The 2008 NSF SHINE WORKSHOP

ABSTRACTS
Comparing the Properties of Magnetic Reconnection in Various Environments
(Gosling / Hesse)

Magnetic Reconnection in the Solar Wind, at the Magnetopause of the Earth and Planets and in Planetary Magnetotails

Russel C.T. (UCLA), T. L. Zhang (OEAW, Austria), Y. S. Ge (UCLA), C. M. Jackman (ICSTM), M. Dougherty (ICSTM), J. T. Gosling (LASP/CU), J. G. Luhmann (UCB)

Magnetic reconnection is controlled by the geometry of the magnetic field and by plasma conditions. The solar wind, the magnetopause, and the magnetotail present quite different geometries in which to test the geometrical dependence. The existence of reconnection at the magnetopause and in the tail of different planets allows an examination of the behavior as a function of plasma conditions. Current sheets in the solar wind appear to produce reconnection signatures, ranging from that of field annihilation to X-line acceleration. Reconnection at the magnetopause provides an ideal geometry for X-line reconnection, but still can be stopped by a high Mach number bow shock producing a high-beta magnetosheath. Both the solar wind and the magnetopause provide lessons on the importance of relative orientation of the magnetic field on opposite sides of the current sheet. Magnetotails evolve to a reconnecting state much differently than solar wind and magnetopause current sheets, as they have antiparallel fields linked by normal components across the current sheets. These normal components must be reduced to near zero for reconnection to take place. Even then it may be slow until the plasma conditions at the X-point become optimum for rapid acceleration.

The Importance of the Hall Effect in Magnetic Reconnection: Comparisons of Hybrid and Hall-less Hybrid *

Malakit K. (University of Delaware), Cassak P. (University of Delaware), Shay M. (University of Delaware), Drake J. (University of Maryland)

Petschek reconnection describes how reconnection is able to proceed fast enough to explain observed energy release rates in eruptive events in the solar corona and Earth's magnetosphere. However, Petschek reconnection does not self-consistently occur in resistive magnetohydrodynamics (MHD). It was shown, for example, in the GEM Magnetic Reconnection Challenge [1] that the presence of the Hall effect is sufficient to set up (fast) Petschek reconnection. While it is well established that resistive MHD simulations without the Hall term give slow (Sweet-Parker) reconnection, the situation in hybrid simulations (particle ions, fluid electrons) is less clear, with some studies finding fast reconnection even without the Hall term[2]. In this study, we examine the role of the Hall term in allowing fast reconnection in hybrid simulations, with careful consideration of the chosen electron dissipation model. [1] J. Birn et al., J. Geophys. Res., 106, 3715 (2001). [2] H. Karimabadi, D. Krauss-Varban, J. D. Huba and H. X. Vu, J. Geophys. Res., 109, A09205 (2004).
Particle Acceleration by Magnetic Reconnection in the Earth's Distant Magnetotail and in Solar Flares

Lin R.P., Krucker S., Oieroset M. (University of California, Berkeley)

We present strong evidence that magnetic reconnection at the Sun and in the magnetosphere often accelerates particles to high energies and sometimes with high efficiency. RHESSI imaging of hard X-ray/gamma-ray continuum often showing double moving sources with simultaneous temporal variations on straddling the flare loop arcade, strong evidence for electron acceleration related to reconnection. RHESSI's unprecedented imaging of the 2.223 MeV gamma-ray line in the 28 October 2003 large flare also shows double sources straddling the flare loop arcade, indicating ion acceleration to >~30 MeV is also related to reconnection. In these large flares as much as 10-50% of the energy released is contained in the accelerated particles. In the Earth's distant (~60 Re) magnetotail, in situ measurements by the Wind spacecraft show that fluxes of electrons up to >~300 keV peaked in the ion diffusion region of a magnetic reconnection event, again indicating particle acceleration related to reconnection. On the other hand, many reconnection events, especially in the solar wind, do not show evidence for significant particle acceleration. At present, we do not understand why particle acceleration occurs in some reconnection events and not others.

Signatures of Magnetic Reconnection from Voyagers 1 and 2

Stevens M.L., Belcher J.M. (MIT Kavli Institute for Astrophysics and Space Research), Kasper J.C. (Smithsonian Astrophysical Observatory)

We use archival interplanetary plasma data from Voyagers 1 and 2 to study signatures of magnetic reconnection in the solar wind over the applicable duration of each mission. Of particular interest to this survey are the driving conditions and evolution of exhaust structures with distance from the sun. We also consider the applicability of the Petschek shock model to these signatures and attempt to constrain the global geometry by solving the Rankine relations at the exhaust boundaries. The Voyager magnetic reconnection survey will soon be made available to the community on the web through MIT.

* Student paper ☉ Invited Paper
Reconnection in Solar Eruptions and Magnetospheric Substorms

Forbes T.G. (UNH)

Magnetospheric substorms, coronal mass ejections (CMEs), and solar flares are usually characterized in terms of models that involve a slow build-up of magnetic energy followed by its sudden release. For magnetospheric substorms, magnetic reconnection plays an important role in both the storage and release phases. For CMEs and flares, however, it is only known for sure that magnetic reconnection plays an important role in the energy release phase. Its role in the storage phase remains speculative. Although the role of reconnection in solar eruptions and magnetospheric substorms is similar, there are some fundamental differences between these phenomena that prevent a one-model-fits-all approach. The field configurations prior to onset are quite different as are the properties of the plasmas in which the reconnection occurs. Therefore, it seems unlikely that the detailed physics of the reconnection processes in these different environments will be the same.
Creation and Propagation of CMEs and Plasmoids: Loss of Equilibrium and Subsequent Evolution (Reeves / Birn)

**Breakout trigger due to peaking of strapping field with altitude**

Bellan P.M. (Caltech)

The horizontal field at the midpoint between two oppositely oriented dipoles maximizes at an altitude that is one quarter of the distance between the two dipoles. Thus, if two dipoles produce a bipolar potential magnetic field that interacts with the current flowing along a magnetic flux tube oriented perpendicular to the bipolar field, the bipolar field can produce a downward force on the flux tube due to JxB interaction between the bipolar field B and the flux tube current J. The bipolar field can be considered to be a 'strapping field' which holds down the flux tube; this was demonstrated in a laboratory experiment [J. F. Hansen and P. M. Bellan, Experimental demonstration of how strapping fields can inhibit solar prominence eruptions, Astrophysical Journal 563, L183 (2001)]. The strapping force will peak at the altitude where the bipolar field is maximum. This situation will provide a breakout trigger mechanism as follows: If the current in the flux tube is slowly increased, the flux tube will move upwards until force balance occurs between the upwards hoop force due to the curved current and the downward force of interaction with the strapping field. However, once equilibrium occurs at the peak value of the bipolar field, any further increase in flux tube current will trigger an explosive instability since the hoop force will push the flux tube to a higher location at which point the strapping field is weaker and so no longer able to balance the upward-directed hoop force.

Transport in the Interplanetary Medium of Coronal Mass Ejections*

Borgazzi A.I. (INPE), A. Lara (Geophysics Institute, National Autonomous University of Mexico), M.V. Alves

Some efforts have been done attempting to describe the transport of interplanetary coronal mass ejections (ICMEs). These structures are originated in the lower solar atmosphere and travel throughout the interplanetary space carrying mass, energy and magnetic flux out of the Sun. Depending on the direction of propagation, strength and direction of their magnetic field, among others parameters, some of these ICMEs impact the Earth's magnetosphere and may produce geomagnetic storms. According to the initial speed of the CMEs, we classified them as fast or as slow; for the first group, ICMEs are in the range of velocities between 400 and 2500 km/s; for the second group, velocities are lower than 400 km/s. The mechanism of momentum transfer between ICMEs and the ambient solar wind proposed here accelerates slow ICMEs and decelerates fast ICMEs. In the case of fast ICMEs, the deceleration process involves the actions of viscous forces between the ICME structure and the medium surrounding. In order to understand the dynamics of the process, we solve a set of differential equations using different expressions for the action of the viscous force. We also include in our model the space variability of the solar wind mass density. As a result we present the velocity behavior of the ICMEs as a function of distance from the Sun. The analytical solutions are presented as well as a discussion and the implications of our results.

* Student paper ☀ Invited Paper
A Comparison of the Formation and Evolution of Magnetic Flux Ropes in Solar Coronal Mass Ejections

Linton M.G. (NRL)

Solar coronal mass ejections and their interplanetary counterparts often show evidence of a twisted flux rope structure that is nearly identical, though of vastly different spatial scale, to plasmoids observed in the Earth's magnetotail. In this talk, I will review the current understanding of flux rope formation, morphology, and evolution in coronal mass ejections and magnetotail plasmoids.

Plasma Flow Features in Current Sheets: Comparisons of Solar and Terrestrial Contexts

Lin J. (Yunnan Astronomical Observatory & Harvard-Smithsonian CfA), Cranmer S.R. (Harvard-Smithsonian CfA), Farrugia C.J. (University of New Hampshire)

Magnetic reconnection plays a crucial role in violent energy conversion occurring in the environments of high electrical conductivity, such as the solar atmosphere, magnetosphere, and fusion devices. We focus on the morphological features of the process two different environments, the solar atmosphere and the geomagnetic tail. In addition to indirect evidence that indicates reconnection in progress or having just taken place, such as auroral manifestations in the magnetosphere and the flare loop system in the solar atmosphere, more direct evidence of reconnection in the solar and terrestrial environments is being collected. Such evidence includes the reconnection inflow near the reconnecting current sheet, and the outflow along the sheet characterized by a sequence of plasmoids. Both turbulent and unsteady Petschek-type reconnection processes could account for the observations. We also discuss other relevant observational consequences of both mechanisms in these two settings. While on face value, these are two completely different physical environments, there emerge many commonalities, for example, an Alfvén speed of the same order of magnitude, a key parameter determining the reconnection rate. This comparative study is meant as a contribution to current efforts aimed at isolating similarities in processes occurring in very different contexts in the heliosphere.

Substorms and CMEs: A Search for a Common Onset Mechanism

Siscoe G. (Boston University), Hesse M., Kuznetsova M. (Community Coordinated Modeling Center) – Presented by Crooker N.

Among cosmic processes that occur in gravitationally constrained magnetized plasmas is a type of event called explosive energy conversion. Substorms at Earth and CMEs on the Sun have been cited as archetypal examples of the explosive energy conversion phenomenon in the heliosphere. This talk reports on a project to determine whether these two examples might have an underlying common cause. The project is aided by the maturity of research that has been conducted on both phenomena, and it is motivated by hope that phenomena so alike in manifestation not be unalike in causation. Two candidates for an onset mechanism

* Student paper ☼ Invited Paper

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that might operate in both settings (the geotail and the solar corona) are sudden onset of rapid reconnection when the threshold for some current-driven micro-instability is exceeded (seemingly favored by substorm researchers) and sudden onset of rapid expulsion when the threshold for a non-equilibrium macro-instability is exceeded (which seems to work for CMEs). The two options have clear phenomenological signatures: in the former, rapid reconnection precedes expulsion; in the latter, expulsion precedes rapid reconnection. As mentioned, the latter has been shown to operate in MHD codes that model CME onset. Here we report on what MHD models say about the relative timing of rapid reconnection and plasmoid expulsion in the geotail.
Is there a Need for More-Detailed Solar-Wind Models (Arge / McPherron)

Demonstrations that the Solar Wind is Not Accelerated by Waves

Roberts D.A. (NASA GSFC)

The present work uses both observations and theoretical considerations to show that hydromagnetic waves cannot produce the acceleration of the fast solar wind and the related heating of the open solar corona. Waves do exist, and can play a role in the differential heating and acceleration of minor ions, but their amplitudes are not sufficient to power the wind, as demonstrated by extrapolation of magnetic spectra from Helios and Ulysses observations. Dissipation mechanisms invoked to circumvent this conclusion cannot be effective for a variety of reasons. In particular, turbulence does not play a strong role in the corona as shown by both observations of coronal striations and theoretical considerations of line-tying to a nonturbulent photosphere, nonlocality of interactions, and the nature of the kinetic dissipation. In the absence of wave heating and acceleration, the chromosphere and transition region become the natural source of open coronal energization. We suggest a variant of the “velocity filtration” approach in which the emergence and complex churning of the magnetic flux in the chromosphere and transition region continuously and ubiquitously produces the nonthermal distributions required. These particles are then released by magnetic carpet reconnection at a wide range of scales and produce the wind as described in kinetic approaches. Since the carpet reconnection is not the main source of the energization of the plasma, there is no expectation of an observable release of energy in nanoflares.

Comparison of BATS-R-US model runs of Oct. 25th, 2000 Halo CME using inputs from ENLIL with Cone Model and ACE observations


The CCMC has run two BATS-R-US model inputs for the Halo CME on Oct. 25th, 2000. The first model run used ACE observations of the ICME as the input. The second model run used results from an ENLIL with Cone Model run as the input to the BATS-R-US model. We have compared and analyzed the two BATS-R-US model runs with the goal of understanding the limitations of predicting magnetospheric activity from solar observations.

* Student paper ☀ Invited Paper
Multiple-Dip Geomagnetic Storms: Solar-Wind Drivers or Internal Magnetospheric Processes (Richardson/Jordanova)

Geo-effective Sheaths in Intense Multiple-dip Geomagnetic Storms: Solar-Heliospheric and Space Weather Perspectives

Lugaz N. (IfA - University of Hawaii), Roussev I. (IfA, University of Hawaii), Sokolov I. (CSEM, University of Michigan), Zhang J. (Rice University)

In about two dozens intense multiple-dip geomagnetic storms during the past solar cycle, one of the Dst peaks below -100 nT was associated with a shock, either via the magnetic field in the sheath or via the compression of the magnetic field in a preceding ejecta. We will discuss the solar origin of such events and explain why for many of these the consideration of the solar sources of the CMEs alone is not sufficient to predict the magnetic field at 1AU. Using examples from three-dimensional MHD simulations carried out with the SWMF, we will show instances of CME-CME interaction and shocks’ merging which may result in such events. We will also discuss how STEREO might be helpful for future space weather prediction of extremely dense and compressed sheaths at 1AU.

The Interplanetary Drivers of Multi-step Geomagnetic Storms

Richardson I. (NASA/Goddard Space Flight Center and CRESST/UMD), Zhang J. (George Mason University)

Although the classic time profile of a geomagnetic storm is of a main phase that eventually reaches maximum intensity, followed by a slower recovery, many of the intense (Dst < -100 nT) storms observed in solar cycle 23 show more complicated structures, including two or more “dips”. We first illustrate examples of various scenarios in which such storms may arise. We then use an automated method to locate the major dips associated with each storm, and identify the interplanetary structures that are responsible for these dips via their embedded southward magnetic fields. Of the 90 intense storms in 1996-2006, 31 (34%) show the classic “one dip” profile, while 44 (49%) had two dips. Another 15 (17%) had 3 or more dips. Examining the near-Earth solar wind data, we find that for 165 dips in the 90 storms, 74 (45%) were caused by interplanetary coronal mass ejections (ICMEs), 49 (30%) by sheaths following shocks, 18 (11%) by corotating interaction regions, and 11 (7%) by shocks running into a preceding ICME. Common causes of two-dip storms include: a first dip produced by southward fields in the sheath upstream of an ICME and a second dip produced by southward fields in the ICME, with an intervening interval of less geoeffective solar wind (~one third of these storms); two intervals of southward field within one ICME (~20%); the passage of two ICMEs, each including southward fields (~one third); and a shock passing through a preceding ICME that includes southward fields (~10%). We conclude that the origin of multiple-dip storms lies in the pattern of southward magnetic fields and intervening less geoeffective regions in the solar wind driver.
An intense geomagnetic storm often shows complicated evolution, manifested by multiple significant dips in the process. An automated method is developed to select intense geomagnetic storms and identify the associated significant dips in a consistent way for the period of 1996-2006, based on the hourly Dst index. Among the 90 intense storms identified, about one third of the events showed the classical “one-step” development, while other events had two or more dips. For the multiple-dip storms, the most common cause is that the first dip is produced by the upstream sheath and the second dip is by the driving ICME. Another common cause is due to the presence of two Bs areas in a single ICME and/or two successive ICMEs close in space. The variety of interplanetary causes of geomagnetic storms will be discussed, as well as the relative geoeffectiveness of these interplanetary structures.
Perpendicular Ion Heating: observations at Earth and theory at the Sun (Chandran / Lysak)

Heating and Accelerating the Solar Wind


While many mechanisms for heating the solar wind have been postulated, none of these mechanisms have been shown to provide sufficient energy to accelerate the solar wind. Much evidence supports heating by ion-cyclotron waves. STEREO provides further support for this hypothesis through the observation of mirror-mode waves that are known to be co-generated with ion-cyclotron waves in other low-beta environments. Mirror-mode waves are robust structures once formed, and can persist for long times, while ion-cyclotron waves are expected to damp rapidly in the core ion distribution and not be seen at 1 AU. Very surprisingly, however, there are strong ion-cyclotron waves in the solar wind at 1 AU under special circumstances. It appears that STEREO is seeing some of the undamped ion-cyclotron waves from the solar wind acceleration region. We discuss ways in which these waves can be formed close to the Sun.

Kinetic dissipation and anisotropic heating in a turbulent collisionless plasma*

Parashar T.N. (University of Delaware), Shay M.A. (University of Delaware), Cassak P. A. (University of Delaware), W. H. Matthaeus

The kinetic evolution of the Orszag-Tang vortex is studied using collisionless hybrid simulations. In magnetohydrodynamics this configuration leads rapidly to broadband turbulence. At small scales, differences from magnetohydrodynamics arise, as energy dissipates into heat almost exclusively through the magnetic field. A key result is that protons are heated preferentially in the plane perpendicular to the mean magnetic field, creating a proton temperature anisotropy as is observed in the corona and solar wind. Preliminary results about the dissipation scale and the distribution of energies at different length scales are discussed.

* Student paper ☼ Invited Paper
Spectroscopic observations from the Ultraviolet Coronagraph Spectrometer (UVCS) on the Solar and Heliospheric Observatory (SOHO) have resulted in empirical models of polar coronal holes, polar plumes, and streamers. These findings have been used to make significant progress toward identifying and characterizing the physical processes that produce extended heating in the corona and accelerate fast and slow solar wind streams. The UVCS scientific observations, which began in April 1996 and continue at this writing, have provided determinations of proton and minor ion temperatures (including evidence for anisotropic microscopic velocity distributions in coronal holes and quiescent equatorial streamers), outflow velocities, and elemental abundances. The variations in these quantities over the solar cycle also have been determined. For example, observations of large polar coronal holes at different phases of the solar cycle indicate that line width is positively correlated with outflow speed and anti-correlated with electron density. The results regarding preferential ion heating and acceleration of heavy ions (i.e., O5+) in polar coronal holes have contributed, significantly, to the advances in understanding solar wind acceleration that have occurred during the past decade. It is important to verify and confirm the key features of these findings. Hence, the results from a new analysis of an expanded set of UVCS data from polar coronal holes at solar minimum by S. R. Cranmer, A. Panasyuk and J. L. Kohl will be presented. This work has been supported by the National Aeronautics and Space Administration (NASA) under Grants NNG06G188G and NNX07AL72G and NNX06AG95G to the Smithsonian Astrophysical Observatory.
SEPs from Heliosphere to Magnetosphere (Luhmann / Hudson)

Effects of Interplanetary Transport on the Interpretation of Solar Energetic Particle Spectra and Composition *

Chollet E.E., Giacalone J. (University of Arizona), Mewaldt R. (California Institute of Technology)

We study the transport of solar energetic particles (SEPs) in the inner heliosphere in order to relate observations made by an observer at 1 AU to the total energy and energy spectrum of energetic particles at the source, assumed to be near the Sun. We use a numerical simulation that integrates the trajectories of a large number of individual particles moving in the interplanetary magnetic field. We model pitch-angle scattering and adiabatic cooling of energetic ions with energies from 50 keV/nucleon to 100 MeV/nucleon. Among other things, we determine the number of times that particles of a given energy cross 1 AU, the average energy loss that they suffer due to adiabatic deceleration in the solar wind, and the form of the fluence spectra as it relates to the source spectrum. We use a number of different forms of the interplanetary spatial diffusion coefficient, a wide range of scattering mean-free-paths, and consider a number of different ion species in order to generate a wide range of simulation results that can be applied to individual SEP events. Application of these results to individual events will be discussed.

Modeling the Transport of Solar Energetic Particles to 1 AU ◊


The basic processes of solar energetic particle (SEP) transport parallel to the mean interplanetary magnetic field are well understood and allow precise modeling of time-intensity and time-anisotropy profiles. We summarize various approaches that have been used. For relativistic protons from various solar events, we have fit data from the Spaceship Earth network of neutron monitors to determine the interplanetary magnetic configuration and scattering mean free path as well as timing of the particle injection to 1-minute accuracy. Such events typically occur amidst highly disturbed interplanetary conditions, so we examine the particle transport within magnetic bottlenecks and interplanetary coronal mass ejections. The high energy particles initially arrive at Earth as an intense beam in an unpredictable direction, so a wide directional coverage is needed to study them and to monitor enhanced radiation near Earth’s polar regions. We also summarize current understanding of the transport of particles perpendicular to the mean magnetic field, which is less precisely determined. The structure of interplanetary turbulence naturally leads to filamentation of magnetic connection from a narrow source region (e.g., for impulsive SEP). From a theoretical perspective, filamentary connection can be described as temporary topological trapping of field lines, and this can account for dropout effects as well as an eventual wide dispersion in heliospheric longitude and latitude. This work was partially supported by the Thailand Research Fund, NSF Grants ATM-0527878 (Neutron Monitors) and ATM-0752135 (SHINE), and NASA Grant NNX08AI47G (Heliophysics Theory).

* Student paper   ◊ Invited Paper
Particle intensities above the streaming limit

Lario D. (JHU/APL), Decker R.B. (JHU/APL), Aran A. (Departament d'Astronomia i Meteorologia, Universitat de Barcelona)

Large solar energetic particle (SEP) events constitute a serious radiation hazard to astronauts and spacecraft systems. It is essential to determine the highest particle intensities reached in SEP events, especially at the energies that pose serious risks to human health and spacecraft performance. It has been argued that the highest particle intensities measured during large SEP events occur in association with the passage of shocks driven by coronal mass ejections known as the Energetic Storm Particle (ESP) component. Furthermore, it has been argued that the intensities measured early in the SEP events (known as the prompt component) are bounded by a maximum-intensity plateau that results from wave-particle interactions that restrict the free streaming of particles (also called the "streaming limit"). We analyze proton intensities measured by the GOES spacecraft at the energy channels P5 (~39-82 MeV) and P7 (~110-500 MeV) during solar cycles 22 and 23 and examine whether the highest intensities were measured during the prompt or the ESP components of the SEP events. We find three (one) SEP events in which the highest proton intensities measured during the prompt component at the energy channels P5 (P7) exceeded by a factor of four or more the previously determined "streaming limit". Arguments to explain intensities during the prompt components exceeding this limit invoke interplanetary conditions that inhibit the amplification of waves resonating with the streaming particles, and/or the presence of interplanetary structures able to confine and/or mirror energetic particles. We analyze these possibilities for each one of these events.

The effect of SEP events associated with CMEs and Flares on Geomagnetic Storms*

Kaur S. (University of Utah)

For solar cycle 23, the effect of Solar Energetic Particle (SEP) events associated with CMEs and flares, on Intense if (Dst<-100nT), Major if (-50nT>=Dst>=-100nT) and Minor if (-20nT>=Dst>=-50nT) type of geomagnetic storms (GMSs) has been investigated. It is observed that the proton flux correlated best with the Intense GMSs, second best with Major GMSs, and the least with Minor GMSs. It has been observed that the solar source location, product of velocity of CMEs (Vcme) with minimum Bz component (Bzmin) of the interplanetary magnetic field (i.e. Vcme.Bzmin) along with the minimum Dst of the sudden storm commencement (SSC) day are the reliable indicators of GMSs types.

* Student paper ☀ Invited Paper
Small-Scale Structure in the Solar Wind and Its Effect on Earth (Borovsky / Lavraud)

Multisatellite Observations of Interplanetary Field Enhancements

Russel C.T. (UCLA), Jian L.K. (UCLA), Luhmann J.G. (UCB)

Interplanetary Field Enhancements (IFE) seen throughout the inner solar system and have been attributed to the interaction of the solar wind with dust. Several times, these structures have been seen sequentially by multiple spacecraft. In each instance, the time delay is consistent with the structure moving roughly with the solar wind. This is consistent with the weak cusp-shaped increase in the magnetic field in the center of an IFE. The field increase is sufficient to slow the flow slightly and deflect it, but not to stop the flow. The launch of STEREO with its staging orbits prior to heliospheric injection has allowed these structures to be studied with up to four spacecraft. These observations verify the previously near solar wind speed propagation of these structures, but also show the slowing and deflection of the solar wind. These observations suggest that macroscopic disturbances, not just microscale disturbances, can be caused in these dust-solar wind interactions and the dust transport out of the solar system may be different than commonly assumed.

X-ray Luminosity from Flaring Active Regions and Related Solar Wind Power

Korreck K. (CFA)

The x-ray luminosity that comes from the sun is linearly dependant on the magnetic flux of this sun. Schwadron, Mc Comas, and DeForest (2006), related x-ray luminosity, magnetic flux and the power available for solar wind. Korreck et al. (2008) has confirmed this theory with observational analysis of x-ray luminosity from Hinode's XRT, SOHO's MDI and SWICS aboard ACE. In the analysis, the XRT luminosity also seems to correlate with power of the solar wind. This relationship will be explored for all C, M, and X class flares seen over the almost 2 years of Hinode's operation. In addition, the high energy particles associated with these flares will be analyzed for a similar relationship with x-rays and unsigned magnetic flux.
Small scale structures at Earth's foreshock: Waves and cavities

Blanco-Cano X. (Instituto Geofisica, UNAM), Omidi N. (Solana Scientific Inc.), Russell C.T. (IGPP, UCLA)

We use global hybrid simulations to study small scale structures in the Earth's foreshock under different IMF geometries. Because ions are treated as particles, these codes give information on both global scales and ion-scale microphysics. When the IMF is oblique (45 degrees to the flow) the foreshock is permeated by sinusoidal, weakly compressive waves, and compressive fluctuations near the shock that evolve into shocklets. Under radial IMF geometry the foreshock is permeated by weakly compressive sinusoidal ULF waves, fast magnetosonic waves propagating at large angles to the field, and density cavities or depressions. We discuss wave origin and the roles that these fluctuations play in solar wind coupling with Earth's magnetosphere. We also show that density cavities or depressions can exist surrounded by waves and that these structures are generated by the interaction of wave modes in the foreshock. Simulation results are compared to Cluster observations.
The Magnetic and Energetic Connection Between the Solar Convection Zone and the Corona (Abbett)

The Twist Limit for Bipolar Active Regions

Moore R. (NASA/MSFC/NSSTC), Falconer D. (UAH/CSPAR/NSSTC), Gary A. (UAH/CSPAR/NSSTC)

We present new evidence that further supports the standard idea that active regions are emerged magnetic-flux-rope omega loops. When the axial magnetic twist of a cylindrical flux rope exceeds a critical amount, the flux rope becomes unstable to kinking, and the excess axial twist is converted into writhe twist by the kinking. This suggests that, if active regions are emerged omega loops, then (1) no active region should have magnetic twist much above the limit set by kinking, (2) active regions having twist near the limit should often arise from kinked omega loops, and (3) since active regions having large delta sunspots are outstandingly twisted, these arise from kinked omega loops and should have twist near the limit for kinking. From each of 36 vector magnetograms of bipolar active regions, we have measured (1) the total flux of the vertical field above 100 G, (2) the area covered by this flux, and (3) the net electric current that arches over the polarity inversion line. These three quantities yield an estimate of the axial magnetic twist in a simple model cylindrical flux rope that corresponds to the top of the active region’s hypothetical omega loop prior to emergence. In all 36 cases, the estimated twist is below the critical limit for kinking. The 11 most twisted active regions (1) have estimated twist within a factor of ~3 of the limit, and (2) include all of our 6 active regions having large delta sunspots. Thus, our observed twist limit for bipolar active regions is in good accord with active regions being emerged omega loops. This work is supported by funding from NASA (Heliophysics GI program and LWS TR&T program), NSF (SHINE program), and AFOSR (MURI program).

Photospheric Magnetic Evolution & Its Coronal Implications

Welsch B.T., Fisher G.H., Abbett W.P., Bercik D.J. (SSL-UCB)

The photospheric electric field both governs evolution of the photospheric magnetic field and controls the flux of magnetic energy (the Poynting flux) and magnetic helicity into the coronal magnetic field. I will discuss recent advances in techniques to estimate the photospheric electric field from observations, as well as applications of these techniques to characterize physical processes relevant to understanding and forecasting space weather.
The “Main Sequence” of Explosive Solar Active Regions

Falconer D., Moore R., Gary A. (MSFC/NASA), Khazanov I. (UAHuntsville)

From ~2000 MDI magnetograms of 44 mature active regions within 30 heliocentric degrees of disk center, we measured active-region magnetic size and total nonpotentiality. Besides displaying the upper limit on active-region size above which the Sun rarely produces active regions and the lower limit on active-region size below which a magnetic flux concentration is not an active region, we discovered that active-region total nonpotentiality has an upper bound that increases with active-region magnetic size. For a given size, an active region can have only so much total nonpotentiality. We show that this limit amounts to an upper bound on a particular measure of an active region’s nonpotentiality per unit flux, that is, an upper bound on a flux-normalized measure of an active region’s nonpotentiality. This limit plausibly represents an upper bound on the overall degree of twist in an active region’s magnetic field. If so, an active region’s magnetic twist can increase to this limit but go no further. After being near the limit for a while the active region can loose nonpotentiality and retreat from the limit. Albeit entirely different physics, this evolution is analogous to how stars evolve to the main sequence, stay there a while and then evolve away from it. Unlike the stellar evolution path, an active region can evolve to its limit multiple times. We present evidence that what is enforcing this upper limit on flux-normalized nonpotentiality is that as an active region’s magnetic field becomes more twisted, it more rapidly releases energy in the form of flares and CMEs. When an active region’s energy-burn-down rate by flares and CMEs equals the rate of buildup of its nonpotential energy, it can get no more nonpotential. The upper limit on flux-normalized nonpotentiality is determined by the burn-down rate dependence on the flux-normalized nonpotentiality and an upper limit on how rapidly an active region’s nonpotentiality can buildup. We are in the process of automating our method of measuring the size and nonpotentiality of an active region, to be used as a forecasting tool. We will run this on the ten-plus years of archived MDI magnetograms to expand the sample of measured active regions by a factor of 10 or more. With the expanded sample, we will better determine the active-region burn-down rate’s dependence on active-region magnetic size and total nonpotentiality, and obtain a better empirical determination of flare and CME probabilities as a function of these two magnetic quantities. We report our approach to automating the measurements of MDI magnetograms. This work is funded by the NSF SHINE Program, by the NASA LWS TR&T Program, by the AFOSR MURI Program, and by the NASA Technical Excellence Initiative Program.
Asymmetry of helicity flux injected by leading and following polarities

Tian L. (Rice University)

The leading magnetic field of bipolar active regions is generally compact, while the following magnetic field is dispersed and fragmented. Seeking the origin of the observed morphological asymmetry of the two polarities is a purpose of this paper. The magnetic field with more twist helicity in an Omega-shaped flux tube may strongly defend possible affections thus to maintain itself integration, when the flux tube rises from the convection zone to break through the photosphere into the corona. Based on the motivation, we separately calculate helicity flux injected by the leading and following polarities using MDI 96 minute line-of-sight magnetograms and local correlation tracking (LCT) technique. A statistical study of thirteen emerging active regions with bipolar magnetic structure displays that the leading polarity injects several times more helicity flux than the following one (3-10 times). This result suggests that the leading magnetic field of the Omega-shaped flux tube possesses much larger amount of twist helicity than the following one, before emergence of the magnetic field generated by some dynamo at the base of the solar convection zone. We argue that the twist helicity asymmetry between the leading and following magnetic field results in the magnetic field asymmetry of the two polarities observed in the photosphere due to the difference of the magnetic tension between them.

Eruption of a coronal flux rope triggered by flux emergence

Torok T. (Paris Observatory)

Observations have revealed a strong association of filament eruptions and coronal mass ejections (CMEs) with the emergence of magnetic flux in the vicinity of or within filament channels. It has been suggested that the emerging flux reconnects with the arcade-like potential field overlying the filament channel and thereby weakens its stabilizing influence on the sheared or twisted core flux located in the filament channel, so that the latter can become unstable and erupt. Corresponding numerical simulations have confirmed this scenario for 2.5D coronal flux rope models. However, these models cannot account for flux rope curvature, photospheric line-tying, 3D reconnection, and 3D instabilities. Here we present the first fully 3D ideal MHD simulations of the eruption of a pre-existing coronal flux rope triggered by flux emergence. We use the coronal flux rope model by Titov and Démoulin as initial condition in the simulations. We then, using the technique described by Fan and Gibson, kinematically emerge a second flux rope nearby or below the Titov and Démoulin flux rope. By varying the position and the magnetic orientation of the newly emerging rope, we find eruption of the Titov and Demoulin rope in some cases, in some cases not. We discuss the physical parameters which determine whether or not an eruption occurs in the simulations and we compare our findings to the conclusions obtained from observations, 2.5D models, and recent 3D simulations of the emergence of magnetic flux in the vicinity of a sheared coronal magnetic arcade.
The role of strong magnetic fields in coronal helicity injection

Tian L. (Rice University)

Sunspots are regions having strong magnetic field, which display as black patches in MDI continuum images. By investigating four active regions with significant flux emergence, we find that the penumbra and umbra of the sunspots are almost covered by the magnetic field over 500 G. The strong field generally possesses 60-70% of total magnetic flux, but takes only 10-15% of total area, which is the central body of flux tubes of active regions. A statistical result of the four emerging active regions with large size, combining with two emerging active regions with small size and four active regions with less flux emergence, displays that the strong field (|B|>500 G) injects 85-95% of total helicity flux. The weak field of active regions (20G <|B|< 500G) injects much less amount of helicity flux, and the positive and negative weak field tends to inject opposite helicity flux. Considering that the movement is easier (harder) for the photospheric mass associated with the weak (strong) field, we argue that the statistical result further suggests that magnetic emergence is a dominant origin in coronal helicity comparing with the horizontal motions of the photospheric mass.

Properties of Coronal Alfven Waves

Tomczyk S., McIntosh S. (NCAR/HAO)

The recent observation of ubiquitous Alfven waves in the solar corona presents an exciting opportunity for probing the structure and magnetic topology of the coronal plasma through coronal seismology. We present the results of a detailed analysis of Alfven wave observations which allow the determination of the relative quantity of outward and inward wave flux. This analysis also provides a k-omega diagnostic diagram of coronal waves. We discuss current and future prospects for coronal seismology with these data.
A New Concept for the Long-Term Build-up to CMEs

Martin S.F., Panasenco O. (Helio Research), Engvold O., Lin Y. (Institute for Theoretical Astrophysics University of Oslo), Litvinenko Y., Forbes T. (University of New Hampshire), Srivastava N. (Udaipur Solar Observatory), Bellan P. (California Institute of Technology), Velli M. (Jet Propulsion Laboratory)

We present a concept of the long-term build-up to CMEs as a series processes that most often take place over intervals of days to weeks rather than hours. We view CMEs as the inevitable product of the build-up of a complex magnetic system that includes the following sequence of common denominators: (1) Cancelling magnetic fields, along photospheric polarity reversal boundaries leading to (2) Creation and maintenance of a filament channel related to the (3) Formation and evolution of filament threads which are a key to the (4) Building and growth of a filament cavity magnetic field leading to the (5) Expulsion of a CME (well described in the literature and not addressed herein). All of these processes are essential and each must be ongoing for a CME to occur. The build-up of this system is fundamental to CMEs whereas triggering mechanisms are secondary. As this complex system continuously stores energy in the corona, it will either force or find any number of triggering mechanisms for the final expulsion of mass. At this stage of exploration of the build-up, we concentrate on measurements and tests to confirm or modify and better understand each process. If our concept is largely correct, we anticipate that CMEs will become predictable by tracking the state of development of the observational signatures of each stage in relation to the environment of the CME site. A key challenge will be to monitor the abundance and magnitude of the small-scale cancellations directly related to the non-potential state, and rate of storage of energy in the building magnetic fields in the system consisting of the filament channel, filament, and filament cavity.

A magnetic charge topology (MCT) model for two active regions observed by Hinode/XRT and TRACE


We introduce two active regions observed by the X-ray Telescope (XRT) on board Hinode and the Transition Region and Coronal Explorer (TRACE). One shows a continuous brightening of the coronal loop in both XRT and TRACE observations. The other shows a brightening in the TRACE observation just after a decrease in X-ray brightness indicating the cooling of the coronal loop. The coronal magnetic topology is derived using the magnetic charge topology (MCT) model for these two active regions applied to magnetograms from the Michelson Doppler Imager (MDI) on board the Solar and Heliospheric Observatory (SOHO). We discuss the results of the MCT analysis in light of the different coronal emission behavior. This work is funded by the Hinode/XRT contract through SAO, and AFOSR contract FA9550-06-C-0019.
An Example of the Long-term Build-up to a CME

Panasenco O., Martin S. (Helio Research), Liewer P. (Jet Propulsion Laboratory, California Institute of Technology), Engvold O., Lin Y. (Institute for Theoretical Astrophysics, University of Oslo), Srivastava N. (Udaipur Solar Observatory)

Using SOHO/MDI and EIT, STEREO/SECHHI/EUVI and STEREO/COR, OSPAN at NSO/Sacramento Peak, and various ground-based solar data, we are studying the history of the evolution of a filament channel, filament and associated photospheric magnetic field changes in an active region, leading to a CME at the west limb on April 9, 2008. This example allows us to trace the long-term development of the site of a CME over an interval of one-half a solar rotation prior to its occurrence. We are able to estimate the magnetic field changes for at least 5 days before the development of the filament and until 1-2 days before the filament, the filament cavity, and CME erupt at the west limb. Our motivations for studying this example of the long-term build-up to a CME are (1) its site along a polarity reversal boundary in the middle of a magnetically simple decaying active region, AR10989, and (2) as an initial test of our concept of the long-term build-up to CMEs. See poster/presentation A New Concept for the Long-Term Build-up to CMEs by Sara Martin et al. This example of a CME reveals all of the key stages that we think are essential in the Sun’s apparent master plan for CME development.

New Views of the Chromosphere from Hinode and 3D Radiative MHD Simulations

De Pontieu B. (LMSAL)

In the past few years, advanced numerical simulations and high-resolution observations with ground-based telescopes and the Broadband Filter Imager (BFI) and Narrowband Filter Imager (NFI) of the Solar Optical Telescope onboard Hinode have revolutionized our view of the chromosphere. We review some of these results, including the discovery of two different types of spicules with different dynamics and formation mechanisms, the finding that the chromosphere is riddled with strong Alfvénic waves, the complex dynamics discovered in prominences, wave propagation and dissipation and their impact on the heating of the chromosphere, etc... We discuss the impact of these results on the connection between photosphere and corona, as well the origin of the solar wind.
What Determines When Reconnection Turns On? Chromosphere, Corona, Solar Wind, Magnetopause, and Magnetotail (Antiochus/Shay)

What Determines when Reconnection Turns on in the Solar Wind, at a Magnetopause and in a Magnetotail

Russel C.T. (UCLA), Zhang T.L. (OEAW, Austria), Nowada M. (NCU, Taiwan), Ge Y.S. (UCLA)

Reconnection is a ubiquitous process in heliospheric and planetary plasmas. Reconnection can take place slowly, as exemplified by the structure of current sheets in the solar wind and the early phase of substorms in the magnetotail. It can also occur rapidly as seen in the onset of the expansion phase of substorms, most spectacularly at Jupiter and Saturn. Observations show that the onset of instability can be approached in two directions: stretching of closed field lines until the field normal to the current sheet reaches a smaller value and the rotation of field on the opposite sides of a current sheet until they are nearly antiparallel. In the first case, the X-line geometry appears after removal of the normal component; in the second, the X-line geometry appears and provides a normal component where none previously appears. While the geometry of the reconnection region is important, so are the plasma conditions. While, in the solar wind and at the magnetopause, reconnection does not alter the plasma conditions in the inflow region, it can in a tail plasma sheet where the density of the plasma and the strength of the field have strong gradients. Thus in the tail, geometry reconnection can begin slowly reaching an explosive state only some time later.

What Determines When Reconnection Turns On in CME Eruptions?

Moore R., Sterling A. (NASA/MSFC/NSSSTC)

We give a synopsis of the signatures of reconnection observed in the onsets of CMEs. Along with observations of a few representative eruption onsets, we present cartoons that lay out the two alternative topologies of the pre-eruption magnetic field configuration (the topology that does allow breakout reconnection and the topology that does not), and that show the timing and location of reconnection within the exploding core field (tether-cutting reconnection) and between the core field and the enveloping field (breakout reconnection). In eruptions in which breakout reconnection is permitted by the field configuration, runaway breakout reconnection begins either slightly (< 1 min) before or simultaneously with the onset of the eruption of the core field and the onset of runaway tether-cutting reconnection low in the core field. In these eruptions and in eruptions in which breakout reconnection is not possible, runaway tether-cutting reconnection begins either soon after or simultaneously with the onset of the eruption of the core field. For either field configuration, the occurrence of the onset and growth of fast reconnection in close synchrony with the onset and acceleration of the eruption suggests that this reconnection both unleashes the eruption and is driven by the eruption. That is, fast reconnection starts and grows only when it renders the erupting field farther out of equilibrium in a way that amplifies the reconnection, which feedback makes the eruption and the reconnection grow explosively. We conclude that what determines when runaway reconnection turns on in CME eruptions is the configuration and

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pre-eruption evolution of the magnetic field. The eventual destabilization of the field results in the onset of the eruption and the onset of runaway reconnection, which starts with the eruption or soon after and is necessary for the eruption to continue. Depending on the specifics of the field configuration and evolution, the eruption is started by runaway reconnection, or by an ideal MHD instability without reconnection, or by both acting in concert. This work is supported by funding from NASA’s Science Mission Directorate through its Heliophysics Guest Investigators Program and its Living With a Star Targeted Research & Technology Program.

Onset of Substorms and Flares/CMEs: Role of Reconnection and Secondary Instabilities

Bhattacharjee A. (UNH)

The problems of substorm onset in the Earth’s magnetosphere and CME/flare initiation are viewed from a common perspective. Both types of plasmas are characterized by high values of the Lundquist number, and produce super-Dreicer electric fields, requiring models that go beyond MHD and include collisionless effects described by a generalized Ohm’s law. Both types of phenomena exhibit an impulsive signature whereby the growth rate changes suddenly, which imposes a strong constraint on theories of reconnection. Both types of systems tend to realize extended thin current sheets in the growth phase, probed by in situ satellites in the Earth’s magnetotail, and inferred indirectly from X-ray images of the Sun. We discuss the stability of extended current sheets which mediate reconnection dynamics in such large systems. We argue that a complete picture of both types of phenomena involve not only collisionless reconnection, but secondary instabilities of extended thin current sheets, such as pressure-driven ballooning instabilities in the Earth’s magnetotail and secondary super-Alfvenic tearing instabilities or loss of equilibrium in the solar corona. We present results from theory as well as simulations, and compare with observations from the magnetotail and the Sun.
Theory of Three-Dimensional Interchange Reconnection in Coronal Hole Dynamics


The role of interchange reconnection on coronal hole dynamics is explored in this investigation. By solving numerically the full 3D MHD equations in spherical coordinates using the Adaptively Refined MHD Solver developed at the U.S. Naval Research Laboratory, the global progression of the magnetic field due to an active region (AR) bipole is examined in detail as it is moves between the topologically open and closed field regions of the coronal magnetic field. The initial magnetic field configuration is a Potential Field Source Surface (PFSS) model constructed from a method of images procedure to incorporate an AR bipole in the quiet-Sun global background field consisting of clearly separated topologically open and closed regions, while maintaining the integrity of a source surface at 3 solar radii. The system is driven in two separate cases by an applied incompressible photospheric flow. In the first instance, the AR magnetic field is initially embedded in the globally closed field region and transported across the coronal hole boundary into the globally open field region; the reverse action is implemented in the second. As the system evolves, transient current sheets develop along the separatrix of the AR bipole producing efficient reconnection, thereby, allowing the bipole to move smoothly from one region to another. This relatively simple structure captures all the essential ingredients necessary for interchange reconnection and is fundamental to understanding the interchange process.

The Catastrophic Onset of Magnetic Reconnection in Solar and Stellar Coronae due to Two-Fluid Effects: Theory and Observations

Cassak P., Shay M. (University of Delaware), Drake J. (University of Maryland), Mullan D. (University of Delaware)

We present a model for the abrupt onset of fast magnetic reconnection in weakly collisional plasmas (such as the solar corona). The Hall effect increases the rate of reconnection by many orders of magnitude above the Sweet-Parker rate. We show that the transition from Sweet-Parker to Hall reconnection occurs catastrophically when length scales fall below the ion gyroradius. This provides a potential mechanism for the onset of coronal eruptions such as flares, CMEs, and micro/nano-flares responsible for coronal heating. An observational prediction of this model is that the thickness of a Sweet-Parker current sheet in the corona is comparable to the ion gyroradius at eruption onset. Indirect evidence suggests this is true of the solar corona, as has been known for some time. We present observational evidence from 107 flare events in 37 sun-like stars that this condition is also met in stellar coronae. These results demonstrate that magnetic reconnection plays an active role in (self-) organizing the conditions of solar and stellar coronae.

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The Weibel Instability in Electron-Positron Plasma Magnetic Reconnection

Liu Y., Swisdak M., Drake J. (U. of Maryland)

Full particle simulations of magnetic reconnection reveal the development of turbulence in the outflow jet during magnetic reconnection in pair plasma. This turbulence facilitates fast reconnection by opening the outflow nozzle, thereby shortening the current layer. We demonstrate that the temperature anisotropy that develops in the outflow plasma is the driver for this turbulence. Using particle simulations and analytic theory we explore the behavior of the Weibel-like instability that grows within a narrow current layer with anisotropic temperature- a geometry designed to mimic the current layers seen in electron-positron reconnection. The theoretically predicted wavelength and growth rate explain the structure of the observed turbulence and determine the length of the outflow nozzle seen in reconnection simulations.

Non-Linear Whistler Waves in Magnetic Reconnection

Schoeffler K.M., Drake J., Swisdak M. (U. of Maryland)

Whistler waves can facilitate fast reconnection by opening up the outflow nozzles of the dissipation region. These outflow nozzles consist of non-linear standing whistler waves. We investigate the properties of one dimensional non-linear standing waves using a full particle in cell code. We discover a process, possibly related to Landau damping, that transfers energy from the magnetic field and bulk flow of whistler waves to heating of the electrons to high energies.
SHINE SESSIONS

Campaign Event: 5-14 December 2006 (Mulligan / Hu)

A Comprehensive View of the 13 December 2006 CME: From the Sun to Interplanetary Space

Liu Y (UC Berkeley), Luhmann J.G. (UCB), Schroeder P.C. (UCB), Wang L. (UCB), Li Y. (UCB), Lin R.P. (UCB), Bale S.D.

The biggest halo coronal mass ejection (CME) since the Halloween storm in 2003, which occurred on 13 December 2006, is studied in terms of its solar source and heliospheric consequences. The CME is accompanied by an X3.4 flare, EUV dimmings and coronal waves. It generated significant space weather effects such as an interplanetary shock, radio bursts, major solar energetic particle (SEP) events, and a magnetic cloud (MC) detected by a fleet of spacecraft including STEREO, ACE, Wind and Ulysses. Reconstruction of the MC with the Grad-Shafranov (GS) method yields an axis orientation oblique to the flare ribbons. Observations of the SEP intensities and anisotropies show that the particles can be trapped, deflected and reaccelerated by the large-scale transient structures. The CME preceding shock is observed at both the Earth and Ulysses when they are separated by 74° in latitude and 117° in longitude, the largest shock extent ever detected. The shock arrival time at Ulysses is well predicted by an MHD model which can propagate the 1 AU data outward. The CME/shock is tracked remarkably well from the Sun all the way to Ulysses by coronagraph images, type II frequency drift, in situ measurements and the MHD model. These results reveal a technique which combines MHD propagation of the solar wind and type II emissions to predict the shock arrival time at the Earth, a significant advance for space weather forecasting especially when in situ data are available from the Solar Orbiter and Sentinels.

Solar Energetic Particle Spectrum on 13 December 2006 Determined by IceTop

Evenson P.A., Bieber J., Pyle R. (University of Delaware)

On 13 December 2006 the IceTop air shower array at the South Pole detected a major solar particle event. By numerically simulating the response of thick Cherenkov detectors with multiple thresholds, deployed at high altitude with no geomagnetic cut-off, we determined the particle energy spectrum in the energy range 0.6 to 7.6 GeV. This is the first such spectral measurement using a single instrument with a well defined viewing direction. We compare the spectrum and its time evolution obtained by IceTop with previously published results. We outline planned enhancements to improve resolution of future solar particle spectra.
Solar Magnetic Field Underlying the Energetic Eruptions in December 2006

Li Y. (SSL – UC Berkeley), B. J. Lynch (SSL, UCB), Yang Liu (HEPL, Stanford University), J. G. Luhmann, D. Krauss-Varban, B. T. Welsch, Ying Liu (SSL UCB)

The sequence of X-class flares with spectacular coronal waves, fast halo CMEs and intense energetic particles in December 2006 originated from active region (AR) 10930. Within an otherwise quiet global magnetic field, the large complex AR including a fast rotating sunspot that introduces sheared magnetic field emerged at ~ 6 deg south into the remnant of a decayed active region. AR10930 held majority magnetic flux and energy concentration of the global solar atmosphere and passed the front side during Dec 5 to 17. We study the eruptive activities through SOHO and HINODE imaging data. The coronal waves were propagating at the order of ~400 km/s, and the speed of the associated halo CMEs were over 1000 km/s. Coronal EUV dimmings were small and short in duration and only clearly observable in difference images. The total unsigned magnetic flux (MDI) of the region increased by ~30% during the ~72 hours prior to the x-flare 2:14UT on Dec 13. PFSS modeling gives highly inclined coronal helmet streamer arcades over the AR, low latitude open field regions from the vicinity of the AR, and revealed no coronal null point in the erupting flux system(s). The post Dec-13-flare arcades compare favorably with the potential field arcades over the horizontal erupting neutral line, but merely ~43 hours later, sufficient free energy was available to power yet another x-class flare at the same neutral line. The IP shock driven by Dec 13 halo CME arrived 1AU on Dec 14 ~14:00UT followed by a Magnetic Cloud ~23:00UT. The MC fluxrope is highly inclined differing from the post flare arcades over the photospheric neutral line.

Relativistic Solar Protons on 2005 January 20 and 2006 December 13

Ruffolo D. (Mahidol Univ., Bangkok), Bieber J. W., Clem J., Evenson P., Pyle R. (Univ. Delaware), Sáiz A. (Mahidol Univ., Bangkok), Wechakama M. (Kasetsart Univ., Bangkok)

From an analysis of observations by the Spaceship Earth network of polar neutron monitors, we determine directional distributions of relativistic solar protons as a function of time during the huge ground level enhancements (GLEs) of 2005 Jan 20 and 2006 Dec 13. For both events, the distribution was extremely anisotropic at times of peak intensity, with a beaming direction that varied rapidly and was quite different from the magnetic field direction. We also numerically modeled the particle transport to study the interplanetary magnetic configuration, interplanetary scattering conditions, and injection profile. In particular, the start time of relativistic particle injection is determined with one-minute accuracy, and is compared with other timing information concerning the flares and CMEs. For the giant GLE of 2005 Jan 20, we infer a spectral index of 5.0 at a median proton energy of 1.4 GeV, and the spectrum matches well with spacecraft observations at lower energy. This event had two injections of relativistic protons, corresponding closely to solar radio emission profiles at 50-500 MHz. In the Spaceship Earth observations, the second peak was much more isotropic. The time-intensity and time-anisotropy profiles can be fit by including a variation in interplanetary scattering, e.g., due to proton-amplified waves, or a magnetic bottleneck beyond Earth. For 2006 Dec 13, the time profiles are well fit when considering a
magnetic bottleneck beyond Earth. For both events, a bottleneck is justified in terms of preceding CMEs and the predicted disturbances in the interplanetary magnetic field. This work was partially supported by the Thailand Research Fund and NSF Grant ATM-0527878.

Modeling the December 13, 2006 SEP event with the PATH model ☼

Verkhoglyadova O. (IGPP, UCR), Li G. (SSL/UC Berkeley, IGPP/UCR), Zank G.P. (IGPP/UCR) and Hu Q. (IGPP/UCR)

The Particle Acceleration and Transport in the Heliosphere (PATH) one-dimensional numerical code was developed at University of California at Riverside. We apply the code to model the mixed SEP event of December 13, 2006. The code is initiated by modeling a quiet-time solar wind and a propagating CME-driven shock. Inner boundary conditions are extrapolated from ACE measurements at 1AU. We assume two energetic particle populations in the modeling, one originating from solar flare particles and the other from solar wind particles accelerated at the traveling shock. Observed shock parameters at 1 AU and flare characteristics are used as input into the code. We assume diffusive shock acceleration mechanism at the shock and model subsequent transport of particles escaped from the shock throughout the interplanetary medium to 1 AU. Time-intensity profiles and spectra of proton and heavy ions are presented and compared with in situ measurements by ACE. Spectral breaks in SEP spectra are studied. Impact of the model free parameters (flare-to-solar wind particle ratio, flare spectrum, shock obliquity, etc.) on the modeling results are discussed.

Multiple Spacecraft View of the Solar Energetic Particle Event of December 14, 2006


We report on observations of a solar energetic particle event made by instruments on five different spacecraft: the Advanced Composition Explorer (ACE), STEREO A and B, WIND, and GOES 11. The event began with an X1.5 soft x-ray flare on December 14 at 22:15 UT, located at W46. At this time the two closely spaced STEREO spacecraft were located outside the Earth's magnetosphere prior to their first lunar swing-by on December 15. An interplanetary shock, associated with an earlier X3.4 event on December 13 in the same active region, passed the Earth on December 14 at ~13:56 (time at ACE). The corresponding magnetic cloud arrived at ~22 UT on December 14, close to the time of the onset of the particle event associated with the X1.5 flare, and extended until ~08 UT on December 15. The intensity of ~14 MeV protons at STEREO A shows three dips by factors of ~ 10 or more during the early stages of this event while the spacecraft was within the magnetic cloud. Similar dips are seen for protons to at least 100 MeV. However, not all these dips were observed at STEREO B. A contributing factor to these different observations is the inverted orientation of STEREO B at this time, causing the instruments on the two STEREO spacecraft to be directed ~perpendicular to each other. Other factors include unusual non-Parker spiral fields and their direction relative to the instrument viewing directions, and the

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field-line connectivity to the Sun. Similar particle intensity dips were seen by instruments on other spacecraft in the near-Earth solar wind, but with reduced amplitude.

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*The Large SEP Events of December 2006* ☀

Cohen C., Cohen C.M.S. (Caltech)

Two large SEP events dominated the active time period of December 5-14, 2006. These events showed significant differences in the spectral shape and composition (both integrated over the event and as a function of time). I will present an overview of the observations made by the ULEIS and SIS instruments on ACE and the LET instrument on STEREO. Additionally there are preliminary results of the charge states of some heavy ions at tens of MeV/n from the MAST instrument on SAMPEX for both events; these will be presented along with estimates of the $^3$He/$^4$He ratios. Some brief comparisons to other events of solar cycle 23 will also be made.

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*SOHO/ERNE observations of the 13 and 14 December, 2006, SEP events*

Makela P. (Catholic University of America), Gopalswamy N. (NASA/GSFC), Valtonen E. (University of Turku)

We describe the observations of the SOHO/ERNE particle instrument during the two SEP events on December 13 and 14, 2006. The ERNE instrument observes 1.8-100 MeV protons and heavier ions from a few MeV/n to a few hundred MeV/n. In a very short time interval on 13-14 December, a sequence of complex events occurred in interplanetary space. At the lower-energy range the particle fluxes were dominated by the approaching shock passing SOHO at 13:57 UT December 14 as observed by SOHO/CELIAS/Proton Monitor and by the interplanetary disturbance that followed. At the higher-energy end of ERNE observations the particle flux showed two distinct particle events. The arrival of the second shock at 17:43 UT on 16 December did not cause a major change in the interplanetary particle flux. During the first part of December, 2006, the SOHO spacecraft had severely limited telemetry due to the permanent problem with spacecraft's main antenna. This unfortunately prevents a detailed analysis of the first two SEP events on December 5 and 6, 2006.
The December 2006 Solar Energetic Particle Events: Unusual Signatures within an Interplanetary Coronal Mass Ejection

Mulligan T., Blake J.B. (The Aerospace Corporation), Leske R.A., Mewaldt R.A. (California Institute of Technology)

The effect of transient magnetic structures such as interplanetary coronal mass ejections (ICMEs) and their associated shocks on the transport of solar energetic particles (SEPs) has long been a topic of interest. In December 2006, a group of SEP events occurred in rapid succession and were observed at the Earth coincident with the passage of an ICME. Recently, ICMEs have been associated with unusually coherent fluctuations in SEP and galactic cosmic ray fluxes and on 14 December 2006 such similar fluctuations are observed by spacecraft both in the solar wind and in the magnetosphere. Studying the unique magnetic geometry and topological connection of ICMEs to the Sun may reveal key information about preferential paths of parallel transport of these particles in the inner heliosphere. Implications for the similarities and differences between the signatures seen at STEREO, ACE, Wind, Polar, and the GOES satellites will be discussed along with some plausible mechanisms.

The December 2006 SEP Events at High Heliospheric Latitudes: the KET/Ulysses Observations

Struminsky A. (Space Research Institute, Moscow), Heber B. (Christian-Albrechts-Universitat Kiel, Germany), Zimovets I. (SRI), Mueller-Mellin R. (CAUK), Gomez-Herrero R. (CAUK), Klassen A. (CAUK)

Four hard X-ray flares occurred on the visible solar disk on December 5, 6, 13 and 14 and resulted in four SEP events near the Earth. The particle signatures of these events were observed by the Ulysses spacecraft at a heliocentric distance of 2.8 AU and above 70 degree South. We present the KET/Ulysses observations of SEP (from 6 MeV/n to 2 GeV/n) during this active period and compare them with those of GOES EPS in Earth orbit and with previous KET/Ulysses observations at southern (2000) and northern (2001) polar latitudes. Three distinct peaks of proton intensity related to the solar events on December 5, 6 and 13 were observed by KET in the 38-250 MeV range (only two of three were visible within 250-2000 MeV), but their time profiles were merged together. Therefore we discuss only general characteristics of the series: the rising phase, the maximum intensities and the decay phase.

- In December 2006 the propagation of <80 MeV protons to high latitudes was complicated in comparison with observations in 2000 and 2001 resulting in a delayed onset and longer rise time to maximum.
- Comparison of Ulysses and GOES proton time profiles shows that on December 5 the propagation conditions to high latitudes and distant longitudes were similar for 250-2000 protons.
- The value of maximum intensity of 38-125 MeV protons does not contradict the upper intensity limit observed at high heliospheric latitudes in 2000 and 2001.
- An equilibrium state of SEP particles in the heliosphere (the reservoir effect) established later in comparison with previous cases due to complicated transport to high latitudes and a contribution of several sources to the time profiles in December 2006. These multipoint observations at large separation in latitude and longitude describe a more complicated picture of particle propagation in the heliosphere which requires new theoretical approaches.
CME Dynamics - What are EUV Waves? (Vourlidas / Roussev)

*Student paper  ☽ Invited Paper

**Studying EUV Emission in Realistic Flare-CME Environments** *

**Downs J.C.** (Institute for Astronomy), **Roussev I.** (Institute for Astronomy), **Lugaz N.** (Institute for Astronomy)

Extreme Ultraviolet (EUV) emission from the solar corona and associated phenomena, such as EIT waves, can be a valuable source of information about the complex conditions and dynamics of eruptive events. Because of the inherent complexity however, EUV emission from the low corona has been difficult to study in detail via global numerical models. As such, we present our work to implement a prescription for the EUV emission of coronal material within the context of a corona/space-weather model used to globally simulate CME events from the Sun to Earth (the Space Weather Modeling Framework, SWMF). Via observation synthesis and the subsequent comparison to SOHO EIT observations, we use this method to provide a new window of insight into the CME events of April 21 and August 24 2002 (both SHINE Campaign Events) as well as to benchmark our EUV synthesis method and physical model for the low corona. Because of the general flexibility of global models, we discuss applications towards studying the large-scale dynamics of events in this regime, particularly EIT waves. Most importantly, once fully developed, this method can be tailored to the fleet of modern EUV sensitive instruments (e.g. STEREO and the upcoming SDO) and, through observation synthesis, provide a general and flexible framework with which to study future events.

*Evidence of Coupled Large-scale Propagating MHD Waves in the EUV Corona*

**Wills-Davey M.J.** (SAO), **Sechler M.** (SAO/CU-Boulder), **Davey A.R.** (SAO)

We identify TRACE and SOHO-EIT EUV observations that contain EIT waves or evidence of EIT waves in the form of loop oscillations. In each case, we find instances of a “precursor” to the EIT wave—a much weaker wave pulse that appears instigated by the same source as the EIT wave, and travels in front of the pulse along the same trajectory. In each case, the wave “precursor” leads to some form of coronal dynamics; we observe loop motions, brightenings or, in one case, the initiation of an EIT wave and a sympathetic coronal mass ejection. These “precursors” are particularly notable in that they travel significantly faster—at least 2× - 4× faster—than their corresponding EIT waves, achieving minimum velocities of 600-1600 km/s. We postulate that these wave “precursors” are, in fact, MHD modes coupled to the EIT waves, and may be a fast-mode-like component correlated with the EIT waves' corresponding slow-mode-like component.
STEREO Observations of EUV Waves

Patsoukaros S. (GMU), Vourlidas A. (NRL), Stenborg G. (Interferometrics Inc)

More than a decade after their discovery by EIT, EUV waves look more mysterious than ever with conflicting interpretations of their origin been proposed and debated. Part of the problem should be attributed to the limitations of EIT observations almost exclusively used in the study of these waves: low temporal cadence, single-temperature and viewpoint coverage. The situation dramatically improved when data from the twin STEREO spacecraft started to become available. These observations provide improvements in 3 important areas: higher image cadence (up to x10), multi-temperature (0.08-2 MK), almost simultaneous coverage and multiple viewpoint observations. We will show how all these unique elements of STEREO observations, and particular their 3D aspect, can place new and important constraints on the mechanisms responsible for EUV waves.

Are EIT Waves Really Waves?

Linker J.A., Mikic Z., Lionello R., Titov V., Riley P. (SAIC)

Since the first observations of EIT waves in the May 1997 CME event (Thompson et al. 1998), their origin and nature has been the subject of considerable debate. Explanation for the signatures include a fast mode shock (Uchida, 1968), fast mode waves (Wang 2000, Wu et al. 2001, Ofman & Thompson 2002, Warmuth et al. 2004, Ofman 2007), solitons (Wills-Davey et al. 2007), and opening of the magnetic field associated with the erupting CME (Attril et al. 2007, Delannee et al. 2008). We have developed MHD models that include energy transport (radiative losses, anisotropic thermal conduction, and coronal heating) in the transition region and solar corona. This more accurate representation of energy flow allows us to compute simulated EUV and X-ray emission and compare directly with observations. We have developed an MHD simulation of the May 97 event, with many characteristics of the actual event, including waves that appear in simulated EIT images. We find that the waves in the simulated event are indeed consistent with MHD waves. We discuss the implications of our work for present and future observations. (Work supported by NASA and CISM, an NSF Science and Technology Center.)
Transport in the Interplanetary Medium of Coronal Mass Ejections

Borgazzi A.I. (INPE), Lara A. (Geophysics Institute, National Autonomous University of Mexico)

Some efforts have been done attempting to describe the transport of interplanetary coronal mass ejections (ICMEs). These structures are originated in the lower solar atmosphere and travel throughout the interplanetary space carrying mass, energy and magnetic flux out of the Sun. Depending on the direction of propagation, strength and direction of their magnetic field, among others parameters, some of these ICMEs impact the Earth's magnetosphere and may produce geomagnetic storms. According to the velocity of the ICMEs, we classified them as fast or as slow; for the first group, ICMEs are in the range of velocities between 400 and 2500 km/s; for the second group, velocities are lower than 400 km/s. The mechanism of momentum transfer between ICMEs and the ambient solar wind proposed here accelerates slow ICMEs and decelerates fast ICMEs. In the case of fast ICMEs, the deceleration process involves the actions of viscous forces between the ICME structure and the medium surrounding. In order to understand the dynamics of the process, we solve a set of differential equations using different expressions for the action of the viscous force. We also include in our model the space variability of the mass density. As a result we present the velocity behavior of the ICMEs as a function of distance from the Sun. The analytical solutions are presented as well as a discussion and the implications of our results.
Hard X-rays and Particle Acceleration in Flares (Krücker)

Observational and Theoretical Interpretation of Energetic Particle Transport in Solar Flares

Daou A.G., Alexander D. (Rice University)

The combination of excellent space-based remote sensing, and image reconstruction techniques, as well as improvements in numerical modeling, help enhance our understanding of particle transport in solar flares. We conduct a rigorous analysis of flare hard X-ray emission using the unprecedented spectral and spatial resolution of the RHESSI telescope data in order to better understand the spectral properties of the emitting electron population in solar flares. We complete our study with a forward-fit to the data using a Fokker-Planck kinetic code, to numerically model the particle transport in phase-space in realistic magnetic geometries and for different particle injection profiles.

Long term non-thermal emission of solar flares and the Neupert effect

Struminsky A., Zimovets I. (Space Research Institute, Moscow)

Observations of hard (Anti-Coincidence System of Spectrometer on INTEGRAL (ACS SPI), >150 keV) and soft (GOES 1-8 A) X-ray emission as well as microwave emission (15.5 GHz) during the solar flare of 2005 September 7 and 2006 December 6 and 13 are analyzed. Time-profiles of non-thermal emission of these flares provide evidence of complex behavior of the solar chromosphere and corona during more than one hour after flare onsets, including several acts of energy release and particle acceleration. In a case of the first two flares the Neupert effect is observed for the most intensive peak of the non-thermal emission, but not during the soft X-ray decay phase, when the hard X-ray and microwave emission is still well above background. At that time the hard X-ray intensity is considerably less in comparison with the main peak, but the microwave intensity doesn’t change significantly. Observations of the long-term hard X-ray emission during the 2006 December 13 event were complicated due to fast arrival of relativistic solar protons, but the Neupert effect was not observed even for the main peak. For the comparable intensities of the microwave emission on December 6 and 13, the maximum hard X-ray intensity on December 13 was depressed by about one order. These facts point out on emission from low density medium and small precipitation to more dense layers during the time, when the Neupert effect is not valid, i.e. emission from the coronal source.

* Student paper ☀ Invited Paper
Hard X-rays, flares, and particle acceleration

Aschwanden M.J. (Solar & Astrophysics Lab., Lockheed Martin)

In this review we focus on new aspects on particle acceleration from recent RHESSI observations, such as: (1) evidence for dipolar, tripolar, and quadrupolar reconnection, (2) displacement of electron and ion acceleration, (3) double ribbon structure, downward-upward motion, and footpoint motion of hard X-ray sources, (3) correlations between hard X-ray fluxes and reconnection rates as well as CME acceleration rate, (4) coronal hard X-ray and gamma-ray emission from occulted flares and trapping regions, and (5) acceleration in flares versus CMEs.

Hard X-ray Emission from the Solar Corona

Hudson H. (SSL-UCB)

We now have a broad spectrum of coronal hard X-ray (>20 keV) sources. The RHESSI data have added a great deal to what was earlier available from Yohkoh/HXT and from miscellaneous disk-occultation sources, starting with the famous event of March 30 1969. In this presentation I give an overview of these observations and their physics, not omitting the intimate relationships between the hard X-ray emission and other signatures, especially in the radio domain. The presentation is intended not to be formal, except that I will dictate a particular structure of topics. The idea is to stimulate discussion and exchange of ideas. Other participants will be free to make extended remarks, with their own graphics if necessary.
Heliospheric Plasma Sheet (Ian Richardson / Vourlidas)

3D flux and pressure pileup, and magnetic reconnection during current sheet formation

Sun X., Intrator T., Lapenta G. (Los Alamos National Laboratory), Furno I.

Magnetically dominated dynamics determine many astrophysical processes including solar flares, coronal mass ejections, and sources of the fast solar wind. While observation by satellites is a key method for researching on natural flux ropes, laboratory experiments can provide more detailed and flexible studies. In the Reconnection Scaling eXperiment (RSX) at Los Alamos National Laboratory, we simulate the natural flux ropes by creating multiple identical current channels with embedded external magnetic fields. We show an experimental example of self consistent, kink instability driven, onset of 3D Sweet Parker reconnection. The local magnetic and kinetic pressure pileup can react back on the drive pressure, and may even stall out the reconnection process. This self consistent experiment addresses important issues in natural plasma phenomena, because it is fully 3D and therefore not constrained by toroidal symmetries that are usually important for most theory, simulations, and experiments.

Initiation and evolution of CMEs from helmet streamers


A traditional picture for CME eruptions is that the magnetic fields underneath a helmet streamer open up to produce a CME. At the tip of the streamer belt is the heliospheric plasma sheet (HPS) which is characterized by slow, dense and cold solar wind. CMEs disrupting the streamer belt and moving through the HPS would be distorted into a concave-outward shape by the interaction with the HPS. For the first time, the interaction between CMEs and the preexisting HPS is clearly imaged by SECCHI and LASCO from the Sun out to several tens of solar radii. The 31 December 2007 CME seems to be induced by flux emergence from the base of the streamer belt, and then appears as a bulge swelling and pushing EUV plumes aside. The CME quickly becomes concave outward owing to the interaction with the preexisting HPS, in contrast with the self-similar evolution of CMEs within several tens of solar radii of the Sun predicted by global MHD simulations. The streamer belt reforms after the CME but is displaced and much thinner than before, and the south coronal hole shrinks due to the migration of the streamer belt. These changes are permanent as can be seen from both the imaging observations and the PFSS modeled coronal magnetic fields. A similar picture is observed for the 5 September 2005 CME. These results are important for understanding the complete picture of CME initiation and propagation, and also indicate crucial clues on how CMEs regulate the global field configuration of the solar corona and the heliosphere which we will discuss based on the results.
Multi-Spacecraft Observations: Heliospheric Plasma Sheet during Solar Minimum


Using the in situ plasma and magnetic field measurements from the twin STEREO spacecraft, we report the study of heliospheric plasma sheet (HPS) in 2007. The following points are our foci: properties of the HPS and their inter-correlations, whether there are multiple current sheets within one HPS, and how interplanetary coronal mass ejections and stream interaction regions interact with the HPS. In addition, during August and September 2007, Venus Express at 0.72 AU was radially aligned first with STEREO B and then STEREO A. They provide us a good chance to study the radial variation of the HPS from 0.7 to 1 AU, such as whether the complexity of HPS increases with distance from the Sun or not.

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Small-scale transients in the slow solar wind during solar activity minimum

**Huttunen E.** (UCBerkeley, University of Helsinki), Luhmann J. (UCBerkeley), Jack Gosling (University of Colorado, Boulder)

We have investigated the structure of slow (< 450 km/s) solar wind from March – October 2007 using observations from the STEREO spacecraft. At solar minimum recurrent high-speed streams dominate the solar wind structure and large-scale ICMEs are not commonly observed. However, small ICME transients that have smaller scale-sizes and/or weaker magnetic fields than typical ICMEs near 1 AU are frequently observed in the slow solar wind. We will discuss the properties of these small transients and how they connect with the overall solar wind structure. We also relate the transients to the large-scale coronal structure and discuss the possible implications to the coronal dynamics.

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Small Coronal Mass Outflows in coronagraphic data

**Robbrecht E.** (NRL/GMU), Berghmans D. (ROB), Van der Linden R.A.M. (ROB), Vourlidas A. (NRL), Howard R. (NRL)

Using the CACTus CME detection software we have constructed a LASCO CME catalog spanning 10 years of observation from 1997 to 2007. The most striking result of the statistical analysis of this catalog was the large number of small events that were detected. Small events have an angular width below 40 degrees and may be bright or faint. Their speeds roughly vary around 200-400 km/s. The latitudinal distribution of these small events shows a strong solar cycle dependance. This suggests that they are linked to large-scale evolution of the solar cycle. We zoom in on several of these events.
Heliospheric evolution and plasma properties of small-scale flux ropes in the solar wind

Cartwright M.L. (UCLA), Moldwin M.B. (UCLA)

We have investigated a new class of solar wind flux ropes that have small length and time (~ 1 hr) scales as compared to day-long magnetic clouds. Typically they show no expansion and have weaker core field signatures compared to their large scale counterparts. They have frequently been observed at one AU but there is only one reported case outside of one AU. We will discuss the evolution of these small-scale flux ropes over heliospheric distances using magnetic and plasma data from HELIOS 1, WIND, ACE, ULYSSES spacecraft. We also discuss their plasma properties (i.e. proton temperature, plasma pressure, etc) to investigate their origin.
Patterns of heavy ion elemental, isotopic, and charge-state composition in impulsive (3He-rich) solar energetic particle (SEP) events provide diagnostics useful for understanding the physics underlying the fractionation that occurs in these events and for testing models of particle acceleration in solar flares. Using measurements from the Solar Isotope Spectrometer on ACE we have investigated the relative abundances of elements from C through Ni and the isotopic composition of Ne and Mg at energies >10 MeV/nuc in a number of impulsive events observed between 1998 and 2004. We report element-element, isotope-isotope, and element-isotope correlations and compare the observed patterns with those found in large, gradual SEP events. Adopting an empirical fractionation model depending on the charge-to-mass ratio, Q/M, of the ions we draw inferences about the ionic charge states of various species and compare them with values measured in some of the same events at lower energies.

The Origin of Low Energy 3He


3He is present in the interplanetary medium throughout the solar cycle. Two main sources are thought to contribute to the abundance of 3He near Earth, a solar and a galactic secondary component, both with distinct spectral shapes. Measuring 3He over a wide energy range is necessary to determine the extent to which the two different populations are present. Preliminary results suggest that 3He is dominated by impulsive solar energetic particle events below ~5 MeV/nuc, while it is has significant contributions from the galactic component above ~15 MeV/nuc. We present 3He observations during solar minimum and solar maximum periods over a critical energy range for understanding the origin of 3He between ~5-15 MeV/nuc using observations from both the Solar Isotope Spectrometer (SIS) and the Cosmic Ray Isotope Spectrometer (CRIS) on ACE. A measure of the 3He/4He ratio over this critical energy range may help to constrain possible origin of these nuclei.
Energetic Electrons in 3He Enhanced Solar Energetic Particle Events

Ho G.C. (Johns Hopkins University Applied Physics Laboratory), Roelof E.C., Mason G.M.

3He-enhanced solar energetic particle (SEP) ion events were found to be accompanied by nonrelativistic electrons in the 10-100 keV energy range. However, there is no clear relationship between the electrons and ions beside their occurrence. We therefore examined the electron associations in the general class of impulsive 4He ion SEP events over the same time period. The general class is statistically indistinguishable from the 3He-enhanced subclass: 43 out of 97 impulsive 4He ion events were associated with impulsive electron events. The weak correlations between maximum electron intensities and maximum helium intensities (either 3He or 4He) are statistically indistinguishable between the general class of impulsive He events and the special class that was 3He enriched. Consequently, we have found no evidence (at the energies we studied) that the energetic electron population that escapes into interplanetary space is causally involved in the preferential enrichment of 3He. However, this does not rule out the possibility that a separate (non-escaping) population of electrons in the corona participates in the preferential acceleration of 3He. An inverse correlation was found between the maximum electron intensities in the beam-like electron events and the event-average 3He/4He ratios. However, an inverse correlation was also observed between the 4He event fluences and the 3He/4He ratios. This implies the 3He fluences in any given 3He-enhanced event is relatively constant, and the variation we observed in the 3He/4He ratio is related only to the 4He fluences in an event. We will discuss the possible implications of these newfound correlations we observed from ACE in this paper.

The Pitch-Angle Distribution Width Between 100 eV to 100 keV During the Solar Electron Burst of 22 March 2002


A compilation of various spacecraft measurements made over the last 30 years suggests that the pitch-angle distribution width of a solar electron burst may have a complex, non-monotonic energy signature. To date, no study has considered the pitch-angle distribution width over a broad energy range during a single solar electron burst. Here we use WIND/3DP data to examine the energy dependence of the pitch-angle distribution width between 100 eV to 100 keV during the solar electron burst of 22 March 2002. This is the first comprehensive analysis of the distribution width during a single burst over such a broad range of energies. We find that the pitch-angle distribution width during this event increased with energy from 0.1-2 keV, followed by a subsequent decrease in width from 2-10 keV, followed by another increase in width above 10 keV. In other words, the distribution width had a local maximum at ~2 keV and a local minimum at ~10 keV. These results imply that the details and effectiveness of the wave-particle scattering mechanism vary with energy.
3He events and the Solar Neutron Connection

**Ryan J.M.** (UNH), MacKinnon A., Kontar E. (University of Glasgow), Bravar U., Legere J., Macri J., Flueckiger E., Pirard B. (University of Bern), Vilmer N. (Observatoire de Paris – Meudon)

Small impulsive 3He, electron-rich events possess a composition that would give rise to solar neutrons if those particles interacted with the solar atmosphere. With a typically soft spectrum, the same ions striking the chromosphere will produce mostly low energy neutrons that are undetectable at Earth. We examine this possibility in the context of earlier and future measurements of neutrons and gamma rays (all performed from 1 AU). We also discuss the possibilities of making discovery detections of low-energy solar neutrons with proposed instrumentation on Solar Sentinels, assessing the instrument sensitivity needed for such measurements.

Solar Sources of 3He-rich Solar Energetic Particle Events

**Nariaki N.** (Lockheed Martin ATC)

Solar energetic particle (SEP) events enriched in 3He (and heavy ions) are often referred to as impulsive, largely for historical reasons that they were often associated with short-duration flares (rather than with long-decay events that typically accompany fast coronal mass ejections (CMEs)). The “impulsive” nomenclature sometimes leads to confusion, since some short-duration electron events may not be 3He-rich and some short-duration solar flares may be associated with CMEs so fast and extended that shock acceleration may be expected. Identification of the solar activity responsible for a 3He-rich SEP event, usually defined at ~1 MeV/n, is a daunting task because of the unclear particle onset time at 1 AU and the long time it takes particles to travel. Nevertheless, elucidating the origin of 3He-rich SEP events may help us better understand the acceleration and transport of particles in and from solar flares and also test the models of the Sun-Earth magnetic field connection. In this talk, I first characterize the solar flares that are clearly associated with 3He-rich SEP events, thanks to the contemporaneous type III radio bursts and electron events. X-ray and EUV data will be analyzed in detail for a handful of solar flares to study their onsets and time variabilities and possible involvement of open field lines (e.g., in the form of a jet). I also address the solar sources of 3He-rich SEP events in a larger sample from the ACE data archive that includes extended periods of 3He enhancement without clear individual injections. I give possible solutions to the problem cases where the solar event is not convincingly identified, and discuss what we need to do to take the next step.
Characteristics of Flares and CMEs Associated with SEP events

Cane H.V., Richardson I.G., von Rosenvinge T.T. (NASA/GSFC)

We have performed a comprehensive analysis of the characteristics of the CMEs, flares and radio bursts (at metric and longer wavelengths) associated with the ~340 >20 MeV proton events that occurred during cycle 23. The smallest particle events are those that are accepted to be flare accelerated. However the characteristics of associated phenomena change smoothly as events becomes more energetic with no clear indication of a property of the solar event that separates particle events into two classes. In particular essentially ALL of the particle events have associated CMEs. The characteristic that most successfully selects for flare particles, as defined by being electron-rich, is the duration and starting frequency of the associated type III radio bursts. These bursts give direct indication of the height in the corona of the acceleration region and the duration may be related to the physical size of the acceleration region. These properties are likely to influence the abundances so that one should not expect flare particles in the most energetic events to have the same composition as those in the smallest events. In other words one cannot rule out the presence of flare particles in the largest events by the absence of the extreme composition seen in the smallest events.
Introduction to Community Models (Linker / Abbett)

Heliospheric Simulations by ENLIL

Odstrcil D. (University of Colorado)

The numerical code ENLIL (Sumerian god of strong wind and storms) is a research tool for simulations of corotating and transient solar wind disturbances. Its inner radial boundary is located beyond the sonic point, typically at 21.5 or 30 solar radii. ENLIL can accept boundary condition information from various analytic, empirical, and numerical coronal models. The outer radial boundary can be adjusted to include planets or spacecraft of interest (e.g., 2 AU to include both Earth and Mars, 5 AU to include Ulysses, 10 AU to include Cassini). We will show examples on how to use ENLIL as assisting tool in predicting conditions at and interpreting remote and in-situ observations by heliospheric spacecraft.

The UCSD Solar Mass Ejection Imager (SMEI) and Interplanetary Scintillation (IPS) Web Database

Jackson B.V. (CASS/UCSD), Hick P.P. (CASS/UCSD), Bisi M.M. (CASS/UCSD), Buffington A. (CASS/UCSD), Clover J.M. (CASS/UCSD)

We present the current state of the UCSD Solar Mass Ejection Imager (SMEI) and interplanetary scintillation (IPS) database maintained and stored on UCSD/CASS Web servers. The IPS database provides real-time access of Solar-Terrestrial Environment Laboratory (STELab), Japan IPS data, and provides a variety of higher-level data products derived from these observations to help in Space Weather Forecasting. The up-to-date UCSD SMEI database includes individual SMEI CCD data frames from each of the three SMEI cameras since launch and first light in February 2003, as well as full-sky maps in a sidereal reference frame that preserve the original resolution and photometric precision. Higher-level products from this database are maintained for select intervals from launch up to the present. The IPS data and the modeling capability demonstrated as real-time data access in these analyses are available at the Community Coordinated Modeling Center (CCMC), as are the IPS data from STELab from the year 2000 up to the present. UCSD/CASS websites: http://ips.ucsd.edu/ http://smei.ucsd.edu/
Using the WSA Coronal and Solar Wind Model

Arge C.N. (Air Force Research Laboratory, Kirtland Air Force Base), McGregor S.L. (Boston University), Mayer L.R. (CU/CIRES & NOAA/SWPC)

The Wang–Sheeley–Arge (WSA) model is a combined empirical and physics based representation of the quasi-steady global corona and solar wind flow. It can be used to model the ambient solar wind speed and interplanetary magnetic field polarity out past Earth and is thus useful for both basic as well as applied (e.g., forecasting recurrent interplanetary disturbances) research purposes. Participants in this session will have the opportunity to learn how to run and use the WSA model, as well ask detailed questions about it. The session will begin with a brief introduction to the model followed by individualized tutorials on how to use it.
Modeling a “Simple” CME from its Eruption to its Interplanetary Propagation out past Earth: The May 13, 2005 Event (ARGE)

An Observational Overview of the 2005 May 13 Campaign Event ☁

Gopalswamy N. (NASA/GSFC)

This talk summarizes the observational results concerning the origin, propagation, and geospace impact of the 2005 May 13 campaign event. The eruption occurred close to the disk center (N11E12) accompanied by a halo CME at 17:12 UT and a long duration flare (M8.0 flare from AR 0759 with a nice post-eruption arcade). There was also a EUV disturbance that spread over the entire disk by 17:07 UT. The CME speed was 1689 km/s in the sky plane. Applying a cone model yields a speed of ~2167 km/s. The CME was associated with a metric type II burst and a spectacular interplanetary type II burst drifting from the Sun all the way to the local plasma frequency in the vicinity the Wind spacecraft. At 17:22 UT, the type II radio emission occurs at ~1 MHz, consistent with the CME height ≥ 6 RO. The SEP event had a slowly rising intensity profile because of the poor connection early in the event, but reached an intensity of ~3000 pfu in the GOES >10 MeV energy channel. The SEP release happened when the CME was >7 RO away from the Sun. The shock arrived at the SOHO spacecraft on May 15 at 02:19 UT and was accompanied by a huge energetic storm particle (ESP) event. The ESP intensity jumped from ~100 pfu to 3000 pfu. Behind the shock, the intensity dropped precipitously from ~1000 to 10 pfu (gradual drop for ~3 h and a sudden drop in <30 min). The solar wind speed jumped from ~500 to 1000 km/s upon the shock arrival. The interplanetary CME was a magnetic cloud of south-north type with a south-turning sheath so it resulted in a prompt super-intense geomagnetic storm on May 15 at 9 UT, when the Dst index reached -263 nT, preceded by a storm sudden commencement (SSC). The SSC coincided with the ESP event and other manifestations of the shock. This talk summarizes the observational results concerning the origin, propagation, and geospace impact of the 2005 May 13 campaign event. The eruption occurred close to the disk center (N11E12) accompanied by a halo CME at 17:12 UT and a long duration flare (M8.0 flare from AR 0759 with a nice post-eruption arcade). There was also a EUV disturbance that spread over the entire disk by 17:07 UT. The CME speed was 1689 km/s in the sky plane. Applying a cone model yields a speed of ~2167 km/s. The CME was associated with a metric type II burst and a spectacular interplanetary type II burst drifting from the Sun all the way to the local plasma frequency in the vicinity the Wind spacecraft. At 17:22 UT, the type II radio emission occurs at ~1 MHz, consistent with the CME height ≥ 6 RO. The SEP event had a slowly rising intensity profile because of the poor connection early in the event, but reached an intensity of ~3000 pfu in the GOES >10 MeV energy channel. The SEP release happened when the CME was >7 RO away from the Sun. The shock arrived at the SOHO spacecraft on May 15 at 02:19 UT and was accompanied by a huge energetic storm particle (ESP) event. The ESP intensity jumped from ~100 pfu to 3000 pfu. Behind the shock, the intensity dropped precipitously from ~1000 to 10 pfu (gradual drop for ~3 h and a sudden drop in <30 min). The solar wind speed jumped from ~500 to 1000 km/s upon the shock arrival. The interplanetary CME was a magnetic cloud of south-north type with a south-turning sheath so it resulted in a prompt super-intense geomagnetic storm on May 15 at 9 UT, when the Dst
index reached -263 nT, preceded by a storm sudden commencement (SSC). The SSC coincided with the ESP event and other manifestations of the shock.

*The Ambient Solar Wind's Effect on ICME Transit Time*

**Case A.W.** (Boston University Center for Space Physics), Spence H. (BU), Owens M. (BU), Riley P. (SAIC), Odstrcil D. (Univ. Colorado)

Most empirical and numerical models of Interplanetary Coronal Mass Ejection (ICME) propagation use the initial CME velocity as their primary, if not only, observational input. These models generally predict a wide spread of transit times (to 1 AU) for ICMEs with the same initial velocity. We use a 3D coupled MHD model of the corona and heliosphere to determine the Ambient Solar Wind's effect on the propagation of ICMEs from 30 solar radii to 1AU. We quantitatively characterize this deceleration by the velocity of the upstream ambient solar wind. The effects of varying solar wind parameters on the ICME transit-time are quantified and can explain the observed spread in transit times for ICMEs of the same initial velocity. We develop an adjustment formula that can be used in conjunction with other models to reduce the spread in predicted transit times of Earth-directed ICMEs.

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**Modeling and prediction of the May 13 2005 event**

**Xie H.** (Catholic University of America), Steyr O.C. (NASA/GSFC), Gopalswamy N. (NASA/GSFC), Hu Q. (UCR)

The SHINE campaign event May 13 2005 CME is a fast halo event, which was seen in LASCO/C3 as a bright (almost symmetric) halo. The event was associated with a M8.0 X-ray flare at N12E11 (AR 10759). EIT 195 images showed a strong brightening with sigmoid structure and a post_loop arcade with its axis tilted to SW and NE of the AR. The event was well observed by both radio (Wind/WAVES) and in-situ observations from 1 AU (ACE, Wind and SOHO) to ~ 5AU (Ulysses). The WAVES observed a nice Sun-Earth event (5000-40 kHz) and both spacecraft at L1 and Ulysses at ~5 AU (surprisingly) observed a magnetic cloud structure. In this work, we study the propagation of the CME (and its driven shock) using numerical simulation (ENLIL+cone model) and empirical techniques (Type II burst method (e.g., Cremades, et al., 2007) and empirical shock arrival (ESA) model (Gopalswamy et al., 2005)). We will compare three methods of predicting CME and the associated driven shock arrival time. We will also test predictions made by numeral simulations against radio and in-situ observations and provide observational constraints to the model.
Origin of the Structure in the Solar Wind (Borovsky / Arge)

Relationship of Interplanetary Shock Micro and Macro Characteristics: A Wind Study

Szabo A. (NASA/GSFC), Koval A. (NASA/GSFC, NPP)

The non-linear least squared MHD fitting technique of Szabo [1994] has been recently further refined to provide realistic confidence regions for interplanetary shock normal directions and speeds. Analyzing Wind observed interplanetary shocks from 1995 to 2001, macro characteristics such as shock strength, Theta Bn and Mach numbers can be compared to the details of shock micro or kinetic structures. The now commonly available very high time resolution (11 or 22 vectors/sec) Wind magnetic field data allows the precise characterization of shock kinetic structures, such as the size of the foot, ramp, overshoot and the duration of damped oscillations on either side of the shock. Detailed comparison of the shock micro and macro characteristics will be given. This enables the elucidation of shock kinetic features, relevant for particle energization processes, for observations where high time resolution data is not available. Moreover, establishing a quantitative relationship between the shock micro and macro structures will improve the confidence level of shock fitting techniques during disturbed solar wind conditions.

Periodic Solar Wind Number Density Structures: their inherent length-scales, how they affect Earth’s magnetosphere, and their possible source *

Viall N.M. (Center for Space Physics, Boston University), Kepko L. (Space Science Center, University of New Hampshire), Spence H. (Center for Space Physics, Boston University)

We recently completed an analysis of the occurrence distribution of statistically significant radial length-scales of periodic solar wind number density structures. We converted 11 years (1995-2005) of solar wind number density data into radial length series segments and Fourier analyzed them to identify all spectral peaks with radial wavelengths between 72 (116) and 900 (900) Mm for slow (fast) wind intervals. The occurrence distributions of these spectral peaks for slow and fast wind, indicate that periodic number density structures occur more often at certain radial length-scales than at others, and are consistently observed within each speed range over most of the 11 year interval. For slow wind, those length-scales are L ~ 73, 120, 136 and 180 Mm. For fast wind, those length-scales are L ~ 187, 270 and 400 Mm. These radial length scales will appear at certain apparent frequencies in Earth’s reference frame dependent upon the solar wind velocity. We repeat the analysis using both the apparent frequencies of the periodic solar wind number density structures and the dayside magnetospheric oscillations in the f = 0.5-5.0 mHz range. We counted the number of times the same discrete frequencies were identified as statistically significant in corresponding solar wind and magnetospheric time series. In 54% of the solar wind segments in which we identified a spectral peak, at least one of the same discrete frequencies was statistically significant in the corresponding magnetospheric data segment. The results argue for the existence of inherent radial length-scales in the solar wind number density that appear at discrete frequencies in Earth’s reference frame and directly drive
global magnetospheric oscillations at the same discrete frequencies. The question remains: why are there particular length-scales in the solar wind density structures? To address this, we use He data to identify possible sources of the structures.

Galactic Cosmic Ray Modulation by Small-Scale Features in the Interplanetary Medium *

Jordan A.P., Spence H.E. (Boston University), Blake J.B. (The Aerospace Corporation), Mulligan T.L. (The Aerospace Corporation), Shaul D.N.A. (Imperial College London), Galametz M. (Imperial College London)

In an effort to uncover the properties of structures in the interplanetary medium (IPM) that modulate galactic cosmic rays (GCRs) on short time scales (on the order of hours), we compare high time resolution, multipoint, space-based GCR data to IPM data. To ensure that features we see in the GCR data actually relate to conditions in the IPM, we look for correlations between the GCR time-series from two instruments onboard the Polar and INTEGRAL (INTErnational Gamma Ray Astrophysical Laboratory) satellites, respectively inside and outside Earth's magnetosphere. We analyze the period of 18-24 August 2006 during which an interplanetary coronal mass ejection (ICME) passed Earth and produced a Forbush decrease (Fd) in the GCR flux. We find two periods--for a total of ten hours--of clear small-scale correlation between the two GCR time-series during these seven days, thus demonstrating that such variations are observable using space-based instruments. Though the first period of correlation appeared to be unrelated to the IPM time-series, we are still able to estimate the size-scales of the inferred IPM structures modulating the GCR flux: ~3000 Mm in GSE x, at least 0 to 450 Mm in y, and at least 200 to 650 Mm in z. The second period of correlation occurred during the initial decrease of the Fd, an event that did not conform to the typical one- or two-step classification of Fds. We show that planar magnetic structures preceding the ICME played a role in initiating the Fd.

Spatial Structure of Solar Electron Bursts and Filamentary Solar Wind

Steinberg J.T., Skoug R.M. (Los Alamos National Laboratory)

Transient solar electron bursts are found in observations at 1.4 keV and lower energies from both ACE and Genesis. More that 200 electron burst events seen simultaneously by ACE and Genesis from late 2001 through early 2004 have been examined. Although the spacecraft were spatially separated by up to a million km at times, the majority of electron burst events were strikingly similar at both spacecraft. The observed similarity indicates that bursts are usually spatially uniform across ACE-Genesis separation distances. However, numerous burst events in the study exhibited non-dispersive modulations that appeared sequentially at one spacecraft then the other. We will discuss the occurrence rate of the non-dispersive modulations and the observed time lag of these features between spacecraft. The observations will be interpreted in light of recent discussions of a filamentary nature for solar wind.

* Student paper ☀ Invited Paper
Investigation Of The Weak Polar Magnetic Fields During The Recent Decline Phase of Solar Cycle 23 *

Lee C.O., Luhmann J.G. (Space Sciences Laboratory, UC Berkeley), de Pater I. (Dept. of Astronomy, UC Berkeley), Odstrcil D. (CIRES/SEC, University of Colorado), Arge C.N. (AFRL), Russell C.T., Jian L.K. (UCLA)

The current solar cycle decline phase and minimum period seems to have unusual properties that appear to be related to weak solar polar magnetic fields. We look to see if there are signatures of this unusual polar field in the IMF for well-documented and observed cycles. In particular, if the solar wind comes from the polar regions, one might expect it to carry less flux if less flux is present there. Using the OMNI data set as well as the recent STEREO observations, we find that for the current solar cycle decline phase the peak distribution for the values of the IMF magnitude is lower compared to the decline phase of previous solar cycles.

Development of solar wind model driven by empirical heat flux

Selwa M.A., Ofman L. (CUA/NASA GSFC), Sittler Jr. E.C. (NASA GSFC)

We are developing a time stationary self-consistent MHD model of the solar corona and solar wind as suggested by Sittler et al. (2003). As the first step we study the simplest 2D MHD case with variable heat conduction, and with empirical heat input combined with empirical momentum addition for the fast solar wind. We use realistic magnetic field based on SOHO/MDI data, and we plan to extend the study to 3D. This study represents the first attempt of fully self-consistent realistic model based on real data and including semi-empirical heat flux with heat conduction.

* Student paper ☀ Invited Paper
We examine statistics of rapid spatial variations of the magnetic field in magnetohydrodynamic (both MHD and Hall-MHD) turbulence, by analysing intermittency properties of the turbulence, and by using methods classically employed to identify discontinuities in the solar wind. The methods give very similar distribution functions of events, identify similar structures, and give comparable average waiting times. The latter, scaled to the solar wind correlation length, agrees with typical waiting times between discontinuities. Comparisons of ACE magnetic field analyses and simulations are given as examples. Almost identical results are obtained using classical discontinuity identification methods and methods based on intermittency analysis. Furthermore, the probability distribution functions of increments in ACE and in several types of MHD simulations reveal a robust structure consisting of small random currents, current cores, and intermittent current sheets. This adds to evidence that solar wind magnetic structures may emerge from intermittent nonlinear dynamical evolution.
Other

3D Reconstructions of the Inner Heliosphere

Bisi M.M. (University of California, San Diego), Jackson B.V., Hick P.P., Buffington A., Clover J.M. (CASS-UCSD)

Interplanetary scintillation (IPS) observations provide a view of the solar wind at all heliographic latitudes from coronagraph fields of view to solar elongation angles >90 degrees from the Sun. The Solar Mass Ejection Imager (SMEI) provides white-light brightness coverage with a better spatial resolution than IPS from about 20 degrees elongation to the anti-solar direction at 180 degrees elongation. These observations can be used to study the evolution of the solar wind, corotating structure, and solar transients as they propagate out into interplanetary space. We use a three-dimensional (3D) reconstruction technique that obtains perspective views from solar corotating plasma and outward-flowing solar wind as observed from the Earth. This is achieved by iteratively fitting a kinematic solar wind model to IPS radio and SMEI white-light observations. This 3D modeling technique permits reconstruction of the density and velocity structures of coronal mass ejections (CMEs) and other interplanetary transients at a relatively coarse resolution, as well as the background solar wind. The resolutions are better both spatially and temporally when used with SMEI white-light observations to perform density reconstructions. Here we present 3D reconstructions of events which include the 28-30 May 2003, 13-15 May 2005, and December 2006 CME periods as observed by SOHO/LASCO using both (when data are available) multi-system IPS and SMEI observations.

What Interplanetary Conditions Produce Quasi-Perpendicular Shocks?

Richardson I.G. (NASA/GSFC), Cane H.V. (University of Tasmania), Kasper J.C. (Smithsonian Astrophysical Observatory)

The angle between the normal to an interplanetary shock front and the upstream magnetic field (theta(Bn)) is expected to influence the process of charged particle acceleration by the shock. Although theta(Bn) is often thought of as a property of the shock, it also depends on the configuration of the interplanetary magnetic field (IMF) through which the shock is traveling. A typical, radially-propagating, CME-driven shock passing through a Parker spiral field at 1 AU would be expected to have theta(Bn)~45 deg.; to produce a quasi-perpendicular shock (theta(Bn)~90 deg.), the magnetic field direction must deviate significantly from the Parker spiral. We have examined the solar wind context of a sample of near-Earth quasi-perpendicular shocks observed in solar cycle 23 and find that these shocks are frequently encountering interplanetary structures such as interplanetary coronal mass ejections (ICMEs), the heliospheric plasma sheet, or other regions that are associated with significant deviations of the IMF direction. We also use Helios 1 and 2 magnetic field observations at 0.3-1 AU to examine how ICMEs may contribute to the formation of quasi-perpendicular shocks in the inner heliosphere.

* Student paper  ☀ Invited Paper

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Space Weather Support to NASA Operations

Turner R.E. (ANSER), St.Cyr C., Guhathakurta L. (NASA)

Space radiation poses a significant risk to NASA-wide activities (human spaceflight, robotic missions and launch operations). Reducing the risk is a multidiscipline challenge, involving operational forecasters, mission planners/operators, and the space physics research community. Improvements are needed in space weather forecasting capabilities to assess and predict the impact of radiation effects on astronauts and operating systems. Traditionally, various aspects of radiation impacts across the agency have been localized, with few interactions or complex interfaces between programs, mission directorates, and functional offices. As NASA fulfills the Vision for Space Exploration and visits more extreme environments of scientific interest; high costs, unacceptable health risks, and unexpected interactions and consequences may result from the new mission content. The complex nature of the prediction, protection, interaction, mitigation, and adverse effects of/from radiation require that NASA consider what, if any, Agency-level initiatives are required to ensure that these complex interactions are understood, that requirements are properly formulated and allocated, and that the systems and concepts of operations that are developed are able to fully support NASA missions. The NASA Office of the Chief Engineer has implemented a one-year study to look at future space weather support architectures. Elements of the study will include:

- Identify NASA Mission Directorates strategic and mission requirements
- Describe current state of space weather/climatology architecture (sensors, models, simulation facilities, and forecasting capability)
- Document current trends in space weather/climatology theory and models
- Prepare NASA operational space weather needs and constraints document

The output of the study will include three alternative architectures:

A New Technique for Finding Electric Fields from Sequences of Vector Magnetograms

Fisher G.H., Welsch B., Abbett B., Bercik D. (UC Berkeley)

The advent of extensive ground-based and space-based vector magnetogram data will greatly improve our quantitative understanding of how magnetic fields evolve in the solar atmosphere. A problem of current interest is the derivation of electric fields or velocity fields from vector magnetogram data, as this is the crucial link between observation and future physics-based time-dependent models of the solar atmosphere. Most previous techniques for deriving \( E \) or \( v \) have used only the normal component of the magnetic induction equation, as it is generally believed that depth derivatives contained in the magnetic induction equation cannot be derived from vector measurements taken within a single layer. We will show that in fact, sufficient information exists within a sequence of vector magnetograms to determine a 3-dimensional electric field whose curl reproduces the observed changes in all 3 components of \( B \). While this is certainly a major step forward, it is also true that the electric field \( E \) itself, as opposed to its curl, is under-constrained by the data. We will discuss how additional constraints may be used to uniquely determine all 3 components of the electric field.
The Solar Wind as a Magnetic Reconnection Laboratory

Gosling J. (University of Colorado)

Magnetic reconnection occurs frequently at thin current sheets in the solar wind and produces exhausts of jetting plasma bounded by back-to-back rotational discontinuities. The exhausts are identified as roughly Alfvénic accelerated plasma confined to field reversal regions that almost always take the form of bifurcated (double-step) current sheets. The exhausts are embedded within the solar wind flow and are convected past a spacecraft on time scales ranging from seconds up to several hours, with time scales less than 100 s being dominant. Near solar minimum reconnection exhausts are swept past Earth at a rate of 40 – 70 events/month, with numerous events being associated with local magnetic field shear angles considerably < 90°. The exhausts are observed predominantly in the low-speed solar wind or in association with interplanetary coronal mass ejections in plasma predominantly having low proton beta; however, reconnection also occurs in the turbulent, high-speed wind from coronal holes, but less frequently. Multi-spacecraft observations demonstrate that the exhausts often result from prolonged (hours) reconnection at extended (up to at least 4.3 x 106 km) and continuous x-lines. Here we provide an overview of reconnection as it occurs in the solar wind and highlight similarities and differences to observations of reconnection as it occurs in other environments.

Multi-Point Energetic Particle Observations of CIRs in the Present Solar Minimum


Since the two STEREO spacecraft entered heliocentric orbit early in 2007, solar energetic particle (SEP) activity has been at a minimum but significant particle enhancements due to corotating interaction regions (CIRs) have regularly appeared at 1 AU, providing an ideal opportunity to study CIR particles free of SEP contamination. As the two STEREO spacecraft move farther apart, the differences in CIR time profiles observed by each become ever greater. Delays of ~3 days are now common between the Behind and Ahead spacecraft, with different features present in the time profiles on each. The timing differences are roughly as expected from the corotation time lag between the two spacecraft, however many of the different features seen at Ahead and Behind may require transient disturbances in the solar wind to alter connection to or transport from the shock, or temporal changes in the CIR shock itself. Using data from the LET and the SIT instruments on STEREO along with measurements from ULEIS and SIS on ACE, we present observations of H and He spectra, anisotropies, and timeprofiles for the CIR events of 2007 and 2008. In particular, we examine the evolution of the time profiles as a function of spacecraft separation in longitude, radius, and heliographic latitude, and investigate the dependence of the timing differences on the location of solar and heliospheric structures such as the heliospheric current sheet and coronal hole boundaries. This work was supported by NASA grants NAS5-03131 and NAG5-12929.
Driven Waves as a Diagnostic Tool for Alfvén Waves in the Solar Corona

Kaghashvili E., Quinn R.A. (Atmospheric & Environmental Research)

Alfvén waves have long been considered to be responsible for an additional energy input into coronal structures because they carry energy and they are hard to damp; this makes it also very difficult to detect them directly. Here, we discuss how driven compressible waves can be used as a diagnostic tool for Alfvén waves. This process operates the following way: Alfvén waves generated by photospheric convective motions propagate upwards along the magnetic structure and, as they propagate, waves coupled with inhomogeneities of the medium produce driven fluctuations which are easier to detect because of their compressive nature. Analytical solutions, derived in our earlier studies [Kaghashvili et al. 2006, 2007], make direct connection between plasma background, driver and driven wave characteristics. A novelty of this mechanism is that it can establish a quantitative link between detected observations and Alfvén waves that drive them.

Spatially dependent heating and ionization in an ICME observed by both ACE and Ulysses

Lepri S.T. (The University of Michigan), Laming J.M. (U.S. Naval Research Laboratory)

The January 21st 2005, Interplanetary Coronal Mass Ejection (ICME) observed by multiple spacecraft at L1 was also observed from January 31 – February 4th 2005, at Ulysses (~3.25 AU). Foullon et al. (2007) conducted an in depth multi-spacecraft study of this ICME and found evidence suggesting that the flanks of a magnetic cloud like structure associated with this ICME were observed at L1 while a more central cut through the associated magnetic cloud was observed at Ulysses. This event allows us to study spatial variation across the ICME and relate it to the eruption at the Sun. In order to examine the spatial dependence of the heating in this ICME, we present an analysis and comparison of the heavy ion composition observed during the passage of the ICME at L1 and at Ulysses. The heavy ion composition is determined within 4 solar radii of the Sun and contains information regarding the heating and energy partitioning during the eruption (e.g. Rakowski et al. 2007). The Solar Wind Ion Composition Spectrometer (SWICS) on board both Ulysses and ACE measure the ionic and elemental abundances of heavy ions in the solar wind. Using SWICS, we compare the heavy ion composition across the two different observations cuts through the ICME and compare it with predictions for heating during the eruption based on the Laming et al. (2004) ionization model and the work of Laming and Lepri (2007) and Rakowski et al (2007).
Determination of 3D CME Trajectories from Stereoscopic Analysis of STEREO Coronagraph Data


We present results demonstrating that the 3D (velocity and direction) trajectory of a CME can be determined from stereoscopic analysis of STEREO coronagraph images. It has been demonstrated that stereoscopic analysis (aka triangulation) of bright coronal features such as loops can be used to determine their 3D location and geometry. In these cases, the emission from these feature comes from relatively localized volumes. This is not the case for bright features in white light images, which may capture scattered light from an extended volume. Even though line of sight (LOS) effects dominate the observed structure seen in white light coronagraph images of STEREO CMEs, we find that by “tiepointing” the bright leading edge of the CME in both images of a stereo pair, we are able to determine the 3D trajectory. This technique has been validated previously using synthetic white light images. Here, to validate our results, we compare our trajectories with CME trajectories determined by a more sophisticated forward-modeling method developed by Thernisien et al (Ap. J. 2006).

High-speed flows and magnetic properties of plasma loops *

Stenson E.V., Bellan P.M. (Caltech)

The study of simple laboratory plasma loops offers a mode of investigation complimentary to more traditional observations of loops in the solar corona. The experiments are highly reproducible, so the same phenomenon can be observed multiple times, from various angles, with a wide range of diagnostics. The plasmas can also be studied with more "hands-on" methods than can be applied to the sun, such as adjusting the magnetic field, varying the composition of the loops to look at mass and density dependence, and directly measuring field strength by inserting probes. Plasma loops are created in the laboratory with a magnetic “gun” similar to those used for making spheromaks, but possessing a different geometry. First, electromagnets establish an arched vacuum field; next, a small amount of neutral gas is released at the footpoints of the arch. Each footpoint is located on one of two electrodes, across which 4-6 kV is applied. This ionizes the gas, then supplies a current to the resulting loop of plasma that forms. The loop evolves further on its own, expanding and kinking in ways similar to what is observed in the solar corona. It is also possible to make two adjacent loops that interact with one another. We will be presenting the results of experiments in which loops were made from two different gases. This technique allows direct observation of high-speed flows from both ends of the loops. The velocities of these flows, calculated from feature tracking, are in good agreement with the theoretical model of magnetically-driven flows (Bellan 2003). Work is also ongoing to acquire measurements of the magnetic field in and around these loops. This data will then be compared to the theory, as well as the magnitude and structure of the field in the absence of the plasma.

* Student paper ☀ Invited Paper
GOES-12 SXI Pointing Refinement and Light Leak Correction

Pettigrew E.D. (Dartmouth College), Hill S. (NOAA/SWPC), Pizzo V. (NOAA/SWPC), Reinard A. (NOAA/SWPC), Biesecker D. (NOAA/SWPC)

The Solar X-ray Imager (SXI) on the GOES-12 weather satellite is an x-ray telescope that was used to image the sun at a one to two minute cadence throughout its lifetime. While it was operational (April 2003 – April 2007), it accumulated over two million images, which are stored and made available to the public by the National Geophysical Data Center (NGDC). In a large subset of this database, the sun-center coordinates that are recorded in image headers have errors of up to 30 arcseconds, significantly reducing the database’s utility to researchers. These errors are strongly correlated to thermal distortions in instrument components and therefore they can be reduced in post-processing with an empirical correction factor based on temperature values. In this project, statistical analyses were performed to determine an appropriate correction factor, which was shown to successfully reduce the pointing errors to fewer than 5 arcseconds for a significant majority of all the images tested. This instrument also experienced several light leaks during its lifetime. A study was done to determine efficient and effective algorithms for correcting two of these light leaks. An existing corrective algorithm was improved and a new corrective algorithm was developed.

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The Effect of Mixed Polarities on Coronal Hole Evolution

Lionello R. (SAIC), Linker J.A., Mikic Z.

We use our 3D MHD algorithm in spherical coordinates to study the interaction of the magnetic field of two small bipoles with a coronal hole. To prescribe the magnetic flux distribution at the lower boundary, we add two bipoles to a smoothed Kitt Peak magnetogram for Carrington Rotation 1913 (late August 1996). Starting from a potential field extrapolation and a 1D solar wind solution, we relax the configuration until coronal holes, streamers, and the heliospheric current sheet are formed. At this point we introduce surface flows, which evolve the magnetic flux distribution at the boundary. We study the reconnection events and the changes in the distribution of closed and open magnetic flux associated with the bipolar active regions.

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Calculating the 3D Velocity of CMEs Using STEREO Beacon Data

de Koning C.A., Pizzo V.J. (NOAA/SWPC), Biesecker D.A. (NOAA/SWPC)

The geometric localization technique [Pizzo and Biesecker, 2004] utilizes a series of lines of sight from two space-based observatories in order to determine gross propagation characteristics of coronal mass ejections (CMEs). This technique was developed to meet the need within the space weather community for a means to accurately determine the gross properties of Earth-directed CMEs from a near-real-time data stream, such as the one provided by the STEREO (Solar TErrestrial RElations Observatory) Space Weather Beacon.
This tool works with all STEREO coronagraph observations, including COR1 and COR2. Here, we employ the geometric localization technique to the CME of 31 December 2007 and present results on the speed and direction of propagation for this CME.

Properties of the Fast and Slow Solar Wind and ICMEs Measured by Ulysses: Three polar orbits of observations *

Ebert R.W., McComas D.J. (SwRI/UTSA), Elliott H.A. (SwRI), Gosling J.T. (LASP/SwRI), Forsyth R.J. (Imperial College)

The Ulysses spacecraft is currently in its third polar orbit of the Sun. This study combines measurements from Ulysses' plasma instrument (SWOOPS) and magnetometers (VHM/FGM) for all three polar orbits in order to analyze the properties of three distinct types of interplanetary plasma: the slow (< 500 km/s) and fast (> 650 km/s) solar wind and interplanetary coronal mass ejections (ICMEs). The intervals of ICME plasma were obtained from the existing Ulysses-SWOOPS ICME list to which we have added 27 events identified in the 2003 through February, 2008 data. We then investigate the radial and latitudinal variations of several plasma and magnetic field parameters (Vp, Va, Tp, Ta, Np, Na, B, β) from 1.3 to 5.4 AU and 80.2°N to 80.2°S, respectively. In comparison to the fast solar wind, the properties of the slow solar wind are more variable at all distances and have a slightly different radial dependence, most notably in the proton temperature. The evolution of the ICME parameters with heliocentric distance was not significantly different to that observed for the solar wind. In terms of latitudinal variations, we found both the slow and fast solar wind to be relatively constant with heliolatitude, with the slow wind cooler and more dense. We did not identify any significant latitudinal gradients in the ICME parameters. Finally, we studied the effects of the solar cycle on the solar wind by comparing the properties of the mid to high latitude fast wind measured over the first and third orbits, which were taken at similar periods in the 11-year sunspot cycle. We found the plasma properties of the fast wind measured during the third orbit to be reduced relative to the first with slightly different radial variations.

Using V1,V2, and STEREO Observations to Advance Heliospheric ENA Models *

Prested C.L., Schwadron N. (Boston University), Opher M. (George Mason University), McComas D. (Southwest Research Institute), Wang L. (University of California, Berkeley)

From hot heliosheath plasma, energetic neutral atoms (ENA's) are born, carrying with them information about the outer boundaries of the heliosphere. To extract this information, heliospheric ENA models will be fitted to the measurements by the Interstellar Boundary Explorer (IBEX). These models, and their subsequent interpretation, are highly sensitive to the assumed distribution of the parent plasma. The 2004 and 2007 in situ measurements of heliospheric plasma by Voyager 1 and 2 indicate the heliosheath plasma pressure is dominated by the pick-up ion (PUI) population. The Voyager probes also find that at the termination shock, ~80% of the solar wind flow energy is transferred to the PUI's. This produces a hot plasma population with a characteristic temperature >10^7 K, or ~1 keV, that
dominates the IBEX energy range. We find that using this PUI distribution, our ENA model agrees with the order of magnitude of the STEREO measurements of 'nose' ENAs. We also discuss possible mechanisms for the heliospheric asymmetries measured by STEREO and the Voyager probes.

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**The Solar Wind Speed in the Inner Heliosphere**

McGregor S.L., Hughes W.J. (Boston University), Arge C.N. (AFRL, Kirtland Air Force Base), Owens M.J. (Boston University), Odstrcil D. (University of Colorado, Boulder)

The Wang-Sheeley-Arge Model (WSA) infers the solar wind speed at 21.5 solar radii from the coronal magnetic field topology, which is calculated using the Potential Field Source Surface (PFSS) and Schatten Current Sheet (CSC) models. Using Helios observations at .3 AU, along with studies by Riley et al. [2003] and Schwadron et al. [2005], we have constrained the empirical magnetic topology/solar wind speed relationship more fully. When this relationship is used to specify the solar wind speed at the inner boundary of the Enlil model, we find that it improves both point-by-point and event (High Speed Enhancement) comparisons between the predicted solar wind speed from the model and in-situ observations. We interpret this as meaning that the solar wind speed in the inner heliosphere is being determined more reliably. The empirical relationship itself suggests that fast solar wind originating from deep within coronal holes varies primarily as a function of magnetic flux tube expansion factor, while slow solar wind depends primarily on the distance from the edge of the open flux region and very little on the expansion of the magnetic flux tube.

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**Turbulent 3D Reconnection**

Lazarian A. (University of Wisconsin at Madison and CMSO), Kowal G. (UW-Madison), Vishniac E. (McMaster)

Reconnection is a fundamental problem that one faces dealing with magnetized plasma. In terms of turbulent cascade, reconnection is necessary to avoid forming small-scale knots, draining energy from the cascade. We show results of numerical testing of the turbulent model of reconnection proposed in Lazarian & Vishniac (1999). These results confirm the aforementioned scheme and show that magnetic reconnection rate depends critically on the level of turbulence. This provides a natural explanation to reconnection bursts associated to Solar Flares. In terms of the turbulent cascade, the obtained rates show that magnetic field can change their topology fast enough to avoid forming magnetic knots.
Magnetic Structure of Corotating Interaction Regions at 1 AU

Broiles T.W., Desai M.I. (Southwest Research Institute/UTSA), Elliott H.A. (Southwest Research Institute)

Corotating Interaction Regions are very large magnetic structures that rotate with the Sun often reoccurring over several Carrington rotations. At distances of 5 AU the magnetic topology takes the form of a plane with its normal vector also being perpendicular to the interaction region. Near the Earth planar magnetic structures (PMS) can also be seen in CIRs, but it is unknown if they are as well developed as those measured with the Ulysses spacecraft. This work looks at planar magnetic structures in CIRs by first creating a suitable list of CIRs using the past 11 years of WIND and ACE data. This list was created by looking for dynamic and magnetic signatures unique to CIRs. Events of interest were not included if they happened in close temporal proximity to a coronal mass ejection (CME). By looking at the magnetic latitude and longitude across an interaction region, it is possible to calculate the azimutal and elevation angle of the magnetic plane using a least square planar fit (LSPF) or minimum variance analysis (MVA). Calculating the orientation of the planar magnetic field in CIRs could potentially be useful for several reasons. First, it may add new insight into how CIRs change as they move away from the Sun. Second, orientation of magnetic field could give a more complete picture into the acceleration processes that are thought to occur in CIRs.

Helioseismic clues to the prediction, emergence, and consequences of large active regions ☾

Hill F. (NSO/GONG)

Helioseismology is beginning to provide information about active regions in a variety of ways. In this talk I will present four paths of investigation: 1) The continual production of far-side maps, which show large active regions on the hemisphere facing away from the Earth. These maps can now provide estimates of the magnetic field strength of the regions, as well as a probability that they will rotate into the Earthward hemisphere. 2) Subsurface vorticity measurements coupled with surface magnetic field strength seem to be a good indicator of the flaring activity of an active region. Temporal variations of the vorticity may prove to be a useful flare predictor. 3) A number of helioseismic searches for pre-emergence indicators are in progress. 4) Data assimilation projects to incorporate the properties of subsurface flows below active regions into evolution forecasts are now in development.
Radio Observations of Electrons from the Corona to the Magnetosphere  
(Kasper / Haggerty)

Multi-Spacecraft EUV Tomography and 3D DEM ☀

Frazin R.A. (University of Michigan), Vasquez A. (University of Buenos Aires), Kamalabadi F. (University of Illinois)

We present, for the first time in space science, tomography based on simultaneous multi-spacecraft images. The input data are in the form of images of the solar corona that were taken in April 2008 by the EIT and EUVI instruments on the SOHO and STEREO A and B satellites. The tomographic process results in 3D emissivities from the 171, 195 and 284 angstrom bands. We use movies of the corona to identify regions of minimal dynamics in which the stationarity assumption (required by the current tomography algorithm) is valid. From the 3D emissivities in these regions we calculate the 3D local differential emission measures (DEM) under the assumption that in each volume element the DEM has a Gaussian distribution. These results represent the first 3D differential emission measure determinations.

Coronal Magnetic Field Properties from MHD Wave Observations with Faraday Rotation

Jensen E.A. (ACS Consulting), Russel C.T. (UCLA)

We demonstrate how Faraday rotation observations of Alfven waves can be used to study the magnetic field magnitude of the corona and the wave energy released from the Sun. We model the 4 minute period Alfven wave observed crossing the lines of sight from Helios to Goldstone, California and Canberra, Australia simultaneously on January 9, 1983. We find that the magnetic field magnitude is equal to the PFSS predicted value. Assuming that this wave is constantly present and transmitting in all directions, we find the wave energy is at least of the order $10^{19}$ W. For comparison, the momentum flux of the solar wind is $10^{20}$ W, and the power required to move through the gravitational potential from the solar surface to 1 AU is $10^{23}$ W.
On Modeling Scintillation from First Principles

Jensen E.A. (ACS Consulting), Breen A., Fallows R. (Univ. of Wales Aberystwyth)

Phase and intensity scintillation observations provide information on the heliospheric electron density and velocity. Density models using these observations require small angle scattering and are currently evaluated by comparison to in situ spacecraft observations. A simple model was constructed of a propagating electromagnetic wave front passing through various boundaries using Snell's Law to simulate scintillation and study the effects of density fluctuations under controlled conditions. The density fluctuations vary as a function of the product of the wave number and solar wind velocity, and the density fluctuations cause a displacement of the signal wave vector relative to the pointing direction of the antenna. This displacement causes a shifting of the electromagnetic waves' frequency (Doppler) and a shift in wave power. Progress on this scintillation simulation model will be presented including the ability to simulate diffraction through the introduction of a wave propagating along one of the boundaries in the model.

Coronal Hard X-ray Emission Associated with Radio Type III Bursts

Krucker S. (SSL, UC Berkeley)

We report on a purely coronal hard X-ray source detected in a partially disk-occulted solar flare by RHESSI that is associated with radio type III bursts and a suprathermal electron event detected near 1 AU by the WIND/3dp instrument. Several observational characteristics suggest that the coronal hard X-ray source is thin target bremsstrahlung emission from the escaping electrons that produce the radio type III bursts.
The Effects of Coronal Dimming Region Dynamics on CME Trajectories

Sechler M. (SAO/ CU-Boulder), Wills-Davey M.J. (SAO)

We present observations of Coronal Mass Ejections (CMEs) in which we compare the trajectory of the CME with the events occurring at its origin. Two types of CME trajectories are observed. In some cases, the CME moves out radially above the associated flaring active region, in accordance with conventional wisdom and most current CME initiation models. In other instances, the CME appears deflected from this expected path. Data show that the course of a deflected CME is influenced by the lateral motion of its associated dimming region low in the corona. We observe three distinct sets of dynamics associated with dimming regions, and find that these dynamics predict the expected CME trajectory.

The CME-Flare Relationship on the Computer

Torok T. (Paris Observatory), Kliem B. (University College London)

Observations of coronal mass ejections (CMEs) and solar flares have revealed a high correlation between the acceleration of the ejecta and the plasma heating and particle acceleration signified by the soft and hard X-ray emissions of the associated flare. The latter are generally thought to result from magnetic reconnection. This finding has stimulated the discussion of the CME-flare relationship, but at the same time it has made it difficult to find a conclusive answer as to whether magnetic reconnection or an ideal MHD instability is the prime cause of CMEs and flares. I will present numerical simulations of unstable flux ropes that show very satisfactory quantitative agreement with erupting filaments, both, confined to the corona and ejective (i.e., developing into a CME). The exponential acceleration of the flux rope, due to the ideal MHD instability, and the development of reconnection flows tend to be synchronized in these simulations, but the ideal process seems to be the primary one: The reconnection flows lag behind the ideal instability in the early phase of one simulation and in the late phase of another. The degree of the correlation depends on the magnetic topology of the erupting configuration, which may permit to infer aspects of the topology from observations of the CME-flare relationship.
What can flares tell us about CME properties?

Reinard A. (NOAA/CU)

In order to predict CME impacts at the Earth, we need to strengthen the connections between remote and in-situ observations of CMEs. Flares offer insight into the amount of energy available during the eruption. Recent studies have indicated that ICME composition, plasma and magnetic properties are correlated with flare magnitude and location on the solar disk. CMEs associated with larger flares tend to have higher levels of compositional enhancements, as well as increased velocity and decreased temperature and density. When those flares occur near disk center, the compositional enhancements are more extreme. These studies serve to strengthen the link between remote and in-situ observations. The results will be presented in the context of the large-scale structure of ICMEs.

Theoretical Predictions of Energy Release in CMEs and Calculations of Flare Emissions ☼

Reeves K.K. (Harvard-Smithsonian Center for Astrophysics), Forbes T.G. (UNH), Linker J. (SAIC), Mikic Z. (SAIC)

Using an analytical loss-of-equilibrium model, we have calculated the energy release accompanying coronal mass ejections. Thermal energy input into the associated flare loops is found by assuming the complete thermalization of the Poynting flux swept into the post-eruption current sheet. This thermal energy is used to calculate flare emissions emanating from the reconnected loops. Although this analytical model produces simulated flare emissions that are consistent with observations, it uses many simplifying assumptions that may affect its ability to predict flare emissions from specific eruptive events on the sun. In order to address these assumptions, we examine the energy inputs and outputs in a CME-associated current sheet modeled with a version of the SAIC MAS MHD code that has gamma set to its proper value of 5/3 and includes explicitly the effects of thermal conduction and radiation.
ON THE FEASIBILITY OF A 3D BIPOLAR BREAKOUT CME IN THE SOLAR WIND

van der Holst B. (University of Michigan), Toth G., Sokolov I., Gombosi T., Manchester W.B., Cohen O., De Zeeuw D.

The initiation and evolution of coronal mass ejections (CMEs) is studied by means of the breakout model embedded in a 3D solar wind in the framework of numerical magnetohydrodynamics. We start from a steady solar wind containing a pre-eruptive bipolar active region on the sun. The orientation of the overarching helmet field is such that a current sheet is formed on the top of the arcade of this bipolar active region. The magnetic tension of the overlying closed magnetic field of the helmet streamer keeps this structure in place. The most crucial element in the initial breakout topology is the existence of an X-point on the leading edge of the central arcade. By applying shear flow, the reconnection with the overlying helmet streamer field is turned on. The breakout reconnection opens the overlying field in an energetically efficient way. Initially, this process will speed up the CME. The simulations will exploit the new spherical grids in BATS-R-US to accurately capture the dynamics.

A Study of the Sympathetic Flare and CME Event on 2005 September 13

Liu C. (Big Bear Solar Observatory), Lee J. (NJIT), Wang H. (NJIT/BBSO), Choudhary D.P. (CSUN), Deng N. (CSUN)

We study a long-duration event occurred along the S-shaped magnetic polarity inversion line (PIL) of the NOAA AR 10808 on 2005 September 13. The whole event consists of three distinct flare episodes (X1.5, X1.4, and M9) and is associated with two fast CMEs. The first phase started with brightenings near the northern PIL, which immediately extended southward and triggered the eruption of a large filament (CME) lying at the southeast PIL. Within 10 minutes, the second flare phase was ignited at the northern main δ spot, which was accompanied by another large erupting flux loop (CME). Meanwhile, plasma flows seen as streams of enhanced density in EUV travelled downward toward the second flare region with an apparent speed as high as 350 km s⁻¹. The flows became emission in Hα when striking the lower atmosphere and later on are co-spatial with the initiation of the third flare. The different flare episodes are identified as separate running flare kernels or ribbons, and are clearly tracked by hard X-ray and radio imagings. We suggest a sympathetic flare/CME scenario for this whole event, and speculate that the high-speed plasma flow could be closely associated with the reconnection process of the second flare and is the driving agent for the third flare.
The Source Region of Coronal Mass Ejections

Lara A. (IGEF-UNAM)

We use the large database of coronal mass ejections (CMEs) observed by LASCO/SOHO during solar cycle 23 to statistically obtain information about the source region of CMEs. By determining the functional form of the position angle (PA) distribution, we are able to construct a random set of CME direction vectors (DV) under the following conditions: (a) assume a radial movement of the CME center of mass and (b) propose a latitude and longitude (lambda, phi) photospheric position for the DV in such a way that (c) the distribution of the projected (in the plane of the sky) DV must be equal to the observed distribution of PAs. We iteratively adjust the proposed positions (lambda, phi) until both distributions are equal, based on the Kolmogorov-Smirnov statistics. In this way, we obtain a set of DV which we use to study the relation between the CME source region and the overall coronal and photospheric magnetic field structures. We found that most CME source regions are situated between high magnetic field regions, and not necessarily are associated to one of such regions. As instance, during the minimum and ascending phase of the cycle, ~85% and ~60%, respectively of the CME source regions are confined to the equatorial plane, between the two active region belts. We conclude from this study that CME sources are in general, high altitude magnetic loops, more precisely, trans-equatorial loops during the minimum and ascending phase of the cycle.

Comparison of Fast and Slow Magnetic Breakout Eruptions

Lynch B.J. (SSL/UCB), Antiochos S.K. (NASA/GSFC), DeVore C.R. (NRL), Luhmann J.G. (SSL/UCB)

We compare the results of two different simulations of magnetic breakout CMEs in 3-dimensions. The first yields an extremely energetic, fast and complex eruption from an extended filament channel. The second yields a more modest, slower flux rope eruption. The field structure and shearing flows that result in the fast breakout CME preserve the normal field and thus maintains a strong field gradient along the entire polarity inversion line as the system builds up shear. The slower breakout CME is generated with a much simpler flow pattern that evolves the normal field on the inner boundary which leaves a large weak field region surrounding most of the polarity inversion line. Significantly more free energy is stored in the extended filament channel and by the end of the simulations the total kinetic energy of the fast eruption is approximately 10 times the slower one. We compare the height-time, velocity, and acceleration profiles and discuss the implications of the source region field structure on the eruption energetics.
**Relationships between flares and CMEs**

**Hudson H.S. (SSL/UCB)**

The relationships between flares and CMEs have been fraught with uncertainties in the recent past, but are now becoming observationally clearer. In particular we now see the impulsive phase of the associated flare to be of major importance in the acceleration of active-region CMEs at least. I discuss the phenomenology and the interpretation of the observations, including the equally-fraught question of the initiation of global waves (helioseismic, Moreton, type II, interplanetary type II, and EIT), and the inferences on flare structure that one can draw from their excitation.

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**Hard X-ray Emissions from the High Corona Associated with CMEs**

**Krucker S. (SSL/UCB)**

For flares occurring 20 or more degrees behind the solar limb, the main thermal and non-thermal hard X-ray (HXR) flare emissions are occulted, and faint HXR emissions from the high corona (>200 arcsec above flare site) can be investigated that is otherwise lost in the limited dynamic range of the observations. For events related to fast (>1500 km/s) backside CMEs, RHESSI generally observes large (>200 arcsec) non-thermal HXR sources that expand and move outwards. The upward motion of the hard X-ray source is slower than the speed of the CME front, but similar as the speed of the filament seen behind the CME front. This suggests that energetic (>10 keV) electrons are being advected outwards in magnetic flux tubes related to the CME.
The Prediction, Emergence, and Consequence of Large Active Regions ( Rast )

Evolution of Spinning and Braiding Helicity in an Emerging Active Region

Belur R., Longcope D.W. (MSU)

Active region magnetic fields are believed to be generated at the base of the convection zone by the dynamo processes. These magnetic fields are concentrated into flux tubes which rise, due to buoyancy, through the convection zone to appear at the photosphere. A theoretical model suggests that all the active regions emerge with some twist and some of them show larger twist than the others. Longcope and Welsch (2000) predicted through theoretical model that an emerging flux tube injects helicity into the corona after its initial emergence, through a rotation of its footpoints. The model also predicted that the rotation rate of the polarities will depend on the rate of flux emergence, and will follow a characteristic time evolution over one or two days. There have been a very few observational study of the helicity injection into the corona by the emerging flux. This poster presents the results of our study on the injection of helicity into the corona in the emerging active region 8578. We use spin helicity to quantify the rotation speed of the emerging polarities. Adding this to the braiding helicity gives the time history of the total helicity injected into the corona during the emergence of this active region.

Modeling the subsurface evolution of emerging active region flux tubes ☼

Fan Y. (National Center for Atmospheric Research)

I will present a set of 3D spherical shell simulations of the buoyant rise of active region flux tubes in the solar convective envelope. It is found that in order for the emerging tube to show a tilt angle consistent with the observed Joy’s law, the initial twist rate of the tube needs to be less than a half of that needed for a cohesive rise. Under such conditions, severe flux loss is found during the rise. It is also found that due to the asymmetric stretching of the rising tube by the Coriolis force, a field strength asymmetry develops with the field in the leading leg (leading in the direction of rotation) of the $\Omega$-shaped emerging tube being stronger than the following, resulting in a more compact morphology in the leading polarity of the emerging active region.
Observational properties of large active regions and consequences of their appearance

Leka K.D. (NWRA)

Large solar active regions mark the appearance of enormous amounts of magnetic flux, strong magnetic and velocity fields, electric current, and stored energy; they are statistically productive of energetic events. When such a large active region appears at the surface, the above properties interact with the extant corona. The Halloween storm period in 2003 is a beautiful demonstration of the impact of a large emerging active region (AR10488) on the already complex corona (primarily due to AR10486). In this talk, I will summarize the magnetic, energetic, and event productivity of large active regions in general, and discuss the impacts their emergence can have on the solar atmosphere.
The Theory of Suprathermal Particle Acceleration (Hill / Giacalone)

Solar Wind and Pick-up Ion Acceleration at an Interplanetary Shock

Summerlin E.J., Baring M. (Rice University)

The acceleration of interstellar pick-up ions as well as solar wind species has been observed at a multitude of interplanetary (IP) shocks by different spacecraft. The efficiency of injection of the pick-up ion component differs from that of the solar wind, and is strongly enhanced at highly oblique and quasi-perpendicular shock events. This paper expands upon previous work modeling the phase space distributions of accelerated ions associated with the shock event encountered on day 292 of 1991 by the Ulysses mission at 4.5 AU. As in the prior work, a kinetic Monte Carlo simulation is employed here to model the diffusive acceleration process. This exposition presents recent developments pertaining to the incorporation into the simulation of the diffusive characteristics incurred by field line wandering (FLW), according to the work of Giacalone and Jokipii. Resulting ion distributions and upstream diffusion scales are presented and compared with Ulysses data. For a pure field-line wandering construct, it is determined that for the parameter space we can explore with this method, the upstream spatial ramp scales are too short to accommodate the HI-SCALE flux increases for 200 keV protons, and that the distribution function for H+ somewhat underpopulates the combined SWICS/HI-SCALE spectra at the shock. This contrasts our earlier theory/data comparison where it was demonstrated that diffusive transport in highly turbulent fields according to kinetic theory can successfully account for both the proton distribution data near the shock, and the observation of energetic protons upstream of this interplanetary shock, using a single turbulence parameter. Reproducing the upstream spatial scale using the diffusive characteristics of FLW would require that particles move more than one gyro-radius perpendicular to the magnetic field in a single mean free path. This is not possible using isotropic scattering. It remains to be seen if FLW can successfully model the downstream energy spectrum or the upstream precursor at energies other than 200 keV.

Preliminary Results on Shock-Associated Energetic Particle Events with Focus on Seed Populations


We examine energetic particle and magnetic fluctuation spectra as measured by the Advanced Composition Explorer (ACE) spacecraft, which are observed in association with interplanetary shocks over the period from 1998 to the present. We characterize the shock parameters as well as the evolving energetic particle and magnetic fluctuation spectra leading up to and following the shock crossing. We divide each observation into background SEP ions and ESP ions that are tied directly to the shock. We assume that the SEP ions were previously shock accelerated, most likely by the same shock, but escaped the confines of the

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foreshock only to re-encounter the shock at 1 AU. As such, they constitute an energetic 
background population that the shock is then able to re-accelerate to higher energies. The 
central question is

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**The Excitation of Magnetic Waves by Solar Energetic Particle Populations**


Solar Energetic Particle (SEP) populations are a common occurrence during the years 
surrounding solar maximum. They are frequently observed coincident with interplanetary 
shocks and their associated Energetic Storm Particle (ESP) populations. However, while it is 
true that SEP ions may be accelerated by shocks (perhaps the very same shocks) closer to the 
sun, the energetic ions escape the scattering confines of the shock to become an independent 
population that evolves far upstream of the shock without direct contact or dependence upon 
the shock's presence or evolution after the initial acceleration phase. We ask the question

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**Automated Detection and Analysis of Interplanetary Shocks** *

Vorotnikov V.S., Smith C.W. (UNH), Hu Q. (University of California at Riverside), Szabo A. (Goddard Space Flight Center), Skoug R.M. (Los Alamos National Laboratory), Cohen C.M.S. (California Institute of Technology), Davis A. (California Institute of Technology)

The ACE real-time data stream provides web-based now-casting capabilities for solar 
wind conditions upstream of Earth. We have built a fully automated code that finds and 
analyzes interplanetary shocks as they occur and posts their solutions on the Web for possible 
real-time application to space weather nowcasting. Shock analysis algorithms based on the 
Rankine-Hugoniot jump conditions exist and are in wide-spread use today for the interactive 
analysis of interplanetary shocks yielding parameters such as shock speed and propagation 
direction and shock strength in the form of compression ratios. At a previous meeting we 
reported on efforts to develop a fully automated code that used ACE Level-2 (science 
quality) data to prove the applicability and correctness of the code and the associated shock-
finder. We have since adapted the code to run ACE RTSW data provided by NOAA. This 
data lacks the full 3-dimensional velocity vector for the solar wind and contains only a single 
component wind speed. We show that by assuming the wind velocity to be radial strong 
shock solutions remain essentially unchanged and the analysis performs as well as it would if 
3-D velocity components were available. This is due, at least in part, to the fact that strong 
shocks tend to have nearly radial shock normals and it is the strong shocks that are most 
effective in space weather applications. Strong shocks are the only shocks that concern us in 
this application. The code is now running on the Web and the results are available to all.

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Hybrid Plasma Simulation of the Heliospheric Termination Shock

Wu P., Schwadron N. (Boston University), Gary P., Winske D. (Los Alamos National Lab)

We report the work of our hybrid plasma simulation of the termination shock. The purpose of this study is to shed light on the shock-heated thermal and suprathermal populations in the heliosheath. Our study will make physical interpretations to explain the Voyager 1 (V1) and the recent V2 observations. The result of our work will be incorporated to predict energetic neutral atom (ENA) observations to be made by the Interstellar Boundary Explorer (IBEX) Mission after its launch in 2008.

Suprathermal Tail Observations from the STICS Instrument on the WIND Spacecraft

Gruesbeck J.R., Lepri S., Zurbuchen T. (University of Michigan)

Observations from ACE, Ulysses, and Voyager of solar wind ions have shown a ubiquitous suprathermal component in their ion velocity distribution functions. These suprathermal tails have been shown to follow a power law with a spectral index of \( \sim -5 \) when accumulated over periods of \( \sim 100 \) days (Gloeckler et al. [2000]; Gloeckler [2003], Simunac and Armstrong [2004]; Fisk and Gloeckler [2006]; Gloeckler and Fisk [2006]). Recent analysis from the SupraThermal Ion Composition Spectrometer (STICS) on the WIND spacecraft enable examination of much higher time resolution observations of such tails in the solar wind. Further investigation of the suprathermal tails and their power law dependencies using velocity distribution functions accumulated on varying time scales, \( \sim 100 \) days and 2 hours has been conducted. We present a preliminary analysis of the observed spectral index during quiet-time solar wind and its evolution with varying solar wind conditions.

Elemental Composition and Spectral Properties of the Quiet-Time Suprathermal Heavy Ion Population during Solar Cycle 23

Al Dayeh M., Desai M.I. (Southwest Research Institute), Dwyer J.R., Rassoul H.K. (Florida Institute of Technology), Mason G.M. (The Johns Hopkins University), Mazur J.E. (The Aerospace Corporation)

We have surveyed the spectral and compositional properties of suprathermal heavy ions during quiet times from January 1995 to December 2007 using Wind/STEP and ACE/ULEIS at energies between 0.04 and 2.56 MeV nucleon-1. Our results show that: (1) the heavy ions from C to Fe exhibit suprathermal tails during the quiet times for all years with spectral indices between -2.24 and -1.26. (2) The suprathermal spectra roll over at increasing e-folding energies that are different for different species with no obvious solar cycle correlation. (3) Quiet-times Fe/O and C/O abundances are correlated with solar cycle activity, reflecting corresponding values measured in solar energetic particle (SEP) events and IP shocks during solar maximum, and solar wind and corotating interaction regions (CIRs) abundances during solar minimum conditions. (4) During the Quiet times of 1998-2003, the average abundance of 3He is \( \sim 28.7\% \) and drops to \( \sim 7.8\% \) in the time period 2004-
We conclude that during the quietest times in the interplanetary space, the suprathermal population (3He and C-through-Fe) is largely affected by pre-accelerated SEP-like material during active solar periods and by CIR or solar-wind like material during periods of low solar activity. We discuss the spectral and compositional properties of the observed quiet-times suprathermal ions and their implications on the origin of the suprathermal population in the interplanetary space.

**Oblique CME-driven Shocks: SEPs, and Upstream and Downstream Waves**

**Krauss-Varban D., Li Y., Luhmann J.G. (SSL, UC Berkeley)**

In the context of developing quantitative models of SEP fluxes and spectra, it is of great interest to understand their intrinsic variability, and to address the question whether the efficiency of different contributing acceleration mechanisms can be predicted. Using ACE data, we have selected a number of undisturbed "energetic storm particle" (ESP) events, i.e., SEP events in which the CME-driven shock passes the spacecraft, to compare observed local proton flux profiles with those obtained from large-scale hybrid simulations (kinetic ions, electron fluid). Interestingly, in the sub-MeV range, we find very little variation of peak proton fluxes with shock normal angle. Conversely, theoretical expectations, typical particle simulations, and bow shock observations all point towards the difficulty of producing energetic ions at oblique shocks. In this work, we pay special attention to the upstream and downstream waves, including the possibility of an upstream "seed turbulence." Previously, we found that for shock-normal angles up to about 50 degrees, the initially dilute upstream ion beam, in a sufficiently large domain, is still capable of generating compressional upstream turbulence. This leads to much enhanced production of energetic ions in sections of the shock that gain quasi-parallel characteristics. However, at yet larger shock-normal angles both simulations and linear theory predict that the initial ion beams are insufficient, while perhaps an upstream "seed turbulence" may be responsible for starting the process. We also find that the level of downstream turbulence is highly variable at oblique shocks, and depends sensitively on a number of parameters and processes, such as the fraction of energetic ions that are mirrored back towards the shock.

**Evidence for a Multi-stage Acceleration Process for Interplanetary Suprathermal He+ and He++**

**Hill M.E. (Johns Hopkins University Applied Physics Laboratory), Schwadron N.A. (Boston University), Hamilton D.C. (University of Maryland)**

We made intensity measurements of 2 – 60 keV/nucleon He+ and He++ with the MIMI / CHEMS (Magnetospheric Imaging Investigation / Charge Energy Mass Spectrometer) instrument during the 1999-2004, 1.5 – 9 AU portion of the Cassini probe’s flight to Saturn. At 40 keV/nuc, well in the suprathermal tail spectrum, the composition ratio He+/He++ of the intensities of the interstellar pickup ion vs. solar wind alpha particles is approximately proportional to r^2, the square of the distance from the Sun. This is not the direct r proportionality that would be naively expected based on the number density ratio, but
agrees very well (< 5%), in radial profile and absolute magnitude, with a straightforward analytical treatment and the detailed EPREM (Energetic Particle Radiation Environment Module) code we’ve developed. The EPREM simulation includes most transport and acceleration effects and in particular includes a stochastic acceleration term, which we find cannot be constant with radius, but must decrease as r^-1 or r^-2. However, despite the excellent agreement for the composition, the radial profiles of the absolute fluxes disagree profoundly; the measured fluxes vary from r^0.5 to r^1.51 for He+, and proportionally to r^-0.4 for He++, compared to r^-1.16 and r^-3.31 dependence, for predicted by the simulation. This suggests that the gradual stochastic acceleration is responsible for the compositional variations but that there is a second velocity-dependent acceleration process that boosts the intensities of both species. Thus, we present new observations from Cassini, which appear to require multiple stages of particle acceleration for He ions in the inner heliosphere.

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**Particle Acceleration in the Heliosphere from the Inside Out**

**Schwadron N.A.** (Boston University), Hill M. (Advanced Physics Laboratory)

The nature and location of particle acceleration in the heliosphere is a longstanding problem. Shocks such as co-rotating interaction regions (CIRs) have traditionally been assumed to be the dominant sites for inner heliospheric particle acceleration near solar minimum. However, building evidence from many different sources suggests a very different picture. CIR shocks become strong around 4 AU; yet particle acceleration appears to start well inside 1 AU, and the rates of particle acceleration steadily fall through the inner heliosphere. Recent observations from Cassini provide new supporting evidence that particle acceleration occurs from the inside out. We discuss here observations and theoretical work highlighting the properties of a needed acceleration mechanism in the inner heliosphere that starts inside 1 AU and falls through the inner heliosphere.

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**Observations of Suprathermal Tails in the Heliosphere and Heliosheath**

**Gloeckler G.** (University of Michigan), Mason G.M., Hill M.E. (Johns Hopkins University Applied Physics Laboratory)

Suprathermal power law tails, with the unique spectral index of –5, on the velocity distributions (or equivalently of –1.5 on differential intensity) of solar wind and pickup ions are commonly observed in the heliosphere as well as the heliosheath. Here we present observations of velocity distributions and differential energy spectra of protons and heavier ions in the heliosheath, and in the heliosphere both during quiet times and in Corotating Ion Events. In particular we examine the energy range where the suprathermal tails roll over and find good agreement with the measured tails using isotropic solar wind frame differential spectra of the form \(dj/dE=jo(E^{1.5})exp[-(m/q)n(E/Ec)^{(1+n)/2}]\), with only two free parameters (\(n\) and \(Ec\)) that depend on ambient solarwind conditions.
The existence of suprathermal charged particles (energies between thermal particles and cosmic-rays) is well-established. Fisk et al. (2000) suggested that the suprathermal particles observed in the solar wind have a velocity spectrum \( f(v) = \text{const.} v^{-5} \) which is "ubiquitous". Although some more-recent observations suggest that the spectrum may not be completely ubiquitous, this is clearly a very significant discovery and deserves close attention. I will review the implications of this observation for the physics of charged particles in the heliospheric plasma. These suprathermal particles must be accelerated locally in the plasma since the cooling due to the expansion of the solar-wind plasma is faster than any reasonable transport from the Sun. Hence local electric fields must do the accelerating. The solar-wind plasma, to a very good approximation, behaves as an ideal hydromagnetic fluid on the relevant scales. Hence, the only electric fields capable of accelerating suprathermal charged particles arise from local flow velocity variations due to turbulent fluctuations, compressions, shock waves or reconnection events. These mechanisms are widely thought to accelerate particles to suprathermal energies in a variety of astrophysical sites. The constraints imposed by the observed \( \alpha v^{-5} \) spectrum will be discussed. Shocks robustly produce power laws, but the -5 index is only one of a continuous range of possible and plausible spectra. Nothing in shock physics has been found which preferentially selects the observed value. Turbulent, or stochastic acceleration does not robustly produce a power law, much less one with a -5 index. Hence the parameters of the charged-particle interaction with the compressions or turbulence must be very carefully tuned. The physics behind this fine-tuning remains controversial. Arguments based on general constraints such as thermodynamics have not yet been widely accepted. As of now, there is no consensus mechanism which accounts for the ~ \( v^{-5} \) observations.
Ion acceleration during magnetic reconnection


We explore the mechanism for ion acceleration during magnetic reconnection to understand the energetic particle spectra produced during flares and in the solar wind. Reconnection driven ion acceleration is initiated as particles move from upstream into the Alfvénic exhaust. In the case of a weak guide field, protons and higher mass particles behave like pickup particles in that they abruptly cross a narrow boundary layer and find themselves in a region of Alfvénic outflow. Their motion then mimics that of a classic pickup ion, gaining an Alfvénic ExB flow in the jet and a thermal speed close to the Alfvén speed. In the case of a strong guide field particle acceleration is strongly enhanced for ions with high mass-to-charge (m/q) ratio since these particles act as pick-up particles while small m/q particles are adiabatic. Once ions become super-Alfvénic their acceleration is, like electrons, dominated by Fermi reflection during island contraction and their energy increases until it is limited by firehose marginal stability. The ion distribution function for super-Alfvénic ions then takes the form of a $v^{-5}$ distribution. During reconnection in a multi-island environment, as in flares, strong enhancements in high m/q ions are expected. The impact of these ideas on ion acceleration in Alfvénic solar turbulence is being explored. This picture is consistent with several observations related to flare and local solar wind ion acceleration: (1) the ubiquitous observations of energy proportional to mass; (2) strong enhancements in high m/q ions during impulsive flares; (3) the temperature increments of solar wind exhausts; and (4) the ubiquitous $v^{-5}$ distributions in the solar wind.

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Solar-wind Turbulence and Discontinuities

Vasquez B.J., Charles W. Smith, Sergei A. Markovskii (University of New Hampshire)

Magnetohydrodynamic (MHD) simulations of Alfvénic turbulence show that a cross-field energy cascade predominates and generates small scale current sheets perpendicular to the ambient magnetic field. In these current sheets, the turbulent fluid energy significantly dissipates. The interplanetary magnetic field shows evidence of both turbulent energy cascades and abrupt layers at ion kinetic scales. We present observational evidence for a predominately cross-field energy cascade and the dissipation of a quasi-2D component. The high-frequency spectral break point between the inertial and dissipation ranges correlates best with a parameter that indicates that the dissipation mechanism is nonlinear. This nonlinear mechanism is shown to be potentially associated with processes involving current layers. Discontinuities in the solar wind are then examined, and their origins are shown to be from the turbulent energy cascade. The discontinuities could then be sites where turbulent energy is dissipated. This work is performed in association with the Living With A Star focus team on Heliospheric Magnetic Fields. Magnetic field and plasma observations come from the Advanced Composition Explorer (ACE) spacecraft.

Short wavelength fluctuations in the solar wind ☼

Bale S.D. (UC-Berkeley)

I review recent measurements of magnetic and electric field and density fluctuations in the solar wind at frequencies of order 1 Hz and above, where a break in the spectral index is often observed. The spectrum above the breakpoint has been associated with a secondary cascade and the eventual dissipation of field and kinetic energy to particle heating. Hence, this frequency range is often called the 'dissipation' range and corresponds to the convected ion gyroscale and/or the ion gyrofrequency. I will give some attention to two points that complicate this scenario: anisotropy instabilities and instrument noise. Fluctuations generated locally by proton and electron temperature anisotropies may have growth rates that peak in this same frequency regime. I will show that the magnetic fluctuations around 1 Hz are well-ordered by the anisotropy instability thresholds. Furthermore, instrument noise levels are rarely accounted in analyses at these frequencies and can be shown to be very important. I will show some examples of magnetic spectra and the associated noise levels.
Role of Kinetic Alfven Waves in Solar Wind Turbulence Spectrum

Sharma R.P., Singh H.D. (Indian Institute of Technology Delhi)

This work present the role of Kinetic Alfven waves and associated nonlinear effects in generating the solar wind turbulence spectrum. Nonlinear dynamical equations are derived in 2D by taking into account of the ponderomotive and joule heating nonlinearities in solar plasmas in low beta conditions. Semi-analytical and numerical solutions are obtained with different initial conditions. Steady state and transient evolutions are studied by using pseudo spectral method. Power spectra and spectral index have been evaluated. Role of Magnetosonic and ion acoustic waves have been studied in detail on spectral index and turbulent spectra.

Perpendicular Transport of Energetic Charged Particles in Nonaxisymmetric Two-Component Magnetic Turbulence

Ruffolo D. (Mahidol Univ., Bangkok), Chuychai P. (Univ. Delaware), Wongpan P. (Mahidol Univ., Bangkok), Minnie J. (Univ. Delaware), Bieber J.W. (Univ. Delaware), Matthaeus W.H. (Univ. Delaware)

We examine energetic charged particle diffusion perpendicular to a mean magnetic field $B_0$ due to turbulent fluctuations in a plasma, relaxing the common assumption of axisymmetry around $B_0$, and varying the ratio of two fluctuation components, a slab component with parallel wavenumbers and a two-dimensional (2D) component with perpendicular wavenumbers. We perform computer simulations mostly for 80% 2D and 20% slab energy and a fluctuation amplitude on the order of $B_0$. The nonlinear guiding center (NLGC) theory provides a reasonable description of asymptotic perpendicular diffusion as a function of the nonaxisymmetry and particle energy. These values are roughly proportional to the particle speed times the field line diffusion coefficient, with a prefactor that is much lower than in the classical field line random walk (FLRW) model of particle diffusion. NLGC predicts a prefactor in closer agreement with simulations. Next we consider extreme fluctuation anisotropy and the approach to reduced dimensionality. For 99% slab fluctuation energy, field line trajectories are diffusive but the particle motion is subdiffusive. For 99% 2D fluctuation energy, both field lines and particle motions are initially subdiffusive and then diffusive, but NLGC gives unreliable results. Time dependence of the running particle diffusion coefficient shows that in all cases asymptotic diffusion is preceded by free streaming and subdiffusion, but the latter differs from standard compound subdiffusion. We can model the time profiles in terms of a decaying negative correlation of the perpendicular velocity due to the possibility of backtracking along magnetic field lines. This work was partially supported by the Thailand Research Fund, NSF Grants ATM-0752135 (SHINE) and ATM-0539995, and NASA Grants NNX08AI47G (Heliophysics Theory) and NNX07AH73G (Heliospheric Guest Investigator).
Mirror-Mode Genesis: Lessons from STEREO

Russel C.T., Jian L.K. (UCLA), Blanco-Cano X. (UNAM), Luhmann J.G. (UCB)

STEREO occasionally detects mirror-mode storms in which small amplitude mirror-mode waves suddenly appear and persist for hours. Two triggers are observed: a sudden increase in plasma beta and weak laminar shocks. Both are consistent with conditions that promote mirror-mode wave growth. These small-amplitude, persistent mirror-mode waves are quite distinct from the isolated deep mirror-mode structures that are seen more frequently in the solar wind. These observations raise the question as to whether these mirror-mode storm waves coalesce and form the more isolated structures.

Observational Constraints for Solar Wind Turbulence

Smith C.W. (UNH)

We will focus almost exclusively on observations of turbulence in the solar wind. We will seek to characterize the turbulent spectrum, its anisotropies and correlations, from the largest to the smallest scales. In the process we will address issues ranging from the turbulent cascade, time scales for evolution, and the processes that dissipate energy to produce heat.

Power Spectrum Anisotropy for Interplanetary Fluctuations Inside 1 AU


The mean interplanetary magnetic field (IMF) is thought to provide a direction that breaks the isotropic symmetry of turbulence by providing a preferred direction. With this hypothesis, several hybrid models for interplanetary turbulence have been proposed where field-aligned wave vectors are coupled to perpendicular wave vectors and the resultant system evolves as a coupled two-component turbulent geometry. However, asymmetry can take on many forms and there are numerous predictions for the observable spectral index of MHD turbulence that derive, in many cases, from different views of the coupling of MHD waves to the turbulence. We call particular attention to the Goldreich and Shridhar model that predicts a -2 power law spectrum for observed wave vectors parallel to the mean magnetic field as well as the Boldyrev prediction of -3/2 spectral indexes. We examine ACE observations of magnetic field and velocity measurements at 1 AU along and Helios observations of the magnetic field inside 1 AU. We use inertial range measurements in several frequency ranges. We examine how the spectral form of computed power spectra depends on the angle between the mean field and the flow.

* Student paper ☀ Invited Paper

- Page 79 -
**STEREO Observations of Strong Ion Cyclotron Waves in the Solar Wind near 1 AU** *


We find strong ion cyclotron waves in the solar wind near 1 AU when the interplanetary magnetic field is more radial than usual. Most of these waves are left-hand elliptically polarized and propagate within five degrees of the magnetic field. We use STEREO plasma data to help determine the characteristics of the waves in the solar wind frame. These waves appear to be generally carried outward and propagating in the direction of the solar wind flow. They are highly Doppler shifted by the fast solar wind flow. In the solar wind frame, they are below the proton gyro-frequency. Similar waves have been observed at other heliocentric distances as well. Understanding the source of these waves may provide insight into the heating and acceleration of the solar wind.

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**On the propagation of energetic particles in interplanetary magnetic turbulence** *

**Guo F., Giacalone J. (University of Arizona)**

With a model for the interplanetary magnetic field including fluctuations produced by random motions of magnetic foot points close to the Sun, we perform test-particle simulations to study the propagation of solar energetic particles (10keV-20MeV protons) in the inner heliosphere. Our model magnetic field power spectrum is Kolmogorov-like with wavelengths from just larger than the coherence scale, leading to field-line random walk, down through very small scales that lead to resonant pitch-angle scattering of the particles. We find that several observational features can be reproduced by our model (e.g. flux).

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**Kinetic Simulations of the Dissipation Range of Solar Wind Turbulence** ☡

**Howes G.G. (UCB), Dorland W. (U Maryland), Cowley S.C. (UCLA), Hammett G.W. (PPPL), Quataert E. (UC Berkeley), Schekochihin A.A. (Imperial), Tatsuno T. (U Maryland)**

The identification of the key physical mechanisms by which the turbulence in the solar wind is dissipated remains a fundamental unsolved problem in heliospheric physics. A variety of mechanisms have been proposed to explain the break in the measured magnetic energy spectrum, including the collisionless damping and the dispersive nature of plasma waves at small scales. The weakly collisional conditions of the solar wind at these small scales mean that a kinetic approach is necessary to describe the dynamics and dissipation of the solar wind turbulence. I will present the first ab initio, fully electromagnetic, kinetic simulations of the magnetized turbulent cascade in the solar wind at the scale of the ion Larmor radius. The results support the hypothesis that the frequencies of turbulent fluctuations in the solar wind remain well below the ion cyclotron frequency both above and below the ion gyroscale.
Anomalous Scaling and Intermittency Effects in Solar Wind MHD Turbulence

Salem C. (Space Sciences Lab, University of California, Berkeley), Mangeney A. (Observatoire de Paris-Meudon, France), Bale S.D. (Space Sciences Lab, University of California, Berkeley)

Anomalous scaling of both magnetic field and velocity fluctuations in the inertial range of solar wind MHD turbulence, as well as intermittency effects have recently been investigated in detail using Wavelet transforms on simultaneous WIND 3s resolution magnetic field and particle data from the MFI and the 3DP experiments, respectively. More specifically, the Haar Wavelet transform was used to compute spectra, structure functions and probability distribution functions (PDFs). This powerful technique allows: (1) for a systematic study of intermittency effects on these spectra, structure functions and PDFs, thus for a clear determination of the actual scaling properties in the inertial range, and (2) for a direct and systematic identification of the most active, singular structures responsible for the intermittency in the solar wind. The analysis of structure functions and PDFs, as well as new results on the nature of the intermittent coherent structures will be presented. The turbulent properties and intermittency effects in different solar wind regimes will be also discussed.

Low frequency Waves Near Interplanetary Shocks observed by STEREO


STEREO spacecraft have measured a high number of interplanetary shocks since mission launch in late 2006. Most of these shocks are generated by fast solar wind streams with only a few associated with ICMEs. We study the characteristics of low frequency waves observed upstream and downstream of these shocks. The use of dual spacecraft observations allows us to understand scales and evolution of shock waves and their associated phenomena. Understanding the characteristics of these shocks and their surrounding regions is of great interest as they play a major role in the acceleration of solar energetic particles (SEPs). Waves can disturb the shock and participate in ion acceleration processes. STEREO dual observations show that the characteristics of IP shocks can change dramatically from one region to another and this also happens to the upstream and downstream wave spectra. While some shocks are preceded by whistler type waves with a significant compressive component, others are associated with upstream small amplitude transverse fluctuations. Downstream we find regions where magnetic field data suggest the existence of mirror modes.
Some MHD and kinetic features of MHD cascade and dissipation in the solar wind


MHD turbulence proceeds through relaxation processes, unless strongly stirred. These are related to conserved quantities such as magnetic helicity, cross helicity and energy. Slow versions are associated with selective decay and global dynamic alignment. The fast versions act locally and try to produce force-free magnetic fields, Beltrami flows, and local directional flow-magnetic field alignment, all in patches. Partially thwarted at short times by global topological constraints, fast relaxation leads to spatial intermittency and the formation for example of current sheets and other coherent structures at small scales. With a mean field, these principles apply at least approximately to the highly anisotropic low frequency part of the turbulence. In the solar wind and other astrophysical plasmas, the implication of multiple ideals conservation laws suggests that spectral laws may be of several, and not just one, type. In addition turbulence may include both low frequency RMHD, and higher frequency more wave-like components. The latter can be easily excited by wave particle interactions. Other plasma effects engage near the ion inertial and gyroscales. In particular, observed small scale solar wind electric field exhibits a strong influence of the Hall term in Ohm’s law, and does not distinguish well among Hall MHD and kinetic models. However there is evidence that both proton and electron kinetic processes are involved in dissipation, i.e. saturation of the growth of magnetic gradients.

Scaling of Energy Spectra and Implications for Ion Heating in the Turbulent Solar Wind

Bhattacharjee A., Chandran B., Isenberg P., Munsri D., Ng C.S., Podesta J. (University of New Hampshire)

The scaling of anisotropic energy spectra in a turbulent magnetized plasma, obeying incompressible MHD equations, has been a subject of considerable research in recent years. While definitive results have been obtained in the regime of weak MHD turbulence, the regime of strong MHD turbulence continues to be a controversial subject. Phenomenologies as well as numerical simulations that support Kolmogorov or Iroshnikov-Kraichnan scaling have been given. In this talk, we will present recent observational evidence from the solar wind that test these phenomenologies. We will then examine the consequences of energy cascade rates predicted by these phenomenologies on ion heating in the solar wind. These findings lead to several important open questions for theory as well as observations.

* Student paper  ☉ Invited Paper
On weak and strong magnetohydrodynamic turbulence

Boldyrev S., Perez J.C. (University of Wisconsin-Madison)

Recent numerical and observational studies contain conflicting reports on the spectrum of magnetohydrodynamic turbulence. In an attempt to clarify the issue we investigate anisotropic incompressible magnetohydrodynamic turbulence with a strong guide field. We perform numerical simulations of the reduced MHD equations in a special setting that allows us to elucidate the transition between weak and strong turbulent regimes. The results of the simulations as well as analytical discussion will be presented.

Hot solar wind helium: direct evidence for local heating by Alfven-cyclotron dissipation

Kasper J.C. (SAO), Lazarus A.J. (MIT), Gary S.P. (LANL)

A study of solar wind hydrogen and helium temperature observations collected by the Wind spacecraft offers compelling evidence of heating by an Alfven-cyclotron dissipation mechanism. Observations are sorted by the rate of Coulomb interactions, or collisional age, in the plasma and the differential flow between the two species. We show that helium is preferentially heated when the flow between the species is small. This heating, which can exceed a factor of six when collisions are infrequent, occurs perpendicular to the magnetic field and is ordered by the Alfven wave speed. These signatures are consistent with predictions of dissipation in the presence of multiple ion species. We also report an unexpected result: observations of efficient heating of helium parallel to the magnetic field for large differential flow relative to the sound speed.
Understanding Prominence Mass (Gilbert / Alexander)

Non-LTE radiative transfer

Labrosse N. (University of Glasgow)

I present the basics of non-LTE radiative transfer and non-LTE prominence diagnostics, focusing on relevant quantities critical for the determination of the prominence mass. I will start with quiescent prominences and then show what are the effects of radial motions of the prominence plasma on the emergent spectrum from elements such as H and He. Some 'real life' examples will be given, using simple 1D prominence models to obtain the hydrogen column densities.

The Lyman-alpha line in active and eruptive solar prominences

Labrosse N. (University of Glasgow)

We investigate the effects of radial motions on the Ly-alpha emission in moving prominences under various temperature and pressure conditions. The ability to compute the Ly-alpha line intensity in active and erupting prominences with our non-LTE radiative transfer code is especially relevant to VAULT and to the LYOT instrument on SMESE. High-cadence imaging allow us to observe the dimming of the line as the prominence expands in the radial direction. In conjunction with our non-LTE radiative transfer code, the diagnostic of the thermodynamical plasma parameters and the velocity field can be done. This provides new constraints for models of filament and prominence eruptions.

Using Prominence Mass Inferences in Different Coronal Lines to Obtain the He/H Abundance

Gilbert H. (Rice University/GSFC), Kilper G. (Rice University), Kucera T. (GSFC), Alexander D. (Rice University)

The present work is an extension of a previous study where we developed a technique for deriving prominence mass by observing how much coronal radiation in the Fe XII (195Å) spectral line is absorbed by prominence material. We apply this method, which allows us to consider the effects of both foreground and background radiation in our calculations, to a sample of prominences absorbing in a coronal line that ionizes both H and He (lambda < 504 Å), and a line that ionizes only H (504 Å < lambda < 911 Å). This approach, first suggested by Kucera et al. (1998), permits the determination of the abundance ratio of neutral helium and hydrogen in the prominence. This ratio should depend on how the prominence is formed, on its current thermodynamic state, and on its dynamical evolution. Thus, it may provide useful insights into the formation and evolution of prominences.
Properties of Prominence Mass Important in Modeling

Panasenco O., Martin S. (Helio Research), Lin Y., Engvold O. (Institute for Theoretical Astrophysics, University of Oslo)

In the more than 55 years since D. Menzel presented the first model that suggesting how the prominence mass could be supported, research in the physics of solar prominences produced a large number of different models. Most of these models follow the original idea and described prominence/filament mass as material in static equilibrium, suspended in dipped magnetic field lines with or without the presence of current sheets. We briefly review the history of development of the majority of prominence models with respect to their concepts of how the prominence mass is supported in the corona. We contrast the assumptions of the models with observational information acquired in the same time frame as the models. With a wealth of new data from high resolution ground-based telescopes and key satellite experiments, there is an abundance of new observational information on prominences and their mass distribution in the prominence spine and barbs that is not yet included in theoretical models. The most important new information that needs incorporation in models is: (1) the mass of all prominences is contained in thin threads and is continuously flowing along the threads (2) fine-scale counterstreaming among the threads is typically present in their quiescent state; (3) the threads exhibit several modes of oscillation; (4) the threads are anchored in the photosphere revealing that prominences have their own magnetic fields separately from surrounding coronal fields. This combination of new observations provides strong evidence that the filament threads are aligned with the local magnetic field. Their field-aligned nature means that prominence threads directly reveal their magnetic structure. As a guide to future MHD models, we have used this observational information to create an empirical thread model of the 3-dimensional configuration of a typical prominence magnetic field.

Precursors to Quiet Sun Filament Eruptions *

Kilper G., Gilbert H., Alexander D. (Rice University)

Coronal mass ejections greatly affect space weather at Earth, and filament eruptions are strongly correlated with CMEs. We analyzed nineteen filament eruptions with a mix of sizes and eruptions types using the H-alpha and He I 10830 intensity data from Mauna Loa Solar Observatory by comparing the amount and location of absorption in these two lines over the days before and after the eruptions. In every event, we found that the ratio between the absorption in H-alpha and He I becomes homogenized throughout the filament at least one full day before the eruption, and the total absorption in both lines increases sharply. The homogenization of the composition and a high level of activity remain until the eruption. We also found several smaller trends involving size and homogenization time, reformation after the eruption, and a relation to heating and cavity size.

* Student paper ☡ Invited Paper
On Asymmetric Eruptive Filaments *

Liu R., Alexander D., Gilbert H. (Rice University)

Filaments are often observed to erupt asymmetrically, during which one leg is fixed to the photosphere (referred to as the anchored leg) while the other undertakes most of the dynamic motions (referred to as the active leg) during the eruptive process. In this paper, we present observations of a group of asymmetric eruptive filaments, in which two types of eruptions are identified: whipping, where the active leg whips upward, and hard X-ray sources shift along the neutral line toward the end of the anchored leg; and zipping, where the visible end of the active leg moves along the neutral line like unfastening a zipper as the filament arch rises and expands, and hard X-ray sources shift along the neutral line away from where the eruption initiates. Both types of asymmetric eruptions can be understood in terms of how the highly sheared filament channel field, traced by filament material, responds to an external asymmetric magnetic confinement where force imbalance occurs in the neighborhood of the visible end of the active leg. The dynamic motions of the active leg have distinct impacts on how hard X-ray sources shift along the neutral line, as observed by RHESSI.

Prominence mass loading ☼

Heinzel P. (Astronomical Institute, Academy of Sciences)

I will discuss recent models of the prominence fine structure and its mass loading. I will review new diagnostics techniques for density and mass loading determinations.
Vector Magnetic Inputs to Global Models (Roussev / DeRosa)

**MDI/SOHO Level 1.8 Magnetograms**

Liu Y., Hoeksema J.T., Scherrer P.H. (Stanford University)

In this paper, we present a detailed description of data processing for the magnetograms taken by the Michelson Doppler Image (MDI) on board the Solar and Heliospheric Observatory (SOHO). The newly updated level 1.8 full disk magnetograms, available to the community via the Solar Oscillations Investigation (SOI) website at $http://soi.stanford.edu/$, have been corrected for some issues recently, including offset and rescaling. We also propose an empirical method to correct for the “MDI” saturation. We further report here some quirks in the level 1.8 full disk magnetograms that we have been aware of but do not have methods for correction. Among them are magnetic field reversal during some major flares, non-uniform noise over solar disk, and cosmic rays. Finally, we present an analysis on the relationship of magnetic fields on the Sun and in the interplanetary space using the updated level 1.8 magnetograms. We found that the average magnetic field over the Sun’s disk is well correlated with the interplanetary magnetic field (IMF). This is supportive of previous studies. No significant correlation is found between the sunspot areas and the average field, indicating that contribution of sunspots to the IMF is limited.

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**Vector Magnetic Fields from the Helioseismic and Magnetic Imager (HMI) Instrument**

Tomczyk S. (NCAR/HAO)

The HMI instrument will soon be returning full disk vector magnetic field maps with a spatial resolution of 1 arcsecond at a nominal temporal cadence of 10 minutes. We will present a summary of HMI vector field data, including a discussion of the nature of the data, expected noise levels, and inference of physical quantities through inversion and disambiguation.

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**Introduction to Using Full-Disk Vector Field Data for the SHINE Community**

Leka K.D. (NWRA)

Vector magnetic field observations have played a large role in the physical understanding of the interaction of solar magnetic fields with the solar plasma. Only with vector field data can one interpret the physically meaningful heliographic magnetic vector, accounting for observational projection effects. The vector data experience within solar physics, however, has been limited to instruments with restricted fields of view, a limitation which is soon to be overcome. In this talk, I will describe the data from present and upcoming instruments such as SOLIS and HMI, and the physical quantities that can be derived from them. Focus will be given to those data sets directly relevant to the SHINE community for studies of the Sun and heliosphere.

* * Student paper  Invited Paper

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Observational Test of Potential Coronal Magnetic Field Model ☼

Lin H. (Institute for Astronomy, University of Hawaii)

Recent advances have made it possible to obtain 2-dimensional line-of-sight magnetic field maps of the solar corona from spectropolarimetric observations of the Fe-13 1075 nm forbidden coronal emission line. Together with the linear polarization measurements that map the azimuthal direction of the coronal magnetic field projected in the plane of the sky containing sun center, these coronal vector magnetograms allow for direct and quantitative observational testing of theoretical coronal magnetic field models. This paper presents a study testing the validity of potential-field coronal magnetic field models. We constructed a theoretical coronal magnetic field model of active region AR 10582 observed by the SOLARC coronagraph in 2004 by a global potential field extrapolation of the synoptic map of Carrington Rotation 2014. Synthesized linear and circular polarization maps from thin layers of the coronal magnetic field model above the active region along the line of sight are compared with the observed maps. We found that the observed linear and circular polarization signals are consistent with the synthesized ones from layers located just above the sunspot of AR 10582 near the plane of the sky containing the Sun center.
What is the Acceleration Mechanism for Anomalous Cosmic Rays and Where is it Happening? (Cummings / Jokipii)

STEREO ENA Observations show Evidence for the Acceleration of Pickup Ions at Termination Shock

Wang L., Bob Lin, Davin Larson, Janet Luhmann (UC Berkeley)

Energetic neutral atoms are remote tracers of energetic ion populations in the outer boundaries of heliosphere. Here we present the first detection and map, by the two STEREO spacecraft at ~0.96 & ~1.1 AU, of energetic, ~4-20 keV neutral atoms produced by charge exchange of suprathermal ions with interstellar neutrals in the heliosheath. These energetic neutral atoms come from a source ~60 degree wide in longitude, with an asymmetric double peak straddling the nose of heliosphere. Their energy spectra suggest that their parent ions are solar wind pickup ions energized by the termination shock (TS). These TS-energized pickup ions contain most of the flow energy dissipated in the TS. They dominate the pressure in the heliosheath and would strongly mediate the TS. Thus, STEREO ENA observations provide information about the first-step acceleration of pickup ions at the TS.

Oh ACRs, Where Art Thou?

Cummings A.C., Stone E.C. (Caltech, Pasadena, CA)

When Voyager 1 and Voyager 2 crossed the solar wind termination shock, the expected spectral shape of anomalous cosmic rays (ACRs) was not observed. It was expected that the source of ACRs was diffusive shock acceleration of inflowing pickup ions at the termination shock. Rather than the expected power law at low energies with a roll off at higher energies, the same modulated spectral shape that had been observed for some time was seen. Thus we did not find the ACR source at the shock locations encountered by Voyager 1 and 2. We will present the observations of the ACR spectra before and after the TS crossings and discuss several models that have been put forward to explain them.
The Acceleration of ACRs in the Heliosheath


Theories have been developed for the acceleration of suprathermal particles in the supersonic solar wind that yield distribution functions with the observed common spectral shape, a power-law in particle speed with spectral index of -5. The acceleration occurs in compressional turbulence, and it competes against the adiabatic deceleration in the expanding mean flow of the solar wind. This competition limits the energies to which particles can be accelerated to a few MeV/nucleon. The heliosheath contains ample compressional turbulence, and no or limited adiabatic deceleration. We should expect then that the same mechanism that is responsible for the acceleration of suprathermal tails in the supersonic solar wind will be responsible for the acceleration of these tails to much higher energies in the heliosheath, and can yield the ACRs. A model for the acceleration and modulation of ACRs in the heliosheath will be presented that can be compared with observations.

Stochastic acceleration in the heliosheath: effect on anomalous cosmic ray spectra

Caballero-Lopez R.A. (IGEF-UNAM, Mexico), Moraal H. (School of Physics, Northwest University, South Africa)

It is generally accepted that shock acceleration by the solar wind termination shock is the primary process that establishes the anomalous cosmic ray component. There may, however, be secondary processes that produce and/or accelerate these particles. Here we point out that stochastic acceleration in the outer heliosheath is such a process.

Acceleration at a dynamic termination shock near a solar minimum

Florinski V. (University of California, Riverside)

The heliospheric termination shock evolves in time in response to transient structures (i.e., MIRs) in the solar wind. We have previously shown that the structures affect the shock position, speed, compression ratio, as well as the transport properties of the plasma in the shock vicinity. This was demonstrated to affect the production of ACRs at lower energies, which rapidly respond to the changes, whereas the higher energy ACRs are less affected because of their high mobility. The interplanetary medium was more quiet at the time of Voyager 2 crossing, although several smaller MIRs were reportedly observed during that period. We examine the evolution of the shock and the resulting particle spectra produced by the interaction of weaker turbulent structures with the termination shock. We also show that the absence of MIRs in the solar wind does not imply a stationary termination shock because the latter is still affected by the structures that entered the heliosheath during the time of more intense solar activity and were reflected back by the heliopause.
Both Voyager spacecraft have now crossed the solar wind termination shock and are in the heliosheath. Below 5 to 10 MeV/nuc, the H and He energy spectra are dominated by termination shock particles (TSPs) accelerated at nearby regions of the shock and convected to the spacecraft. After Voyager 2 (V2) crossed the TS at 84 AU in August 2007, the TSP H spectrum was harder than the concurrent TSP spectrum at Voyager 1 (V1) at 104 AU, and at 5 MeV the intensity at V2 was ~3 times that observed at V1. The V2 TSP H spectrum has since evolved and is approaching that observed by V1. At ~10 to 75 MeV/nuc, the spectra are dominated by anomalous cosmic rays (ACRs) that appear to have a source elsewhere on the shock or in the heliosheath. The ACR He intensity at ~15 MeV/nuc has been increasing steadily since late 2005 and is approaching the expected source intensity at V1 at 106 AU. Over that same period, the ACR He intensity with E>60 MeV/nuc has been essentially constant with no gradient between V1 and V2, indicating a steady ACR source that uniformly fills the outer heliosphere beyond ~77 AU. These and other aspects of the Voyager observations will be reviewed. This work was supported by NASA under contract NAS7-03001.

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**Acceleration of ACRs at the Termination Shock**

**Kota J.** (University of Arizona)

We utilize a 2-D numerical code modeling the acceleration and transport of energetic particles around a termination shock that is offset with respect to the Sun. We conduct numerical simulations to explore which part of the termination shock are ACRs seen by the two Voyager spacecraft accelerated at and how they are transported to Voyagers. Numerical results shall be presented and implications shall be discussed.

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**Particle Acceleration at the Blunt Termination Shock**

**Schwadron N.A.** (Boston University), McComas D. (Southwest Research Institute)

Voyagers' recent and long-anticipated passage into the heliosheath contradicted the prediction that we would observe the source of anomalous cosmic rays accelerated by the termination shock. The observed energetic protons reveal a power-law spectrum below several MeV, but above several-10 MeV the spectrum falls more sharply, and we observe the familiar bump caused by modulation of anomalous cosmic rays. This talk develops the theoretical framework to include the motions and drift of particles during diffusive shock acceleration at a three-dimensional (3-D) termination shock, including cross-field diffusion, and curvature and gradient drifts. Our model supports the concept of McComas and Schwadron that because of the termination shock’s blunt structure with a strong nose-to-tail asymmetry, there should be a strong deficit of locally accelerated anomalous cosmic rays (ACRs) near the nose. With reasonable parameters for the scattering mean free path and the
ratio of perpendicular to parallel diffusion, the model produces an energy spectrum that agrees well with the Voyager observations near the termination shock. These parameters also lead to an acceleration time to 10 MeV of about 1 yr, which is comparable to previous estimates derived from the observed charge states of ACRs. Thus, we provide a theory for diffusive acceleration at the blunt termination shock. The predictions of this theory are consistent with Voyager’s observations, showing a lack of ACRs accelerated near the nose of the termination shock and the ACR acceleration timescale derived from ACR charge states.

A Possible Approach to the Acceleration of ACR at the Termination shock

Jokipii J.R., Giacalone J., Kota J. (University of Arizona)

We consider the acceleration of charged particles and anomalous cosmic rays (ACR) at propagating shocks and especially at the heliospheric termination shock, when upstream turbulence or geometry causes spatial and temporal variations of the shock. These may help us to understand the heretofore puzzling observations of energetic particles at both propagating shocks and the termination shock. Upstream turbulence has a broad spectrum and produces both temporal and spatial variations along the shock face and also normal to the shock. In addition, the nonspherical geometry of the heliosphere produces longer term spatial variations. We will present the results of a new analytic solution and simulations. We find that, downstream, increasing (positive) spatial gradients together with modulation-like spectral turnovers and multiple-power-law spectral features can be produced by plausible fluctuations at the shock. Such effects also result in our calculations from large-scale, or global, spatial structure. These various effects will be compared with observations energetic particles associated with propagating heliospheric shocks and Voyager observations of ACRs near the termination shock and in the heliosheath.
CME-driven shocks: particle acceleration and plasma radiation

Schmidt J.M., Gopalswamy N. (NASA-GSFC)

CME-driven shocks are effective radio radiation generators and accelerators for Solar Energetic Particles (SEPs). We present simulated 3 D time-dependent radio maps of second order plasma radiation generated by CME-driven shocks. We also investigated the simulated static Alfven speed distribution in a realistic streamer belt environment around the Sun before a CME eruption. This environment determines, if a shock can develop and how steep it can grow. Only a steep shock can provide for an effective particle acceleration. The observed CME eruption occurred in the middle of the base of an extended streamer. There, the Alfven speed increases from a very low value in the vicinity of the Sun with very dense solar wind, to a maximum at about three solar radii heliocentric distance. Such an increase is necessary for a CME-driven shock to develop. Next to the launching site of the CME, where the solar wind outflow speed is higher and the density becomes lower, this maximum is found at larger heliocentric distances. At the border of the streamers, where the density becomes very large due to compression, the Alfven speed drops to almost zero. Above three solar radii heliocentric distance, the Alfven speed slowly decreases over the CME launching site. This is a requirement for the shock to become steeper. During the simulated CME eruption, we followed the Alfven speed distribution in the vicinity of the shock. There, a ratio of shock speed to Alfven speed of about four is well maintained up to 24 solar radii heliocentric distance in our simulations. This means that a CME-driven shock, once developed, maintains its acceleration potential for energetic particles over a large heliocentric distance.

Alfven Profile in the Lower Corona: Implications for Shock Formation

Evans R.M., Opher M. (George Mason University), Manchester W., Gombosi T. (University of Michigan)

Observations of type II radio bursts and energetic electron events indicate that shocks can form at 1-3 solar radii and are responsible for the GeV/nucleon energies observed in ground level Solar Energetic Particle (SEP) events. Here we provide the first study of the lower corona produced from ten state-of-the-art models. In particular we look to the Alfven speed profiles as criteria for shock formation, independent of exciting agent (e.g. flares and CMEs). Global MHD models produce Alfven speed profiles which are in conflict with observations: a) multiple SEP events are observed with a single exciting agent, but most profiles are missing the “hump” required to form multiple shocks; b) few slow CMEs cause large SEP events, but most profiles drop very quickly, allowing all slow CMEs to drive strong shocks to form between 1-3Rs. Simplified Alfven wave-driven wind models have steeper profiles but are still in disagreement with multiple shock formation. Only studies that include Alfven waves with physically based damping are in agreement with observations. This implies the results of these 1D local studies must be included in global models before we can study shock formation in the lower corona.

* Student paper ☀ Invited Paper

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50 Years Later: Why is the Solar Wind Supersonic?

Velli M. (JPL, Caltech)

Although we have known the solar wind is supersonic for almost 50 years now, it is little known that the structure of the stationary solar wind solutions found by Parker are fundamentally connected to the Bondi solutions for spherically symmetric accretion, and that the transition between these flows occurs catastrophically, shocks playing a fundamental role. Though these results have been published for some time, they have never been presented at a conference, and I think they have interesting educational value: so this is really a tutorial talk, for younger students and post-docs getting into the field, describing the Parker theory and Parker diagram in a way which may surprise. It should not really be a poster, rather an informal talk to be fit somewhere into the schedule.

Downstream structure and evolution of a simulated CME-driven sheath in the lower solar corona

Liu Y. (UNH), Opher M. (George Mason University), Wang Y.

We investigate for the first time, the evolution of a CME sheath in the lower corona. In particular, we investigate the transition of the magnetic field from the interplanetary magnetic field to the ejecta in the sheath downstream of a CME-driven shock using a simulated CME in the lower solar corona. Most of the features of the sheath match the observed ICMEs at 1AU. We show that the field rotation in the sheath occurs in a two-layer structure. In the first layer, Layer 1, the magnetic field rotates in the coplanarity plane (plane of shock normal and the upstream magnetic field), and in Layer 2 rotates off this plane. We investigate the evolution of the two layers as the sheath evolve away from the Sun. Close to the Sun, Layer 2 dominates the width of the sheath diminishing its importance as the sheath evolve away from the Sun; consistent with observations at 1AU. More investigations, on the two-layer structure dependence on latitude, CME speed and the comparisons with the ICME observations at 1AU are required in future studies.
Shock Formation Observed by STEREO

Russel C.T., Jian L.K. (UCLA), Blanco-Cano X. (UNAM), Luhmann J.G. (UCB)

Coronal and interplanetary shocks arise in two different ways: in coronal mass ejections, which, if they are ejected at above the solar wind speed, eventually decelerate to the solar wind speed; and in stream interaction regions where the jump in velocity across the stream interface is constant, but the Mach number associated with the velocity jump increases because of the changing solar wind parameters with heliocentric distance. Comparison of Pioneer Venus, Venus Express, Wind and ACE shock statistics indicate that the region from Venus to Earth’s orbit is an incubator for shocks. Thus it is not surprising that STEREO has caught several shocks in formation, strengthening by the coalescence of two weak shocks to form a stronger shock. These shocks tell us much about the physical processes that underlie the dissipation in low Mach number shocks.

The Theory of Shock Formation in the Corona ☄

Lee M.A. (UNH)

The possible sites of shock formation in the corona are described briefly including the bow wave driven ahead of an accelerating CME, the pressure pulse launched by impulsive flare energy release, and the termination of a plasma jet driven by magnetic reconnection. Shock formation is first investigated quantitatively using Burger’s equation in one dimension to establish the dependence of the rate of formation on amplitude and viscosity. The influence of geometry (e.g. the geometry of a “driver” such as a CME, or the formation of a spherical shock front) and the coronal magnetic field (e.g. the magnitude and variation of the Alfvén speed and the plasma-beta) will then be discussed more qualitatively. One key issue that will be addressed is the Mach number of the formed shock relative to the “critical Mach number,” which together with magnetic obliquity controls the injection of the ambient plasma into the process of diffusive shock acceleration.

White Light CME Shocks: A Case Study from STEREO/SECCHI *

Ontiveros V.Z. (George Mason University), Vourlidas A. (Naval Research Laboratory)

We perform a multi spacecraft analysis of a fast CME on December 31st, 2007 using LASCO and SECCHI A and B coronagraph images. This is the fastest CME in 2007 with good coronagraph coverage from all three spacecraft. We use calibrated images to estimate the electron volume density, mass and kinetic energy for this event. We compare the results from each instrument. We used the Solar Corona Raytrace software to create a 3D bow-shock density model that fits a CME-driven shock signature observed in LASCO images and compare this geometry to the SECCHI observations. This work is funded by the LWS TR&T program.

* Student paper ☄ Invited Paper
MHD Simulations of the Structure, Evolution and Appearance of CME-driven Shocks ☉

Manchester W.B. (University of Michigan), Vourlidas A. (Naval Research Lab.), Toth G. (University of Michigan), Lugaz N. (University of Hawaii)

Fast Coronal Mass Ejections (CMEs) drive strong shocks from the corona through interplanetary space where these large-scale disturbances accelerate particles typically associated with gradual events. The acceleration of solar energetic particles (SEPs) is strongly dependent on shock speed and geometry, which may exhibit significant temporal and spatial variations as the shock propagates. Here, we examine the three-dimensional (3-D) magnetohydrodynamic simulations of CMEs, and find that the ambient solar wind structure strongly affects the evolution of CME-driven shocks. Variations in wind speed deform the shock front resulting in strong meridional flows and compressions in the CME sheath. We also find that CMEs can cause stream interactions that result in reverse shocks Sun-ward of the CME. Finally, we present recent simulations of CME events that show the manifestations of shocks can be clearly identified in coronagraph images. Understanding and predicting such CME driven shocks is a necessary step in building a quantitative model of SEP acceleration and transport that can be used to forecast and mitigate the radiation hazards.

Understanding the Evolution and Nature of Shocks in the Lower Corona

Opher M. (Georges Mason University)

Although our understanding of shocks has been advanced in recent years, we still lack a comprehensive study on how the evolution of shocks (and their characteristics) is affected by the environment in which they propagate. In particular, it is expected that the efficiency of the acceleration of particles will depend on the shock’s geometry and strength, which will be a function of the shock’s initial structure and the solar wind environment into which it propagates. I will summarize our current work where we are investigating the evolution of shocks in the lower corona and its effect on the interplanetary magnetic field (Liu et al. 2007, 2008); the effect of different magnetic drivers (Loesch et al. 2008); and the background Alfven speed in the lower corona (Evans et al. 2008).