, not by any physics constraints, and will be extended up to 10 sec in 2014.) We also found the use of $n=2$ RMP has prevented a locked-mode from being disruptive (at least within the RMP phase). To cope with run-away electrons and/or off-normal events, a soft landing algorithm has been developed and confirmed capable of ramping down the plasma current safely. The enhanced understanding and demonstration of steady-state, high-performance plasmas in KSTAR will elevate the level of confidence about the success of ITER and beyond.

1Supported by Ministry of Science, ICT, and Future Planning in Korea

3:48PM UO3.00010 Towards Current Profile Control in ITER: Potential Approaches and Research Needs1. E. SCHUSTER, J.E. BARTON, W.P. WEHNER, Lehig University — Many challenging plasma control problems still need to be addressed in order for the ITER Plasma Control System (PCS) to be successfully achieve the ITER project goals. For instance, setting up a suitable toroidal current density profile is key for one possible advanced scenario characterized by noninductive sustainment of the plasma current and steady-state operation. The nonlinearity and high dimensionality exhibited by the plasma demand a model-based current-profile control synthesis procedure that can accommodate this complexity through embedding the known physics within the design. The development of a model capturing the dynamics of the plasma relevant for control design enables not only the design of feedback controllers for regulation or tracking but also the design of optimal feedforward controllers for a systematic model-based approach to scenario planning, the design of state estimators for a reliable real-time reconstruction of the plasma internal profiles based on limited and noisy diagnostics, and the development of a fast predictive simulation code for closed-loop performance evaluation before implementation. Progress towards control-oriented modeling of the current profile evolution and associated control design has been reported following both data-driven and first-principles-driven approaches. An overview of these two approaches will be provided, as well as a discussion on research needs associated with each one of the model applications described above.

1Supported by the US Department of Energy under DE-SC0001334 and DE-SC00010661.

4:00PM UO3.00011 Control Solutions for High Performance in ITER with Test Blanket Modules1. M.J. LANCTOT, J.S. DEGRASSIE, R.J. LA HAYE, C. PAZ-SOLDAN, E.J. STRAIT, R.J. BUTTERY, GA, J.A. SNIPES, ITER, H. REIMERDES, EPFL-CRPP, N.C. LOGAN, J.-K. PARK, W.M. SOLOMON, B. GRIESON, PPPL, J.M. HANSON, Columbia U. — DIII-D experiments indicate applied $n=1$ fields can be used in high performance plasma regimes to reduce to a tolerable level the impact of the Test Blanket Modules (TBMs) error field (EF) on energy and particle confinement. Active coils, designed to mock-up the magnetic EF from two TBMs in one ITER equatorial port, were used to mimic the magnetization from the reduced-activation ferritic martensitic steel used in present TBM designs. The optimal correction fields, identified by maximizing the plasma toroidal angular momentum, reduced the impact of the TBM EF on energy, particle, and momentum confinement at $\beta_p = 2.9$ by $60\%$, a factor of 2 improvement over previous results at $\beta_p = 1.8$. This improved performance of $n=1$ control fields at high beta is consistent with the hypothesis that the strong beta dependence of TBM EF effects observed in previous campaigns is due mainly to amplification of the $n=1$ component of the TBM EF. Similar performance was obtained with either internal or external $n=1$ error field control coils. The results suggest that the impact of the TBM related EFs on high beta operation can be controlled with the external correction coils in ITER.

1Work supported by the US DOE under DE-FC02-04ER54698, DE-AC02-99CH11466 and DE-FG02-04ER54761.

4:12PM UO3.00012 ICRF-induced core impurities: Source and transport studies of ICRF conventional and field aligned ICRF antennas1. S.J. WUKITCH, B. LABOMBARD, Y. LIN, MIT PSFC, M.L. REINKE, Univ. York, J. TERRY, MIT PSFC, AND ALFATOR C-MOD TEAM — Ion cyclotron range of frequency power (ICRF) is considered a good candidate to provide bulk heating for ITER and future reactors. A primary challenge to ICRF utilization is to minimize plasma-material interaction using techniques that scale to continuous operation in a thermonuclear environment. New Alcator C-Mod experiments investigate impurity contamination associated with ICRF operation determining whether it is predominantly a result of increased source, transport or some combination. Previous work showed a field aligned (FA) antenna could significantly reduce core high-Z impurity contamination and lower limiter impurity sources compared to a toroidally aligned antenna. However, measurements of the RF-enhanced plasma potentials showed little difference between antennas designs. To investigate impurity penetration/screening directly, trace nitrogen is injected at different poloidal/toroidal locations, measuring core nitrogen levels in the presence and absence of ICRF power. This provides insight into transport changes associated with the RF and antennas concepts.

1Supported by US DOE award DE-FC02-99ER54512
4:24PM UO3.00013 Modeling the ITER ICRF Antenna with Integrated Time Domain RF Sheath and Plasma Physics, DAVID SMITHE, Tech-X Corporation, DANIEL D’IPPOLITO, JAMES MYRA, Lodestar Corporation, CSWPI COLLABORATION — We present results from computer simulations of detailed 3D models of the ICRF launcher assembly, including straps, Faraday Shields, and vessel wall [1]. These simulations provide exquisite detail of the antenna near fields, and the sheaths between plasma and the metallic components of the launcher. Significant work has been done to create a sheath model [2] that allows us to estimate local values of sheath potential everywhere on the 3D structure, so that we can estimate RF rectified plasma potential [3]. Those potentials are in turn a likely source of sputtering and impurity creation, when the antennas are operating, and we discuss ongoing work to quantify these effects. Additional study of the antenna near fields also investigates slow waves which can exist in the low density scrape-off layer, and may impact power balance, and also sheath amplitudes. Movies of the 3D field and sheath oscillations will be shown. [1] “Quantitative Modeling of ICRF Antennas with Integrated Time Domain RF Sheath and Plasma Physics,” David N. Smith et. al., Proceedings of the 28th Topical Conf. on RF Power in Plasmas, AIP Publishing (2013). [2] “A radio-frequency sheath boundary condition and its effect on slow wave propagation,” D. A. D’Ippolito and J. R. Myra, Phys. Plasmas vol. 13, p. 102508, 2006. [3] “RF Models for Plasma-Surface Interactions: Sheath Boundary Conditions with Dielectrics,” T. G. Jenkins and D. N. Smite, Proceedings of the 2014 ICOPS/BEAMS Conf.

3Supported by DOE grants DE-08ER54593 and DE-FG02-09ER55006.

4:36PM UO3.00014 Measurements of relativistic emission from runaway electrons in Alcator C-Mod: spectrum, polarization, and spatial structure, ROBERT GRANETZ, ROBERT MUMGAARD, MIT Plasma Science and Fusion Center — At low densities, runaway electrons (RE's) can be generated during the flattop of Alcator C-Mod discharges with highly relativistic energies, γ ≫ 1, allowing careful study under steady conditions. These RE's emit light in a narrow forward-peaked cone which is detected with a number of diagnostics, including spectrometers, a video imaging camera, and polarimetry (using the MSE system), in addition to the standard hard x-ray detectors. These measurements of the relativistic emission can provide information about the RE energy distribution, pitch angle distribution, and spatial distribution. Unlike most other tokamaks, C-Mod's high magnetic field shifts the peak of the continuum emission into the visible, due to the smaller gyroradius and higher gyro-frequency, allowing for excellent spectral coverage with standard spectrometers, and thus detailed comparison to theoretical predictions of synchrotron and bremsstrahlung spectra. Additionally, camera images occasionally show highly structured formations. Profiles of the polarization fraction and polarization angle show radial structure, including a jump of 90° outboard of the magnetic axis, in qualitative agreement with recent theoretical calculations for relativistic electrons in a tokamak field.

4:48PM UO3.00015 Influence of DIII-D Experiments on the Design of the ITER Shattered Pellet Injection System, N. COMMAUX, D. SHIRAKI, L.R. BAYLOR, S.J. MEITNER, S.K. COMBS, Oak Ridge National Laboratory, N.W. EIDETIS, General Atomics, E.M. HOLLMANN, V.A. IZZO, R.A. MOYER, U. California San Diego — Shattered pellet injection (SPI) is a prime candidate for ITER disruption mitigation because of its deeper penetration and larger particle flux compared to massive gas injection (MGI). The ITER disruption mitigation system will likely use high Z impurities such as neon. An upgrade of the SPI on DIII-D (the only operating SPI in the world) enables for the first time ITER relevant relevant injection characteristics: 400 torr-L neon pellets. The design of the SPI system is described as well as its evolution due to the results from DIII-D experiments and ITER design requirements. Recent experiments focused on differences in particle assimilation, thermal, and current quench characteristics compared to MGI. Radiation asymmetries are regarded as a potential issue on ITER. Studies using MGI have showed that these effects can be significant on present devices. They are compared to new SPI results since they could influence the implementation of the SPI on ITER.

1This work is supported by the U.S. Department of Energy

4:48PM UO3.00015 Influence of DIII-D Experiments on the Design of the ITER Shattered Pellet Injection System, N. COMMAUX, D. SHIRAKI, L.R. BAYLOR, S.J. MEITNER, S.K. COMBS, Oak Ridge National Laboratory, N.W. EIDETIS, General Atomics, E.M. HOLLMANN, V.A. IZZO, R.A. MOYER, U. California San Diego — Shattered pellet injection (SPI) is a prime candidate for ITER disruption mitigation because of its deeper penetration and larger particle flux compared to massive gas injection (MGI). The ITER disruption mitigation system will likely use high Z impurities such as neon. An upgrade of the SPI on DIII-D (the only operating SPI in the world) enables for the first time ITER relevant injection characteristics: 400 torr-L neon pellets. The design of the SPI system is described as well as its evolution due to the results from DIII-D experiments and ITER design requirements. Recent experiments focused on differences in particle assimilation, thermal, and current quench characteristics compared to MGI. Radiation asymmetries are regarded as a potential issue on ITER. Studies using MGI have showed that these effects can be significant on present devices. They are compared to new SPI results since they could influence the implementation of the SPI on ITER.

1This work is supported by the U.S. Department of Energy under DE-AC05-00OR22725, DE-FC02-04ER54698 and DE-FG02-07ER54917.

Thursday, October 30, 2014 2:00PM - 5:00PM — Session UO4 Hydro Instabilities II
Salon E - Mario Manuel, University of Michigan

2:00PM UO4.00001 Reduced indirect drive RT instability growth using a decaying first shock at the National Ignition Facility, ANDREW MACPHEE, KEVIN BAKER, DANIEL CASEY, PETER CELLIERS, DANIEL CLARK, Lawrence Livermore National Laboratory, EMILIO GIRALDEZ, General Atomics, ALEX HAMZA, KENNETH JANCAITIS, OGDEN JONES, JEREMY KROLL, KAI LAFORTUNE, BRIAN MACGOWAN, JOSE MILOVICH, Lawrence Livermore National Laboratory, ABBAS NIKKROO, General Atomics, LUC PETERSON, KUMAR RAMAN, HARRY ROBEY, VLADIMIR SMAKYUK, CHRISTOPHER WEBER, CLIFFORD WIDMAYER, STEVEN HAAN, Lawrence Livermore National Laboratory, LAWRENCE LIVERMORE NATIONAL LABORATORY TEAM — Hydrodynamic instabilities and poor fuel compression are major factors for capsule performance degradation in ignition experiments on the NIF. We are developing modified drives to reduce instability growth compared to previous ignition pulses whilst maintaining the low fuel adiabat needed for increased compression. Laser drive profiles with a decaying first shock (“adiabat shaping”) were developed that alter the Richtmyer-Meshkov growth phase and reduce the subsequent inflight Rayleigh-Taylor growth. Using in-flight x-ray radiography of ablation front growth in NIF experiments. It is timely then to combine these two results and ask how current ignition pulse shapes could be modified so as to improve implosion performance, namely fuel compressibility, while maintaining the stability properties demonstrated with the high foot. This talk presents a survey of pulse shapes intermediate between the low and high foot extremes in search of a more optimal design. From the database of pulse shapes surveyed, a higher picket version of the original low foot pulse shape shows the most promise for improved compression without loss of stability.

1This work performed under the auspices of U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

2:12PM UO4.00002 A survey of pulse shape options for a revised plastic ablator ignition design, DANIEL CLARK, DAVID EDER, STEVEN HAAN, DENISE HINKEL, OGDEN JONES, MICHAEL MARINAK, JOSE MILOVICH, JAYSON PETERSON, HAROLD ROBEY, JAY SALMONSON, VLADIMIR SMAKYUK, CHRISTOPHER WEBER, Lawrence Livermore National Laboratory — Recent experimental results using the “high foot” pulse shape on the National Ignition Facility (NIF) have shown encouraging progress compared to earlier “low foot” experiments. These results strongly suggest that controlling ablation front instability growth can dramatically improve imploding implosion performance, and vessel wall [1]. These simulations provide exquisite detail of the antenna near fields, and the sheaths between plasma and the metallic components of the launcher. Significant work has been done to create a sheath model [2] that allows us to estimate local values of sheath potential everywhere on the 3D structure, so that we can estimate RF rectified plasma potential [3]. Those potentials are in turn a likely source of sputtering and impurity creation, when the antennas are operating, and we discuss ongoing work to quantify these effects. Additional study of the antenna near fields also investigates slow waves which can exist in the low density scrape-off layer, and may impact power balance, and also sheath amplitudes. Movies of the 3D field and sheath oscillations will be shown. [1] “Quantitative Modeling of ICRF Antennas with Integrated Time Domain RF Sheath and Plasma Physics,” David N. Smith et. al., Proceedings of the 28th Topical Conf. on RF Power in Plasmas, AIP Publishing (2013). [2] “A radio-frequency sheath boundary condition and its effect on slow wave propagation,” D. A. D’Ippolito and J. R. Myra, Phys. Plasmas vol. 13, p. 102508, 2006. [3] “RF Models for Plasma-Surface Interactions: Sheath Boundary Conditions with Dielectrics,” T. G. Jenkins and D. N. Smite, Proceedings of the 2014 ICOPS/BEAMS Conf.

Supported by DOE grants DE-08ER54593 and DE-FG02-09ER55006.

2:12PM UO4.00002 A survey of pulse shape options for a revised plastic ablator ignition design, DANIEL CLARK, DAVID EDER, STEVEN HAAN, DENISE HINKEL, OGDEN JONES, MICHAEL MARINAK, JOSE MILOVICH, JAYSON PETERSON, HAROLD ROBEY, JAY SALMONSON, VLADIMIR SMAKYUK, CHRISTOPHER WEBER, Lawrence Livermore National Laboratory — Recent experimental results using the “high foot” pulse shape on the National Ignition Facility (NIF) have shown encouraging progress compared to earlier “low foot” experiments. These results strongly suggest that controlling ablation front instability growth can dramatically improve implosion performance, namely fuel compressibility, while maintaining the stability properties demonstrated with the high foot. This talk presents a survey of pulse shapes intermediate between the low and high foot extremes in search of a more optimal design. From the database of pulse shapes surveyed, a higher picket version of the original low foot pulse shape shows the most promise for improved compression without loss of stability.

1This work performed under the auspices of U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
2:24PM UO4.00003 Measurement of the Shock Velocity and Symmetry History in Decaying Shock Pulses. Kevin Baker, Jose Milovich, Oggie Jones, Harry Robey, Vladimir Smalyuk, Daniel Casey, Peter Celliers, Dan Clark, LLNL, Emilio Giraldez, GA, Steve Haan, Alex Hamza, Laura Berzak-Hopkins, Ken Jaanaitis, Jeremy Kroll, Kai Lafortune, Brian Macgowan, Andrew Macphee, John Moody, LLNL, Abbas Nikroo, GA, Luc Peterson, Kumar Raman, Chris Weber, Clay Widmayer, LLNL. — Decaying first shock pulses are predicted in simulations to provide more stable implosions and still achieve a low adiabat in the fuel, enabling a higher fuel compression similar to “low foot” laser pulses. The first step in testing these predictions was to measure the shock velocity for both a three shock and a four shock adiabat-shaped pulse in a keyhole experimental platform. We present measurements of the shock velocity history, including the decaying shock velocity inside the ablator, and compare it with simulations, as well as with previous low and high foot pulses. Using the measured pulse shape, the predicted adiabat from simulations is presented and compared with the calculated adiabat from low and high foot laser pulse shapes. This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344.

2:36PM UO4.00004 Adiabat shape Laser Pulses for ablation front instability control and high fuel compression1. Jose Milovich, O.S. Jones, L. Berzak-Hopkins, D.S. Clark, K.L. Baker, D.T. Casey, A.G. Macphee, J.L. Peterson, H.F. Robey, V.A. Smalyuk, C.R. Weber, LLNL. — At the end of the NIC campaign a large body of experimental evidence showed that the point-design implosions driven by low-adiabat pulses had a high degree of mix [1]. To reduce instability a high-adiabat (∼3x higher picket drive) design was fielded in the National Ignition Facility (NIF). The experimental results from this campaign [2] have shown considerable improvement in performance (10x neutron yields) over the point design with little evidence of mix. However, the adiabat of the implosions may be too high to achieve ignition for the available laser energy. To overcome this difficulty, and to take advantage of the high-picket drives that combined the virtue of both designs. These pulses can be thought of achieving adiabat shaping, where the ablator is set in a higher adiabat for instability control, while the fuel is maintained at a lower adiabat favoring higher fuel compression. Using these pulses, recent experiments at the NIF have indeed shown reduced growth rates. In this talk we will present the design of high-yield low-growth DT ignition experiments using these adiabat-shaped pulses.

1Work performed under the auspices of the U.S. D.O.E. by LLNL under contract DE-AC52-07NA27344.

3:00PM UO4.00006 Measurements of hydrodynamic instability growth with 3-D capsule modulation growth experiments1. S.V. Weber, D.T. Casey, D.S. Clark, J. Field, S.W. Haan, V.A. Smalyuk, LLNL, A. Nikroo, N. Rice, General Atomics — Growth of 3-D modulations in NIF CH ablator capsules has been measured by inflight radiography of imploding shells through a reentrant keyhole. Gated images are taken near the time of peak shell velocity at a convergence ratio of about five. We have looked at shells with native roughness and with outer surface roughness enhanced by a factor of about four. Three-dimensional simulations have been carried out using surfaces reconstructed from measured power spectra and also from point by point metrology of the actual capsule surface. Comparison of measured and simulated radiographs tests our understanding of modulation growth as well as addressing whether there are significant seeds for growth that have been overlooked.

1This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

3:12PM UO4.00007 Simulations of the “tent” and its signatures in NIF ignition implosions1. B.A. Hammel, R. Tommasini, H.A. Scott, V. Smalyuk, Lawrence Livermore National Laboratory — NIF capsules are supported in the hohlraum by two thin (~50 nm) Formvar films (“tent”). We report on highly-resolved Hydra simulations of the perturbation that develops on the capsule as a result of this support geometry. The simulations indicate that details of the geometry (e.g. the depart angle of the tent from the capsule surface) are important in determining the size of the final capsule areal density perturbation. Simulated diagnostic signatures of the capsule perturbation, including “in-flight” radiographs and the shape of the x-ray emission from the compressed core are in general agreement with experiments. We are designing dedicated measurements to fully validate the simulations.

1Prepared by LLNL under Contract DE-AC52-07NA27344.

3:24PM UO4.00008 Preparing for Polar-Drive Imprint Experiments at the National Ignition Facility. A. Shvydky, M. Hohenberger, P.B. Radha, R.S. Craxton, V.N. Goncharov, J.A. Marozas, F.J. Marshall, P.W. McKenty, T.C. Sangster, Laboratory for Laser Energetics, U. of Rochester — Control of laser-induced nonlinearities is critical for the success of polar-drive ignition experiments at the National Ignition Facility (NIF). Laser-imprint studies in laser-driven spherical shell targets will be performed at the NIF in Q1 and Q2 of FY15. Corrugated spherical, cone-in-shell targets with sinuosoidal surface modulations will provide a reference for calculating the equivalent surface roughness of the imprint using the current NIF phase plates and beam smoothing. DRACO simulations are used to design the spherical-imprint experiments and set the initial shell thickness, cone geometry, laser pulse, and laser beam pointings. Results of DRACO simulations will be presented, evaluating the expected experimental x-ray radiographs. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

3:36PM UO4.00009 Measurements of Laser Imprinting Using 2-D Velocity Interferometry. T.R. Boehler, G. Fiksel, J.X. Hsu, V.N. Goncharov, T.C. Sangster, Laboratory for Laser Energetics, U. of Rochester, P.M. Celliers, LLNL — Evaluating laser imprinting and its effect on target performance is critical to direct-drive inertial confinement fusion research. Using high-resolution velocity interferometry, we measure modulations in the velocity of shock waves produced by the 351-nm beams on OMEGA. These modulations result from nonlinearities in the drive laser beams. We use these measurements to evaluate the effect on imprinting of multibeam irradiation and metal layers on both plastic and cryogenic deuterium targets driven with 10-ps pulses. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.
4:00PM UO4.00011 Measuring Mix in Direct-Drive Cryogenic DT Implosions Using Soft X-Ray Narrowband Backlighting
C. STOECKL, R. EPSTEIN, G. FIKSSEL, V.N. GONCHAROV, S.X. HU, D.W. JACOBS-PERKINS, R.K. JUNQUIST, C. MILEHAM, P.M. NILSON, T.C. SANGSTER, W. THEOBALD, Laboratory for Laser Energetics, U. of Rochester — Rayleigh–Taylor mix is widely seen as the major source of perturbations, which limit the performance of low-adiabat cryogenic implosions in both direct- and indirect-drive inertial confinement fusion experiments. Backlit images of cryogenic direct-drive implosions recorded with a narrowband x-ray imager using an aspherically bent quartz crystal for the Si He_x line at ~1.86 keV show a clear signature of carbon from the CD outer shell of the cryogenic target mixing into the DT layer at the end of the acceleration phase. These implosions are driven on a low adiabat with a high in-flight aspect ratio (IFAR). Comparison with post-processed 1-D hydrodynamic simulations show that these absorption seen in the backlit images is ~5× larger than expected, consistent with mixing ~0.2% of carbon into the DT shell. Experiments with a slightly higher adiabat and lower IFAR match the predictions of clean 1-D simulations showing no signature of carbon mix. This material is based upon work supported by the Department of National Nuclear Security Administration under Award Number DE-NA0001944.

4:12PM UO4.00012 Mix and instability growth seeded at the inner surface of CH-ablator implosions on the National Ignition Facility
S.W. HAAN, P.M. CELLERS, G.W. COLLINS, C.D. ORTH, D.S. CLARK, P. AMENDT, B.A. HAMMEL, H.F. ROBEY, Lawrence Livermore National Laboratory, H. HUANG, General Atomic — Mix and hydro instability growth are key issues in implosions of ignition targets on NIF. The implosions are designed so that the amplitude of perturbations is thought to be determined by initial seeds to the hydrodynamic instabilities, amplified by an instability growth factor. Experiments have indicated that growth factors can be calculated fairly well, but characterizing the initial seeds is an ongoing effort. Several threads of investigation this year have increased our understanding of growth seeded at the CH/DT interface. These include: more detailed characterization of the CH inner surface; possible other seeds, such as density irregularities either from fabrication defects or arising during the implosion; experiments on the Omega laser measuring velocity modulations on shock fronts shortly after breaking out from the CH, which can seed subsequent growth; and the possible significance of non-hydrodynamic effects such as plasma interpenetration or spall-like ejecta upon shock breakout. This presentation describes these developments, the relationships between them, and their implications for ignition target performance.

4:24PM UO4.00013 Measurements of ablation-front hydrodynamic instability growth in high-density carbon (HDC) ignition targets at the National Ignition Facility
D. CASEY, V. SMALYUK, L. PETERSON, L. BERZAK HOPKINS, T. BUNN, LNL, L. CARLSON, GA, S. HAAN, D. HO, LNL, D. HOOVER, GA, J. KROLL, O. LANDEN, S. LE PAPE, A. MACKINNON, A. MACPHEE, N. MEEZAN, J. MILOVICH, LNL, A. NIKROO, GA, B. REMINGTON, H. ROBEY, S. ROSS, LNL — High-density carbon (HDC) has emerged as a promising ablator for ignition experiments at the National Ignition Facility (NIF) partly because of its efficient coupling of the drive energy to fuel. Experiments during the National Ignition Campaign using a CH plastic ablator have shown that instability growth and the resultant mix of plastic into the hotspot was a significant source of overall the observed performance degradation. Likewise, mix of HDC ablator into the hotspot may also be a concern, as growth rates for HDC are comparable to CH and ablator/dopant is higher Z than CH ablators making the consequences potentially more severe. To help understand this issue, we plan to perform the first instability growth measurements of W-doped HDC implosions with preimposed mode 60 and mode 90 perturbations in convergent geometry using actual ignition targets and drives. These results will be presented and compared to ignition design simulations.

4:36PM UO4.00014 Modeling Mix in ICF Implosions
C.R. WEBER, D.S. CLARK, B. CHANG, D.C. EDER, S.W. HAAN, O.S. JONES, M.M. MARINAK, J.L. PETERSON, H.F. ROBEY, Lawrence Livermore National Laboratory — The observation of ablator material mixing into the hot spot of ICF implosions correlates with reduced yield in National Ignition Campaign (NIC) experiments. Higher Z ablator material radiatively cools the central hot spot, inhibiting thermonuclear burn. This talk focuses on modeling a “high-mix” implosion from the NIC, where greater than 1000 ng of ablator material was inferred to have mixed into the hot spot. Standard post-shot modeling of this implosion does not predict the large amounts of ablator mix necessary to explain the data. Other issues are explored in this talk and sensitivity to the method of radiation transport is found. Compared with radiation diffusion, Sn transport can increase ablation front growth and alter the blow-off dynamics of capsule dust.

4:48PM UO4.00015 Rayleigh–Taylor instability experiments in quasi-isentropically compressed Al targets at the Shenguang2 Laser
JIAQIN DONG, Shanghai Institute of Laser Plasma — We present experiments on the Rayleigh-Taylor (RT) instability in pure Al foils at ∼34GPa pressure using a laser based, ramped-pressure acceleration technique. A line VISAR velocity diagnostic is developed to measure the drive on separate targets, and an X-rays K-B Microscope is used to measure the RT growth with 4.75keV Ti He_x x-ray backlighter. RT growth factors in solid state and melted Al, driven by approximate plasma loader, are measured and compared. Material strength suppresses the RT growth rate dramatically.

Thursday, October 30, 2014 2:00PM - 4:48PM –
Session UO5 High-intensity Laser-plasma Interactions
Galerie 2 - Hui Chen, Lawrence Livermore National Laboratory
2:00PM UO5.00001 Absorption of high-contrast, intense short laser pulses on solids1

ANDREAS KEMP, LAURENT DIVOL, LLNL — We study the interaction of a 101 / 10fes intense laser pulse with solid aluminum using 1D and 2D kinetic / collisional particle simulations. In particular we are interested in an accurate description of the early phase of the interaction where the target is still cold, assuming that no plasma formation has set in before the arrival of the pulse. While most of the laser pulse is reflected, penetration of light into the skin layer and collisional heating lead to fast heating of the skin layer, and an increasing absorption of light into several groups of energetic electrons. We discuss details of the resulting electron spectrum, and plasma conditions expected immediately behind the interaction region under realistic conditions.

1This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

2:12PM UO5.00002 Simulations of High Intensity Short Pulse Lasers Incident on Reduced Mass Targets Using LSP1

FRANK W. KING, CHRIS ORBAN, KRAMER U. AKLI, DOUGLASS SCHUMACHER, The Ohio State University — We present the results of a series of fully kinetic 2D simulations using the PIC code LSP for the study of the heating and deformation of reduced mass targets. These simulations model a full scale laser pulse incident on full scale targets as a function of intensity, spot size, pre-plasma, and target lateral extent and thickness. We observe that the target deformation and heating has a strong dependence on intensity of the laser pulse and creation of a shock in the target. We also include a comparison of 2D and 3D kinetic runs that allows us to compare temperatures.

1Work supported by the FSC under grant DE-FC02-04ER54789 and the NNSA under grant DE-NA0001976 and allocations of computing time from the Ohio Supercomputer Center and XSEDE.

2:24PM UO5.00003 Simulation of Laser Pulse Driven Terahertz Generation in Inhomogeneous Plasmas1

CHENLONG MIAO, University of Maryland, JOHN PALASTRO, Icarus Research, Bethesda, Maryland, THOMAS ANTONSEN, University of Maryland — Intense, short laser pulses propagating through plasma generate THz radiation. Full format PIC simulations and theoretical analysis are conducted to investigate two mechanisms of ponderomotively driven THz radiation: transition radiation, and slow wave phase matching enabled by corrugated plasma channels. The first mechanism occurs as a laser pulse crosses a plasma boundary [1] and is analogous to transition radiation emitted by charged particle beams. The THz radiation resulting from this transition radiation mechanism (TRM) is characterized by conical emission and a broadband spectrum with the maximum frequency occurring near the plasma frequency. The second mechanism occurs in axially periodic plasma channels [2, 3]. These channels support electromagnetic modes with slow wave (Floquet-type) dispersion, which can be phase matched to the ponderomotive current. The slow wave phase-matched radiation (SWPM) is characterized by lateral emission and a coherent spectrum with sharp modes associated with the channel.

1Supported by US DoE.

2:36PM UO5.00004 Temperature Measurements of Fusion Plasmas Produced by Laser-Irradiated D2—3He or CD4—3He Clustering Gases

W. BANG, Los Alamos Natl Lab, T. DITMIRE, H. QUEVEDO, G. DYER, A.C. BERNSTEIN, M. DONOVAN, E. GAUL, UT Austin, M. BARBUI, A. BONASERA, K. HAGEL, J.B. NATOWITZ, Texas A&M — We report on experiments in which a mixture of D2 or CD4 clusters and 3He gas was irradiated by a petawatt-laser pulse, generating nuclear fusion reactions such as D(d, 3He)n, D(d, t)p, and 3He(d, p)4He. We measured the yields of fusion neutrons and protons from these reactions and found them to agree with yields based on a simple cylindrical plasma model. The plasma temperature was determined by two different methods. In the first, it was derived from time-of-flight data of deuterium ions ejected from D2 or CD4 clusters. In the second, it was measured from the ratio of neutron yield to proton yield from D(d, 3He)n and 3He(d, p)4He reactions, respectively. The temperatures determined by these two methods agree well, indicating (i) the ion energy distribution is not significantly distorted when ions travel in the disassembling plasma; (ii) the kinetic energy of deuterium ions, especially the hottest part responsible for nuclear fusion, is well described by a near-Maxwellian distribution.

2:48PM UO5.00005 Measurements of Surface Magnetic Fields Driven by Refluxing Electrons in OMEGA EP Experiments

A. DAVIES, D. HABERBERGER, A.A. SOLODOV, D.H. FROULA, Laboratory for Laser Energetics, U. of Rochester, L. CEURVORST, U. of Oxford, P.A. NORREYS, U. of Oxford and Rutherford Appleton Laboratory — A polarimeter was used to measure the field strength, spatial extent, and temporal evolution of magnetic fields generated around the focus of an intense (I ≈ 9 × 1018 W/cm2) 100-ps OMEGA EP laser pulse. The interaction of the laser with solid Cu targets was probed using the 4ω diagnostic system. The magnetic field was observed to expand radially from the focal point along the target surface as a coronal plasma forms. The laser-plasma interactions were modeled using OSIRIS particle-in-cell and LSP hybrid model simulations. Initial results suggest that the magnetic field is generated by electrons traveling near the speed of light spreading radially from the interaction point. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.

3:00PM UO5.00006 OMEGA EP OPAL: A Path to a 100-PW Laser System

D.D. MEYEROHER, S.-W. BAHK, J. BROMAGE, D.H. FROULA, D. HABERBERGER, S.X. HU, B.E. KRUSCHWITZ, R.L. MCCRARY, J.F. MYATT, P.M. NOLSON, J.B. OLIVER, C. STOECKL, W. THEOBALD, L.J. WAXER, J.D. ZIEGEL, Laboratory for Laser Energetics, U. of Rochester — The four-beam OMEGA EP Laser System at the Laboratory for Laser Energetics could be reconfigured to pump an optical parametric chirped-pulse-amplification (OPCPA) laser system. Current estimates suggest that energies in excess of 2 kJ in a 20-fs pulse would be possible with four-beam pumping. This could lead to peak intensities above 1023 W/cm2. Additional configurations could include two femtosecond beams, or a combination of femtosecond, picosecond, and nanosecond kilojoule-class laser beams. This talk will describe the potential system and some of the physics opportunities for which it would provide access. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001944.
3:12PM UO5.00007 Ultra-intense Pair Creation using the Texas Petawatt Laser and Applications\(^1\), EDISON LIANG, ALEXANDER HENDERSON, TAYLOR CLARKE, WILLIE LO, PETR CHAGUINE, Rice University, GILLISS DYER, NATHAN RILEY, KRISTINA SERRATTO, MICHAEL DONOVAN, TODD DITMIERE, University of Texas at Austin — Pair plasmas and intense gamma-ray sources are ubiquitous in the high-energy universe, from pulsar winds to gamma-ray bursts (GRB). Their study can be greatly enhanced if such sources can be recreated in the laboratory under controlled conditions. In 2012 and 2013, a joint Rice-University of Texas team performed over 130 laser shots on thick gold and platinum targets using the 100 Joule Texas Petawatt Laser in Austin. The laser intensity of many shots exceeded \(10^{21}\) W cm\(^{-2}\) with pulses as short as 130 fs. These experiments probe a new extreme regime of ultra-intense laser - high-Z solid target interactions never achieved before. In addition to creating copious pairs with the highest density (>10\(^{15}\) e\(^{-}\) cm\(^{-3}\)) and emergent \(e^{+}/e^{-}\) ratio exceeding 20% in many shots, these experiments also created the highest density multi-MeV gamma-rays, comparable in absolute numbers to those found inside a gamma-ray burst (GRB). Potential applications of such intense pair and gamma-ray sources to laboratory astrophysics and innovative technologies will be discussed.

\(^1\)Work supported by DOE HEDLP program.

3:24PM UO5.00008 Absorption of ultra-intense intense laser pulse in self-generated pair plasma \(^1\), THOMAS GRISMAYER, MARIJA VVRANC, GoLP/Instituto de Plasmas e Fusao Nuclear, Instituto Superior Tecnico, Universidade de Lisboa, Lisbon, Portugal, RICARDO FONSECA, DCT/IISCT Lisbon University Institute, 1649-026 Lisbon, Portugal, LUIS SILVA, GoLP/Instituto de Plasmas e Fusao Nuclear, Instituto Superior Tecnico, Universidade de Lisboa, Lisbon, Portugal — Plasma physics in extreme fields requires taking into account Quantum Electrodynamics effects such as non-linear Compton scattering and Breit-Wheeler pair production. Such effects intervene in laser-plasma interactions at ultra high intensities (\(\sim 10^{23}\) W/cm\(^{2}\)). The self-consistent modeling of these scenarios is challenging since some localized regions of ultra-intense field will produce a vast number of pairs that may cause memory overflow during the simulation. To overcome this issue, we have developed a merging algorithm that allows merging a large number of particles into fewer particles with higher particle weights while conserving local particle distributions. This algorithm is crucial to investigate the laser absorption in self-generated pair plasmas. During the interaction, the laser energy is converted into pairs and photons and the absorption become significant when the plasma density reaches the critical density. We present the results of 3D PIC-QED simulations (Osiris 2.0) showing the respective fraction of laser energy transferred into pairs and photons. The dependence of the laser absorption on the laser parameters for various configurations is also discussed.

\(^1\)This work was performed under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344, and funded by LDRD (#12-ERD-062)

3:36PM UO5.00009 The Scaling of Positron Production in Intense Laser-Solid Interactions\(^1\), HUI CHEN, A. LINK, F. FIUZA, A. HAZI, S.R. NAGEL, J. PARK, R. TOMMASINI, G.J. WILLIAMS, LLNL, Y. SENTOKU, U. Reno Nevada, D.D. MEYERHOFE, J.F. MYATT, LLE, P. AUDEBERT, LULI, R. FEDOSEJEVS, S. KERR, U. Alberta, M. HILL, D. HOARTY, L. HOBBBS, S. JAMES, AWE — The dependence of positron yield on laser energy was observed to be nonlinear through experiments using the laser facilities at Jupiter, OMEGA EP, and ORION for laser energies of 100 - 1500 J and intensities of \(10^{18} - 10^{20}\) Watts/cm\(^{2}\). The measured yield increases as \(\sim E_{L}^{2}\), faster than that predicted by simple estimates using GEANT4. This scaling results from a combination of higher energy electrons produced at increased laser intensity and the presence of unexpected recirculation of MeV electrons in the mm-thick target. Experimental results together with analytical and Monte-Carlo simulations of the data will be presented.

\(^1\)Work supported by DOE HEDLP program.

4:00PM UO5.00011 Proton probing of a relativistic laser interaction with near-critical plasma \(^2\), LOUISE WILLINGALE, C. ZULICK, A.G.R. THOMAS, A. MAKSIMCHUK, K. KRUSHELNICK, University of Michigan, P.M. NILSON, C. STOECKL, RICARDO TORRES, CLPU, MARCO BORGHESI, Queen University Belfast, DAVID NEELEY, Central Laser Facility, PAUL MCKENNA, University of Strathclyde — The interaction of an intense laser pulse with a solid target produces high energy electrons at the target-vacuum boundary. For sufficiently high laser intensities and thin targets, the electrons become relativistic and rapidly expand into vacuum, lowering the peak electron density. The combined increase in the relativistically-corrected critical density and the reduction in the target electron density results in the onset of relativistic induced transparency (RIT) during the laser pulse, enabling the remainder of the pulse to propagate through the target and further interact with the accelerated electrons. We report on measurements of the collective dynamics of laser driven electrons in the RIT regime. The 2D profile of the beam of accelerated electrons is shown to change from an ellipse to a circle, consistent with two-dimensional simulations in the case of limited RIT, to a double-lobe structure aligned perpendicular to it, for a larger degree of RIT. The temporal dynamics of the interaction are investigated via PIC simulations. The implications of RIT for laser-driven ion acceleration is also explored.

\(^2\)Work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0002028.

4:12PM UO5.00012 Investigation of collective electron dynamics in relativistically transparent laser-foil interactions \(^3\), ROSS GRAY, DAVID MACLELLAN, BRUNO GONZALEZ-IZQUIERDO, HAYDN POWELL, University of Strathclyde, DAVID CARROLL, Central Laser Facility, CHRISTOPHER MURPHY, University of Edinburgh, LUCA STOCKHAUSEN, CLPU, DEAN RUSBY, GRÆME SCOTT, Central Laser Facility, ROBBIE WILSON, University of Strathclyde, NICOLA BOOTH, DAN SYMES, STEVE HAWKES, Central Laser Facility, RICARDO TORRES, CLPU, MARCO BORGHESI, Queen University Belfast, DAVID NEELEY, Central Laser Facility, PAUL MCKENNA, University of Strathclyde — The interaction of an intense laser pulse with a solid target produces high energy electrons at the target-vacuum boundary. For sufficiently high laser intensities and thin targets, the electrons become relativistic and rapidly expand into vacuum, lowering the peak electron density. The combined increase in the relativistically-corrected critical density and the reduction in the target electron density results in the onset of relativistic induced transparency (RIT) during the laser pulse, enabling the remainder of the pulse to propagate through the target and further interact with the accelerated electrons. We report on measurements of the collective dynamics of laser driven electrons in the RIT regime. The 2D profile of the beam of accelerated electrons is shown to change from an ellipse aligned along the laser polarization direction in the case of limited RIT, to a double-lobe structure aligned perpendicular to it, for a larger degree of RIT. The temporal dynamics of the interaction are investigated via PIC simulations. The implications of RIT for laser-driven ion acceleration is also explored.

\(^3\)Supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0002028.
4:24PM UO5.00013 The Effect of Pre-formed Plasmas on Relativistic Electron Acceleration1, JAEBUM PArk, LAURENT DIVOL, HUI CHEN, SABRINA NAGEL, G. JACKSON WILLIAMS, Lawrence Livermore Natl Lab, SHAUN KERR, Univ. of Alberta, Canada — Pre-formed plasmas have been extensively studied and are known to affect relativistic electrons production via laser-plasma interactions. However, there are still many unknowns, such as laser energy absorption vs. scale-length and material dependence. We have investigated the pre-formed plasmas effects on relativistic electrons by simultaneously measuring the plasma density with a 2w optical interferometer and relativistic electron energy distributions on the LLNL Titan laser. The pre-formed plasmas were produced on Parylene-N and Ti targets by a separate laser and/or the ASE of the short pulse (SP) laser with upper $10^{19}$ W/cm² at 1w. A 3-D wedge geometry HYDRA simulation is used to benchmark sub-critical density and infer scale-length at the critical density. Electron energy ratios of along the SP beam to the target back normal show stronger pre-formed plasmas effects on creation of relativistic electrons from Parylene-N than Ti.

1This work was performed under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344 and funded by LDRD (#12-ERD-062).

4:36PM UO5.00014 Time-resolved studies in ultra-intense laser-solid interactions, JAMES GREEN, ALEX ROBINSON, DEAN RUSBY, LUCY WILSON, Central Laser Facility, STFC, CHRIS MURPHY, University of Edinburgh, RACHEL DANCE, ROSS GRAY, DAVID MACLELLAN, PAUL MCKENNA, University of Strathclyde, CHRIS RIDGERS, University of York — The study of fast electron transport in laser-solid interactions is crucial for many key applications. Laser-accelerated particle beams will require compact laser systems operating at high repetition rates, hence experimental effort to characterise acceleration processes using femtosecond laser sources is crucial. A thorough understanding of fast-electron acceleration and transport underpins the development of most of these applications, necessitating both temporally and spatially-resolved measurements. Here an overview will be presented of unique fast electron transport results from the Astra Gemini laser ($10^{21}$ W cm⁻², 40 fs). Using high resolution rear surface optical probing, together with complementary ion acceleration measurements, we have undertaken a study of the earliest stages of fast electron dynamics. How various target and laser parameters directly affected both the electron distribution and subsequent ion acceleration will be detailed, with computational modeling supporting the experimental observations.

Thursday, October 30, 2014 2:00PM - 4:36PM — Session UO6 Kinetic Effects Galerie 3 - Suxing Hu, University of Rochester

2:00PM UO6.00001 Exploration of kinetic and multi-ion-fluids effects in D³He and T³He gas-filled implosions using multiple nuclear reaction histories, HONG SIO, HANS RINDERKNECHT, MICHAEL ROSENBERG, ALEX ZYLSTRA, FREDRICK SEGUIN, MARIA GATU JOHNSON, CHIKANG LI, RICHARD PETRASSO, Massachusetts Institute of Technology, NELSON HOFFMAN, KRIGORY KAGAN, KIM MOLVIG, Los Alamos National Laboratory, PETER AMENDT, CLAUDIO BELLEI, SCOTT WILKS, Lawrence Livermore National Laboratory, CHRISTIAN STOECKL, VLADIMIR GLEBOV, RICCARDO BETTI, THOMAS SANGSTER, JOSEPH KATZ, Laboratory for Laser Energetics — To explore kinetic and multi-ion-fluid effects in D³He and T³He gas-filled shock-driven implosions, multiple nuclear reaction histories were measured using the upgraded Particle Temporal Diagnostic (PTD) on OMEGA. For D³He gas-filled implosions, the relative timing of the DD and D³He reaction histories were measured with 20 ps precision. For T³He gas-filled implosions (with 1-2% deuterium), the relative timing of the DT and D³He reaction histories were measured with 10 ps precision. The observed differences between the reaction histories on these two OMEGA experiments are contrasted to 1-D single-ion hydro simulations for different gas-fill pressure and gas mixture. This work is supported in part by the U.S. DOE, LLNL, LLE, and NNSA SSGF.

2:12PM UO6.00002 Studies of multi-ion-fluid yield anomaly in shock-driven implosions, H.G. RINDERKNECHT, M.J. ROSENBERG, C.K. LI, A.B. ZYLSTRA, H. SIO, M. GATU JOHNSON, J.A. FRENJE, F.H. SEGUIN, R.D. PETRASSO, MIT, P.A. AMENDT, C. BELLEI, S.C. WILKS, G. ZIMMERMAN, LLNL, N.M. HOFFMAN, G. KAGAN, K. MOLVIG, LANL, V.YU. GLEBOV, C. STOECKL, F.J. MARSHALL, W. SEKA, J.A. DELETTREZ, T.C. SANGSTER, R. BETTI, V.N. GONCHAROV, D.D. MEYERHOFER, LLE — A. NIKROO, GA — Anomalously reduced yields relative to hydrodynamically calculated values have been observed for mixtures of D³He compared to pure D2 gas-filled implosions in a series of shock-driven implosions on OMEGA. An extensive suite of measurements including temporal and spatial measurements of both the DD- and D³He-fusion reactions were obtained to identify the origin and physics behind this anomalous yield reduction. Measured spectral linewidths of fusion products suggest that the D ions are not thermalized to He during the burn, contributing to the reduced yield. The hypothesis that ion-species separation due to diffusive processes contributes to the observed yield reduction is explored using hydrodynamic simulations incorporating ion diffusion. Recent observations by Rosenberg et al. of a yield reduction with increased ion-ion mean free path do not explain the observed anomalous yield trend. Future work that will directly probe species separation with high-precision relative fusion reaction rate measurements between DD-neutrons and D³He-protons using the DualPTD instrument is discussed. This work was supported in part by the U.S. DOE, LLNL, LLE, and LLNL.


2:24PM UO6.00003 Studies of ion kinetic effects in OMEGA shock-driven implosions using fusion burn imaging, M.J. ROSENBERG, F.H. SEGUIN, H.G. RINDERKNECHT, H. SIO, A.B. ZYLSTRA, M. GATU JOHNSON, J.A. FRENJE, C.K. LI, R.D. PETRASSO, MIT, P.A. AMENDT, S.C. WILKS, G. ZIMMERMAN, LLNL, N.M. HOFFMAN, G. KAGAN, K. MOLVIG, LANL, V. YU. GLEBOV, C. STOECKL, F.J. MARSHALL, W. SEKA, J.A. DELETTREZ, T.C. SANGSTER, R. BETTI, D.D. MEYERHOFER, LLE, S. ATZENI, Universita Di Roma “La Sapienza”, A. NIKROO, GA — Ion kinetic effects have been inferred in a series of shock-driven implosions at OMEGA from an increasing yield discrepancy between observations and hydrodynamic simulations as the ion-impact mean free path increases. To more precisely identify the nature and impact of ion kinetic effects, spatial burn profile measurements of DD and D3He reactions in these D3He-filled shock-driven implosions are presented and contrasted to both purely hydrodynamic models and models that include ion kinetic effects. It is shown that in implosions where the ion mean free path is equal to or greater than the size of the fuel region, purely hydrodynamic models fail to capture the observed burn profiles, while a model that includes ion diffusion is able to recover the observed burn profile shape. These results further elucidate the ion kinetic mechanisms that are present under long mean-free-path conditions after shock convergence in both shock-driven and ablative-driven implosions. This work was supported in part by the U.S. DOE, LLNL, LLE, and LLNL.

ions of any generation. The method is applied to “burn” in the hot fuel in inertial confinement fusion capsules. This process have experimentally detectable signatures, including in neutron spectra. We present a method which uses plasma Monte Carlo techniques to include large-angle Coulomb collisions cause energetic fusion reactivity. Ion-ion Coulomb collisions are implemented with a pairwise scheme that conserves number, momentum, and energy. The influences of the albedo and temperature of the boundary, ion slowing on electrons, ambipolar electric fields, fusion alphas, and a Cu minority species are studied. Reductions in fusion reactivity are quantified. For DT at 9 keV, the Gamow peak in the fusion reactivity is at 29 keV, but the KL decrements in the ion tail from Maxwellian are observed to occur at higher energies so that the Maxwellian-averaged formula for the fusion reactivity using the space-time local temperatures and densities gives a good fit to the kinetic fusion rate. Kinetic effects are nevertheless important in determining end losses, velocity tail decrements and anisotropy, and ion axial plasma profiles for density, kinetic energy, fluxes, and flows. [1] D. B. Henderson, Phys. Rev. Lett. 33, 1142 (1974). [2] K. Molvig, et al., Phys. Rev. Lett. 109, 095001 (2012). *Work performed for the USDOE under contract DE-AC52-07NA27344 at Lawrence Livermore Nat. Lab.

Supported by an EPSRC Doctoral Prize Fellowship

2:36PM UO6.00004 Kinetic Plasma and Turbulent Mix Studies using DT Plastic-shell Implosions with Shell-thickness and Pressure Variations, Y. KIM, H.W. HERRMANN, N.M. HOFFMAN, M.J. SCHMITT, P.A. BRADLEY, G. KAGAN, LANL, S. GALEs, C.J. HORSFIELD, M. RUBERY, A. LEATHERLAND, AWE, M. GATU JOHNSON, MIT, V. GLEBOV, W. SEKA, F. MARSHALL, C. STOECKL, LLE, J. CHURCH, LLNL — Kinetic plasma and turbulent mix effects on inertial confinement fusion have been studied using a series of DT-filled plastic-shell implosions at the Omega laser facility. Plastic capsules of 4 different shell thicknesses (7.4, 15, 20, 29 micron) were shot at 2 different fill pressures in order to vary the ion mean free path compared to the size of fuel region (i.e., Knudsen number). We varied the empirical Knudsen number by a factor of 25. Measurements were obtained from the burn-averaged ion temperature and fuel areal density. Preliminary results indicate that as the empirical Knudsen number increases, fusion performances (e.g., neutron yield) increasingly deviate from hydrodynamic simulations unless turbulent mix and ion kinetic terms (e.g., enhanced ion diffusion, viscosity, thermal conduction, as well as Knudsen-layer fusion reactivity reduction) are considered. We are developing two separate simulations: one is a reduced-ion-kinetics model and the other is turbulent mix model. Two simulation results will be compared with the experimental observables.

2:48PM UO6.00005 Particle Simulations of Knudsen Layer Effects on DT Fusion*, BRUCE COHEN, ANDRIS DIMITS, GEORGE ZIMMERMAN, SCOTT WILKS, Lawrence Livermore National Laboratory — Kinetic effects have been shown to degrade fusion reactivities near an absorbing bounding surface in some circumstances, the so-called Knudsen layer (KL) effect. There is renewed interest in the KL effect [1] in the context of inertial fusion [2]. We report particle simulations (1D Cartesian in space, 3D in velocity) of the transport of deuterium and tritium (DT) plasma in a system with a partially absorbing boundary and including Coulomb collisions and the effects of non-Maxwellian velocity distribution functions on fusion reactivity. Ion-ion Coulomb collisions are implemented with a pairwise scheme that conserves number, momentum, and energy. The influences of the albedo and temperature of the boundary, ion slowing on electrons, ambipolar electric fields, fusion alphas, and a Cu minority species are studied. Reductions in fusion reactivity are quantified. For DT at 9 keV, the Gamow peak in the fusion reactivity is at 29 keV, but the KL decrements in the ion tail from Maxwellian are observed to occur at higher energies so that the Maxwellian-averaged formula for the fusion reactivity using the space-time local temperatures and densities gives a good fit to the kinetic fusion rate. Kinetic effects are nevertheless important in determining end losses, velocity tail decrements and anisotropy, and ion axial plasma profiles for density, kinetic energy, fluxes, and flows. [1] D. B. Henderson, Phys. Rev. Lett. 33, 1142 (1974). [2] K. Molvig, et al., Phys. Rev. Lett. 109, 095001 (2012). *Work performed for the USDOE under contract DE-AC52-07NA27344 at Lawrence Livermore Nat. Lab.

3:00PM UO6.00006 Molecular Dynamics Investigations of the Ablator/Fuel Interface during Early Stages of Inertial Confinement Fusion1, LIAM STANTON, Lawrence Livermore National Laboratory, MICHAEL MURILLO, Los Alamos National Laboratory, JAMES GLOSIL, Lawrence Livermore National Laboratory — At the National Ignition Facility, high-powered laser beams are used to compress a small target to generate fusion reactions. A critical issue in achieving this is the understanding of mix at the ablator/fuel interface. Mixing occurs at various length scales, ranging 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 molecular dynamics approach to model these processes, in which the ions are treated as classical point particles. Because we must reach extremely large length and time scales, we have developed a simplified electronic structure model, which includes time- and space-dependent ionization levels, external heating and electron-ion energy exchange. Simulation results are presented and compared with other models and experiments.

3:12PM UO6.00007 Self-Diffusion in Dense Plasmas, JULIE STERN, MICHAEL MURILLO, Los Alamos National Laboratory — Large angle scattering has been shown to be important in ICF plasmas [Turrell et al. PRL 112, 245002 (2014)]. We use molecular dynamics to obtain effective Coulomb logarithms across coupling regimes through a careful study of self-diffusion in screened ionic systems. Through a theoretical analysis of the MD data, we assess the applicability of the Coulomb logarithm in different regimes, finding three distinct regimes of transport. Although theoretical models of Ornstein-Uhlenbeck typically model Brownian motion processes, they cannot fully capture collective dynamics in all regimes of plasma coupling. Modified memory based theoretical OU models are introduced. In order to make the models more accurate, the role of stochastic charge fluctuations relative to the mean ionization state <z> is investigated. The Yukawa pair potential is combined with a Stewart-Pyatt continuum lowers Saha method. Transport coefficients using average charges <Z> are compared with charge state distributions (Z). We model the time-evolving charge state fluctuations using a discrete stochastic evolution algorithm. Mixtures are investigated and compared to single-species. *murillo@lanl.gov

3:24PM UO6.00008 Modeling viscosity and diffusion of plasma mixtures across coupling regimes, PHILIPPE ARNAULT, CEA, DAM, DIF 91297 Arpajon, France — Viscosity and diffusion of plasma for pure elements and multicomponent mixtures are modeled with the high-temperature low-density weakly coupled regime to the low-temperature high-density strongly coupled regime [1]. Thanks to an atom in jellium modeling, the effect of electron screening on the ion-ion interaction is incorporated through a self-consistent definition of the ionization. This defines an effective One Component Plasma, or an effective binary Ionic mixture, which is representative of the strength of the interaction [2, 3]. For the viscosity and the interdiffusion of mixtures, approximate kinetic expressions are supplemented by mixing laws applied to the excess viscosity and self-diffusion of pure elements. The comparisons with classical and quantum molecular dynamics results reveal deviations in the range 20-40% on average with almost no predictions further than a factor of 2 over many decades of variation. Applications in the inertial confinement fusion context could help in predicting the growth of hydrodynamic instabilities.

3:36PM UO6.00009 Effects of large-angle collisions on inertial confinement fusion plasmas1, A.E. TURRELL, M. SHERLOCK, S.J. ROSE, London, South Kensington, London, SW7 2AZ, UK — Large-angle Coulomb collisions cause energetic fusion produced ions to scatter thermal fuel ions to many times their initial energy in a single collision, creating fast "knock-on" ions. These collisions are not included in models of plasmas based on fluids or the Vlasov-Fokker-Planck equation but they affect the exchange of energy in fusion plasmas, and the evolution of ion distribution functions. It is well known that the relative importance of large-angle Coulomb collisions to small-angle collisions is O(1/lnΛ). Their effects are expected to be important in the 2 < ln Λ < 5 regime, which includes high intensity laser-plasma interactions at solid density, ICF, and stellar cores. In this regime, large-angle collisions are infrequent but have noticeable effects because they transfer large amounts of energy per collision. Knock-on ions generated by this process have experimentally detectable signatures, including in neutron spectra. We present a method which uses plasma Monte Carlo techniques to include the effects of large-angle Coulomb collisions in fusion plasmas and which self-consistently evolves distribution functions according to the creation of knock-on ions of any generation. The method is applied to “burn” in the hot fuel in inertial confinement fusion capsules.


1Supported by an EPSRC Doctoral Prize Fellowship
3:48PM UO6.00010 Numerical modeling of radiation physics in kinetic plasmas [I]1, YASUHIKO SENTOKU, IOANA PARASCHIV, RYAN ROYLE, RISHI PANDIT, ROBERTO MANCINI, Department of Physics, University of Nevada, Reno — High energy density plasmas created by ultraintense short laser light emit intense x-rays via atomic processes. There is no simulation code available to study the critical details of X-ray emission/absorption and the plasma formation with femtosecond temporal resolution. Since the plasmas are created in less than 1 ps, thermalization or equilibrium cannot be assumed so that we must treat the plasma kinetically. We have developed a novel simulation tool based on the collisional particle-in-cell (PIC) code, PICLS, in which we can now solve the X-ray transport and photoionization self-consistently with the plasma dynamics. This talk introduces the idea of the numerical model of the radiation transport and also introduces several approaches such as Bremsstrahlung, K-α emission, and XFEL-matter interaction, of which details are presented in the following talks.

1Supported by US DOE DE-SC0008827.

4:00PM UO6.00011 Numerical modeling of radiation physics in kinetic plasmas [II]1, IOANA PARASCHIV, YASUHIKO SENTOKU, ROBERTO MANCINI, University of Nevada, Reno — X-ray radiation is an important feature of ultra-intense laser interactions with high Z materials. In order to take into account the radiation effects in the high energy density plasmas created by such interactions, we have modified the collisional particle-in-cell code PICLS to self-consistently model the x-ray radiation transport (RT). Solving the equation of radiation transport requires the creation of a non-LTE database of emissivities and opacities as functions of photon frequency for given densities, bulk electron temperatures, hot electron temperatures, and hot electron fractions. The database was generated using results computed by a non-equilibrium, collisional-radiative atomic kinetics code. Using the two-dimensional RT-PICLS code we have studied the X-ray transport in an ultrafast heated target and the dependence of the emitted K-α radiation on the fast electron dynamics in the solid target. The details of these results obtained from the implementation of the radiation transport model into the PICLS calculations will be reported in this presentation.

1Work supported by the DOE Office of Science grant no. DE-SC0008827 and by the NNSA/DOE grants no. DE-FC52-06NA27616 and DE-NA0002075

4:12PM UO6.00012 Numerical modeling of radiation physics in kinetic plasmas [III] - γ-ray transport via Bremsstrahlung in ultra-fast heated high Z matter1, RISHI PANDIT, YASUHIKO SENTOKU, University of Nevada Reno — Radiation transport code coupled with fully relativistic collisional Particle-in-Cell (PIC) code, PICLS, has been developed to study the transport of X-ray photons produced in laser-solid interaction. We have implemented the radiation cross-section of relativistic Bremsstrahlung to simulate γ-ray transport in ultrafast heated high Z matter by an intense short pulse laser. We discuss the laser energy dependence of the emission energy and the intensity dependence of the angular distribution of γ-rays. By solving the transport of hard X-rays, we find that high energy photons emitted by relativistic electrons are co-moving with the electrons and they are intensified continuously. As a result the γ-rays have the signature of the fast electrons' temporal and spatial distribution. We also calculate the number of pairs by solving the Bethe-Heitler cross-section in the radiation transport simulation. Comparing the details of γ-rays via Bremsstrahlung and pair creation with varying laser intensities in simulations, we will discuss the laser parameters and the target conditions (material) to produce the higher yield.

1Supported by US DOE DE-SC0008827.

4:24PM UO6.00013 Numerical modeling of radiation physics in kinetic plasmas [IV] – Isochoric heating by intense X-ray laser-produced photoelectrons, RYAN ROYLE, YASUHIKO SENTOKU, University of Nevada, Reno — An intense, hard X-ray laser such as an XFEL is an attractive light source since it can directly heat solid matter isochorically to a temperature of millions of degrees on a time scale of a few tens of femtoseconds, which is much shorter than the plasma expansion time scale. The X-ray laser interaction with carbon, aluminum, silicon, and copper is studied with a particle-in-cell code that solves the photoionization and X-ray transport self-consistently. Photoionization is the dominant absorption mechanism and non-thermal photoelectrons are produced with energy near the X-ray photon energy. The photoelectrons' stopping range requires the creation of a non-LTE database of emissivities and opacities as functions of photon frequency for given densities, bulk electron temperatures, hot electron temperatures, and hot electron fractions. The database was generated using results computed by a non-equilibrium, collisional-radiative atomic kinetics code. Using the two-dimensional RT-PICLS code we have studied the X-ray transport in an ultrafast heated target and the dependence of the emitted K-α radiation on the fast electron dynamics in the solid target. The details of these results obtained from the implementation of the radiation transport model into the PICLS calculations will be reported in this presentation.

Thursday, October 30, 2014 2:00PM - 3:36PM –
Session UO7 Expanding Plasmas, Shocks, and Astrophysical Plasmas
Galerie 6 - Auna Moser, Los Alamos National Laboratory

2:00PM UO7.00001 Instabilities observed at the bubble edge of a laser produced plasma during its expansion in an ambient tenuous plasma1, BO RAM LEE, Tech Univ Darmstadt, S.E. CLARK, University of California, Los Angeles, D.H.H. HOFFMANN, Tech Univ Darmstadt, C. NIEMANN, University of California, Los Angeles — The Raptor kJ class 1053nm Nd:Glass laser in the Phoenix laser laboratory at University of California, Los Angeles, is used to ablative a dense debris plasma from a graphite or plastic target embedded in a tenuous, uniform, and quiescent ambient magnetized plasma in the Large Plasma Device (LAPD) which provides a peak plasma density of $n_i \sim 10^{19}$ cm$^{-3}$. Its background magnetic field can vary between 200 and 1200G. Debris ions from laser produced plasma expand out conically with super-Alfvénic speed ($M_A$ $\sim$ 2) and expel the background magnetic field and ambient ions to form a diamagnetic bubble. The debris plasma interacts with the ambient plasma and the magnetic field and acts as a piston which can create collisionless shocks. Flute-type instabilities, which are probably large Larmor radius Rayleigh Taylor instabilities or lower hybrid drift instabilities, are developed at the bubble edge and also observed in the experiment. The amplitude and wavelength dependence of the instabilities, which might be a strong function of debris to ambient mass to charge ratio, is studied and the experimental results are compared to the two dimensional hybrid simulations.

1the Deutsche Forschungsgemeinschaft in the framework of the Excellence Initiative Darmstadt Graduate School of Energy Science and Engineering (GSC1070)
2:12PM UO7.00002 Spectroscopic Measurement of High-Frequency Electric Fields in the Interaction of Explosive Debris Plasma with Ambient, Magnetized Background Plasma. ANTON BONDARENKO, DEREK SCHAEFFER, ERIK EVerson, ERIC CLARK, STEPHEN VINCENA, BART VAN COMPERNOLLE, SHREEKRISHNA TRIPATHI, CARMEN CONSTANTIN, CHRIS NIEMANN, UCLA — The explosive expansion of dense, high-beta debris plasma into relatively tenuous, magnetized background plasma is relevant to a wide array of astrophysical and space environments. Electric fields play a fundamental role in the coupling of momentum and energy from debris to background, and emission spectroscopy provides a powerful diagnostic for assessing electric fields via the Stark effect. A recent experiment utilizing a unique experimental platform at UCLA that combines the Large Plasma Device and the Raptor laser facility has investigated the super-Alfvénic, quasi-perpendicular expansion of a laser-produced carbon (C) debris plasma through a preformed, ambient, magnetized helium (He) background plasma via emission spectroscopy. Spectral profiles of the He II 468.6 nm line have been analyzed via single-mode and multi-mode time-dependent Stark broadening models for hydrogen-like ions, yielding large magnitude (∼100 kV/cm), high-frequency (∼100 GHz) electric fields. The measurements suggest the development of an electron beam-plasma instability, and a simple instability saturation model demonstrates that the measured electric field magnitudes are feasible under the experimental conditions.

2:24PM UO7.00003 Laboratory Experiments on Propagating Plasma Bubbles into Vacuum, Vacuum Magnetic Field, and Background Plasmas. ALAN G. LYNN, YUE ZHANG, MARK GILMORE, University of New Mexico, SCOTT HSU, Los Alamos National Laboratory — We discuss the dynamics of plasma “bubbles” as they propagate through a variety of background media. These bubbles are formed by a pulsed coaxial gun with an externally applied magnetic field. Bubble parameters are typically \( n_b \sim 10^{20} \text{ m}^{-3} \), \( T_e \sim 5 \sim 10 \text{ eV} \), and \( T_i \sim 10 \sim 15 \text{ eV} \). The structure of the bubbles can range from unmagnetized jet-like structures to spheromak-like structures with complex magnetic flux surfaces. Some of the background media the bubbles interact with are vacuum, vacuum with magnetic field, and other magnetized plasmas. These bubbles exhibit different qualitative behavior depending on coaxial gun parameters such as gas species, gun current, and gun bias magnetic field. Their behavior also depends on the parameters of the background they propagate through. Multi-frame fast camera imaging and magnetic probe data are used to characterize the bubble evolution under various conditions.

2:36PM UO7.00004 Towards the generation of collisionless electron-positron shocks in the laboratory: Ultrafast thermalisation of laser-driven relativistic plasma jets. MICKAEL GRECH, Laboratoire d'Utilisation des Lasers Intenses, MATHIEU LOBET, CEA/DAM Ile de France, France, CHARLES RUYER, CEA/DAM Ile-de-France, EMMANUEL D'HUMIÈRES, CELIA, Université Bordeaux 1, MARTIN LEMOINE, Institut d' Astrophysique de Paris, France, ARNAUD DEBAYE, LAURENT GREMILLET, CEA/DAM Ile de France, France — Weibel-mediated collisionless shocks between high-velocity, counter-streaming (electron-ion or electron-positron) plasma flows have been extensively investigated over the past years to gain understanding of various extreme astrophysical scenarios. Here, we examine a concept of colliding pair plasmas that exploits the extreme electromagnetic fields envisioned on compressed LMJ-class laser projects. We present the first self-consistent numerical study, using QED-PIC simulations, of the creation (through the multi-photon Breit-Wheeler process) and subsequent interaction of two counter-streaming, relativistic pair flows driven from laser-irradiated thin Al foils. Fast-growing Weibel instabilities are found to be induced by ultra-fast thermalisation of the pair jets through the buildup of a MT magnetostatic barrier. The associated gamma-ray generation, its effect on electron-positron thermalisation, as well as the subsequent shock formation are analysed in detail.

2:48PM UO7.00005 Collisionless Weibel shocks: Full formation mechanism and timing. ANTOINE BRET, Universidad Castilla La Mancha, Spain, ANNE STOCKEM, Ruhr-Universitöt Bochum, Germany, RAMESH NARAYAN, Harvard-Smithsonian Center for Astrophysics, USA, LUIS O. SILVA, Instituto Superior Tecnico, Portugal — Collisionless shocks in plasmas play an important role in space physics (Earth’s bow shock) and astrophysics (supernova remnants, relativistic jets, gamma-ray bursts, high energy cosmic rays). While the formation of a fluid shock through the steepening of a large amplitude sound wave has been investigated for long, there is currently no detailed picture of the mechanism responsible for the formation of a collisionless shock. We unravel the physical mechanism at work and show that an electromagnetic Weibel shock always forms when two relativistic collisionless, initially unmagnetized, plasma shells encounter. The predicted shock formation time is in good agreement with 2D and 3D particle-in-cell simulations of counterstreaming pair plasmas. By predicting the shock formation time, experimental setups aiming at producing such shocks can be optimised to favourable conditions [1].


3:00PM UO7.00006 Particle acceleration in non-relativistic collisionless shocks. FREDERICO FIUZA, Lawrence Livermore National Laboratory — Supernova remnant shocks are thought to be the dominant source of cosmic rays up to PeV energies; however, the mechanisms for shock formation, magnetic field amplification and particle acceleration in these scenarios are not yet fully understood. I will present detailed multi-dimensional particle-in-cell simulations of shock formation and particle acceleration in non-relativistic scenarios, both unmagnetized and magnetized. These first principles simulations, for unprecedented temporal and spatial scales, help bridge the gap between fully kinetic and hybrid modeling. The results show that electron acceleration is favored at quasi-perpendicular shocks, whereas ion acceleration is more efficient at quasi-parallel shocks. Moreover, it is possible to observe that in initially unmagnetized plasmas, where the shocks are mediated by the Weibel instability, particle acceleration can also occur. I will discuss the importance of these results for current astrophysical models and the possibility of observing particle acceleration in shocks in near future laboratory experiments.

3:12PM UO7.00007 Observing the two-photon Breit-Wheeler process for the first time. OLIVER PIKE, EDWARD HILL, STEVEN ROSE, Imperial College London, FELIX MACKENROTH, Max Planck Institute for Nuclear Physics, Heidelberg — As the inverse of Dirac annihilation, the Breit-Wheeler process [1], the production of an electron-positron pair in the collision of two photons, is the simplest mechanism by which light can be transformed into matter. It is also of fundamental importance in high-energy astrophysics, both in the context of the dense radiation fields of compact objects [2] and the absorption of high-energy gamma rays travelling intergalactic distances [3]. However, in the 80 years since its theoretical prediction, this process has never been observed. Here, we present the design of a new class of photon-photon collider [4], which is capable of detecting significant numbers of Breit-Wheeler pairs using current-generation technology. We further show how our scheme could be implemented on existing laser facilities; successfully achieving this would represent the advent of a new type of high-energy physics experiment.

3:24PM UO7.00008 Theory of the leptonic cascade in magnetospheres of Kerr black holes\footnote{Supported by grant DOE grant DE-FG02-07ER54940 and NSF grant AST-1209665.}. MIKHAIL MEDVEDEV, ALEX FORD, BRETT KEENAN, University of Kansas — It is believed that relativistic jets observed in Active Galactic Nuclei, blazars, quasars and micro-quasars, radio-active galaxies and some other systems host rapidly spinning (Kerr) black holes (BH) and are powered by Blandford-Znajek mechanism, which converts the BH rotational energy into Poynting flux. For this process to occur, the BH may be immersed into the external magnetic field (presumably brought in by the accreting plasma) and plasma must be created around a BH (in vacuum, the B-field takes the Ward solution, which delivers zero Blandford-Znajek power). This, plasma production in the so-called “gap” region of the BH magnetosphere is crucial for the jets to exist. Here we present analytical theory of the plasma production, on the leptonic cascade. We present conditions (ambient photon spectrum, luminosity, magnetic field strength, BH spin) needed for the cascade multiplicity to exceed unity, i.e., for the astrophysical systems to exhibit powerful jets. We discuss how temporal variations of these parameters can turn the jets off and on.

\[ n = \frac{1}{2} \text{ rotational mode. Depending on value of applied end-biasing electric field, the n = 1 tilt and subsequent growth of the n = 2 rotational mode becomes unstable. Hybrid simulations with non-symmetric BCs with/without end-shorting show strongly unstable n = 1 radial shift (wobble) mode. The effects of energetic beam ions on FRC stability properties have been also investigated numerically using a hybrid version of the HYM code. Stability properties of co-interchange (kink) modes with different toroidal mode numbers n = 1-4 and the beam driven instabilities have been studied for realistic TAE equilibrium and slowing down distribution for the beam ions.} \]

2:00PM - 2:00PM — Session UP8 Poster Session VIII: FRC, Spheromaks, Stellarators and Other Magnetic Confinement Systems; HEDP & ICF: Hydro, Simulations and Diagnostics — Preservation Hall —

UP8.00001 FRC, SPHEROMAKS, STELLARATORS AND OTHER MAGNETIC CONFINEMENT SYSTEMS —

UP8.00002 Overview of the C-2 Field-Reversed Configuration Experimental Program and Future Plan on C-2 Upgrade \footnote{Supported by grant DOE grant DE-FG02-07ER54940 and NSF grant AST-1209665.}, XIAOKANG YANG, HIROSHI GOTA, MICHL BINDERBAUER, MICHEL TUSZEWSKI, HOUYANG GUO, EUSEBIO GARATE, DAN BARNES, SERGEI PUTVINSKI, TOSHIKI TAJIMA, LEIGH SEVIER, Tri Alpha Energy, Inc. — C-2 is the world’s largest compact-toroid (CT) device at Tri Alpha Energy that produces field-reversed configuration (FRC) plasmas by colliding/merging oppositely-directed CTs and seeks to study the evolution, heating and sustainment effects of neutral-beam (NB) injection into FRCs \cite{1, 2}. Recently, significant progress has been made in C-2 on both technology and physics fronts, achieving \( \sim 5 \text{ ms stable plasmas with a dramatic improvement in confinement. FRCs are stabilized with an edge biasing using end-on plasma-guns and/or electrodes, and are partially sustained with NB injection (20 keV Hydrogen,} \sim 4 \text{ MW). Recent work to reduce scrape-off layer and radiative losses has succeeded in reducing the average power balance deficit to} \sim 1.5 \text{ MW. Increasing plasma pressure and electron temperature are now observed during brief periods of the discharge, which indicate a sign of NB injection effect such as accumulating fast-ions as well as heating core/edge plasmas. Highlights of these advances, broader C-2 experimental program, and future plan on upgrading the C-2 device with new NBs (15 keV, up to 10 MW injection power, selectable beam injection angle) will be presented.} \]

\begin{thebibliography}{1}
\end{thebibliography}

UP8.00003 Three-Dimensional Hybrid Simulations of Field-Reversed Theta-Pinch Discharges, YURI OMECHENKO, Trinum Research, Inc. HOMA KARIMABADI, SciberQuest, Inc. — The field-reversed theta-pinch discharge is a well-known method for creating the field-reversed configuration (FRC) considered to be one of the most promising candidates for an economical fusion reactor. Using an asynchronous parallel hybrid code, HYPERS, we have conducted first-ever 3D simulations of such discharges under realistic physical conditions that include applied magnetic field coils, ion-ion collisions and the Chodura resistivity. Unlike all other existing hybrid codes, HYPERS does not step spatially distributed variables synchronously in time but instead performs numerical time integration by executing asynchronous discrete events: updates of particles and fields carried out as frequently as dictated by local physical time scales. As a result, not only HYPERS produces robust and accurate results with speedups of several orders of magnitude compared to traditional simulations but for the first time this code made it possible to study end-to-end kinetic dynamics of 3D laboratory plasma systems under experimental plasma conditions that make application of other codes very difficult if not altogether impossible. We discuss physical properties of FRCs obtained in simulations and mechanisms responsible for their spontaneous toroidal spin-up.

UP8.00004 A Field-Reversed Configuration Plasma Translated into a Neutral Gas Atmosphere, JUN’ICHI SEKIGUCHI, TOMOHICO ASAII, TSUTOMU TAKAHASHI, HIROTOSHI ANDO, MAMIKO ARAII, SERI KATAYAMA, Nihon University, TOSHIKI TAKAHASHI, Gunma University — A field-reversed configuration (FRC) is a compact toroid dominantly with poloidal magnetic field. Because of its simply-connected configuration, an FRC can be translated axially along a gradient of guide magnetic field, and trapped in a confinement region with quasi-static external magnetic field. FRC translation experiments have been performed several facilities. Translation speed of those translated FRCs is comparable with super-Alfvenic speed of approximately 200km/s. In this experiments, FRC translation has been performed on the FAT (FRC Amplification via Translation) facility. Achieved translation speed in the case of translation into a confinement chamber maintained as the vacuum state is in the range from 130 to 210 km/s. On the other hand, FRC translation into a statically filled deuterium gas atmosphere has also been performed. In the case of translation into filled neutral gas, FRC translation speed is approximately 80km/s and the separatrix volume has extremely expanded compared with the case of a vacuum state. The phenomenon suggests the presence of regeneration process of translation kinetic energy back into the internal plasma energy during the translation process.

\footnote{This work was partially supported by “Nihon University Symbolic Project.” The authors gratefully acknowledge contributions from Nac Image Technology Inc. on the fast camera measurements.}

UP8.00005 Numerical study of rotational instabilities and beam ion effects in FRC using the HYM code, ELENA BELOVA, PPPL, D. BARNES, S. DETTRICK, A. NECAS, Tri Alpha Energy, TAE TEAM TEAM — Numerical study of FRC spin-up and the effects of plasma production on FRC stability has been performed using a 3D nonlinear hybrid version of the HYM code for TAE FRC experimental parameters. The n = 1 tilt mode is found to be weakly unstable in 5-9 FRC, and it saturates nonlinearly at small amplitude. Simulations including the particle loss and periodic BCs show all low-n modes stable for large resistivity. End-shorting results in faster spin-up and instability of n = 2 rotational mode. Depending on value of applied end-biasing electric field, the n = 1 wobble or n = 2 rotational mode becomes unstable. Hybrid simulations with non-symmetric BCs with/without end-shorting show strongly unstable n = 1 radial shift (wobble) mode. The effects of energetic beam ions on FRC stability properties have been also investigated numerically using a hybrid version of the HYM code. Stability properties of co-interchange modes with different toroidal mode numbers n = 1-4 and the beam driven instabilities have been studied for realistic TAE equilibrium and slowing down distribution for the beam ions.
Kinetic particle simulation of turbulence in an FRC geometry, Daniel Fulton, Calvin Lau, Ihor Holod, Zhihong Lin, University of California, Irvine, Sean Detrick, Michel Binderbaeur, TriAlpha Energy, Toshiki Taima, University of California, Irvine, and TriAlpha Energy — Core turbulence in a Field Reversed Configuration (FRC) is studied using the Gyrokinetic Toroidal Code with modified equilibrium geometry. The code solves the gyrokinetic equation for ions and the drift kinetic equation for electrons. The simulation region is an annulus which excludes plasma near the O-point to avoid breakdown of the gyrokinetic dynamics of ions. The C-2 FRC equilibrium is introduced to study similar conditions as found in the C-2 experiments, where the core ion temperature is found to be 6 eV and the electron temperature is found to be 4.5 eV. The simulations include electron temperature fluctuations leading to E x B drifts and plasma rotation. The simulation exhibits a class of drift modes that appear as flute-like drift modes. These results should provide guidance for future experiments on C-2.

UP.000006 Latest Electron Temperature and Density Measurement in C-2 High Performance Regimes, Kan Zhai, John Kinley, Heleen Zhang, Tri Alpha Energy, Inc., P.O. Box 7010, Rancho Santa Margarita, CA 92688, Benoît Leblanc, Princeton Plasma Physics Laboratory, Princeton, NJ 08543, THE TAE TEAM — A new high performance regime of C-2 FRC Plasma was found and experimentally investigated during our latest campaigns. The core ion temperature is found to be > 45 eV, which is the highest in C-2 history. The electron temperature is also measured using Thomson scattering, the electron temperature and density profiles and their temporal evolution are investigated for this new operational regime and are compared with the cases of our previously obtained high performance regime. It is found that for the new regime the electron temperature is higher, both in the FRC core and edge regions. In the period from 0.5 ms to 1 ms, both the core and the edge electron temperature increase. Analogously the excluded magnetic flux radius increases during this period as well, which suggests possible electron heating as well as the potential toward sustainment of the C-2 FRC plasma. The electron density measurement shows flat and hollow radial profiles and the core/edge density stays flat in time. Detailed experimental setup and results will be presented in the meeting.

UP.000007 Development of Compact Toroid Injector for C-2 FRCs, Tadafumi Matsumoto, Junichi Sekiguchi, Tomohiko Asai, Nihon University, Hiroshi Gota, Eusebio Garate, Ian Allfrey, Travis Valentine, Brett Smith, Mark Morehouse, Tri Alpha Energy, Inc., THE TAE TEAM — A new high performance regime of C-2 FRC Plasma was found and experimentally investigated during our latest campaigns. The core ion temperature is found to be > 45 eV, which is the highest in C-2 history. The electron temperature is also measured using Thomson scattering, the electron temperature and density profiles and their temporal evolution are investigated for this new operational regime and are compared with the cases of our previously obtained high performance regime. It is found that for the new regime the electron temperature is higher, both in the FRC core and edge regions. In the period from 0.5 ms to 1 ms, both the core and the edge electron temperature increase. Analogously the excluded magnetic flux radius increases during this period as well, which suggests possible electron heating as well as the potential toward sustainment of the C-2 FRC plasma. The electron density measurement shows flat and hollow radial profiles and the core/edge density stays flat in time. Detailed experimental setup and results will be presented in the meeting.

UP.000008 Z-effective from Bremsstrahlung Emission in the C-2 FRC, Eusebio Garate, Nathan Bolte, Deepak Gupta, Hiroshi Gota, Ian Allfrey, John Kinley, Kurt Knapp, Tri Alpha Energy, Inc., and THE TAE TEAM — An absolutely-calibrated 12-chord Bremsstrahlung array has been implemented on C-2 and is being used to infer Z-effective profiles and line-averaged values. Electron-ion Bremsstrahlung light at a given wavelength is a function of electron temperature, electron density, and the average ionic charge, Z-effective. Electron density is measured with interferometry and electron temperature is measured directly with Thomson scattering or is inferred by pressure balance. Custom band-pass filters at 523.4 nm were chosen to avoid line-radiation. Z-effective radial profiles show a peak near the separatrix and line-averaged values show an increase in time. For shots where density and temperature profiles were available, Z-effective inside the separatrix was found to be 1.28 for the first ms. These data suggest that C-2 FRC’s do not suffer from high levels of edge-light contamination, which allows Z-effective monitoring with a single chord. *M. W. Binderbauer et al., Phys. Rev. Lett. 105, 045003 (2010).

UP.000010 Beam-instabilities and their impact on anomalous neutron reactivity, Ales Necas, Scott Nicks, Toshiki Taima, Richard Magee, TriAlpha Energy, TRIALPHA ENERGY TEAM — Field Reversed Configuration (FRC) toroidal current is sustained with the neutral beam injection (NBI). Thermal plasma is deuterium and beams are hydrogen. If there exists some beam driven modes that can make clumpy distribution in its phase space of the beam-plasma system, the plasma bulk portion of the clumpiness can contribute to enhance the fusion reaction. Anomalous increase of neutrons originating from thermonuclear D + D reaction is observed signaling rise of thermal ions temperature. It is useful to study a beam heating of the thermal ions via a beam-driven instability). Thus it is of crucial interest if and what kind of beam-driven instabilities are available for the C-2 experimental conditions under which this anomalous neutron yield is observed (see accompanying abstract). As a starter, the hot plasma electrostatic dispersion relation with the ion beam is investigated as to determine possible growth rate and heating associated with the beam.

UP.000011 Advanced Biasing Experiments on the C-2 Field-Reversed Configuration Device, Matthew Thompson, Sergey Korepanov, Eusebio Garate, Xiaokang Yang, Hiroshi Gota, Jon Douglass, Ian Allfrey, Travis Valentine, Nolan Uchizono, Tri Alpha Energy, THE TAE TEAM — The C-2 experiment seeks to study the evolution, heating and sustainment effects of neutral beam injection on field-reversed configuration (FRC) plasma. Recently, substantial improvements in plasma performance were achieved through the application of edge biasing with coaxial plasma guns located in the divertors [1]. Edge biasing provides rotation control that reduces instabilities and E x B shear that improves confinement. Typically, the plasma gun arcs are run at ~ 10 MW for the entire shot duration (~ 5 ms), which will become unsustainable as the plasma duration increases. We have conducted several advanced biasing experiments with reduced-average-power plasma gun operating modes and alternative biasing cathodes in an effort to develop an effective biasing scenario applicable to steady state FRC plasmas. Early results show that several techniques can potentially provide effective, long-duration edge biasing. *M. Tuszewski et al., Phys. Rev. Lett. 108, 255008 (2012)

UP.000012 Fast Global Imaging of the C-2 Field-Reversed Configuration and Divertor Plasmas, Erik Granstedt, Tri Alpha Energy, A. L. Roquemore, Princeton Plasma Physics Laboratory, A. Longman, R. Hayashi, E. Yankoski, Tri Alpha Energy, THE TAE TEAM — Two high-speed, filtered cameras have been used to view the dynamics of the C-2 FRC plasma in order to examine macroscopic plasma evolution, rotation, and non-axisymmetric perturbations. This instrument consisted of a Phantom v7.3 camera coupled to imaging optics via a 15-f, 1000 x 800 pixel coherent fiber bundle. A filter wheel was set between shots to view edge-dominated emission from neutral D, C III, or Li I-II, or core-dominated emission from O III-V. Perturbations rotating in the ion diamagnetic direction were observed both during the FRC and after the transition to an open field-line plasma. The divertor instrument consisted of a Phantom v5.2 camera with D3 filter and was used to examine divertor neutral density under various gas puffing, magnetic field, and electrode biasing configurations. Both instruments were photometrically calibrated to measure absolute emissivity in order to obtain estimates of neutral and impurity density.

UP8.00013 Gyro-Scale Turbulence in the C-2 Field Reversed Configuration, L. SCHMITZ, University of California Los Angeles, B. DENG, H. GOTA, T. TAJIMA, D. GUPTA, J. DOUGLASS, M. BINDERBAUER, Tri Alpha Energy, Inc., E. RUSKOV, University of California Irvine, THE TAE TEAM — Short-scale electron-mode turbulence ($0.5 \leq k_{\rho_e} \leq 40$; where $k_{\rho_e}$ is the toroidal wavenumber and $\rho_e$ is the ion sound gyroradius) has been observed in the C-2 FRC via multi-channel Doppler Backscattering. Density fluctuation levels $\bar{n}/n$ are substantial near the separatrix and in the scrape-off layer (SOL) plasma, and very low in the FRC core. Turbulent structures are observed to propagate radially outwards from the separatrix into the SOL. SOL fluctuation levels are reduced by a large factor ($\lesssim 10$) at high mirror plug ratio ($R_p = 20$), with concomitant improvements in FRC particle and energy confinement. Reduced radial correlation lengths $(\lambda_c < \rho_p)$ and turbulence decorrelation rates are measured near the separatrix. A non-monotonic toroidal wavenumber spectrum is observed in the FRC core ($\bar{n}/n$ increases with toroidal wavenumber for $k_{\rho_e} < 10$ and decreases exponentially for high $k_{\rho_e}$). These observations are qualitatively consistent with quenching of long wavelength ion modes via $E \times B$ velocity shear or Finite Larmor radius effects, and dominant residual electron-mode core plasma turbulence.

UP8.00014 Time-evolution of ion-temperature radial profiles for high performance FRC (HPF) plasma in C-2, DEEPAK GUPTA, E. GRANSTEDT, S. GUPTA, R. MAGEE, D. OSIN, M. TUSZEWSKI, Tri Alpha Energy, TAE TEAM — Measurements of ion temperature profile and its time evolution is important for the understanding of FRC confinement and transport properties. Recently, in C-2 plasma device, FRCs with significantly improved confinement and transport properties are observed (HPF14) using higher formation DC field and Lithium wall conditioning. Time evolutions of ion-temperature profiles in these FRCs are measured using upgraded impurity ions passive Doppler spectroscopy system. Measured line integration profiles are inverted to get the local ion-temperature profiles, by taking in to consideration the local emissivity and directed ion-velocity. These profiles are measured under different C-2 operation conditions; for example, Neutral Beam power, plasma gun and magnetic field configurations. Radial profiles of ion temperature and its time evolution will be presented. Comparison of ion-temperature time-evolution with neutron measurements, deuterium-ion temperature measurements, and 1-d transport modeling will also be presented.

UP8.00015 Measurement of density fluctuations and particle transport in C-2, BIHE DENG, SCOTT AEFSKY, JOHN KINLEY, Tri Alpha Energy, Inc., TAE TEAM — In the C-2 field reversed configuration experiment [1], long wavelength density fluctuations are measured for the first time by a newly developed far infrared (FIR) laser far forward scattering diagnostics. The dynamics of the frequency spectrum, spatial distribution, scaling with density gradient and other plasma equilibrium parameters are characterized. On the other hand, density profile evolution and particle transport are measured by the multi-chord two-color CO2/HeNe interferometer. The correlation between measured density fluctuations and particle transport will be examined.


UP8.00016 VUV Spectra observed in C-2 FRC plasma, DMITRY OSIN, JON DOUGLASS, MICHEL TUSZEWSKI, Tri Alpha Energy, TAE TEAM — A grazing incidence flat-field spectrometer was installed for observation of vuv-spectra in C-2 FRC experiment. Wavelength calibration was done by observing spectra of six different gases produced by a hollow-cathode discharge lamp. In addition, in-situ calibration and alignment were performed utilizing neutral-beam heated gases. Wavelength regions between 16 nm and 170 nm was investigated with accuracy of about 0.02 nm. VUV-spectral lines of the most abundant impurity ions were identified both for Plasma Gun and C-2 plasmas. In addition to D spectrum, strong lines of O III-VI, N IV-V, C II-III, and Fe II ions were observed during the plasma lifetime. VUV radiative power losses within energy range from 7.3 eV to 81 eV were estimated based on the calculated FIR dimensions.

UP8.00017 Transport study of the C-2 FRC plasma, MARCO ONOFRI, SEAN DETTRICK, DANIEL BARNES, TOSHIKI TAJIMA, SANGEETA GUPTA, ERIK TRASK, LOTHAR SCHMITZ, Tri Alpha Energy, TAE TEAM — The 2D transport code Q2D is used to study transport in the C-2 Field Reversed Configuration with neutral beam injection. The code solves the MHD equations including source terms due to neutral beams, which are calculated by a Monte Carlo technique. We compare numerical simulations with experimental results obtained in C-2, where 6 neutral beams are injected into the plasma with energy of 20 keV and total power of 4.2 MW. Q2D simulations of C-2 start from an initial equilibrium and different values of the transport coefficients are used to study their effect on the evolution of the FRC. We investigate different transport coefficients, including those based on the TAE transport scaling. For the recent HPF14 confinement regime in C-2 we study the coupling between the scrape-off layer (SOL) and the FRC core by changing the mirror-plug constriction. We also observe that the number of fast ions is affected by the density of neutrals, which cause charge exchange, and beam shinethrough, which also depends on SOL transport. These results are also compared with the 1D version of our transport code Q1D.

UP8.00018 C2 Lithium Campaign Power Balance, ERIK TRASK, BIHE DENG, JON DOUGLASS, EUSEBIO GARATE, DEEPAK GUPTA, SANGEETA GUPTA, MICHEL TUSZEWSKI, Tri Alpha Energy, AND THE TAE TEAM — Several key changes have lead to record performance of the Tri Alpha Energy’s (TAE) C2 Field Reversed Configuration (FRC) device. Wall conditioning changes from titanium to lithium have decreased radiative losses, while changes in the magnetic field of the SOL and jet have substantially increased energy confinement times. An overview of 0D power flows and timescales will be presented demonstrating that ions behave classically, that anomalous electron losses have been substantially reduced, and that plasma sustainment will require modest increases in heating power. These observations will be quantitatively analyzed as well as compared with both theoretical modeling of the TAE transport and numerical simulations (Q2D).

UP8.00019 Plasma flow and electron losses in the expander divertor of FRC, P. YUSHMANOV, D. BARNES, S. DETTRICK, S. GUPTA, Tri Alpha Energy, D. RYUTOV, Lawrence Livermore National Laboratory, S. KRASHENINNIKOV, University of California, San Diego, A. NECAS, S. PUTVINSKI, Tri Alpha Energy — Expander divertor is planned to be used in the design of next generation FRC device. The main goal of experimental expansion is to decrease heat load on the target plates and slow down heat losses through electron channel. A comprehensive study of expander divertor physics is initiated in Tri Alpha. It started with revision of pre-sheath electrostatic potential formation in the expander using both analytic and numerical means. An adaptation of 3D code KSOL has been developed to analyze expander physics and electrostatic potential formation. Initial results are presented. The key issue of the study is the analysis of the interaction of plasma with neutrals. Presence of neutrals affects expander physics in several ways. First of all, charge exchange and ionization modify pattern of ion flow in the expander magnetic field. That changes plasma density profile and affects formation of pre-sheath electrostatic potential. Second, ionization (as well as secondary electron emission) creates population of cold electrons in the expander which flow into confinement vessel and enhance out-flux of hot electrons. Distribution of neutrals is calculated in realistic geometry of expander divertor and effect on electron losses is evaluated.
UP8.00020 Propagation and dynamics of microwaves in the ECRH frequency range for the FRC, FRANCESCO CECCHERINI, LAURA GALEOTTI, Tri Alpha Energy, MARCO BRAMBILLA, Max Planck Institute für Plasmaphysik, Germany, DANIEL C. BARNES, XIAOKANG YANG, Tri Alpha Energy, TAE TEAM — A previously developed FLR code for ICRR studies has recently been upgraded to include the frequency range of interest for ECRH applications. This full wave code is able to use very fine meshes (grid spacing down to $10^{-3}$ cm on a single cpu) so that even wavelengths very short with respect to the wall radius can be resolved well. The first wave propagation scheme we have addressed - and in part used for benchmark purposes also - is given by a source placed at a few cm from the first wall with a current oscillating in the longitudinal direction and an ordinary wave propagating in the radial direction. Such a wave propagates through the plasma until the required conditions for O-X-B mode conversion are encountered. The mode-converted electrostatic wave generated at the upper hybrid frequency behaves according to the expected dispersion relation and it is studied in terms of the launched frequency. Initial results indicate that in an elongated FRC configuration under study, the possibility to satisfy all conditions required to have electron absorption in the region beyond the SOL through the O-X-B conversion process strongly depends on the plasma radial profile. Details on this scheme and different examples will be presented.

UP8.00021 Measurements of classical fast ion confinement with fusion product diagnostics, RICHARD MAGEE, RYAN CLARY, SERGEY KOREPANOV, ARTEM SMIROV, EUSEBIO GARATE, IAN ALLFREY, TRAVIS VALENTINE, Tri Alpha Energy, Inc., Rancho Santa Margarita, CA 92688, USA, THE TAE TEAM — Neutral beam injected fast ions play a critical role in the C-2 field reversed configuration plasma helping to sustain magnetic flux against resistive decay and heating the plasma via Coulomb collisions. The fast ions are well confined; due to the relatively low magnetic field strength the fast ions have large, machine-size orbits that permit them to average over otherwise deleterious fluctuations. These same orbits however, have large radial excursions that result in greater interaction of fast ions with edge neutrals and a greater potential for charge exchange losses. In this presentation, the fast ion slowing down time is determined from the decay in neutron flux following beam termination. It is found that the slowing down scaling is close to classical (i.e., $\tau \sim T_{ei}^{2/3}/n_e$) and that charge exchange losses are only significant for ions with 1.5x the nominal injection energy. We will also present initial data from a newly installed proton detector, which complements the temporal resolution of the neutron detector with spatial resolution. The detector will be used to diagnose the axial profile of confined fast ions.

UP8.00022 Improved Magnetic Reconnection Experiment at FRC Device, MING XU, RUIJIE ZHOU, DANIEL VASQUEZ, TIAN-SEN HUANG, Prairie View A&M University, PRAIRIE VIEW SOLAR OBSERVATORY TEAM — With experimental facility’s improvement, magnetic reconnection has been further studied at Prairie View rotamak device. By adding one toroidal current in the central part of the rotamak device, the cutting of one magnetic field reverse configuration (FRC) as two FRCs in the experiment process becomes more obvious. Differing from the magnetic reconnection experiments conducted at other labs, where magnetic reconnection is formed with two ware-coiled currents buried in a chamber with large scale magnetic field, in our magnetic reconnection experiment the main source of the magnetic field is plasma current. Thus, the magnetic reconnection experiments conducted at rotamak device are closer to the one occurring in the space and on the sun. At the present stage, our experiments focus on the study of the change in electron temperature during the magnetic reconnection process. Furthermore, the ion temperature and plasma flow can be easily achieved from fast ion Doppler spectroscopy (IDS) diagnostic system [1], which makes the magnetic reconnection process more clearly.


UP8.00023 Microwave Heating Experimental at Prairie View Rotamak, RUIJIE ZHOU, MING XU, DANIEL VASQUEZ, TIAN-SEN HUANG, Prairie View A&M University, PRAIRIE VIEW SOLAR OBSERVATORY TEAM — A 6kW 2.45GHz microwave generator has been added, and a study of microwave heating experiment is performed at Prairie View Rotamak. This is the first time to apply microwave heating to a rotating magnetic field drive field reversed configuration. Rotamak is a compact torus that the toroidal plasma current is driven by means of an externally applied rotating magnetic field (RMF) with a large plasma current being generated to reverse the external equilibrium magnetic field on the symmetry axis, so a field-reversed configuration (FRC) is formed. The plasma current is produced by external rotating magnetic field, the plasma equilibrium shape is controlled by the magnetic shaping coils. The added microwave with power adjustable is injected from the top of the plasma chamber. In the experiment: $f_{pe} \approx 10^4$ GHz and $f_{ce} \approx 30$MHz ($f_{ce} < < f_{pe}$, where $f_{pe}$, $f_{ce}$ are respectively electron plasma and cyclotron frequencies and $f$ is the frequency of microwave). Consequently, the interaction between microwave and plasma is more complicated, and a series of experiments are performed at Prairie View Rotamak and some results are achieved for the following experiment. At first, a comparison experiment is performed for FRC and ST cases, and the coupling effect between high frequency microwave and plasma is being studied. Secondly, the microwave can offer a new method to affect some of MHD instabilities (such as tilt mode). n=1 tilt instability has been suppressed by magnetic shaping coils previously.

UP8.00024 Results on a 15-Joule theta-pinch FRC-physics test cell for space propulsion research, CARRIE HILL, NOLAN UCHIZONO, ERC, Inc, MICHAEL HOLMES, US Air Force — The U.S. Air Force Research Laboratory-Edwards has developed a new experimental test cell to study the physics of Field-Reversed-Configuration (FRC) formation, equilibrium, and acceleration at low-energy for space propulsion. The test-cell is compatible with a variety of plasma sources, including theta-pinch and rotating magnetic field sources. The first plasma source installed in the test-cell was a low-energy (15 J/pulse) theta-pinch source. This source has been tested at full energy with a xenon propellant and argon propellant at a range of fill densities (1-50 mTorr) and bias fields up to 1 kG. The test-cell was equipped with a suite of diagnostics to monitor plasmoid formation, include voltage and current transducers, an excluded flux array, internal magnetic field probes, emission spectroscopy, and Langmuir probes. Several pre-ionization schemes were tested with the source as well to investigate their effectiveness on plasmoid formation. Results on the theta-pinch plasma studies are presented here.

UP8.00025 Gasification and Ionization of Chemically Complex Liquids for FRC Injection, MICHAEL HOLMES, Air Force Research Laboratory, CARRIE HILL, ERC, Inc. — Ion thrusters provide reliable and efficient spacecraft propulsion but are limited to noble gas propellants to limit chemical attack of components. However, thrusters based on Field Reversed Configuration (FRC) plasmas are becoming a reality. High beta compact-toroids are generated within an FRC thruster and then expelled to provide thrust. The closed field lines restrict the plasma from attacking thruster components. More convenient propellants such as water are therefore possible. The FRC thruster would generate a series of compact-toroids (plasmoids) to develop continuous spacecraft thrust. Each plasmoid ejection would empty the discharge region. The feed system would then refill the discharge region with partially ionized gas for the next discharge. The ionization part of this feed system is the subject of this paper. The question is how to produce a uniform, chemically complex, ionized gas within the discharge region that optimizes compact-toroid formation? We will be measuring chemical state, ionization state, and uniformity as the propellant enters the discharge region.
UP8.00026 Effects of electrode coating on the CTIX injector performance during high-Z CT formation and acceleration. D. BUCHENAUER, Sandia National Laboratories, R.D. HORTON, R. EVANS, R. KLAUSER, University of California, Davis, B.E. MILLS, Sandia National Laboratories, D.Q. HWA, University of California, Davis — One application of high velocity compact toroids (CTs) is the ability to deliver ions of various species to the magnetic axis of tokamak plasmas. The fast formation and acceleration of the CTs can react to rapidly changing events in a tokamak operation such as disruptions. As proposed in theoretical models, high-Z ions delivered to the magnetic axis of a reactor-grade tokamak have the benefit of cooling runaway electrons by the bremsstrahlung process and limiting the runaway electrons final energy and the potential damage to tokamak components. The Compact Toroid Injection Experiment (CTIX) is currently being used to demonstrate efficient production of high-Z CT plasmas using acceleration of noble gases (He, Ne, Ar) puffed in the acceleration region. From previous observations of electrode damage due to repetitive operation of the CTIX injector with hydrogen CT’s, it was decided to coat the inner electrode surfaces with vacuum-sprayed tungsten. The CT characteristics are measured using optical techniques, interferometry, and internal magnetic field probes. A detailed comparison of the CT behavior and parameters using the different electrodes, stainless steel and tungsten-coated Inconel, will be reported. In addition, analysis of the measured damage to the electrode surface will guide future improvements to the injector design that will yield the best high-Z CTs for the mitigation of runaway electrons.

UP8.00027 High-beta spherical tokamak startup in TS-4 merging experiment by use of toroidal field ramp-up. YASUHIRO KAMINOU, Univ of Tokyo, TORU II, National Institute for Fusion Science, JOJI KATO, MICHIAKI INOMOTO, YASUSHI ONO, Univ of Tokyo, TS GROUP TEAM, NATIONAL INSTITUTE FOR FUSION SCIENCE COLLABORATION — We demonstrated the formation method of an ultrahigh-beta spherical tokamak by use of a field-reversed configuration and a spheromak in TS-4 device (R ~ 0.5m, A ~ 1.5, Ip ~ 30-100kA, B ~ 100mT). This method is composed of the following steps: 1. Two spheromaks are merged together and a high-beta spheromak or FRC is formed by reconnection heating. 2. External toroidal magnetic field is added (current rising time ~ 50µs), and spherical tokamak-like configuration is formed. In this way, the ultrahigh-beta ST is formed. The ultrahigh-beta ST formed by FRC has a diamagnetic toroidal field, and it is presumed to be in a second-stable state for ballooning stability, and the one formed by spheromak has a weak paramagnetic toroidal magnetic field, while a spheromak has a strong paramagnetic toroidal magnetic field. This diamagnetic current derives from inductive electric field by ramping up the external toroidal magnetic field, and the diamagnetic current sustains high thermal pressure of the ultrahigh-beta spherical tokamak. And the beta of the ultrahigh-beta ST formed by FRC reaches about 50%. To sustain the high-beta state, 0.6MW neutral beam injection and center solenoid coils are installed to the TS-4 device. In the poster, we report the experimental results of ultrahigh-beta spherical tokamak startup and sustainment by NBI and CS current driving experiment.

UP8.00028 Prospects for US Stellarator Research. JEFFREY HARRIS, Oak Ridge National Laboratory, US STELlarator CommuniTY COLLABORATION — Stellarators ensure plasma confinement using flux surfaces generated by external coils. The confinement properties of a stellarator are entirely determined by its complex 3D magnetic configuration. A suitably designed stellarator reactor thus offers the prospect of steady-state, ignited, disruption-free operation with minimal active control. The challenge for stellarator research is to develop techniques that allow optimization and confident extrapolation of configuration designs to reactor-scale devices. US researchers have made significant contributions to stellarator analysis and optimization which are in use around the world, but the US domestic stellarator program is small, and operates only two university-scale stellarator facilities: HSX (University of Wisconsin) and CTH (Auburn University). To increase its role in stellarator development in the next ten years, the US stellarator community is leveraging its expertise in national collaborative efforts on the large, superconducting stellarator devices W7-X (Germany) and LHD (Japan), with a particular focus on 3D divertor physics. Progress on these large experiments will set the stage for a new US stellarator experiment to explore the physics of quasi-symmetric stellarator confinement.

UP8.00029 The Physics Program for the QUASAR facility. D.A. GATES, S.A. LAZERSON, G.H. NEILSON, M. ZARNSTORFF, Princeton Plasma Physics Laboratory, O. SCHMITZ, H. FRERICHS, University of Wisconsin-Madison — The QUASi-Axisymmetric Research (QUASAR) stellarator is a new facility which can solve two critical problems for fusion, disruptions and steady-state, and which provides new insights into the role of symmetry in plasma confinement. The principle of quasi-axisymmetry will be used in QUASAR to study how tokamak-like systems can be made disruption-free and steady-state with low recirculating power, while also improving upon features of tokamaks, such as; stable at high pressure with high confinement, and scalable to a compact reactor. The two large stellarator experiments - LHD and W7-X - are pioneering facilities capable of developing 3D physics understanding at large scale and for very long pulses. The QUASAR design is unique in being QA and optimized for confinement, stability, and moderate aspect ratio (4.5). Important elements of the physics program for QUASAR are: establishing the physics basis of the design by demonstrating stable operation at high-$\beta$ simultaneous with good neoclassical confinement, understanding the concomitant turbulent transport, and understanding the dependence of the underlying transport on magnetic geometry. An additional important element of the program will be understanding the physics characteristics of a QA stellarator with an high flux expansion ergodic edge.

UP8.00030 Plans for first plasma operation on Wendelstein 7-X. THOMAS SUNN PEDERSEN, Max Planck Institute for Plasma Physics, W7-X TEAM TEAm, TOPICAL WORKING GROUP OP1.1 PHYSICS COLLABORATION — Wendelstein 7-X construction is nearing completion and the commissioning phase has started, in preparation for first plasma. The first plasma operation phase (OP1.1) will last about 3 months and will, despite the relatively short pulse lengths, provide the opportunity to study a number of interesting phenomena, including limiter scrape-off layer physics, heat pulse propagation, energy, particle, and impurity confinement in the electron root, and measurements and, if necessary, correction of resonant field errors. A progress report on commissioning will be given, and elements of the physics program planned for OP1.1 will be explained, together with a status report on the installation and commissioning of key diagnostics.

1Supported by USDOE, under contract No. DE-AC05-00OR22725 with UT-Battelle, LLC

2This work supported by DoE Contract No. DEAC02-76CH03073

4Includes participants from EUROFUSION and US-W7-X collaboration
UP8.00031 The impact of profile variability on bootstrap current and ballooning stability in W7-X. A.S. WARE, University of Montana, S.P. HIRSHMAN, Oak Ridge National Laboratory. The impact of a range of density, electron temperature, and ion temperature profiles on self-consistent bootstrap current, ballooning stability, and the magnetic structure of equilibria in computational studies of the W7-X stellarator is examined. Previous work has shown that even a small bootstrap current can change the rotational transform profile and thus, change the magnetic configuration, especially in the edge region. In this work, free-boundary equilibria for the W7-X coil configuration have been obtained over a range of pressure, density and temperature profiles, including equilibria with self-consistent bootstrap current (i.e., where the plasma current is solely from the bootstrap current). The impact of these profiles on bootstrap current, magnetic structure in the edge, and ballooning stability is examined. The formation of islands in the edge regions and correlation with ballooning stability is discussed. Methods of ameliorating the impact of bootstrap current will be discussed.

1Work supported by U.S. Department of Energy under Grant DE-FG02-03ER54699 at the University of Montana.

UP8.00032 A Specialized IR Endoscope for High Resolution Views in the W7-X Stellarator. GLEN WURDEN, Los Alamos National Laboratory, MARCEL JAKUBOWSKI, JUERGEN BALDUH, Max Planck Inst. for Plasma Physics, Greifswald. As part of the US/German collaboration on W7-X, we report on the design and preparation of a relay lens-based endoscope for infrared observations of the W7-X limiter and divertor components, during early operation. We plan a 100 degree field of view which can be steered with a stainless turning mirror, directed towards either a graphite limiter in OPL1.1, or a test divertor unit with scraper element in OPL1.2. Optical access is obtained using a water-cooled, shutter-protected, reentrant viewing tube, which can be mounted in several possible diagnostic ports. It will contain 2.2 meter long borescope optics working at 1/4 in the 3-5 micron wavelength band. Software for real-time acquisition and analysis written in Matlab with multi-core GPU image processing will also be discussed.

UP8.00033 Initial characterization of electron cyclotron heated plasmas in the Columbia Non-Neutral Torus. KENNETH HAMMOND, FRANCESCO VOLPE, Columbia U., SAMUEL LAZERSON, PPPL. The Columbia Non-Neutral Torus (CNT) is a stellarator at Columbia University recently modified for the study of quasi-neutral plasmas heated by 2.45 GHz electron cyclotron waves. Using a simple configuration of four circular planar coils, it generates magnetic surfaces with the lowest aspect ratios (1.9-2.7) ever attained by a stellarator. The low magnetic field (0.09 T), combined with the possibility of electron Bernstein wave heating above the cutoff density, could make CNT suitable for research of magnetohydrodynamic equilibrium and stability at high beta. Additional plans for future work include novel microwave and magnetic diagnostics, heating with electron cyclotron and helicon waves, and error field studies. Here we present an experimental characterization of the parameters of CNT’s first microwave-heated plasmas. We present Langmuir probe measurements of temperature and density profiles, fast camera images, and equilibrium reconstructions computed by the VMEC code.

UP8.00034 Constructing a Small Modular Stellarator in Latin America. IVAN VARGAS, JAIME MORA, CARLOS OTAROLA, JOSE ASENJO, ESTEBAN ZAMORA, JEFERSON GONZALEZ, CARLOS PIEDRA, Costa Rica Institute of Technology. The small modular stellarator SCR-1 (Stellarator of Costa Rica 1) is a 2-field period device with a circular cross-section vessel under construction in Costa Rica ($R_0=0.238$ m, $\langle a \rangle =0.059$ m, $R_0/a > 4.0$). Expected plasma volume is $0.016$ m$^3$, 10 mm thick vacuum vessel. The magnetic field strength at the centre is 44 mT which will be produced by 12 copper modular coils with 4.35 kA-turn each. This field is EC resonant at $R_0$ with 2.45 GHz as 2$^{1/2}$ harmonic, from 2/3 kW magnetrons. SCR-1 has a designed stellarator UST-1. As a first step, the objectives focus on training human resources and identifying problems related to the design and construction of small modular stellarators. We present the engineering problems encountered and the proposed solutions related to: thickness, material and construction method for the vacuum vessel, layout and design of ports, method of construction for coils, coils fixing, welding procedure, microwave input, control and data acquisition systems, design and test of diagnostics. Temperature, resistance, voltage and power calculations as a function of time were performed for the electrical circuit under different wire configurations per modular coil to select the power supply taking into account the available budget.

UP8.00035 Two-dimensional impurity transport study in stochastic magnetic field layer at low- and high-density discharges of LHD. SHIGERU MORITA, TETSUTAROU OISHI, National Institute for Fusion Science, HONGMING ZHANG, Department of Fusion Science, Graduate University for Advanced Studies, MASASI KOBAYASHI, MOTOHICHI GOTO, GAKUSHI KAWAMURA, National Institute for Fusion Science, XIANLI HUANG, Department of Fusion Science, Graduate University for Advanced Studies. Edge stochastic magnetic field layer of Large Helical Device (LHD) consists of short and long open magnetic fields ranging in 10$^{-2}$ cm$^{-3}$ and 10$^{-3}$ cm$^{-3}$, whereas it shows single trajectory at low-density discharges ($n_e \approx 5 \times 10^{12}$ cm$^{-3}$). Due to the stochasticity, particles are deflected by magnetic islands and are transported towards the outside region. In order to study the parallel impurity transport two-dimensional impurity emissions from several impurity species have been measured in EUV wavelength range (10-500Å) and a clear impurity footprint along poloidal X-point trajectory is observed. The poloidal impurity footprint, e.g., CIV, is separated into double trajectories at low-density discharges ($n_e \geq 5 \times 10^{13}$ cm$^{-3}$), whereas it shows single trajectory at low-density discharges ($n_e \leq 2 \times 10^{13}$ cm$^{-3}$). The result clearly indicates the presence of the friction force. The 2-D distribution analyzed by 3-D edge transport code, EMC3-EIRENE is discussed on the friction force and temperature gradient force along magnetic fields.

1This work was partly supported by the JSPS-NRF-NSFC A3 Foresight Program in the field of Plasma Physics (NSFC: No.11261140328, NRF : No. 2012K2A2A6000443).

UP8.00036 Chaotic coordinates for the Large Helical Device. STUART HUDSON, Princeton Plasma Physics Laboratory, YASUHIRO SUZUKI, National Institute for Fusion Science. The study of dynamical systems is facilitated by a coordinate framework with coordinate surfaces that coincide with invariant structures of the dynamical system. For axisymmetric systems, a continuous family of invariant surfaces is constructed so that the flux surfaces are “straight” and the islands become “square.”

For non-integrable systems, e.g. stellarators, perturbed tokamaks, this continuous family is broken. Nevertheless, coordinates can still be constructed that simplify the description of the dynamics. The Poincaré-Birkhoff theorem, the Aubry-Mather theorem, and the KAM theorem show that there are important structures that are invariant under the perturbed dynamics; namely the periodic orbits, the cantori, and the irrational flux surfaces. Coordinates adapted to these invariant sets, which we call chaotic coordinates, provide substantial advantages. The regular motion becomes straightforward, the irrational motion is bounded by, and dissected by, coordinate surfaces that coincide with surfaces of locally-minimal magnetic-fieldline flux. The chaotic edge of the magnetic field, as calculated by HINT2 code, in the Large Helical Device (LHD) is examined, and a coordinate system is constructed so that the flux surfaces are “straight” and the islands become “square.”
UP8.00037 Electromagnetic gyrokinetic simulation of turbulent transport in high ion temperature discharge of Large Helical Device\(^1\), AKIHIRO ISHIZAWA, National Institute for Fusion Science, TOMO-HIKO WATANABE, Nagoya University, HIDEO SUGAMA, National Institute for Fusion Science, SHINYA MAEYAMA, Japan Atomic Energy Agency, MASANORI NUNAMI, NORIYOSHI NAKAJIMA, National Institute for Fusion Science — Turbulent transport in a high ion temperature discharge of Large Helical Device (LHD) is investigated by means of electromagnetic gyrokinetic simulations including kinetic electrons. A new electromagnetic gyrokinetic simulation code GKV+ enables us to examine electron heat and particle fluxes as well as ion heat flux in finite beta heliotron/stellarator plasmas [1]. This problem has not been previously explored because of numerical difficulties associated with complex three-dimensional magnetic structures as well as multiple spatio-temporal scales related to electromagnetic ion and electron dynamics. The turbulent fluxes, which are evaluated through a nonlinear simulation carried out in the K-super computer system, will be reported.


\(^1\)This research uses computational resources of K at RIKEN Advanced Institute for Computational Science through the HPCI System Research project (Project ID: hp140044)

UP8.00038 Effect of neoclassical poloidal viscosity and resonant magnetic perturbation on the response of the m/n=1/1 magnetic island in LHD , HUANG BOTSZ, The Graduate University for Advanced Studies (Sokendai), SHINSUKE SATEKE, RYUTARO KANNO, YOSHIRO NARUSHIMA, SATORU SAKAKIBARA, SATOSHI OHDACHI, National Institute for Fusion Science — In the LHD experiments in which m/n=1/1 resonant magnetic perturbation (RMP) amplitude is ramped up, it is observed that the perturbed field is initially shielded, and when the amplitude exceeds a threshold value, the field penetrates into the plasma and m/n=1/1 magnetic island appears. It is also found that the threshold amplitude depends on the magnetic field configuration of LHD, that is, on the magnetic axis position. It is expected that the poloidal force balance between the electromagnetic force and the drug force from poloidal rotation determines the threshold of island formation. Since neoclassical poloidal viscosity (NPV) in LHD strongly depends on the magnetic axis position, we investigate the relationship between NPV and the threshold amplitude of m/n=1/1 RMP to penetrate by using drift-kinetic simulation code FORTEC-3D. ExB poloidal rotation determined from the ambipolar radial flux condition is taken into account in the evaluation of NPV. We mainly focus on the situation that the external magnetic perturbation is compensated by the plasma response and therefore the effect of RMP on the total NPV is shielded. However, by using a simple model to express the penetrated magnetic perturbation, we will also study the dependence of NPV on the RMP amplitude.

UP8.00039 MHD instabilities limiting beta value in LHD and the interaction with error field , SATORU SAKAKIBARA, YUKI TAKEMURA, KIYOMASA WATANABE, SATOSHI OHDACHI, YOSHIRO NARUSHIMA, KATSUJI ICHIGUCHI, KATSUMI IDA, KENJI TANAKA, TOSHIKO TOKUZAWA, NAOMI TAKEIRI, National Institute for Fusion Science, LHD EXPERIMENT TEAM — Characteristics of MHD instabilities limiting beta value have been investigated in unstable regime of ideal interchange mode in LHD to optimize magnetic configuration of heliotron-type fusion reactor. We accessed ideal-unstable regimes by enhancing magnetic hill and reducing magnetic shear. The magnetic hill was enhanced by shifting magnetic axis position, Rax, to the inward, whereas the magnetic shear was reduced by increasing plasma current and plasma aspect ratio. In the enhanced magnetic hill configuration, m/n = 2/1 mode with a finite frequency appeared when Rax < 3.55 m, and strong growth of the mode was observed after stop of the mode rotation. Then central beta value was dropped by 30%. In the reduced magnetic shear configuration, m/n = 1/1 mode was destabilized when the plasma current exceeded a threshold, the mode significantly grew after the stop of the rotation as well as the case of m/n = 2/1 mode, which degraded the central beta by about 60%. The onset of the mode was qualitatively consistent with ideal stability boundary, the occurrence of the collapse was independent of an existence of an error field (EF). In the configuration with the error field, the spatial structure of the mode after the stop of the rotation was almost the same as that of the EF, while it changed at random in the reduced EF case.

UP8.00040 Modeling propagating heat pulses in the Large Helical Device , HAO ZHU, Centre for Fusion, Space and Astrophysics, Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom, RICHARD DENDY, Euratom/CCFE Fusion Association, Culham Science Centre, Abingdon, Oxfordshire OX14 3DB, United Kingdom, SANDRA CHAPMAN, Centre for Fusion, Space and Astrophysics, Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom, SHIGERU INAGAKI, Research Institute for Applied Mechanics, Kyushu University, Fukuoka 816-8580, Japan — Rapid edge cooling induced by pellet injection in Large Helical Device plasmas generates inward propagating pulses with either large positive or negative deviations of the electron temperature at the core [Inagaki et al, Plasma Phys. Control. Fusion 52 (2010) 075002]. By applying a traveling wave transformation, we find that this model can match experimental data for pulse peaks, shapes and propagation velocities within a broad radial range from plasma edge to core.

UP8.00041 Overview of CTH research\(^1\), M.C. ARCHMILLER, M.R. CIANCIO, D.A. ENNIS, M.M. GOFORTH, J.D. HANSON, G.J. HARTWELL, J.D. HEBERT, J.L. HERFINDAL, S.F. KNOWLTON, X. MA, D.A. MAURER, M.D. PANDYA, N.A. ROBERDS, P.J. TRAVERSO, Auburn University — Goals of the Compact Toroidal Hybrid (CTH) experiment are to: (1) investigate the dependence of plasma disruptive behavior on the level of applied 3D magnetic shaping; (2) test and advance the V3FIT reconstruction code; and (3) study the implementation of an island divertor. Progress towards these goals and other developments are summarized. The disruptive density limit exceeds the Greenwald limit as the vacuum transform is increased, but a threshold for avoidance is not observed. Low-q disruptions, with 1.1 <q(a) <2.0, cease to occur if the vacuum transform is raised above ~ 0.07. Application of vacuum transform can reduce and eliminate the vertical drift of elongated discharges that would otherwise be vertically unstable. While reconstructions using external magnets give accurate estimates of the enclosed toroidal flux and quantities near the plasma boundary, internal diagnostics (such as Thomson scattering and 2D two-color SXR cameras) are being developed to extend the range of accuracy into the plasma core. NIMROD is used to model the current ramp phase and predicts the formation of symmetry-breaking magnetic islands. An island divertor design has begun with connection length studies to model energy deposition on divertor plates located in an edge 1/3 island.

\(^1\)This work is supported by US Department of Energy Grant No.s DE-FG02-00ER54610 and DE-FG02-03ER54692
UP8.00042 Characteristics of Low-\(q(a)\) Disruptions in the Compact Toroidal Hybrid\(^1\), M.D. PANDYA, M.C. ARCHMILLER, D.A. ENNIS, G.J. HARTWELL, D.A. MAURER, Auburn University — Tokamak disruptions are dramatic events that lead to a sudden loss of plasma confinement. Disruptions that occur at low edge safety-factor, \(q(a)\), limit the operation of tokamaks to \(q(a) \geq 2\). The Compact Toroidal Hybrid (CTH) is a torus-tokamak hybrid with a helical field coil and vertical field coils to establish a stellarator equilibrium, while an ohmic coil induces plasma current. A feature of the CTH device is the ability to adjust the vacuum rotational transform, \(\iota_{\text{vac}}\), by varying the ratio of current in the helical and toroidal field coils. The value of edge \(\iota_{\text{vac}}\) can be varied from about 0.02 to 0.3 (\(\iota_{\text{vac}} < 0.3\)). Plasma discharges in CTH are routinely observed to operate with \(q(a) < 2\), and in some cases as low as \(q(a) \sim 1.1\). In CTH, low-\(q(a)\) disruptions are observed with a dominant \(m/n=3/2\) precursor. The disruptivity of plasma discharges is over 80% when \(\iota_{\text{vac}} < 0.04\) (\(q_{\text{vac}}(a) < 25\)) and as \(\iota_{\text{vac}}(a)\) is increased further, the disruptivity of the plasma discharges decreases. The disruptions are completely suppressed for \(\iota_{\text{vac}}(a) > 0.07\). [1]

\(^1\)This work is supported by US Department of Energy Grant No. DE-FG02-00ER54610.

UP8.00043 3D Equilibrium Reconstruction with Improved Magnetic Diagnostics on the Compact Toroidal Hybrid\(^1\), X. MA, M. CIANCIOSA, J.D. HANSON, G.J. HARTWELL, S.F. KNOWLTON, D.A. MAURER, Auburn Univ — We present non-axisymmetric equilibrium reconstruction of stellarator plasmas whose magnetic configuration is strongly modified by ohmically driven plasma current. These experiments were performed on the Compact Toroidal Hybrid device using the V3FIT reconstruction code [1] and a set of 50 magnetic diagnostics external to the plasma edge. The reconstructed equilibria give accurate estimates of the toroidal flux within the last closed flux surface and information near the plasma boundary region including the edge safety factor, plasma shape, and current density of these highly non-axisymmetric plasmas. While the poloidal cross-section of these discharges becomes more circular with the addition of driven plasma current, toroidally the underlying \(n=5\) stellarator periodicity is enhanced. Eddy current effects are small for the eddy current model considered in the presence of plasma current. The remaining systematic error is associated with a vertical shift of the plasma breaking stellarator symmetry along with the use of only external magnetic diagnostics.


\(^1\)This work is supported by US Department of Energy Grant No. DE-FG02-00ER54610.

UP8.00044 Design and implementation of a Thomson scattering diagnostic for the Compact Toroidal Hybrid Experiment\(^1\), P.J. TRAVERSO, D.A. MAURER, D.A. ENNIS, G.J. HARTWELL, M.M. GOFORTH, S.D. LOCH, A.J. PEARCE, M.R. CIANCIOSA, Auburn University — A Thomson scattering system using standard commercially available components has been designed for the non-axisymmetric plasmas of the Compact Toroidal Hybrid (CTH). The initial system takes a single point measurement and will be used to assess options for an upgrade to a multi-point system providing electron temperature and density profiles. This single point measurement will reduce the uncertainty in the reconstructed peak pressure by an order of magnitude for both ohmically driven, current-carrying plasmas and future gyrotron-heated stellarator plasmas. A principle design goal is to minimize stray laser light, geometrically on the machine side and spectrally on the collection side, to allow measurements of both full and half Thomson scattered spectral profiles. The beam, generated by a frequency doubled Continuum 2 J Nd:YaG laser, is passed vertically through an entrance Brewster window and an aperturing baffle system to minimize stray light. Light collection, spectral processing, and signal detection are accomplished with an f/# ~ 1 aspheric lens, a Holospec f/1.8 spectrometer, and an Andor iStar DH740-18U-C3 image intensified camera. The estimated number of scattered photons per channel will be of the order of \(5 \times 10^3\) with a signal to noise ratio of \(S/N = 19\).

\(^1\)This work is supported by U.S. Department of Energy Grant No. DE-FG02-00ER54610.

UP8.00045 Development of a Coherence Imaging Diagnostic for the Compact Toroidal Hybrid\(^1\), D.A. ENNIS, M.C. ARCHMILLER, M.R. CIANCIOSA, J.D. HANSON, G.J. HARTWELL, D.A. MAURER, Auburn University — A new optical coherence imaging diagnostic is planned for time-resolved measurements of ion emissivity, velocity, and temperature in the Compact Toroidal Hybrid (CTH). The coherence imaging technique measures the spectral coherence of a visible emission line with an imaging interferometer of fixed delay. Coherence imaging has a number of potential advantages when compared to dispersive Doppler spectroscopy, including higher throughput and the capacity to provide 2D spectral images, making it advantageous for investigating the non-axisymmetric geometry of CTH plasmas. The coherence imaging technique can also be extended to yield the orientation and magnitude of the magnetic field by measuring the polarized spectral components due to Zeeman splitting. A spectral survey of the visible emission for a range of CTH discharges is being conducted to identify possible spectral lines that will motivate forward modeling of the plasma emissivity using the V3FIT equilibrium reconstruction code. Initial results from this diagnostic will aid in characterizing the equilibrium ion parameters in both the edge and the core of CTH plasmas for planned island divertor and MHD mode-locking experiments.

\(^1\)Work supported by USDoE grant DE-FG02-00ER54610.


UP8.00046 Observations of the Sawtooth Instability in the Compact Toroidal Hybrid\(^1\), J.L. HERFINDAL, D.A. MAURER, G.J. HARTWELL, D.A. ENNIS, S.F. KNOWLTON, M.C. ARCHMILLER, Auburn University — Sawtooth instabilities have been observed in the Compact Toroidal Hybrid (CTH), a current-carrying stellarator/tokamak hybrid device. The sawtooth instability is driven by ohmic heating of the core plasma until the safety factor drops below unity resulting in the growth of an \(n=1\) kink-tearing mode. Experiments varying the vacuum rotational transform are being conducted to study sawtooth property dependence on vacuum flux surface structure. CTH has an extensive collection of internal diagnostics capable of detecting the signatures of sawtooth instabilities: three two-color XSR cameras, a bolometer, and a three-channel 1 mm interferometer. The conditions for the onset of sawteeth, size of the inversion radius, and characteristics such as the rise and crash timescales are investigated as functions of the vacuum rotational transform, electron density and temperature.

\(^1\)This work is supported by U.S. Department of Energy Grant No. DE-FG02-00ER54610.
UP8.00047 Enhancements, Parallelization and Future Directions of the V3FIT 3-D Equilibrium Reconstruction Code¹.

M.R. Cianciosa, J.D. Hanson, D.A. Maurer, G.J. Hartwell, M.C. Archmiller, X. Ma, J. Hercfindal, Auburn University — Three-dimensional equilibrium reconstruction is spreading beyond target physics functions. One such function is related to the bunched-averaged grad-B drift velocity of trapped particles such as alphas in a fusion reactor. In an HSX reactor, the alpha particle confinement is degraded because of the modular coil ripple. Increasing the number of coils improves the alpha confinement, but also leads to an increase in the effective ripple. Thus, minimizing effective ripple by itself is not a sufficient figure of merit for energetic particle confinement. Of particular interest for optimization is the exploration of configurations in HSX which can lower turbulent transport. Optimizing for ITG turbulence in HSX also leads to an increase in the effective ripple. Thus, minimizing effective ripple by itself is not a sufficient figure of merit for energetic particle confinement.

1 This work was supported by US Department of Energy Grant No. DEFG-02-03ER-54692B.

UP8.00048 VMEC Initialized NIMROD Simulations of CTH¹.

N.A. Roberds, J.D. Hanson, M. Cianciosa, J. HEBERT, Auburn University, S.E. Kruger, J.R. King, Tech-X Corporation — Using an experimentally reconstructed equilibrium for initial conditions, a whole device fluid simulation can be used to gain insight into the dynamics of an experimental shot. A module has been developed to initialize the extended MHD code NIMROD [1] using the output from VMEC [2]. VMEC is a 3D inverse equilibrium code used in reconstructions of Compact Toroidal Hybrid (CTH) discharges. While this module is essential for simulations of CTH based on reconstructions, it could also be useful for simulating tokamaks and other devices where 3D shaping of the equilibrium fields is important. Results are presented for free boundary simulations of CTH in support of efforts to investigate disruptions. Additionally, a NIMROD simulation of the Biro-Wu MHD shocktube benchmark case is presented.

¹ Work supported by US Department of Energy Grant No. DEFG-02-03ER-54692B.


UP8.00049 Island Formation in the Current Rise Phase of CTH Discharges¹.

J.D. HEBERT, J.D. Hanson, Auburn University, NIMROD TEAM — The 3D extended MHD code NIMROD [1] has been modified to model the Compact Toroidal Hybrid (CTH), a five-field period torus/tokamak hybrid device located at Auburn University. In many shots with inductively driven current in CTH, hesitations in the current rise portion of the discharge are observed. V3FIT reconstructions of the current rise demonstrate that the edge rotational transform (ρ000) is near a low order rational suggesting that island formation at or near the edge may be responsible for the current hesitations. The initial stages of the current drive were self-consistently modeled using NIMROD and experimentally relevant vacuum fields, loop voltages, initial temperatures and initial densities. Results show the formation of field-period-symmetry-preserving islands near the plasma edge as well as the coalescence of these islands into larger, symmetry-breaking island chains which modify the distribution of the current in the plasma, phenomenologically similar to what is expected during a current hesitation in the experiment.

¹ Work supported by US Department of Energy under grant DE-FG02-03ER54692. This research used resources of NERSC, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

UP8.00050 Modeling of Divertor Plates in the Compact Toroidal Hybrid¹.

G.J. Hartwell, C.M. Small, D.A. Ennis, J.D. Hanson, S.F. Knowlton, D.A. Maurer, Auburn University — In long pulse length stellarator experiments, edge island divertors can be used as a method of plasma particle and heat exhaust. Knowledge of the detailed power loading on these structures and its relationship to the long connection length scrape off layer physics is a new Compact Toroidal Hybrid research thrust. We report the results of connection length studies for divertor plates to be installed in the Compact Toroidal Hybrid (CTH), a five field period torus/tokamak hybrid device located at Auburn University. In many shots with inductively driven current in CTH, hesitations in the current rise portion of the discharge are observed. V3FIT reconstructions of the current rise demonstrate that the edge rotational transform (ρ000) is near a low order rational suggesting that island formation at or near the edge may be responsible for the current hesitations. The initial stages of the current drive were self-consistently modeled using NIMROD and experimentally relevant vacuum fields, loop voltages, initial temperatures and initial densities. Results show the formation of field-period-symmetry-preserving islands near the plasma edge as well as the coalescence of these islands into larger, symmetry-breaking island chains which modify the distribution of the current in the plasma, phenomenologically similar to what is expected during a current hesitation in the experiment.

¹ Work supported by US Department of Energy under Grant DE-FG02-03ER54692. This research used resources of NERSC, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

UP8.00051 Overview of the Present HSX Program and Plans for HSX/U¹.

David Anderson, HSX Plasma Laboratory, University of Wisconsin-Madison, THE HSX TEAM — Heat pulse propagation experiments yield electron thermal diffusivities comparable to those obtained from power balance, showing that HSX electron transport is not stiff. Nonlinear gyrokinetic calculations using GENÉ are used to calculate the saturated heat flux under experimental conditions. A new 80-cell internal magnetic diagnostic array is used for equilibrium reconstruction using the V3FIT code including the effect of eddy currents as modeled with the SPARK code. CXRS measurements of Pfirsch-Schlüter ion flows give inferred radial electric fields larger than previous estimates, but still smaller than neoclassically predicted values. New MSE systems to directly measure and model the radial electric field are under implementation. Measurements of the edge properties and structure in HSX are compared to models from EMC3-EIRENE. A proposed major upgrade is under consideration for HSX to modify the vacuum vessel section to increase its original application to T-stellarators. New three-dimensional equilibrium reconstructions with results from whole shot reconstructions. We will show benchmarking and profiling results of initial performance improvements through the addition of OpenMP and MPI support. We will discuss future directions of the V3FIT code including steps taken for support of the W-7X stellarator.

¹Supported by USDOE under Grant DE-FG02-93ER54622.

UP8.00052 Targeted Physics Optimization in the HSX Stellarator¹.

Joseph Talmaridge, Benjamin Faber, HSX Plasma Laboratory — To plan out future experiments in HSX, we have developed a code to vary the currents in the auxiliary coils and optimize for specific target physics functions. One such function is related to the bunched-averaged grad-B drift velocity of trapped particles such as alphas in a fusion reactor. In an HSX reactor, the alpha particle confinement is degraded because of the modular coil ripple. Increasing the number of coils improves the alpha confinement, but also leads to an increase in the effective ripple. Thus, minimizing effective ripple by itself is not a sufficient figure of merit for energetic particle confinement. Of particular interest for optimization is the exploration of configurations in HSX which can lower turbulent transport. Optimizing for ITG turbulence in HSX configuration can be achieved so that the calculated saturated turbulent heat flux is reduced by a factor of 2 from the standard QHS configuration. However, experimental data showed that the confinement was degraded in the new configuration; gyrokinetic calculations confirm that TEM and ETG are the dominant microinstabilities in HSX, not ITG. Present optimization studies are focused on plasma flows and TEM stabilization.

¹This work was supported by DOE grant DE-FG02-93ER54622.
The design of a MSE polarimetry diagnostic for the measurement of radial electric fields on the HSX stellarator, T. DOBBINS, S.T.A. KUMAR, D.T. ANDERSON, F.S.B. ANDERSON, UW-Madison — HSX is a quasi-symmetric stellarator that is designed to reduce neoclassical transport. Neoclassical codes estimate a large positive radial electric field (40-50 kV/m) near the core of the HSX plasma. Impurity ion flow measurements could not resolve this large electric field. A single channel, dual PEM (Photo Elastic Modulators) MSE polarimetry diagnostic has therefore been designed for the HSX stellarator to directly measure the radial electric field near the core of the plasma. The design has been optimized to get a maximum change in polarization angle from a radial electric field with a good spatial resolution. A change in radial electric field as small as 1.5 kV/m can be detected with a careful selection of the sightline. The diagnostic design and initial characterization are presented.

Spectral MSE study on HSX and Non-Statistical Beam Level Populations, C. RUIZ, S.T.A. KUMAR, HSX Plasma Lab, Department of Electrical and Computer Engineering, UW-Madison, O. MARCHUCK, Forschungszentrum Juelich, GmbH, Germany, F.S.B. ANDERSON, D.T. ANDERSON, HSX Plasma Lab, Department of Electrical and Computer Engineering, UW-Madison — A spectral MSE diagnostic is investigated for measuring Er and B field in the plasma. This method relies on the spectral fitting of the Stark multiplet components and knowledge of the excited beam level populations. In some cases a statistical approach to the populations has been shown to deviate from experimental results. Here, we present a method for measuring Er and the B field components using two simultaneous views of the plasma without the knowledge of the beam level populations if the line emission from the Stark multiplet components is resolvable. However, this is not the case with a 30 keV diagnostic neutral beam and a 1 T magnetic field and knowledge of the beam level populations is required. In our experiment with line average densities ranging from $2 \times 10^{13}$ to $5 \times 10^{15}$ m$^{-3}$ the atomic levels are expected to be non-statistically populated. A systematic study is then performed and data is compared to collisional-radiative models which calculate the level populations for a specific set of experimental parameters of density and magnetic field. Spectra from H-alpha and H-beta line emissions are simultaneously measured and their ratio is taken and compared to the statistical and non-statistical case.

Core Density Turbulence in the HSX Stellarator, C.B. DENG, D.L. BROWER, University of California, Los Angeles, D.T. ANDERSON, F.S.B. ANDERSON, B. FABER, S.T.A. KUMAR, K.M. LIKIN, J.N. TALMADGE, University of Wisconsin-Madison — Density fluctuations are measured in the core of the HSX stellarator using a non-perturbing, multi-channel, interferometer system. Measurements show that broadband density fluctuations with $k_z < 2$ cm$^{-1}$, f = (20-200) kHz correlates with density gradient and plasma flow. The density fluctuation level is observed to decrease with increasing ECRH power as both the electron temperature, and its gradient, along with plasma flow increase. Electron temperature gradient is eliminated as drive for the observed turbulence. GENE simulations show that the density-gradient-driven TEM may be responsible for the observed density fluctuations. Low-frequency coherent modes are also observed in different magnetic configurations, mirror and QHS. The identifications of these coherent modes will be explored.

Neoclassical calculations of radial electric field and plasma flow in HSX beyond the monoenergetic assumption, J. SMONIEWSKI, J.N. TALMADGE, S.T.A. KUMAR, HSX Plasma Lab, University of Wisconsin, S. SATAKE, NIFS, M. LANDREMAN, University of Maryland — The radial electric field in the plasma core has been measured to be in the range of 2-5 kV/m during ECRH. The measured value is in good agreement with the ion root electric field calculated using the neoclassical code PENTA. However, PENTA also calculates that there should be a large electron root very close to the axis on the order of 30-50 kV/m. To date, no evidence of this electric field has been found. The PENTA code is a momentum conserving extension of the DKES code. The underlying DKES code makes a monoenergetic approximation which is known to break down when the electric field is near resonant values. We present electric field and plasma flow results from the SFINS and FORTEC-3D codes, neither of which make the monoenergetic assumption, to benchmark the PENTA calculations. SFINS is a drift-kinetic continuum code, and FORTEC-3D is a Monte Carlo code that also retains radial coupling. Initial results appear to show little difference between the three codes for HSX relevant parameters. In addition, we present recent results from bias probe experiments.

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This work was supported by DOE grant DE-FG02-93ER54222.

This work was supported by DOE grant DE-FG02-93ER54222.
UP8.00059 Measurement of Pfirsch-Schluter flows and radial electric field in the HSX Stellarator. T.A. KUMAR, F.S.B. ANDERSON, D.T. ANDERSON, J.N. TALMADGE, HSX Plasma Laboratory, UW-Madison — Inboard-outboard asymmetry in the toroidal C+6 ion flow has been measured using the Charge Exchange Recombination Spectroscopy in the HSX stellarator. Measurements indicate the presence of counter-streaming Pfirsch-Schluter (PS) ion flows. Experiments are done in 100 kW ECRH heated methane plasmas of line averaged density \( \sim 4 \times 10^{18}/m^3 \) and central electron temperature \( \sim 2 \text{ keV} \). Measurements are made for both the quasi-helically symmetric configuration and for the configuration where the symmetry is deliberately broken using auxiliary coils. It has been observed that the flows, both mean and the PS flows, are larger for the broken symmetry configuration compared to the helically symmetric configuration. The radial electric field, which is proportional to the magnitude of the PS flow, is larger than the previous measurements but still significantly less than the neoclassically calculated value.

1This work is supported by the US DOE.

UP8.00060 Exploration of improved neutral fueling and exhaust by a pumped limiter at the edge magnetic island chain of the HSX Stellarator. L. STEPHEY, A. BADER, S. KUMAR, O. SCHMITZ, D.T. ANDERSON, J.N. TALMADGE, F.S.B. ANDERSON, C. HEGNA, Univ of Wisconsin, Madison — A carbon limiter was introduced into the natural 8/7 magnetic island flux tube in the edge of HSX. Global H-alpha measurements suggest that this limiter can concentrate the neutral recycling. This limiter setup is similar to the local island divertor at LHD and is an important step on the way to equipping HSX with a localized neutral particle exhaust capability. The aim is to reduce the currently dominant fueling from wall recycling. Molecular dissociation and charge exchange contribute to a high neutral density in the core of HSX. With the recycling source concentrated at the limiter and the exhaust directly removed, fueling from designated gas sources will be significantly enhanced over the contribution from wall recycling. A sophisticated setup of suited spectroscopic diagnostics will be implemented to study the neutral fueling processes and how they are impacted by the limiter. Results from these exploratory steps from the initial observations with a test limiter will be presented. The initial results will also be compared to EMC3-EIRENE modeling. *Supported by DOE grant DE-FG02-93ER54222

UP8.00061 Simulated Stellarator Edge Behavior with Modified HSX Coils. A. BADER, L.A. STEPHEY, D.T. ANDERSON, UW - Madison, Y. FENG, IPP Greifswald, C.C. HEGNA, O. SCHMITZ, J.N. TALMADGE, UW - Madison — Predicting the edge behavior of a 3D device is a difficult but necessary requirement in the design of new fusion devices. In this poster we focus on prototypical stellarators generated through modifications to the HSX coils. We employ both helical coils to change the island size without altering the rotational transform, and divertor dipole coils to alter the internal structure of the islands. To determine the edge behavior of the designs we use simple metrics obtained through vacuum field-line following along with advanced simulation capabilities from the coupled codes EMC3-EIRENE. We show that strike point locations and concentrations can be altered with substantial changes to edge island sizes. Changes to the internal structure of the islands, producing alterations to flow structures and plasma density, but do not have a significant impact on strike point calculations or predicted heat flux. Results have implications on the role of islands in edges of stellarators and other 3D devices.

1Work supported by DOE-SC0006103.

UP8.00062 Overview of the HIT-SI3 experiment. D.A. SUTHERLAND, T.R. JARBOE, B.A. NELSON, B.S. VICTOR, A.C. HOSSACK, K.D. MORGEN, G.J. MARKLIN, C.H. HANSEN, T.K. FRYETT, University of Washington, HIT-SI RESEARCH TEAM — Operations have begun on the upgraded steady-inductive helicity injected torus experiment (HIT-SI3) at the University of Washington. This experiment uses three coplanar inductive helicity injectors to form and sustain a spheromak equilibrium. Toroidal currents of 40 kA have been obtained in helium plasmas with 6 MW of injector power. We seek to further the understanding and development of imposed-dynamo current drive (IDCD) and demonstrate current profile control and externally driven plasma rotation on HIT-SI3. Validated and verified MHD codes (NIMROD and PSI-TET) are being developed using HIT-SI3 as a validation platform. Dynamic neutrals are being added to PSI-TET in an effort to encapsulate their likely important role in HIT-SI3 that is not captured by either code presently. A two-photon absorption laser induced fluorescence (TALIF) system is being implemented to provide spatial neutral profile information that will be compared with PSI-TET. The digital-feedback control system for HIT-SI3 has been upgraded to three integrated Blackfin micro-controller boards per injector. Two boards drive the flux and voltage tank circuits, presently in a pre-programmed manner. The third board monitors the injector current and informs the voltage and flux boards of the presence of plasma, allowing a change in pulse-width duty cycle for the plasma load.

UP8.00063 Ion Dynamics in HIT-SI and HIT-SI3 with Comparisons to NIMROD and PSI-TET Simulations. A.C. HOSSACK, R.N. CHANDRA, K.D. MORGEN, C.H. HANSEN, T.R. JARBOE, B.A. NELSON, C. AKCAY, B.S. VICTOR, University of Washington, T. HANAO, M. NAGATA, University of Hyogo — The helicity injected torus with steady inductive current drive (HIT-SI) is a spheromak with 55 cm major radius and bow-tie cross section. Two inductive helicity injectors, on opposite sides of the confinement volume, form and sustain the spheromak plasma. A one meter focal length, ion Doppler spectrometer with a high speed video camera is used to simultaneously image light from chords across toroidal and poloidal sections of HIT-SI. C III emission data were collected at 145 kHz, ten times the helicity injector frequency, to resolve the dynamics of the injectors. Plasma motion and flows are shown to be predominately driven by the oscillating helicity injectors. Measurements are compared to synthetic diagnostics and velocity fields from 3D, extended-MHD NIMROD and PSI-TET simulations. Both codes evolve the Hall-MHD equations with dynamic pressure. Biorthogonal decomposition of measured and synthetic spectroscopy data is presented as a noise filtering and analysis technique. Additionally, initial results from HIT-SI3 are presented. Work supported by USDoE and ARRA.

UP8.00064 Advances in NIMROD Modeling of the HIT-SI Experiment. KYLE MORGAN, T.R. JARBOE, C. AKCAY, University of Washington — Previous two-fluid simulations of the HIT-SI experiment using the NIMROD code at low injector frequencies have served as a launching point for modeling of both pressure effects related to Steady Inductive Helicity Injection (SIHI) and the new HIT-SI3 injector configuration. Results from the end of HIT-SI operation have encouraged the inclusion of pressure effects in NIMROD modeling. Previous calculations using NIMROD assumed uniform temperature and density profiles, producing good agreement with low injector frequency operations \( (f_{inj} < \frac{vinj}{a}) \) but poor agreement at high injector frequencies \( (f_{inj} > \frac{vinj}{a}) \). Experimental observations at these higher frequencies give evidence of pressure driven activity, as well as a higher volume averaged \( \beta \). The full anisotropic Braginskii thermal conduction model has been applied in NIMROD calculations of HIT-SI and shows improvement in qualitative agreement at high injector frequencies, while maintaining results at low frequencies. In addition, modeling of the new 3-injector configuration of HIT-SI3 will serve as a source of validation of the model.
Up8.00065 Sustained spheromaks with ideal \(n = 1\) kink stability and pressure confinement. B.S. VICTOR, C. AKCAY, C.J. HANSEN, A.C. HOSSACK, T.R. JARBOE, K.D. MORGAN, B.A. NELSON, D.A. SUTHERLAND, University of Washington — Increasing the injector frequency up to 68.5 kHz on the HIT-SI experiment produced, for the first time, sustained spheromaks with pressure confinement and current gains of nearly 4. During sustainment only imposed \(n = 1\) activity is observed indicating \(n = 1\) kink stability at injector frequencies of 14.5, 36.8, 53.5 and 68.5 kHz. The injectors drive the edge of the plasma to a high \(\lambda = \mu_{oi}/B\) with a low \(\lambda\) region forming in the center. Imposed fluctuations cause the current penetration that maintains the kink-stable profile. A Shafranov shift is consistently seen at frequencies of 53.5 and 68.5 kHz, which is above the estimated sound transit frequency, \(v_1/a\) of HIT-SI. The PSI-TRI equilibrium solver is used to estimate the plasma pressure. In addition the magnetic profiles have improved toroidal symmetry at higher injector frequencies. Initial analysis of the density evolution and the internal magnetic fields of HIT-SI3 will also be presented.

1 Work supported by USDoE.

Up8.00066 An Imposed Dynamo Current Drive Experiment: Demonstration of Confinement. THOMAS JARBOE, CHRIS HANSEN, AARON HOSSACK, GEORGE MARKLIN, KYLE MORGAN, BRIAN NELSON, DEREK SUTHERLAND, BRIAN VICTOR, University of Washington — An experiment for studying and developing the efficient sustainment of a spheromak with sufficient confinement (current-drive power heats the plasma to its stability, \(\beta\)-limit) and in the keV temperature range is discussed. A high-\(\beta\) spheromak sustained by imposed dynamo current drive (IDCD) is justified because: previous transient experiments showed sufficient confinement in the keV range with no external toroidal field coil; recent results on HIT-SI show sustainment with sufficient confinement at low temperature; the potential of IDCD of solving other fusion issues; a very attractive reactor concept; and the general need for efficient current drive in magnetic fusion. The design of a 0.55 m minor radius machine with the required density control, wall loading, and neutral shielding for a 2 s pulse is presented. Peak temperatures of 1 keV and toroidal currents of 1.35 MA and 16% wall-normalized plasma beta are envisioned. The experiment is large enough to address the key issues yet small enough for rapid modification and for extended MHD modeling of startup and code validation.

Up8.00067 Plasma Control in Symmetric Mirror Machines. W. HORTON, W.L. ROWAN, University of Texas at Austin, IGOR ALVARADO, National Instruments, X.R. FU, Los Alamos National Laboratory, A.D. BEKLEMISHEV, Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia — Plasma confinement in the symmetric rotating mirror plasma at the Budker Institute shows enhanced confinement with high electron temperatures with end plates biasing. Improved confinement is achieved by biasing end plate cells in the expansion tanks so as to achieve an inward pointing radial electric field. The negative potential well produces vortex plasma rotation similar to that in the negative potential well of Ohmic heated tokamaks. This plasma state has similarity with the lower turbulence level regimes documented in the Helimak, Perez et al. PoP 2006. Vortex Confinement, A.D. Beklemishev, et al. 2010.

Up8.00068 Proto-CIRCUS tilted-coil tokamak-torsatron hybrid: design and construction. M. DOUMET, B.Y. ISRAELI, K.C. HAMMOND, R.M. SWEENEY, F.A. VOLPE, Columbia U., D.A. SPONG, ORNL, A.W. CLARK, USMA, Y. KORNBLUTH, Yeshiva U. — An innovative magnetic confinement concept is based on a toroidal configuration in which the toroidal field coils are tilted and interlinked with each other. Field line tracing and equilibrium calculations suggest that this configuration can generate rotational transform with lower plasma current and exhibit less effective magnetic ripple than tokamaks of comparable size. These properties may have interesting implications for disruptions and steady-state operation. Proto-CIRCUS is a tabletop device recently constructed at Columbia University to test this concept. It features six interlocked coils with independently adjustable radial positions and tilt angles. Plasma will have major and minor radii of approximately 16 cm and 5 cm, respectively. Start-up, heating and current drive will initially rely on 2.45 GHz electron cyclotron waves. Here we describe the design and construction of the device and present the results of numerical optimizations aimed at minimizing the required plasma current. Flux surface measurements will confirm whether this relatively simple concept can generate the expected rotational transform.

Up8.00069 ABSTRACT WITHDRAWN

Up8.00070 Simulation of Neutral Beam current drive in C2 FRC Plasmas. SANGEETA GUPTA, SEAN DETTRICK, DAN BARNES, TOSHIKI TAJIMA, ERIK TRASK, Tri Alpha Energy, TRI ALPHA ENERGY TEAM — Recently, improved high confinement regime is observed in C2 FRC plasma due to better wall conditions and higher formation magnetic field. In this regime, measured excluded flux increases in time and then decreases as the neutral beam coupling with FRC decreases. These plasmas were simulated using Quasi-1D (Q1D) plasma transport code using reduced parallel and perpendicular transport coefficients. In the simulations a reduced poloidal flux decay rate is observed in the presence of neutral beams. Numerical results showing comparison with experimentally observed excluded flux radius, line integrated electron density, electron and ion temperature will be presented.

Up8.00071 HEDP & ICF: HYDRO, SIMULATIONS & DIAGNOSTICS

Up8.00072 The corrugation instability of a piston-driven shock wave. JASON BATES, U.S. Naval Research Laboratory — We investigate the dynamics of a shock wave that is driven into an inviscid fluid by the steady motion of a two-dimensional planar piston with small corrugations on its surface. This problem was first considered by Freeman [Proc. Royal Soc. A. 228, 341 (1955)], who showed that piston-driven shocks are unconditionally stable when the medium through which they propagate is an ideal gas. Here, we generalize his work to account for a fluid with an arbitrary equation of state. We find that shocks are stable when \(-1 < h < h_c\), where \(h\) is the D'Yakov parameter and \(h_c\) is a critical value less than unity. For values of \(h\) within this range, linear perturbations imparted to the front at time \(t = 0\) attenuate asymptotically as \(t^{-3/2}\) or \(t^{-1/2}\). Outside of this range, they grow — at first quadratically and later linearly — with time. Such instabilities are associated with non-equilibrium fluid states and imply a non-unique solution to the hydrodynamic equations. These results may have important implications for driven shocks in laser-fusion and astrophysical environments. As a benchmark of this analysis, we compare our solution with one derived independently by Zaidel [J. Appl. Math. Mech. 24, 316 (1960)] for stable \(h\)-values and find excellent agreement.

1 This work was supported by DOE/NNSA.
Radiative shock experiments on LIL and Gekko

**UP8.00073 Radiative shock experiments on LIL and Gekko**

Michele Koenig, Roman Yurchak, Laboratoire LULI - CNRS, France, Claire Michaut, Patrice Barroso, LUTH, France, Emeric Falize, Alexis Casner, Stephane Laffite, Serge Bouquet, CEA DAM - DIF, France, Youichi Sakawa, ILE, Osaka, Japan, Taichi Morita, Kyushu University, Japan, Paul Drake, Department of Atmospheric, Oceanic, and Space Sciences, U. of Michigan, USA, Alexander Pelka, Helmholtz-Zentrum Dresden-Rossendorf, U. Dresden, Germany, Sébastien Lepape, LULI, USA —

For more than a decade, we have currently performed laboratory experiments in connection with astrophysical phenomena in order to improve our understanding in the field of radiation hydrodynamics so to validate numerical schemes and assumptions in simulations. Here, recent experimental results on high-momentum shock waves generated by high-power lasers such as Gekko (Japan) and LIL (laser integration line) are presented. Many visible diagnostics were implemented (interferometry, self-optical pyrometry, 2D snapshot imagers) providing measurements of the shock and precursor velocities, temperature, electronic density and 2D shock front shape. Results will be compared with 2D radiation hydrodynamic simulations.

Science on NIF Eagle Nebula

**UP8.00074 Science on NIF Eagle Nebula**

Jave Kane, David Martinez, Lawrence Livermore National Laboratory, Marc Pound, University of Maryland, Robert Heeter, Lawrence Livermore National Laboratory, Alexis Casner, CEA/DAM/Cesta, Bruno Villette, CEA, Roberto Mancini, University of Nevada —

For over fifteen years astronomers at the University of Maryland and scientists at LLNL have investigated the origin and dynamics of the famous Pillars of the Eagle Nebula and similar parsec-scale structures at the boundaries of HII regions in molecular hydrogen clouds. Eagle Nebula is one of the National Ignition Facility (NIF) Science programs, and has been awarded two days of NIF shots to study the cometary model of pillar formation. The NIF shots will feature a new long-duration x-ray source prototyped at the Omega EP laser, in which multiple hohlraums mimicking a cluster of stars are driven with UV light in series for 10 ns each to create a 30 ns output x-ray pulse. The drive generates deeply nonlinear hydrodynamics in the Eagle science package, which consists of a dense layer of plastic and foam core embedded in lower-density background foam. The scaled Omega EP shots validated the multi-hohlraum concept, showing that earlier time hohlraums do not degrade later time hohlraums by preheat or by ejecting ablated plumes that deflect the later beams. The Omega EP shots impacted three 2.8 mm long by 1.4 mm diameter Cu hohlraums with 4.3 kJ per hohlraum. At NIF each hohlraum will be 4 mm long by 3 mm in diameter and will be driven with 80–100 kJ.

Additions and Improvements to the FLASH Code for Simulating High Energy Density Physics Experiments

**UP8.00075 Additions and Improvements to the FLASH Code for Simulating High Energy Density Physics Experiments**

Donald Lamb, Christopher Daley, Anshu Dubey, Milad Fatenejad, Norbert Flocke, Carlo Graziani, Dongwook Lee, Petros Tzeferacou, Klaus Weide, Flash Center for Computational Science, University of Chicago —

FLASH is an open-source, finite-volume Eulerian, spatially adaptive, radiation hydrodynamics and magnetohydrodynamics code that incorporates capabilities for a broad range of physical processes, performs well on a wide range of computer architectures, and has a broad user base. Extensive capabilities have been added to FLASH to make it an open网贷 for the academic high energy density physics community. We summarize these capabilities, with particular emphasis on recent additions and improvements, and present the results of several verification tests. We also describe several collaborations with the National Laboratories and the academic community in which FLASH has been used to simulate high energy density physics experiments.

New Features of Radiation-Hydrodynamics Code HELIOS

**UP8.00076 New Features of Radiation-Hydrodynamics Code HELIOS**

Igor Golovkin, Joseph MacFarlane, Viktoriya Golovkina, Subodh Kulkarni, Prism Computational Sciences, Inc. —

HELIOS is a 1-D magneto-radiation-hydrodynamics code designed to study the hydrodynamic evolution of plasmas in planar, cylindrical, and spherical geometries. Applied energy sources include laser or particle beams, external radiation sources, or electrical currents (in cylindrical geometry). HELIOS-SE is an enhanced version of HELIOS which includes the option to simulate the dynamics of non-LTE plasmas using a self-consistent collisional-radiative (C-R) model. Radiation transport models include flux-limited diffusion and multi-angle short characteristics methods. We will discuss some features of HELIOS as well as recently developed angle-dependent radiation boundary conditions. Time-, angle-, and photon-energy-dependent radiation drive for this model can be computed with 3-D view factor code VISRAD.

VISRAD, 3-D Target Design and Radiation Simulation Code

**UP8.00077 VISRAD, 3-D Target Design and Radiation Simulation Code**

Viktoriya Golovkina, Joseph MacFarlane, Igor Golovkin, Subodh Kulkarni, Prism Computational Sciences, Inc. —

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, LMJ, Z, and PLX. 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 through 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 (e.g., that of any laser beam, target component, or diagnostic port). Analytic modeling for laser beam spatial profiles for OMEGA DPPs and NIF CPPs is used to compute laser intensity profiles. We will discuss some features of HELIOS as well as recently developed angle-dependent radiation boundary conditions. Time-, angle-, and photon-energy-dependent radiation drive for this model can be computed with 3-D view factor code VISRAD.

Integrating 3D Printing into Target Fabrication at the University of Michigan

**UP8.00078 Integrating 3D Printing into Target Fabrication at the University of Michigan**

Sallee Klein, Robb Gillespie, Michael Deiningier, Carlos Di Stefano, Mario Manuel, Wesley Wan, Carolyn Kuranz, Paul Keiter, Paul Drake, University of Michigan —

The integration of 3D printing into target fabrication has been a challenge. As target designs for high-energy-density experiments have become more complex, utilizing 3D printing is the natural progression, opening up the possibilities of very sophisticated, repeatable, yet inexpensive targets that require far less lead time than traditional means. At the University of Michigan we utilize the technique of machined acrylic bodies and mating components, to minimize target-to-target variability and assemble more reproducible targets. By combining 3D printing with traditional machining, we are able to take advantage of the very best part of both aspects of manufacturing. We present several recent campaigns to showcase and introduce our techniques and our integration of 3D printing, which has maintained our success of complex target designs with simple and inexpensive construction.

Non-Born-Oppenheimer Molecular Dynamics Method for Dense Plasmas

**UP8.00079 A Non-Born-Oppenheimer Molecular Dynamics Method for Dense Plasmas**

David Michta, Princeton Plasma Phys Lab, Lawrence Livermore National Lab, Liam Stanton, Mike Surh, Frank Graziani, Michael Murillo, Lawrence Livermore National Lab —

Warm Dense Matter, characterized by partially degenerate and moderately coupled electrons, is a regime realized in laser experiments, planetary interiors, and early stages of inertial confinement fusion. “Ab initio” molecular dynamics is an extremely accurate method built upon a Born-Oppenheimer (BO), plane-wave, pseudo-potential electronic structure calculation. However, these assumptions are not appropriate for several important problems in dense plasmas. We desire an electronic treatment that is both dynamical and quantum mechanical. Our approach combines ion MD with an electron fluid model based on orbital-free density functional theory (OF-DFT), which ensures high-quality equation of state. We discuss theoretical predictions of collective modes (electron plasma waves, ion-acoustic waves, etc.) and density fluctuations (dynamic structure factor, etc.). We have implemented fast, conservative numerical methods based on implicit time stepping and finite volume. We present this method using a region of high electron density. Results will be compared to reverse Monte Carlo simulations.

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Exploring the limits of the “SNB” multi-group diffusion nonlocal model. JONATHAN BRODICK, CHRISTOPHER RIDGERS, York Plasma Institute, Department of Physics, University of York, Heslington, York, YO10 5DD, UK, ROBERT KINGHAM, Plasma Physics Group, Room 724 Blackett Laboratory, Imperial College London, London SW7 2AZ, UK — A correct treatment of nonlocal transport in the presence of steep temperature gradients found in laser and inertial fusion plasmas has long been highly desirable over the use of an ad-hoc flux limiter. Therefore, an implementation of the “SNB” nonlocal model (G P Schurtz, P D Nicolai & M Busquet Phys. Plas. 7 4238 (2000)) has been benchmarked against a fully-implicit kinetic code: IMPACT. A variety of scenarios, including relaxation of temperature sinusoids and Gaussians in addition to continuous laser heating have been investigated. Results highlight the effect of neglecting electron inertia \( \frac{\partial \mathbf{j}}{\partial t} \) as well as question the feasibility of a nonlocal model that does not continuously track the evolution of the distribution function. Deviations from the Spitzer electric fields used in the model across steep gradients are also investigated. Regimes of validity for such a model are identified and discussed, and possible improvements to the model are suggested.

Discrete Diffusion Monte Carlo for Electron Thermal Transport. JEFFREY CHENHALL, DUC CAO, RYAN WOLLAEGER, GREGORY MOSES, University of Wisconsin, Madison — The iSNB (implicit Schurtz Nicolai Busquet) electron thermal transport method of Cao et al. is adapted to a Discrete Diffusion Monte Carlo (DDMC) solution method for eventual inclusion in a hybrid IMC-DDMC (Implicit Monte Carlo) method. The hybrid method will combine the efficiency of a diffusion method in short mean free path regions with the accuracy of a transport method in long mean free path regions. The Monte Carlo nature of the approach allows the algorithm to be massively parallelized. Work to date on the iSNB-DDMC method will be presented. This work was supported by Sandia National Laboratory - Albuquerque.

iFP: an optimal, fully conservative, fully implicit, 1D-2V Vlasov-Fokker-Planck solver for ICF capsule simulation. L. CHACON, W. TAITANO, A.N. SIMAKOV, D.A. KNOLL, LANL — ICF plasmas can become weakly collisional during the implosion process, with collisional mean-free-paths comparable to the system size. In this regime, kinetic phenomena become important, and a fully kinetic treatment is needed to assess their impact on compression and yield in ICF capsules. In this study, we present the first (to our knowledge) fully conservative (mass, momentum, and energy), fully nonlinearly implicit Vlasov-Rosenbluth-Fokker-Planck solver in 1D-2V. The approach achieves exact numerical conservation by nonlinearly enforcing the collision operator symmetries, and by enslaving numerical truncation errors. The approach features an adaptive scheme in velocity space that optimally resolves the distribution function locally, thus substantially decreasing the velocity space resolution requirements regardless of temperature disparity and variations. Solver-wise, the code relies on demonstrated Jacobian-free Newton-Krylov strategies. We will demonstrate the efficiency and accuracy properties of the scheme with several challenging 1D-2V and 1D-2V numerical examples.

Improved inline model for nonlocal electron transport in HYDRA. M.M. MARINAK, G.D. KERBEL, M.V. PATEL, H. ROBEY, Lawrence Livermore National Laboratory, C.P. RIDGERS, University of York, R.J. KINGHAM, Imperial College London — The nonlocal electron transport model in HYDRA has been improved in several respects. The original multigroup model has been extended to include the cascade in energy as particles slow down, yielding a more accurate range. The model was also extended to account for contributions to the energy loss rate due to bound electrons. These are among the important modifications that have enabled the package to simulate classes of suprathermal electrons. We show recent calculations using the model that suggest superthermal electrons could be having a significant effect on performance of cryogenic capsule implosions on the National Ignition Facility. We evaluate the nonlocal transport model’s accuracy by comparison with an electron VFP code. Comparisons assess the accuracy of the calculated thermal transport for plasmas relevant to NIF experiments.

Design process for applying the nonlocal thermal transport iSNB model to a Polar-Drive ICF simulation. DUC CAO, GREGORY MOSES, University of Wisconsin, Madison, JACQUES DELETTREZ, TIMOTHY COLLINS, University of Rochester Laboratory for Laser Energetics — A design process is presented for the nonlocal thermal transport iSNB (implicit Schurtz, Nicolai, and Busquet) model to provide reliable nonlocal thermal transport in polar-drive ICF simulations. Results from the iSNB model are known to be sensitive to changes in the SNB “mean free path” formula, and the latter’s original form required modification to obtain realistic preheat levels. In the presented design process, SNB mean free paths are first modified until the model can match temperatures from Goncharov’s thermal transport model in 1D temperature relaxation simulations. Afterwards the same mean free paths are tested in a 1D polar-drive surrogate simulation to match adiabats from Goncharov’s model. After passing the two previous steps, the model can then be run in a full 2D polar-drive simulation. This research is supported by the University of Rochester Laboratory for Laser Energetics.

Towards a Full Braginskii Formulation in HYDRA. JOSEPH KONING, LLNL — The magnetic field package in the ICF radiation transport simulation code HYDRA currently contains a resistive MHD solver and includes the dielectric pressure source term, anisotropic electron thermal conduction and magnetic field effects on alpha charged particle transport. This package has been improved with the addition of Nernst and Hall terms implemented using a discrete differential forms method. The Nernst magnetic term includes a limiting method for any large thermal or magnetic gradients. The Nernst thermal term results in a non-symmetric matrix solved using GMRES. The Hall term is discretized using methods based on constrained transport magnetic advection. All of the terms utilize discrete differential forms methods to maintain zero magnetic divergence exactly while properly treating the appropriate continuity of all vector field terms.

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UP8.00086 Radiation Hydrodynamic Parameter Study of Inertial Fusion Energy Reactor Chambers

RYAN SACKS, GREGORY MOSES, University of Wisconsin—Madison — Inertial fusion energy reactors present great promise for the future as they are capable of providing baseline power with no carbon footprint. Simulation work regarding the chamber response and first wall insult is performed with the 1-D radiation hydrodynamics code BUCKY. Simulation with differing chamber parameters are implemented to study the effect of gas fill, gas mixture and chamber radii. Xenon and argon gases are of particular interest as shielding for the first wall due to their high opacity values and ready availability. Mixing of the two gases is an attempt to engineer a gas cocktail to provide the maximum amount of shielding with the least amount of cost. A parameter study of different chamber radii shows a consistent relationship with that of first wall temperature ($\sim 1/r^2$) and overpressure ($\sim 1/r^3$). This work is performed under collaboration with Lawrence Livermore National Laboratory.

1 J.F. LATKOWSKI et al., Fusion Sci. Tech. 60, 54 (2011)
3 R. SACKS et al., Fusion Sci. Tech., publication pending.

UP8.00087 A Two-Dimensional Hydrocode to Study the Deceleration Phase and Hot-Spot Formation in Inertial Confinement Fusion Implosions

K.M. WOO, A. BOSE, R. BETTI, Laboratory for Laser Energetics and Fusion Science Center, U. of Rochester, J.A. DELETTREZ, K.S. ANDERSON, R. EPSTEIN, Laboratory for Laser Energetics, U. of Rochester — A hydrocode named RAGE was developed to study the final stage of an implosion starting from the coasting phase, including hot-spot formation and thermonuclear burn. Recently, a flux-limited multigroup diffusion approximation model has been added to study the transport of radiation energy in the deceleration phase of a spherical inertial confinement fusion target. Numerical results from the multigroup model indicate a good agreement with LILAC 1-D simulations. The code is used to study effects of radiation on the hotspot formation and distortion. Results from 2-D runs are presented and the effect of radiation transport on the deceleration-phase Rayleigh–Taylor instability is discussed. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0001344 and the Office of Fusion Energy Sciences Number DE-FG02-04ER54786.

UP8.00088 Simulations of Xenon Activation in Indirect Drive Exploding Pushers on NIF

SCOTT M. SEPKE, LAURA BERZAK HOPKINS, CHARLES CERJAN, MARTY MARINAK, Lawrence Livermore National Laboratory — The indirect drive exploding pusher (IDEP) has proven to be a robust and well understood platform for experiments at the National Ignition Facility. We investigate the effect of adding xenon dopant in different concentrations to the DT gaseous fuel in IDEP capsules at various fill densities of experimental relevance — 1.5–3 mg/cc — through integrated capsule-hohlraum simulations using HYDRA. The primary metrics used to evaluate the performance are changes in neutron shock flash time and bang time, neutron yield, and the neutron time of flight temperature. In addition, the new post-processing code KUDU is used to explore the nuclear activation of the xenon dopant for natural xenon as well as pure Xe-124 and Xe-134 using the new post-processing code KUDU: a multiprocess (MPI), multithreaded (POSIX threads), and accelerator capable (CUDA and OpenACC) rate equation solver developed at Lawrence Livermore National Laboratory for radiochemistry modeling.

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UP8.00089 Multispecies plasma transport issues in ICF

ERIK VOLD, KIM MOLVIG, ARCHIS JOGLEKAR, MARIO ORTEGA, Los Alamos Natl Lab — In recent years there has been a renewed interest in plasma transport, both at the kinetic level and in multi-species fluid approximations, to better understand observed degradation in ICF performance. Analysis and numerical computations of multispecies fluid approximations examine the scales of plasma viscosity and species mass flux driven by gradients in composition, ion and electron pressure (barodiffusion) and temperature (Soret effect). The mix layer between plasma species and the pressure and temperature gradient coefficients are sensitive to the choice of composition as a molar or mass fraction, and implications are examined. A central focus here is to compare the coefficients of the gradient force terms determined from a rigorous kinetic derivation (Molvig, et.al., 2014) to other forms derived for the transport coefficients. The particle velocity dependence of the Coulomb collisions determines species friction drag and thus limits the species drift flux, leading to a dependence of the diffusion coefficient on the averaged particle mass through the mix layer profile, unlike that in molecular diffusion. This factor combined with the barodiffusion and kinetic coefficients determines a highly asymmetric mix layer profile shape between low z and high z plasma components near total pressure and temperature equilibrium. The temperature gradient can act to inhibit or increase the species mass flux and examples relevant to ICF are given. Plasma viscosity in the momentum equation is shown to significantly modify a 1D ICF convergence trajectory and reduces maximum temperature, while accounting for viscous dissipation of the energy.

UP8.00090 Kinetic Effects at Material Interfaces in ICF Implosions

S.C. WILKS, W. CABOT, H. WHITLEY, J. GREENOUGH, B.I. COHEN, J. BELOF, G. ZIMMERMAN, P.A. AMENDT, S. LEPAPE, L. DIVOL, A. DIMITS, F. GRAZIANI, LLNL, K. MOLVIG, E. ORTEGA, LANL, C.K. LI, R. PETRASSO, MIT, S. LAFFITE, O. LARROCHE, M. CASANOVA, L. MASSE, CEA — The mixing of materials at an interface (ID) is a well-known problem in inertial confinement fusion (ICF) because the mixing is a complex process with anisotropic effects. This work describes the effects of mixing on ICF performance, for example the DT - Carbon interface in an ICF capsule, which is a complex process. In general, rad-hydro codes do an excellent job of modeling the important processes during an ICF implosion. However, there are certain times during the implosion when kinetic effects of the ions may play a role in how two materials mix across the interface between them, even in the absence of shocks moving through them. The Knudsen layer effect is one such example. We will describe results of multi-ion species hybrid LSP simulations where the ions are treated kinetically and the electrons are treated as a fluid. We observe that the DT and carbon ions diffuse across the interface in a self-similar manner, at a rate proportional to the square root of time, in agreement with diffusion theory. The resulting ion distributions for each species (on both sides of the interface) will be presented, and the result of this mixing on the yield will be discussed for ICF capsules. Preliminary results of a related mixing that occurs at the gas-hohlraum wall interface will also be presented.

1 K. Molvig. et al., PRL, 109, 095001 (2012)

UP8.00091 Validation of a Laser-Ray Package in an Eulerian Code

PAUL BRADLEY, MIKE HALL, Los Alamos National Laboratory, PATRICK MCKENTY, TIM COLLINS, DAVID KELLER, Laboratory for Laser Energetics, University of Rochester — A laser-ray absorption package was recently installed in the RAGE code by the Laboratory for Laser Energetics (LLE). In this presentation, we describe our use of this package to implode Omega 60 beam symmetric direct drive capsules. The capsules have outer diameters of about 860 microns, CH plastic shell thicknesses between 8 and 32 microns, DD or DT gas fills between 5 and 20 atmospheres, and a 1 ns square pulse of 23 to 27 kJ. These capsule implosions were previously modeled with a calibrated energy source in the outer layer of the capsule, where we matched bang time and burn ion temperature well, but the simulated yields were two to three times higher than the data. We will run simulations with laser ray energy deposition to the experiments and the results to the yield and spectroscopic data. Work performed by Los Alamos National Laboratory under contract DE-AC52-06NA25396 for the National Nuclear Security Administration of the U.S. Department of Energy.

1 Performed under auspices of U.S. DOE by LLNL, contract DE-AC52-07NA27344. LLNS, LLC.
UP8.00092 Computational Simulations of Radiation Driven Low – Convergence NIF Capsules1 , ROBERT PETERSON, RICHARD OLSON, JOHN KLINE, Los Alamos National Laboratory, STEPHAN MACLAREN, JAY SALMONSON, Lawrence Livermore National Laboratory — Experiments are planned on the NIF laser at Lawrence Livermore National Laboratory, in which capsules with thick CH ablator will be imploded with x-rays produced in vacuum or near vacuum hohlraums. These capsules are expected to implode to convergence ratios of 13 to 37 and will serve as a test of the ability of simulation codes to agree with experimental measurements in the regime. The convergence ratio will be adjustable by modifying the DT gas density. The CH ablator going to be thick enough that we believe that the predominant instabilities on the ablator/gas surface will be Richtmyer-Meshkov. The Rayleigh-Taylor instabilities generated on the surface of the ablator should not penetrate the ablator. This presentation will show 2-D computer code simulations of these experiments and will show how the neutron yield varies with the asymmetry of the radiation drive. The drive symmetry in the experiments will be controlled by the laser. The experimental neutron yields will be compared with the 2-D simulation results, once the experiments take place.

1This work was performed under the auspices of the U. S. DOE by LANL under contract DE-AC52-06NA25396, and by LLNL under contract DE-AC52-07NA27344.

UP8.00093 Analysis of results from high-foot NIF ignition capsules1 , T. R. DITTRICH, J. D. SALMONSON, P. A. AMENDT, I. F. BERZAK HOPKINS, D. A. CALLAHAN, D. E. HINKEL, O. A. HURRICANE, T. MA, A. E. PAK, H. S. PARK, G. B. ZIMMERMAN, Lawrence Livermore National Laboratory, G. A. KYRALA, Los Alamos National Laboratory, M. J. ROSENBERG, H. G. RINDERKNECHT, Massachusetts Institute of Technology — Encouraging results have been obtained using a strong first shock during the implosion of carbon-based ablator ignition capsules. These “high-foot” implosion results show that capsule performance degrades from 1D expectations as laser power and energy are increased. Possible causes of this deviation include disruption of the hot spot by jets originating in the capsule fill tube and kinetic effects in the fuel. Results of simulations investigating these effects will be presented.

1This 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

UP8.00094 Investigation of Inter-Ion Species Diffusion in Inertial Confinement Fusion Implosions1 , HANS W. HERRMANN, YONGHO KIM, NELSON M. HOFFMAN, MARK J. SCHMITT, GRIGORY KAGAN, STEVEN H. BATHA, Los Alamos Natl Lab, WARREN J. GARBETT, COLIN J. HORSFIELD, MICHAEL S. RUBERY, STEVEN GALES, AWE — Anomalous fusion yield degradation has been observed for gas fill mixtures in inertial confinement fusion (ICF) implosions. These mixtures have included D/3He [Rygg, et al., Phys Plasmas, 13, 052702 (2006)], D/T/3He [Herrmann, et al., Phys Plasmas, 16, 056312 (2009)], D/Ar [Lindl, et al., Phys Plasmas, 11, 339-491 (2004)] and even D/T [Casey, et al., PRL 108, 075005 (2012)]. Fuel ion segregation has been suggested as a possible cause [Amendt, et al., PRL 18, 056308 (2011); Kagan, et al., Phys Let A 10.1016 (2014)]. Segregation may be caused by inter-ion species diffusion driven by gradients in plasma pressure, temperature and electric field, either across a relatively narrow shock boundary or across the entire interior of the compressed capsule. It is expected that lower Z &/or A ions will diffuse outward while higher Z &/or A diffuse inward. In the case of D/T/3He, the 3He diffuses inward to the hotter core, reducing the DT reactivity. A D/T/H mixture should result in H diffusing outward, leaving the hotter core D & T rich and hence enhance reactivity over the simulated expectation. Past results will be reviewed and plans for a hydro-equivalent comparison D/T/3He and D/T/H will be presented.

1Research conducted under the auspices of the U.S. Department of Energy under contract DE-AC52-06NA25396

UP8.00095 Calculations for Indirectly Driven Be capsule Implosion Experiments at Omega1 , GEORGE KYRALA, JOHN KLINE, ELIZABETH MERRITT, Los Alamos National Laboratory — Beryllium (Be) ablator offer an attractive path to ignition on the National Ignition Facility (NIF). They offer better ablation rate, higher efficiency, and higher ablation velocity than the currently used CH or Diamond capsules. We have designed a capsule of Be for implosions at Omega to test our understanding of Be implosions in the foot of the anticipated NIF pulse, ∼ 100-110 eV for a period of 1 -2 ns drive. We calculated the emission profile, diameter, and implosion time. We will present a comparison to the completed experiments using either Be or CH ablator. We also will provide calculations of the effect of adding different amounts of an Argon dopant on the expected x-ray yield and emission shapes.

1This work is supported by the US DOE.

UP8.00096 Transport implications of hydrodynamic mix on hot-spot performance in inertial confinement fusion . BHUVANA SRINIVASAN, Virginia Tech and Los Alamos National Laboratory, XIANZHU TANG, Los Alamos National Laboratory — In an inertial confinement fusion target, energy loss due to thermal conduction from the hot-spot will inevitably ablate fuel ice into the hot-spot, resulting in a more massive but cooler hot-spot, which negatively impacts fusion yield. Hydrodynamic mix due to the Rayleigh-Taylor instability at the gas-ice interface can aggravate the problem via an increased gas-ice interfacial area across which energy transfer from the hot-spot and ice can be enhanced. We quantify this mix-enhanced transport effect on hot-spot fusion-performance degradation using contrasting 1-D and 2-D hydrodynamic simulations, and identify its dependence on effective acceleration, Atwood number, and ablation speed. In the presence of magnetic fields, the thermal conduction is reduced which reduces the effect of ablative stabilization on mix mitigation while also reducing the amount of cold fuel being ablated into the hot-spot. A characterization of the transport enhanced mix characteristics with and without magnetic fields is performed to identify a regime where fusion-performance degradation is reduced by mix mitigation, through which the amount of cold fuel being ablated into the hot-spot is minimized.

UP8.00097 Perturbation theory and numerical modelling of weakly and moderately nonlinear incompressible Richtmyer-Meshkov instability . M. HERRMANN, Arizona State University, A.L. VELIKOVICH1 , Plasma Physics Division, Naval Research Laboratory, S.I. ABARZHI, Carnegie Mellon University — A study of incompressible two-dimensional Richtmyer–Meshkov instability by means of high-order Eulerian perturbation theory and numerical simulations is reported. Nonlinear corrections to Richtmyer’s impulsive formula for the bubble and spike growth rates have been calculated analytically for arbitrary Atwood number and an explicit formula has been obtained for it in the Boussinesq limit. Conditions for early-time acceleration and deceleration of the bubble and spike have been derived. In our simulations we have solved 2D unsteady Navier-Stokes equations for immiscible incompressible fluids using the finite volume fractional step flow solver NGA developed by Desjardins et al. J. Comput. Phys. 227, 7125 (2008), coupled to the level set based interface solver LIT, Herrmann, J. Comput. Phys. 227, 2674 (2008). The impact of small amounts of viscosity and surface tension on the RMI flow dynamics is studied numerically. Simulation results are compared to the theory to demonstrate successful code verification and highlight the influence of the theory’s ideal inviscid flow assumption. Theoretical time histories of the interface curvature at the bubble and spike tip and the profiles of vertical and horizontal velocities have been favorably compared to simulation results, which converge to the theoretical predictions as the Reynolds and Weber numbers are increased.

1Work supported by the US DOE/NNSA.
UP8.00098 Mitigation of initial imprinting with diamond ablator, HIROKI KATO, KEISUKE SHIGEMORI, YOUICHIRO HIRONAKA, ILE Osaka Univ, HIDENORI Terasaki, TATSUHIRO SAKAIYA, RYOUTA HOSOGI, Osaka University Graduate School of Science, MITSUO NAKAI, HIROSHI AZECHI, ILE Osaka Univ — In direct drive inertial confinement fusion, where laser light directly irradiates the target, surface perturbations on the target are seeded by initial imprint due to laser irradiation nonuniformity. It is the initial imprint that become the seed of the hydrodynamic instability, and decisive solutions for the mitigation of initial imprinting is required. We focused on material stiffness of ablator as an idea that was effective for the mitigation of imprinting and adapted the diamond with low compressibility as an ablator material. In the imprint experiments, the diamond foils were irradiated with a foot pulse at an intensity of $\sim 4.0 \times 10^{12} \text{W/cm}^2$ with 1.3 ns width, on which a stationary spatial nonuniformity with sinusoidal shape of $100 \mu$m wavelength was imposed by implementing a grid mask. The foils were subsequently accelerated by a uniform main laser pulse of $\sim 1.0 \times 10^{14} \text{W/cm}^2$ and imprinted perturbation were observed to be amplified by Rayleigh-Taylor instability through face-on x-ray backlighting measurements. We deduced the equivalent initial surface roughness for the imprinted foil. We verified the mitigation of initial imprinting with diamond from the quantitative evaluation.

UP8.00099 A New Theory of Mix in Omega Capsule Implosions1, DANA KNOLL, LUIS CHACON, RICK RAUENZAHN, ANDREI SIMAKOV, WILLIAM TAITANO, LESLIE WELSER-SHERRILL, LANL — We put forth a new mix model that relies on the development of a charge-separation electrostatic double-layer at the fuel-pusher interface early in the implosion of an Omega plastic ablator capsule. The model predicts a sizable pusher mix (several atom %) into the fuel. The expected magnitude of the double-layer field is consistent with recent radial electric field measurements in Omega plastic ablator implosions. Our theory relies on two distinct physics mechanisms. First, and prior to shock breakout, the formation of a double layer at the fuel-pusher interface due to fast preheat-driven ionization. The double-layer electric field structure accelerates pusher ions fairly deep into the fuel. Second, after the double-layer mix has occurred, the inward-directed fuel velocity and temperature gradients behind the converging shock transports these pusher ions inward. We first discuss the foundations of this new mix theory. Next, we discuss our interpretation of the radial electric field measurements on Omega implosions. Then we discuss the second mechanism that is responsible for transporting the pusher material, already mixed via the double-layer deep into the fuel, on the shock convergence time scale. Finally we make a connection to recent mix motivated experimental data on

1This work conducted under the auspices of the National Nuclear Security Administration of the U.S. Department of Energy at Los Alamos National Laboratory, managed by LANS, LLC under contract DE-AC52-06NA25396

UP8.00100 Numerical Investigation of a New Electrostatic Double-Layer Driven Kinetic Mix Mechanism for an Omega Plastic Ablator Capsule, WILLIAM TAITANO, DANA KNOLL, LUIS CHACON, ANDREI SIMAKOV, Los Alamos National Laboratory — The primary mix mechanisms considered so far by the ICF community are hydrodynamic processes such as Rayleigh-Taylor and Richtmyer-Meshkov instabilities. However, recent experiments on the Omega facility indicate that mix is happening both deeper and earlier than what the hydrodynamic models predict [1]. Additionally, there have been observations of a strong electric field within the ICF capsule on the Omega facility that cannot be explained by quasi-neutral fluid theory alone. A recent theoretical study of a new kinetic mix mechanism for an Omega plastic ablator capsule, based on an electrostatic double-layer field at the fuel-pusher interface has predicted a mix amount and electric field strength that are consistent with some experiments [2]. We have pursued a careful computational study to further refine and expand these theoretical results. We seek to obtain better estimates of the strength of the double-layer electric field and its effect on mix in an Omega plastic ablator capsule. We show numerically the existence of the postulated double-layer electric field, and quantify its impact on mix. We also show preliminary result of mix on an Omega plastic ablator capsule with titanium tracer.


UP8.00101 Implosion spectroscopy in Rugby hohlraums on OMEGA, FRANCK PHILIPPE, VERONIQUE TASSIN, LAURENT BITAUD, PATRICIA SEYTOR, CHARLES REVERDIN, CEA, DAM, DIF, F-91297 Arpajon, France — The rugby hohlraum concept has been validated in previous experiments on the Omega laser facility. This new hohlraum type can now be used as a well-characterized experimental platform to study indirect drive implosion, at higher radiation temperatures than would be feasible at this scale with classical cylindrical hohlraums. Recent experiments have focused on the late stages of implosion and hotspot behavior. The capsules included both a thin buried Titanium tracer layer, 0-3 microns from the inner surface, Argon dopant in the deuterium gas fuel and Germanium doped CH shells, providing a variety of spectral signatures of the plasma conditions in different parts of the target. X-ray spectroscopy and imaging were used to study compression, Rayleigh-Taylor instabilities growth at the inner surface and mix between the shell and gas.

UP8.00102 Proving diamonds under ultra-high pressure with sound velocity measurements, KEISUKE SHIGEMORI, ILE Osaka Univ, KATSUYA SHIMIZU, YASUHIRO ASAKURA, KYOKUGEN, Osaka Univ., TATSUHIRO SAKAIYA, TADASHI KONDO, GSS, Osaka Univ., YOICHIRO HIRONAKA, ILE, Osaka Univ. TETSUO IRIFUNE, GRC, Ehime Univ., HITOSHI SUMIYA, Sumitomo Electric Industries, TOSHIHIKO KADONO, HIROSHI AZECHI, ILE Osaka Univ — Diamond under terapascal (TPa) regime is of great interest on its phase transition to a post diamond phase. Many experimental works have been done on the diamond at the TPa regime by measuring the shock parameters (shock velocity, particle velocity). We measured sound velocities of shock-compressed diamond under several pressures by means of x-ray backlighting technique. Experiments were done on GEKKO-HIPER laser irradiation facility at Institute of Laser Engineering, Osaka University. We obtained sound velocities at a pressure of 0.4 - 2.0 TPa by changing the laser intensity. The experimental sound velocity suggests that a clear discontinuity at around 0.7 TPa where the melting of the diamond starts. The sound velocity drops then slightly increases with increasing pressure. The slope of the speed over 1 TPa is lower than that under 0.7 TPa, indicating the melting of the diamond.

UP8.00103 Surface current density distribution measurements of an electrically exploded foil via B-dot probe array data inversion1, E.L. RUDEN, D.J. AMDAHL, R.H. COOKSEY, P.R. ROBINSON, Air Force Research Laboratory, Directed Energy Directorate, F.T. ANALLA, D.J. BROWN, M.R. KOSTORA, Leidos, Inc., J.F. CAMACHO, NumerEx, LLC — Measurements are presented of the current per unit length as a function of the transverse distance from the center of a water-tamped 80 $\mu$m Al foil that narrows to a central width of 15.2 cm as it explodes into warm dense matter by Ohmic heating. Current is delivered by the discharge of a 36 $\mu$F capacitor bank charged to 30 kV and discharged to a peak current of 342 kA in 2.0 $\mu$s. The distribution is calculated by the linear regularized inversion of signals from an array of B-dot probes distributed along the foil’s central half-width. The probes are far enough away from the foil (1 cm) be noninvasive and mechanically undisturbed during the time of interest. These results are compared to 3-D MHD ALEGRA simulations of the geometry driven by an external coupled two-loop lumped circuit model which accurately represents the driver. The goal of the effort is to test, in conjunction with other diagnostics, ab initio models of the equation of state and electrical conductivity of matter under conditions encountered in single-shot pulsed power devices (1 - 10 eV and 0.1 - 1 $\times$ solid density).

1This work was supported by AFOSR LRIR 11RD02COR.
UP8.00104 Spectroscopic Analysis and Thomson Scattering Diagnostics of Wire Produced Plasma

CHRISTOPHER PLECHATY, Riverside Research, Beavercreek, OH 45431, VLADIMIR SOTNIKOV, Air Force Research Laboratory, Wright Patterson AFB, OH 45433, DANIEL MAIN, Riverside Research, Beavercreek, OH 45431, JAMES CAPLINGER, S4 Inc., Fairborn, OH 45324, AUSTIN WALLERSTEIN, TONY KIM, Air Force Research Laboratory, Wright Patterson AFB, OH 45431 — The Lower Hybrid Drift Instability (LHDI) in plasma is driven by the presence of inhomogeneities in density, temperature, or magnetic field (Krall 1971, Davidson 1977), and occurs in systems where the electrons are magnetized and the ions are effectively unmagnetized. The LHDI is thought to occur in magnetic reconnection (Huba 1977), and has also been investigated as a mitigation technique which can allow for communications to take place through the plasma formed around hypersonic aircraft (Sotnikov 2010). To further understand the phenomenology of the LHDI, we plan to carry out experiments at the Air Force Research Laboratory, in the newly formed Plasma Physics Sensors Laboratory. In experiment, a pulsed power generator is employed to produce plasma by passing current through single, or dual-wire configurations. To characterize the plasma, a Thomson scattering diagnostic is employed, along with a visible spectroscopy diagnostic. Huba, J. D., et al., grl, 4, 125-128 (1977). Davidson, R. C., et al., Phys. of Fluids 20, 301-310 (1977). Krall, N., Phys. Rev. A 4, 2094 (1971). Sotnikov, V. I., AGU Fall Meeting Abstracts. Vol. 1. 1

1This work was performed under the auspices of the U.S. Department of Defense by Riverside Research under Contract BAA-FAR650-13-C-1539.

UP8.00105 Characterization of Turbulent Non-Uniform Exploding Wire Plasma Using High Resolution Interferometry, Schlieren and Shadowography Imaging

J. CAPLINGER, S4 Inc, Fairborn, OH 45432, G. SARKISOV, Raytheon Ktech, Albuquerque, NM 87123, A.J. WALLERSTEIN, V. SOTNIKOV, Air Force Research Laboratory, Wright Patterson AFB, OH 45433, J. LUNDBERG, Z. REED, Riverside Research, Beavercreek, OH 45432 — High resolution interferogram, Schlieren, and shadowgraph imaging has been used to characterize an exploding wire plasma. Using an 80 kV high voltage pulse generator with a rise time of 5 ns, exploding wire plasmas are created in aluminum, gold, tin, stainless steel, platinum and silver wires. The plasma is probed over a period of 3-7 ns using a 532 nm frequency doubled Nd:YAG Q-switched laser. The resulting laser radiation is imaged as an interferogram using an air-wedge interferometer, a shadowgraph and as a Schlieren image using two CCDs. Calculations resulting from the interferograms reveal ionizations between 10-20% for Aluminum wires at atmospheric pressure. This is confirmed by the Schlieren images as the refraction caused by neutrals is dominant. Single wire, two parallel wires, and other two wire configurations are investigated. Additionally, influence of chamber pressure on plasma uniformity, shock wave propagation velocity and instabilities is presented.

1Work supported by the Air Force Research Laboratory.

UP8.00106 Electron density and effective atomic number (Zeff) determination through x-ray Moiré deflectometry

MARIA PIA VALDIVIA LEIVA, DAN STUPTMAN, MICHAEL FINKENTHAL, JHU — Talbot-Lau based Moiré deflectometry is a powerful density diagnostic capable of delivering refraction information and attenuation from a single image, through the accurate detection of X-ray phase-shift and intensity. The technique is able to accurately measure both the real part of the index of refraction δ (directly related to electron density) and the attenuation coefficient μ of an object placed in the x-ray beam. Since the atomic number Z (or Zeff for a composite sample) is proportional to these quantities, an elemental map of the effective atomic number can be obtained with the ratio of the phase and the absorption image. The determination of Zeff from refraction and attenuation measurements with Moiré deflectometry could be of high interest in various fields of HED research such as shocked materials and ICF experiments as Zeff is linked, by definition, to the x-ray absorption properties of a specific material.

1This work is supported by U.S. DoE/NNSA Grant No. 435 DENA0001835

UP8.00107 Characterization of spatially resolved high resolution x-ray spectrometers for HEDP and light-source experiments

K.W. HILL, M. BITTER, L. DELGADO-APARICIO, P. EFTHIMION, N. PABLANT, Princeton Plasma Physics Laboratory, J. LU, Chongqing University, China, P. BEIERSDORFER, H. CHEN, E. MAGEE, Lawrence Livermore National Laboratory — A high resolution 1D imaging x-ray spectrometer concept comprising a spherically bent crystal and a 2D pixelated detector is being optimized for diagnostics of small sources such as high energy density physics (HEDP) and synchrotron x-ray or x-ray free electron laser experiments. This instrument is used on tokamak experiments for measurement of spatial profiles of Doppler ion temperature and plasma flow velocity, as well as electron temperature. Laboratory measurements demonstrate a resolving power E/ΔE of 10,000 and spatial resolution better than 10 μm. Good performance is obtained for Bragg angles ranging from 23 to 63 degrees. Initial tests of the instrument on HEDP plasmas are being performed with a goal of developing spatially resolved ion and electron temperature diagnostics.

1This work was performed under the auspices of the US DOE by PPPL under contract DE-AC02-09CH11466 and by LLNL under contract DE-AC52-07NA27344.

UP8.00108 Measurements of X-ray spectra from irradiated gold foils at the OMEGA Laser facility

JOSHUA DAVIS, PAUL KEITER, PAUL DRAKE, SALLEE KLEIN, JEFF FEIN, University of Michigan — In many HED systems high intensity x-rays can be used to measure plasma properties such as density and temperature. At the OMEGA laser facility, these X-rays are produced by irradiating a metal foil with high-intensity lasers, which heats the foil and causes it to act as a quasi-continuum x-ray source for radiography or absorption spectroscopy. As this emission is quasi-continuous and the transmission of x-rays through a material varies with photon energy a well-characterized x-ray source is vital. Therefore, in order to optimize diagnostics reliant upon x-rays it is necessary to gain a better understanding of how the x-ray emission from these targets varies over time and varying beam energy. We will present experimental results studying the effect that beam energy and pulse length have on M-band and sub-keV x-ray emission generated from a 2μm thick gold disk using time-resolved spectroscopy and a Henway crystal spectrometer. 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-NA0001840, and through the Laboratory for Laser Energetics, University of Rochester by the NNSA/OICF under Cooperative Agreement No. DE-FC52-08NA28302.

UP8.00109 Calibration of the LLNL Imaging Proton Spectrometer

A.M. RASMUS, M.J.-E. MANUEL, C.C. KURANZ, S. KLEIN, P.X. BELANCOURT, J.R. FEIN, M.J. MACDONALD, R.P. DRAKE, University of Michigan — Ann Arbor, A.U. HAZI, B.B. POLLOCK, J. PARK, G.J. WILLIAMS, H. CHEN, LLNL — Ultra intense short pulse lasers incident on solid targets (e.g. Au foil) produce well collimated, broadband proton beams. These proton beams can be used to characterize magnetic fields in high-energy-density systems. The Imaging Proton Spectrometer (IPS) was previously designed and built (H. Chen 2010, RSI) for use with such laser produced proton beams. The IPS has an energy range of 50keV-40MeV with a resolving power (E/ΔE) of about 250 at 0.5 MeV and 350 at 2 MeV, as well as a single spatial imaging direction. In order to better characterize the imaging capability of this diagnostic, a 3D FEA solver has been used to calculate the magnetic field of the IPS. Particle trajectories are then obtained via numerical integration to calculate the imaging axis of the IPS. Experiments using alpha sources will be used to verify the calculated calibration. This work is funded by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, grant number DE-NA0001840. Work by LLNL was performed under the auspices of U.S. DOE under contract DE-AC52-07NA27344.
UP8.00110 Characterization of argon cluster targets in high-density, continuous gas jets

DONGGYU JANG, University of Maryland, College Park & Gwangju Institute of Science and Technology, YONG SING YOU, YAN TAY, LUKE HAHN, HOWARD MILCHBERG, University of Maryland, College Park, HYEONG SUK, Gwangju Institute of Science and Technology, KI-YONG KIM, University of Maryland, College Park — We have developed a simple all-optical method for characterizing the average cluster size, number of clusters per unit volume (density), and mass fraction of clusters in gas jets. In this technique, we combine three optical diagnostics—forward/backward Mie scattering detection, 90 degree scattering imaging, and neutral gas interferometry. We also demonstrate its use in characterizing a continuous gas jet. In particular, we have investigated the spatial variation of cluster parameters for continuous cluster jets produced by cryogenic cooling. This technique, in principle, can serve as an in-situ diagnostic for characterizing cluster jets prior to injecting high-intensity laser pulses for driving intense laser-cluster interactions. In particular, our cryogenically-cooled, continuous cluster source can produce relatively large clusters (≈70 nm), favorable in many laser-cluster experiments including plasma waveguide generation, with a moderate clustering ratio (≈20%). Such a cluster source can be used as a potential target for intense, high-repetition-rate (>kHz) laser pulses.

UP8.00111 Preliminary results of equation of state measurements using imaging x-ray Thomson spectrometer

PATTERSON BELANCOURT, University of Michigan, WOLFGANG THEOBALD, Laboratory for Laser Energetics, PAUL KEITER, University of Michigan, TIMOTHY COLLINS, MARK BONINO, Laboratory for Laser Energetics, PAWEL KOZLOWSKI, University of Oxford, PAUL DRAKE, University of Michigan, UNIVERSITY OF MICHIGAN TEAM, LABORATORY FOR LASER ENERGETICS TEAM, UNIVERSITY OF OXFORD TEAM — Understanding the equation of state of materials under shocked conditions is important for laboratory astrophysics and high-energy-density physics experiments. The goal of the experiments discussed here is to create a platform for equation of state measurements in shocked foams on Omega EP. The target of interest for these experiments is shocked carbonized resorcinol formaldehyde foam with an initial density of 0.34 g/cc. Lasers irradiate an ablator, driving a shock into the foam. Conditions prior to the shock are at 10 Gbar and 2000 K. The shock is diagnosed using x-ray Thomson scattering spectroscopy (XRTS). The XRTS is a spatially resolved x-ray beam while imaging in one spatial dimension. Preliminary results from these experiments will be shown. This work is funded by the U.S. Department of Energy, through the NNSA-DS and SC-OES Joint Program in High-Energy-Density Laboratory Plasmas, grant number DE-NA0001840, and the National Laser User Facility Program, grant number DE-NA0000850, and through the Laboratory for Laser Energetics, University of Rochester by the NNSA/OICF under Cooperative Agreement No. DE-FC52-08NA28302.

UP8.00112 Level shifting in intense KrF laser-xenon cluster interactions

KENNETH WHITNEY, Berkeley Research Associates, JACK DAVIS, TZVETELINA PETROVA, Naval Research Laboratory — A variety of experiments were carried out in which gases composed of xenon clusters were irradiated with 230 fs pulses of 248 nm wavelength laser radiation at intensities, 10^{19} W/cm^{2}. At these intensities, the laser pulses self-focused and amplified x-ray emissions occurred in the plasma channels that were formed. A significant feature of these emissions was the irreproducibility of their wavelengths, i.e., amplification was seen at wavelengths of 2.71, 2.804, 2.86, and 2.88 Angstroms. A theoretical model of a cluster’s expansion and ionization dynamics was subsequently constructed that identified the atomic transition involved in this x-ray amplification, i.e., it was able to reproduce the observed gains. However, the ionization model did not attempt to calculate the observed line shifts. A laser intensity dependent level shift calculation will be described in this talk that, when added to the theoretical model, will allow a comparison to the experimental data to be made.

UP8.00113 Bright X-ray Source Development at the National Ignition Facility

M.J. MAY, K.B. FOURNIER, J.D. COLVIN, M.A. BARRIOS, K. WIDMANN, H. CHEN, M. SCHNEIDER, LLNL, Y.P. OPACHICH, NSTec, S.P. REGAN, UNR — High x-ray conversion efficiency (XRCE) K-shell and L-shell sources are being developed for High Energy Density (HED) experiments for use as backlighters and for the generation of x-ray-absorption radiography x-ray microscope images. The K-shell conversion efficiency K-shell Source (E/dE \sim 50 \% ) spectra were recorded. Details of the experiment and XRCE’s will be discussed. This work was done under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

UP8.00114 Synthetic Spectra for Krypton Filled/Germanium Doped Pipes as a Laser Driven K-shell Source

JOHN GIULIANI, NICHOLAS OUART, ARATI DASGUPTA, Naval Research Laboratory, KEVIN FOURNIER, Lawrence Livermore National Laboratory, JOHN APRUZEDE, Engility Corp., ROBERT CLARK, Berkeley Research Assoc. — Recent results from Kr filled pipes on the National Ignition Facility have demonstrated 1.6 keV/sr of Kr K-shell or 20 keV into 4π steradian. The observed Kr He-alpha and Ly-alpha lines indicate a temperature of 6 - 8 keV, but the strong underlying continuum emission is characterized by a significantly lower temperature (\sim 1keV). Using radiation-hydrodynamic modeling we consider a similar target but with a germanium dopant on the inside of the epoxy pipe. After partial absorption of the laser energy by the Kr fill, the remaining energy in the beam is deposited onto the inner pipe wall. The resultant inward ablation leads to a structured, multi-component plasma. Radially resolved spectra are calculated for various density and temperature profiles of the Ge/Kr mix within the target. The Ge K-shell line emission is between 10 keV and its cold K-edge absorption at 11.1 keV. The He-alpha line of Kr is at 13.1 keV. The objective is to develop a diagnostic for the strong continuum observed in [1]. If this feature arises from a cold envelope surrounding the Kr hot spot, then the Ge K-shell lines may enable measurement of its radial extent and temperature.

1Work supported by DOE.

UP8.00115 Characterization of ultrashort pulse laser-produced miniature hohlraum XUV sources

ANDREW MCKELVEY, ANTHONY RAYMOND, CALVIN ZULICK, ANATOLY MAKSIMCHUK, JOHN NEES, VICTOR YANOVSKY, VLADIMIR CHVYKOV, ALEXANDER THOMAS, KARL KRUSHELNICK, Univ of Michigan - Ann Arbor — Experiments at the National Ignition Facility (NIF) allow the radiative properties of dense, high-temperature matter to be studied at previously unreachable regimes, but are limited by cost and system availability. A scaled down system using ultra-short pulse lasers and delivering energy to a much smaller hohlraum could be capable of reaching comparable energy densities by depositing the energy in a significantly smaller volume before ablation of the wall material closes the cavity. The laser is tightly focused through the cavity and then expands to illuminate the wall with an intensity closer to that of a long pulse laser. Experiments were performed on a number of short-pulse Ti:sapphire tabletop laser systems. Targets include cavities machined in bulk material using low laser powers, and then shot in situ with a single full power pulse as well as micron scale pre-fabricated targets. Spectral characteristics were measured using a flat-field soft X-ray spectrometer and a seven channel filtered photo cathode array. These broadband EUV sources may allow opacity and atomic physics measurements with plasma and radiation temperatures comparable to NIF type hohlraums, but with a significantly higher repetition rate and in a university scale system.

1Work supported by DOE/NNSA.
UP8.00116 Differential hard x-ray imaging of HED/ICF plasmas using Compton scattering\(^1\). FREDERIC HARTEMANN, LLNL — Tunable, narrow-bandwidth, picosecond x-ray pulses can be produced via Compton scattering. Such pulses can be used for high-contrast K-edge imaging of specific ions in a plasma. In addition, the K-edge shift due to ionization and screening could also be studied using such x-rays. Details of a Compton scattering x-ray source will be presented, along with methods for spectral resolution and imaging, and information retrieval of the ion states and plasma conditions.

\(^{1}\)Prepared by LLNL under Contract DE-AC52-07NA27344.

UP8.00117 The MIT Accelerator Laboratory for Diagnostic Development for OMEGA, Z and the NIF\(^{1}\) , R. PETRASSO, M. GATU JOHNSON, E. ARMSTRONG, D. OROZCO, H.G. RINDERKNECHT, J. ROJAS HERRERA, M. ROSENBERG, H. SIO, A. ZYLSTRA, J. FRENJE, C.K. LI, F.H. SEGUIN, MIT, K. HAHN, B. JONES, C.L. RUIZ, SNL, T.C. SANGSTER, LLE — The MIT Linear Electrostatic Ion Accelerator\(^3\) generates D-D and D-3He fusion products, which are used for development of nuclear diagnostics for OMEGA, Z, and the NIF. Fusion reaction rates around \(10^7 \text{s}^{-1}\) are routinely achieved with this accelerator, and fluence and energy of the fusion products are accurately characterized. Diagnostics developed and calibrated at this facility include CR-39 based charged-particle spectrometers, neutron detectors, and the particle Time-Of-Flight (pTOF) CVD-diamond-based bang time detector. The accelerator is also a vital tool in the education of graduate and undergraduate students at MIT. This work was supported in part by SNL, DOE, LLE and LLNL.

\(^{1}\)Rosenberg et al. RSI (2012)

UP8.00118 Measuring radial profiles of nuclear burn in ICF implosions at OMEGA and the NIF using proton emission imaging\(^1\) . F.H. SEGUIN, H.G. RINDERKNECHT, M. ROSENBERG, A. ZYLSTRA, J. FRENJE, C.K. LI, R. PETRASSO, MIT, F.J. MARSHALL, T.C. SANGSTER, LLE, N.M. HOFFMAN, LANL, P.A. AMENDT, C. BELLEI, S. LE PAPE, S.C. WILKS, LLNL — Fusion reactions in ICF implosions of D\(^3\)He-filled capsules produce 14.7-MeV D\(^3\)He protons and 3-MeV DD protons. Measurements of the spatial distributions of the D\(^3\)He and DD reactions are studied with a penumbral imaging system that utilizes a CR-39-based imaging detector to simultaneously record separate penumbral images of the two types of protons. Measured burn profiles are useful for studying implosion physics and provide a critical test for benchmarking simulations. Recent implosions at OMEGA of CD capsules containing \(^3\)He gas fill\(^2\) and SiO\(_2\) capsules containing low-pressure D\(^3\)He gas\(^4\) were expected to have hollow D\(^3\)He burn profiles in the \(^3\)He-filled capsule, due to fuel-shell mix, but penumbral imaging showed that the reactions were centrally peaked due to enhanced ion diffusion. The imaging technique is to be implemented soon on the NIF. This work was supported in part by NLUF, DOE, and LLE.


UP8.00119 Design of a compact, low-energy-charged-particle-spectrometer for stellar nucleosynthesis experiments at OMEGA and the NIF\(^1\) , E. ARMSTRONG, J. FRENJE, M. GATU JOHNSON, C.K. LI, H. RINDERKNECHT, M. ROSENBERG, F.H. SEGUIN, H. SIO, A. ZYLSTRA, R.D. PETRASSO, MIT — A compact “Orange” Spectrometer is being designed for measurements of alpha and proton spectra in the range of \(1-5 \text{MeV}\) produced in low-yield \(^3\)He\(^\text{H}\) experiments at the OMEGA laser and at the National Ignition Facility (NIF). Particle ray-tracing through magnetic fields, modeled by COMSOL, were conducted with the code Python. The goal is to identify an optimal setup for a spectrometer to measure alpha particles at relatively low energies and at low yield. Ability to study the alpha particles in addition to the protons is essential for understanding the nuclear physics governing the final-state interactions between pairs of particles in the three-body final state. This work was supported in part by the U.S. DOE and NLUF.

UP8.00120 Impact of x-ray dose on the CR-39 response to 1-9 MeV protons with application to proton spectroscopy at OMEGA and NIF\(^1\) , J. ROJAS-HERRERA, H.G. RINDERKNECHT, M. GATU JOHNSON, A. ZYLSTRA, M. ROSENBERG, H. SIO, MIT — CR-39 is a clear plastic nuclear track detector utilized in many nuclear diagnostics fielded in large-scale inertial confinement fusion (ICF) facilities. Large x-ray fluences in ICF experiments may impact the CR-39 response to incident charged particles. A thick-target bremsstrahlung x-ray machine was used to expose CR-39 to various x-ray doses to determine their impact on the CR-39 response to protons. This x-ray machine emits Cu-\(\alpha\) line-radiation at 8 keV and has been absolutely calibrated using radiochromic film. The CR-39 detectors were then exposed to D\(^3\)He-protons generated by the MIT Linear Electrostatic Ion Accelerator. The regions of the CR-39 exposed to x-rays showed a smaller track diameter than those not exposed to x-rays. For example, a dose of 60 \(\pm\) 1.3 Gy results in a decrease of 53% in the track diameter, while a dose of 5 \(\pm\) 0.1 Gy causes a decrease of 7.5% in the track diameter. Doses of approximately 5 Gy are typical on CR-39 detectors used to diagnose ICF implosions at OMEGA and the NIF. The resulting data will be used to evaluate how x-ray doses received by CR-39 in OMEGA and NIF experiments affect the recorded data. This undergraduate research was supported in part by the U.S. DOE, NLUF, DOE, LLE and LLNL.

\(^{1}\)Prepared by LLNL under Contract DE-AC52-07NA27344.

UP8.00121 Charged Particle Detection with CR-39 under High Yield Conditions in ICF Experiments\(^1\) , D. OROZCO, M. ROSENBERG, M. GATU JOHNSON, H. SIO, H.G. RINDERKNECHT, A. ZYLSTRA, F.H. SEGUIN, R.D. PETRASSO, MIT — CR-39 is a solid-state nuclear track detector commonly used in Inertial Confinement Fusion (ICF) experiments for detecting individual charged particles. Under high yield conditions at OMEGA and NIF, detecting individual particle tracks becomes very difficult because of track overlap. The fluence on the CR-39 when this becomes a problem is approximately \(10^9 \text{tracks/cm}^2\). A scattering foil behind a pinhole aperture (“scattering pinhole”) can be added in front of the CR-39 in order to reduce the fluence on the CR-39 by a factor related to the pinhole size, scattering angle of the foil, distance from the implosion to the foil, and the distance from the foil to the CR-39. This has been. For example, 400 micron foil behind a 300 micron pinhole 9mm in front of a piece of CR-39 can reduce the fluence of 15MeV protons by a factor of \(\sim 50\). The scattering pinhole is also being used at OMEGA in order to detect alphas produced in D + T and D + 3He reactions. This work was supported in part by the U.S. DOE and NLUF. *Rosenberg et al. RSI 85, 043302
We will also discuss plans for coupling to the spatially three-dimensional, extended MHD code M3D-C of the dynamic formation of the ohmic and bootstrap currents. Several applications of this hybrid code will be presented, including an ELM-like pressure collapse.

Plasmas derived in a Chapman-Enskog-like fashion, ensuring that collisions dominate to the bounce resonance stabilization. This understanding is critical for future design and operation of magnetic fusion devices. In NSTX, variations of plasma rotation profile and collisionality alter RWM stability, and reproduce marginal stability conditions, but with the ion precession drift stabilization dominant compared to ion precession drift resonance stabilization at q<sub>min</sub> = 1.6 and 2.8 in the plasma stored energy (up to 60 percent) limit performance in DIII-D high normalized beta plasmas at high minimum safety factor, q<sub>min</sub>, near 3.5 and lead to full disruptions in NSTX. Kinetic RWM stabilization theory implemented in the MISK code can quantitatively explain the observed destabilization, with the results having important complementarity between devices. DIII-D experimental high beta, β<sub>N</sub> plasma stored energy (up to 60 percent) limit performance in DIII-D high normalized beta plasmas at high minimum safety factor, q<sub>min</sub>, near 3.5 and lead to full disruptions in NSTX. Kinetic RWM stabilization theory implemented in the MISK code can quantitatively explain the observed destabilization, with the results having important complementarity between devices. DIII-D experimental high beta, β<sub>N</sub> plasma stored energy (up to 60 percent) limit performance in DIII-D high normalized beta plasmas at high minimum safety factor, q<sub>min</sub>, near 3.5 and lead to full disruptions in NSTX. Kinetic RWM stabilization theory implemented in the MISK code can quantitatively explain the observed destabilization, with the results having important complementarity between devices.
Numerical validation studies have been performed using NIMROD [1], which models the injectors as boundary conditions on the flux conservor, and PSI-TET [2], which models the entire plasma volume. Results from these studies will be presented, illustrating application of the BD method. A simplified (constant, uniform density and temperature) Hall-MHD model has accurately modeled the current amplification achieved when the injectors are driven with a frequency of 14.5 kHz. However at higher frequencies (30 kHz < f_{\text{inj}} < 70 kHz) this simplified model does not reproduce the experimental current amplification. In addition, simulations have yet to accurately reproduce the internal q profile, an important factor in equilibrium stability, indicating additional physics may be required to achieve full agreement.


Work supported by the US Department of Energy.

Friday, October 31, 2014 8:00AM - 9:00AM
Session XR1 Review: From Microjoules to Megajoules and Kilobars to Gigabars: Probing Matter at Extreme States of Deformation Acadia/Bissonet - Mark Koecke, West Virginia University

8:00AM XR1.00001 From microjoules to megajoules and kilobars to gigabars: probing matter at extreme states of deformation 1, BRUCE A. REMINGTON, Lawrence Livermore National Laboratory — Over the past 3 decades there has been an exponential increase in the newly emerging field of matter at extreme states of deformation and compression. This has been due to the confluence of new experimental facilities, new experimental techniques, new theory, and new multiscale simulation techniques. Regimes of science and research hitherto thought out of reach in terrestrial settings are now being accessed routinely. High energy lasers and pulsed power facilities are accessing high pressure macroscopic states of matter, and next generation light sources combined with smaller drive lasers are probing the quantum response of matter at the atomic level. Combined, this gives multiscale experimental access of the properties and dynamics of matter from femtoseconds to microseconds and from kilobars to gigabars of pressure. There are a multitude of new regimes of science and research that these new developments make possible. Examples include planetary formation dynamics, asteroid and meteor impact dynamics, space hardware response to hypervelocity interplanetary dust impacts, reactor component response to prolonged exposure to radiation damage, advanced research into light weight armor, and capsule dynamics in inertial confinement fusion (ICF). I will review highlights and advances in this rapidly developing field of science and research, touching on experiments at a wide range of facilities (NIF, Z, Omega, Jupiter, Trident, Vulcan, Orion, LULI, LIL, Gekko, Shenguang, LCLS, DCS). I will also review a wide variety of sophisticated new experimental techniques being developed and new developments in theory and multiscale modeling.

1This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Friday, October 31, 2014 9:30AM - 12:30PM
Session YI1 Fast Ions, Momentum Input, RF, and Current Drive Acadia - Zhihong Lin, University of California, Irvine

9:30AM YI1.00001 Novel Reactor Relevant RF Actuator Schemes for the Lower Hybrid and the Ion Cyclotron Range of Frequencies 1, PAUL BONOLI, MIT Plasma Science and Fusion Center — This paper presents a fresh physics perspective on the onerous problem of coupling and successfully utilizing ion cyclotron range of frequencies (ICRF) and lower hybrid range of frequencies (LHRF) actuators in the harsh environment of a nuclear fusion reactor. The ICRF and LH launchers are essentially first wall components in a fusion reactor and as such will be subjected to high heat fluxes. The high field side (HFS) of the plasma offers a region of reduced heat flux together with a quiescent scrape off layer (SOL). Placement of the ICRF and LHRF launchers on the tokamak HFS also offers distinct physics advantages: The higher toroidal magnetic field makes it possible to couple faster phase velocity LH waves that can penetrate farther into the plasma core and be absorbed by higher energy electrons, thereby increasing the current drive efficiency. In addition, re-location of the LH launcher off the mid-plane (i.e., poloidal “steering”) allows further control of the deposition location. Also ICRF waves coupled from the HFS couple strongly to mode converted ion Bernstein waves and ion cyclotron waves waves as the minority density is increased, thus opening the possibility of using this scheme for flow drive and pressure control. Finally the quiescent nature of the HFS scrape off layer should minimize the effects of RF wave scattering from density fluctuations. Ray tracing / Fokker Planck simulations will be presented for LHRF applications in devices such as the proposed Advanced Divertor Experiment (ADX) and extending to ITER and beyond. Full-wave simulations will also be presented which demonstrate the possible combinations of electron and ion heating via ICRF mode conversion.

1Work supported by the US DoE under contract numbers DE-FC02-01ER54546 and DE-FC02-99ER54512.
10:00AM YI1.00002 Measurements of LHCD current profile and efficiency for simulation validation on Alcator C-Mod, ROBERT T. MUMGAARD, MIT PSFC — Lower hybrid current drive (LHCD) is an effective tool to significantly modify the magnetic equilibrium by driving off-axis, non-inductive current. On Alcator C-Mod, an upgraded Motional Stark Effect (MSE) diagnostic enables the current profile to be accurately reconstructed during plasmas with strong LHCD and a hard X-ray camera measures the fast electron Bremsstrahlung profile. LHCD is applied for &gt;4 current equilibration times, producing fully-relaxed magnetic equilibria in plasmas with non-inductive current fraction up to unity at currents up to 1.0 MA. C-Mod has developed an extensive database of LHCD performance, spanning a wide range in plasma current, launched n0f, LHCD power, T<sub>e</sub>, and plasma density. This dataset provides a unique platform for validation of LHCD current drive simulations with the plasma shape, density, field and LH frequency range envisioned for ITER and future reactors. In these conditions the measured current drive efficiencies are similar to that assumed for ITER with values up to 0.4*10<sup>20</sup>A/Wm<sup>2</sup> despite being in a weak single-pass absorption regime. The driven current is observed to be off-axis, broadening the current profile, raising q0 above 1, suppressing sawteeth, decreasing/reversing the magnetic shear and sometimes destabilizing MHD modes and/or triggering internal transport barriers. Measurements indicate increased efficiency at increased temperature and plasma current but with a complicated dependence on launched n0f. The MSE-constrained reconstructions show a loss in drive current efficiency as the plasma density is increased above n<sub>e</sub> &gt;1.0x10<sup>20</sup> m<sup>-3</sup> consistent with previous observations of a precipitous drop in hard x-ray emission. Additionally, the measured driven current profile moves radially outward as the density is increased. Ray tracing simulations using GENRAY-CQL3D qualitatively reproduce these trends showing the rays make many passes through the plasma at high density and predicting a narrower current and HXR profile with than that observed in the experiment. This work is supported by USDA awards DE-FC02-99ER54512 and DE-AC02-09CH11466.

10:30AM YI1.00003 Taming the ICRF Antenna - Plasma Edge Interaction using Novel Field-Aligned ICRF Antenna on Alcator C-Mod<sup>1</sup>, YIJUN LIN, MIT Plasma Science and Fusion Center — For ICRF antenna utilization in future fusion reactors, taming the antenna-plasma edge interaction while robustly coupling RF power is a critical challenge. Using a novel field-aligned (FA) ICRF antenna where the antenna straps are perpendicular to the total magnetic field, we have shown dramatically improved ICRF antenna performance. The FA antenna has significantly reduced antenna impurity sources, core impurity contamination and radiated power compared to conventional toroidally aligned antennas. The FA antenna also has load tolerance to plasma transients and significantly reduced RF-enhanced heat flux. The emerging physics picture is that the FA antenna minimizes generation of slow wave fields (E//B polarization). This reduction in slow wave lowers the local RF sheath around the ICRF antenna, and thus lowers the impurity source at low antenna structure. Simplified antenna simulations show a strong reduction in slow wave fields. The reduction of the slow wave field also impacts the antenna load tolerance. With the slow wave present, the antenna impedance is strongly modified by the slow wave coupling between antenna straps and this coupling is dependent upon the local density. With reduced slow wave coupling, the antenna reactive impedance is defined by the strap geometry and independent of the plasma whereas the real impedance is determined by the fast wave coupling. Experimentally we have found that the FA antenna loading has similar trends versus plasma current and densities to TA antennas, but the FA antenna reflection coefficient has significantly reduced variation, particularly during L-H and H-L transitions, and ELMy. Further comparisons of the FA and TA antennas are underway with an extensive array of diagnostics to characterize the RF plasma edge interaction and the latest results will be presented.

1Supported by US DoE awards DE-FC02-99ER54512 at MIT.

11:00AM YI1.00004 Fast Ion Transport Studies in DIII-D High β<sub>N</sub> Steady-State Scenarios<sup>1</sup>, C.T. HOLCOMB, Lawrence Livermore National Laboratory — DIII-D research is identifying paths to optimize energetic particle (EP) transport in high β<sub>N</sub> steady-state tokamak scenarios. Operation with q<sub>min</sub> &gt; 2 is predicted to achieve high β<sub>N</sub>, confinement, and bootstrap fraction. However DIII-D experiments have shown that Alfven eigenmodes (AE) and correlated EP transport can limit the performance of some q<sub>min</sub> &gt; 2 plasmas. Enhanced EP transport occurs in plasmas with q<sub>min</sub> = 2-2.5, q<sub>p</sub> = 5-7, and relatively long slowing down time. Strong AE are present, the confinement factor H<sub>98</sub> = 1.6-1.8 and β<sub>N</sub> is limited to ~3 by the available power. These observations are consistent with EP transport models having a critical gradient in β<sub>f</sub>. However, adjusting the parameters can recover classical EP confinement or improve thermal confinement so that H<sub>98</sub> &gt; 2. One example is a scenario with β<sub>p</sub> and β<sub>N</sub> ≈ 3.2, q<sub>min</sub> &gt; 3 and q<sub>p</sub> ≈ 11 developed to test control of long pulse, high heat flux operation on devices like EAST. This has an internal transport barrier at ρ ≈ 0.7, bootstrap fraction &gt;75%, density limit fraction 0.1, and H<sub>98</sub> &gt; 2. In these cases AE activity and EP transport is very dynamic - it varies between classical and anomalous from shot to shot and within shots. Thus these plasmas are close to a threshold for enhanced EP transport. This may be governed by a combination of a relatively low V<sup>2</sup>β<sub>f</sub> due to high thermal confinement and lower beam power, short slowing down time, and possibly changes to the q-profile. Another example is scenarios with q<sub>min</sub> ≈ 1. These typically have classical EP confinement and good thermal confinement. Thus by using its flexible parameters and profile control tools DIII-D is comparing a wide range of steady-state scenarios to identify the key physics setting EP transport.

1Work supported by the US Department of Energy under DE-AC52-07NA27344, SC-G0930402, DE-FC02-04ER54698, and DE-AC02-09CH11466.

11:30AM YI1.00005 Ion Loss as an Intrinsic Momentum Source in Tokamaks<sup>1</sup>, J.A. BOEDO, University of California San Diego — A series of coupled experiments in DIII-D and simulations provide strong support for the kinetic loss of thermal ions from the edge as the mechanism for toroidal momentum generation in tokamaks. Measurements of the near-separatrix parallel velocity of D<sup>+</sup> with Mach probes show a 1-2 cm wide D<sup>+</sup> parallel velocity peak at the separatrix reaching 40-60 km/s, up to half the thermal velocity, always in the direction of the plasma current. The magnitude and width of the velocity layer is in excellent agreement with a first-principle, collisionless, kinetic computation of selective particle loss due to the loss cone [1] including for the first time the measured radial electric field, E<sub>r</sub>, in steady state. C<sup>++</sup> rotation in the core, measured with charge exchange recombination (CER) spectroscopy is correlated with the edge D<sup>+</sup> velocity. XGC0 computations [2], which include collisions and kinetic ions and electrons, show results that agree with the measurements, and indicate that two mechanisms are relevant: 1) ion orbit loss and 2) a growing influence of the Pfirsch-Schluter mechanism in H-mode conditions. The inclusion of the measured E<sub>r</sub> in the loss-cone model [1] drastically affects the width and magnitude of the velocity profile and improves agreement with the Mach probe measurements. A fine structure in E<sub>r</sub> is found, still of unknown origin, featuring large (10-20 kV/m) positive peaks in the SOL and at, or slightly inside the separatrix of low power L- or H-mode conditions. This high resolution probe measurement of E<sub>r</sub> agrees with CER measurements where the techniques overlap. The flow is attenuated in higher collisionality conditions, consistent with a depleted loss-cone mechanism.

1Supported by the US DOE under DE-FG02-07ER54917, DE-FC02-08ER54977, & DE-FC02-04ER54698.

Supported by US DoE awards DE-FC02-99ER54512 at MIT.
12:00PM YI.00006 Energy Coupling and Coupling of Neutral-beam-driven Compressional Alfven Eigenmodes to Kinetic Alfven Waves in NSTX. ELENA BELOVA, PPPL. — Experimental observations from the National Spherical Torus Experiment (NSTX) have linked strong activity of global (GAEs) and compressional (CAEs) Alfven eigenmodes with a flattening of the electron temperature profile in beam heated plasmas in NSTX [1]. Previous theoretical studies attributed this effect to an enhanced electron transport due to these modes [2]. This work presents the first self-consistent simulations of neutral-beam-driven CAEs demonstrating an important alternative, an efficient energy channeling mechanism that will occur for any unstable CAE in NSTX or other toroidal devices. Three-dimensional hybrid MHD-particle simulations using the HYM code for an NSTX discharge (141398) show unstable CAEs for a range of toroidal mode numbers, n=4-9, and frequencies below the ion cyclotron frequency. It is found that an essential feature of CAE modes in NSTX is their coupling to kinetic Alfvén waves (KAW) that occurs on the high-field side at the flux surface of the fast ion Larmor radius. The beam-driven CAE can mode-convert to KAW, channeling energy from the beam ions at the injection region near the magnetic axis to the location of the resonant mode conversion at the edge of the beam density profile. This mechanism can explain the reduced heating of the plasma core in NSTX. The NBI power transferred to one CAE has been estimated as up to P=0.4MW, based on measured displacement amplitudes and HYM calculated mode structure. The energy flux from the CAE to the KAW and dissipation at the resonance location can have a direct effect on the temperature profile up to several hundred eV. It is shown that strong CAE/KAW coupling follows from the dispersion relation, and will occur for any unstable CAE in NSTX or other toroidal devices, independent of toroidal mode number or frequency.


Friday, October, 31, 2014 9:30AM - 12:30PM Session YI2 Technology of Plasma Facing Surfaces, Landau-Spitzer Award and Post Deadline Talk

10:00AM YI2.00001 Landau-Spitzer Award: Fast-Ion Transport in the ASDEX Upgrade and DIII-D Tokamaks. MANUEL GARCIA-MUNOZ, IPP-Garching. — Unprecedented insight into the fast-ion transport caused by a broad range of fluctuations has been made possible in the ASDEX Upgrade (AUG) and DIII-D tokamaks thanks to a new set of fast-ion diagnostics developed in the framework of a transatlantic collaboration. The temporal evolution of the fast-ion radial profile with velocity-space resolution has been measured in the AUG tokamak with the implementation of the Fast-Ion D-Alpha (FIDA) technique and associated analysis tools developed originally by the DIII-D group. Time resolved phase-space measurements of fast-ion losses made in DIII-D with a scintillator-based Fast-Ion Loss Detector (FILD) developed at AUG have revealed crucial details of the fast-ion dynamics in the presence of a broad range of MHD perturbations. The joint application of these techniques to AUG and DIII-D plasmas has advanced our understanding of the variable interaction responsible for the fast-ion transport induced by Alfven Eigenmodes (AEs), Sawteeth and Edge Localized Modes (ELMs). Accurate measurements of the fast-ion radial profile have demonstrated the weak or negligible effect that microturbulence has on fast-ion transport. Additionally, multiple FILD and FIDA systems in both devices show a significant increase in EP loss due to externally applied 3D fields (such as those used for ELM control). A survey of the most relevant experimental and modelling results obtained through this collaboration will be presented. This work was carried out together with B. Geiger (IPP-Garching), W.W. Heidbrink (UC-Irvine), D. C. Pace, M. A. Van Zeeland (General Atomics) and the ASDEX Upgrade and DIII-D Teams.

Work supported in part by the US Department of Energy under DE-FC02-04ER54698. This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement number 633055.

10:00AM YI2.00002 Plasma Sputtering Robotic Device for In-Situ Thick Coatings of Long, Small Diameter Vacuum Tubes. ADY HERSHCOVITCH, Brookhaven National Laboratory. — A novel robotic plasma magnetron mole with a 50 cm long cathode was designed manufactured & operated. Reason for this endeavor is to alleviate the problems of unacceptable ohmic heating of stainless steel vacuum tubes and electron clouds, due to high secondary electron yield (SEY), in the BNL Relativistic Heavy Ion Collider (RHIC). The magnetron mole was successfully operated to copper coat an assembly containing a full-size, stainless steel, cold bore, RHIC magnet tubing connected to two types of RHIC bellows, to which two additional pipes made of RHIC tubing were connected. To increase cathode lifetime, movable magnet package was developed, and thickest possible cathode was made, with a rather challenging target to substrate (de facto anode) distance of less than 1.5 cm. Achieving reliable steady state magnetron discharges at such a short cathode to anode gap was rather challenging, when compared to commercial coating equipment, where the target to substrate distance is 10’s cm; 6.3 cm is the lowest experimental target to substrate distance found in the literature. Additionally, the magnetron developed during this project provides unique anti-directional uniform coating. The magnetron is mounted on a carriage with spring loaded wheels that successfully crossed bellows and adjusted for variations in vacuum tube diameter, while keeping the magnetron centered. Electrical power and cooling water were fed through a cable bundle. The umbilical cables system is driven by a motorized spool. Excellent coating adhesion was achieved. Measurements indicated that well-scrubbed copper coating reduced SEY to 1, i.e., the problem of electron clouds can be eliminated. Room temperature RF resistivity measurement indicated that 10 µm Cu coated stainless steel RHIC tube has conductivity close to that of pure copper tubing. Excellent coating adhesion was achieved. Device detail and experimental results will be presented.

Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH1-886 with the US Department of Energy.

10:30AM YI2.00003 High Performance Discharges in the Lithium Tokamak eXperiment (LTX) with Liquid Lithium Walls. JOHNN SCHMITT, Princeton Plasma Physics Laboratory. — The possibility of a liquid metal first wall for a fusion reactor has been extensively discussed. Small-area liquid lithium limiters and divertor targets have been installed in tokamaks, but no confinement device has ever operated with a large-area liquid lithium wall. Here we report the first-ever successful operation of a tokamak with a large area (2 m², or 40% of the total plasma surface area) liquid lithium wall in the Lithium Tokamak eXperiment (LTX). These results were obtained with a new, electron beam-based lithium evaporation system, which can deposit a liquid lithium coating on the hot (300 °C) wall of LTX in a five-minute period. Preliminary analyses of diagnostically other data for discharges operated with a liquid lithium wall indicate that confinement times increased by 10× compared to discharges with helium-dispersed solid lithium coatings. Ohmic confinement times exceeded ITER98P(y,2) scaling by up to a factor of four. LTX lacks auxiliary heating, so these confinement improvements represent changes in electron confinement. Spectroscopic analysis of the discharges using the Johns Hopkins University transmission grating extreme ultraviolet spectrometer indicates that oxygen levels in the discharges run against liquid walls were significantly reduced compared to discharges operated against solid lithium walls. This differs strongly from earlier trials of molten lithium walls in LTX, which showed evidence for strong oxygen influx from walls operated at similar temperatures. At present, the Thomson scattering system is undergoing upgrades and realignment, after which confinement times obtained with magnetic diagnostics will be compared with kinetic measurements. A second electron beam will be installed to extend liquid lithium wall operation to 4 m² coverage, or >80% of the total plasma surface area. Results with expanded liquid lithium wall area will be presented.

Supported by US DOE contracts DE-AC02-09CH11466 and DE-AC52-07NA27344.
11:00AM YI2.00004 In-situ erosion and deposition measurements of plasma-facing surfaces in Alcator C-Mod

This work was supported by U.S. DOE Grant No. DE-FG02-94ER54235 and Cooperative Agreement No. DE-FG02-99ER54512.

11:30AM YI2.00005 The Effects of Temperature and Oxidation on Deuterium Retention in Solid and Liquid Lithium Films on Molybdenum Plasma-Facing Components

This work was supported by DOE contract No. DE AC02-09CH11466.

12:00PM YI2.00006 GDT Experiments with Electron Heating

1In collaboration with the GDT Group.


9:30AM - 9:30AM —

Session YP8 Poster Session IX: Supplemental and Postdeadline Posters Preserved Hall - YP8.00001 SUPPLEMENTAL —

YP8.00002 The evolution of the Rayleigh-Taylor and Richtmyer-Meshkov instabilities in a finite height domain

The work is supported by the US National Science Foundation; Moved to poster by APS.

YP8.00003 The scientific prototype, the only reasonable next step for the American MFE program; why FESAC will never solicit my advice again

YP8.00004 Purely-growing fast reconnection from a fourth-order fluid equation1, PAUL BELLAN, Caltech — If either finite electron inertia or finite resistivity are included in 2D magnetic reconnection, the two-fluid equations become a pair of second-order differential equations coupling the out-of-plane magnetic field and vector potential to each other to form a fourth-order system. The coupling at an X-point is such that out-of-plane even-parity electric and odd-parity magnetic fields feed off each other to produce instability. The instability growth rate is given by an eigenvalue of the fourth-order system determined by boundary and symmetry conditions. The instability is a purely growing mode, not a wave, but has growth rate of the order of the whistler frequency. The spatial profile of both the out-of-plane electric and magnetic eigenfunctions consists of an inner concave region having extent of the order of the electron skin depth, an intermediate convex region having extent of the order of the ion skin depth, and a concave outer exponentially decaying region. If finite electron inertia and resistivity are not included, the inner concave region does not exist and the coupled pair of equations reduces to a second-order differential equation having non-physical solutions at an X-point.

1Supported by USDOE, NSF, and AFOSR.

YP8.00005 Effect of parallel heat flux in the gyroviscous tensor on tearing mode instability in two-fluid magnetohydrodynamic model1, ATSUSHI ITO, National Institute for Fusion Science, J.J. RAMOS, PSFC, MIT — Two-fluid magnetohydrodynamic (MHD) models with ion gyroviscous tensor are used to study finite Larmor radius effects on MHD instabilities such as the tearing mode instability. However, the conventional two-fluid models are valid for collisional plasmas. In the fluid moment equations for low collisionality plasmas, the parallel heat flux that arises in the gyroviscous force due to the non-Maxwellian part of the velocity distribution function cannot be neglected [1]. The effect of parallel heat flux in the gyroviscous tensor on the tearing mode instability in low collisionality plasmas is investigated by eigenmode analysis. The linear eigenmode equations for the tearing mode instability including the perturbed parallel heat flux in the gyroviscous tensor are derived from the fluid moment equations and are numerically solved.

1This work was partially supported by Japan/U.S. Cooperation in Fusion Research and Development, JSPS KAKENHI Grant Number 24740375, and by U.S. D.O.E grants DEFG02-91-ER54109 and DEFC02-08ER54969.

YP8.00006 Preliminary Results for Coded Aperture Plasma Diagnostic1, MAGNUS HAW, PAUL BELLAN, Caltech — A 1D coded aperture camera has been developed as a prototype for a high speed, wavelength-independent, plasma imaging diagnostic. Images are obtained via a coded or masked aperture that modulates incoming light to produce an invertible linear transform of the image on a detector. The system requires no lenses or mirrors and can be thought of as a multiplexed pinhole camera (with comparable resolution and greater signal than a single pinhole). The inexpensive custom-built system has a 13x1cm field of view, a vertical spatial resolution of 2mm, and a temporal resolution of 1μs. Visible light images of the Caltech MHD-driven jet experiment agree with simultaneous images obtained with a conventional camera. For the simple jet geometry, the system can also extract depth information from single images. Further work will revolve around improving shielding and acquiring X-ray and EUV scintillators for imaging in those wavelengths.

1Supported by DOE, NSF

YP8.00007 Robustness of the filamentation instability in arbitrarily oriented magnetic field, ANTOINE BRET, Universidad Castilla La Mancha — The filamentation (Weibel) instability plays a key role in the formation of collisionless shocks which are thought to produce Gamma-Ray-Bursts and High-Energy-Cosmic-Rays in astrophysical environments. While it has been known for long that a flow-aligned magnetic field can completely quench the instability, it was recently proved in 2D that in the cold regime, such cancelation is possible if and only if the field is perfectly aligned. Here, this result is finally extended to a 3D geometry. Calculations are conducted for symmetric and asymmetric counter-streaming relativistic plasma shells. 2D results are retrieved in 3D: the instability can never be completely canceled for an oblique magnetic field. In addition, the maximum growth-rate is always larger for wave vectors lying in the plane defined by the flow and the oblique field. On the one hand, this bears consequences on the orientation of the generated filaments. On the other hand, it certifies 2D simulations of the problem can be performed without missing the most unstable filamentation modes [1].


YP8.00008 Comparison of the spherical and ellipsoidal bubble models in laser wakefield accelerator, MYUNGHOO CHO, YOUNGKUK KIM, MINSUB HUR, Ulsan Natl Inst of Sci & Tech — The bubble in the laser wakefield electron accelerator generally takes an ellipsoidal shape. However, the electron trapping condition in such a general shape has not been fully investigated yet. In this presentation, we describe our improved theory of electron trapping in an ellipsoidal bubble; especially we focus on the trapping condition for a transversely elongated one, which is not well explained by the spherical bubble model. First we introduce and compare the spherical and ellipsoidal bubble formation derived from Maxwell’s equation. Specifically we introduce the relation between the bubble size and the field slope in longitudinal and transverse directions. Then we investigate the electron trapping condition by numerically integrating the equations of motion. From a series of numerical calculations, we found that the trapping is dominantly determined by the transverse bubble size, which makes the trapping condition much less restrictive than in the completely spherical bubble. To confirm our theoretical prediction, we carried out 3D PIC simulations, which exhibited good agreement with the theory.

YP8.00009 Characterization of the Inductively Heated Plasma Source IPG6-B, MICHAEL DROPMANN, RENE LAUFER, GEORG HERDICH, CASPER - Baylor University / IRS - University of Stuttgart, LORIN MATTHEWS, TRUELL HYDE, CASPER - Baylor University — In close collaboration between the Center for Astrophysics, Space Physics and Engineering Research (CASPER) at Baylor University, Texas, and the Institute of Space Systems (IRS) at the University of Stuttgart, Germany, two plasma facilities have been established using the Inductively heated Plasma Generator 6 (IPG6). The facility at Baylor University (IPG6-B) operates at a frequency of 13.56 MHz and a maximum power of 15 kW. A vacuum pump of 160 m3/h in combination with a butterfly valve allows pressure control over a wide range. Intended fields of research include basic investigation into thermo-chemistry and plasma radiation, plasma shell environments and high heat fluxes e.g. those found in fusion devices or during atmospheric re-entry of spacecraft. After moving the IPG6-B facility to the Baylor Research and Innovation Collaborative (BRIC) it was placed back into operation during the summer of 2014. Initial characterization in the new lab, using a heat flux probe, Pitot probe and cavity calorimeter, has been conducted for Air, Argon and Helium. The results of this characterization are presented.
Anisotropic Radiation Transport Experiments on the OMEGA Laser. JONATHAN HAGER, NICK LANIER, JOHN KLINE, KIRK FLIPPO, JONATHAN WORKMAN, Los Alamos National Laboratory, H.C. BRUNS, M. SCHNEIDER, M. SACULLA, T. MCCARVILLE, Lawrence Livermore National Laboratory — A new experimental platform is being developed at the OMEGA laser to generate an anisotropic radiation source to provide data that will challenge our implementation of Implicit Monte Carlo (IMC) radiation transport models. A low density silica aerogel foam physics package is mounted to a laser driven half-hohlraum. The x-ray drive from the hohlraum is modified by a filter and aperture to decrease the optical thickness of the foam and increase the source anisotropy. Point projectors for backlighting are used to measure the hydrodynamic response to the Marshak wave once it goes subsonic. The temperature of the driven foam can also be inferred using absorption spectroscopy when a titanium dopant is introduced. Experimental results using a Ti doped foam will be presented with analytic calculations and 2-D radiation hydrodynamic simulations demonstrating the impact of the source anisotropy on the measurable parameters in the foam.

Extension of GCPA for Simulating Non-Axisymmetric Systems. IHOR HOLOD, Univ of California - Irvine, DONALD SPONG, Oak Ridge National Laboratory — Effects of magnetic field non-axisymmetry are important for all magnetic confinement systems, including tokamaks, stellators, and reversed field pinches. In this work we present recent upgrade of GTC global gyrokinetic model to use general 3D toroidal equilibria and to study the associated phenomena. We have initially applied new capability to simulate electrostatic ITG, and fast ion driven electromagnetic TAE modes in the LHD stellator.

Characterization of Terahertz Radiation from a Counter-Pulse Scheme in a Magnetized Plasma. MIN SUP HUR, MYUNG-HOON CHO, YOUNG-KUK KIM, UNIST — We studied a novel scheme of generating a quasi-continuous terahertz radiation from counter-propagating laser pulses colliding in a magnetized plasma. In this system, the strong ponderomotive force of colliding pulses leaves a standing oscillation of an electron current around the collision point, which acts as an antenna of the electromagnetic radiation in the terahertz frequency regime. Theoretically it was found that the terahertz amplitude scales with square of P, where P is the power of the driving pulse, while it scales just with P for a single pulse case. So the radiation intensity can be enhanced by tens of times from that of Cherenkov wake scheme driven by a single laser pulse. Furthermore, it was found that, due to the growth of the central field, which is a direct result of driven-diffusion of the electric field near the cutoff, the density gradient of the plasma even increases the peak power of the terahertz radiation.

Characterizing Hot Electron Generation and Transport via Bremsstrahlung Emission on the High Intensity OMEGA EP Laser. J. PEEBLES, C. MCGUFFEY, K. KRAULAND, A. SOROKOVIKOVA, B. QIAO, S. KRASHENNINIKOV, F. N. BEG, Univ of California - San Diego, M. S. WEI, R. B. STEPHENS, General Atomics, C. D. CHEN, B. WESTOVER, H. S. MCLEAN, Lawrence Livermore National Laboratory — The investigation of high intensity laser generated fast electron beams is important for a number of High Energy Density Science applications, which include proton sources and fast ignition among others. A series of experimental campaigns performed using the kilojoule, 10-ps OMEGA EP laser closely examined the impact of a preformed plasma on laser plasma interaction and electron generation. Here we present the analysis of the measured bremsstrahlung x-ray radiation and the inferred results on fast electron characteristics. Simulations, performed with the Monte-Carlo code package ITS 3.0, generate the x-ray response of the target to an injected electron beam with a given temperature, energy and divergence angle. The simulated x-rays are then compared to those collected by the bremsstrahlung spectrometers, which allows us to characterize fast electrons created in the experiment. Preliminary results show a decrease in hard electron temperature with an increase in pre-pulse, which is further corroborated by magnetic electron and Cu-Ko spectrometers. This work performed under the auspices of the US DOE under contracts DE-FOA-0000583 (FES, NNSA), DE-NA0002026 (NLUF) and DE-FC02-04ER54789 (FSC).

Analysis and simulation of double tearing modes. Y. NISHIMURA, J.M. CHEN, C.Z. CHENG, Institute of Space and Plasma Sciences, National Cheng Kung University — Tokamak experiments with non-monotonic q-profile have attracted attention to the stability problem of double tearing modes. Interestingly, double tearing modes are one of the good examples where the pressure anisotropy effects become prominent. The bootstrap current contribution on the D'' depends on the sign of (dp/dr)/s (s is the magnetic shear, (dp/dr) is the pressure gradient), which is different on the inner surface and the outer surface. The D'' matrix, including off diagonal elements are calculated by solving exterior equation. The analysis is compared with the numerical results from a three dimensional initial value simulation. The nonlinear evolution of toroidally asymmetric m/n = 7/1 island chains has been investigated. To incorporate the pressure anisotropy, the kinetic-fluid model is employed which replace the pressure evolution equation with the second order moment of the kinetic ions and electrons from kinetic (particle) simulation.

Nonlinear kinetic modeling of stimulated Raman scattering in a non-uniform and non-stationary plasma. DIDIER BENISTI, CEA, DAM, DIF — We provide a theoretical description of stimulated Raman scattering that allows for collisionless dissipation as described in [1] (and, in particular, of the nonlinear reduction of the Landau damping rate), and that accounts for the nonlinear frequency shift of the plasma wave and for the growth of sidebands. Non-uniform and non-stationary effects are derived by making use of a variational principle. The central direction of propagation of the pump laser is calculated with the usual ray-tracing method. However, non-paraxial equations are used for the plasma and scattered waves in order to account for the self-focusing induced by the nonlinear frequency shift.

Nonlinear current profile control in DIII-D. E.M. SCHUSTER, J.E. BARTON, M.D. BOYER, W.P. WEHNER, Lehigh University, J.R. FERRON, D.A. HUMPHREYS, A.W. HYATT, G.L. JACKSON, T.C. LUCE, M.L. WALKER, General Atomics — Experimental results successfully demonstrate the potential of physics-model-based control for systematic attainment of desired q profiles, with the subsequent benefit of enabling exploration and reproducibility. The control scheme is designed by embedding a nonlinear, control-oriented, physics-based model of the plasma dynamics into the control design process. This modeling approach combines first-principles based empirical correlations obtained from physical observations, which leads to PDE models capturing the high-dimensionality and nonlinearity of the plasma response. Model-based control design includes not only the synthesis of feedback controllers for robust regulation or tracking, but also the determination of optimal feedback actuator trajectories for a systematic approach to scenario planning. Feedback+feedback (closed loop) control experiments in DIII-D consistently demonstrate improved current-profile control performance relative to feedforward (open loop) control alone.

Supported by the US Department of Energy under DE-SC0001334, DE-SC0010661 and DE-FC02-04ER54698.
YP8.00017 MHD modes rotation and locking threshold studies in ITER-like plasmas, VADIM YANOVKSIY, PAOLO ZANCA, ROBERTO PACCAGNELLA, Consorzio RFX — The non-linear dynamics of rotating tearing modes electromagnetically interacting with conducting shell is simulated for the parameters expected in ITER and their locking thresholds are calculated. The work is motivated by the fact that the relatively slow mode rotation during disruptions is considered to be particularly dangerous in ITER for its possible large detrimental effect through the excitation of a resonant response of the mechanical structures. The study is based on a simple cylindrical model for the evolution of the rotating MHD modes determined by the Rutherford equation, their coupling to the plasma flow and to the resistive wall. The modelling reveals the conditions under which the modes are likely to rotate or to lock during disruptions events. In addition, the comparison with the results obtained in nonlinear 3D plasma simulations is performed.

YP8.00018 Ferromagnetic effect on the rotational stabilization of the resistive wall modes in tokamaks, VADIM YANOVKSIY, Consorzio RFX, VLADIMIR PUSTOVITOV, Kurchatov Institute — The plasma stability in tokamaks with a ferromagnetic wall is analyzed because the presence of ferritic materials is expected in the ITER test blanket modules, and experiments with such elements are planned on the JT-60SA tokamak. The study is based on the dispersion relation for ferromagnetic resistive wall modes (RWMs) obtained in the cylindrical approximation by coupling the solution in the external region with arbitrary plasma model assuming only linearity of the plasma response to external perturbations. In contrast to the traditional thin wall approach to RWMs, the wall is treated as magnetically thick. We show that the rotational stabilization of RWMs, which in our model is similar to that observed in DIII-D and other tokamaks [M. S. Chu and M. Okabayashi, Plasma Phys. Control. Fusion 52, 123001 (2010)] allowing the plasma operation above the no-wall stability limit, becomes stronger in the presence of ferromagnetic wall compared to the case of non-ferromagnetic wall, and is possible even at lower rotation frequency, estimated as several kHz at realistic conditions. Simple analytical formulas describing the effect as well as their applicability ranges are presented.

YP8.00019 Simulation of EGAM with GTS, GE WANG, GUOYONG FU, WEIXING WANG, Princeton Plasma Physics Laboratory — Energetic particle induced geodesic acoustic mode is studied using the gyro-kinetic code GTS, where the electrons, ions and energetic particles are treated as fully kinetic species. The unstable EGAM is growing up when the beta of energetic particles increases up to the threshold. The eigen-frequency and growth rate of EGAM mode are benchmarked with the NEMROBE using the doubly bumped distribution function of the energetic particles. The frequency of the nonlinear EGAM is observed to chirp during the marginal instability of the EGAM. The EGAM plays a role in the ITG turbulence and therefore it will influence the transport of energetic particles in tokamaks. We will discuss our results on this issue.

YP8.00020 Introduction to the Neutrosophic Quantum Theory, FLORENTIN SMARANDACHE, Univ of New Mexico — Neutrosophic Quantum Theory (NQT) is the study of the principle that certain physical quantities can assume neutrosophic values, instead of discrete values as in quantum theory. These quantities are thus neutrosophically quantized. A neutrosophic value of a physical quantity is a neutrosophic interval, i.e., a set of neutrosophic numbers. Neutrosophic quantum theory combines classical mechanics and quantum mechanics. Neutrosophic quantum theory is an extension of quantum mechanics where the concept of probability is replaced by the concept of neutrosophic probability. Neutrosophic quantum theory is a generalization of quantum mechanics where the concept of probability is replaced by the concept of neutrosophic probability. Neutrosophic quantum theory is the study of the principle that certain physical quantities can assume neutrosophic values, instead of discrete values as in quantum theory. These quantities are thus neutrosophically quantized. A neutrosophic value of a physical quantity is a neutrosophic interval, i.e., a set of neutrosophic numbers. Neutrosophic quantum theory combines classical mechanics and quantum mechanics. Neutrosophic quantum theory is an extension of quantum mechanics where the concept of probability is replaced by the concept of neutrosophic probability. Neutrosophic quantum theory is the study of the principle that certain physical quantities can assume neutrosophic values, instead of discrete values as in quantum theory. These quantities are thus neutrosophically quantized. A neutrosophic value of a physical quantity is a neutrosophic interval, i.e., a set of neutrosophic numbers. Neutrosophic quantum theory combines classical mechanics and quantum mechanics. Neutrosophic quantum theory is an extension of quantum mechanics where the concept of probability is replaced by the concept of neutrosophic probability. Neutrosophic quantum theory is the study of the principle that certain physical quantities can assume neutrosophic values, instead of discrete values as in quantum theory. These quantities are thus neutrosophically quantized. A neutrosophic value of a physical quantity is a neutrosophic interval, i.e., a set of neutrosophic numbers. Neutrosophic quantum theory combines classical mechanics and quantum mechanics. Neutrosophic quantum theory is an extension of quantum mechanics where the concept of probability is replaced by the concept of neutrosophic probability.

YP8.00021 Lifting the Vlasov-Maxwell bracket by Lie-transform methods, A.J. BRIZARD, SMC, P.J. MORRISON, IFS and UT Austin, M. VITTOT, L. DE GUilleBON, CPT CNRS Luminy — The Vlasov-Maxwell equations possess a Hamiltonian structure expressed in terms of a Hamiltonian functional and a functional bracket. In the present work, the transformation ("lift") of the Vlasov-Maxwell bracket induced by the dynamical reduction of single-particle dynamics is investigated when the reduction is carried out by Lie-transform perturbation methods. A formal proof of the Jacobi identity for the reduced Vlasov-Maxwell bracket is presented. The ultimate goal of this work is to derive explicit Hamiltonian formulations for the guiding-center and gyrokinetic Vlasov-Maxwell equations that have important applications in our understanding of turbulent magnetized plasmas. A comparison with a bracket structure for the gyrokinetic Vlasov-Poisson equations derived by Dirac-constraint method will be presented.


YP8.00022 POSTDEADLINE —

YP8.00023 Wavelength Dependence of UV Effect on Etch Rate and Noise in CR-39, MICAH WIESNER, NATHAN TRAYNOR, JAMES MCELERICAN, STEPHEN PALADINO, SUNY Geneseo, CRAIG SANGSTER, MICHELLE MCCUSKEY, Laboratory for Laser Energetics — The use of CR-39 plastic as a SSNTD is an effective technique for recovering data in high-energy particle experiments including inertial confinement fusion. To reveal particle tracks after irradiation, CR-39 is chemically etched at elevated temperatures with NaOH, producing signal pits at the nuclear track sites that are measurable by an optical microscope. CR-39 pieces also exhibit etch-induced noise, either surface roughness or pit-like features not caused by nuclear particles, which negatively affects the ability of observers to distinguish actual pits. When CR-39 is exposed to high intensity UV light after nuclear irradiation and before etching, an increase in etch rates and pit diameters is observed. UV exposure can also increase noise, which in the extreme can distort the shapes of particle pits. Analyzing the effects of different wavelengths in the UV spectrum we have determined that light of the wavelength 255 nm increases etch rates and pit diameters while causing less background noise than longer UV wavelengths. Preliminary research indicates that heating CR-39 to elevated temperatures (~ 80 ℃) during UV exposure also improves the signal-to-noise ratio for this process.

1 Funded in part by a grant from the DOE through the Laboratory for Laser Energetics

YP8.00024 ABSTRACT WITHDRAWN —
YP8.00025 An Electromagnetic Gauge Technique for Measuring Shocked Particle Velocity in Electrically Conductive Samples, DAVID CHENG, AKIO YOSHINAKA, Defence Research and Development Canada - Suffield — Electromagnetic velocity (EMV) gauges are a class of film gauges which permit the direct in-situ measurement of shocked material flow velocity. The active sensing element, typically a metallic foil, requires exposure to a known external magnetic field in order to produce motional electromotive force (emf). Due to signal distortion caused by mutual inductance between sample and EMV gauge, this technique is typically limited to shock waves in non-conductive materials. In conductive samples, motional emf generated in the EMV gauge has to be extracted from the measured signal which results from the combined effects of both motional emf and voltage changes from induced currents. An electromagnetic technique is presented which analytically models the dynamics of induced current between a copper disk moving as a rigid body with constant 1D translational velocity toward an EMV gauge, where both disk and gauge are exposed to a uniform external static magnetic field. The disk is modeled as a magnetic dipole loop where its Foucault current is evaluated from the characteristics of the fields, whereas the EMV gauge is modeled as a circuit loop immersed in the field of the magnetic dipole loop, the intensity of which is calculated as a function of space and, implicitly, time. Equations of mutual induction are derived and the current induced in the EMV gauge loop is solved, allowing discrimination of the motional emf. Numerical analysis is provided for the step response of the induced EMV gauge current with respect to the Foucault current in the moving copper sample.

YP8.00026 Progress Towards a Microtrap Array for Positron Storage, ALIREZA NARIMANNEZHAD, MARC H. WEBER, JOSHUAH JENNINGS, CHANDRASEKAR MINNAL, KELVIN G. LYNN, Center for Materials Research, Washington State University — The storage of positrons has been a key for antimatter research and applications. One important goal is the attempt to reach higher densities of confined antimatter particles. Progress in this area is explored through a novel microtrap array with large length to radius aspect ratios and radii of the order of tens of microns. The proposed design consists of microtraps with substantially lower barrier potentials than conventional Penning-Malmberg traps arranged in parallel within a single magnet. Simulations showed positron plasma with 1E10 cm⁻³ density evolves toward a rigid-rotation phase in each microtrap while 10 V barriers confined the plasma axially. A trap of 4 cm length including more than 20,000 microtraps with 50 micron radii was fabricated and tested. Experiments conducted with electrons in a test structure addressing each microtube with a narrow beam will be described. This will explore the basic physics of the microtraps. Observed results were promising and they open a new avenue for manipulating high-density non-neutral plasmas.

YP8.00027 A Complementary Type of Electrochromic Device by Radio Frequency Magnetron Sputtering System, LUTFI OKSUZ, MELEK KIRISTI, FERHAT BOZDUMAN, AYSEGUL UYGUN OKSUZ, Suleyman Demirel University — Electrochromic (EC) devices can change their optical properties reversibly in the visible region (400-800 nm) upon charge insertion/extraction reactions according to the applied voltage. A complementary type of EC device composes of two electrochromic layers, which is separated by an ionic conduction layer (electrolyte). In this work, the EC device was fabricated using vanadium oxide (V2O5) and titanium doped tungsten oxide (WO3-TiO2) electrodes. The EC electrodes were deposited as thin film structures by a reactive RF magnetron sputtering system in a medium of gas mixture of argon and oxygen. Surface morphology of the films was characterized by scanning electron microscopy (SEM) and atomic force microscopy (AFM). Electrochemical property and durability of the EC device was investigated by a potentiostat system. Optical measurement was examined under applied voltages of ± 2.5 V by a computer-controlled system, constantly.

YP8.00028 High Current Electron Beam Emission Driven by a Nonlinear Transmission Line, DAVID FRENCH, BRAD HOFF, SUSAN HEIDGER, Air Force Research Laboratory — Simulations of an electron beam diode driven by a modulated voltage pulse provided by a nonlinear transmission line (NLTL) will be presented. Based on a previous low voltage experiment [1] the new design operates at 250 kV and provides a multi-kA modulated electron beam based on the modulated drive signal from a ferrite based NLTL. The NLTL driver has been demonstrated experimentally and is tunable from 900-1400 MHz with pulse durations from 4-17 ns. Particle-In-Cell simulations in ICEPIC show the modulated voltage signal results in a modulated electron beam current emitted directly from the cathode in a few cm annular beam. Expected results and the experimental design for the electron beam diode and diagnostics will also be presented.

YP8.00029 High-Speed Particle-in-Cell Simulation Parallelized with Graphic Processing Units for Low Temperature Plasmas for Material Processing, MIN YOUNG HUR, Pusan National University, JOHN VERBON-COEUR, Michigan State University, HAE JUNE LEE, Pusan National University — Particle-in-cell (PIC) simulations have high fidelity in the plasma device requiring transient kinetic modeling compared with fluid simulations. It uses less approximation on the plasma kinetics but requires many particles and grids to observe the semantic results. It means that the simulation spends lots of simulation time in proportion to the number of particles. Therefore, PIC simulation needs high performance computing. In this research, a graphics processing unit (GPU) is adopted for high performance computing of PIC simulation for low temperature discharge plasmas. GPUs have many-core processors and high memory bandwidth compared with a central processing unit (CPU). NVIDIA GeForce GPUs were used for the test with hundreds of cores which show cost-effective performance. PIC code algorithm is divided into two modules which are a field solver and a particle mover. The particle mover module is divided into four routines which are named move, boundary, Monte Carlo collision (MCC), and deposit. Overall, the GPU code solves particle motions as well as electrostatic potential in two-dimensional geometry almost 30 times faster than a single CPU code.

YP8.00030 Discontinuous Galerkin modeling of Scrape-Off Layer Turbulence, TESS BERNARD, FRANCOIS WAELBROECK, CRAIG MICHOSKI, University of Texas at Austin — Turbulence plays an important role in determining the transport and heating of space, astrophysical, and laboratory plasmas. Modeling this turbulence is particularly challenging because of the ability of the plasma to support waves with disparate space-time scales as well as to generate both short and long wavelength through nonlinear processes. Using a discontinuous Galerkin code called ArcOn, turbulence in the Texas Helimak is modeled. The Helimak experiment at the University of Texas aims to model the conditions in the scrape-off layer (SOL) of fusion devices. Effective modeling of this region is very important because much of the thermal power in fusion devices flows through it to divertor plates that must survive the resulting erosion and redeposition. It has been shown that electric biasing in this region can be used to reduce and control turbulence. The ArcOn code is used to simulate such potential biasing, with the goal of improving the theoretical understanding of this phenomena and its role in other fusion devices, in addition to the Helimak.
The outboard perturbation amplitude is larger compared to the inboard one and the ELM crash seems to be initiated by the bursts of the outboard ELM filaments, rotation of the outboard ELM filaments. This discrepancy suggests an asymmetry in the poloidal and/or toroidal flow of ELM filaments. In the crash dynamics, an ECEI system [2]. The poloidal mode spacing of the inboard ELM filaments is much larger than the ballooning mode spacing predicted from the images of KSTAR H-mode plasmas.

The experimental work was primarily funded by DOE Grant Number: DE-S0008803, the DARPA PULSE program, and ARO W911NF-12-1-0436.

The work is supported by NSF CBET 1336375.

This work is supported by NRF Korea, US DoE.
YP8.00037 Feasibility of an experiment to measure stopping powers in solid-density deuterium plasmas at OMEGA. B. LAHMANN, H.-G. RINDERKNECHT, A.B. ZYLSTRA, J.A. FRENJE, C.K. LI, F.H. SEGUNI, R.D. PETRASSO, MIT, S. REGAN, C. SANGSTER, LLE, F. GRAZIANI, G.W. COLLINS, J.R. RYGG, LLNL, P. GRABOWSKI, UC Irvine, S. GLENZER, Stanford University, P. KEITER, U Mich — An experimental design to measure the stopping powers of charged-particles through solid-density, fully-ionized deuterium plasmas at temperatures around 10 eV is investigated. Stopping power in this regime is crucial to the understanding of alpha-heating and burn in Internal Confinement Fusion. Recent work by A.B. Zylstra et al. on the OMEGA laser facility has demonstrated such measurements of stopping power in partially ionized Be plasmas, by measuring the downshift of D$^+$-protons or D$^+$-alphas, the latter of which is directly applicable to the stopping of DT-alphas in ignition experiments. This work was supported in part by the U.S. DOE, NLUF, LLE, and LLNL.


YP8.00038 Design of a Dual-Beam Electron Gun. MICHAEL LAMBRITCH, MICHAEL HAWORTH, WILKIN TANG, PETER MARDAHL, Air Force Research Laboratory — A dual beam electron gun is being designed as the driver for a microwave amplifier utilizing the two-stream instability. The two-stream amplifier was designed to use relativistic electron beams, and has achieved 30 dB gain at 9 GHz in 2-D ICEPIC simulations. Two annular electron beams are launched with different current, radii, and energies, co-propagating down a cylindrical waveguide to create the two-stream instability used for amplification. The parameters for the electron gun to create these beams simultaneously are stringent. The beam temperature must remain less than 0.5%, and the amount of transverse energy of the beam as it enters the drift tube must be as close to zero as possible, as both of these parameters severely degrade the amplification and efficiency of the amplifier. The dual-beam electron gun will be designed with TRAC (Field Precision, LLC), and will initially utilize a Friedman-style electron gun for the outer radius beam co-located with a "cookie-cutter" electron gun to create the inner radius beam. The design will seek to minimize beam spin and energy spread.

YP8.00039 Measurements of Reynolds stress and its contribution to momentum balance in the HSX stellarator1, ROBERT WILCOX, DAVID ANDERSON, JOSEPH TALMADGE, SIMON ANDERSON. University of Wisconsin - Madison — It has been predicted that for a sufficiently optimized quasi-symmetric stellarator, the neoclassical non-ambipolar transport and viscosity can be small enough that other terms, such as the Reynolds stress resulting from plasma turbulence, can compete with it in the momentum balance to determine the rotation and radial electric field. In this case, the experimental flows may deviate from values calculated using the ambipolarity constraint by purely neoclassical codes such as DKE5 and PENTA which are commonly used for stellarators. Using multi-tipped Langmuir probes in the edge of the HSX stellarator, the radial electric field and parallel ion flows are found to deviate from the values calculated by PENTA in the edge of the optimized quasi-helically symmetric (QHS) configuration. A large Reynolds stress flow drive is measured via fluctuating floating potential signals in the same radial region as the measured deviation from neoclassical calculations. Probe measurements are made at two locations on the device near the maximum of variation of magnetic geometry on a flux surface. Experiments have been run in both the QHS configuration and configurations with the symmetry intentionally broken to explore the relationship between the neoclassical optimization and the measured deviation of the flows from the calculated neoclassical value.

1Supported under USDOE grant DE-FG02-93ER54222

YP8.00040 Waves in a strongly coupled 2D superparamagnetic dusty plasma1. M. ROSENBERG, University of California, San Diego, G.J. KALMAN, Boston College, Z. DONKO, P. HARTMANN, Wigner Research Centre for Physics, Hungarian Academy of Sciences, S. KYRKOS, Le Moyne College — In a two-dimensional (2D) dusty plasma composed of superparamagnetic dust grains and immersed in an external magnetic field, the dust interacts via both Yukawa and magnetic dipole-dipole interactions. The induced magnetic dipole moments of the grains all lie along the magnetic field B. When the direction of B is tilted with respect to the dust layer, the interaction between the grains becomes anisotropic. We have theoretically considered the behavior of waves in the strongly coupled liquid phase of this system [1], using the Quasi-Localized Charge approximation combined with molecular dynamics simulations. The analysis is confined to magnetic tilt angles where the interaction remains repulsive in the dust layer, which allows for a stable equilibrium. Two new directions are explored. One relates to possible coupling between in-plane and out-of-plane polarized modes in a quasi-2D liquid phase, taking into account the effect of an external potential that confines the layer. The other relates to the crystalline state and how different lattice structures can arise and how they affect wave behavior.


3Work partially supported by NSF and NASA.

YP8.00041 Impure tokamak pedestals with strong radial electric field1, SILVIA ESPINOSA, PETER J. CATTO, MIT Plasma Science and Fusion Center, Cambridge, MA, USA — A high confinement mode pedestal has density and potential variation on the poloidal ion gyroradius scale. As a result, the ExB-drift associated with radial electric field can compete with the poloidal projection of parallel ion streaming, making alternate neoclassical descriptions necessary. In addition, Alcator C-Mod experiment1 make it clear that the impurity diamagnetic drift contribution must be allowed to be comparable to the impurity poloidal and toroidal flows to measure the radial electric field. Furthermore, Churchill et al1 experimentally observe stronger poloidal variation of the impurity density than predicted by the most comprehensive theoretical models developed to date. A neoclassical ordering valid for slowly varying background ion temperature profiles in supersonic pedestals has been formulated that allows impurity diamagnetic flow effects to enter to lowest order. It results in strong poloidal impurity variation and possibly provides a more realistic model for pedestal observations, by extending the seminal work of Helander1.

1Work supported by the U.S. Department of Energy Office of Science under Award Number DE-FG02-91ER-54109 and by "La Caixa" Fellowship.
2C. Theiler et al., Nucl. Fusion 54,083017
3R.M. Churchill et al., Nucl. Fusion 53,122002
4P. Helander, Phys. Plasmas 5,3999

YP8.00042 Electrode Biasing Experiment In KMAX Tandem Mirror. XUAN SUN, QING ZHANG, MING LIU, PEIYUN SHI, MUNAN LIN, University of Science and Technology of China — An electrode biasing system has been installed on KMAX (Keda Mirror with AXSymmetry) tandem mirror machine to control the rotation speed. It consists of a metal disk-type and a concentric ring-shaped electrode. On each of them there are 12 embedded single probes distributed uniformly in the azimuthal direction plus a single probe on the center. An adjustable power supply provides the biasing voltage from -1kV to 1kV, and a SCR with rising time ~ 10μs and maximum current up to 3000A is used to switch on the circuit. While most of applied voltages are lost on the sheath, the plasma potentials have been found to change substantially.
YP8.00043 Investigation on the shaping of poloidal flow in the biased electrode experiment1. YI YU, HAJUN REN, HUAJIE WANG, TAO LAN, YUMEI HOU, SHUANGYUAN FENG, YIZHI WEN, CHANGXUAN YU, MINYOU YE, USTC, USTC TEAM — Investigations on the drives of the poloidal flow are presented in this article. The poloidal flow is the main contributor to the radial electric field. Not only Reynolds stress but also the Lorentz’s force can drive the poloidal flow. The Reynolds stress accounts for about a quarter of the contribution to the poloidal flow in the biased electrode discharges. Investigations on the drives of poloidal flow and the spectra analyses in the biasing experiments show the momentum and energy transfer from the high frequency turbulence into the low frequency poloidal shear flow via Reynolds stress.

YP8.00044 Electron fluid simulations of 2D electron vortices1, JUSTIN ANGUS, STEVE RICHARDSON, JOSEPH SCHUMER, STEVE SWANEKAMP, Naval Research Laboratory, PAUL OTTINGER, Engility Corporation — The production of electron vortices in current-carrying plasmas has been observed in recent 2D particle-in-cell (PIC) simulations of the plasma-opening switch. In the presence of a background density gradient in 2D Cartesian systems, vortices will drift in the B × Grad(n) direction, where B is the magnetic field vector and n is the background plasma density. Vortices are important because of the possible role they play in the penetration of magnetic fields into plasmas. The time scales relevant to electron vortices are typically small enough such that the ions can be considered as infinitely massive and motionless. Here we present results of numerical simulations of 2D, seeded electron vortices in an inhomogeneous background using the cold, collisionless electron fluid equations coupled to the full set of Maxwell’s equations. The results of these simulations are compared with results of PIC simulations and the underlying physics of the drift is explored in detail.

YP8.00045 GRIM: An Implicit Code for Nonideal General Relativistic MHD, MANI CHANDRA, Dept of Astronomy, University of Illinois Urbana-Champaign, CHARLES GAMMIE, Dept of Astronomy, and Dept of Physics, University of Illinois Urbana-Champaign — Highly sub-Eddington black hole accretion flows like Sgr A* are expected to be collisionless yet are commonly modeled as an ideal fluid. Electron conduction, anisotropic viscosity, and viscosity can be important in a collisionless plasma and will potentially alter the dynamics and radiative properties of the flow from that in ideal fluid models. We present a new code, GRIM, that enables conduction and other effects to be efficiently incorporated into a GRMHD code. GRIM is a fully implicit Newton-Krylov shock capturing code that converges at second order on smooth flows. It features an efficient and automated Jacobian assembly with finite differences that uses graph coloring to exploit the sparsity of the discretization of a pde. This makes it easy to incorporate additional physics. The code correctly captures classical GRMHD test problems as well as a new suite of test problems with anisotropic conductivity. As a test and an example application we report on a relativistic version of the magneto-thermal instability, and we show an example integration of a black hole accretion flow.

YP8.00046 Magnetic field formation and interaction via biermann battery effect for laboratory cluster blast waves, ALBERTO MAROCCHINO, Dipartimento SBAI, Universit di Roma “La Sapienza,” Italy, LORENZO ROMAGNANI, LULI, Ecole Polytechnique, CNRS, CEA, UPMC, Palaiseau, France, ANNA LEVY, Sorbonne Universités, UPMC, Paris 06, CNRS, INSP, UMR 7588, INSP, F-75005, Paris, France, SATOSHI JINNO, YUJI FUKUDA, Kansai Photon Science Institute (KPSI), Japan Atomic Energy Agency (JAEA), Kyoto, Japan, LIVIA LANCIA, Dipartimento SBAI, Università di Roma “La Sapienza,” Italy, ALESSANDRA RAVASIO, LULI, Ecole Polytechnique, CNRS, CEA, UPMC, Palaiseau, France, ANGELO SCHIAVI, Dipartimento SBAI, Università di Roma “La Sapienza,” Italy, STEFANO ATZENI, Dipartimento SBAI, Università di Roma “La Sapienza,” Italy, DOMENICO DORIA, MARCO BORGESI, Centre for Plasma Physics, The Queen’s University, Belfast, UK — A recent campaign on the ELFIE laser at LULI investigated laboratory Blast Waves (BW) relevant to astrophysical scenarios. A 25–21 laser was focused into an Argon cluster gas in order to launch an intense Blast Wave (c ~ 0.5M/c3). Its evolution was investigated from the early Coulomb explosion to late times (~ 50ns) via proton radiography, revealing an intense electric field with B-field traces at early times, and no fields detected in the later, purely hydrodynamic phase. Simulations performed with the DUED code reproduce well the experiment, confirming magnetic field formation in the early phase, where the Biermann Battery term is for a short time dominant. At late times, magnetic field diffusion becomes dominant with the B-field diffusing away in front of the BW and only a small portion captured within the remnant.

YP8.00047 Ions acoustic oscillations driven by ion flow in a finite length systems, OLEKSANDR KOSHKAROV, ANDREI SMOLYAKOV, University of Saskatchewan, IGOR KAGANOVICH, Princeton Plasma Physics Laboratory, VICTOR ILGISONIS, Russian Research Centre “Kurchatov Institute” — Plasma with stationary flow are common in a number of application such as diagnostics with emissive probes, plasma electronics and electric propulsion devices. The presence of plasma flows often lead to the instabilities in such systems and subsequent development of large amplitude perturbations. In this work we consider dynamics of ion acoustic oscillations in a plasma equilibrium flow of ions. It is shown that the finite flow induces the instability due to coupling of the negative and positive energy modes. The mode coupling occurs via boundary conditions in a finite length system. The instability is studied via combination of analytical theory and numerical methods utilizing Godunov and multiple shooting schemes. The instability diagram is obtained as a function of the flow velocity and the system length.

YP8.00048 Gradient-drift and low hybrid modes in Hall plasmas, IVAN ROMADANOV, WINSTON FRIAS, ANDREI SMOLYAKOV, University of Saskatchewan, YEVENGY RAITSES, IGOR KAGANOVICH, Princeton Plasma Physics Laboratory — Hall plasmas with electron E × B drift often exhibits wide range of unstable modes affecting operation and performance of various devices, e.g. such as magnetrons and Hall thrusters. The plasma density and magnetic field gradients were previously identified as important source of low wavelength modes (Simon-Hoh or so called anti-drift mode). The shorter wavelength instabilities, such as low-hybrid, are also triggered by density and magnetic field gradients. On other hand, the low-hybrid modes are excited by collisional processes. Interaction of gradient-drift and low hybrid modes in presence of dissipation has a complex characters depending on the modes wavelength. Here, we investigate the characteristics such interaction for typical parameters of Hall thrusters.

YP8.00049 Envelope structures of coupled drift-zonal flow system in a dissipative tokamak plasma1, ANURAJ PANWAR, CHANG-MO RYU, Department of Physics, POSTECH, Pohang, Korea 790-784, RAGHVENDRA SINGH, WCI Center for Fusion Theory, NFRI, Daejeon 305-333, South Korea — In this paper, the modulational instability and associated envelope structures of coupled drift-zonal flow system in a dissipative tokamak plasma is investigated. Dissipative non-linear Schrodinger (NLS) equation is derived by using the derivative perturbation expansion method to govern the dynamics of modulated waves. Dissipative effects due to the collisions and kinematic viscosity significantly modify the growth of modulational instability. Dissipative NLS equation admits the localized solutions in the form of drift wave envelope solitons along with shock like zonal flow structures. The height of drift wave envelope solitons and zonal flow shock structures decreases with the increase in collisional and viscous dissipation.

1R&D program through NFRI and grant NRF-2012-0000590 Korea.
YP8.00050 Physics Properties of High Ratio Compression Gases, CHENG LI, YIAN LEI, Peking Univ — High ratio adiabatic compression of gasses can reach very high temperature. In a conical liquid metal compression device, very high compression ratio up to 10^9 to 1 can be quite easily achieved. Idea gas compression would give a temperature rise of 10^9 times of original room temperature, which is tens of keVs, reaching the realm of nuclear fusion. However, as the gas is dissociated and ionized by under high temperature, the real situation is not so optimistic. We analyzed the physics of the high ratio compression of normal gasses, taking account of dissociation, ionization, radiation loss, and possible energy loss due to gas (plasmas) and wall interaction, and try to find the formalism for the temperature and pressure in the process. The above mechanism drastically lowered the temperature of adiabatic compression. We also discussed the possibility of fusion by pure compression.

YP8.00051 ABSTRACT WITHDRAWN –

YP8.00052 Measurements of Plasma Temperature and Density Profiles Using Grid Image Refractometry for Laser Fusion Research1, JAECHUL OH, Research Support Instruments, J.L. WEAVER, M. KARASIK, L.Y. CHAN, U. S. Naval Research Laboratory — Electron density (n_e) and temperature (T_e) profiles of coronal plasma have been experimentally characterized using the grid image refractometer recently implemented at the Nike KrF laser facility (Nike-GIR). This instrument measured propagation angles and transmissions of probe laser (λ = 263 nm, Δt = 10 psec) beamlets refracted through a CH plasma produced by the Nike laser pulse (~ 1 nsec FWHM) with the intensity of 1.1 × 10^15 W/cm^2. The measured angles were processed by an iterative algorithm to construct self-consistent n_e profiles. The spatial profile of T_e was also examined using the obtained n_e profiles and the measured transmission data. The resulting n_e and T_e profiles were verified to be self-consistent with the measured quantities of the refracted probe light.

1Work supported by DoE/NNSA and performed at Naval Research Laboratory.

YP8.00053 Experimental investigation of the interaction between a short high-intensity laser pulse and a long and hot plasma, CLEMENT GOYON, CEA, DAM, DIF, F-91297 Arpajon, France, SYLVIE DEPIERREUX, CEA, DAM, DIF, CLAIRE BACCOU, LULI, CLÉMENT COURVOISIER, CEA, DAM, DIF, GUILLAME LOISEL, VINCENT YAHIA, LULI, NATALIA BORISOENKO, P. N. Lebedev Physical Institute, PAUL-EDOUARD MASSON-LABORDE, CEA, DAM, DIF, ANDREI OREKHOV, P. N. Lebedev Physical Institute, OLGA ROSMEJ, GSI, VLADIMIR TIKHONCHUK, CELIA, CHRISTINE LABAUNE, LULI — Shock ignition (SI) is a two steps alternative direct-drive scheme for inertial fusion. The first one is a several nanoseconds long compression with low intensity beams. The second one is a several hundred of picoseconds stage using high intensity beams to create a converging shock leading to ignition. The coupling of this intense pulse with the coronal plasma is the most unknown of this scheme. We have designed an experiment that couples a high intensity laser pulse (526nm 20J 1-12 ps) and a high-energy laser pulse (526nm 400J 1.5 ns). We are able to study the interaction in the intensity range from 1015 up to 3.1016 W/cm2 relevant to the interaction of the SI spike in preformed, hot (1 keV) and long (mm scale) plasmas. The picosecond beam was used with a random phase plate as the interaction pulse. We present the first measurements of time-resolved backscattered spectra from the smoothed picosecond beam as well as the transmitted intensity distribution through the plasma. We find that Brillouin instability can be responsible for up to 60% reflectivity in plasmas while Raman reflectivity stays at low levels.

YP8.00054 Numerical modeling and simulation of a magnetohydrodynamic(MHD) generators, HYOUNGKEUN KIM, National Energy Technology Laboratory (ORISE), E. DAVID HUCKABY, RIGEL WOODSIDE, THOMAS OCHS, National Energy Technology Laboratory — A MHD generator is a device that extracts electricity directly from thermal energy and kinetic energy. In a MHD generator, a supersonic fluid flow under applied magnetic field is used to produce electricity without any moving mechanical parts. Two numerical solvers have been developed to predict the dynamics of the fluid and the electricity generation efficiency: a 1D MHD code for quick assessment and design calculations and a 2D supersonic fluid flow under applied magnetic field is used to produce electricity without any moving mechanical parts. The coupling of this intense pulse with the coronal plasma is the most unknown of this scheme. We have designed an experiment that couples a high intensity laser pulse (526nm 20J 1-12 ps) and a high-energy laser pulse (526nm 400J 1.5 ns). We are able to study the interaction in the intensity range from 1015 up to 3.1016 W/cm2 relevant to the interaction of the SI spike in preformed, hot (1 keV) and long (mm scale) plasmas. The picosecond beam was used with a random phase plate as the interaction pulse. We present the first measurements of time-resolved backscattered spectra from the smoothed picosecond beam as well as the transmitted intensity distribution through the plasma. We find that Brillouin instability can be responsible for up to 60% reflectivity in plasmas while Raman reflectivity stays at low levels.

YP8.00055 Pulse Thermal Conductivity in Alcator C-Mod L-mode and I-mode Plasmas1, A.J. CREELY, MIT, E.M. EDLUND, PPPL, N.T. HOWARD, ORISE, A.E. HUBBARD, A.E. WHITE, MIT — L-mode plasmas are characterized by high energy confinement, similar to H-mode, but with L-mode-like particle confinement, making L-mode very favorable for reactors due to the natural absence of Edge Localized Modes (ELMs) [D.G. Whyte et al 2010 Nucl. Fusion 50, 105005]. It is also observed at Alcator C-Mod that core turbulence (0.4 < r/a < 0.8) is reduced in I-mode compared to L-mode [A.E. White et al 2014 Nucl. Fusion 54, 083019]. Power balance analysis indicates that the effective thermal diffusivity, is reduced in I-mode as well, and linear gyrokinetic analysis suggests that the growth rate of the ion temperature gradient mode is reduced in I-mode. It is of interest to consider perturbative transport analysis, not just steady state analysis. We calculate a perturbative thermal diffusivity from the propagation of heat pulses generated by sawtooth crashes. Preliminary analysis indicates that the heat pulse thermal diffusivity is reduced by 35% in I-mode compared to L-mode, which appears, superficially, to be consistent with the overall improved energy confinement in I-mode.

1This work is supported by the US DOE under grants DE-SC0006419 and DE-FCo2-99ER54512-CMOD.

YP8.00056 Correlation of dust injection rate and microwave penetration of an overly dense plasma layer, ERIC D. GILLMAN, US Naval Research Laboratory, JEREMIAH WILLIAMS, Wittenberg University, BILL AMATUCCI, US Naval Research Laboratory — Microparticle injection into a plasma discharge, producing a dusty plasma, has been shown to significantly reduce the electron density as electrons are captured during the microparticle charging process. This has in turn been shown to increase the transparency and penetration of microwaves into an overly dense plasma layer. Results from these studies focus on understanding the correlation between the rate of microparticle injection and effects on microwave penetration of the plasma layer, as well as microwave scattering off of the charged microparticles. These studies are applicable for mitigating the communications radio blackout problem experienced by hypersonic vehicles and may have additional applications for satellite communications.
YP8.00057 3D Diagnostics of Plasma Interactions with Surface

ALEXANDER MUSTAFAEV, ARTIOM GRABOVSKYI, ANASTASIYA STRAKHOVA, National University of Mineral Resources “Mining”, VLADIMIR SOUKHOMLINOV, Saint-Petersburg State University — The plasma-surface interactions play an important role in various kinds of plasma applications. In the same time the physical behind of these processes is not well understood, that’s why developing new plasma diagnostics methods is the main task for plasma engineering. This talk presents 3D diagnostics method of plasma interaction with surface, which has been developed for wide range of plasma types. In knudsen diode with surface ionization the processes of secondary electron emission (SEE) from poly-crystal surfaces has been investigated. It is shown that SEE yield can be indeed very high (∼0.8) but still not approaching unity. This result is explained by additional reflection of primary electrons from a potential barrier near the poly-crystal surface. The contribution of electron reflection from the barrier and the surface has been identified and studied. In plasma of helium and mercury glow discharge this method has been successfully applied for measurements of electron and ion distribution functions. The reliability of the method has been tested by comparing experimentally measured distributions of electrons and ions with results of theoretical calculations, taking into account ambipolar field in plasma. This work was supported by Education Ministry of Russian Federation.

YP8.00058 Generation of high-density, thin gas jets for high repetition-rate experiments

YUAN TAY, LUKE HAHN, YONG-SING YOU, HOWARD MILCHBERG, KI-YONG RIM, University of Maryland, College Park — We have investigated the production of thin (50 - 500 microns), high-density (10^{19} - 10^{21} cm^{-3}) gas jets at high backing pressure (1000 psi) and cryogenic temperature (100 K). Capillary tubes with various diameters are used to produce thin and dense gas jets in continuous flow. The gas density profiles are characterized by optical interferometry. Rayleigh/Mie scattering is also monitored to check the presence of argon clusters. Our result shows a peak gas density of 10^{21} cm^{-3} near the nozzle orifice, approaching the critical plasma density at 800 nm laser wavelength when the gas target is singly ionized. This high-density gas jet, achieved by high backing pressure and cryogenic cooling, can allow studies of laser interaction with overdense plasmas in gas targets, without generating unwanted debris as in solid targets.

1Work supported by DOE and DTRA.

YP8.00059 Electon oscillation damping in ultracold plasmas

WEI-TING CHEN, JACOB ROBERTS, Colorado State University — By applying sharp electric field pulses to an ultracold plasma (UCP), it is possible to induce an electron center-of-mass oscillation around the ion center-of-mass. This oscillation damps at a rate that is dependent on UCP parameters such as electron temperature, UCP charge neutrality, electron density, and others. By tuning the experimental parameters of the UCP carefully, the main contribution to the damping rate is electron-ion collisions. Thus, the electron-ion collision rate can change in these systems. Our recent experimental results are reported, as well as our plans to extend these measurements further towards a more strongly-coupled electron component regime.

1supported by the AFOSR

YP8.00060 Development of the Small Helicon Magnetoplasma Thruster (SHMAPT)

CELSO RIBEIRO, JORGE ANDRES-DIAZ, RALPH GARCIA-VINDAS, ELIAN CONEJO, GERARDO PADILLA-VIQUEZ, ALEXIS DEVITRE, Centro de Investigacion en Ciencias Atomicas Nucleares y Moleculares, Universidad de Costa Rica, ESTEBAN AVENDANO, Escuela de Fisica, Universidad de Costa Rica, EDUARDO CALDERON, LEONARDO LESSER-ROJAS, Escuela de Ingenieria Mecanica, Universidad de Costa Rica — Magnetoplasma-based electric rocket devices are envisaged to be used for the same tasks as those of ion thrusters (e.g. satellites’ orbital correction). So far, the electroless types seem as the only feasible way to lead manned missions into deep space. We have constructed a small helicon magnetoplasma thruster (SHMAPT) to study the physics of helicon plasma (e.g. the double helicon structure) and its relation with the thrust, specific impulse, and the plasma-wall interaction, using a variety of gases. Diagnostic developments have been planned using Mach and Langmuir probes, strain-gauges, and light emission spectroscopy. SHMAPT is composed by a water-cooled cooper helicon antenna (6 cm length, 2.6 cm diameter) mounted onto a sapphire tube (1.5 mm thickness, 2.5 cm external diameter, 40 cm length). The antenna is coupled to a commercial 13.56 MHz source with variable power (initially up to 600 W and later up to 5 kW). Two NdFeB permanent magnets, each of 0.24 T, are fitted at the extremities of the antenna. This structure is assembled into a square 0.07 m^3 high vacuum chamber pumped by a 50 l/s turbo pump backed by a 2.5 m^3/h diaphragm pump. Preliminary results will be presented.

3Acknowledgments to National Instruments for DAC-Control unit

YP8.00061 Calibration of ^{22}Na Using the Sum-Peak Counting Method

MOLLIE BIENSTOCK, State University of New York at Geneseo, RYAN FITZGERALD, National Institute for Standards and Technology — A calibrated positron emitter, ^{22}Na, is needed for nuclear cross section measurements. The peak of this source was performed using a self-calibrating sum-peak counting method which has the potential to replace calibrated sources for various other applications. The sum-peak method was used with three different detector setups: a single high purity germanium detector, a 4”x5” NaI well detector and the same NaI well detector paired with a 3”x3” NaI detector, obtaining a 4π-counting geometry. The ^{22}Na decays via positron emission mostly to an excited state of ^{22}Ne which promptly de-excites and emits a 1275 keV gamma ray. The 511 keV gamma ray produced from the positron annihilation with the 1275 keV gamma generating a 1786 keV peak in the observed spectra. The total counts in the three peaks as well as the total counts observed in the spectrum are used to calculate a value for the activity of the source. In order to get a better understanding of the source and the detector geometries, a simulation of the setups was generated using EGDesign software that uses Monte Carlo simulations to model radiation transport. Using this program, and subsequent Monte Carlo calculations, a model of the spectra produced from each setup was created and used to fit theory to data and get a more accurate number for the activity of the source. Results obtained from this experiment are being compared to independent measurements from HPGe gamma ray spectrometry and 4π NaI integral counting using calibrated detectors.

Friday, October 31, 2014 12:30PM - 1:30PM –
Session ZR1 Door Prize Drawing

Acadia/Bissonet - Mark Koepke, West Virginia University

12:30PM ZR1.00001 Door Prize Drawing —