2025

MagNetUS Workshop Abstracts

June 2 - 5, 2025

Morgantown, West Virginia

Invited Talk

Interplay of dust ordering and potential structures in magnetized low temperature plasmas

Author: Siddharth Bachoti

Affiliation: Auburn Univeristy

Abstract:

Imposed ordering (first observed in the Magnetized Dusty Plasma eXperiment (MDPX) [1]) occurs when micron-sized dust particles form 4-fold symmetric structures, aligned with the square gridded conducting mesh. Dust particles move along elongated electric potential structures from the mesh in a magnetic field, revealing plasma potential structures. The strength and morphology of these structures vary with magnetic field, neutral pressure, and mesh geometry. We aim to quantify dust phases from 6-fold self-ordering to 4-fold imposed-ordering as magnetization increases using different mesh geometries, characterizing the plasma potential structures. Results from recent experiments in MDPX are presented.

This work is supported by the NSF and the US Department of Energy.

[1] E. Thomas, et al., Phys. Plasmas, 22, 030701 (2015)

Invited Talk

What Heats the Solar Wind? Perspectives and Progress from Parker Solar Probe

Author: Trevor Bowen

Affiliation: UC Berkeley, Space Sciences Laboratory

Abstract:

The processes underlying collisionless heating and dissipation are fundamental problems in plasma and astrophysics research. In situ observations from spacecraft in collisionless plasma environments provide significant constraints on how these processes operate and their relative efficiency as a means for dissipating turbulent energy. Here we highlight the importance of understanding kinetic phase space signatures as a means to constrain collisionless dissipation mechanisms via approximation by diffusive approximation schemes. We highlight recent progress in understanding signatures of stochastic heating, cyclotron resonance, and Landau damping via observations from the Parker Solar Probe (PSP) mission. Importantly, our observations reveal that a range of heating mechanisms are likely important in explaining observed phase-space plasma signatures.

Invited Talk

AI for connecting simulation and experiment in plasma science and fusion energy

Author: Michael Churchill

Affiliation: PPPL

Abstract:

This presentation seeks to explore and suggest answers to the question: how can we best use AI for scientific discovery with experiment? In the first part, I will first give an in-depth overview of diffusion/flow matching AI models, including how they are being used for generative AI across many modalities including image, video, and protein structure. I will then show how these same fundamental AI techniques can be used for scientific discovery, focusing on a technique simulation-based inference (SBI). SBI enables expansive comparison of simulation models with experimental measurements, providing a principled, Bayesian methodology to determine uncertainty in physics parameters from experiments. I will discuss application to plasma physics diagnostics, both single and multiple diagnostic systems. I will also discuss how such models can form the basis of high-fidelity digital twins, forming hybrid simulation + data models for improved predictions which can be transferable to new devices.

In the second part, I will discuss emerging agentic AI tools which can aid in scientific workflows and research discovery. The development of reasoning capabilities in large language models and the ability to incorporate tool calls allows these AI models to explore and verify hypothesis, and exploit areas of promising directions. While the search space is extremely large, newer commercial AI models are using evolutionary algorithms (Google Deepmind AlphaEvolve) or other means (Microsoft Discovery) to intelligently traverse the space of possibilities. While these tools are new and developing, the principles are providing promising routes for expanding scientist capabilities for automatic parts of the scientific process.

Invited Talk

The CHIMERAS Project: Design Framework for the Collisionless HIgh-beta Magnetized Experiment Researching Astrophysical Systems

Author: Seth Dorfman

Affiliation: Space Science Institute

Abstract:

From the near-Earth solar wind to the intracluster medium of galaxy clusters, collisionless, high-beta, magnetized plasmas pervade our universe. Energy and momentum transport from large-scale fields and flows to small scale motions of plasma particles is ubiquitous in these systems, but a full picture of the underlying physical mechanisms remains elusive. The transfer is often mediated by a turbulent cascade of Alfvénic fluctuations as well as a variety of kinetic instabilities; these processes tend to be multi-scale and/or multi-dimensional, which makes them difficult to study using spacecraft missions and numerical simulations alone (Dorfman et al. 2023; Lichko et al. 2020, 2023). Meanwhile, existing laboratory devices struggle to produce the collisionless, high ion beta ($\beta_i \gtrsim 1$), magnetized plasmas across the range of scales necessary to address these problems. For example, direct observation of the Alfvén wave parametric instability, an important non-linear process that limits the solar wind parameter space (Bowen, et al, 2018), has not been achieved in the laboratory in part due to Alfvén wave damping (Li, et al, 2024).

As envisioned in recent community planning documents (Carter et al. 2020; Milchberg and Scime 2020; Baalrud et al. 2020; Dorfman et al. 2023; NASEM 2024), it is important to build a next generation laboratory facility to create a $\beta_i \gtrsim 1$, collisionless, magnetized plasma in the laboratory for the first time. A Working Group has been formed and is actively defining the necessary technical requirements to move the facility towards a construction-ready state. Recent progress includes development of target parameters and diagnostic requirements as well as identification of a need for source-target device geometry. As the working group is already leading to new synergies across the community, we anticipate a broad community of users funded by a variety of federal agencies (including NASA, DOE, and NSF) to make copious use of the future facility.

Invited Talk

Characteristics and constraints of plasma sheaths at shallow magnetic field incidence

Author: Alessandro Geraldini

Affiliation: EPFL

Abstract:

Just like all laboratory plasmas, the plasma in a fusion device is intertwined with its solid boundaries. Far away from the walls, transport is successfully described and simulated by fluid or kinetic models which average over the quasi-circular Larmor orbits of charged particles, and solve for the electric field via quasineutrality. Turbulence in the edge region has emerged as crucial in determining the overall confinement in the device, and the wall ultimately sets the boundary conditions. Yet, due to the typically grazing incident angle of the magnetic field lines, ion gyro-orbits deform to non-circular in a region near the wall called the magnetic presheath, as the electric field directed towards the target becomes so large and inhomogeneous, at the gyro-radius length scale, that it causes sheared ExB flows tangential to the target of the order of the thermal velocity. In order to reflect electrons and keep the outflow ambipolar, the electric field even closer to the target, within the actual Debye sheath, becomes inhomogeneous on the scale of the Debye length, thus breaking quasineutrality and possibly also deforming electron gyro-orbits. I will present a theoretical framework and a numerical scheme that allow to iteratively and quickly obtain numerical solutions of the steady state of the magnetised plasma sheath (Debye sheath + magnetic presheath) for shallow magnetic field incidence at the wall, relevant to fusion devices. The code also returns the ion distribution function reaching the target, important for sputtering, and the reflected electron distribution function, which determines the net electron fluxes to the wall. I will also outline the necessary conditions for a monotonic and steady-state sheath solution to exist, and discuss the possible implications of the nontrivial constraints that emerge when gradients tangential to the target affect transport to the wall.

Invited Talk

A First-Principles-informed Framework for Runaway Electron–Whistler Interactions in Tokamak

Author: Yashika Ghai

Affiliation: Oak Ridge National Laboratory

Abstract:

Resonant interactions between high-energy runaway electrons (REs) and whistler waves can significantly alter RE dynamics by enhancing pitch-angle scattering and increasing synchrotron radiation losses. Recent DIII-D experiments have demonstrated that externally launched whistler waves can mitigate RE-induced damage to plasma-facing components [1,2]. However, a comprehensive framework for modeling RE transport in the presence of whistler fields remains underdeveloped.
To address this gap, we couple two advanced computational tools: AORSA, which computes whistler eigenmodes for a given plasma equilibrium, and KORC, a kinetic orbit code that tracks full-orbit RE trajectories in prescribed wave fields. To the best of our knowledge, this is the first time such simulations have been performed that capture toroidal mode coupling and full-wave structure from AORSA, while using full-orbit dynamics in KORC to resolve pitch-angle scattering in realistic tokamak equilibria.
Results from AORSA+KORC simulations show that the statistical moments—mean, variance, skewness, and kurtosis—of RE pitch-angle and normalized kinetic energy displacements increase rapidly in the presence of whistler fields, indicating REs scattering to large pitch angles due to wave-particle interactions. We observe energy-dependent changes in the ensemble- averaged RE kinetic energy, with the strongest enhancement occurring for initial energies in the 1–5 MeV range, reinforcing the possibility of resonant energy transfer. Our findings also indicate an energy-dependent scaling for RE transport in pitch angle and kinetic energy, that varies between diffusive, sub-diffusive and super-diffusive for different values of the initial runaway electron kinetic energy. Further analysis of RE pitch-angle and energy distributions over time provides deeper insight into the underlying transport mechanisms.
By revealing the non-diffusive character of RE–whistler interactions, this work advances the theoretical understanding of RE transport and lays the foundation for developing targeted mitigation strategies in next-generation tokamak experiments.

[1] D. A. Spong et al., Phys. Rev. Lett., 120, 155002 (2018).

[2] W. W. Heidbrink at al., Plasma Phys. Control. Fusion, 61, 14007 (2019).

Invited Talk

Light drag in plasmas

Author: Renaud Gueroult

Affiliation: Laplace Toulouse France

Abstract:

Wave drag phenomena refer to the modifications of wave properties induced by the medium's motion, as first observed by Fizeau for visible light propagating through a water flow. In isotropic dielectrics these phenomena are classically known to scale as the Fresnel drag coefficient (n_g-1/n), with ng and n the group and refractive index, respectively. For typical dielectrics this drag coefficient is typically of order 1, and dragging effects are accordingly small and generally negligible.
There are however a number of reasons to believe this may not hold true in plasmas, and thus that wave drag may play a role on wave physics. First, plasmas support waves with low group velocity, leading to large group index and thus to large drag coefficient, similarly to those leveraged to observe these effects with visible light in slow light media [1]. Second, magnetized plasmas are anisotropic media, leading to a richer phenomenology.
In this talk I will discuss what we have learned on wave drag in magnetized plasmas, as well as how these effects may be observed in laboratory experiments and notably LAPD.

[1] Franke-Arnold et al., Rotary Photon Drag Enhanced by a Slow-Light Medium (2011), Science, 333, 65,

Invited Talk

Feasibility study of non-Maxwellian distribution Measurement using an oblique view in ITER electron cyclotron emission diagnostics

Author: Saeid Houshmandyar

Affiliation: Institute for Fusion Studies, The University of Texas at Austin

Abstract:

A longstanding discrepancy between electron temperatures measured by electron cyclotron emission (ECE) diagnostics and Thomson scattering (TS) has been attributed to non-Maxwellian features in the electron momentum distribution. Initially observed in JET and TFTR tokamaks, this discrepancy manifests as higher ECE temperatures (TECE) compared to TS temperatures (TTS) when central electron temperatures exceed 7 keV. However, JET-DT experiments have revealed cases where TECE can either exceed or fall below TTS. These inconsistencies are expected to become more pronounced in ITER, where the temperature is projected to reach ~25 keV.
The performance of the oblique view for the ITER-ECE diagnostics has been reassessed. GENRAY 3D ray-tracing has been utilized to calculate emission, absorption, and radiation transport for both thermal and nonthermal electron velocity distribution functions (EVDF). Non-Maxwellian distributions were generated by distorting EVDF from the Maxwellian distribution in the range of u < 1.5uth.
The simulated ECE spectra across multiple cyclotron frequency harmonics suggest that the O-mode emission at the first harmonic and the X-mode emission at the second harmonic may yield unreliable temperature measurements. However, emissions at higher harmonics can provide accurate temperature information using ECE instruments. Furthermore, the analysis shows that the locations of distortions in the EVDF with respect to EC harmonic resonances have a significant effect on the nature of the non-thermal emissions. Additionally, the simulation suggests that non-thermal emissions may not be detected in the radiation temperature spectra at the oblique angle due to Doppler broadening dominating the relativistic effects on the radiation temperature.

Invited Talk

Anomalous Ion Heating in Ultra-Low Safety-Factor Toroidal Pinch Plasmas

Author: Armand Keyhani

Affiliation: University of Wisconsin-Madison

Abstract:

Ultra-Low-q (ULq) plasmas are defined as having an edge safety-factor q(a) between 0 and 1. This regime lies between the reversed-field pinch which has $q(a)<0$ and the tokamak which has $q(a)>2$. ULq plasmas are poorly understood because tokamaks are increasingly susceptible to external kink instability as q(a) approaches 2. In MST, the thick conducting shell maintains global stability, and recently implemented high-bandwidth programmable power supplies allow for steady ULq operation with plasma current up to 300 kA and toroidal field up to 0.13 T. Magnetic fluctuations, electron density, and impurity ion temperatures (T_i) in ULq plasmas with $0.4<q(a)<0.9$ have been characterized using coil arrays, infrared laser interferometry, and passive Doppler-spectroscopy. Boron-IV (282.2 nm) temperatures are observed as high as 400 eV, up to approximately 4X the electron temperature. T_i is nearly constant and has a non-linear dependence on q(a). T_i generally increases as q(a) decreases and peaks at $q(a)\sim0.65$. T_i also has a strong non-linear dependence on average plasma density where a factor of 4X decrease in density can cause a factor of 10X increase in T_i. As toroidal field and plasma current are increased at constant q(a), T_i increases linearly, global resistance remains nearly constant, and Ohmic input power increases quadratically. Results suggest that the ion heating is associated with broadband magnetic fluctuations with peak amplitudes at frequencies of 10-25 kHz. Ti is most correlated with the rotation speed and amplitudes of the n = 2, 3, and 5 modes. Potential heating mechanisms including ion cyclotron resonance damping, stochastic heating, and viscous damping are evaluated.

Work supported by US DOE grants DE-SC0018266 and DE-SC0020245, and by NSF grant PHY 1828159.

Invited Talk

Reconnection-Driven Electron Acceleration

Author: Ripudaman Singh Nirwan

Affiliation: West Virginia University

Abstract:

Magnetic reconnection converts the magnetic energy available in a plasma to the kinetic energy of its constituent particles. In the simplest case, it occurs between anti-parallel magnetic field lines meeting in a plane. A more general variant known as 'component reconnection' involves field lines reconnecting at an angle, giving a non-zero magnetic field component perpendicular to the plane of reconnection. This component is known as the 'guide field' and it is normalised to the reconnecting component. It controls the particle-scale dynamics of reconnection and influences the ensuing particle acceleration.

Component reconnection occurs in the Earth's magnetosphere, along with a variant known as 'electron-only' reconnection which precludes ion dynamics. West Virginia University's PHAse Space MApping (PHASMA) experiment can generate electron-only reconnection with a variable guide field. We have used this platform to study electron acceleration along the local magnetic field as a function of the guide field and found that electron acceleration is enhanced as the guide field is reduced. This occurs with the formation of non-thermal electron energy distribution functions (EEDFs) whose peak energies increase as the guide field decreases. A cross-over occurs at a guide field of 10, when the spatio-temporal production of energetic electrons in PHASMA increases dramatically. Measurements for this case reveal the production of a non-thermal, multi-component EEDF in conjunction with bulk electron heating along the local magnetic field.

Invited Talk

Kink-driven magnetic reconnection as the driver of a laboratory jet

Author: Byonghoon Seo

Affiliation: Embry-Riddle Aeronautical University

Abstract:

Solar jets are transient and impulsive phenomena frequently observed in the solar atmosphere. They are candidates for playing a crucial role in energizing the solar corona and driving the solar wind by transferring mass and momentum. Although observations, theories, and simulations have proposed mechanisms for solar jet generation, the fundamental question of how solar jets are initiated, heated, and accelerated at their source remains unresolved. In this talk, we introduce the experiment performed at Embry-Riddle Aeronautical University and present evidence that kink-driven magnetic reconnection serves as a mechanism for the acceleration of a laboratory filamentary blowout jet. A flux rope is formed and becomes a filamentary jet. The jet becomes unstable due to kink instability when the Kruskal-Shafranov instability criterion is met, leading to an inflow of reconnecting fields. As a result of kink-driven magnetic reconnection, ions are substantially energized, enhancing the acceleration of the jet. Based on compelling evidence observed from the laboratory, we propose that kink-driven magnetic reconnection might act as a key driver for laboratory blowout jets and is relevant to solar jets associated with kink instability and magnetic reconnection.

Invited Talk

Artificial intelligence for modeling and control of complex magnetized plasma systems

Author: Ricardo Shousha

Affiliation: PPPL

Abstract:

Authors:
R. Shousha, P. Steiner, A. Jalalvand, J. Seo, S.K. Kim, K. Erickson, A. Rothstein, H. Farre, C. Byun, M.S. Kim and E. Kolemen

Abstract:
Magnetized plasma systems, such as those in fusion devices, are challenging to model and control because of their nonlinear behavior, coupled physical processes, and diagnostic limitations. Traditional physics-based methods often lack the flexibility or computational efficiency required for real-time scenarios, restricting predictive accuracy and control performance. Recent advances in artificial intelligence have allowed us to address some of these limitations. For example, real-time tokamak plasma state-estimation frameworks (e.g., RTCAKENN[1]) predict multiple plasma profiles—including electron density, temperature, pressure, current density, safety factor, ion temperature, and toroidal rotation—even under conditions of diagnostic sparsity. AI-enhanced spectroscopic techniques further enable ion profile determination from relatively simple measurements, reducing the need for costly or less robust neutral beams. Additionally, AI-based super-resolution approaches infer high-fidelity data by leveraging correlations among multiple diagnostics, offering new insights into phenomena such as ELMs and magnetic island formation. Deep reinforcement learning and other machine learning–driven strategies have also demonstrated improved control of plasma instabilities, including tearing mode avoidance[2], and the optimization of actuator configurations for ELM suppression in devices such as KSTAR and DIII-D[3]. These developments indicate that AI-based approaches, demonstrated in the context of tokamak modeling and control, may hold potential for broader application across magnetized plasma systems as well.

[1] Ricardo Shousha et al 2024 Nucl. Fusion 64 026006
[2] Jaemin Seo et al.. Nature 626, 746–751 (2024)
[3] SangKyeun Kim et al Nat Commun 15, 3990 (2024)

Invited Talk

Kolmogorov turbulence characterstics in dusty plasma vortex flows

Author: Sanat Kumar Tiwari

Affiliation: Indian Institute of Technology Jammu

Abstract:

TBA

Invited Talk

Low-temperature plasma chemistry for next-generation semiconductor fabrication

Author: Luca Vialetto

Affiliation: Stanford University

Abstract:

Emerging technologies for micro-/nano-electronics fabrication rely on plasma processing. Engineering such devices requires a more precise process control which may be attained with a knowledge-based design of related plasma processes.

Modeling and simulation of such surface-facing process plasmas, paired with measurement data of the fabricated devices, may enable physical interpretation and guide the process design. However, despite significant increases in computational power, comprehensive multi-scale simulation remains challenging due to the complex dynamics of multi-component plasmas interacting with surfaces and critical gaps in fundamental input data for these models.

This presentation addresses the data requirements for next-generation plasma processing models, with particular focus on gas and surface kinetics. I will first present swarm analysis methods for extracting fundamental data from electron transport equation solutions and experimental measurements. Next, I will introduce a comprehensive surface kinetics model that accounts for chemisorption, physisorption, adatom diffusion, and physical sputtering mechanisms. This model, validated against experimental data, enables extraction of reaction rates for heterogeneous processes critical to fabrication outcomes.

Finally, an integrated model including plasma simulations and a data-driven surface kinetics model is presented. I will demonstrate how this hybrid approach overcomes current limitations and show its transferability to diverse applications across plasma processing and propulsion systems, establishing a foundation for more accurate and efficient plasma-based fabrication processes.

Contributed Talk

Localized variability in the upper ionospheric structure driven by the Mars-Solar wind interaction

Author: Sara Ali

Affiliation: West Virginia University

Abstract:

This study focuses on the Mars upper ionosphere responds to the impinging solar wind. Mars doesn't have a significant global magnetic field, and the solar wind subsequently interacts directly with the gravitationally bound and electrically conducting upper ionosphere to form an induced magnetosphere that is highly dynamic and structure that responds quickly (in minutes or less) to changes in upstream solar wind conditions. More specifically, variability in ionospheric density and temperature structure is observed by orbiting spacecraft both within individual orbit passes and between consecutive orbits, even when solar quiet conditions are present (i.e. no space weather events). We use Mars Atmosphere and Volatile EvolutioN (MAVEN) data to examine this variability via case studies and statistical studies, to determine the physical processes at play, and how their contributions vary with upstream solar wind conditions. This presentation will present preliminary results that characterize the variability of the ionospheric density structure observed over several weeks of observations

Contributed Talk

X-Ray Emissions from Runaway Electrons During Whistler-Wave Activity and Current Ramps in MST Tokamak Plasmas

Author: Ben Antognetti

Affiliation:

Abstract:

One route for mitigation of runaway electrons (RE) in tokamaks stems from the excitation of whistler waves due to a RE-driven kinetic instability. This instability causes pitch-angle scattering of fast electrons, limiting their parallel velocity. We study RE dynamics in low-density (ne ~ 10^17 m^−3) tokamak plasmas at low toroidal field, BT = 0.13 T, in the Madison Symmetric Torus (MST). A high-time-resolution soft-x-ray detector operating in pulse height analysis mode is used to measure x-ray emission on a radial viewing chord. Whistler-frequency magnetic fluctuations are measured by a high-frequency B-dot probe inserted to r/a = 0.8. Quasi-periodic bursts of whistlers and x-rays appear, typically with repeated ~0.3 ms windows of activity followed by ~0.3 ms of quiet time. Time-resolved energy spectra of the x-ray emission show a peak around 4 keV only for high-flux periods. While these bursts of x-ray activity only appear when whistler-waves are present, there is an inverse correlation between whistler amplitude and x-ray flux. MST has recently developed programmable power supplies that allow fine control over the poloidal and toroidal magnetic field circuits. By programming plasma current ramps, we induce short increases in the loop voltage by up to 10 V from a base value ~2 V. The soft x-ray measurement shows a corresponding increase in flux indicating an influence over some combination of the RE generation and effective RE radial-diffusion rates. As the current ramp time is decreased from 8 ms down to 0.1 ms, with the change in current kept constant, the x-ray flux increases by an order of magnitude while the average x-ray energy increases by less than 20%.

Work supported by U.S. DOE award DE-SC0018266 and NSF award PHY 1828159

Contributed Talk

Compressible MHD turbulence in the solar wind and the interstellar medium

Author: Amitava Bhattacharjee

Affiliation: Princeton University

Abstract:

Compressible magnetohydrodynamic (MHD) turbulence is a ubiquitous state for many astrophysical and space plasmas, including the solar wind and the interstellar medium of our galaxy. Yet, basic statistics describing compressible, magnetized turbulence remain uncertain. Utilizing unprecedented grid resolutions of up to 10,080 cube cells, we simulate magnetized compressible turbulence in the world's largest MHD simulation (to appear in Nature Astronomy, May, 2025). We measure two coexisting kinetic energy cascades in the turbulence separating the plasma into scales that are non-locally interacting, supersonic and weakly magnetized (with the power-law exponent $n \sim 2$) and locally interacting, subsonic and highly magnetized ($n \sim 3/2$), in wave number space. We show that the 3/2 spectrum can be explained with both scale-dependent energy fluxes and velocity-magnetic field alignment. The magnetic energy spectrum forms a local cascade ($n \sim 9/5$), deviating from any known ab initio theory. Within the 3/2 cascade, the plasma becomes aligned in a scale-dependent manner, with all primitive variables and their curls tending towards parallel and anti-parallel states in localized regions, Beltramizing, Taylorizing, and Alfvenizing the plasma on these scales. We associate this with the tendency of turbulence to deplete its nonlinearities, which has significant implications for the asymptotic state of MHD turbulence, challenging existing theories (Physical Review Letters, under review). The predicted scalings on density fluctuations are compared with MMS and Solar Probe data and are in good agreement (Astrophysical Journal Letters, 2025). Possible implications for laboratory experiments will be discussed.

Contributed Talk

Phase mixing of Alfvén waves in the laboratory under conditions scaled to match coronal holes

Author: Sayak Bose, T. Carter, M. Hahn, S. Tripathi, S. Vincena, and D.W. Savin

Affiliation: Princeton Plasma Physics Laboratory, Columbia University in the city of New York, University of California Los Angeles

Abstract:

Inhomogeneity in plasma density in a direction transverse to the magnetic field in coronal holes are thought to cause phase mixing which aid the dissipation of wave energy, and thus, contribute to coronal heating. We have studied Alfvén wave propagation under conditions similar to coronal holes in the Large Plasma Device located at University of California, Los Angeles. The transverse density gradient was produced by simultaneously operating two plasma sources of different diameters located at the two ends of the machine. The larger diameter source was used to produce a low-density background plasma, while a smaller diameter source was used to produce a high-density core at the axis of LAPD. The phase velocity parallel to the magnetic field was observed to vary radially in the presence of a transverse density gradient. Fourier analysis shows that the dominant of wave magnetic field shifts to higher values of $k_\perp$ (perpendicular wave number) as the wave propagates away from the antenna in the presence of a density gradient. However, no such shift is observed in the value of $k_\perp$ for wave propagation in a uniform plasma. In the presence of a gradient this shift to higher $k_\perp$ is accompanied by a significant reduction in wave energy. This energy reduction is more prominent for steeper gradients. This wave energy reduction may contribute to plasma heating. These results are presented as they pertain to coronal holes.

Contributed Talk

First Demonstration of Resonant Pitch-Angle Scattering of Relativistic Electrons by Externally-Launched Helicon Waves

Author: Hari Choudhury

Affiliation: Columbia University

Abstract:

Relativistic Electrons (REs) pose a formidable risk to future high-current tokamaks such as ITER and SPARC. Any effective mitigation strategy must seek to reduce the maximum RE energy since that determines the potential for damage deep inside plasma-facing components. Resonant wave-particle interactions provide such a means of phase-space control, since pitch-angle scattering of REs increases the synchrotron damping they experience and hence limits their maximum energies. Externally-launched helicon waves (i.e., whistler waves, fast waves in the lower-hybrid range) are observed to limit the growth and maximum energy of REs in low-density Ohmic DIII-D tokamak plasmas. Owing to the low density of these plasmas, an appreciable RE population forms after 1-2 seconds. The waves are then launched anti-parallel to the plasma current, so that the normal Doppler-shifted wave-particle resonance condition with REs of ~8 MeV is satisfied. Following the application of helicon waves, the synchrotron and non-thermal electron-cyclotron emissions, both strong functions of the perpendicular energy of the REs, increase. The total hard x-ray emission, a proxy for the RE population, ceases to grow. Energy-resolved hard x-ray measurements show a striking decrease in the number of high-energy REs (> 7 MeV) to below the noise floor and a significant increase in low-energy REs (< 4 MeV). These observations strongly support the hypothesis that resonant REs are pitch-angle scattered by the waves and then, because of an increase in synchrotron emission, are damped down to lower energies. This occurs despite the toroidal electric field remaining high enough to drive exponential RE growth in the absence of helicon waves. These results open new directions for limiting the maximum energy of RE populations in laboratory and fusion plasmas.

Contributed Talk

Overview of the “Junior” Levitated Dipole Experiment at OpenStar Technologies

Author: Darren T. Garnier

Affiliation: OpenStar Technologies, Ltd.

Abstract:

OpenStar Technologies is a private fusion company exploring the levitated dipole concept for commercial fusion energy production. OpenStar’s first experiment called “Junior” is comprised of a 1.5 MA, 0.55 MJ REBCO high-temperature superconducting magnet with a designed peak field strength of 5.6 Tesla, a 5.2 m vacuum vessel, and multi-frequency ECRH power < 50 kW. Importantly, this experiment integrates novel HTS power supply technology on board the dipole magnet, leveraging the advances made in HTS technologies since the last levitated dipole experiments of LDX. Recently, OpenStar has completed its first experimental campaign with the Junior experiment. As a user facility, Junior offers excellent opportunities to investigate fundamental plasma physics phenomena of interest to basic plasma science, space physics, and fusion communities, including but not limited to: multi-scale plasma turbulence and energy cascades, self-organization phenomena, high-beta ($\beta > 1$) plasma stability regimes, "artificial radiation belt" formation, non-linear Alfvén wave dynamics, wave-particle and wave-wave interactions in magnetospheric geometries, and the effect of pressure anisotropy on stability and confinement. Further, the integration of novel HTS magnet technology significantly enhances experimental capabilities compared to previous levitated dipole experiments, enabling studies at higher field strength and reduced operational costs. We anticipate operation as a user facility at the start of calendar year 2026.

Contributed Talk

Introducing a New DoE Collaborative Research Facility: FLARE

Author: Hantao Ji

Affiliation: Princeton Plasma Physics Laboratory

Abstract:

The FLARE (Facility for LAboratory Reconnection Experiments; flare.pppl.gov) device is a new experiment for the study of magnetic reconnection in the multiple X-line regimes in the reconnection phase diagram [1,2], directly relevant to space, solar, astrophysical, and fusion plasmas. Funded by NSF, the device was originally constructed and tested in the main campus of Princeton University. Funded by DoE and Princeton University, the FLARE device has been relocated to and installed at PPPL with a full set of initial diagnostics and an upgraded set of the power supplies and infrastructure required to provide access to new regimes of magnetic reconnection. The first plasmas were successfully generated on April 14, 2025 at PPPL, and currently it is transitioning to the initial operation and research phase. The capabilities of the facility and its initial plan will be presented in preparation as a DoE collaborative research facility. Numerical predictions using the state-of-the-art particle-in-cell code, VPIC, will be discussed to guide the first physics operation of FLARE and to interpret the obtained experimental results.

[1] H. Ji and W. Daugton, Physics of Plasmas 18, 111207 (2011).
[2] H. Ji, W. Daughton, J. Jara-Almonte, A. Le, A. Stanier, J. Yoo, Nature Reviews Physics 4, 263 (2022).

Contributed Talk

A novel parallel-kinetic-perpendicular moment model for magnetized plasmas

Author: James (Jimmy) Juno

Affiliation: Princeton Plasma Physics Lab

Abstract:

Many plasma systems, from pulsar magnetospheres to magnetic confinement devices, are highly magnetized. Simultaneously these myriad of plasma environments are often sufficiently tenuous and hot to be best described by kinetic theory and the full six dimensional Boltzmann-Maxwell system of equations, thus making these systems computationally demanding to model. To facilitate new kinetic models of magnetized plasmas, I will discuss a recent innovation which separates the parallel and perpendicular dynamics starting from the kinetic equation while staying agnostic to the inclusion of effects important to consider in diverse environments, such as strong flows in certain fusion reactors, relativistic energies in astrophysical plasmas, or complex boundary conditions and geometry in lab plasma modeling. The key component of the derivation lies in a spectral expansion of only the perpendicular degrees of freedom, analogous to spectral methods which have grown in popularity in recent years for gyrokinetics, while retaining the complete dynamics parallel to the magnetic field. We thus leverage our intuition that a magnetized plasma's motion is different parallel and perpendicular to the magnetic field, allowing for the treatment of complex phase space dynamics parallel to the magnetic field but at reduced computational cost. This approach also naturally couples to Maxwell's equations, thus permitting everything from a transition across energy scales in astrophysical plasmas to the straightforward inclusion of all aspects of an experiment, from vacuum regions to external coils. The utility of this approach will be demonstrated with simulations of laboratory plasma experiments.

Contributed Talk

The Effect of Nonlocality and Stochasticity on Electron Diffusion in Magnetized Plasma from Lab to Space

Author: Evdokiya Kostadinova

Affiliation: Auburn University

Abstract:

The dynamics of magnetic field topology in magnetized plasma can result in both nonlocality and stochasticity, both of which are expected to affect electron cross-field diffusion. Here we use a spectral approach to investigate how such phenomena cause changes in the electron diffusion, including a cross-over from subdiffusion to superdiffusion. The spectral approach allows to map nonlinear dynamics in phase space to a linear problem where one studies the energy spectra of Hamiltonian operators in Hilbert space. The Hamiltonians are selected to model magnetized plasma with magnetic islands that undergo spontaneous or induced structural bifurcations and stochastization of magnetic field lines. The Hamiltonian for each structural state is informed from experimental data from laboratory magnetized plasma as well as measurements from Earth's magnetosphere. For each case, we calculate the probability for continuous energy spectrum (i.e., extended states) as a function of stochasticity and range of nonlocal interactions. We discuss how these reduced-model analytical predictions can be used as a viable scaling technique to connect lab astro/space research to mission data.

Contributed Talk

A novel scheme for measuring the growth of Alfven wave parametric decay instability using counter-propagating waves

Author: Feiyu Li

Affiliation: New Mexico Consortium

Abstract:

The parametric decay instability (PDI) of Alfven waves–where a pump Alfven wave decays into a backward-propagating child Alfven wave and a forward ion acoustic wave—is a fundamental nonlinear wave-wave interaction and holds significant implications for space and laboratory plasmas. However, to date there has been no direct experimental measurement of PDI. Here, we propose a novel and experimentally viable scheme to quantify the growth of Alfven wave PDI on a linear device using a large pump Alfven wave and a small counter-propagating seed Alfven wave, with the seed wave frequency tuned to match the backward Alfven wave generated by standard PDI. Using hybrid simulations, we show that energy transfer from the pump to the seed reduces the latter's spatial damping. By comparing seed wave amplitudes with and without the pump wave, this damping reduction can be used as a direct and reliable proxy for PDI growth. The method is validated in our simulations across a range of plasma and wave parameters and agrees well with theoretical predictions. Notably, the scheme exhibits no threshold for PDI excitation and is, in principle, readily implementable under current laboratory conditions. This scheme is a critical step toward solving the challenge of experimentally accessing Alfven wave PDI and provides an elegant method that may be used to validate fundamental theories of parametric instabilities in controlled laboratory settings..

Contributed Talk

Looking for Magnetosonic Waves at Mars: Preliminarily Statistics and Occurrence Rate

Author: Samy Salem

Affiliation: West Virginia University

Abstract:

Except for the small patches of the magnetic crustal field, Mars does not have a well-developed dipole magnetic field, allowing the solar wind to interact directly with the gravitationally bound and electrically conducting ionosphere. Such interaction can result in many plasma structures that propagate in the magnetosphere of Mars. Magnetosonic waves (MSW) are one of those low frequency (in the range of 0.02 - 1 Hz) waves that propagate in the range of proton cyclotron frequency and are generated by the interaction between the magnetosphere of Mars with the solar wind. MSW at Mars have been observed to propagate into the ionosphere where they damp and deposit energy. Using the set of 10 years of in-situ measurement data of the two magnetometers (MAG) and thermal ions instrument (STATIC) that are installed on the Mars Atmosphere and Volatile EvolutioN (MAVEN), NASA mission to Mars, we have developed an automated algorithm routine to identify the MSW utilizing 3D wave polarization analysis techniques and the fluctuations in magnetic and plasma pressures. Based on a case study of 7 days, the occurrence rate of the waves is ~ 20 %. We have also identified two modes, fast and slow, by which the magnetic and plasma thermal pressure oscillations of the MSW are either in-phase or anti-phase, respectively. Distributions of wave's frequencies and powers as well as the altitudes are obtained. Preliminary analysis on how much the existence of the MSW overlapping with Mars upper ionosphere plasma content happen will be studied. Also, the influence of upstream solar wind conditions might have on the generation of MSW will be studied, including both normal and extreme solar and space weather events. This study will provide insight into how the Mars-solar wind interaction can control the energy and particle input from the Sun into the Mars atmosphere and how these energy and particles drive processes such as ion heating that results ion escape from Mars.

Contributed Talk

Laboratory observation of lower hybrid drift waves during the formation of current sheet in anti-parallel magnetic reconnection

Author: Peiyun Shi

Affiliation: PPPL

Abstract:

Magnetic reconnection is widely recognized as one key process to power most energetic and explosive phenomena throughout the universe by reconfiguring magnetic field topology in plasmas, while releasing the stored magnetic energy. A build-up phase must precede the sudden onset of fast reconnection to accumulate the required magnetic energy to be released. Numerical simulations suggest that lower hybrid drift waves (LHDWs) can facilitate the initiation of fast reconnection. In MRX, an additional reconnection electric field is applied to the initially weak reconnection field to study the transient phase, in which current sheet thins. LHDWs are excited during the current sheet thinning and the reconnection magnetic field pileup. These LHDWs are spatially and temporally correlated to the electron pressure gradient, suggesting the diamagnetic drift as a free energy source of LHDWs. Our results suggest that observed LHDWs can provide additional electron heating in the current sheet during the current sheet formation. This potentially enhance kinetic effects in the electron diffusion region, thereby facilitating fast reconnection.

Contributed Talk

Vortex Evolution from a Strain Pulse: Competition Between Adiabaticity and Instability.

Author: Swarnima Singh

Affiliation: University of California, San Diego

Abstract:

The E × B drift of pure electron plasmas in a Penning–Malmberg trap serves as a model for 2D vortex dynamics in inviscid fluids. Similar vortex behavior is observed in systems such as high-intensity beam transport and drift-wave turbulence phenomena. The current study investigates the response of an initially axisymmetric vortex to a half-sinusoidal strain pulse, which mimics the finite impulse kicks in such flow environments. Dynamics during the finite waveform has the potential to capture both adiabatic invariant breaking [1] and instability growth [2]. Vortex evolution is characterized as a function of peak strain amplitude and pulse duration (T). The adiabatic invariant, or action, is defined via the phase-space area enclosed by the orbit and inferred from vortex ellipticity at the pulse end. At low strain amplitudes, the system exhibits periodic breaking of the adiabatic invariant, with good agreement between experimental results and a model assuming an elliptical vortex with uniform vorticity [3]. This breaking is found to be bounded above by a power-law envelope, scaling as T^2. At higher strain, the vortex undergoes separatrix crossing, and the maximum elongation exceeds $\lambda \geq 3$, exceeding the Moore–Saffman instability threshold [4]. In this regime, experimental observations diverge from the uniform vorticity ellipse model, indicating the onset of instability-driven dynamics, with separatrix crossing shown to depend on the pulse duration. Two-dimensional mapping of change in action as a function of strain amplitude and pulse duration reveals the presence of periodic islands in parameter space. The effects of vortex profile shape on stability and evolution will also be discussed, along with the potential for repeated pulses to drive complex or turbulent states.

References

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4. Plenum Press, New York, pp. 339-354 (1971).

Contributed Talk

The role of ions in electron-only reconnection in the PHAse Space MApping experiment

Author: Katey Stevenson

Affiliation: West Virginia University

Abstract:

Here we present the first laboratory measurements of both ion and electron temperatures during electron-only reconnection. Ion and electron velocity distribution functions (VDFs) are measured using pulsed laser-induced fluorescence (LIF) and Thomson scattering, respectively. Temperatures are measured throughout different phases of the reconnection process. No significant ion heating is observed but tracking the evolution of ion and electron temperatures helps to form a more complete picture of energy allocation in electron-only reconnection. A detailed discussion of the experimental challenges of measuring ion velocity distribution functions in PHASMA plasmas will be presented.

Contributed Talk

Magnetized plasma experiment on layering and inhomogeneous mixing in a fluctuating array of vortices

Author: Richard Sydora

Affiliation: University of Alberta, Canada

Abstract:

In this work we investigate layering and staircase dynamics using a fluctuating vortex array (FVA) which intrinsically drives inhomogeneous mixing. The FVA is one of the simplest routes to staircase formation and involves particle and energy transport between marginally overlapping cells. The layering mechanism involves rapid homogenization within cells and slower transport across cell boundaries. The regulation of transport by these two timescales causes layering. In order to establish this physical system, a vortex array is created in a large linear magnetized plasma device (LAPD at UCLA) that is designed to have a system of tangent eddies with neighboring cells in the lattice. To generate the vortex lattice in the experiment, a smaller lanthanum hexaboride (LaB6) cathode source is placed at the opposite end of the device relative to the main discharge large area LaB6 cathode. A carbon mask containing a patterned array of holes is placed in front of this smaller cathode. When this smaller cathode is biased to a mesh anode in front of the main discharge cathode, a dynamical vortex lattice with local and global vortical azimuthal and axial flows is established. In the near field region of the lattice, the local plasma potential forms a well, which induces ExB differential rotation of the lattice resulting in azimuthally symmetric inhomogeneous boundary layers that are on the scale of the mask holes in the initial lattice structure (roughly ten gyroradii). A series of mixing layers is interspersed with the boundary layers and an analysis of the cross-field transport indicates that two timescales are present, one associated with the rapid homogenization within the layer and the other connected with slower transport across the layers. A detailed analysis of the sources of the combined fluctuation-driven and collisional transport is presented.

Contributed Talk

The Plasma Science Virtual Laboratory for Classroom Learning and Laboratory Prototyping

Author: Jason TenBarge

Affiliation: Princeton University

Abstract:

In this presentation, I will demonstrate new features of the Plasma Science Virtual Laboratory (https://vlab.plasmascience.scigap.org/), which has been developed through the NSF CSSI program to facilitate advanced plasma and space weather simulations across various high performance computing platforms through a user-friendly web interface. The web interface allows a user to perform Gkeyll multi-fluid and fully kinetic continuum simulations from a variety of editable, pre-defined input scripts, including reconnection, instabilities, global magnetospheres, and the Large Plasma Device (LAPD) at UCLA. The simulations are carried out on NSF HPC resources, and the user can visualize the data from the simulations within the web interface. In this presentation, I will present recent advances in the Virtual Laboratory interface which incorporates Python Jupyter Notebooks and has been successfully deployed in a classroom setting. In addition, the utility of the Virtual Laboratory for employing Gkeyll simulations to prototype LAPD experimental campaigns will be demonstrated.

Contributed talk

Resonant Electron Energization via Wave Damping in Laboratory Reconnection

Author: Sonu Yadav and Earl Scime

Affiliation: West Virginia University

Abstract:

Wave–particle interactions are fundamental mechanisms in plasma physics, governing the transfer of energy and momentum from macroscopic fields to microscopic particle populations. In magnetic reconnection, these interactions play a critical role in mediating wave generation, particle acceleration, and energy dissipation, ultimately shaping the dynamics and efficiency of the reconnection process. Understanding these couplings is essential for interpreting both space and laboratory plasma observations. In this work, we investigate wave–particle interactions in a collisionless, low-beta flux rope plasma generated by the PHAse Space MApping (PHASMA) device, a dedicated experiment designed to study magnetic reconnection driven by merging flux ropes. Electron velocity distribution functions (EVDFs) are measured via incoherent Thomson scattering, while a linear array of Langmuir probes captures propagating plasma wave activity. The measured EVDFs exhibit clear non-Maxwellian features, including a cold electron beam centered near the resonant wave phase velocity ($v=\omega/k$). The negative slope of the beam distribution at the phase speed indicates that the electron beam is gaining energy via wave damping. This observation provides direct evidence of resonant energy transfer from waves to particles. Using wave–particle correlation techniques, we quantify the instantaneous power density change, confirming that wave damping contributes to electron energization during reconnection.

Contributed Talk

Bifurcated Current Sheets and Their Role in Energy Conversion during Magnetic Reconnection

Author: Jongsoo Yoo

Affiliation: Princeton Plasma Physics Laboratory

Abstract:

We report observations of bifurcated current sheets (BCS) in the Magnetic Reconnection Experiment (MRX), NASA's Magnetospheric Multiscale Mission (MMS), and the Parker Solar Probe (PSP). BCS are characterized by a double-peaked current density, strong localized electric fields, and sudden density increase. We show that the presence of BCS implies the existence of an electrostatic potential well that facilitates energy conversion during magnetic reconnection. Using a simplified electron momentum equation in the ion frame, we demonstrate that the depth of this potential well can be directly estimated from magnetic field variations across the BCS. This estimate is quantitatively consistent with both MRX and MMS observations. Supporting 2D open-boundary particle-in-cell simulations further reveal that BCS structures persist into the downstream region only when reconnection remains in a quasi-steady state, providing a potential explanation for their infrequent observation in the magnetosphere.

Poster

Laboratory Study of Alfvén Wave Steepening

Author: Mel Abler

Affiliation: Space Science Institute & UCLA

Abstract:

Alfvénic fluctuations - fluctuations with correlated or anti-correlated magnetic-field and velocity fluctuations perpendicular to the background magnetic field - are thought to be ubiquitous in magnetized astrophysical plasma environments and are observed across a range of scales in our own solar wind. Recent theoretical work by Mallet et al [1] proposes a Hall-driven mechanism by which small-scale, oblique Alfvén waves may undergo a one-dimensional nonlinear steepening process only at dispersive length scales smaller than the ion inertial length (e.g. when one or more of $k_{\perp\rho s}$, $k_{\perp de}$, or $k_{\parallel di}$ becomes significant). This work presents comprehensive laboratory tests of this steepening model, comparing predictions for the amplitude of the harmonic of a driven wave to experimental measurements from the Large Plasma Device (LAPD); we additionally characterize the effectiveness of this steepening as an energy transfer mechanism via comparison to other nonlinear Alfvén wave interactions. These tests span inertial ($v_A \gg v_{th,e}$) to kinetic ($v_A \ll v_{th,e}$) conditions at low β, with results showing changes to the structure of the harmonic across these conditions indicating that 2D dynamics may be important to the observed steepening.

Poster

Energetic electron interaction with magnetic islands in MMS and DIII-D

Author: Sydney Battles, Evdokiya Kostadinova, Jessica Eskew, Bradley Andrew

Affiliation: Auburn University

Abstract:

Here we investigate the interaction between magnetic islands and energetic electrons from lab to space through comparison of data from NASA's Magnetospheric Multiscale (MMS) mission and experiments at the DIII-D tokamak. We compare magnetic islands in the Earth's magnetotail to magnetic islands caused by 3D coil perturbations in laboratory magnetized plasmas. The analysis of MMS data focuses on identifying reconnection-driven bipolar signatures in the boundary-normal magnetic field, using minimum variance analysis to transform magnetic field data into a local-boundary normal coordinate system appropriate for visualizing the local magnetic topology. We developed a semi-automated Python workflow that streamlines event selection, coordinate transformation, and diagnostic plotting to detect magnetic islands with minimal manual input. To characterize the island interaction with energetic electrons, we incorporate particle data from the Fast Plasma Investigation (FPI) instrument, identifying key features such as the energy and density distribution of electron populations across the islands. The MMS data is compared against magnetic reconstructions of islands in DIII-D and energy distributions form DIII-D emission diagnostics. Our methodology provides a foundation for future cross-regime studies and contributes to a unified understanding of magnetic reconnection and island-driven transport processes from lab to space.

Poster

Turbulence Measurements of Steady State and Pulsed Power Plasmas on PHSAMA

Author: Gustavo E Bartolo

Affiliation: West Virginia University

Abstract:

In this study, we investigate the wavenumber Power Spectral Density (PSD) of fluctuations in steady state helicon plasmas and during pused flux rope mergers in the Phase Space Mapping (PHASMA) experiment at West Virginia University. Optical measurements are obtained using a Photron Nova-S9 fast camera, while turbulence is characterized via floating potential measurements from a custom-built probe designed to suppress common-mode noise. All experiments are conducted in argon. Lateral imaging of plasma light emission reveals high-frequency (sub-300 kHz), temporally localized oscillations correlated with reconnection events, along with lower-frequency modes that may correspond to whistler waves. Previous measurements identified steep wavenumber spectra-up to $k^{-5.3}$- in both helicon plasmas (near ion cyclotron and electron skin depth scales) and flux rope mergers (near ion sound scales). To corroborate the non-perturbative optical measurements, a multitip probe is used to extract radial, azimuthal, and lateral PSDs by correlating floating potential signals.

Poster

Measurements of Ionospherically Relevant Ion-Ion and Ion-Neutral Cross Sections

Author: George Collier

Affiliation: West Virginia University

Abstract:

We present experimentally determined ion-ion and ion-neutral collisional cross-sections for various ionospheric compositions at different altitudes conducted in a laboratory environment. Cross-section measurements were performed in the Space and Beam Experiment (SABER) at West Virginia University using an ion gun to accelerate H2, O2 He, Ar, N, and N_2, and NO ions. The ions are directed through a gas mixture and the transmitted current collected using a Faraday cup. To recreate the conditions and gas composition of the ionosphere at various altitudes, an array of mass flow controllers was employed controlling H_2, O_2 He, Ar, and N_2, and NO composition. Additionally, a helicon source is used to produce a level of ionization corresponding to the altitude being simulated. Current models of ionospheric ion-neutral collision frequencies show significant variability compared to estimates derived from radar observations. Accurate measurements of these collision cross-sections are crucial for enhancing our understanding of Magnetosphere-Ionosphere-Thermosphere coupling.

Poster

External magnetic field effects on the development of space debris-driven solitons

Author: Vikram Dharodi

Affiliation: West Virginia University

Abstract:

Due to ongoing global space exploration efforts, an estimated 170 million pieces of debris currently orbit in the low Earth orbit region. This space debris poses a serious threat to commercial and national security assets operating in orbit. One promising approach involves using plasma phenomena to aid debris detection. Electrically charged debris traveling through the plasma environment may excite ion-acoustic solitons, which propagate upstream of the debris. These solitons could provide a novel early-warning mechanism for spacecraft. In this study, we model lower Earth orbit plasma conditions using particle-in-cell simulations. We perform two- and three-dimensional numerical investigations to examine the influence of an external magnetic field on the evolution of solitons.

Poster

Analysis of fluctuation activity in tokamak plasmas above the Greenwald density limit in the Madison Symmetric Torus

Author: Joseph Flahavan

Affiliation: University of Wisconsin - Madison

Abstract:

Recent experiments in the Madison Symmetric Torus (MST) have demonstrated the capability of sustaining stable tokamak plasmas with densities far above the Greenwald limit, up to 18 n_G at $<n_e> = 9x10^{19}$ m^-3. The Greenwald limit, n_G, is an empirically determined upper limit on the line-averaged electron density, $<n_e>$, for stable operation of current-carrying toroidal laboratory plasmas, including tokamaks. The limit is defined as $n_G\ [10^{20}\ m^{-3}\ ]\ =\ I_p[MA]/(\pi * a[m]^2)$, meaning n_G is proportional to the average toroidal current density. Above this limit, other devices commonly experience edge detachment and disruption. The mechanism responsible for this limit is not fully understood, with leading theories focusing on edge turbulence and radiative power loss. In MST experiments, tokamak plasmas are generated with plasma current I_p = 40-55 kA and toroidal field B_T = 0.13T, corresponding to edge safety factor in the range q(a) = 2.2-3. At increased densities, with $<n_e >$ above 2 n_G, a distinct equilibrium is seen to develop with broadened electron density and current density profiles. This is believed to be the result of a radiative collapse, similar to what is seen in stellarators above the Sudo density limit, which scales input power instead of current density. Here, we present analyses of fluctuation frequency spectra across the range of tokamak plasma densities accessible to MST. Data acquired from an 11-chord far-infrared interferometer, edge-measured magnetics, and internal probes is processed by auto-power and cross-power spectral densities. Changes in this frequency dependence are characteristic of shifts in turbulence in the plasma. As edge turbulence is suggested to play a role in Greenwald mechanism, particular attention is given to variations in spectra near the plasma edge. Differences in fluctuations between the two types of tokamak equilibrium are discussed.

Work supported by U.S. DOE awards DE-SC0020245 and DE-SC0018266 and NSF award PHY 1828159.

Poster

Alfvénic Turbulence in Multiple Regimes: Results from Prior LAPD Experiments and Plans for the Near-Future

Author: Samuel Greess

Affiliation: Queen Mary University of London

Abstract:

Turbulence is ubiquitous throughout different space plasma environments, facilitating the cascade of energy down to smaller and smaller length scales. That said, the different parameter regimes at which these plasmas exist have a significant effect on the way the cascade develops. Though in-situ measurements can provide a wealth of knowledge about the properties of space turbulence, they are limited by their spatial extent relative to the plasma environment and their reproducibility. Laboratory plasma experiments like those run on the LArge Plasma Device (LAPD) at the University of California-Los Angeles can provide insight complementary to satellite data. The space plasma turbulence group at Queen Mary University of London (QMUL) has run Alfvén wave experiments on LAPD studying weak and strong interactions at a range of $k_\perp\rho_s$ values, from very small (MHD limit) up to order unity (kinetic limit). The change in the properties of the drive waves and their interaction products between these limits has been quantified via detailed measurements of magnetic and electric field fluctuations in multiple different counter-propagating wave configurations. Further data runs allowed for an analysis of the residual energy- and cross helicity-dependent properties of the interactions. With this experimental setup, the fundamental physics of the three-wave interaction can be studied in detail while minimizing the impact of other solar wind phenomena.

Poster

A Dipole Trap for Non-neutral Plasma Studies

Author: Subin Han

Affiliation: Lawrence University

Abstract:

A magnetic dipole has the necessary symmetry, similar to a Penning-Malmberg trap, to take advantage of canonical angular momentum conservation for confining non-neutral plasma. Recent theory and computation identified global thermal equilibrium states where the plasma resides in an equatorial ring outboard of the magnet (Steinbrunner 2023); they are therefore likely to be accessible in a trap with a supported magnet. The predicted states require tailored electrostatic boundary conditions and a bias on the magnet. We present preliminary data from a new dipole trap constructed at Lawrence University that aims to test whether these states are experimentally accessible. In the Lawrence Non-neutral Dipole (LND) device, a neodymium magnet (3" diameter disk with a surface magnetic field of 2.3 kG on axis) is mounted on a central support and can be biased relative to the vacuum chamber as theory demands. We employ a LaB6 emitter to inject electrons from the equator and use multiple copper wall probes to monitor image charge signals.

This work is supported by the National Science Foundation under Grant No. 2206620.

P. Steinbrunner, T. M. O'Neil, M. R. Stoneking, and D. H. E Dubin, J. Plasma Phys. 89, 935890401 (2023).

Poster

Using Machine Learning to Investigate Three-Dimensional Magnetic Reconnection within PHASMA

Author: Gabriela Himmele

Affiliation: West Virginia University

Abstract:

The PHASMA (PHAse Space MApping) facility at West Virginia University employs pulsed plasma guns to study magnetic reconnection through the interaction of merging magnetic flux ropes. This study, encompassing approximately 730 shots of helium double flux ropes, clusters data from fast photodiodes and Thomson-scattering with similar bias currents via machine-learning techniques. Comparative evaluation shows that dynamic time warping of the bias current time series data paired with k-medoids clustering results in best clustering of the data because of its ability to handle temporal shifts and subtle variations as compared to standard Euclidean measures. Three distinct clusters appeared in the Thomson Scattering data with electron temperatures of 3.2 +/- eV, 3.3+/-0.07 eV, and 2.7 +/- 0.03 eV. Each cluster appears to correlate with significant differences in the underlying discharge physics. When unsupervised learning was applied to correlate photodiode signals and uncover additional inter-shot similarities, 5 distinct clusters appear in the photodiode data. The long-term goal of this analysis method is to be able to focus on specific discharge features that result in significant levels of wave-particle interactions specific to magnetic reconnection. Another goal of the analysis to develop a method of localizing the time and location of reconnection to better synchronize triggered measurements.

Poster

Helical structures in low-safety-factor toroidal plasmas near the Kruskal-Shafranov limit

Author: Noah Hurst

Affiliation: University of Wisconsin - Madison

Abstract:

In the region of edge safety factor $0 < q(a) < 2$ between the reversed-field pinch and the tokamak, there exists a regime of low-safety-factor toroidal plasmas that is difficult or impossible to access in most devices due to disruptive kink instabilities. In the Madison Symmetric Torus (MST), this regime can be accessed in steady conditions due to a thick, conductive, close-fitting wall that delays growth of the resistive wall mode, and a high-voltage, high-bandwidth, feedback-controlled power supply driving the plasma current [N. C. Hurst, et al., Phys. Plasmas 29, 080704 (2022)]. We present results of experiments with plasmas in MST near the Kruskal-Shafranov limit, $q(a) = 1$, providing insight into a regime of toroidal plasma operation that is not well characterized. As the limit is approached from above, strong, global $m/n = 1/1$ helical structures are observed rotating past several diagnostics. When $q(a)$ is very close to 1, these modes lock to the machine wall and grow to large amplitude up to 25% of the poloidal field at the plasma edge. The ability to lock these modes at particular phases using applied resonant magnetic perturbations is demonstrated. Discharges with $2/3 < q(a) < 3/4$ are also presented, where two nearly resonant modes compete for dominance.

Work supported by US DOE grants DE-SC0018266 and DE-SC0020245, and by NSF grant PHY 1828159.

Poster

Evolution of a Laboratory Arched Magnetized Plasma in a Strapping Field with variable Decay Index

Author: Garima Joshi

Affiliation: UCLA

Abstract:

The strapping magnetic field plays a fundamental role in both the formation and dynamic evolution of arched magnetic structures in the solar atmosphere. By providing magnetic tension that confines and supports these arches, it influences their stability and morphology. When an arched plasma becomes unstable, its interaction with the overlying strapping field can lead to dramatic energy releases, driving explosive solar phenomena such as flares, plasma jets, and coronal mass ejections (CMEs). This interplay between the restraining magnetic field and eruptive plasma structures is a key mechanism underlying solar activity. The exact mechanism that drives solar eruptions is yet to be fully understood. The torus instability is one of the key mechanisms that drives eruptions and it critically depends on the decay index of an arched plasma. The decay index measures the rate of the overlying magnetic field decay with distance from the arched plasma foot-points. Therefore, an in-depth understanding of the role of the strapping magnetic field in destabilizing an arched plasma is vital for predicting solar activity. We have conducted a laboratory experiment with analogs of solar-arched plasma in the Solar Plasma Device (SPD) at UCLA. The arched plasma (b » 10-3, Lundquist number » 102–105, plasma radius/ion-gyroradius » 20, B » 1000 G at foot points, repetition rate = 0.5 Hz) evolves in a large-scale magnetic field with a variable decay index. The evolution of the arched plasma is recorded using three-dimensional measurements of vector magnetic field, plasma density, and electron temperature. The role of decay index, magnetic shear, and relative strengths of the arched and strapping magnetic field in the formation of nearly stable, oscillatory, and eruptive will be discussed.
This research is primarily supported by the US Department of Energy under award number DE-SC0022153.

Poster

Experimental observation of precursor solitons in a flowing plasma

Author: Krishan Kumar

Affiliation: West Virginia University

Abstract:

The population of space debris continues to grow at an alarming rate in Low Earth Orbit (LEO). These debris are a serious threat to active space assets and are also responsible for delaying mission launches. Detecting individual small-sized debris using optical techniques or directly through radar scattering poses significant technical challenges. Sen et al. [Advances in Space Research, 56 429–435 (2015)] proposed a fore-wake model in a plasma medium which could be used for detecting and tracking small-sized orbital debris. Truitt et al. [Journal of Spacecraft and Rockets, 57 876–897 (2020)] further investigated the fore-wake phenomenon as a function of the size, velocity, and orbital parameters about the Earth of the debris. The first experimental demonstration of the generation of a precursor soliton in a flowing dusty plasma over a charged object was reported by Jaiswal et al. [Phys. Rev. E 93, 041201 (2016)]. In this work, we report successful detection of precursor solitons in a flowing plasma for space-relevant plasma conditions. The experiments are performed in the Space Plasma Simulation Chamber (SPSC) at the Naval Research Laboratory (NRL). A series of biased rings placed at the end of the SPSC are used to create a radial electric field along with an applied axial magnetic field resulting in an azimuthal plasma flow. The inferred flow speed (assuming the driven flow is the E x B speed) changes in a wide range by different combinations of radial electric fields and axial magnetic fields. A debris object is placed in the chamber such that plasma flows over it. The detection of these solitons through radar scattering could give early warning, aiding satellites and manned spacecraft to avoid collisions.

Poster

3D Thomson Scattering Measurements of Electron Heating in Helicon Plasmas

Author: Jacob E.A. Lord, Peiyun Shi, Earl E. Scime, Sonu Yadav

Affiliation: West Virginia University

Abstract:

Helicon discharges are frequently used as plasma sources in laboratory experiments thanks to their high ionization rate and electron temperature. However, it remains elusive how electrons are heated and interact with helicon waves. We directly measure the helicon wave phase-sorted electron velocity distribution functions and electron temperature anisotropy to distinguish between the possible particle-field interactions in helicon plasmas. A new 3D Thomson Scattering apparatus has been developed to measure electron velocity distribution functions in the helicon source as well as in the PHAse Space MApping (PHASMA) experiment. The new Thomson Scattering collection optics are modular so that it can be moved to different locations in PHASMA. Preliminary measurements of the RF phase resolved parallel electron velocity distribution function in the helicon source will be presented.

Poster

Advancements in Multi-Photon Laser-Induced Fluorescence for Diagnosing Plasma

Author: Jacob McLaughlin

Affiliation: West Virginia University

Abstract:

In conventional laser-induced fluorescence (LIF) measurements, the Doppler-broadened velocity distribution function (VDF) is obtained by recording the injected laser wavelength while monitoring the induced fluorescence. Measured signal is proportional to the laser intensity to the nth power, where n is the number of photons absorbed in the scheme (n=1 for single photon, n=2 for two-photon absorption, etc.). To maximize laser intensity and therefore fluorescent signal, pulse-widths are becoming increasingly short. The consequence of ultrashort pulses (< ns) is laser linewidths which are too broad in wavelength to resolve VDFs. Still, these lasers are useful for temporally resolving the time scales of fluorescent decays and for high rep-rate measurements of absolute densities in fusion-relevant plasmas, spacecraft thrusters, and plasma processing. Extracting the VDF is still possible if the emission is spectrally resolved, rather than the laser absorption. This technique is becoming more feasible as camera and spectrometer technology develop. Conventional LIF also integrates over the two velocity dimensions orthogonal to the laser k vector. If a distribution function in two velocity dimensions is desired, one must resort to more difficult optical pumping techniques such as optical tagging. Spectrally-resolving the emission of an LIF measurement using a narrow-linewidth laser provides the VDF in the direction of emission collection, only for particles with the selected velocity in the laser propagation direction, thus providing a two-velocity-dimensional measurement of the VDF. The complexity of the diagnostic may be increased to avoid integrating over any velocity dimension and therefore obtain the full, 6-D VDF in future studies. Presented are preliminary results showing the feasibility of the diagnostic technique as a step forward in the LIF diagnostic technique for fundamental plasma science, plasma processing, and as a fusion-relevant diagnostic technique.

Poster

Laboratory measurements of whistler-mode wave polarization as a function of wave normal angle

Author: Julia Nordstrom, Jim Schroeder, Josh Meyer, Earl Scime, Sonu Yadav, Tommy Steinberger, Katey Stevenson

Affiliation: Wheaton College

Abstract:

Whistler-mode waves are found in the Earth's outer radiation belt, where the electron population is highly variable. It is believed that whistler-mode waves play a role in accelerating electrons in this belt. Wave normal angle is predicted to be an important factor in these interactions. Because of diagnostic advances, there are new opportunities to study the effect of wave normal angle on whistler-mode wave-electron interactions in the laboratory with high precision. A phased array antenna has been constructed to launch whistler-mode waves in the PHAse Space MApping (PHASMA) facility at West Virginia University. Data from a movable magnetic pickup coil give wave field components, their relative amplitudes, and their phase, all as a function of wave normal angle. This has enabled a detailed comparison of data with results from three-dimensional cold plasma theory. A robust understanding of the whistler-mode waves being generated is a necessary precursor to studying the wave-particle interactions responsible for space weather phenomena in the radiation belts. This material is based upon work supported by the National Science Foundation under NSF CAREER Award AGS-2238191.

Poster

Exploring the Science of Plasma Physics on DIII-D National Fusion Facility

Author: Dmitri Orlov

Affiliation: UC San Diego

Abstract:

DIII-D is a premier plasma research facility dedicated to advancing the science of plasma behavior, improving stability, and managing hot plasmas. A core principle of the DIII-D program is the belief that developing fusion energy solutions requires a deep scientific understanding. To this end, DIII-D is equipped with an extensive array of plasma diagnostics, enabling detailed studies of plasma mechanisms and behaviors. This effort is bolstered by collaboration with numerous universities and national laboratories, which contribute diverse expertise and innovative ideas.
A significant initiative within DIII-D is its engagement with discovery plasma science, which began in 2016. This initiative has significantly enhanced understanding of the fundamental physics shared between fusion plasma science and fields such as magnetosphere, solar physics, astrophysics, and low-temperature plasmas. Key areas of study include magnetic reconnection, wave-particle interactions, plasma-material interactions, and turbulence.
DIII-D is currently undergoing a series of upgrades aimed at further advancing scientific understanding. Additionally, improvements to plasma diagnostics will support these upgrades, providing more comprehensive data on plasma behavior.
Supported under DOE DE-FC02-04ER54698 and DE-FG02-05ER54809.

Poster

Design and Calibration of Magnetic Sense Coil for Time-Varying Magnetic Field Measurements

Author: Makesi Pantor, Sonu Yadav, Earl E.Scime

Affiliation: West Virginia University

Abstract:

Abstract: Magnetic sense coils or "$\dot{B}$-probe" coils are simple devices used to measure the fluctuations in magnitude of time-varying magnetic fields. From Faraday's Law of induction, the time derivative of the magnetic field is directly related to the induced voltage in the sense coil, V, the number of turns in each coil, N, and the area of each coil, A. Here we present results from a new $\dot{B}$ array in the PHAse Space MApping (PHASMA) experiment. The coils are wound on 3D printed, alumina forms to reduce manufacturing time and improve mechanical strength of previously used materials. Each probe coil consists of 60 turns of 40-AWG copper wire around a 3 mm diameter coil. Two orthogonal windings are employed to allow for independent $\dot{B}$ measurements in the x and y axes. Calibration of the eighteen sense coils is accomplished with a pulsed copper rod to determine voltage response for known $\dot{B}$ values. Calibrated sense coils are installed in a motorized probe that traverses the radius of the PHASMA machine. Measurements confirm magnetic reconnection occurring between adjacent flux ropes of PHASMA, validating the performance of the improved diagnostic.

Poster

First plasma with the WLPD RF source

Author: Jim Schroeder, Julia Nordstrom, Emma VanderKooi, Andrew Lamb, Josh Meyer

Affiliation: Wheaton College (IL)

Abstract:

The Wheaton Linear Plasma Device (WLPD) achieved first plasma in 2025. It is designed to be a testbed for experiments in linear magnetized plasmas, similar, though at a smaller scale, to UCLA's LAPD and WVU's PHASMA. The WLPD is intended for studying whistler-mode wave physics relevant to Earth's radiation belts, and it will also emphasize availability for education and outreach. The WLPD will use a helicon source to create overdense plasmas relevant to Earth's radiation belts. A simple circuit model has been used to select variable vacuum capacitors needed to create a matched load. The constructed matching network is paired with a commercially available 27 MHz 1700 W RF amplifier. Theory, design, and initial performance of the WLPD RF plasma source will be presented. This material is based upon work supported by the National Science Foundation under NSF CAREER Award AGS-2238191.

Poster

Status of FLARE (Facility of LAboratory Reconnection Experiments)

Author: Peiyun Shi

Affiliation: PPPL

Abstract:

Magnetic reconnection is one of ubiquitous plasma physics processes responsible for various explosive and energetic phenomena observed throughout the universe. The reconnection occurs in a widely spanning parameter space that can be organized in phase diagrams [Ji and Daughton, Phys. Plasma 18, 111207 (2011)], characterized by the Lundquist number S and normalized system size λ. The FLARE (Facility of LAboratory Reconnection Experiments) laboratory experiments target poorly explored multiple X-line reconnection regimes of both large S and λ values, which is closely relevant to reconnection in space and astrophysics plasmas. Multi-scale physics coupling global MHD scales and local ion and electron kinetic scales during magnetic reconnection will be investigated.

FLARE has been successfully commissioned, and first plasmas were achieved in April 2025. FLARE is presently being transitioned to its initial operating mode. We will present FLARE operational and diagnostics capabilities and discuss the major scientific reconnection questions to be addressed by FLARE initial operations. Finally, we will introduce future plans to operate FLARE as one DOE collaborative research facility.

Poster

Overview of current research activities in the Magnetized Plasma Research Lab (MPRL): a collaborative research facility at Auburn University

Author: Saikat Chakraborty Thakur

Affiliation: Auburn University

Abstract:

The Magnetized Plasma Research Laboratory (MPRL) at Auburn University explores fundamental plasma and complex/dusty plasma phenomena covering a large parameter regime from unmagnetized plasmas to strongly magnetized plasmas with a mission to serve as an open access, multi-user collaborative research facility. The centerpiece of the laboratory is the Magnetized Dusty Plasma Experiment (MDPX), a highly flexible plasma device with excellent diagnostic access to study the unique regime of high magnetic fields (up to 4 T), at relatively low density (~ 10^14 – 10^16/m^3) and low electron (Te < 5 eV) and ion temperature (Ti < 0.05 eV). Other instruments include ALEXIS, a linear plasma device for simulating space plasma and basic plasma experiments, and a wide variety of "tabletop" scale unmagnetized, low temperature plasma devices. Here, we will give an overview of recent studies from MPRL such as pattern formation of filamentary structures at high magnetic fields, nanoparticle growth in plasmas, laser trapping of dust particles, studies of dust clusters and dust thermodynamics, using dust as a diagnostic, controlling dust charging and dynamics by externally applied UV light, studies of dust acoustic waves at high magnetic field, development of new laser-based plasma diagnostics etc.

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Poster

Exploring hairpin resonator configurations for high electron density measurements in inductively coupled and magnetized plasmas

Author: Mycha J Valle

Affiliation: UCLA

Abstract:

When immersed in a plasma, a hairpin probe can measure electron densities from the shift of the resonant frequency of the hairpin structure relative to the electron plasma frequency. Previous efforts have developed hairpin probe hardware and theory that enable measurements of electron densities up to approximately 10^{12} cm-3, with the use of both quarter-wavelength and three-quarter-wavelength hairpin probes in a transmission mode together with the associated microwave electronics [1]. More recent theories for interpreting hairpin measurements use a transmission line model to accurately relate the resonant frequency of the probe and the electron density, including the resistive effects of a hairpin partially immersed with epoxy. These models have been used to accurately extract density measurements in inductively coupled plasmas; however, the models do not reliably account for measurements in magnetized plasmas. We present a novel hairpin design and model that minimizes the resistive effects of the epoxy and potentially provides measurements of electron plasma densities up to 10^{13} cm-3, while also allowing the probes to be reliably used in magnetized plasmas, like those created in the Large Plasma Device (LAPD) at UCLA

Poster

Suppression of Magnetic Reconnection Current Sheets in Partially Ionized Background Plasmas

Author: Sonu Yadav

Affiliation: West Virginia University

Abstract:

Magnetic reconnection is a fundamental plasma process that enables rapid energy conversion across laboratory, space, and astrophysical environments. While fast reconnection in fully ionized, collisionless plasmas is relatively well understood, the conditions leading to reconnection suppression—especially in partially ionized plasmas under strong guide fields—remain less explored. In this work, we experimentally investigate the suppression of magnetic reconnection in a low-beta, partially ionized plasma with a strong axial guide field ($B_g/B_{rec} \approx 25$). The background plasma ionization fraction is systematically varied between 10% and 40%. The experiments are performed in a flux rope merging configuration embedded within a steady helicon-driven background plasma. In-plane magnetic field measurements from B-dot probe arrays reveal significant broadening of the current sheet, delayed onset of reconnection, and a reduction in peak reconnecting current density as the background plasma ionization fraction decreases. These results suggest a suppression mechanism driven by ion-neutral drag and enhanced collisionality. This study provides new insights into reconnection dynamics in magnetized, partially ionized plasmas, with implications for solar chromospheric reconnection, protoplanetary disk evolution, and onset physics in low-temperature laboratory plasmas.