plasma flows and ion-cyclotron heating will be discussed. RFP, spherical tokamak, spheromak, reconnection experiments, and linear machines. Several mechanisms of ion heating including viscous damping of turbulent mechanisms of the energy conversion are poorly understood. In this presentation I will cover examples of ion heating from many laboratory plasmas, including such as during sawtooth crashes in the tokamak and the Reversed Field Pinch (RFP). Even though this phenomenon has been observed for a long time specific reconnection as result of conversion of magnetic energy into thermal energy. In many cases, magnetic reconnection and the associated heating occur impulsively, FIKSEL, University of Wisconsin-Madison and Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas — In many laboratory plasmas this picture. In many dilute astrophysical plasmas, the mean free path along magnetic field lines can be very large compared to the gyroradius. As a result, thermal conduction is anisotropic along, but not across, magnetic field lines. In this regime, the condition for convective stability is significantly modified by the anisotropic heat flux, resulting in two buoyancy instabilities: the magnetothermal instability (MTI) and the heat-flux-driven buoyancy instability (HBI). Using MHD simulations with anisotropic thermal conduction, I demonstrate that these instabilities drive a magnetic dynamo, realign magnetic fields, and enhance or suppress thermal conduction, respectively. I discuss the application of these instabilities to the intracluster medium of clusters of galaxies in relation to their large-scale thermal structure, magnetic fields, and cooling flows. I also briefly discuss the relevance of the HBI to cold fronts in the ICM, such as in Abell 3667. Finally, I will briefly mention some ongoing work on heating of cooling cores with buoyant bubbles and discuss the long-standing cooling flow problem.

This work was partially supported by NASA under grant NNG 05GH39G and by NSF under grant AST 05-49577.

A Tale of Two Instabilities: Simulation of Buoyancy Instabilities in the Intracluster Medium1. JAN PARRISH, UC Berkeley — In many dilute astrophysical plasmas, the mean free path along magnetic field lines can be very large compared to the gyroradius. As a result, thermal conduction is anisotropic along, but not across, magnetic field lines. In this regime, the condition for convective stability is significantly modified by the anisotropic heat flux, resulting in two buoyancy instabilities: the magnetothermal instability (MTI) and the heat-flux-driven buoyancy instability (HBI). Using MHD simulations with anisotropic thermal conduction, I demonstrate that these instabilities drive a magnetic dynamo, realign magnetic fields, and enhance or suppress thermal conduction, respectively. I discuss the application of these instabilities to the intracluster medium of clusters of galaxies in relation to their large-scale thermal structure, magnetic fields, and cooling flows. I also briefly discuss the relevance of the HBI to cold fronts in the ICM, such as in Abell 3667. Finally, I will briefly mention some ongoing work on heating of cooling cores with buoyant bubbles and discuss the long-standing cooling flow problem.

1 This work was partially supported by NASA under grant NNG 05GH39G and by NSF under grant AST 05-49577.

Saturday, May 2, 2009 3:30PM - 5:18PM –
Session D6 GPAP DPP: Ion Heating in Turbulent Plasmas Governor’s Square 16

3:30PM D6.00001 Scenarios for Ion Heating in Low Frequency MHD Turbulence1, W.H. MATTHAEUS, University of Delaware, Newark, DE 19716 — Dissipation of a magnetohydrodynamic cascade is of considerable interest in understanding the solar corona and solar wind, as well as in diverse circumstances in astrophysical and laboratory plasma physics. The problem is considerably complicated when the collisionality of the medium is low, due to the potential role of a variety of kinetic processes. Familiar cases such as cyclotron heating or linear Vlasov decay are typically described for homogeneous plasmas, and substantial generalizations may be required for the structured conditions that occur naturally in intermittent turbulence. A first step toward understanding dissipation is a description of the cascade, which when a large scale magnetic field is present is expected to be highly anisotropic in a way that favors perpendicular spectral transfer. Parallel cascade may not be entirely negligible however, especially through compressive channels. Perpendicular cascade gives rise to structures such as current sheets. Substantial evidence, using test particles, but recently in observations and in kinetic simulations, suggests that heating can occur due to ion interaction with these structures. In particular, perpendicular heating of ions is expected, and parallel heating of electrons. This may give rise to a two stage dissipation mechanism that first removes some energy near ion scales, and then much of the remaining energy at electron scales. Between these scales, wave energy may sometimes be enhanced due to reversible or linear kinetic processes. This perspective, while not fully explored in terms of self consistent inhomogeneous plasma physics, maybe provide a perspective on how low frequency waves can generate an MHD cascade that links ultimately to kinetic scales, where fluctuation energy vanishes in favor of increased entropy and internal energy. A number of observations are consistent with this picture.

1 Research supported by NASA Heliophysics Theory NNX08AI47G, and NSF ATM 0539995 and the SHINE program NSF ATM 0752135.

4:06PM D6.00002 Ion Heating from Magnetic Reconnection in Laboratory Plasmas1, GENNADY FIKSEL, University of Wisconsin-Madison and Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas — In many laboratory plasmas ions are much hotter than expected from classical heating mechanisms such as electron-ion collisions. Frequently, ion heating is observed during magnetic reconnection as result of conversion of magnetic energy into thermal energy. In many cases, magnetic reconnection and the associated heating occur impulsively, such as during sawtooth crashes in the tokamak and the Reversed Field Pinch (RFP). Even though this phenomenon has been observed for a long time specific mechanisms of the energy conversion are poorly understood. In this presentation I will cover examples of ion heating from many laboratory plasmas, including RFP, spherical tokamak, spheromak, reconnection experiments, and linear machines. Several mechanisms of ion heating including viscous damping of turbulent plasma flows and ion-cyclotron heating will be discussed.

1This work was supported by the US D.O.E. and N.S.F.
amplified by the ICM turbulence through small-scale dynamo processes, can be the origin of cluster-wide magnetic fields. 

While micro Gauss (\(\mu G\)) fields can evolve into milli Gauss fields, we have found that evaporation can occur only from the cluster “surface”, namely either (i) the gas is completely unmagnetized (\(B\) \(\ll\) \(10^{-9}\) Gauss) in the ICM, or (ii) \(B\) \(\gg\) \(10^{-9}\) Gauss) in the cluster envelope. This lowers the cluster-averaged fraction of the evaporated hot gas to few percent or less. However, if the missing hot component is indeed \(\sim\) \(10^9\) ergs while micro Gauss (\(\mu G\)) fields can distribute over \(\sim\) Mpc scales throughout the whole cluster. This finding shows that magnetic fields from AGNs, being further amplified by the ICM turbulence through small-scale magnetic processes, can be the origin of cluster-wide magnetic fields.

Galaxy clusters could be the site of distinctive particle acceleration processes including acceleration along large scale structure formation shocks. Studies of how cosmic rays and magnetic fields interact with the intercluster medium will provide a better understanding of the pressure and energy budget of galaxy clusters. The previous gamma-ray space telescope, EGRET, placed upper limits on the non-thermal emission. We now present early results on galaxy clusters using data from the Fermi/LAT.

8:42AM G8.00002 MHD Turbulence, Dynamo, and the Origin of Magnetic Fields in Galaxy Clusters. HUI LI, LANL, HAO XU, LANL/UCSD — We present self-consistent cosmological magnetohydrodynamic (MHD) simulations that simultaneously follow the formation of a galaxy cluster and the magnetic field ejection by an active galactic nuclei (AGN). We find that the magnetic fields ejected by the AGN, though initially distributed in relatively small volumes, can be transported throughout the cluster and be further amplified by the intra-cluster medium (ICM) turbulence during the cluster formation process. The ICM turbulence is generated and sustained by the frequent mergers of smaller halos. A cluster-wide dynamo process is shown to exist in the ICM and amplify the magnetic field energy and flux. The total magnetic energy in the cluster can reach \(\sim 10^{61}\) ergs while micro Gauss (\(\mu G\)) fields can distribute over \(\sim\) Mpc scales throughout the whole cluster. This finding shows that magnetic fields from AGNs, being further amplified by the ICM turbulence through small-scale magnetic processes, can be the origin of cluster-wide magnetic fields.

8:54AM G8.00003 Are ICM Magnetic Fields Generated from Scratch by Cosmic Rays?*. MIKHAIL MEDVEDEV, University Of Kansas, OLGA ZAKUTNYAYA, Space Research Institute, Russia — The origin of the micro-Gauss magnetic fields in galaxy clusters is one of the outstanding problem of modern cosmology. The intra-cluster medium (ICM) plasma is not static, as is seen in cosmological simulations and deduced from observational data. The motions are turbulent and supersonic with a number of merger and accretion shocks. We propose here that cosmic rays (CR) accelerated by the shocks are a natural and inevitable source of magnetic fields which are produced due to the CR streaming motion via a Weibel-type plasma instability. We develop a self-similar model of a CR pre-shock and demonstrate that, in contrast to the conventional lore, the generated magnetic fields (i) are large-scale (of order the shock curvature radius, \(\sim\) 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 order a fraction of the CR 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 ICM at essentially a few cluster light-crossing times.

Supported by AST-0708213, NNX-08AL39G, DE-FG02-07ER54940.

9:06AM G8.00004 Anisotropic thermal conduction in cosmological cluster formation simulations. MATEUSZ RUSZKOWSKI, University of Michigan, IAN PARRISH, University of California at Berkeley, MARCUS BRUEGGEN, Jacobs University — We investigate the role of the magnetothermal instability (MTI) in the cosmological cluster formation simulations. Our simulations self-consistently incorporate the effects of the field amplification by the structure formation (i.e., gravitational collapse and shearing) and by anisotropic thermal conduction, as well as the effects of violent sloshing motions (e.g., due to mergers) that tend to slow down the field growth. We quantify the effects of these processes on the temperature and density profiles, the strength and topology of the magnetic fields as well as the effective thermal conduction in the intracluster medium.

9:18AM G8.00005 Limits on Gas Evaporation from Galaxy Clusters*. OLGA ZAKUTNYAYA, Space Research Institute, Russia, MIKHAIL MEDVEDEV, University of Kansas — Recent observations of a number of galaxy clusters using the Sunyaev-Zel’dovich effect indicate that about 1/3 of baryonic mass is missing from the hot intra-cluster medium (ICM), which is significantly larger than the fraction of stars and cool gas, which account for only about 10%. Here we address the question whether the remaining 22 ± 10% can be accounted for by thermal evaporation of gas from clusters. We have found that evaporation can occur only from the cluster “surface”, \(r \sim r_{\text{vir}}\), and not from its interior. We evaluated particle diffusion through the magnetized ICM for several scenarios of ICM turbulence and found that diffusivity is suppressed by at least a factor of 100 or more, compared to the Spitzer value. Thus, only particles from radii \(r \gtrsim 0.9r_{\text{vir}}\) can evaporate. Diffusion of particles from inside the cluster, \(r \lesssim 0.9r_{\text{vir}}\), takes longer than the Hubble time. This lowers the cluster-averaged fraction of the evaporated hot gas to few percent or less. However, if the missing hot component is indeed due to evaporation, this strongly constrains the magnetic field structure in the cluster envelope, namely either (i) the gas is completely unmagnetized (\(B \lesssim 10^{-21}\) gauss) in the cluster halo or (ii) the magnetic fields in the ICM are rather homogeneous and non-turbulent.

Supported by AST-0708213, NNX-08AL39G, DE-FG02-07ER54940.
9:30AM G8.00006 Measuring Sunyaev-Zel’dovich Scaling Relations with APEX-SZ, AMY BENDER, University of Colorado at Boulder, APEX-SZ COLLABORATION\(^1\) — Accurately measuring the masses of galaxy clusters is critical to the precise constraint of cosmological parameters using cluster surveys. Detecting clusters with the Sunyaev-Zel’dovich effect (SZE) is extremely promising and the observed flux is theoretically shown to be an excellent proxy for total cluster mass. We present 150 GHz observations of the SZE taken using the APEX-SZ camera; a 330 element TES bolometer array mounted on the APEX telescope in northern Chile. We combine SZE and X-ray analysis for several clusters and compare relationships between the observable SZE flux and total cluster mass with expected values from theory and simulations. Our sample contains both relaxed and merging clusters over a wide redshift range allowing us to probe the dependence of our correlations on the dynamical and evolutionary state of the clusters.

\(^1\)http://bolo.berkeley.edu/apexsz/group.html

9:42AM G8.00007 Supermassive Black Holes and Spiral Structure in Disk Galaxies\(^1\), DANIEL KENNEFICK, University of Arkansas, Fayetteville, MARC SEIGAR, University of Arkansas, Little Rock, JULIA KENNEFICK, CLAUD LACY, University of Arkansas, Fayetteville, ARKANSAS GALAXY EVOLUTION SURVEY (AGES) COLLABORATION — Our collaboration has recently identified an interesting relation between supermassive black hole (SMBH) mass and the pitch angle of spiral arms in disk galaxies whose SMBH mass has been measured with some precision. I discuss this relation and the uses to which it might be put in permitting estimates of SMBH mass for distant normal galaxies for which only imaging data is available, as well as its possible significance for our understanding of galactic structure.

\(^1\)NASA EPSCOR

9:54AM G8.00008 Galactic archaeology in action space, ROBYN SANDERSON, MIT — Working in action space offers an instructive alternative view of the process of hierarchical assembly in galaxies, but performing the necessary canonical transformation formally requires both complete phase space information of a stellar population and knowledge of the correct galactic potential, neither of which is generally available. I use the approximate-action method pioneered by MacMillan and Binney (2008) to examine the remnant of a late-time merger in M31, which was modeled by Fardal et al. (2007).

10:06AM G8.00009 Galaxy Mergers with Adaptive Mesh Refinement: Star Formation and Hot Gas Outflow\(^1\), JI-HOON KIM, Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, JOHN WISE, Laboratory for Astronomy and Cosmology, NASA GSFC, TOM ABEL, Kavli Institute for Particle Astrophysics and Cosmology, Stanford University — In hierarchical structure formation, galaxy mergers are frequent and known to affect galaxy properties dramatically. Because of the non-linear coupling between pc and Mpc scales, high-resolution simulations are indispensable to comprehend galactic interactions. To this end, we present the first adaptive mesh refinement (AMR) simulation of two merging, low mass, initially gas-rich galaxies (\(2.0 \times 10^{10}\, M_\odot\) each), including star formation and feedback. With galaxies resolved by \(~2 \times 10^7\) total computational elements, we achieved unprecedented resolution of the multiphase interstellar medium, finding that a widespread starburst occurs in the merging galaxies via shock-induced star formation. Using the high dynamic range of AMR we also follow the interplay between the galaxies and the embedding medium depicting how galactic outflows and a hot metal-rich halo form. These results demonstrate that AMR provides a powerful tool in understanding interacting galaxies.

\(^1\)This work was partially supported by William R. and Sara Hart Kimball Stanford Graduate Fellowship.