The excitation of whistler-mode chorus waves in a laboratory plasma
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Motivated by the puzzles of chorus wave excitation in space and by their recognized importance in radiation belt dynamics, the excitation of whistler-mode chorus waves is studied in the Large Plasma Device at UCLA, by the injection of a helical electron beam into a cold plasma. Incoherent broad-band whistler waves similar to magnetospheric hiss are observed in the laboratory plasma. Their mode structure is identified by the phase-correlation technique. It is demonstrated that the waves are excited through a combination of Landau resonance, cyclotron resonance and anomalous cyclotron resonance. To account for the finite size effect of the electron beam, linear unstable eigenmodes of whistler waves are calculated by matching the eigenmode solution at the boundary. It is shown that the perpendicular wave number inside the beam is quantized due to the constraint imposed by the boundary condition. Darwin particle-in-cell simulations are carried out to study the simultaneous excitation of Langmuir and whistler waves in a beam-plasma system. The electron beam is first slowed down and relaxed by the rapidly growing Langmuir wave parallel to the background magnetic field. Subsequently, the electrons that compose the high-energy tail of the core plasma are trapped by the large amplitude Langmuir wave and are accelerated in the parallel direction. The excitation of whistler waves through Landau resonance is limited by the saturation of Langmuir waves, due to a faster depletion rate of the beam free energy from the inverted population by the latter compared to the former.

Plasma kinetics in the inner heliosphere and the NASA Solar Probe Plus mission
Stuart D. Bale
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I will describe measurements of the electron velocity distribution function in the solar wind at 1 AU using the 3DP instrument on NASA’s WIND spacecraft. Three distinct populations of electrons are observed and the collisional coupling between the cool, dense 'core' electron population and the solar wind protons can be observed directly. This Coulomb coupling relationship can be used probe the electron distribution of the solar corona and suggests that the coronal electron population will be highly non-thermal. I will also describe the NASA Solar Probe Plus mission, which will launch in 2018 and orbit the Sun with a final perihelion altitude of 9.8 solar radii, well within the predicted Alfven surface. Solar Probe Plus will make the first ever in situ measurements of plasma heating processes in the solar corona.
Method for determining $k(w)$ from a single-point measurement
Paul M. Bellan, Caltech

A method is described for determining the 3D wave-vector $k(w)$ of quasi-neutral plasma waves using magnetic field and electric current measurements made by a single spacecraft [1]. No knowledge of any dispersion relation is required and, in fact, the method reveals the dependence of $k$ on $w$. Knowledge of $k(w)$ can then be used to remove the space-time ambiguity produced by frequency Doppler shift associated with spacecraft motion so the actual plasma-frame wave dispersion relation is determined with no theoretical assumptions. Also, knowing $k(w)$ enables determination of the vector potential from the current in which case the complete wave information is recovered; i.e., all Fourier amplitudes are known as well as the phase dependence for each frequency. The method involves applying the Wiener-Khinchin theorem to cross-correlations of the current and magnetic field oscillations and to auto-correlations of the magnetic field oscillations. The wave-vector is proportional to the ratio of the Fourier transforms of these cross- and auto-correlations. The method requires that each wave frequency component map to a unique wave-vector, a situation presumed true in many spacecraft measurement situations. Synthetic data examples validate the method and the method has recently been used successfully on data from the MMS spacecraft [2].

2. D. Gershman et al., Nature Comm.| 8:14719 | DOI: 10.1038/ncomms14719 (2017)

Exploring the effect of conducting endcaps on Shercliff layer instability in the Princeton MRI Experiment
Kyle Caspary, Princeton Plasma Physics Laboratory

Rotating shear flows of a conducting fluid or plasma with decreasing angular speed with radius in the presence of a weak magnetic field are subject to the Magneto Rotational Instability (MRI). The MRI is proposed to be the mechanism to generate and sustain turbulence, which enhances angular momentum transport in some accretion disks. The Princeton MRI experiment is a modified Taylor-Couette device used to study rotating MHD flows with a GaInSn eutectic working fluid. It utilizes two coaxially differentially rotating cylinders with split endcaps to produce quasi-Keplerian flows. Diagnostics include internal magnetic probes on the inner and outer cylinders and Ultrasound Doppler Velocimetry (UDV). The experiment has been upgraded to improve mechanical operation and to increase the expected MRI saturation levels by installing electrically conductive endcaps. Measurements of the fluid velocity field and perturbed magnetic field are compared with results from the Spectral Finite Element Maxwell and Navier Stokes (SFEMaNS) code in order to understand the effects boundary effects such as Ekman flows and Shercliff layer instabilities. Work has been done to better understand the evolution of the Shercliff layer instability as the endcap boundary conditions change from insulating to conducting. It has been observed that, with insulating endcaps, the Shercliff layer
instability has a threshold corresponding to an Elsasser number ($\Lambda$) of 1 for the differentially rotating galinstan and is characterized by a transition from $m > 1$ to a dominant $m = 1$ mode. The conducting endcap experiments show a lower stability threshold which corresponds to $\Lambda = 1$ using the material properties (density, conductivity) of the copper endcaps instead of the GaInSn fluid. In contrast to observations with insulating endcaps, the instability with conducting endcaps shows fluctuating power in multiple higher $m$ modes.

**Recent Progress in Solar Wind Turbulence**  
Christopher H K Chen – Imperial College, London

I will summarise some of the recent progress that we have made in understanding plasma turbulence in the solar wind. At large scales, where the turbulence is predominantly Alfvénic, observations show some support for a cascade based on the critical balance principle, and also support some recent residual energy models that explain the different behaviour of the velocity and magnetic fluctuations. The compressive component of the turbulence is measured to be more spatially anisotropic than the Alfvénic part, which may explain why it does not undergo the strong collisionless damping that would otherwise be expected. And at small scales, a transition to a kinetic Alfvén turbulence is observed. However, many open questions remain, and I will discuss these, together with some thoughts about how future space missions and laboratory experiments may enable some of them be answered.


**New challenges in asymmetric reconnection**  
Li-Jen Chen  
Goddard Space Flight Center  
Astronomy Department, University of Maryland, College Park

The Magnetospheric Multiscale (MMS) mission has made discoveries that challenge our current understanding of reconnection with asymmetric upstream conditions. The challenges present new opportunities for laboratory experiments and simulation/theory studies. Among the challenges are the electron heating and transport in an ion-scale layer where gyrotropic magnetosheath-like electrons are observed upstream of the magnetospheric separatrix with intense lower hybrid wave turbulence. I will discuss a few of these challenges that take us beyond 2D reconnection models and compare the MMS results with applicable laboratory measurements from the Magnetic Reconnection eXperiment in Princeton.
Gyrokinetic Dynamic Fidelity Refinement (GK-DFR)
Bill Dorland, University of Maryland

Gyrokinetic algorithms are in wide use for fusion and heliospheric problems. Even in light of Moore’s Law, since the late 1980’s most of the advances in GK simulation capabilities have come from algorithm improvements. Together, advances (software and hardware) have brought insights and new questions to therefore, but the pace of algorithmic advances seems to have slowed just as these new questions demand ever more efficient codes. We always wish to perform more detailed and higher resolution simulations. Perhaps Dynamic Fidelity Refinement (DFR) is part of the next wave of algorithmic improvement. In other fields, Adaptive Mesh Refinement (AMR) algorithms have enabled breakthrough insights. DFR is essentially an adaptation of AMR techniques to simulations of phase space. A new GK-DFR code has been designed and built for GPU hardware. It thus promises potentially radical acceleration in both hardware and software (depending on the application; no single algorithm is best for all problems). Critical issues for DFR algorithm design will be presented, together with demonstrations of the technique for problems of interest to the IPELS community.

Anisotropic Electron Tail Generation during Tearing Mode Magnetic Reconnection
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Magnetic reconnection (MR) plays an important role in particle transport, energization, and acceleration in space, astrophysical, and laboratory plasmas. In the Madison Symmetric Torus (MST), discrete MR events release large amounts of energy from the equilibrium magnetic field. Particle heating and energization observed in MST are connected to tearing MR, but the mechanisms are not yet fully understood.

A large fraction of the magnetic energy released in MR is transferred to the ions in non-collisional processes with signatures of anisotropic heating, mass and charge dependence, and energetic ion tail formation. Unlike the ions, the thermal electron temperature decreases at reconnection events, which is consistent with enhanced electron heat transport due to increased magnetic fluctuations and stochastic transport. However, recent high-speed x-ray spectrum measurements reveal transient formation of a non-Maxwellian energetic electron tail during MR, characterized by a power-law ($E^{-\gamma}$) with the spectral index ($\gamma$) decreasing from 4.15 to 2.15, and then increasing rapidly to 6.77 after MR due to increased stochastic
transport. The spectral index at the time of MR also decreases with increasing change in magnetic energy. The x-ray emission peaks in a radial view and is symmetric in the toroidal direction, indicating an anisotropic electron tail is generated. The toroidal symmetry of the electron tail implies runaway acceleration is not a dominant process, consistent with the inductive electric field being 10X smaller than the Dreicer field during MR. Modeling of bremsstrahlung emission shows that a power-law electron tail distribution that has strong perpendicular anisotropy and is localized near the magnetic axis is consistent with x-ray measurements in the radial and toroidal views. This implies that the electron tail formation during MR most likely results from a turbulent wave-particle interaction.

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Three-dimensional coherent plasmoids in current-carrying plasmas
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Abstract
Plasmoid-mediated reconnection is examined using nonlinear three-dimensional resistive MHD simulations in a global toroidal geometry. An initial poloidal flux is created, in this case utilizing the helicity injection technique, in the presence of a toroidal guide field. We explore the physics of plasmoids reconnection for flux closure during plasma formation. Two types of current sheets are formed during flux expansion. First, a rare, classical example of plasmoid formation in a tokamak is demonstrated during helicity injection, where the injected magnetic field lines are oppositely directed near the injection region and form elongated Sweet-Parker current sheets (primary reconnecting current sheet). At high Lundquist number a transition to plasmoid instability has been shown in a large-scale toroidal fusion plasma.2 Consistent with the theory, fundamental characteristics of the plasmoid instability, including fast reconnection rate, have been observed in these realistic simulations.

Second, edge current sheets are formed due to the poloidal flux compression near the plasma edge and shown to provide the free energy for non-axisymmetric magnetic fluctuations, the 3-D edge current-sheet instabilities. The role of these 3-D magnetic fluctuations in the on-set of axisymmetric current-carrying plasmoids is examined. It is found that 3-D magnetic fluctuations can cause local flux amplification to trigger axisymmetric reconnecting plasmoids formation at the reconnection site.2 We also show coherent current-carrying _lament (ribbon-like) structures wrapped around the torus that are nonlinearly formed due to nonaxisymmetric reconnecting current sheet instabilities, the so-called peeling-like edge localized modes.3 These fast-growing modes saturate by breaking axisymmetric current layers isolated near the plasma edge and go through repetitive relaxation cycles by expelling current
radially outward and relaxing it back. The 3-D coherent current-carrying \_lament structures and their nonlinear dynamics due to the dynamo ejection are relevant to flares, which also exhibit ejection of field-aligned filamentary structures into the surrounding space.


**Pulsed Magnetic Reconnection, Drift Waves, and Turbulence**

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Magnetic reconnection is one of the most important fundamental processes in space and laboratory plasmas and has been the primary target of many numerical simulation efforts. The Magnetospheric Multiscale (MMS) mission is designed to make direct measurements of the electron physics of magnetic reconnection in 3D. These observations verify many of the predictions made by numerical simulations, but also indicate that, in some cases, magnetic reconnection in 3D may be more turbulent and time varying than expected. The particular case that we examine is asymmetric reconnection at the magnetopause. Magnetic reconnection at the magnetopause has asymmetric structure due to a significant difference between the properties of the plasma in the magnetosheath and those in the magnetosphere. Because of higher density, inflow to the reconnection region from the magnetosheath carries substantial ion momentum flux, which is ultimately slowed and diverted by a Hall electric field normal to the magnetopause current sheet. Interestingly, the electron drift due to the Hall electric field supplies the current along the X-line creating an extremely thin current sheet. In this thin current sheet, MMS observations also show that strong magnetic field fluctuations with frequencies above the ion cyclotron frequency but below the lower hybrid frequency. The magnetic field fluctuations are consistent with a thin, oscillating current sheet that is corrugated along the electron flow direction (along the X-line), which is a type of electromagnetic drift wave. The magnetic field fluctuations are seen in six events confirmed as asymmetric magnetic reconnection. These observations suggest that turbulence and time variation may be common in asymmetric reconnection, penetrate into the electron diffusion region, and possibly influence the magnetic reconnection process.
Energetic particle interactions with turbulence in the laboratory
I. Furno, F. Manke, M. Baquero, A. Fasoli, P. Ricci

Understanding the interaction of suprathermal ions with turbulence is fundamental to unveil the physics governing a wide variety of phenomena in astrophysical and laboratory plasmas. Examples range from particle dropouts during impulsive solar energetic particle events to transport of alpha particles in fusion reactors. Advances are hampered by difficulties in diagnosing distant astrophysical plasmas as well as fusion-grade plasmas. Here, I report on experimental, numerical and theoretical investigations of suprathermal ion dynamics in the laboratory device TORPEX at the Swiss Plasma Center, which permits full characterization of the dynamics of suprathermal ion and plasma turbulence.

In TORPEX, suprathermal ions are locally injected in turbulent plasmas using a miniaturized source and detected using grid-energy analyzers. Using a combination of three-dimensional measurements and dedicated first-principle numerical simulations, I will show that the classical diffusive paradigm in which the mean-square displacement of an ensemble of particles grows linearly in time, \( <x^2(t)> \propto t^g \) with \( g=1 \), is not adequate to describe the complexity of suprathermal ion transport in TORPEX. Instead, the full spectrum of non-diffusive transport is observed, ranging from sub-diffusive, \( g < 1 \), to super-diffusive, \( g > 1 \).

The mechanism responsible for the non-diffusive transport is clearly identified, revealing that the transport character is determined by the interaction of the suprathermal ion orbits with the intermittent turbulent structures, and is strongly affected by the ratio of the suprathermal ion energy to the background plasma temperature.

Finally, I present first time-resolved measurements of the cross-field dynamics revealing highly intermittent traces of the suprathermal ion current in both super-diffusive and quasi-diffusive transport regime. This demonstrates that standard statistical observables used to measure the intermittency of a signal, such as the skewness, cannot be used alone to determine the nature of transport. At the same time, measurements of the mean-square displacement may not unequivocally provide the underlying system dynamics. This work links observations usually
inaccessible in astrophysical plasmas, namely energy resolved three-dimensional
time-averaged measurements, with Eulerian time-resolved measurements, which
are often the only way to study such systems.

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The collision of magnetic flux ropes, non-local Ohm’s law and time domain structures


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Magnetic flux ropes are bundles of twisted magnetic fields and their associated
current. They are common on the surface of the sun (and presumably all other stars)
and are observed to have a large range of sizes and lifetimes. They can become
unstable and resulting in coronal mass ejections that can travel to earth and indeed,
have been observed by satellites. Single and multiple flux ropes have been
reproducibly generated in the LArge Plasma Device (LAPD) at UCLA. Using a series
of novel diagnostics, the following key quantities, $\overline{\mathbf{B}}, \overline{\mathbf{V}}, \overline{\mathbf{\rho}}, \overline{\mathbf{\alpha}}, \overline{\mathbf{\tau}}$ (\(\mathbf{\tau}\) is the plasma flow
and \(\mathbf{\rho}\), the plasma potential) have been measured at more than 48,000 spatial
locations and 7,000 time steps. The construction and deployment of the diagnostic
probes; conditional averaging techniques; and, calculation of relevant quantities
will be presented. From these measurements, $\overline{\mathbf{J}}, \overline{\mathbf{A}}, -\overline{\mathbf{\nabla}} \phi, -\overline{\nabla} \mathbf{A} \cdot \mathbf{P} = nk_e T$, magnetic
Helicity, and Quasi-Separatrix Layer (QSL) are derived from the data. Every term in
Ohm’s law is evaluated across and along the local magnetic field and the plasma
resistivity derived. Ohms law does not yield a physically meaningful resistivity and
the data meets a condition for non-locality. The Kubo AC conductivity yields
meaningful results for the global resistivity. The resistivity in the reconnection
region is also evaluated using the canonical helicity. Time domain structures (spiky
electric fields) are observed to move from the reconnection region to the edges of
the current channels. Their motion, spatial morphology and statistical quantities
associated with them will be presented.

Work done at the Basic Plasma Science Facility at UCLA, which is supported by the
US Department of Energy and the National Science Foundation.
Collisionless Interaction of a Magnetized Ambient Plasma and a Field-Parallel Laser Produced Plasma

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We present the first laboratory measurements of collisionless coupling between a super-Alfvénic ($\textit{M}_A \sim 5$) field-aligned debris plasma moving parallel to the background field and a large, magnetized ambient plasma ($\text{He, } n_0 \sim 10^{13}$ cm$^{-3}$). A laser-produced debris plasma is created by focusing the Raptor laser (200 J, 25 ns) on a planar plastic target embedded in the ambient Large Plasma Device (LAPD) plasma at the University of California, Los Angeles. The resulting ablated material interacts with the ambient plasma over a length of over 12 m. Magnetic flux probes (bdots), Langmuir probes, and a high temporal resolution monochromator were used to diagnose the interaction. Waves observed are consistent with excitation of the Right Hand Instability near the target. Results are compared to 2D hybrid simulations as well as analytical predictions.

PIC simulation studies of merging processes of spheromak-like and spherical-tokamak-like plasmoids

Ritoku Horiuchi
National Institute for Fusion Science

Two different types of merging processes of two plasmoids have been examined by means of two-dimensional PIC simulation. One is a counter helicity merging process of two spheromak-like (SP) plasmoids without any guide field component perpendicular to reconnection magnetic field. The other is a merging process of two spherical-tokamak-like (ST) plasmoids with a strong guide field in a reconnection region. In contrast to collisionless reconnection in an open system, most of plasma and energy are confined inside a newly formed plasmoid after the merging in the present simulation. By comparing the simulation results, we have examined the detailed mechanisms of merging and energy transfer processes for two cases, and clarified the guide field dependence. It is found that the merging process is suppressed due to the strong guide field for the ST case, while the EM energy is efficiently transferred to particles through the merging process for the SP case. The detailed mechanism will be discussed in the presentation.
Magnetic Flux Ropes in Heliophysics: An approach through the Grad-Shafranov equation
Qiang Hu (Department of Space Science, University of Alabama in Huntsville)

We provide a review of quantitative characterization of magnetic flux ropes throughout the Heliosphere. In particular, we present an approach based on the Grad-Shafranov (GS) equation, kin to plasma fusion science, describing two dimensional configurations such as tokamak and spheromak, even intrinsically three-dimensional stellarators. The novel technique, so-called GS reconstruction, utilizes the GS equation to derive two and a half dimensional configuration of space plasmas in either cylindrical or toroidal geometry from in-situ spacecraft data. Specific case studies will be presented for magnetic flux ropes embedded in Coronal Mass Ejections (CMEs), including analysis of their source region properties. We will present detailed GS reconstruction of magnetic flux ropes at 1 AU, yielding a complete set of physical parameters including magnetic flux, current, relative magnetic helicity, and field-line twist distributions. We relate these results with the corresponding source region properties to elucidate on the origination especially via magnetic reconnection on the Sun. Physical processes also of interest to laboratory plasmas such as magnetic reconnection and magnetohydrodynamic instability will be discussed. We aim to contribute to the increasing interest in the formation/origination and evolution of magnetic flux ropes of a range of scales in space and their connection to lab plasmas.

Experimental Detection of Plasmoids During Two-Fluid, Resistive Reconnection
J. Jara-Almonte, H. Ji, M. Yamada, J. Yoo, and W. Fox

Magnetic reconnection is an inherently localized process and mechanisms coupling global scale dynamics are not well understood. A leading candidate is the breakdown of elongated, reconnecting current sheets into numerous smaller current sheets – the plasmoid instability. In the Magnetic Reconnection Experiment (MRX), recent hardware improvements have extended the accessible parameter space and allow for the study of long-lived, elongated current sheets. Moreover, by using Argon, cool, high density, and reproducible plasmas are formed which allows for a detailed statistical study of collisional reconnection. As a result, we have conclusively measured the onset of plasmoids during resistive, anti-parallel reconnection for the first time. The current sheet thickness is intermediate between the ion and electron kinetic scales such that the plasma is strongly in the Hall-MHD regime. Surprisingly, plasmoids are observed at Lundquist numbers (<100) well below theoretical predictions (>10^4). The number of plasmoids formed scales with both Lundquist number and current sheet aspect ratio. Finally, plasmoids are shown to couple local and global physics by enhancing the reconnection rate. Implications for both astrophysical plasmas and future laboratory experiments will be discussed.
Solar magnetic self-organization:
A case for a shallow thin solar magnetic structure
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Abstract
Self-organization effects of magnetized laboratory plasma are shown to have a powerful effect in the Sun and provide a feasible way to reconcile the size of the solar dynamo with the resistive diffusion timescales associated with its size. The resulting model consists of a thin, stable magnetic equilibrium covering most of the solar surface below the photosphere, arranged in a mesh within the supergranules. The equilibrium is reshaped and reorganized on an 11-year half-cycle due to slow, large-scale solar activities. This periodic readjustment of the equilibrium triggers the observed magnetic activity, and the thinness of the equilibrium makes the solar dynamo powerful enough to also fuel other solar phenomena, such as the chromosphere, the corona, the solar wind, and the current in the solar current sheet. A physics-based description of the solar magnetic activity is presented that agrees with observations, including the power to the chromosphere and corona, the heliospheric current sheet and its magnitude at the earth, the 180 degree flipping of the magnetic fields and the pattern of the radial magnetic field in the solar cycle, the flipping of the polar magnetic flux, sunspots, the differences of the corona during solar minimum compared to solar maximum and the plasma structure in solar prominences.

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FLARE: a New User Facility for Studies of Multiple-Scale Physics of Magnetic Reconnection and Related Phenomena Through in-situ Measurements

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The FLARE device (Facility for Laboratory Reconnection Experiments; flare.pppl.gov) is a new intermediate-scale plasma experiment under construction at Princeton for the studies of magnetic reconnection in the multiple X-line regimes directly relevant to space, solar, astrophysical, and fusion plasmas, as guided by a
reconnection phase diagram [Ji & Daughton, Phys. Plasmas 18, 111207 (2011)]. All major components have been already fabricated and currently the device is being assembled and tested. Initial comprehensive set of research diagnostics is being constructed. The main diagnostics is an extensive set of magnetic probe arrays, covering multiple scales from local electron scales (~2 mm), to intermediate ion scales (~10 cm), and global MHD scales (~1 m). The main advantage to use this facility is the ability to simultaneously provide in-situ measurements over all of these relevant scales. By using these laboratory data, not only the detailed spatial profiles around each reconnecting X-line are available for direct comparisons with spacecraft data, but also the global conditions and consequences of magnetic reconnection, which are often difficult to quantify in space, can be controlled or studied systematically. The planned procedures and example topics as a user facility will be discussed in details, including international collaborations.

Magnetothermodynamic: Measuring the equation of state of a MHD plasma
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In SSX, we produce a magnetized plasma plume using a coaxial magnetized plasma gun located at one end of a cylindrical vessel. The plasma plume then is allowed to relax and flow through a glass tube to a stagnation flux conserver (SFC), located at the other end of the cylindrical vessel. The velocity of the plume is measured using a time of flight technique during its passage through the glass tube using a  \( \hat{B} \) probe array. Whereas the measurements of density (using HeNe laser interferometry), ion temperature (using Ion Doppler spectroscopy) and volume of the magnetized plasma (using the  \( \hat{B} \) probe array) are carried out inside the compression volume (SFC). While flowing through the glass tube, plasma can be accelerated using a pulsed magnetic field. The pulsed magnetic field is produced by discharging a capacitor through a theta pinch coil with a quarter cycle rise time faster than 1 \( \mu \)s. The experiments are aimed at accelerating the magnetized plasma to high velocities (\( \approx 200 \text{ km/s} \)). The accelerated plasma further compresses to a small volume in the SFC via stagnation and leads to heating of ions. We produce a PV diagram by using the temperature, the plasma density and the volume of the magnetic structure measured inside the SFC. The equation of state of the compressed plasma is analyzed to estimate the adiabatic compression of the magnetized plasma and the results will be presented. The direct measurement of stagnation, compression and heating in the SSX device may contribute towards a better understanding of compression events at the magnetopause driven by the solar wind.

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Using Velocity-Space Structure of Field-Particle Correlations to Characterize Energy Transfer in Space and Laboratory Plasmas
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Characterizing the mechanisms governing energy transfer between electromagnetic fields and charged particles in a turbulent, magnetized plasma is an essential task in the study of both laboratory and space plasmas. A number of classes of mechanisms have been proposed that mediate this field-particle energy transfer, including resonant (e.g. Landau and cyclotron damping), stochastic, and spatially intermittent (e.g. energization associated with current sheets and reconnection sites) mechanisms. Generally, the energy transfer fundamentally depends on the nonlinear field-particle interaction term in the Vlasov equation, and the structure of this interaction as a function of coordinate and velocity phase space can be used to characterize the transfer. A field-particle correlation, based upon the Lorentz acceleration term, is therefore a useful tool to identify the nature of the energy transfer in a given plasma system. We provide a brief derivation of the correlation, as well as a number of examples of its application to increasingly complex kinetic simulations. We also discuss potential application of the field-particle correlation to laboratory and spacecraft measurements, with particular emphasis on the effects of collisions and limited instrumental resolution.

Radiation Belt Wave Observations on the Van Allen Probes and Opportunities for Lab Experiments
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The physics of the creation, loss, and transport of radiation belt particles is intimately connected to the electric and magnetic fields which mediate these processes. A large range of field and particle interactions are involved in this physics from large-scale ring current ion and magnetic field dynamics to microscopic kinetic interactions of whistler-mode chorus waves with energetic electrons. To measure these kinds of radiation belt interactions, NASA implemented the two-satellite Van Allen Probes mission. As part of the mission, the Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) investigation is an integrated set of instruments consisting of a tri-axial fluxgate magnetometer (MAG) and a Waves instrument includes a tri-axial search coil magnetometer (MSC). These wave measurements include AC electric and magnetic fields from 10Hz to 400 kHz. We show a variety of waves thought to be important for wave particle interactions in the radiation belts: EMIC waves, magnetosonic waves, and whistler mode waves including upper and lower band chorus. Several of these wave modes could benefit from laboratory studies to further refine our understanding of the detailed physics
of the wave-particle interactions which lead to energization, pitch angle scattering, and cross-field transport. Examples are shown to illustrate some of these wave/particle processes to show relationships between wave activity and particle process observed in the inner magnetosphere.

**Magnetic reconnection experiments with pulsed power driven colliding plasma flows**

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We present a study of magnetic reconnection in a quasi-two-dimensional pulsed power driven laboratory experiment [1, 2]. The plasma in these experiments is created and accelerated by the JxB force of the driving, ~Mega-Ampere level currents, forming long lasting, intrinsically magnetised, super-sonic plasma flows [3] with thermal and kinetic betas on the order of unity. The annihilation of the anti-parallel magnetic fields in the reconnection layer leads to strong ion heating and formation of fast, super-Alfvenic outflows. Different regimes of reconnection can be accessed by changing the plasma material (carbon or aluminium), which allows to vary the plasma electron temperature and the Lundquist number. In the case of reconnection in carbon plasma [2], we observe the repeated formation and ejection of plasmoids, consistent with the predictions from semicollisional plasmoid theory. The relatively large spatial and temporal scales characterizing this experimental platform, together with an excellent diagnostic access, allow detailed characterization of the key plasma parameters [4] for quantitative comparison of the experimental results with numerical simulations.

References

**Laboratory evidence of spontaneous electrostatic and electromagnetic transition of low frequency Kelvin-Helmholtz waves**

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The Kelvin-Helmholtz (KH) instability plays a significant role in transport of mass, momentum, and energy in solar-terrestrial space plasmas [Hasegawa, Nature, 2004]. Recently, ion- scale plasma waves have been observed inside a KH vortex, and these waves are responsible for the cross-scale energy transport between fluid, electron, and ion scales, which is a compelling and fundamental problem of plasma physics [Moore, Nature Physics, 2016]. In the work, a direct experimental evidence indicates that there is an spontaneous electrostatic and electromagnetic mode conversion of KH waves. These waves were generated by the Kelvin-Helmholtz instability driven by the macroscopic velocity shears, which is often encountered in solar wind and magnetopause. This is achieved in a controlled laboratory plasma device (Keda Space Plasma EXperiment, KSPEX) using an interpenetrating plasma method [Y, Liu, Rev. of Sci. Instrum., 2016]. Fluctuations of electron density, potential, and magnetic field were detected, and low frequency plasma waves in the range sub-ion cyclotron frequency were observed. The wave is predominately perpendicular propagating electrostatic with short wavelength when the velocity shear is lower than a threshold. However, it transforms to a long wavelength quasi-parallel propagating electromagnetic wave. This electromagnetic wave can transport energy away from the region of wave generation, and it might be used to explain the cross scale energy transport in the interaction of solar wind and quasi-parallel propagating electromagnetic wave. This electromagnetic wave can transport energy away from the region of wave generation, and it might be used to explain the cross scale energy transport in the interaction of solar wind and magnetopause.

Formation of high-speed electron jets during magnetic reconnection in laser-produced plasma
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Flow-driven magnetic reconnection in high-energy-density laser-produced plasma has recently been conducted. In this paper, we perform two-dimensional (2D) particle-in-cell (PIC) simulations to study the interactions of two colliding laser-produced plasma bubbles with self-generated toroidal magnetic field, and two cases are investigated: in one case the two plasma bubbles have anti-parallel magnetic field (APcase) in the colliding region, and in the other case they have parallel magnetic field (Pcase). In both cases, we can find the quadrupole structure of the
out-of-plane magnetic field, the Hall electric field and electron energization in the colliding region. However, only in AP-case, we can observe three well-collimated in-plane electron jets. Two electron jets along the magnetic field at the edge of the plasma bubbles is formed after the electrons are trapped and accelerated by the out-of-plane electric field between the two colliding bubbles, and then move outward along the magnetic field. The high-speed electron jet in the middle of the outflow region is formed after the electrons are reflected and accelerated by the magnetic field in the pileup region, which is moving outward quickly. We demonstrate that beside the annihilation of magnetic field in the colliding region of the two laser-produced plasma bubbles, the three well-collimated electron jets can be considered as the evidence for laser-produced plasma magnetic reconnection. Electron acceleration in these two cases has also been analyzed.

**Plasmoid instability | bridging theory and experiments**

N. F. Loureiro

Reconnection research carried out during the last decade strongly suggests that reconnection sites (current sheets) should be violently unstable to the formation of multiplemagnetic islands, or plasmoids, in what has come to be known as the plasmoid instability. Analytical and numerical results indicate that stochastic plasmoid dynamics may be responsible for setting the reconnection rate, enabling efficient conversion of magnetic energy, and the onset of reconnection itself.

Most of these statements, if not all, have not yet been satisfactorily confirmed in experiments, although recent claims of experimental observation of plasmoids, and new experimental platforms that are just coming online, suggest that such experimental confirmation may be forthcoming. One of the difficulties in bridging experiments with what is known from theory is that the overlap in parameter space between theoretical/numerical and ex-perimental plasmas has been, at best, marginal in most studies that have been carried out.

This talk will focus on discussing the plasmoid instability in an interesting corner of parameter space where, although collisions are important, kinetic effects cannot be neglected. As it turns out, in this regime (which we call semi-collisional), the critical Lundquist number required to access the plasmoid instability is a function of the kinetic effects (specifically, of the ratio of the system size to the relevant ion kinetic scale, $p_s$ or $d_i$), and can be significantly lower than the (experimentally challenging) MHD requirement of $S \sim 10^4$ (Loureiro & Uzdensky, Plasma Phys. Control. Fusion, 2016). This result significantly eases the experimental requirements for accessing the plasmoid regime of reconnection; in addition, it should enable high-resolution numerical studies of the plasmoid instability in 3D geometries.
High Lundquist number collisionless reconnection on the Terrestrial Reconnection Experiment

J. Olson

As the collisionality of a plasma decreases, the ion and electron fluids decouple during magnetic reconnection, giving rise to the quadrupolar Hall magnetic fields. By decreasing the collisionality even further, kinetic features such as electron pressure anisotropy are able to develop [1], characterizing a new regime of collisionless reconnection. Recent PIC simulations have shown that collisions can still impede the development of pressure anisotropy and the more unique structures in the currents and magnetic fields during reconnection [2], constraining this regime to Lundquist numbers of $S > 10c(m_i/m_e)L/d_i$ (for anti-parallel reconnection), where $c < 1$ is an experimental scale factor and $L$ is the system size. The Terrestrial Reconnection Experiment (TREX), in operation at the Wisconsin Plasma Astrophysics Laboratory [3], was designed and built in order to study this regime. In its first campaign, TREX unexpectedly observed the spontaneous formation of secondary islands at the electron scale for $S\sim10^4$ and relatively small system size [4]. With recent upgrades to the facility including new drive coils and capacitor bank, TREX increased its reconnection drive by a factor of 10. Recent experiments have achieved Lundquist numbers approaching $10^5$, well within the collisionless regime where pressure anisotropy can develop unimpeded and is expected in the inflow (and outflow for guide-field reconnection). In comparison to earlier experiments, we observe that the width of the current layer decreases from $\sim8d_e$ to $\sim2d_e$, consistent with results from fully collisionless kinetic simulations.

References

Scaling Study of Reconnection Heating in Torus Plasma Merging Experiments

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Since 1985, we have been investigating toroidal plasma merging and reconnection for high-power heating of spherical tokamak (ST) and field-reversed configuration (FRC), using TS-3 (ST, FRC: R~0.2m, 1985~), TS-4 (ST, FRC: R~0.5m, 2000~), UTST (ST: R~0.45m, 2008~) and MAST (ST: R~0.9m, 2000~) devices. The series of merging experiments made clear the promising scaling and characteristics of reconnection heating: (i) its ion heating energy that scales with square of the reconnecting magnetic field $B_{rec}$, (ii) its energy loss lower than 10%, (iii) its ion heating energy in the downstream 10 time larger than its electron heating energy at around X-point and (iv) low dependence of ion heating on the guide (toroidal) field.
The $B_{\text{rec}}^2$-scaling was obtained when the current sheet is compressed to the order of ion gyrodadius. In the case of insufficient compression, the measured ion temperature was lower than the scaling prediction. Based on this scaling, we realized a significant ion heating over 1.2keV in the world-largest ST merging experiment: MAST [1,2] after detailed 2D elucidation of ion and electron heating up to 250eV in TS-3 and TS-4 ST merging experiments [3,4]. This promising scaling leads us to new high $B_{\text{rec}}$ reconnection heating experiments for future direct access to burning plasma regime: TS-U (2017~) in University of Tokyo and ST-40 in Tokamak Energy Inc. (2017~). This presentation reviews major progresses in those toroidal plasma merging experiments for physics and fusion applications of magnetic reconnection.


The ST merging is useful not only for (1) ST heating but also for (2) magnetic helicity injection/current drive of ST plasma. Its reversed process: the plasmoid ejection from ST plasmas is now fully controlled by coil currents for future “dynamic divertor” operations They revealed clear energy-conversion mechanisms of magnetic reconnection: huge outflow heating of ions in the downstream and Ohmic heating of electrons around the X-point. The reconnection outflow accelerates ions up to 70-80% of Alfven speed of reconnecting magnetic field, and they are thermalized by fast shock-like density pileups in the downstreams. The series of experiments agree that the reconnection heating energy is proportional to square of the reconnecting magnetic field. The guide toroidal field does not affect the bulk heating of ions and electrons, probably because the reconnection/ outflow speeds are determined mostly by the externally driven influx by the help of several fast reconnection mechanisms. Their mechanisms are qualitatively agree well with various PIC simulations [2] and with the Hinode satellite observation of solar coronal heating [1]. Those physics, particularly the reconnection heating and acceleration lead us to the up-graded high magnetic field merging experiments.

Interactions Between Energetic Ions and Alfvénic Instabilities in Tokamaks

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The tokamak approach to controlled nuclear fusion employs a toroidally-shaped magnetic field configuration to confine plasmas at temperatures beyond 20 keV. Future reactors aim to utilize the deuterium-tritium fusion reaction due to its favorable cross-section, where this DT reaction produces a 14 MeV neutron and a 3.5 MeV alpha particle. While the neutron is collected by the surrounding structure to allow for energy extraction, the alpha particle must be confined such that it
transfers its energy to plasma, thereby maintaining fusion temperatures. This self-heated scenario is known as a burning plasma state. The fusion-alpha population is supra-thermal and supra-Alfvénic, however, and is therefore able to excite plasma instabilities, e.g., Alfvén eigenmodes (AEs) that cause detrimental alpha transport and reduce fusion power output. Existing tokamaks study these phenomena using supra-Alfvénic (or nearly so) energetic ion populations produced by auxiliary heating with particle beams or injected radio-frequency waves. Energetic ions drive Alfvénic instabilities through resonant energy exchange producing modes at frequencies within plasma continuum gaps. The resulting energetic ion transport is sensitive to the spatial overlap of individual AEs. As the mode drive increases, the AE overlap becomes sufficient to produce stochastic energetic ion orbits and a considerable increase in transport. Energetic ions can also be expelled to the tokamak wall through AE interactions in which the ion energy is only slightly decreased, meaning that plasma heating is lost and there is great potential for damage to the plasma facing surfaces. Advanced diagnostics are used to measure both the confined and the lost energetic ion populations, including spectroscopic and physical probe methods. Theoretical treatments, including massively parallel particle following simulations, reproduce experimental observations using measured mode and plasma properties as inputs. Recent developments focus on enabling control of these instabilities through modification of the energetic ion velocity distribution such that ion-wave interactions are minimized. This work is supported under Department of Energy contract DE-FC02-04ER54698.

Overview of the design of 3D magnetic reconnection and dipole experiments at Harbin Institute of Technology

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A new magnetic reconnection experiment, the Asymmetric REconnection eXperiment-3 Dimensional (AREX-3D), and a new dipole experiment, the Dipole Research EXperiment (DREX), are currently being designed as key parts of Space Plasma Environment Research Facility (SPERF) at Harbin Institute of Technology in Harbin, China. The AREX-3D aims to provide a unique experimental platform, employing a unique set of coils, for studying reconnections in 3D geometry relevant to magnetopause and magnetotail to address: the role of electron and ion-scale dynamics in the current sheet; particle and energy transfer from magnetosheath to magnetosphere; particle energization/heating mechanisms during magnetic
reconnection; 3D effects in fast reconnection, e.g. the role of 3D magnetic null point. The DREX aims to provide a laboratory platform to simulate physics processes in the inner magnetosphere, e.g. trapping, acceleration, and transport of energetic charged particles, in a dipole magnetic field configuration. Here, we present an overview of the design of AREX-3D and DREX. Plasma diagnostics plan and engineering design of important coils will also be briefly presented.

THOR (Turbulence Heating ObserveR) is one of the three candidates for selection as the next ESA M-class mission (M4). THOR will be the first mission ever flown in space that is fully dedicated to study turbulence and how turbulence energizes plasma. Turbulent fluctuations are ubiquitous in astrophysical plasmas and reach up scales as large as stars, bubbles and clouds blown out by stellar winds, as well as entire galaxies. However, most of the irreversible dissipation of energy associated to turbulent fluctuations occurs at very small scales, the so-called kinetic scales, where the plasma no longer behaves as a fluid and the properties of individual plasma species (electrons, protons and heavier ions) become important. THOR will explore the kinetic plasma processes and will lead to an understanding of the basic plasma heating and particle acceleration mechanisms, of their effect on different plasma species and of their relative importance in different turbulent regimes. THOR will achieve this by making detailed in situ measurements of the closest available dilute and turbulent magnetized plasmas - the Near-Earth’s space - at unprecedented temporal and spatial resolution. THOR focuses on particular regions in space: the pristine solar wind, the Earth’s bow shock and interplanetary shocks, and the compressed solar wind regions downstream of shocks. These regions are selected because of their different turbulence properties and they reflect the properties of a number of distant astrophysical environments. In such way, THOR measurements will help understanding the fundamental behavior of plasma in the universe. Here we present THOR’s science and as well as the current status of mission and payload studies.
Development of a methodology for deriving Plasmaspheric Total Electron Content from In-Situ electron density measurements in highly eccentric equatorial orbits
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(1) School of Engineering and Informatics, University of Sussex, Brighton, United Kingdom. Total Electron Content (TEC) measurements yield very high values in the Near-Equatorial regions, which extends approximately ± 20° - 25° on either sides of the magnetic equator. Ironically, the bulk of the research on TEC profile and behavior has been carried out with respect to mid-latitude regions. Recently, efforts have been undertook by the scientific community in the equatorial belt as well as the international community to carry out research in this area, especially so after the advent of the GNSS such as GPS and their widespread usage. Nevertheless, much more studies need to be done.

The contribution of the Upper Plasmasphere (the altitudes above semi-synchronous orbit height up to the Plasma pause height) to the TEC at any given location has been and continues to be an un-quantified component. So far, as TEC could not be measured directly and needs to be derived from other parameters, it has not been possible to derive this component from traditional methods such as incoherent scattering radars, ground based ionosondes, satellite sounders and GNSS dual frequency measurements. Dual frequency measurements from GNSS such as GPS, GLONASS and Galileo cannot be employed as the Upper Plasmaspheric altitudes are above the satellite orbit altitudes of these GNSS.

The PEACE instrument in the Chinese – European Space Agency Double Star TC1 (TanCe 1) satellite and its highly eccentric equatorial orbit provide an excellent opportunity to build Upper Plasmaspheric TEC components in the Equatorial region from empirical in-situ measurements of electron density along the orbit in the 20000km to 40000km altitude range. The high eccentricity and the low perigee, high apogee of the TC1 orbit and the resulting smaller incident angle the orbital trace makes while in the a above altitude range resulting from it provide the ideal geometric opportunity to build the methodology and utilise the in-situ electron density measurements for the calculation of the Upper Plasmaspheric TEC component.

Furthermore, the suitability of the variation of the Inclination Angle of the mission makes TC1 an equatorial mission that was very much confined to the Near-Equatorial region approximately ± 200 - 250 on either sides of the magnetic equator. As the most pronounced absolute TEC values and variations are within this
region, TC1 data offers an excellent opportunity to build a TEC database of this region. The methodology developed and presented in this research generates a first time ever (comprehensive) database of Upper Plasmaspheric TEC components along the orbital path of the TC1, using a methodology of approximation equating arcs of the orbits to straight-line TEC Bars, which utilizes highly complex and advanced mathematics. This research aims to develop this methodology as such that the Plasmaspheric TEC component can be determined by applying it on the in situ measurements of electron density measured by any satellite having an eccentric elongated orbit.

Laboratory astrophysics studies using large-scale laser systems:
Weibel-instability mediated collisionless shock experiment

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ABSTRACT
Collisionless shock, in which the coulomb mean-free-path is much longer than the shock-front thickness, is ubiquitous in space and astrophysical plasmas. It is believed that collisionless shocks are the sources of cosmic rays. In such collisionless plasmas, wave particle interactions and collective effects of electromagnetic fields play an essential role in the shock formation. In addition to local observations of space plasmas by spacecraft and global emission measurements of astrophysical plasmas, laboratory experiments can be an alternative approach to study the formation of collisionless shocks.

We investigated Weibel-instability mediated collisionless shock (Weibel shock) in a self-generated magnetic field using large-scale laser systems.

On Omega (LLE, USA) laser experiments with CH/CH double-plane target, plasma parameters of counter-streaming flows were measured by collective Thomson scattering [1], and temporal evolution of Weibel filaments were observed by D-3He fusion produced proton radiography [2].

On the National Ignition Facility (NIF) experiments, CD/CD and CD/CH double-plane target was used. The transition from collisional to collisionless flows was investigated as the foil separation gets larger. Excess neutrons, when comparing the CD/CD and CD/CH interactions, indicated a strong thermalization [3]. We used D-3He proton radiography for the first time on the NIF and investigated temporal evolution of the Weibel instability and shock formation.

REFERENCES
LABORATORY OBSERVATION OF HIGH-MACH NUMBER, LASER-DRIVEN MAGNETIZED COLLISIONLESS SHOCKS

D. B. Schaeffer\textsuperscript{1}, W. Fox\textsuperscript{2}, D. Haberberger\textsuperscript{3}, G. Fiksel\textsuperscript{4}, A. Bhattacharjee\textsuperscript{1,2}, D. H. Barnak\textsuperscript{3,5}, S. X. Hu\textsuperscript{3}, and K. Gemaschewski\textsuperscript{6}

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Collisionless shocks are common phenomena in space and astrophysical systems, including solar and planetary winds, coronal mass ejections, supernovae remnants, and the jets of active galactic nuclei. Of particular interest are the class of high-Mach number shocks, which are believed to efficiently accelerate particles to some of the highest observed energies. Only recently, however, have laser and diagnostic capabilities evolved sufficiently to allow the detailed study in the laboratory of the microphysics of collisionless shocks over a large parameter regime. We present the first laboratory generation of high-Mach number magnetized collisionless shocks created through the interaction of an expanding laser-driven plasma with a magnetized ambient plasma. Time-resolved, two-dimensional imaging of plasma density and magnetic fields shows the formation and evolution of a supercritical shock propagating at magnetosonic Mach number $M_{\text{ms}} \approx 12$. Particle-in-cell simulations constrained by experimental data further detail the shock formation and separate dynamics of the multi-ion-species ambient plasma. The results show that the shocks form on timescales as fast as one gyroperiod, aided by the efficient coupling of energy, and the generation of a magnetic barrier, between the piston and ambient ions. The development of this experimental platform complements present remote sensing and spacecraft observations, and opens the way for controlled laboratory investigations of high-Mach number collisionless shocks, including the mechanisms and efficiency of particle acceleration. The platform is also flexible, allowing us to study shocks in different magnetic field geometries, in different ambient plasma conditions, and in relation to other effects in magnetized, high-Mach number plasmas such as magnetic reconnection or the Weibel instability.

MHD Turbulence in the Laboratory: Exploring Turbulence Analysis Techniques of Space in a Terrestrial Experiment.
David Schaffner – Bryn Mawr College

Broadband magnetic turbulence is generated in a laboratory setting using the magnetically dynamic, hot plasma generated by a plasma gun source. The plasma is
launched from the gun into a flux conserving chamber free from background magnetic fields where it is allowed to evolve and attain a minimum energy state under the constraint of helicity conservation. Windows of time during this evolution are found to exhibit steady-state turbulent fluctuations of density, flow, and magnetic field. A wide variety of fluctuation analysis techniques are employed on this data, some motivated by turbulence research of the solar wind and some motivated by fusion turbulence. Techniques include spectrum and variance anisotropy analyses, radial and temporal correlations, probability distributions of increments and intermittency, multi-and mono-fractal scaling, and permutation and statistical complexity. This suite of techniques is employed on data over a range controllable experimental parameters including initial stuffing flux, helicity, and gas injection timing in order to observe variations and trends in turbulence behavior. Results of these laboratory-based statistical analyses can be compared and contrasted to similar research conducted using satellite data in an effort to better overall understand magnetic turbulence phenomena.

Measurement of electron acceleration by inertial Alfvén waves in the LAPD

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Inertial Alfvén waves occur in plasmas where $v_A > v_{te}$ and the scale of wave field structure across $B_0$ is comparable to the electron skin depth. Such waves have an electric field aligned with $B_0$ that can accelerate electrons. It is likely that electrons are accelerated by inertial Alfvén waves in the auroral magnetosphere and contribute to the generation of auroras. While rocket and satellite measurements show a high level of coincidence of between inertial Alfvén waves and auroral activity, definitive measurements of electrons being accelerated by inertial Alfvén waves are lacking. Continued uncertainty stems from the difficulty of making a conclusive interpretation of measurements from spacecraft flying through a complex and transient process. A laboratory experiment can avoid some of the ambiguity contained in spacecraft measurements. Experiments have been performed in the Large Plasma Device (LAPD) at UCLA. Inertial Alfvén waves were produced while simultaneously measuring the suprathermal tails of the electron distribution function. Measurements of the distribution function use resonant absorption of whistler mode waves. During a burst of inertial Alfvén waves, the measured portion of the distribution function oscillates at the Alfvén wave frequency. The phase space response of the electrons is well-described by a linear solution to the Boltzmann equation. Experiments have been repeated using electrostatic and inductive Alfvén wave antennas. The oscillation of the distribution function is described by a purely Alfvénic model when the Alfvén wave is produced by the inductive antenna. However, when the electrostatic antenna is used, measured oscillations of the distribution function are described by a model.
combining Alfvénic and non-Alfvénic effects. Ongoing work is searching for nonlinear resonant acceleration of electrons by inertial Alfvén waves, a process believed to power a significant fraction of auroras.

This work was supported by the NSF GRFP and grants from NSF, DOE, and NASA. Experiments were performed at the Basic Plasma Science Facility which is funded by DOE and NSF.

Shear-Alfvén waves and the interesting influence of microinstabilities in weakly collisional high-β plasmas
J. Squire - Caltech

Microinstabilities, in particular the fire hose and mirror instabilities, are expected to be fundamental to the dynamics of many weakly collisional space and astrophysical plasmas. They occur because changes in the magnetic field in high-β plasmas readily create pressure anisotropies that exceed the magnetic pressure. Moreover, by limiting further growth of anisotropy and scattering particles, the nonlinear saturation of microinstabilities has a strong influence on large-scale plasma dynamics. I will explore some of the unexpected physics that occurs when microinstabilities are excited by large-amplitude MHD waves. Shear-Alfvén waves present a particularly interesting case: because the wave’s restoring force arises due to magnetic tension, if its amplitude is large enough to excite fire hose fluctuations, it will also be "interrupted" and unable to oscillate. This process causes the sudden dissipation of large-scale mechanical energy into heat, without the usual route through turbulence, and demonstrates the power of microscale fluctuations to control plasma dynamics on the largest scales. I will finish with a discussion of ongoing efforts to observe and diagnose the fire hose instability in the laboratory.

NONLINEAR CONVECTIVE HEAT TRANSPORT IN THE PRESENCE OF MULTIPLE INTERACTING MAGNETIZED ELECTRON TEMPERATURE FILAMENTS
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Results are presented from basic heat transport experiments and numerical simulations of multiple magnetized electron temperature filaments in close proximity. This arrangement samples cross-field transport from nonlinear drift-Alfven waves and large-scale convective cells. Experiments are performed in the Large Plasma Device (LAPD) at UCLA. The setup consists of three biased CeB6 crystal cathodes that inject low energy electrons (below ionization energy) along a strong magnetic field into a pre-existing large and cold plasma forming 3 electron temperature filaments embedded in a colder plasma, and far from the machine walls.
The cathodes are mounted on separate probe drives for variable positioning and each have a separate power supply that allows for individual DC voltage biasing capabilities. A triangular spatial pattern is chosen for the thermal sources and multiple axial and transverse probe measurements allow for determination of the cross-field mode patterns and axial filament length. It has previously been reported that single thermal filaments exhibit spontaneous excitation of thermal waves [1], and that the temperature gradient drives drift-Alfvén waves that lead to enhanced cross-field transport [2]. We have characterized these waves on an individual filament when a single source is activated. When the 3 sources are activated, and in close proximity, a complex wave pattern emerges due to interference of the various wave modes thus leading to enhanced cross-field transport. Detailed mode analysis and comparison with nonlinear simulations will be reported.


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**Onset of explosive magnetic reconnection and transition to turbulence in astrophysical and laboratory plasmas**

Anna Tenerani - UCLA

Magnetic reconnection is a process that leads to global changes of magnetic field line connectivity by releasing, often explosively, part of the magnetic energy to the surrounding plasma in the form of kinetic energy and heat, via a localized mechanism of effective magnetic dissipation. For this reason magnetic reconnection is considered one of the most important mechanisms of energy conversion and magnetic field reorganization acting in astrophysical and laboratory plasmas. Although our knowledge has been greatly advanced in the last few decades, the problem of how and under which conditions magnetic reconnection can be triggered explosively after a relatively long and quiescent state in weakly collisional/collisionless plasmas (as observed e.g. in solar flares, geomagnetic substorms and sawtooth crashes in tokamaks) still remains open.

Here we discuss a possible scenario for the triggering of explosive reconnection via the onset of an ‘ideal’ tearing instability within forming current sheets, and show results from numerical simulations in a MHD, 2D-configuration. We demonstrate that the same reasoning, if applied recursively, can describe the complete nonlinear disruption of the original current sheet and can provide a model that explains the resulting magnetic energy spectrum that develops within the reconnecting layer. We discuss possible implications for turbulence phenomenology, observations and controlled laboratory experiments.

Alfvén waves and instabilities in a laboratory arched magnetized plasma
Shreekrishna Tripathi, Department of Physics and Astronomy, UCLA

Arched magnetoplasma structures that carry electrical current ubiquitously exist in the solar atmosphere. A variety of Alfvén waves and instabilities (e.g., fast/slow/EUV waves, global-kink, and Kelvin-Helmholtz) have been detected in recent space and ground based observations. There is a special focus on understanding the characteristics of these waves and instabilities due to their relevance to the emerging area of coronal seismology. Initial results from a laboratory experiment on excitation of Alfvén waves and global kink-modes in an arched magnetized plasma will be presented. The arched magnetoplasma (plasma b » 10^{-3}, Lundquist number » 10^2–10^5, plasma radius/ion-gyroradius » 20, B » 1000 Gauss at footpoints) was created using a lanthanum hexaboride (LaB₆) plasma source and it evolved in an ambient magnetoplasma produced by another LaB₆ source (See Ref. [2] for details). The experiment runs continuously with a 0.5 Hz repetition rate. Hence, the plasma and wave parameters were recorded with a good resolution (spatial-resolution/magnetoplasma-length » 10^{-3}, temporal-resolution/eruption-time » 10^{-3}) using movable Langmuir and three-axis magnetic-loop probes. Images of the magnetoplasma were recorded using a fast-CCD camera. In these experiments, the main focus is on the direct measurement of propagation and damping characteristics of Alfvén waves and kink-mode oscillations. The kink-mode oscillations were observed as transverse oscillations across the symmetry plane of the arched plasma. The relative magnitudes of the parameters of the arched and ambient magnetoplasma were varied to simulate a variety of conditions relevant to coronal loops and solar prominences, examine the relevance of the existing models of global kink-modes, and investigate the dispersion characteristics of Alfvén waves in the presence of an electrical current in a magnetoplasma.

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Prof. Marco Velli,
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The magnetic field is fundamental to solar activity and shapes the interplanetary environment, as clearly shown by the full three dimensional monitoring of the heliosphere provided by the measurements of the Helios, Ulysses, SOHO, ACE, Wind, STEREO, Hinode, IRIS, SDO, and Voyager spacecraft. Magnetic fields are also the source for coronal heating and the very existence of the solar wind; produced by the sun’s dynamo and emerging into the corona, magnetic fields become a conduit for waves, act to store energy, and then propel plasma into the heliosphere in the form of Coronal Mass Ejections (CMEs). In 2018 the Solar Probe Plus (SPP) mission will launch to carry out the first in situ exploration of the outer solar corona and inner heliosphere. Direct measurements of the plasma in the closest atmosphere of our
star should lead to a new understanding of the questions of coronal heating and solar wind acceleration. I will describe the SPP scientific objectives, instrument suites, and models of solar magnetic activity, coronal heating, and solar wind acceleration that SPP may confirm or falsify. Connections to relevant laboratory plasma experiments will be discussed: these include Alfvén wave turbulence, magnetic reconnection, and electron and ion heating and acceleration in complex magnetic fields.

The Fluid-like Behavior of Compressive Fluctuations in the Collisionless Solar Wind
Daniel Verscharen (University of New Hampshire), Christopher H. K. Chen (Imperial College London), Robert T. Wicks (University College London)

The fast solar wind is a collisionless magnetized plasma. Therefore, deviations from thermodynamic equilibrium can develop, and a kinetic description of the plasma becomes necessary. We discuss the properties of the dispersion relations and polarization properties of kinetic slow modes and magnetohydrodynamic slow modes. We compare theoretical predictions for the fluctuations in the three lowest velocity moments (density, bulk velocity, and pressure) of the proton distribution function associated with large-scale compressive slow modes to solar-wind observations at 1 au. We find that the predictions from magnetohydrodynamics (MHD) are in a better agreement with the data than the kinetic predictions, even at times when the collisionality of the plasma is low. This surprising result suggests that some unknown kinetic process assumes the role of collisions in suppressing fluctuations in heat flux. Possible candidates for such a process include fluctuating-moment effects, wave-particle scattering on small-scale fluctuations, and anti-phase-mixing. We also discuss the relation of the large-scale compressive plasma modes to the observed pressure balanced structures in the solar wind.

Observation of whistler waves frequency modulation in a mirror-confined ECR discharge plasma
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We investigate the nonequilibrium mirror-confined plasma created and sustained by high-power microwave radiation of a gyrotron under the electron cyclotron resonance condition (ECR discharge). Resonant plasma heating results in the formation of at least two electron components, one of which, more dense and cold, determines the dispersion properties of the high-frequency waves, and the second, a small group of energetic electrons with a highly anisotropic velocity distribution, is responsible for the excitation of unstable waves. Dynamic spectra and the intensity of stimulated electromagnetic emission are studied with high temporal resolution. Interpretation of observed data is based on the cyclotron maser paradigm, in this context, a laboratory modeling of non-stationary wave-particle interaction
processes have much in common with similar processes occurring in the magnetosphere of the Earth, planets, and in solar coronal loops.

During the developed discharge phase, we registered microwave emission in a direction along the ambient magnetic field at frequencies about a half of electron cyclotron frequency. Every radiation pulse is strongly correlated with precipitations of energetic electrons. At a large density of the background plasma during the stationary ECR discharge stage cyclotron instabilities of the extraordinary waves are suppressed, because their dispersive properties are strongly modified by the background plasma. Emission of dense plasma at frequencies below electron cyclotron frequency is most naturally related to the whistler mode instability.

The distinctive feature of this type of instability is the presence of the selected frequencies (more than ten) in the spectrum, which are arranged equidistantly relatively to each other. These frequencies of spectral components are slightly changing in time while the distance between them remains constant. In the present work, we study features of the observed whistler waves with such a frequency modulation and discuss the origin of this modulation.

**Interactions of kink-unstable flux ropes and shear Alfvén waves**

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Magnetic flux ropes and shear Alfvén waves occur simultaneously in plasmas ranging from solar prominences, the solar wind, and the earth’s magnetotail. If the flux ropes evolve to become unstable to the kink mode, interactions between the kink oscillations and the shear waves can arise, and may even lead to nonlinear phenomena. Experiments aimed at elucidating such interactions are performed in the upgraded Large Plasma Device at UCLA. Flux ropes are generated using a 20 cm × 20 cm LaB₆ cathode discharge (with L = 18 m and plasma beta ∼ 0.1.) The ropes are embedded in an otherwise current-free, cylindrical (r = 30cm) ambient plasma produced by a second, BaO cathode. Shear Alfvén waves are launched using externally fed antennas. Kink-unstable oscillations and driven shear waves are observed to generate sidebands about the higher, shear wave frequency (evident in power spectra) via three-wave coupling. This is investigated through bi-coherence calculations and k-matching. Informational complexity and entropy of the time series are also explored. Future work will focus on antenna-launched waves to study the variation of amplitude and frequency, as well as a possible evolution to a turbulent state using higher amplitude drivers.

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Plasma instabilities for parallel collisionless shock formation at LAPD

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Previous research on parallel collisionless shocks, which constitute an important part of the Earth's bow shock region, has been limited to satellite measurements and simulations. However, whether and how these collisionless shocks form depends on a wide range of parameters and scales, some of which can be established and measured more easily in a laboratory experiment like the Large Plasma Device (LAPD) at UCLA.

Two types of plasma instabilities dominate in experiments at LAPD: Free-streaming carbon ions can excite both the resonant right-hand instability and the non-resonant mode. I will discuss the physical mechanism behind these instabilities, how they contribute to our goal of generating a parallel collisionless shock and which conditions are necessary for this formation.

Recent Developments on Space Plasma Environment Research Facility (SPERF)

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The Space Plasma Environment Research Facility (SPERF), a major national research facility for space physics studies in China, is part of Space Environment Simulation Research Infrastructure (SESRI) at Harbin Institute of Technology (HIT). It is designed to provide a laboratory experimental platform to reproduce the geomagnetosphere configuration for investigations on essential space plasma phenomenon, such as asymmetric magnetic reconnection, acceleration/loss and wave-particle interaction of energetic particles in the radiation belt, and the influence of magnetic storms on the inner magnetosphere. The facility has three systems, of Asymmetric Reconnection EXperiment (AREX), Dipole Research Experiment (DREX), and Tail Research EXperiment (TREX). AREX is mainly focused on three dimensional (3D) dayside magnetopause reconnection, DREX mainly investigates acceleration/loss and wave-particle interaction of energetic particles and also the influence of magnetic storms on the inner magnetosphere, while TREX investigates the hydromagnetic waves excited by high speed flows and the dipolarization process, as well as 3D magnetic reconnection processes. The plasma is produced by an electron cyclotron resonance (ECR) source to generate a background “artificial radiation belt” and seed electrons, and then enhanced by
discharges of a hot cathode (LaB6) or a biased cold cathode to generate the plasma in high density. A series of electrostatic and magnetic probes are used to diagnose the plasma parameters. And other diagnostics are also applied. The design and construction status, and the planned research will be discussed.

**Understanding the dynamics of magnetic reconnection from space and laboratory plasmas**

Masaaki Yamada
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I will present recent findings in the research of asymmetric and symmetric magnetic reconnection both in laboratory and space plasmas [1]. In spite of the huge difference (106-107) in physical scales, we find remarkable commonality between the properties and the dynamics of the reconnection layer in laboratory and space plasmas. The recent significant progress in diagnostics in the both fields made us possible to directly compare the observed physics processes. I will at first focus on the energy deposition to electrons near the electron diffusion layer with and without guide field. The experimental results on the energy conversion and partitioning are also discussed and compared with quantitative estimates based on two-fluid analysis as well as space observations. Furthermore, we have observed whistler waves and lower-hybrid frequency fluctuations at the lower density side of asymmetric reconnection layer on MRX [2]. The experimental results are remarkably consistent with the recent space observations from MMS [3]. We directly compare the data from the MRX with the recent MMS observations which show very similar power spectra.

In collaboration with J. Yoo, J. Jara-Almote, H. Ji, and C. Myers


**The Dynamics of Turbulence and Shear Flow that drive a Confinement Bifurcation in a Tokamak Plasma**

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Magnetically confined plasmas undergo a rapid transition from a low-confinement state (L mode) to a high-confinement state (H-mode) as the heating power across the boundary surface exceeds a specific threshold. Experimental analysis
demonstrates that the evolution and dynamics of gradient-driven drift-wave turbulence plays a central role in this process. The bifurcation from L to H mode (L-H transition) is characterized by a rapid suppression of turbulence at the plasma edge and buildup of a sharp edge pressure pedestal, ExB shear flow layer, and transport barrier. In order to understand the role of microscopic edge turbulence and flow dynamics across the L-H transition, 2D turbulence and flow measurements are obtained with Beam Emission Spectroscopy before, during and after the L-H transition on the DIII-D tokamak. It is found that immediately before the transition, a turbulent Reynolds stress-driven shear flow arises rapidly (< 1 ms). This is consistent with the model that increased power flux leads to increased turbulence, an increasing turbulent Reynolds stress, shear flow development and a rapidly changing edge flow that triggers the transition as turbulence is suppressed and energy transferred from turbulence to the shear flow. The transition power threshold has empirical dependencies on several parameters, including: toroidal magnetic field, electron density, ion mass. Detailed analysis of turbulence characteristics demonstrates that the presence of two counter-propagating broadband turbulence modes appears to be connected with a lower power threshold. This observation suggests a commonality between the complex behavior of turbulence modes, their interactions, and the L-H power threshold that can inform a more complete L-H transition physics model since current empirical scaling laws do not explain the underlying physical processes.

**Plasma electron hole oscillatory velocity instability**
Chuteng Zhou, Ian H. Hutchinson

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