# 18th ANNUAL INTERNATIONAL ASTROPHYSICS CONFERENCE
## ORAL ABSTRACTS

| | |
|---|---|
| Bellan, Paul | ***Experimental Observations of a Cascade from the MHD Scale to the Non-MHD Scale***<br>Paul Bellan, Caltech, USA<br><br>An astrophysically relevant time-dependent, three-dimensional, multi-scale cascade of distinctive and disparate plasma phenomena is observed in considerable detail in a laboratory experiment at Caltech. The analysis and modeling of these observations have produced many new insights into plasma behavior. In brief, the observed multi-scale cascade sequence is: MHD jet propagation, MHD kink instability, MHD Rayleigh-Taylor instability, and then non-MHD energetic particle creation and whistler wave emission. Simple initial/boundary conditions lead to this complex, yet well-resolved reproducible sequence. The initial/boundary conditions provide magnetic helicity and mass injection in axisymmetric geometry. Helicity injection occurs via an electrostatic potential difference imposed across two electrodes linked by the same magnetic flux. The electrodes are a disk and a coaxial concentric annulus; these are linked by the magnetic flux from a coil producing a dipole magnetic field. An electrostatic potential drop applied across the linked electrodes drives an electric current along the linking magnetic field. This current produces magnetic forces that form a long collimated MHD-driven jet which is essentially a scale model of an astrophysical jet. The injected mass feeds the lengthening jet. On attaining the critical length at which the Kruskal-Shafranov kink instability criterion is satisfied, the jet kinks. The kink lateral acceleration creates an effective gravity that provides the environment for spontaneous development of a Rayleigh-Taylor instability. The Rayleigh-Taylor ripples choke the jet cross-section; this choking amplifies the jet axial electric current density to the point that ideal MHD fails and various phenomena beyond the scope of MHD are abruptly instigated. These non-MHD phenomena include EUV radiation, X-ray emission, and whistler wave radiation. The X-rays are surprising because the jet plasma is so cold and collisional that one would not expect electrons to be accelerated to the high energy required for X-ray production. This observation has motivated a model showing how a small cohort of electrons in a highly collisional plasma can be accelerated to extreme energies by a sub-Dreicer inductive electric field; this cohort has a much greater population than the very tiny set of electrons that are initially moving so fast as to runaway in the electric field. |
| Che, Haihong | ***Solar Coronal Electron Acceleration in Multi-island Magnetic Reconnection***<br>H. Che, UMCP/GSFC, USA<br>G. P Zank, UAH, USA<br><br>In-situ observations of the solar wind and X-ray observations of solar flares show that energetic electrons commonly demonstrate a power-law energy distribution v^{-a} with a ~ 5-7 . These energetic electrons are thought to be produced by magnetic reconnection associated with flares. How magnetic reconnection accelerates electrons to form such a soft power-law energy spectrum is a challenge in solar physics and heliophysics. We report a numerical (particle-in-cell) and theoretical investigation of how multi-island magnetic reconnection accelerate electrons. |
| Golla, Thejappa | ***Observational Evidence for Langmuir Solitons in Solar Type III Bursts***<br>G. Thejappa, University of Maryland, USA<br>R.J. MacDowall, NASA/GSFC, USA<br><br>The source regions of solar type III radio bursts are the regions of very intense Langmuir wave packets excited by the bump-on-tail distributions of energetic electrons accelerated during solar flares. We report the high time resolution observations of some of these wave packets, which provide unambiguous evidence for Langmuir solitons formed as a result of oscillating two stream instability (OTSI). We show that (1) these wave packets occur as intense localized one-dimensional magnetic field aligned wave packets, (2) their measured half-widths and peak amplitudes are inversely correlated to each other, so that the narrower the wave packet, the greater is its amplitude; this inverse correlation is the characteristic feature of Langmuir solitons formed as a result of balance between the non-linearity related self-compression and dispersion related broadening of the wave packets, (3) their FFT spectra contain peaks corresponding to side bands and low frequency enhancements in addition to pump Langmuir waves, whose frequencies and wave numbers satisfy the resonance conditions of the four-wave interaction known as the oscillating two stream instability (OTSI), and (4) they are accompanied by their ponderomotive force induced density cavities. We also report the observations of three dimensional Langmuir wave packets, which satisfy the threshold conditions for the spatial collapse, and whose spectra contain the signatures of the second and third harmonics, excited as a result of three wave interactions involving the daughter products of the OTSI. We will discuss the implication of these observations for theories of solar radio bursts. |

| | |
|---|---|
| Gopalswamy, Nat | ***On the Shock Source of Sustained Gamma-ray Emission from the Sun: Understanding Two Unusual Events***<br>Nat Gopalswamy, NASA/GSFC, USA<br>Pertti Mäkelä, Catholic University, USA<br>Seiji Yashiro, Catholic University, USA<br>Alejandro Lara, UNAM, Mexico<br>Hong Xie, Catholic University, USA<br>Sachiko Akiyama, Catholic University, USA<br><br>It has recently been shown that the spatially and temporally extended gamma-ray emission in solar eruptions are caused by >300 MeV protons precipitating on the Sun from shocks driven by coronal mass ejections (CMEs). The gamma-rays result from the decay of neutral pions produced in the proton-proton interaction when the >300 MeV protons collide with those in the chromosphere. The evidence comes from the close correlation between the durations of the sustained gamma-ray emission (TSGRE) and the associated interplanetary (IP) type II radio bursts (TII) (Gopalswamy et al., 2018, ApJ 868, L19). The linear relation TSGRE = (0.9±0.1)TII + (0±1.6) was obtained using 13 SGREs that lasted for >5 hr. The relation continues to hold when an additional 6 events with duration >3 hr were considered. However, there were two significant exceptions, which need to be explained. (1) The 2011 June 02 SGRE event had a duration of ~7 hr, but the IP type II burst had two brief episodes within the SGRE time interval. Furthermore, the solar energetic particle event (SEP) observed by STEREO-Behind was very tiny. (2) The large SEP event on 2012 March 13 had >300 MeV protons, yet there was no SGRE event. In this paper, we provide explanations for these two events and show that they are consistent with the IP shock source for SGRE events. In the 2011 June 2 event, CME interaction seems to have played a major roles in that a preceding CME mirrored the protons back to the primary CME shock to get reaccelerated before precipitating on the Sun. In the case of the 2012 March 13 event, there was no solar exposure during the first 90 minutes of the eruption, so an SGRE event is likely missed. The later exposures suggest the possibility of SGRE decaying toward the background. According to the criterion for SGRE duration established in Gopalswamy et al. (2018), the duration from the peak of the associated soft X-ray flare to the mid time between the last gamma-ray signal data point and the background data point is ~5.6 hr. This duration matches with the duration of the associated IP type II radio burst. While the SGRE event would not have been identified without the presence of the type II burst, the consistency is remarkable. This study uses gamma-ray data from Fermi, CME data from SOHO and STEREO, and type II burst data from Wind and STEREO. |
| Klein, Kristopher | ***A Preferential Ion Heating Zone Near The Sun: What is it, Where is it, and What Drives it?***<br>Kristopher Klein, University of Arizona, USA<br>Justin Kasper, University of Michigan, USA<br>Mihailo Martinovic, University of Arizona, USA<br>Daniel Vech, University of Michigan, USA<br><br>Characterizing the thermodynamics of the Sun's corona and outer atmosphere is essential to understanding its expansion and the acceleration of the solar wind. Driven by observations at 1 AU, we construct a model for a region near the Sun's surface where minor ions are preferentially heated compared to protons by some unspecified mechanism. Beyond this region, the relative temperatures of the ions are only affected by collisional relaxation. Using decades of measurements from 1 AU, we determine that the outer boundary of this surface is tens of solar radii from the Sun's surface, and we study its dynamic behavior as a function of solar cycle. Many mechanisms have been proposed which may drive preferential ion heating. We consider one mechanism, the breaking of ion magnetic moments via stochastic heating by low frequency Alfvenic turbulence, and determine using observations from the Wind and Helios missions if such heating is consistent with this preferential heating zone. Our work indicates that Parker Solar Probe will be the first mission to enter this zone and directly measure, and thereby identify, the mechanisms controlling the young solar wind. |

| | |
|---|---|
| Lu, Quanming | ***Formation of Power Law Spectra of Energetic Electrons during Multiple X Line Magnetic Reconnection***<br>Huanyu Wang, University of Science and Technology of China, China<br>Yu Liu, University of Science and Technology of China, China<br><br>In this paper, with 2D PIC simulations, we study the formation of power-law spectra of energetic electrons in multiple X line magnetic reconnection with a strong guide field. The processes of both magnetic reconnection and electron acceleration can be separated into two stages. In the first stage, two X lines appears at the border and center of the simulation domain, and then two magnetic islands are formed. In this stage, electrons are accelerated mainly by parallel electric fields, and a power-law spectrum of energetic electrons is generated with the appearance of the second X line. In the second stage, the two magnetic islands merge into one big island. Besides parallel electric fields, Fermi mechanism also plays an important role in the production of energetic electrons, and its contribution is comparable to that of parallel electric fields when the electron energy is sufficiently large. In this stage, the generated power-law spectrum of energetic electrons becomes harden. In general, the acceleration efficiencies by both parallel electric fields and Fermi mechanism become higher with the increase of electron energy, and the tendency is more obvious for Fermi mechanism. Therefore, both parallel electric fields and Fermi mechanism are important in the formation of power-law spectra of energetic electrons during multiple X line reconnection. We also investigate the influences of the ionelectron temperature ratio, guide field, and initial flux perturbation on the formed power-law spectra of energetic electrons. |
| Pierrard, Viviane | ***Consequences of the Presence of Suprathermal Electrons and Ions in the Solar Wind Kinetic Model***<br>Viviane Pierrard, Royal Belgian Institute for Space Aeronomy, Belgium<br><br>Velocity distribution functions of plasma particles measured by spacecraft in the solar wind and many other space plasmas show enhanced suprathermal tails. Such distributions can be fitted by different velocity distribution functions such as Kappa distributions decreasing as a power law of the velocity or with a sum of Maxwellians with different temperatures. The presence of nonthermal populations in space plasmas, and in particular in the solar corona and the solar wind, has important consequences concerning particle acceleration and plasma heating [1]. These effects are well described by the kinetic approach using non thermal distributions. A kinetic model of the solar corona and the solar wind has been developed for electrons, protons and minor ions [2]. It allows us to test the effects of enhanced populations of suprathermal particles. We show important consequences for the temperature of the different species. Moreover, the presence of suprathermal electrons plays an important role in the acceleration of the solar wind. We also show the evolution of the suprathermal particles with the radial distance as observed by different spacecraft and how wave-particle interactions can explain some observed features like the temperature anisotropies [3].<br><br>Using machine learning, we also improved the boundary conditions obtained from photospheric observations to obtain the best predictions at 1 AU with the kinetic exospheric model we have developed. Solar wind observations from Cluster, Helios, OMNI and Ulysses are studied to compare with the predictions of the model.<br><br>References<br><br>[1] V. Pierrard, M. Lazar, Kappa distributions: theory and applications in space plasmas, Solar Physics, vol. 287, N° 1, 2010, 153-174, doi: 10.1007/s11207-010-9640-2.<br><br>[2] V. Pierrard, M. Pieters, Coronal heating and solar wind acceleration for electrons, protons and minor ions obtained from kinetic models based on Kappa distributions, J. Geophys. Res. Space Physics, 119, 2014, 9441-9455, doi: 10.1002/2014JA020678.<br><br>[3] V. Pierrard, M. Lazar, S. Poedts, S. Stverak, M. Maksimovic, P. M. Tranicek, The Electron Temperature and Anisotropy in the Solar Wind. 1. Comparison of the core and halo populations, Solar Phys. 291(7), 2016, 2165-2179, doi: 10.1007/s11207-016-0961-7. |
| Richardson, John | ***Plasma Observations Across the Heliopause***<br>John Richardson MIT, USA<br>John Belcher MIT, USA<br><br>Voyager 2 crossed the heliopause on November 9 2018. The plasma density increased several months prior to the crossing at roughly the same time the galactic cosmic rays began to increase. At the boundary the solar wind fluxes in the sunward looking detectors dropped to background levels. Signal is observed in the D-cup which is oriented toward the T direction. We will show plasma data leading up, at, and across the heliopause in the interstellar medium and discuss what we have learned about this plasma. |

| | |
|---|---|
| Wang, Linghua | ***The in situ Electron Acceleration at ICME-driven Shocks***<br>Linghua Wang, Peking University, China<br><br>We present a comprehensive study of the in-situ electron acceleration at 74 ICME-driven shocks observed by the WIND 3DP instrument at 1 AU from 1995 through 2014. For all these shock cases, both the suprathermal electron fluxes in the ambient solar wind and downstream, J_A and J_D, generally fit well to a double-power-law spectrum with an upward break around 2 keV. For the shock cases with significant electron flux enhancements across the shock, the downstream electron spectral index appears similar to (mostly larger than) the ambient electron spectral index, ranging from ~2 to ~6 with a sharp peak between 3 and 4 (semi-uniformly distributed between ~2 to ~3.2), at energies below (above) the break. Among the shock parameters, JD correlates the most with the magnetosonic Mach number, while the electron flux enhancement across the shock, J_D /J_A, correlates the most with the magnetic compression ratio. On the other hand, J_D /J_A peaks mainly in the in the directions perpendicular to the interplanetary magnetic field. Also note that quasi-perpendicular shock cases behave similarly to quasi-parallel shocks, but with stronger electron flux intensities and enhancements. These results suggest that the shock electron acceleration at 1 AU could favor the shock drift acceleration. The interplanetary shocks could accelerate solar wind strahl/halo electrons at energies below ~2 keV, while they could contribute to the production of solar wind superhalo electrons at energies above ~2 keV. |
| Yoon, Peter | ***Weakly Turbulent Nonlinear Wave-Particle Interactions in Space and Astrophysical Plasmas***<br>Peter H. Yoon, KASI, Korea/UMD, USA/KHU, Korea<br><br>Weakly nonlinear and incoherent interactions among waves and plasma particles can be described by perturbative nonlinear kinetic theory known in the plasma physics literature as the weak turbulence theory. In the context of space physics, the weak turbulence analysis of electron beam-plasma interaction pertains to two prominent examples. One is the physical origin of non-thermal electron distribution function observed in space. It is well known that the solar wind electron distribution function can be empirically fitted with the celebrated kappa distribution function (Vasyliunas 1968), but its origin was not understood. The weak turbulence theory of electron beam-plasma interaction and ensuing Langmuir turbulence can naturally explain the generation of electron kappa distribution function (Yoon 2014). The stationary kappa distribution function for the electrons that forms as a result of interaction with saturated Langmuir turbulence spectrum may be equivalent to the non-extensive statistical equilibrium state (Tsallis 2009, Livadiotis 2017). Another application is on the radiation generation during the course of electron beam-plasma interaction process. The emission of electromagnetic radiation at the plasma frequency and/or its harmonic(s) is known in the literature as the plasma emission, and it is the fundamental process responsible for the solar type II and type III radio bursts (McLean and Labrum 1985). Many theories have been developed in the literature since the decade of 1950s (Melrose 1980), but complete theoretical/numerical demonstration of plasma emission starting from the electron beam-plasma instability process has not been done until recently (Ziebell 2015). The plasma emission result when Langmuir turbulence energy is partially converted to electromagnetic radiation via nonlinear processes. This talk will overview the latest development on this research topic.<br><br>References<br><br>D. B. Melrose, Plasma Astrophysics, Vol. 1 and 2 (Gordon and Breach, 1980).<br><br>V. M. Vasyliunas, JGR, 73, 2839 (1968).<br><br>P. H. Yoon, JGR, 119, 7074 (2014).<br><br>C. Tsallis, Introduction to Nonextensive Statistical Mechanics (Springer-Verlag, 2009).<br><br>G. Livadiotis, Ed., Kappa Distributions (Elsevier, 2017).<br><br>D. J. McLean and N. R. Labrum, Solar Radiophysics : Studies of Emission From the Sun at Metre Wavelengths (Cambridge, 1985).<br><br>L. F. Ziebell, P. H. Yoon, L. T. Petruzzellis, R. Gaelzer, and J. Pavan, ApJ, 806, 237 (2015). |

| | |
|---|---|
| Zank, Gary | ***The Pickup Ion Mediated Solar Wind***<br>G.P. Zank, University of Alabama in Huntsville, USA<br>L. Adhikari, University of Alabama in Huntsville, USA<br>L.-L. Zhao, University of Alabama in Huntsville, USA<br>P. Mostafavi, University of Alabama in Huntsville and Princeton University, USA<br>E.J. Zirnstein, Princeton University, USA<br>D.J. McComas, Princeton University, USA<br><br>The New Horizons Solar Wind Around Pluto (NH SWAP) instrument [McComas et al 2008] has provided the first direct observations of interstellar hydrogen and helium pickup ions (PUIs) at distances between ~11.26 and 38 AU in the solar wind [McComas et al 2017]. The observations demonstrate that the distant solar wind beyond the hydrogen ionization cavity is indeed mediated by PUIs. The creation of PUIs modifies the underlying low-frequency turbulence field responsible for their own scattering. The dissipation of these low-frequency fluctuations serves to heat the solar wind plasma, and accounts for the observed non-adiabatic solar wind temperature profile and a possible slow temperature increase beyond ~30 AU. We develop a very general theoretical model that incorporates PUIs, solar wind thermal plasma, the interplanetary magnetic field, and low-frequency turbulence to describe the evolution of the large-scale solar wind, PUIs, and turbulence from 1 - 84 AU, the structure of the perpendicular heliospheric termination shock, and the transmission of turbulence into the inner heliosheath, extending the classical models of Holzer, 1972 and Isenberg, 1986. A detailed comparison of the theoretical model solutions and observations derived from the Voyager 2 and NH SWAP data sets shows excellent agreement between the two for reasonable physical parameters. |
| Zieger, Bertalan | ***Particle Acceleration by Dispersive Magnetosonic Waves in the Inner Heliosheath***<br>Bertalan Zieger, Boston University, USA<br><br>The solar wind in the inner heliosheath beyond the termination shock (TS) is a non-equilibrium collisionless plasma consisting of thermal solar wind ions, suprathermal pickup ions (PUI) and electrons. Since the thermalization time scale is much larger than the convection time scale, and the convection time scale is much larger than the isotropization time scale of PUI, the three-fluid description of the solar wind plasma is a reasonable approximation. In this presentation, we briefly review the theory of dispersive shock waves in multi-ion non-equilibrium plasma. In such plasma, two fast magnetosonic wave modes exist: the high-frequency fast mode that propagates mainly in the PUI and the low-frequency fast mode that propagates in the thermal solar wind ions [Zieger et al., 2015]. Both of these wave modes are dispersive on fluid scale. Recently we have shown that the TS crossing observed by Voyager 2 is a subcritical quasi-stationary dispersive shock wave or oscilliton, which appears as a trailing wave train downstream the TS [Zieger et al., 2015]. Here we present high-resolution three-fluid MHD simulations of nonlinear magnetosonic waves at the TS and in the inner heliosheath up to 8 AU downstream of the TS. Downstream propagating nonlinear PUI waves grow until they steepen into PUI shocklets (thin current sheets). We show that upstream-to-downstream transmissions across a number of forward PUI shocklets can efficiently accelerate both ions and electrons through the shock drift acceleration mechanism deep in the inner heliosheath, which is a potential mechanism of anomalous cosmic ray (ACR) acceleration as well. The relative energy gain of accelerated particles depends only on the compression ratio of the shocklets, which results in a power law velocity distribution. Our theoretical results are also applicable to particle acceleration downstream of low-Mach-number subcritical interplanetary shocks at 1 AU. |