Yosemite 2010

Magnetic Reconnection

An Interdisciplinary Workshop

February 8-12, 2010
Yosemite National Park, California

Yosemite 2010 Program Committee

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Meeting at a Glance

Monday, February 8	
5:00 pm - 8:00 pm	Workshop Registration and Icebreaker

Tuesday, February 9	
7:45 am - 12:15 pm	A. Reconnection at the Sun
	B. Reconnection in the Magnetosphere and the Solar Wind
5:30 pm - 7:30 pm	C. Reconnection in the Laboratory

Wednesday, February 10	
7:55 am - 12:10 pm	D. Reconnection in Extreme Environments
	E. Dissipation/Structure of the Diffusion Region 1
5:30 pm - 7:10 pm	F. Dissipation/Structure of the Diffusion Region 2
8:00 pm - 10:00 pm	G. Posters

Thursday, February 11	
7:55 am - 12:10 pm	H. Initiation/Cessation of Reconnection
	I. Particle Acceleration in Reconnection
5:30 pm - 7:30 pm	J. Reconnection in Different Plasma Regimes: Scaling

Friday, February 12	
7:55 am - 11:35 am	K. Coupling the Global to the Local 1
	L. Coupling the Global to the Local 2
5:30 pm - 6:40 pm	M. Wrapping It Up: The Big Picture
7:30 pm - 8:30 pm	Reception
8:30 pm - 10:30 pm	Banquet

All sessions except for the poster session (G) are held in the Cliff/Falls Room of the Yosemite Lodge. The poster session, the reception, and the banquet are held in the Ahwahnee Hotel.

Tuesday, February 9, 2010

Session A: Reconnection at the Sun	
7:45 am	**Welcoming Remarks**
8:00 am - 8:40 am	**R. Moore**: Observed Aspects of Reconnection in Solar Eruptions (Tutorial)
8:40 am - 9:00 am	**K. Schrijver**: Reconnection in the Small-Scale Solar Field
9:00 am - 9:20 am	**C. DeForest**: Interchange Reconnection in Polar Jets
9:20 am - 9:40 am	**H. Warren**: Evidence for Magnetic Reconnection in Solar Flares
9:40 am - 10:00 am	**A. Vourlidas**: Observations of Large-scale Reconnection in Streamers and CMEs
10:00 am - 10:15 am	**Break**
Session B: Reconnection in the Magnetosphere and the Solar Wind	
10:15 am - 10:55 am	**T. Phan**: In-Situ Observations of Magnetic Reconnection in the Solar Wind, Magnetosheath, and Magnetosphere (Tutorial)
10:55 am - 11:15 am	**J. Gosling**: Magnetic Reconnection in the Solar Wind Associated with Small Field Shear Angles
11:15 am - 11:35 am	**S. Fuselier**: Observational Evidence of Component and Anti-Parallel Reconnection at the Earth's Magnetopause
11:35 am - 11:55 am	**L.-J. Chen**: Formation and Structure of Magnetic Islands and Current Layers during Magnetotail Reconnection
11:55 am - 12:15 pm	**General Discussion**
12:15 pm - 5:30 pm	**Break**
Session C: Reconnection in the Laboratory	
5:30 pm - 6:10 pm	**M. Yamada**: Reconnection in the Laboratory (Tutorial)
6:10 pm - 6:30 pm	**R. Magee**: Characteristics of Non-Collisional Ion Heating in the MST RFP
6:30 pm - 6:50 pm	**M. Brown**: Reconnection-Driven Ion Heating and Plasma Relaxation in SSX
6:50 pm - 7:10 pm	**T. Intrator**: Experimental 3D Reconnection and Unexpected Dynamics of Flux Ropes
7:10 pm - 7:30 pm	**General Discussion**

Wednesday, February 10, 2010

Session D: Reconnection in Extreme Environments	
7:55 am	**Announcements**
8:00 am - 8:40 am	**D. Uzdensky**: Reconnection in Extreme Astrophysical Environments (Tutorial)
8:40 am - 9:00 am	**S. Zenitani**: Two-Fluid Simulations of Relativistic Magnetic Reconnection in Electron-Positron Plasmas
9:00 am - 9:20 am	**M. Swisdak**: The Role of Turbulent Outflow Jets in Electron-Positron Plasmas
9:20 am - 9:35 am	**General Discussion**
Session E: Dissipation/Structure of the Diffusion Region I	
9:35 am - 10:15 am	**M. Hesse**: The Inner Workings of Magnetic Reconnection: Diffusion Region in the Balance (Tutorial)
10:15 am - 10:30 am	**Break**
10:30 am - 10:50 am	**W. Matthaeus**: Reconnection and Turbulence
10:50 am - 11:10 am	**G. Kowal:** Fast Reconnection in Weakly Stochastic Magnetic Fields
11:10 am - 11:30 am	**R. Torbert**: Observing the Electron Diffusion Region with MMS
11:30 am - 11:50 am	**General Discussion**
11:50 am - 12:10 pm	**Break**
Session F: Dissipation/Structure of the Diffusion Region II	
5:30 pm - 6:10 pm	**M. Fujimoto**: Reconnection and Waves (Tutorial)
6:10 pm - 6:30 pm	**H. Ji**: Turbulence during Magnetic Reconnection in MRX
6:30 pm - 6:50 pm	**H. Che**: Structure & Dynamics of Electron Holes Produced during Magnetic Reconnection
6:50 pm - 7:10 pm	**M. Ashour-Abdalla:** Electron Energization as a Result of Magnetotail Reconnection
8:00 pm - 10:00 pm	**Poster Session G at the Ahwahnee Hotel**

Contributed Posters

J. **Berchem**, J. R. Richard, and C. P. Escoubet - *Topology and Dynamics of Merging at the Dayside Magnetopause: Global Simulation of the Response of Cusp Precipitation to Fast Northward Turnings of the IMF*

J. **Birn** - *Magnetic Reconnection and the Properties of Fast Flows in MHD Simulations*

A. **Borg** - *Characterization of Magnetotail Reconnection Events Observed by the Cluster Satellites*

R. E. **Denton**, B. Sonnerup, J. Birn, W.-L. Teh, J. F. Drake, M. M. Swisdak, M. Hesse, and W. Baumjohann - *Test of Methods to Infer the Magnetic Reconnection Directions from Spacecraft Data*

M. **El-Alaoui**, M. Ashour-Abdalla, R. L. Richard, and M. L. Goldstein - *Dependence of Magnetotail Reconnection on the IMF: Idealized MHD Simulations Revisited*

M. **Fujimoto**, K.G. Tanaka and I. Shinohara - *Producing the Most Energetic Electrons at the Anti-X-line upon a Merger of Large Magnetic Islands*

J. **Hwang**, M. L. Goldstein, E. Lee, and J. S. Pickett - *Cluster Observation of Multipile Dipolarization Front (DF) Events Deforming Mid-Tail Magnetic Topology: Rayleigh-Taylor Instability Unstable DF Causes the Drift of an Arc during the Growth Phase of Substorm?*

E. **Lee** and G. Lapenta - *Enhanced Tearing: A Hall-type Extension of the Theory of Collisionless Tearing*

M. **Linton**, M. Selwa, and S. Lukin - *Numerical Simulations of Flux Rope Reconnection in Coronal and Laboratory Environments*

K. **Malakit**, M. A. Shay, P. A. Cassak, and C. Bard - *Full-Particle Simulations vs. the Scaling Analysis of Collisionless Asymmetric Reconnection: the Gross Properties*

J. C. **Meyer**, M. A. Shay, and P. A. Cassak - *Two-Fluid Simulations of 3D Magnetic Reconnection with a Guide Field in Current Sheets*

T. E. **Moore**, F. A. Bibi, M.-C. Fok, D. K. Olson, and M. Opher - *The Reconnection X Line for Specified Interacting Field*

N. A. **Murphy**, J. C. Raymond, and K. E. Korreck - *The Energy Budget and Plasma Heating Rates of a Coronal Mass Ejection*

M. **Oka**, T. -D. Phan, J. Eastwood, M. Fujimoto, and I. Shinohara - Particle Acceleration by Multi-Island Coalescence

V. **Roytershteyn**, W. Daughton, L. Yin, B. J. Albright, K. J. Bowers, S. Dorfman, H. Ji, M. Yamada, H. Karimabadi - *Influence of Current-aligned Instabilities on Dynamics of Driven Magnetic Reconnection in Weakly Collisional Regimes*

D. E. **Wendel**, P. H. Reiff, and M. L. Goldstein - *Impact of Magnetic Draping, Convection, and Field Line Tying on Magnetopause Reconnection Under Northward IMF*

Thursday, February 11, 2010

Session H: Initiation/Cessation of Reconnection	
7:55 am	**Announcements**
8:00 am - 8:40 am	**A. Bhattacharjee**: Initiation and Cessation of Fast Magnetic Reconnection: a Tutorial
8:40 am - 9:00 am	**J. Egedal**: Reconnection Onset and 3D Effects in VTF
9:00 am - 9:20 am	**P. Cassak**: Extending Hall Reconnection to Large-scale Reconnection in the Corona
9:20 am - 9:40 am	**J. Karpen**: CME Initiation and Reconnection
9:40 am - 09:55 am	**General Discussion**
09:55 am - 10:10 am	**Break**
Session I: Particle Acceleration in Reconnection	
10:10 am - 10:50 am	**J. Drake**: Particle Heating and Acceleration in Magnetic Reconnection (Tutorial)
10:50 am - 11:10 am	**S. Krucker:** Electron Acceleration in Solar Flares: RHESSI Observations
11:10 am - 11:30 am	**M. Øieroset:** In Situ Satellite Observations of Particle Acceleration during Reconnection
11:30 am - 11:50 am	**S. White**: Radio Observations of the Sun and Magnetic Reconnection
11:50 am - 12:10 pm	**General Discussion**
12:10 pm - 5:30 pm	**Break**
Session J: Reconnection in Different Plasma Regimes: The Problem of Scaling	
5:30 pm - 6:10 pm	**W. Daughton**: Scaling of Magnetic Reconnection in Collisional and Kinetic Regimes (Tutorial)
6:10 pm - 6:30 pm	**M. Shay**: The Scaling of Reconnection to Large-scale Systems
6:30 pm - 6:50 pm	**N. Loureiro**: Current Sheet Instability and Plasmoid Formation in MHD
6:50 pm - 7:10 pm	**J. Raymond**: Observations of Islands in Coronal Current Layers
7:10 pm - 7:30 pm	**General Discussion**

Friday, February 12, 2010

Session K: Coupling the Global to the Local I	
7:55 am	**Announcements**
8:00 am - 8:40 am	**S. Antiochos**: Coupling the Global to the Local (Tutorial)
8:40 am - 9:00 am	**M. Velli**: Role of Fine-scale Processes in the Global Structure and Heating of the Corona
9:00 am - 9:20 am	**Y.-M. Huang**: Line-tied Reconnection
9:20 am - 9:40 am	**M. Kuznetsova**: Multiscale Modeling of Magnetic Reconnection
9:40 am - 10:00 am	**General Discussion**
10:00 am - 10:15 am	**Break**
Session L: Coupling the Global to the Local II	
10:15 am - 10:55 am	**P. Travnicek**: Global Kinetic Modeling of Magnetospheres
10:55 am - 11:15 am	**P. Yoon:** Integrating Kinetic Instabilities into Global Models of Reconnection
11:15 am - 11:35 am	**General Discussion**
11:35 pm - 5:30 pm	**Break**
Session M: Wrapping It Up: The Big Picture	
5:30 pm - 6:00 pm	**M. Goldstein**: MMS: NASA's Reconnection Mission
6:00 pm - 6:40 pm	**E. Zweibel:** Reconnection: A Universal Plasma-Physical Process
Reception and Banquet at the Ahwahnee Hotel	
7:30 pm - 8:30 pm	Reception
8:30 pm - 10:30 pm	Banquet

ABSTRACTS

Tuesday: Session A: Reconnection at the Sun

Observed Aspects of Reconnection in Solar Eruptions
R. Moore

Signatures of reconnection in major CME (coronal mass ejection)/flare eruptions and in coronal X-ray jets are illustrated and interpreted. The signatures are magnetic field lines and their feet that brighten in flare emission. CME/flare eruptions are magnetic explosions in which: The field that erupts is initially a closed arcade. At eruption onset, most of the free magnetic energy to be released is not stored in field bracketing a current sheet, but in sheared field in the core of the arcade. The sheared core field erupts by a process that from its start or soon after involves fast "tether-cutting" reconnection at an initially small current sheet low in the sheared core field. If the arcade has oppositely-directed field over it, the eruption process from its start or soon after also involves fast "breakout" reconnection at an initially small current sheet between the arcade and the overarching field. These aspects are shown by the small area of the bright field lines and foot-point flare ribbons in the onset of the eruption. At either small current sheet, the fast reconnection progressively unleashes the erupting core field to erupt with progressively greater force. In turn, the erupting core field drives the current sheet to become progressively larger and to undergo progressively greater fast reconnection in the explosive phase of the eruption, and the flare arcade and ribbons grow to become comparable to the pre-eruption arcade in lateral extent. In coronal X-ray jets: The magnetic energy released in the jet is built up by the emergence of a magnetic arcade into surrounding unipolar "open" field. A simple jet is produced when a burst of reconnection occurs at the current sheet between the arcade and the open field. This produces a bright reconnection jet and a bright reconnection arcade that are both much smaller in diameter that the driving arcade. A more complex jet is produced when the arcade has a sheared core field and undergoes an ejective eruption in the manner of a miniature CME/flare eruption. The jet is then a combination of a miniature CME and the products of more widely distributed reconnection of the erupting arcade with the open field than in simple jets. Cartoons illustrating the above characteristics are presented along with representative examples of observed CME/flare eruptions and jets. The main point to be drawn from the observations is that, for either a pre-eruption current sheet or a pre-simple-jet current sheet to remain quasi-static and stable against fast reconnection, it must remain much smaller in span than the driving arcade. Conversely, a current sheet comparable in span to the driving arcade can be made only dynamically, by eruption of the driving arcade, and continually undergoes massive fast reconnection.

Reconnection in the Small-Scale Solar Field
K. Schrijver

The magnetic field that threads the solar surface emerges from within the Sun as bipolar regions with scales that range from large "active regions" (with sizes up to about 200,000 km) down to "ephemeral regions" at the smallest currently observable scales of order 200 km. The high emergence frequency of the ensemble of ephemeral regions causes all photospheric flux outside active regions to be replaced on time scales from hours to days (depending on local conditions and length scales). The atmosphere above this seething field continually adjusts to the changing boundary conditions, by apparently smoothly forming new connections as opposite polarities approach each other, by intermittent small flaring, or by eruptions that appear to be small-scale counterparts of coronal mass ejections. Overall, many of the properties of the small-scale solar field are smooth extensions of the properties of large-scale active regions at least down to scales of several thousand kilometers; effects of partial ionization of the chromosphere and of plasma-beta values that straddle unity throughout the quiet-Sun corona remain to be quantified.

Evidence for Magnetic Reconnection in Solar Flares
H. Warren

Because of the small spatial scales involved, the direct observation of magnetic reconnection in the solar corona is impossible with current instrumentation. There is, however, considerable indirect observational evidence for magnetic reconnection during solar flares. Perhaps the most compelling evidence comes from the supra-arcade downflows that have been observed by SXT/Yohkoh, TRACE, and SUMER/SoHO above post-flare loop arcades. These downflows are thought to be related to highly stretched field lines that have recently reconnected and are relaxing to a lower energy state. Additional indirect evidence for magnetic reconnection comes from the hydrodynamic modeling of solar flares. Models based on the evolution of a single flux tube cannot account for the light curves and spectral profiles observed in solar flares. The observations can, however, be reproduced if we account for the fact that energy is released into a succession of flux tubes, consistent with the magnetic reconnection scenario.

Observations of Large-scale Reconnection in Streamers and CMEs
A. Vourlidas

Abstract: Many models of Coronal Mass Ejection (CME) initiation and solar wind generation invoke reconnection as a means to achieve the eruption and release of the coronal material. White light and EUV observations of the high corona provide tantalizing evidence for at least some of the predictions / expectations of these models, such as flux rope formation, creation of narrow ray-like structures behind CMEs, topological changes in streamers, etc. In my talk, I compile and review observations from coronagraphs and EUV imagers over the last 15 years that provide indirect evidence for reconnection in the high corona. I will particularly emphasize recent results from the STEREO mission, which seem to provide new insights and constrains for the modeling of plasma ejection from the Sun.

Tuesday: Session B: Reconnection in Magnetospheres and the Solar Wind

In-Situ Observations of Magnetic Reconnection in the Solar Wind, Magnetosheath, and Magnetosphere
T. Phan

The near-Earth space provides a natural laboratory where collisionless reconnection can be studied by in-situ measurements. Reconnection has been observed at the dayside magnetopause, in the magnetotail, in the solar wind, and in the magnetosheath region downstream of the Earth's bow shock. The studies of these regions have provided valuable information on the large-scale as well as micro-physical properties of reconnection. However, the boundary conditions for reconnection in these various regions are vastly different and consequently, the properties of reconnection deduced from these regions often seem contradictory. In this talk I will present an overview of the current understanding of the structure and dynamics of reconnection based on observations in the solar wind, magnetosheath, and the magnetosphere. Topics that will be discussed include: Structure of reconnection diffusion region. Patchy versus extended reconnection X-lines. Bursty versus steady reconnection. Onset conditions for reconnection. Particle energization in reconnection.

Magnetic Reconnection in the Solar Wind Associated with Small Field Shear Angles
J. T. Gosling

Reconnection in the solar wind produces extensive Petschek-like exhausts of roughly Alfvénic jetting plasma bounded by back-to-back rotational discontinuities that bifurcate a reconnecting current sheet. A spacecraft at 1

AU typically encounters 2-3 events/day in the low-speed wind and within ICMEs, but only 1 event every 2 days in the high-speed wind from coronal holes. Reconnection exhausts are found most frequently in association with local field shear angles < 90°; we have identified reconnection exhausts with local field shear angles as small as 15°. Thus component reconnection, in which the so-called guide field is comparable to or stronger than the anti-parallel field components, prevails in the solar wind. This preference for small field shear angles simply reflects the fact that most current sheets in the solar wind at 1 AU are associated with relatively small field rotations; such current sheets also tend to be relatively thin, thus enabling the reconnection process.

Observational Evidence of Component and Anti-Parallel Reconnection at the Earth's Magnetopause
S. A. Fuselier, K. J. Trattner, and S. M. Petrinec

Magnetic reconnection occurs at the Earth's magnetopause between magnetosheath and magnetospheric magnetic fields. Initially, it was suggested that this process occurs where these two fields are exactly anti-parallel. For the magnetopause, the anti-parallel reconnection lines extend from the two cusps in the northern and southern hemispheres and the orientation of these two reconnection lines depend on the orientation of the external Interplanetary Magnetic Field. It was quickly realized that the forcing of shocked solar wind against the magnetopause may drive reconnection in the subsolar region even if the magnetic fields are not anti-parallel there. This so-called component reconnection would produce a single, long reconnection line that is centered on the subsolar point and extends over the entire dayside magnetopause. On the theoretical side, initial simulations also focused on anti-parallel reconnection. However, it was demonstrated that the process is very different when a guide-field (that is, a component that is not strictly anti-parallel across the current sheet) is introduced in the simulations, even if this guide field is very small. Reconciling the observational and theoretical understandings of component (i.e., non-zero guide field) and anti-parallel reconnection is difficult. On the observational side, spacecraft most often cross the magnetopause at a location that is well removed from the reconnection site. The location of the reconnecting fields cannot be easily determined from data obtained during a crossing. Even for crossings that occur near a reconnection site, the orientation of the fields relative to the current layer are not known with sufficient accuracy to determine if theoretical conditions of anti-parallel reconnection are satisfied. Nonetheless, there are observations that indicate that both types of reconnection occur at the Earth's magnetopause. In this talk, these observations are reviewed and it is demonstrated that the observations fit an empirical model that determines the type of reconnection as a function of external conditions.

Formation and Structure of Magnetic Islands and Current Layers during Magnetotail Reconnection
L.-J. Chen

The structures of magnetic islands and current layers during magnetotail reconnection are discussed, based on Cluster observations, to address open questions concerning dynamics of reconnection diffusion regions and suprathermal electron production. The ion-skin-depth-scale magnetic islands have enhanced electron densities, temperatures, and bipolar in-plane electric fields within, consistent with secondary magnetic islands formed at elongated electron current layer. Inside these islands, suprathermal electron bursts are found to peak at density compression sites. In between two islands, a spatially extended current layer of the electron-skin-depth scale is observed to co-locate with a layer of Hall electric fields, and host unmagnetized electrons. Suprathermal electrons are also observed at the electron current layer, but with much lower energy and flux intensity than those inside magnetic islands, indicating that the islands are more effective in producing suprathermal electrons than the electron current layer. Electron distribution function arrays from the four Cluster spacecraft show distinct electron regions with distinct field-line connectivities within the ion diffusion region, providing the ground for the above discoveries.

Tuesday: Session C: Reconnection in the Laboratory

Recent Experimental Results on Driven Reconnection

M. Yamada

Examples of reconnection phenomena in different laboratory plasmas are highlighted focusing on driving mechanisms; sawtooth relaxation in tokamak and RFP fusion plasmas, merging of toroidal plasmas, and driven reconnection in MRX.

In toroidal fusion plasmas, magnetic configuration changes abruptly caused by magnetic reconnection. Sawtooth relaxation in a tokamak plasma, which represents a repetitive change of the electron temperature profile, provides a good example of magnetic reconnection. During the relaxation phase of sawtooth, a rapid flattening of the electron temperature profile occurs and the pitch of field lines changes suddenly as the field lines break and rearrange themselves to form a new topological profile. In the reversed field pinch (RFP) and spheromak plasmas, a sudden re-arrangement of filed lines in a inner flux surface can trigger another rearrangement in the outer flux surfaces, invoking a global magnetic relaxation event. In these plasmas, magnetic reconnection is often driven by an externally driven ideal kink 3-D MHD instability and the reconnection time is much faster than the Sweet-Parker time.

Magnetic reconnection physics have been also investigated by use of axially merging two spheromaks. The 3-D features of magnetic reconnection were found to be quite different from the conventional 2-D features depending on whether the plasma toroids have co-helicity or counter-helicity merging configurations. Characteristics of driven reconnection was investigated and a quantitative dependence of reconnection rate on external force was documented.

One form of controlled driven experiment is to program magnetic field line evolution after arranging reconnecting magnetic field configurations. The merging speed of oppositely directed field lines is controlled by the external electric field provided by pulsed coil currents as is the case in the MRX device. It is found that the local reconnection velocity is influenced by the external forcing. Even the local reconnection dynamics which include Hall effects and the electron pressure tensor force can be affected by external forcing.

Characteristics of Non-Collisional Ion Heating in the MST RFP

R. Magee, R. Den Hartog, D. Craig, G. Fiksel, S. Kumar, J. Sarff, and MST Team

In the Madison Symmetric Torus (MST) reversed-field pinch (RFP), discrete bursts of magnetic reconnection are driven by resonant tearing modes. These events liberate a large amount of energy (~20 kJ) from the equilibrium magnetic field, of which a significant fraction (10-25%) becomes ion thermal energy. The ion temperature is observed to increase by as much as a factor of four to values much greater than T_e, precluding electron-ion collisions as the mechanism. Recent experimental observations have added to the collection of known features of the heating, but a coherent theoretical model remains elusive. This talk will focus on two observations in particular. First, a newly installed toroidal viewing chord for the charge exchange recombination spectroscopy (CHERS) system has allowed a detailed comparison of the parallel and perpendicular impurity ion temperature dynamics in the core of the MST. Preliminary data show the complete absence of a parallel temperature increase above a density threshold of n_e ~ 1.0e13 cm^{-3}, and a temperature anisotropy that persists much longer than the collisional isotropization time. Second, Rutherford scattering measurements of the bulk ion temperature in discharges with different fuel gases (H, D, He) have revealed that the heating efficiency, defined as the ratio of the change in ion thermal energy to the change in magnetic energy, increases as the square-root of the ion mass. Finally, the observed features of anomalous ion heating in the RFP will be summarized as a means of evaluating current theoretical models.

Reconnection-Driven Ion Heating and Plasma Relaxation in SSX
M. R. Brown

The Swarthmore Spheromak Experiment (SSX) studies magnetic reconnection and plasma relaxation by forming two magnetized plasma rings called "spheromaks" with coaxial plasma guns, and injecting them into the opposite sides of a flux conserver. The flux conserving boundaries are provided by highly conducting copper walls. The merging volume is maintained at high vacuum and is free of vacuum magnetic fields. Four different geometries have been studied in SSX in the past decade, including trapezoidal oblate (L/R = 1.2) geometry, and three cylindrical geometries, slightly prolate (L/R = 2.0), prolate (L/R = 3.0), and super prolate (L/R = 10). The magnetic helicity of the spheromaks can be individually chosen, allowing for both co- and counter-helicity merging, both of which have been studied.

Ion heating due to magnetic reconnection is measured in the SSX reconnection device for a variety of ion masses and charge states with a high resolution ion Doppler spectrometer. The velocity resolution of the instrument is $\leq$ 5 km/s. Peak ion temperatures of 100 eV have been recorded during reconnection events as well as out flows up to ±40 km/s. Spheromak merging in a new slightly prolate flux-conserving boundary (R = 0.2 m; L = 0.4 m) often results in excitation of several unstable, turbulent MHD modes with a dynamical evolution to a preferred final state. Massive ions are doped at the 1% level in an otherwise pure hydrogen plasma. After reconnection and instability, we measure a period of reconnection-driven ion heating with peak temperatures for argon (Ar^{+++}) $T_{Ar} \cong 20$ eV, for carbon (C^{++}) $T_C \cong 40$ eV , and for helium (He^{+}) $T_{He} \cong 75$ eV (averaged over many shots). Ion temperatures in the turbulent high corona and solar wind are known to scale with the ion mass ($T_i \propto M_i$). Laboratory measurements of ion temperature during reconnection-driven events in the MST reversed field pinch have a particular scaling ($T_i \propto \sqrt{M_i}$) whereas impulsive events in the SSX reconnection device appear to have another scaling ($T_i \propto Z/M_i$). Computer simulations are being planned to help sort out the discrepancies but evidently, different physics pertains in each system. It seems likely that turbulent, reconnection-driven ion heating depends on details like the fluctuation spectrum of turbulence and waves, the spatial extent of the heating zone, and the duration of the reconnection event(s). Ion heating results and evidence of dynamical relaxation to preferred states in SSX will be presented.
*Supported by US DOE and NSF.

Experimental 3D Reconnection and Unexpected Dynamics of Flux Ropes
T. Intrator, X. Sun, L. Dorf, I. Furno, and G. Lapenta

Interactions of mutually attracting flux ropes are closely related to three dimensional (3D) magnetic reconnection in realistic geometry. Examples that are 3D and not toroidal include in nature: Solar coronal loops, coronal holes, astrophysical jets; and in the laboratory: spheromaks, Z pinch, spacecraft thrusters, etc. An experimental laboratory model in the Reconnection Scaling Experiment (RSX) can create 1, 2 or more long, thin flux ropes, with current embedded parallel to an externally imposed magnetic guide field. These current channels mutually attract via strong, ideal MHD JxB forces. We show for the first time in a linear experimental device that two mutually attracting flux ropes may bounce back instead of merging together. There is a competition between attraction forces due to parallel flux rope currents and repulsion from field line bending of in plane magnetic field B_f with curvature radius a of the flux rope, elastic plasma compression, and field line bending of the out of plane magnetic field B_z with curvature radius R_c. We show that bouncing dynamics occur if the line bending force density from out of plane $B_z{}^2/(m_0R_c)$ exceeds that due to in plane $B_f^2/(m_0a)$. Otherwise the ropes merge. Further reduction in field line bending force results in violently erratic magnetic states. Merge vs bounce dynamics affect evolution, statistical mechanics of the end states, and probably turbulence.

Wednesday: Session D: Reconnection in Extreme Environments

Magnetic Reconnection in Extreme Astrophysical Environments

D. Uzdensky

Most of the magnetic reconnection research done to date has been motivated by applications to systems such as the solar corona, the Earth magnetosphere, and magnetic confinement devices for thermonuclear fusion. These environments are characterized by relatively low energy densities, where the plasma is adequately described as a mixture of equal numbers of electrons and ions whose numbers are conserved and where the dissipated magnetic energy always stays with the plasma.

In contrast, in this talk I will introduce the emerging direction of research --- reconnection in High Energy-Density Plasmas, in which photons play as important a role as electrons and ions. Namely, radiation pressure and radiative cooling may become dominant factors in the pressure and energy balance, respectively. This research is motivated in part by the rapid theoretical and experimental advances in the new subfield of High-Energy Density Physics, and in part by several important problems in modern High-Energy Astrophysics. In my talk, I will first discuss the astrophysical examples of High Energy Density reconnection and then describe our present status of physical understanding of it by presenting the broad picture and outlining the key physical processes. Most notable among these astrophysical applications are situations involving reconnection of magnetar-strength (10^{14} - 10^{15} Gauss) magnetic fields. The most important examples are giant flares in soft-gamma repeaters (SGRs), releasing of up to 10^{47} of energy in just a fraction of a second, and rapid magnetic energy release in either the central engines or in the relativistic jets of Gamma Ray Bursts (GRBs). The magnetic energy density in both of these environments is so enormous (of order 10^{28} erg/cc) that, when it is suddenly released, the plasma is heated to relativistic temperatures (up to 10 MeV). As a result, electron-positron pairs are inevitably created in copious quantities. The pairs make the reconnection layer optically thick, thereby trapping gamma- photons. The plasma pressure inside the layer is then dominated by combined radiation and pair pressure. At the same time, the timescale for radiation diffusion across the layer may be still shorter than the global (along the layer) Alfven transit time, and hence the effects of radiative cooling on the thermodynamics of the layer have to be included. In addition, the high pair density can make the reconnection layer highly collisional, essentially independent of the upstream plasma density. This makes various collisionless effects negligible, so that resistive MHD (with both Spitzer and Compton resistivity) applies. I will conclude by outlining the most pressing open questions and challenges.

Two-Fluid Simulations of Relativistic Magnetic Reconnection in Electron-Positron Plasmas

S. Zenitani

Magnetic reconnection draws recent attention in high-energy astrophysical settings such as the pulsar magnetosphere and pulsar winds. In these environments, the relativity plays a role in electron-positron pair plasmas. Over the past decade, basic properties of relativistic magnetic reconnection have been extensively studied by PIC simulations, which have exhibited a wide variety of plasma instabilities. However, although there is a high demand, the number of MHD/fluid simulation works beyond kinetic scales has been quite limited. In this focused talk, we will introduce our recent works on relativistic magnetic reconnection by means of a newly-developed relativistic two-fluid code. The nonlinear, long-term, and quasi-steady system evolutions in basic Harris configurations will be presented. We will also discuss the structure of the relativistic Petschek reconnection and implications for the relativistic reconnection theories.

The Role of Turbulent Outflow Jets in Electron-Positron Plasmas
M. Swisdak, Y. H. Liu and J. F. Drake

Numerical simulations of reconnection in electron-positron (pair) plasmas provide an interesting window into the role turbulence plays in current theories of whistler-mediated Hall reconnection. Because of the system's mass symmetry the Hall term vanishes from the generalized Ohm's law, suggesting that perhaps pair reconnection is slow, as in the classic Sweet-Parker picture. Large particle-in-cell simulations of pair reconnection confirm that the reconnection rate remains fast even as the system size changes by a factor of 8. For the largest systems a Weibel-like temperature anisotropy instability in the X-line outflow broadens the current layer and permits fast reconnection. This instability can be suppressed both artificially and for certain parameter choices, leading to non-steady behavior and a decrease in the reconnection rate.

Wednesday: Session E: Dissipation/Structure of the Diffusion Region I

The Inner Workings of Magnetic Reconnection: Diffusion Region in the Balance
M. Hesse

The question of whether the microscale controls the macroscale or vice-versa remains one of the most challenging problems in plasmas. A particular topic of interest within this context is collisionless magnetic reconnection, where both points of views are espoused by different groups of researchers. This presentation will focus on this topic. We will begin by analyzing the properties of electron diffusion region dynamics both for guide field and anti-parallel reconnection, and how they can be scaled to different inflow conditions. As a next step, we will study typical temporal variations of the microscopic dynamics with the objective of understanding the potential for secular changes to the macroscopic system. The research will be based on a combination of analytical theory and numerical modeling.

Reconnection and Turbulence
W. H. Matthaeus

Due to the close relationships between magnetic reconnection and MHD scale turbulence, it may be difficult to entirely separate the two phenomena. MHD turbulence would be very different if one could “switch off” reconnection. Conversely, reconnection is greatly affected by the presence of turbulence. These connections are sometime obscured by a focus on global static laminar equilibria, and the lack of adequate computational resources and methods. Here we review aspects `of the influence of turbulence on reconnection. (I) In large scale turbulence (2D or 3D) magnetic structures are constantly interacting. One aspect of this interaction is reconnection, which is driven by fluctuations in pressure, magnetic field and electric field. A broad range of reconnection rates is possible [1], approaching Alfvénic rates in terms of global parameters. (II) In large scale reconnection, small scale MHD turbulence can provide an enhanced of effective resistivity that increases transport in the diffusion region [2,3,4]. Reconnection rates are thus enhanced [2,5,6], possibly to Alfvénic, Reynolds number independent rates. (III) Turbulent fluctuations entering the diffusion region can directly modify magnetic field topology, which changes the problem at a fundamental level without resistivity or expenditure of energy [7,8]. In 2D the appearance of multiple X-points in the reconnection zone affords multiple reconnection sites, and an overall acceleration of the process [7]. Study of multiple island - multiple X-point effects has recently been revived in the context of secondary instabilities of long current sheets at high Reynolds number [9,10], but the effect on the topology is the same. (IV) Nonlinear reconnection generates additional fluctuations that feed back on the reconnection process [2,7,11,12]. This may involve elongated current sheets, bursty flows, multiple small islands, nonlinear outflow interactions, or through launching of wave-like fluctuations by finite size reconnected islands. (V) New results suggest that there may be an even greater requirement for numerical accuracy that previously thought in order to accurately compute small scale dynamics near reconnection zones. Evidently the resolution required for suppression of phase errors and small scale Gaussianization is greater than that required for accuracy of the wavenumber spectrum. Careful interpretation of numerical results is called for. [1] S. Servidio et al, *PRL*, **102, 115003** (2009). [2] W.H. Matthaeus and S.L. Lamkin *Phys. Fluids* **29, 2513 (**1986). [3] H. Strauss. *ApJ.*, **326, 412** (1988); *Phys. Fluids*, **29, 3668** (1986). [4] E. Kim and P. H. Diamond, *Phys. Lett A*, **291, 407** (2001). [5] D. Smith et al, *Geophys. Res. Lett*, **31 L02805** (2004). [6] N. F. Loureiro et al, *Mon Not Roy Astron. Soc.*, **399, L146** (2009). [7] W. H. Matthaeus and S. Lamkin, *Phys. Fluids*, **28, 303** (1985). [8] G. Kowal et al, *ApJ*, **700, 63** (2009). [9] D. Biskamp, *Phys Fluids*, **29. 1520** (1986). [10] A. Bhattacharjee et al, *Phys. Plasmas*, **16, 112102** (2009). [11] G. LaPenta, *PRL*, 100, **23** (2008). [12] E. Priest and T. Forbes, Magnetic Reconnection, Cambridge U. Press (2000).

Observing the Electron Diffusion Region with MMS
R. B. Torbert

In most theories of reconnection, the electron diffusion region plays a key role in determining the topology and dynamics of non-ideal processes that convert magnetic energy to mechanical energy. In all theories, thin currents layers are critical regions where the electron flow may not be frozen to the magnetic field and energy conversion may take place. This talk will elaborate the ability of the upcoming MMS mission to identify and characterize such thin, fast-moving regions, and to provide new observations that will advance the understanding of reconnection.

Wednesday: Session F: Dissipation/Structure of the Diffusion Region II

Reconnection and Waves
M. Fujimoto

Because magnetic reconnection is a dynamic multi-scale process, its connection to wave phenomena over a broad frequency range is inevitable. There are various ways to look at the coupling between reconnection and waves: (1) Reconnection involves formation of thin current sheets. Electron kinetic effects are activated there and are recorded in the wave data. (2) Waves can modify the current sheet internal structure. This would have significant impact on the reconnection triggering process. (3) Waves that facilitate electron-ion momentum exchange can be responsible for the dissipation mechanism to trigger and/or maintain reconnection. (4) Reconnection in reality does not proceed in a steady two-dimensional manner. Non-steady three-dimensional reconnection leads to emission of low-frequency waves that have interesting remote effects. A review of past results and on-going efforts will be made from these perspectives. As an output, I will try to create a chart that clarifies which wave feature tells what aspect of reconnection physics.

Experimental Study of Electromagnetic Fluctuations During Reconnection In MRX
H. Ji, S. Dorman, M. Yamada, J. Yoo, and E. Oz

Turbulence can play important roles in determining reconnection rate and the associated energy dissipation. More specifically, the turbulence may explain the discrepancies between the measured thickness of the electron diffusion layer in MRX and best available 2D kinetic simulations. In this talk, after a brief review of the previous measurements of electromagnetic fluctuations in the reconnecting current sheets in MRX, the most recent experimental results will be discussed. It is found that the bursts of electromagnetic fluctuations are typically associated with large local current density and "disruptions" of current channel. These impulsive behaviors are highly 3D in nature, and are also often accompanied by local fast reconnection and global current sheet distortion.

Structure & Dynamics of Electron Holes Produced during Magnetic Reconnection
H. Che, J. F. Drake, M. Goldman, M. Swisdak, P. Yoon, and D. Newman

The current sheets localized around the magnetic x-line and separatrices are signatures of magnetic reconnection. The intense currents can drive streaming instabilities. The resonance between particles and waves leads to energy exchange. Electron holes form if the wave gains enough energy from resonant electrons to trap them and are destroyed as the trapped electrons gain back energy from the wave. This process transforms the directed kinetic energy of electrons into thermal energy. The study of turbulent dissipation has the potential to clarify the role of anomalous resistivity in fast magnetic reconnection, a long-standing puzzle. I will focus on introducing the fundamental concepts related to electron holes and the new research results on their dynamics. In particular, we have discovered that the changing of phase speed of the streaming instabilities is an effective mechanism to transport the momentum from high velocity electrons to low velocity electrons and ions. The competition among streaming instabilities results in the coexistence of different types of electron holes, which greatly enhance the electron heating in magnetic reconnection.

Electron Energization as a Result of Magnetotail Reconnection
M. Ashour-Abdalla, M. Zhou, D. Schriver, M. El-Alaoui, X. Deng, R. Richard, and R. Walker

Observations of energetic electrons during a dipolarization front indicate that particles in the near-Earth magnetotail gain large amounts of energy (>100 keV) in a short amount of time (~ minutes). In this talk we use theory and simulations to explain the observed acceleration. To understand electron transport in the time dependent magnetospheric electric and magnetic fields we use global magnetohydrodynamic (MHD) simulations with large scale kinetic (LSK) calculations. Initial calculations for electrons indicate that the most energetic electrons to reach the spacecraft started their journey close to the magnetotail reconnection site. Moreover, it is found that adiabatic motion (Fermi and betatron) may not be sufficient to account for the observed energies. Wave-particle interactions play an important role in electron energization and to examine this phenomenon we will use particle in cell (PIC) simulations. One conclusion is that both adiabatic acceleration and wave particle interactions are necessary to understand the electron heating.

<u>Wednesday: Session G: Poster Session</u>

Topology and Dynamics of Merging at the Dayside Magnetopause: Global Simulation of the Response of Cusp Precipitation to Fast Northward Turnings of the IMF
J. Berchem, J. R. Richard, and C. P. Escoubet

The distribution and dynamics of particles precipitating into the polar cusps contain fundamental information about the large-scale topology and evolution of the reconnection of the interplanetary magnetic field (IMF) with the geomagnetic field. In particular, the occurrence of discrete structures in energy-latitude dispersion of precipitating particles observed by spacecraft as they cross the polar cusps suggests that significant spatial and temporal changes in the merging process occur at the dayside magnetopause as it interacts with IMF discontinuities. We use comparisons between actual ion measurements and results of numerical simulations of the cusp's response to fast rotations of the IMF to determine the large-scale topology and dynamics of the merging region at the dayside magnetopause. The study is based on consecutive crossings of the northern mid-altitude cusp by the Cluster satellites and uses global magneto-hydrodynamic simulations together with time-dependent large-scale kinetic computations. Comparisons between ion dispersions computed from the simulations and Cluster measurements indicate that the occurrence of unsteady large-scale structures observed in energy-latitude dispersions of precipitating particles is related to the spatial variation of the reconnection region as the cusp expands poleward after its interaction with the IMF discontinuity.

Magnetic Reconnection and the Properties of Fast Flows in MHD Simulations
J. Birn

The properties of earthward flow bursts are investigated using 3D MHD simulations of magnetotail dynamics. Two scenarios are considered: In scenario A, reconnection is initiated in the near tail by imposing localized resistivity, causing plasmoid ejection and magnetic field collapse. In scenario B, the evolution results from artificially lowering the entropy content of a magnetic flux tube. In either case fast earthward flows develop, causing earthward propagating "dipolarization fronts" and field-aligned current systems. The properties of these fronts are further investigated in the regime where they are slowed and stopped nearer to the Earth.

Characterization of Magnetotail Reconnection Events Observed by the Cluster Satellites
A. Borg

Reconnection in the Earth's magnetotail drives large scale reconfiguration of plasma and fields, contributing to plasma transport and significant particle acceleration, most dramatically displayed in the form of substorms. This paper focuses on 18 reconnection events identified from a period of six years of magnetotail data recorded by the Cluster satellites. The identification criteria consist of: Observation of ion outflow regions with appropriate polarization of the magnetic field z-component and the existence of a quadrupole Hall magnetic field in the candidate reconnection area. Each of these events is scrutinized using magnetic field and particle data from the FGM, CIS, PEACE and RAPID instruments. We have carried out an initial characterization of the events by comparisons amongst the events but also to neutral sheet crossings by Cluster where no reconnection was observed to be taking place, with an aim to make comparisons or provide input to simulations of reconnection.

Test of Methods to Infer the Magnetic Reconnection Directions from Spacecraft Data
R. E. Denton, B. Sonnerup, J. Birn, W.-L. Teh, J. F. Drake, M. M. Swisdak, M. Hesse, and W. Baumjohann

When analyzing data from a cluster of spacecraft (such as Cluster or MMS) crossing a site of magnetic reconnection, it is desirable to be able to determine the orientation of the reconnection site. If the reconnection is quasi-two dimensional, there are three key directions, the direction of in homogeneity (direction across the reconnection site), the direction of the reconnecting component of the magnetic field, and the direction of rough invariance ("out of plane" direction).

Using simulated spacecraft observations of an MHD simulation of magnetic reconnection, we test a method based on the gradient of the vector magnetic field, and find that the directions can be well determined. The results from this method}, however, can be in error if there are systematic calibration errors in the magnetic field measurements. The effect of these errors can be eliminated if the average gradient is subtracted from a time series of gradient values before they are used for the analysis. The velocity of the structure relative to the spacecraft can also be determined using the time derivative and gradient of the magnetic field. Calibration errors can be eliminated in this case also if the average time derivative and gradient are subtracted from the time series of values before they are used for the analysis.

Dependence of Magnetotail Reconnection on the IMF: Idealized MHD Simulations Revisited
M. El-Alaoui, M. Ashour-Abdalla, R. L. Richard, and M. L. Goldstein

Magnetospheric processes are driven by solar wind conditions, but because there are frequent changes in the solar wind the cause and effect relationships between solar wind drivers and magnetotail reconnection are hard to determine. The role of internal instabilities, for instance, is difficult to assess because of the complex external driving. High resolution MHD simulations have performed well in reproducing observed intervals indicating that they are doing a good job of modeling the reconnection process on a large scale. Reconnection in collisionless plasma is a kinetic process; however, all of the pertinent kinetic processes are preceded by the formation of thin current sheets with strong local enhancements of the current. Thus, even though MHD cannot model the kinetic physics of reconnection, it can model the reconfiguration of the magnetosphere that leads to reconnection and the consequences of reconnection. The convection process that forms the thin current sheets and the associated reconnection regions are basically MHD processes. Therefore, we will use MHD codes to delineate when and why reconnection regions are formed, even though the description will lack some details of the reconnection process itself. Early MHD simulations focused on obtaining the overall configuration of the magnetosphere for idealized solar wind conditions. To understand basic physical processes in the magnetotail we return to idealized cases using high resolution MHD simulations. In this study we will perform systematic MHD simulation studies driven by an idealized time series of solar wind parameters to establish basic cause and effect relationships between the solar wind variations and the reconnection process.

Producing the Most Energetic Electrons at the Anti-X-line upon a Merger of Large Magnetic Islands
M. Fujimoto, K.G. Tanaka and I. Shinohara

We show via two-dimensional full-particle simulations that an anti-X-line facilitating a merger of large magnetic islands produces the most energetic electron component in the system. The strong electron acceleration is because the anti-reconnection is in such a driven manner that the associated electric field is an order of magnitude larger than those available upon normal reconnection. A possible application of the results to the electron acceleration process in solar flares is discussed.

Cluster Observation of Multipile Dipolarization Front (DF) Events Deforming Mid-Tail Magnetic Topology: Rayleigh-Taylor Instability Unstable DF Causes the Drift of an Arc during the Growth Phase of Substorm?
J. Hwang, M. L. Goldstein, E. Lee, and J. S. Pickett

We present Cluster observation of a series of a dipolarization front (DF) of a period of ~3.5 minutes at the central current sheet in the Earth's magnetotail. The fast earthward flow observed behind each DF with a velocity corresponding to the Alfvén velocity indicates that the flow bursts might have been generated by bursty, patchy reconnection that occurred tailward of the spacecraft. Each DF is followed by significant fluctuations in the x- and y-components of the magnetic field after an about 1 minute delay. Based on the multi-spacecraft timing analysis, the DFs are found to propagate mainly earthward at ~160-335 km/s with a thickness of 900-1500 km, similar to the ion inertial length. The third DF is, however, found to move mostly dawnward, possibly due to the pressure of pre-existing plasmas energized by the first two DFs, and the last, week DF is found to retreat tailward. The B_x/B_y fluctuation is seen to move dawnward (mainly) and earthward, with its boundary normal pointing to $(x, y, z)_{GSM} = \pm(0.6, -0.7, 0.4)$. Strongly enhanced field-aligned beams are observed coincidently with the B_x/B_y fluctuations. From the observed pressure imbalance between two (front/rear) regions separated by the DF, and the consideration of the limited extent of reconnection X-line along the y-dimension in the farther tail, we speculate that Rayleigh-Taylor instability (RTI) unstable DF might have caused the deformation of the mid-tail magnetic topology (i.e., with a dent at around the midnight sector, when viewed from the north), which generates significant field-aligned currents, and possibly powers the auroral arc during the substorm processes. The dawn-dusk (with a bit earthward) motion of the structure associated with the development of RTI-unstable DF might explain the azimuthal (north-to-south) drift of the arc during the growth phase of the substorm.

Enhanced Tearing: A Hall-type Extension of the Theory of Collisionless Tearing
E. Lee and G. Lapenta

Enhancement of two-dimensional reconnection by the Hall effect was proposed by Sonnerup (1979) and since then has been supported by theoretical, observational, experimental, and numerical results. The decoupling of electron and ions within the ion diffusion region create currents that distort the symmetric structure of the magnetic field and enable particle accelerations that enhance the rate of magnetic field reconnection. This distortion of field line symmetry has important consequences for collisionless tearing, which in classical theory is dominated by a single mode of even symmetry. In our analyses, we extend the theory of collisionless tearing to allow for small departures from the classical configuration that can help to explain the enhanced rates of reconnection and such features as a quadrupolar field structure observed both in simulation and in observations.

Numerical Simulations of Flux Rope Reconnection in Coronal and Laboratory Environments
M. Linton, M. Selwa, and S. Lukin

We will present simulations exploring the three dimensional reconnection dynamics of colliding twisted magnetic flux ropes. These collisions have been proposed as a source of coronal flare initiation, and have also been explored recently in a number of laboratory experiments. We will show how the relative orientation of both the ropes themselves and their twist field dramatically changes the dynamics and energy release of the resulting reconnection. We will show how these effects apply to initially cylindrical ropes, to initially arched ropes rooted in a line-tied photospheric boundary, and to initially toroidal ropes (spheromaks). We will discuss the implications of these results both for models of solar flares and for recent results reported by laboratory experiments.

Full-Particle Simulations vs. the Scaling Analysis of Collisionless Asymmetric Reconnection: the Gross Properties
K. Malakit, M. A. Shay, P. A. Cassak, C. Bard

Asymmetric reconnection is magnetic reconnection in which the upstream conditions (magnetic field and density) on either side of the x-line vary. It is applicable to reconnection at the dayside magnetopause, reconnection in laboratory fusion devices, and sometime reconnection in the solar corona. Recently, Cassak and Shay [2007] proposed a theory, based on Sweet-Parker type scaling analysis, to explain properties of asymmetric reconnection. Although this theory has been thoroughly tested with MHD and two-fluid simulations, it has not been verified that the inclusion of kinetic proton and electron physics will not fundamentally alter the properties of asymmetric magnetic reconnection. Using the kinetic PIC code p3d, we perform a careful scaling study to test the Cassak and Shay, 2007 scaling predictions. The reconnection electric field and outflow speed match the scaling predictions quite well. Moreover, the close-to-prediction outflow density verifies that the downstream mixing assumption is valid.

Two-Fluid Simulations of 3D Magnetic Reconnection with a Guide Field in Current Sheets

J. C. Meyer, M. A. Shay, and P. A. Cassak

Although much progress has been made in our understanding of reconnection in two dimensions, the transition to three-dimensional reconnection is much more difficult, owing to the added complexity in system in addition to the expense of numerical simulations. We present 3D two-fluid simulations of magnetic reconnection in an initially 1D current sheet. Previous studies have found that the propagation and growth of finite length x-lines is fundamentally determined by the equilibrium current carriers[1]. We revisit this phenomenon, exploring the affect a guide field on the x-line growth. [1] Lapenta, G. et al., *Geophys. Res. Lett.*, **33, L10102**, 2006, doi:10.1029/2005GL025124

The Reconnection X Line for Specified Interacting Field

T. E. Moore, F. A. Bibi, M.-C. Fok, D. K. Olson, M. Opher

We explore the hypothesis that when magnetized plasmas interact, an X-line spreads away from the region of maximum field shear along characteristic X lines within the boundary between the interacting fields. The form of the dayside magnetopause reconnection X line has recently been predicted (Moore et al., *JGR* 2002) and observed (Pu et al., *JGR* 2007; Wang et al., *AOGS* 2009-ST18-02-PM2-P-020). We describe this method as applied to the terrestrial magnetosphere and then apply it to the interaction at the heliopause between the heliospheric and interstellar magnetic fields. While direct measurements at the heliopause are very limited at present, we can predict the global configuration of heliopause reconnection as a function of the interstellar magnetic field orientation and compare this to new observations of the interstellar boundary. Using a 3D magnetohydrodynamic simulation (Opher et al., *Science* 2007), a solution is obtained for representative specified interstellar fields. From this solution, we can identify the heliopause by selecting an appropriate isothermal surface. The change in magnetic field across this boundary implies an expected configuration for the extended reconnection X line at the heliopause. The shape of the heliopause X line is derived as a function of the orientation of the interstellar magnetic field and compared with the "ribbon" feature recently discovered by the IBEX mission (McComas et al., *Science* 15 Nov 2009).

The Energy Budget and Plasma Heating Rates of a Coronal Mass Ejection

N. A. Murphy, J. C. Raymond, and K. E. Korreck

Several recent observational results suggest that significant heating of coronal mass ejections (CMEs) continues even after the ejected plasma leaves the flare site. We use measurements of a CME observed by the Ultraviolet Coronagraph Spectrometer (UVCS) aboard the SOHO spacecraft in conjunction with a time-dependent ionization code to find the plasma heating rates. The inferred heating rates are then compared to the kinetic energy determined from UVCS and white light coronagraph measurements. The heating of the ejecta is likely due to dissipation of the magnetic field but the mechanism remains unknown. We assess the relevance of theories of the flux rope heating and discuss connections with similar phenomena in laboratory plasma experiments. Bubbles and flow bursts in MHD magnetotail simulations.

Particle Acceleration by Multi-Island Coalescence
M. Oka, T. -D. Phan, J. Eastwood, M. Fujimoto, I. Shinohara

Particle-in-cell (PIC) simulations of multi-island coalescence are performed to study particle acceleration. We found that ions are accelerated by the inductive electric field generated at each end of magnetic islands as a result of island collision. The acceleration process is similar to the recently proposed Fermi process of electrons in a contracting magnetic island, but, in the present case, the ions have large gyro-radii so that they can gain significant amount of energy by a single interaction with an island edge. Electrons are also confirmed to be accelerated by the contracting island mechanism, but the most energetic electrons are found to be directly accelerated by the reconnection electric field at the merging point of two islands or the so-called 'anti-reconnection' point. By tracing the trajectories of the most energetic electrons, we found a variety of different energization mechanisms. Finally, we discuss energy partitions between ions and electrons and between thermal and non-thermal component.

Influence of Current-aligned Instabilities on Dynamics of Driven Magnetic Reconnection in Weakly Collisional Regimes
V. Roytershteyn, W. Daughton, L. Yin, B. J. Albright, K. J. Bowers, S. Dorfman, H. Ji, M. Yamada, H. Karimabadi

Influence of current-aligned instabilities on magnetic reconnection attracted considerable interest for a long time, mostly as means of introducing "anomalous" dissipation. In this work, we investigate the role played by instabilities of thin current layers in the dynamics of reconnection in weakly collisional regimes, where the layer thickness is below ion kinetic scales, reconnection rate scales relatively weakly with dissipation and system size, and reconnection field is of the order of runway critical field. To this end, we performed fully kinetic 3D simulations with a Monte-Carlo treatment of Coulomb collisions in the geometry mimicking Magnetic Reconnection eXperiment (MRX). Simulation results are compared with predictions from linear Vlasov theory and experimental observations from MRX. Consistent with experimental results and earlier collisionless simulations of reconnection in neutral sheet geometry, two classes of instabilities with frequencies in the lower-hybrid range are observed. A short wavelength mode with wavelength of the order of electron gyroradius is localized at the edge of the current layer, while a longer wavelength electromagnetic instability is localized at the center. The resulting fluctuations produce both a finite contribution in the average out-of-plane force balance at the center of the current sheet and structural perturbations of the current layer. Their role in global reconnection dynamics is discussed.

Impact of Magnetic Draping, Convection, and Field Line Tying on Magnetopause Reconnection Under Northward IMF
D. E. Wendel, P. H. Reiff, and M. L. Goldstein

We simulate a northward IMF cusp reconnection event at the Earth's magnetopause using the Open GGCM resistive MHD code. The ACE input data, solar wind parameters, and dipole tilt belong to a 2002 reconnection event observed by IMAGE and Cluster. Based on a fully three-dimensional global skeleton of separators, nulls, and parallel electric fields, we show how magnetic draping, convection, and ionospheric field line-tying play a role in producing a series of locally reconnecting nulls with flux ropes. The flux ropes lie in the cusp along the global separator line of symmetry. In 2D projection, the flux ropes have the appearance of a tearing mode with a series of 'x's' and 'o's' but bearing a kind of 'guide field' that exists only within the magnetopause. The reconnecting field lines in the string of flux ropes involve IMF and both open and closed Earth magnetic field lines. The observed magnetic geometry reproduces the findings of a superposed epoch and impact parameter study derived from the Cluster magnetometer data for the same event. The observed geometry has repercussions for spacecraft observations of cusp reconnection and for the imposed boundary conditions of reconnection simulations.

Thursday: Session H: Initiation/Cessation of Reconnection

Initiation and Cessation of Fast Magnetic Reconnection: a Tutorial

A. Bhattacharjee

The onset of fast magnetic reconnection is widely studied in the context of substorms in the Earth's magnetosphere, eruptive flares, and laboratory experiments. These observations place strong constraints on theory, which must explain not only a fast reconnection rate but also a sudden increase in the time-derivative of the reconnection rate. We will show by means of theory and high-resolution simulations that important features of such dynamics in systems of moderate size can be accounted for in one unifying framework by means of the Hall MHD model. The theory also elucidates the role of diamagnetic drifts that can quench nonlinearly the onset of fast reconnection. Thus, the theory explains not only when reconnection is near-explosive, but also when it cedes.

The problem takes on additional complexity when it is applied to large systems, which have been the subject of considerable interest recently. Thin current sheets in systems of large size that exceed a critical value of the Lundquist number are unstable to a super-Alfvénic tearing instability, referred to as the plasmoid instability because it is a copious source of plasmoids (or magnetic islands). As a result of this instability, the system is shown to realize a fast nonlinear reconnection rate that is independent of the Lundquist number of the plasma.

Extending Hall Reconnection to Large-scale Reconnection in the Corona

P. A. Cassak, J. F. Drake, M. A. Shay, and L. S. Shepherd

We investigate outstanding issues for incorporating small-scale Hall physics into large-scale coronal settings, paying particular attention to the onset of fast reconnection and the nature of Sweet-Parker reconnection in high Lundquist number plasmas. The reconnection that mediates magnetic energy release in solar eruptions likely takes place at very small length scales deep within large-scale structures present in the solar corona. It has been argued that collisionless effects such as the Hall effect, which operate at scales smaller than the ion gyroradius, can account for the rapid reconnection rate inferred in observations. More recently, it was argued that the transition from slow Sweet-Parker (collisional) reconnection to Hall reconnection in weakly collisional plasmas is catastrophic, which could provide a physical mechanism for the abrupt onset of solar eruptions. While much progress has been made, applying this basic physical scenario to coronal parameters (with its extremely high Lundquist numbers) is very challenging. A major conundrum lies in our lack of understanding of Sweet-Parker reconnection at high Lundquist numbers, which is marked by the presence of secondary islands. It is widely accepted that they make Sweet-Parker reconnection faster, but it is not known how much faster, nor their full impact on the catastrophic onset of Hall reconnection.

In this talk, we discuss a few relevant results based upon theoretical and numerical studies. (1) During suitably quasi-steady temporal evolution at modestly high Lundquist numbers, we show that the reconnection rate with secondary islands is faster than classical Sweet-Parker reconnection by the square root of the number of islands, in agreement with a recent model [Daughton et al., *Phys. Rev. Lett.*, **103, 065004** (2009)]. Therefore, the speed-up of Sweet-Parker reconnection is governed by how many secondary islands are present, and a firm prediction of whether the reconnection remains slow or becomes fast awaits a better understanding of secondary island formation. (2) Reconnection in the corona is likely embedded, meaning the diffusion region is on a much smaller scale than the macroscopic current sheet. We show that this diminishes secondary island generation, slows the reconnection, and broadens the diffusion region relative to predictions using the macroscopic magnetic field. (3) In light of these results, we discuss how secondary islands at large Lundquist numbers impact the onset of Hall reconnection. Implications for solar eruptions are discussed.

CME Initiation and Reconnection
J. T. Karpen

Coronal mass ejections (CMEs) are the most massive explosions in the heliosphere, and the primary drivers of geoeffective space weather. This talk will be focused on fast CMEs, which travel at Alfvénic speeds as high as 2500 km/s. These ejections are associated with solar flares, prominence eruptions, and energetic particles accelerated near the Sun and in interplanetary space. CMEs require sufficient energy storage, in the form of magnetic stress, and rapid release of this energy. Although it is generally agreed that magnetic reconnection is the key to fast CME initiation, different models incorporate reconnection in different ways. One promising model --- the breakout scenario --- involves reconnection in two distinct yet interconnected locations: breakout reconnection ahead of the CME, and flare reconnection behind it. This model has been validated through 2D and 3D MHD simulations and favorable comparison with the observed properties of many fast CMEs. I will discuss what we have learned about the onset and evolution of breakout and flare reconnection from recent high-resolution 2D simulations of CME initiation with adaptive mesh refinement and numerical resistivity.

Thursday: Session I: Particle Acceleration in Reconnection

Particle Heating and Acceleration in Magnetic Reconnection
J. F. Drake

The magnetic energy released during magnetic reconnection appears as high-speed flows, heat and energetic particles. In flares the fraction of energy going into energetic particles is large. In the magnetosphere the conversion to energetic particles is sometimes observed but is apparently less efficient than in the sun. In solar wind reconnection events ion heating is observed but there is no energetic component of either species. How this conversion of magnetic energy takes place and why the conversion efficiency is so high in some situations but not other is not understood. Recent developments in our understanding of reconnection have important implications for understanding energetic particle production. In the corona reconnection at a single large x-line appears to be incapable of explaining the large numbers of energetic electrons. On the other hand, the current layers that develop near reconnection sites are likely to break up into volume-filling magnetic islands whose dynamics and size spectrum are may control particle acceleration. Satellite measurements provide evidence for secondary island formation during reconnection in the magnetosphere and corona with some evidence that energetic particles are associated with magnetic islands. Exploring reconnection in such a complex environment is in its infancy. Electrons in a multi-island system can be accelerated by both parallel electric fields and Fermi reflection in contracting magnetic islands. Ions crossing into the outflow exhausts from reconnection gain energy through a pickup process and super-Alfvénic ions can also undergo acceleration during island contraction and merger. There is some evidence from simulations that the plasma beta may be a control factor in reconnection-driven particle acceleration -- in finite beta systems contracting magnetic islands quickly bump against the firehose condition and reconnection shuts down. Whether this can explain the efficiency of particle acceleration in flares versus the higher beta solar wind and Earth's magnetosphere remains an open question. In the talk observations and theoretical developments will be reviewed.

Electron Acceleration in Solar Flares: RHESSI Observations
S. Krucker

Solar flares are efficient particle accelerators. Flare-accelerated electrons produce bremsstrahlung emission in the hard X-ray range. Hard X-ray observations therefore provide an excellent diagnostic to study electron acceleration in solar flares. I will give an introduction of solar flare hard X-ray observations, in particular from RHESSI, and discuss these observational results relative to magnetic reconnection models.

In Situ Satellite Observations of Particle Acceleration during Reconnection
M. Øieroset

In-situ satellite observations in the Earth's magnetosphere show that reconnection can accelerate particles to high energies. However, the observations have not revealed the dominant acceleration sites or process. Some studies suggest that particles are accelerated to high energies predominantly in the reconnection outflow region, while others indicate a source in the vicinity of the reconnection diffusion region itself, yet others point to energization associated with magnetic islands. In this talk I will review these various observations and discuss the possibility that different acceleration mechanisms, all associated with reconnection, may coexist. I will also contrast these observations with the lack of high energy particle production seen in solar wind reconnection exhausts.

Radio Observations of the Sun and Magnetic Reconnection
S. White

This paper will critically review radio phenomena on the Sun from the point of view of magnetic reconnection. Topics will include the issue of radio bursts on open and closed field lines, magnetic connectivity revealed by images of microwave bursts, and the implications of radio observations of a range of very different phenomena for the nature of energy release and particle acceleration.

Thursday: Session J: Reconnection in Different Plasma Regimes: The Problem of Scaling

Scaling of Magnetic Reconnection in Collisional and Kinetic Regimes
W. Daughton, V. Roytershteyn, B. Albright, H. Karimabadi, L. Yin, and K. Bowers

In various applications in space, laboratory and astrophysical plasmas, magnetic reconnection is thought to occur over a wide range of plasma collisionality in systems that are vastly larger than the underlying kinetic scales. To make reliable predictions, it is important to identify the essential physics in various regimes and use this knowledge to develop reliable scalings. Working towards this goal, researchers typically divide the problem into collisional and kinetic reconnection and employ both reduced fluid models and fully kinetic treatments. At the present time, there remain some considerable uncertainties in both regimes, regarding the scaling of the reconnection dynamics, the precise transition criteria between regimes, and the fidelity of reduced fluid models in kinetic plasmas. Recently, it has become possible to rigorously model the transition between collisional and kinetic regimes by including a Fokker-Planck treatment of Coulomb collisions within the kinetic simulations. This new approach permits a direct solution of the full plasma kinetic equation, which forms the theoretical basis for all fluid models. In this talk, the present understanding of magnetic reconnection is reviewed in both fully collisional and kinetic parameter regimes, with an emphasis on new developments in the past few years. Results from the new Fokker-Planck kinetic simulations are used to guide the discussion, and illustrate new developments, such as the formation of plasmoids (secondary islands) within the reconnection layers. There is mounting evidence that plasmoids may be a common feature of large-scale reconnection layers in both collisional and kinetic plasmas.

Depending on the parameter regime, these plasmoids may play an important role in influencing the scaling of reconnection. Furthermore, the formation of plasmoids within the collisional regime can play an essential role in driving the system towards kinetic scales, where kinetic reconnection mechanisms take over. During this transition, the reconnection electric field can rapidly exceed the Dreicer limit, resulting in the formation of extended electron-scale layers which are also unstable to plasmoid formation. The collisional kinetic simulations are an ideal tool to study these various problems. Understanding the similarities and differences with reduced fluid models may lead to improved fluid closures and allows us to better predict scaling properties of magnetic reconnection in very large systems.

The Scaling of Reconnection to Large-scale Systems
M. Shay

Magnetic Reconnection is a multiscale boundary layer process. As such, it is notoriously difficult to study because a complete description requires both resolving the microscopic diffusion region where frozen-in is broken and also simulating the macroscopic global dynamics which are driven by reconnection. A key question regarding reconnection has been: Can theories of magnetic reconnection reproduce the energy release rates inferred from observations? This presentation will review the progress made in answering this question in the past decade. The bottom line is that in a limited scope, reconnection simulations are converging on the conclusion that predicted reconnection rates do in fact match observations. What is still controversial, however, is the physics mechanisms necessary to allow such fast reconnection rates. Recent results regarding this controversy will be presented, and our current understanding will be outlined.

Current Sheet Instability and Plasmoid Formation in MHD
N. F. Loureiro, D. A. Uzdensky, A. A. Schekochihin, S. C. Cowley, and R. Samtaney

Magnetic reconnection is a ubiquitous plasma physics phenomenon, characterized by rapid reconfiguration of the magnetic field topology. Within the simplest plasma framework — single fluid resistive MHD — the Sweet-Parker (SP) model provides the currently accepted description of reconnection. Famously, however, the SP model predicts reconnection rates, which are orders of magnitude too slow to explain observations. It is known that fast reconnection rates can be obtained in more complex, collisionless descriptions of the plasma. However, in some situations the density is sufficiently high that the current layer is collisional and resistive MHD should apply. Can reconnection be fast in those environments? The SP model disregards two essential facts: first, that most, if not all, plasmas where reconnection takes place are likely to be turbulent; second, that the current layers predicted by the SP theory are now realized to be violently unstable to plasmoid (secondary island) formation. In this talk, we discuss the effects of turbulence and plasmoids in MHD reconnection. We present the first analytical theory of the instability of SP-like current sheets and formation of plasmoid chains. Results of direct numerical simulations are shown, validating the theoretical predictions and detailing the complex nonlinear evolution of this instability. These results strongly suggest that high-Lundquist-number reconnection is inherently time-dependent and hence call for a substantial revision of the standard Sweet-Parker quasi-stationary picture. When turbulence is added to the background, we obtain reconnection rates whose dependence on the plasma resistivity (h) is much shallower than the SP h 1/2 dependence, indicating that fast reconnection is possible within the resistive MHD framework.

Observations of Islands in Coronal Current Layers
J. Raymond and N. Murphy

Outward moving blobs in the current sheets that connect CMEs to the associated flare loops have been attributed to islands formed by the tearing mode or a related instability, and their speeds have been used as estimates of the Alfven speed. We discuss the tearing mode interpretation and the level of variability of high temperature UV emission somewhat lower in the current sheet.

Friday: Session K: Coupling the Global to the Local I

Coupling the Global to the Local
S. K. Antiochos

Understanding how processes couple across spatial scales is one of the most difficult challenges in all of physics, and is undoubtedly the main obstacle to developing predictive models for space weather. Cross-scale coupling is especially important for understanding magnetic reconnection, because the process can take on dramatically different global forms, (e.g., Sweet-Parker versus Petschek), depending on the detailed properties of the kinetic-scale diffusion region. I will describe how the coupling between global and local is critical for determining whether reconnection in the Sun and magnetosphere leads to quasi-steady or explosive activity. The issue of global-local coupling is so critical to understanding and predicting space weather, such as CMEs/flares and geomagnetic storms, that the NASA LWS Program has established a focus science team whose goal is to advance our theories and methods for calculating global-local coupling in the corona and magnetosphere. I will review the various approaches that are being taken to solve the challenges of global-local coupling in magnetic reconnection, and discuss opportunities for future progress. This work was supported by the NASA TR&T and HTP programs.

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