2012 US-Japan Workshop on Magnetic Reconnection (MR2012)

Book of Abstracts

May 23-25, 2012
Princeton, New Jersey

Photo: Princeton University, Office of Communications

Workshop website: http://mr2012.pppl.gov

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Meeting Announcement

We are pleased to announce the 2012 US-Japan Workshop on Magnetic Reconnection (MR2012) will be held at Princeton University from May 23 to 25, 2012. This is the latest in a series of meetings on the same subject since the first workshop in 1998, also held in Princeton. The scientific topics include:

- General Reconnection Physics (Theoretical and Numerical Studies)
- Magnetic Reconnection in Solar Plasmas (Solar Flares, Coronal Mass Ejections, Coronal Heating, Solar Wind, etc.)
- Magnetic Reconnection in Magnetosphere (Magnetotail, Magnetopause, Substorms, etc.)
- Magnetic Reconnection in Astrophysical Systems (Accretion Disks, Protostars, AGN Jets, Cluster of Galaxies, Pulsar Wind, etc.)
- Magnetic Reconnection in Laboratory Experiments (Basic and fusion plasma experiments)

Support

This meeting is in part supported by Princeton Plasma Physics Laboratory, also by the JSPS Core-to-Core Program on CMSO.

Scientific Organizing Committee (SOC):

Hantao Ji (PPPL, Chair, Organizer)
Spiro Antiochos (NASA-GSFC)
James Drake (U. Maryland)
Michael Hesse (NASA-GSFC)
Ritoku Horiuchi (NIFS)
Masahiro Hoshino (U. Tokyo)
Ryoji Matsumoto (Chiba U.)
Yasushi Ono (U. Tokyo)
Kazunari Shibata (Kyoto U.)
Ellen Zweibel (U. Wisconsin)

Workshop Coordinators and Supporting Staff
Carol Austin
Terry Greenberg
Olga Tishinin
Lynda Lauria

WEDNESDAY, MAY 23, 2012

8:00am Registration

8:25am Announcements

Astrophysical Reconnection (E. Zweibel, U. Wisconsin)

8:30am **M. Hoshino** (U. Tokyo): Magnetic Reconnection and Particle Acceleration during Kinetic Magneto-Rotational Instability in an Accretion Disk

8:55am **R. Matsumoto** (Chiba U.): Three-dimensional, Magnetohydrodynamic Simulations of Disk Dynamos

9:10am **J. McKinney** (Stanford): Reconnection near Black Holes

9:35am **H. Takahashi** (NAOJ): Radiative MHD Simulation of Relativistic Magnetic Reconnection

10:00am Break

Reconnection in Lab (Y. Ono, U. Tokyo)

10:20am **P. Bellan** (Caltech): Dynamics of Open-field-line MHD Configurations

10:45am **M. Brown** (Swarthmore): Spectroscopic observation of simultaneous bi-directional reconnection outflows in SSX

11:00am **T. Gray** (Swarthmore): Turbulence, selective decay, and merging in the SSX plasma wind tunnel

11:15am **H. Tanabe** (U. Tokyo): Ion and Electron Heating during Magnetic Reconnection in TS-3, TS-4 and MAST Torus Plasma Merging Experiments

11:30am **M. Gryaznevich** (Culham): Magnetic reconnection studies on MAST

11:45am **M. Brookhart** (U. Wisconsin): Stability of hollow and reversed current channels in a Line-Tied Screw Pinch

12:00pm Lunch

Reconnection Theory and Reconnection in Space (M. Hesse, NASA-GSFC)

1:30pm **W. Daughton** (LANL): Influence of Magnetic Shear and Profile Asymmetry on Reconnection at the Magnetopause

1:55pm **P. Pritchett** (UCLA): Three-Dimensional Effects, or the Lack Thereof, in Asymmetric Collisionless Magnetic Reconnection

2:10pm **P. Cassak** (West Virginia U.): Guide Field Dependence of X-line Spreading in Three-Dimensional Magnetic Reconnection

2:25pm **T. Nakamura** (LANL): Kinetic aspects of the vortex-induced reconnection in collisonless plasmas: 2D and 3D PIC simulations

2:40pm **H. Che** (NASA-GSFC): Anomalous Momentum Transport in Fast Electron Heating Process and the role in Magnetic Reconnection

2:55pm **M. Goldstein** (NASA-GSFC): Dissipation of magnetofluid turbulence as observed on the scale of the Larmor radius

3:10pm **P. Wyper** (U. Sheffield): Spine-Fan Reconnection

3:25pm **Discussion (E. Zweibel, U. Wisconsin)**

3:45am Break

4:00pm **Poster Session (18 Posters)**

5:30pm Adjourn

Magnetic Reconnection and Particle Acceleration during Kinetic Magneto-Rotational Instability in an Accretion Disk

Masahiro Hoshino
University of Tokyo

Magnetic reconnection during Magneto-Rotational Instability (MRI) is known to play an important role on the angular momentum transport in astrophysical accretion disks, and the nonlinear time evolution of magneto-rotational instability has been extensively investigated by using MHD simulations. However, our understanding of the kinetic (collisionless) behavior of MRI is limited. In this talk, we study the kinetic (collisionless) MRI and particle acceleration by focusing on magnetic reconnection by using 2d and 3d-PIC simulations. We discuss that the channel flow initiated at the nonlinear stage of MRI leads to a strong pressure anisotropy due to an action of MRI dynamo, and the anisotropic channel flow becomes unstable for the collisionless tearing mode/reconnection. As a result, the kinetic reconnection is initiated and after the onset of reconnection non-thermal power law energy spectrum N(E)=E**(-p) with a hard spectral index p=1-1.5 is quickly formed. We also discuss that the kinetic MRI is one of candidate mechanisms to explain the nonthermal particles observed around a massive black hole of Sgr A*.

Three-dimensional Magnetohydrodynamic Simulations of Disk Dynamos

Ryoji Matsumoto (Chiba University) and Mami Machida (Kyushu University)

We carried out global magnetohydrodynamic simulations of dynamos in differentially rotating disks such as galactic gas disks and accretion disks. Equatorial plane is included in the simulation region to enable the growth of the structure non-symmetric to the equatorial plane. Numerical results indicate that magnetic fields are amplified in the disk by the magneto-rotational instability(MRI). When the plasma β in the surface layer of the disk decreases below 5, the magnetic flux buoyantly escapes from the disk by Parker instability, forming magnetic loops in the disk corona. The buoyant escape of the magnetic flux induces the growth of magnetic fields with opposite polarity inside the disk, and drive quasi-periodic reversal of mean azimuthal magnetic fields. The time scale of the field reversal is about 10 rotation period.

Even when we start from initial azimuthal magnetic fields symmetric to the equatorial plane, mean azimuthal magnetic fields anti-symmetric to the equatorial plane tend to grow. By post processing the results of simulations assuming galactic gravitational potential, we obtained all sky maps of the Faraday rotation of polarized electromagnetic waves, which can be compared with observations. When the central object is a black hole, observations of the time variations of the polarization angle of radiation may enable us to confirm the dynamo activity. Since the synchrotron emissivity depends on the strength of magnetic fields, the dynamo activity of the inner torus can be the origin of low-frequency quasi-periodic oscillations (QPOs) observed in black hole candidates.

We also discuss the effects of cooling on disk dynamos. When the cooling instability takes place in the disk, mean azimuthal magnetic fields anti-symmetric to the equatorial plane reconnect when the disk shrinks in the vertical direction. Mean azimuthal magnetic flux symmetric to the equatorial plane may remain after the cooling instability, and support the disk by magnetic pressure.

Reconnection near Black Holes

Jonathan McKinney

Stanford University

Magnetic reconnection occurs near black holes during accretion due to the accumulated magnetic field, due to dynamo-generated fields, and during expulsion of magnetic fields. I discuss these in the context of fully 3D GRMHD simulations.

Radiative MHD Simulation of Relativistic Magnetic Reconnection

Hiroyuki R. Takahashi
National Astronomical Observatory of Japan

The efficiency of the energy conversion rate in the relativistic magnetic reconnection is investigated by means of Relativistic Resistive Magnetohydrodynamic (R2MHD) simulations. We confirmed that the simple Sweet-Parker type magnetic reconnection is a slow process for the energy conversion as theoretically predicted by Lyubarsky (2005). After the Sweet-Parker regime, we observed a growth of the secondary tearing mode in the elongated current sheet. Then the energy conversion rate and the outflow velocity of reconnection jet are rapidly increased.

Next, we extend our R2MHD code to R3MHD code by including the radiation effects (Relativistic Resistive Radiation Magnetohydrodynamics R3MHD) to construct a more realistic model of relativistic reconnection. The radiation field is described by the 0th and 1st moments of the radiation intensity. The code has already passed some 1-dimensional and multi-dimensional numerical problems. We demonstrate the first results of R3 MHD simulation and discuss the radiation effects on the dynamics of the magnetic reconnection.

Dynamics of Open-field-line MHD Configurations

P. M. Bellan, A. L. Moser, and E. V. Stenson

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Abstract
The Taylor relaxation theory prediction that there exists a unique minimum-energy state towards which a magnetized plasma invariably relaxes has applicability to magnetic fusion confinement (spheromaks and RFP's), the solar corona, and certain astrophysical plasmas. While Taylor theory predicts the minimum-energy end state reasonably well, it does not even attempt to describe what actually *happens*, i.e., does not predict the dynamics underlying relaxation. Furthermore, Taylor theory assumes zero beta whereas actual plasmas have finite beta. The actual dynamics underlying self-organization of a magnetized plasma has been investigated using two related devices, a coaxial magnetized plasma gun and a bipolar magnetized plasma gun. Experimental observations using high speed imaging that resolves sub-Alfven time scales have given insights into what happens during Taylor relaxation and also have revealed unexpected and altogether new phenomena. Measurements revealed that a highly collimated MHD-driven plasma flow, i.e., a magnetized plasma jet, is a critical feature of the dynamics. The jet velocity is found to be in good agreement with an MHD acceleration model. These MHD jets are self-collimating as a result of interaction between the magnetic pinch force and jet stagnation. Depending on the flaring of the flux tube radius, open flux tubes can have jets flowing into the flux tube from both ends or from just one end. Jets kink when the Kruskal-Shafranov stability limit is breached; the effective gravity resulting from the acceleration of a sufficiently strong kink can cause a fine-scale, extremely fast Rayleigh-Taylor instability that erodes the current channel to be smaller than the ion skin depth. This cascade from the ideal MHD scale of the kink to the non-MHD ion skin depth scale results in a fast magnetic reconnection whereby the jet breaks off from its source electrode.

Supported by USDOE, NSF, AFOSR

Spectroscopic observation of simultaneous bi-directional reconnection outflows in SSX

M. R. Brown, T. Gray, C. Myers, E. Belova

Swarthmore College

Swarthmore, PA 19081 USA

We report a direct spectroscopic measurement of simultaneous bi-directional outflows from a reconnection event in the SSX plasma merging experiment. The result is a combination of spectroscopic and magnetic measurements, coupled with a recent 3D MHD simulation (see Myers, et al, Physics of Plasmas (2011)). Merging SSX plasmas have electron density up to $10^{21}\ m^{-3}$, temperatures $T_e \sim T_i \cong 20$ eV, and typical large-scale magnetic fields of 0.1 T. These parameters give an external Alfvén speed of 70 km/s. The plasma is fully ionized and fully magnetized $\rho_i \ll R$, where $R = 0.2\ m, L = 0.6\ m$ is the outer flux conserving boundary of the plasma (defined by a cylindrical copper wall). The global Lundquist number in these large-scale merging SSX plasmas is $S = \mu_0 V_A R/\eta_\perp \cong 1000$, whereas the local Lundquist number at the layer is much smaller. Outflow speeds are Alfvénic and Abel analysis shows that the outflows are generated in the plasma core. Analysis of outflow speed coupled with external measurements of reconnection electric field and assumption of Spitzer resistivity predict an aspect ratio of the reconnection layer and reconnection rate that are close to that measured in the experiment and in simulations. The fully 3D MHD simulation reproduces outflow speeds as well as the small-scale dimensions of the layer. The simulation predicts a steady outflow, whereas the experimental outflow is bursty. A simple prediction of the layer width using Spitzer resistivity underestimates the absolute scale of the layer, indicating other than resistive, Sweet-Parker physics is at play.

Work supported by US DOE and CMSO.

Turbulence, selective decay, and merging in the SSX plasma wind tunnel* T. Gray, M. Brown, K. Flanagan, D. Weinhold *Swarthmore College* and V. Lukin *NRL* - A helical, relaxed plasma state has been observed in a long cylindrical volume. The cylinder has dimensions $L = 1$ m and $R = 0.08$ m. The cylinder is long enough so that the predicted minimum energy state is a close approximation to the infinite cylinder solution. The plasma is injected at $v \geq 50$ km/s by a coaxial magnetized plasma gun located at one end of the cylindrical volume. Typical plasma parameters are $T_i = 25$ eV, $n_e \geq 10^{15}$ cm^{-3}, and $B = 0.25$ T. The relaxed state is rapidly attained in 1–2 axial Alfvén times after initiation of the plasma. Magnetic data is favorably compared with an analytical model. Magnetic data exhibits broadband fluctuations of the measured axial modes during the formation period. The broadband activity rapidly decays as the energy condenses into the lowest energy mode, which is in agreement to the minimum energy eigenstate of $\nabla \times \vec{B} = \lambda \vec{B}$. While the global structure roughly corresponds to the minimum energy eigenstate for the wind tunnel geometry, the plasma is high beta ($\beta = 0.5$) and does not have a flat λ profile.

Merging of two plasmoids in this configuration results in noticeably more dynamic activity compared to a single plasmoid. Localized fluctuations at the ion cyclotron frequency are observed many Alfvén times after the plasmoid is initiated. These episodes of activity exhibit several characteristics associated with magnetic reconnection, though the global structure of the plasma is not known. Strong flows and impurity ion (CIII) heating, obtained with ion doppler spectroscopy, are often correlated with these bursts of activity.

*Supported by US DOE and NSF.

Ion and Electron Heating during Magnetic Reconnection in TS-3, TS-4 and MAST Torus Plasma Merging Experiments

H. Tanabe, T. Yamada, A. Kuwahata, H. Oka, M. Annoura, Y. Hayashi, S. Kamio, M. Inomoto, Y. Ono and M. Gryaznevich*

Graduate School of Frontier Sciences, University of Tokyo

* EURATOM/CCFE Fusion Association, Culhum Science Center

For the past ten years, we have studied plasma heating during magnetic reconnection using 2-D Doppler diagnostics in TS-3 and TS-4. The measured ion and electron temperature profile indicates that electrons are heated mainly inside the current sheet by its Ohmic heating power, ions are heated mainly by the reconnection outflow damping in the two downstream areas. The reconnection outflow converts energy of reconnecting magnetic field $B_{//}$ mostly to the ion thermal energy, indicating that the reconnection heating energy is proportional to $B^2_{//}$.

We have started the world largest reconnection experiment with torus plasma merging device MAST, to extend the reconnection heating experiment over 1keV for fusion plasma heating. A high spatial resolution (130 channels) Thomson scattering system found a direct evidence of double density peaks moving toward the downstream and electron heating localized around the reconnection point. A new finding is that the electron temperature in the downstream increases up to 500eV at about 20ms (comparable to $\tau_{Ee\text{-}i}$) after the completion of the merging. Its most probable explanation is slow energy conversion from hot ions at the two downstream regions to electrons. We are now installing a new high resolution Doppler tomography diagnostics for the first profile measurement of ion temperature during and after the magnetic reconnection in MAST.

Magnetic reconnection studies on MAST.

M Gryaznevich & MAST team.

[1]*Euratom/CCFE Fusion Association, Culham Science Centre, Abingdon, UK*

Magnetic reconnections are often observed in high-temperature, low-collisional MegaAmp Spherical Tokamak (MAST) plasmas. They happen during MHD events, e.g. sawteeth, Internal Reconnection Events (IRE), Edge Localised Modes (ELMs) and also during merging-compression plasma formation process. The merging-compression start-up has been successfully used for the plasma formation on START, MAST and other spherical tokamaks (STs) and recently has been intensively studied using high-resolution Thomson Scattering (TS) and other diagnostics on MAST. During this process, two plasma rings merge together to form high-temperature (up to 1.2keV) plasma with densities of the order of 10^19m^-3. Typical toroidal magnetic field in these experiments is up to 0.5T and typical plasma currents achieved after the merging is up to 500kA. In the talk, recent results of 2D electron temperature and density profiles measurements and their analysis will be presented, as well as preliminary results of the ion temperature measurement. A brief overview of the MAST facility and diagnostics will be given.

Stability of hollow and reversed current channels in a Line-Tied Screw Pinch

Matthew Brookhart, Carlos Paz-Soldan, Cary Forest

April 25, 2012

Theories of coronal loop formation and stability indicate that current in coronal loops may be created by twisting vortices in the photosphere at the line-tied footprints of loops. Such convection necessarily creates a coaxial current structure where current on axis flows oppositely to current at larger radii. To study the equilibria and MHD stability of these Zero-Net Current structures, the modular current injection scheme on the Rotating Wall Machine at the University of Wisconsin - Madison has been modified to allow coaxial current injection. Different levels of coaxial current drive are shown to produce radically different stability criterion. Instaibilities are studied through shot-to-shot averaging of 2D internal equilibrium profiles, external magnetic measurements, and current at the linear ends of the device. Instabilities in the Rotating Wall Machine (RWM) show coherent oscillations but also ocassionally exhibit reconnection events that periodically flatten the current profile and change the magnetic topology. The line-tied boundary conditions present in the device provide an ideal analogue to coronal loop and solar flare physics.

Influence of Magnetic Shear and Profile Asymmetry on Reconnection at the Magnetopause

William Daughton[1], Vadim Roytershteyn[2] and Homa Karimabadi[2]

[1]Los Alamos National Laboratory, Los Alamos, NM
[2]University of California San Diego, La Jolla, CA

Fully kinetic 3D simulations are leading to a variety of new predictions regarding the onset and nonlinear evolution of magnetic reconnection within current layers relevant to the Earth's magnetopause. During the onset phase, primary flux ropes appear within the initial ion-scale current layer, while at later times secondary flux ropes are spontaneously generated within elongated electron-scale current sheets that develop nonlinearly as part of the reconnection process. The details of both phases are strongly influenced by the amount of magnetic shear across the layer as well as the inherent profile asymmetries that exist. When the electron layers form in low-β regions, the lower-hybrid drift instability (LHDI) can grow rapidly and suppress the formation of secondary flux ropes, while in high-β regions the dynamics of the electron layers are strongly influenced by temperature anisotropy. These results offer a range of new predictions for both current and upcoming spacecraft missions.

Three-Dimensional Effects, or the Lack Thereof, in Asymmetric Collisionless Magnetic Reconnection

P.L. Pritchett[1] and F.S. Mozer[2]

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2. Space Sciences Laboratory, University of California, Berkeley, CA 94720

The 2-D approximation has been remarkably successful in describing the features and dynamics of collisionless magnetic reconnection. With no spatial variation allowed in the out-of-plane (y) direction, the electric field E_y is then purely inductive, $E_y = -\partial A_y/\partial t$. Numerous 2-D models all predict that this field should have the value $E_y \sim 0.1 v_A B_0$. Despite this theoretical agreement, numerous observations have been reported of much more intense E_y fields, particularly on the magnetosphere side of the subsolar magnetopause.

We use a 3-D particle-in-cell simulation model for an asymmetric current sheet configuration (with an asymmetry factor $B_z/n = 30$ between the magnetosphere and magnetosheath sides of the current layer and a large enough value of the ion to electron mass ratio = 200 to permit excitation of LHDI waves) to investigate the role of 3-D effects in magnetic reconnection without a guide field. LHDI type modes are observed to be localized in the strong density gradient region along the magnetosphere separatrices (Fig. 1a) and to satisfy a $\mathbf{k} \cdot \mathbf{B} = 0$ condition. These waves are very strong $\sim 4 v_A B_0 \sim 100$ mV/mv, propagate in the dawnward direction at a small fraction of the Alfvén speed, and exhibit characteristic discrete oscillation frequencies between the proton cyclotron frequency and the lower hybrid frequency (consistent with THEMIS observations). These waves are localized well away from the X line and, despite their intensity, appear not to alter the underlying 2-D reconnection rate (Fig. 1b, 1c).

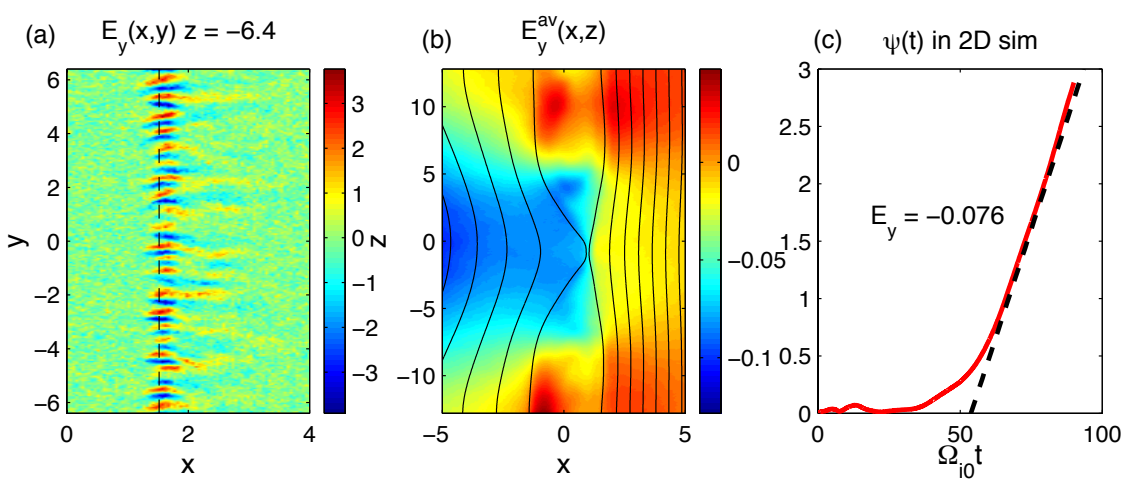

Figure 1. (a) Strong LHDI type E_y fields along the magnetosphere separatrix (dashed line) in xy plane at $z = -6.4$; (b) Average over all y of the E_y field in the 3-D simulation; (c) reconnected flux function in corresponding 2-D simulation (E_y = slope of dashed line).

Title:

Guide Field Dependence of X-line Spreading in
Three-Dimensional Magnetic Reconnection

Authors:

L. S. Shepherd[1], P. A. Cassak[1], T.-D. Phan[2],
M. A. Shay[2,3], and J. T. Gosling[4]

Affiliations:

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[2]University of California, Berkeley
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Abstract:

Magnetic reconnection occurring naturally in space and laboratory settings often begins in a spatially localized region and spreads in the direction normal to the reconnection plane as time progresses. This has been studied numerically for magnetotail applications such as substorms and bursty bulk flows; it was shown by a number of authors that X-lines spread due to the motion of whichever species carries the current. For these simulations, the out-of-plane (guide) field was typically zero or very small. However, the spreading of reconnection X-lines has been observed or inferred in other settings in which a significant guide field is expected to be present. For example, laboratory experiments with a large guide field (Katz et al., Phys. Rev. Lett., **104**, 255004, 2010) revealed X-line spreading in both directions at the Alfven speed based on the guide magnetic field. Additionally, in the Bastille Day flare, the flaring region spreads in both directions normal to the inferred reconnection plane (Qiu et al., Ap. J., **725**, 319, 2010). Thus, the observations clearly imply that the nature of X-line spreading is qualitatively different with and without a guide field. We present theoretical arguments to predict the condition on the guide field at which the nature of the spreading switches from being caused by the current carriers to being caused by Alfven waves and present three-dimensional two-fluid numerical simulations which agree with the predictions (Shepherd and Cassak, in preparation). Applications for solar eruptions and reconnection in the solar wind will be discussed.

Kinetic aspects of the vortex-induced reconnection in collisonless plasmas: 2D and 3D PIC simulations

T.K.M. Nakamura[1], W. Daughton[1], H. Karimabadi [2], H. Hasegawa[3], and I. Shinohara[3]

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(2) University of California San Diego, La Jolla, California, USA

(3) Institute of Space and Astronautical Science, JAXA, Sagamihara, Kanagawa, Japan

Abstract

We investigate the reconnection process induced by the MHD-scale Kelvin-Helmholtz (KH) vortex by using 2D and 3D fully kinetic simulations. The KH vortex has long been considered as one of the most important phenomena for causing momentum and energy transport or direct plasma mixing in collisionless plasmas. In this presentation, we focus on the case in which the moderate strength of the magnetic shear coexists with the velocity shear layer. Such a configuration is thought to occur on the flanks in the planetary magnetospheres such as the Earth and Mercury. We will contrast results from the symmetric and asymmetric (density jump across the layer) configurations and explore 3D effects on the evolution and the resulting transport. Past 2D MHD and two-fluid simulations showed that the flow of the KH vortex strongly compress the current sheet (the shear layer), and hence can quickly drive reconnection even in MHD-scale boundary layers. Indeed, recent in-situ observations succeeded in showing direct evidence of reconnection between flow vortices. Our recent 2D (PIC) simulations newly revealed that the so-called vortex-induced reconnection (VIR) is commonly accompanied by the multiple magnetic island formation in the current sheet compressed by the KH vortex. This multiple island formation process leads to efficient plasma mixing within the vortex as well as particle acceleration. In the asymmetric case where there is a density jump across the velocity shear layer, secondary KH waves along the edge of the vortex are generated and eventually cause turbulence within the vortex. In our presentation, we will discuss relevance of these findings to the problem of the planetary low-latitude boundary layer (LLBL) formation.

Anomalous Momentum Transport in Fast Electron Heating Process and the role in Magnetic Reconnection

H.Che{1}, M. Swisdak{2}, J. F. Drake{2,3}, P. H. Yoon{3}, and M. L. Goldstein{1}

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2:Department of Physics, University of Maryland, College Park, MD, 20742, USA
3:IPST, University of Maryland, College Park, MD, 20742, USA

Abstract

We found that in current-driving plasma with \Omega_{ce}/\omega_{pe} < 1, a factor of 10 times stronger Buneman instability than in plasma with \Omega_{ce}/\omega_{pe} > 1 develops and causes fast growth and decay of electric field, which leads to wave-particle interactions over a broad velocity range in a few tens of electron cyclotron periods. The resulting overlapping resonance in phase space produces phase mixing and fast electron heating. The electron temperature increases 10 times in this short heating process. I will discuss the role of anomalous momentum in this anomalous heating process. The potential roles of both anomalous heating and momentum transport in reconnection will be discussed.
This program is supported by NASA Postdocal Program Fellowship (NPP).

Dissipation of magnetofluid turbulence as observed on the scale of the Larmor radius

Melvyn Goldstein (NASA/GSFC), F. Sahraoui (Laboratoire de Physique des Plasmas, CNRS-Ecole Polytechnique-UPMC), Silvia Perri (Univ. of Calabria), Haihong Che (NASA/GSFC/NPP), Peter Hunana (NASA/GSFC/NPP)

High time resolution magnetic field measurements from the four Cluster spacecraft have revealed new features of the properties of magnetofluid turbulence at small spatial scales, approaching the dissipation regime at scales close to the electron gyroscale. Various analysis techniques and theoretical ideas have been put forward to account for the properties of those measurements. We have used multipoint spectral techniques to obtain the dependence of plasma frame frequency on wave number. The results indicate that the fluctuations are consistent with being quasi-static ($\omega \ll \omega_{ci}$) and quasi-two-dimensional kinetic ($k_{\parallel} \ll k_{\perp}$) Alfvénic turbulence (KAW). We argue that these KAW have group speeds along the direction of the background magnetic field that are many times the local electron thermal speed at scales $k\rho_i \gg 1$. In the spatial domain, the magnetic field (in the two-dimensional plane that is approximately normal to the background magnetic field) is intermittent and is characterized by small current sheets (on the scale of the proton inertial length) and multiple discontinuities and large rotations of the magnetic field. These current sheets occasionally exhibit magnetic fluctuations in the minimum variance direction (parallel to the current sheet) and, less pronounced, in the out-of-plane direction (parallel to the background solar wind magnetic field) that are consistent with the KAW spectral results for $k\rho_i \gg 1$. Current work involves simulating the situation with a three-dimensional PIC code.

Spine-Fan Reconnection

P. F. Wyper & Rekha Jain
School of Mathematics and Statistics, University of Sheffield, UK

Three dimensional (3D) neutral points are important locations in the solar corona for energy release and magnetic topology change through magnetic reconnection.

The Spine-Fan reconnection mode of 3D null points is the natural analogue of X-point reconnection in 2D. Here the Spine and Fan collapse locally toward one another, forming a current sheet at an angle to both. Previous studies of this process focus on the idealized case of symmetric driving to form the current sheet. However, from observations the solar atmosphere has been shown to be highly dynamic with perturbations often lacking temporal or spatial symmetry.

We present results from numerical simulations of the Spine-Fan reconnection process driven by more generic perturbations with temporal asymmetry and varying spatial extent. We investigate the Spine-Fan collapse with asymmetric driving and consider the qualitative trends in peak reconnection rate and current for different driving velocities and plasma resistivities in a variety of driving scenarios. For certain cases we also discuss the time evolution of particle trajectories for this Spine-Fan scenario by studying the optimum energy for various pitch angles using time-snapshots taken from our simulations.

We find large differences in the peak values of reconnection rate and current attained depending on the form of driving. This indicates the number of degrees of freedom in 3D reconnection, highlighting the need for high temporal and spatial knowledge of the surrounding flows for a clear interpretation of the reconnection process.

MR2012 POSTER PROGRAM

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2	Tearing modes of (0,n) play a major rule in many RFP physical processes such as ion heating, momentum transport, and magnetic relaxation	Almagri, A.
3	Electric fields in the electron layer and secondary plasmoids during collisionless reconnection with negligible guide field	Chen, L.-J.
4	Distribution of Plasmoids in Large Scale Magnetic Reconnection	Huang, Y.-M.
5	Magnetic Fluctuations with Ion Cyclotron Range of Frequency during Fast Reconnection in Plasma Merging Experiment	Kuwahata, A.
6	Impact of Density and Gas Pressure on the Rate of Magnetic Reconnection	Lin, J.
7	The tearing instability and reconnection with force-free Harris geometry in 3D PIC simulations	Liu, Y.-H.
8	MHD simulation of solar chromospheric evaporation jets in the oblique coronal magnetic field	Matsui, Y.
9	Solar-relevant magnetic flux ropes in the laboratory: initial results and experimental plans	Myers, C.
10	Fluctuation signatures of reconnection sites	Roytershteyn, V.
11	Particle Acceleration by Reconnection at 3D Null Points	Stanier, A.
12	Quantitative Study of Guide Field Effects on Hall Reconnection in a Laboratory Plasma	Tharp, T.
13	Multi-Hierarchy Simulation with Domain Dynamic Conversion for Magnetic Reconnection Studies	Usami, S.
14	Magnetic Reconnection with Optically Thin Radiative Cooling	Uzdensky, D.A.
15	Cluster observations of non-ideal behavior at three-dimensional magnetic nulls in the turbulent magnetosheath	Wendel, D.
16	Measurement of the Hall electric field and its effects on ion dynamics	Yoo, J.
17	Magnetohydrodynamic structure of a plasmoid in fast reconnection in low-beta plasmas	Zenitani, S.
18	Magnetic reconnection in near venusian Magnetotail	Zhang, T.

Bursty, Broadband Electromagnetic Waves Associated with Three-Dimensional Nulls Observed in Turbulent Magnetosheath Reconnection

M.L. Adrian and D.E. Wendel
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We investigate observations of intense bursts of electromagnetic wave energy in association with the thin current layers of turbulent magnetosheath reconnection. These observed emissions — typically detected in the layers immediately outside of the current layer proper — form two distinct types: (i) broadband emissions that extend continuously to 10s of Hertz; and (ii) structured bursts of emitted energy that occur above 80-Hz, often displaying features reminiscent of absorption bands and are observed near the local minima in the magnetic field. We present detailed analyses of these intense bursts of electromagnetic energy and quantify their proximity to X-/O-nulls and magnetic spine connected null pairs, as well as their correlation — if any — to the amount of magnetic energy converted by the process of magnetic reconnection.

Tearing modes of (0,n) play a major rule in many RFP physical processes such as ion heating, momentum transport, and magnetic relaxation

A. Almagri, C. B. Forest, D. Den Hartog, V. Mirnov, J. Reusch, T. Tharp, D. Schnack, and J. S. Sarff

Center for Magnetic Self Organization in Laboratory and Astrophysical Plasma
University of Wisconsin-Madison

Tearing instability and nonlinear coupling results in multiple magnetic reconnection layers in the RFP and a rich island structure is generated. The role of multi- harmonics of the m=0 mode is investigated experimentally using insertable probes and by using nonlinear resistive MHD computation (DEBS). The m = 0 modes facilitate a nonlinear cascade and global core-to-edge communication through coupling with m=1 modes. Quasi-periodic impulsive reconnection events (sawteeth) are a feature of the RFP discharges. Nonlinear resistive MHD computation with DEBS reproduces a sawtooth cycle with features very much like MST observations. Evolution of the magnetic equilibrium and the excited tearing mode spectrum are very similar, but the mode amplitudes in DEBS are systematically 2 times or so larger than experiment. The m=0 modes are measured to be linearly stable throughout the sawtooth cycle. The equilibrium magnetic field can be controlled to remove the m=0 resonance in “non reversed” plasmas. Also, occasionally the m=0 mode will “miss a beat” in the sawtooth rhythm. In these cases, the global relaxation character, ion heating, and momentum breaking are muted. *Work supported by CMSO and DoE.

Electric fields in the electron layer and secondary plasmoids during collisionless reconnection with negligible guide field

Li-Jen Chen, Bill Daughton, Roy Torbert, and Amitava Bhattacharjee

Hall electric fields of the electron-skin-depth scale have been shown to be a key observable of the electron current layer during collisionless magnetic reconnection with negligible guide field [Chen et al., JGR, 2008]. Embedded in the electron-scale Hall electric field is a layer of electric field that points in directions opposite to the Hall electric field. This inversion electric-field layer is a collective effect of electron meandering orbits, and corresponds to a hole structure in the electron phase space [Chen et al., PoP, 2011]. This poster will show how these two types of electric fields evolve with phases of reconnection, including the phase when secondary plasmoids are generated in the electron current layer. In a fully kinetic plasma that allows local violation of charge neutrality, the electron current layer during reconnection develops excess negative charge, in addition to a strong electron out-of-plane flow. These features of the electron current layer are passed on to secondary plasmoids that form in the layer, and remain at the plasmoid cores as the plasmoids grow. The observations of the above electric field features are partially addressed by measurements from the four Cluster spacecraft. Both the inversion electric field and electron phase-space hole structures are beyond the resolution of Cluster, but within the instrument capability of the upcoming NASA mission Magnetospheric MultiScale (MMS). In-situ studies of these structures will be made in the near future with the MMS measurements.

Distribution of Plasmoids in Large Scale Magnetic Reconnection

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Abstract

Recent theoretical and numerical studies show strong evidences that current layers in large scale magnetic reconnection events become unstable to a super-Alfvénic plasmoid instability. The reconnection layer breaks into a chain of plasmoids connected by secondary current sheets, which may become unstable again, leading to another round of plasmoid formation. Eventually the system reaches a statistical steady state governed by complex dynamics of formation of new plasmoids, as well as plasmoid loss due to advection and plasmoid coalescence. The hierarchical structure of plasmoids naturally suggests self-similarity across scales, which often leads to power-laws. In this work, the distribution function $f(\psi)$ magnetic fluxes ψ in plasmoids is studied for resistive magnetic reconnection in high-Lundquist-number regime via direct numerical simulations. The distribution function is found to follow a power-law $f \sim \psi^{-1}$, contrary to a $f \sim \psi^{-2}$ power-law suggested earlier by Uzdensky *et al.* [PRL **105**, 235002]. Numerical evidence indicates that large plasmoids tend to avoid coalescing with each other, which is a phenomenon identified as the source of discrepancy. Taking into account this important effect, a theoretical model is proposed, yielding solutions consistent with the numerical findings. In addition to these theoretical developments, plasmoid distributions in post-CME current sheets from both observational data and numerical simulations will be presented.

Magnetic Fluctuations with Ion Cyclotron Range of Frequency during Fast Reconnection in Plasma Merging Experiment

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Magnetic reconnection drives explosive release of magnetic energy in magnetized plasmas, such as solar flares in solar corona, magnetic substorms in the earth's magnetosphere, and anomalous plasma heating and acceleration in laboratory plasmas. Particularly interested questions are "How does fast magnetic reconnection happen?" and "How is magnetic energy converted to plasma kinetic/thermal energy?". We have been experimentally investigated these issues in terms of MHD waves, current sheet instabilities, and plasmoid ejection in plasma merging device.

Magnetic fluctuations were observed during reconnection inside the current sheet in plasma merging experiment with a guide field: the guide field at the X-point B_x of 45mT is comparable to the reconnecting field $B_{//}$. The frequency spectrum of fluctuations has clear peak at 1.5-2MHz, which is as high as local ion gyro frequency. The current sheet width decreased when magnetic fluctuations appeared. Its width was finally compressed shorter than the ion skin depth and reconnection electric field increased as the sheet width decreased. Furthermore, the fluctuation had large amplitude, which is larger than 10% of reconnecting magnetic field, and propagated to the downstream region with 50% of Alfvén velocity and dumped significantly at the current sheet edge.

These results indicate that the fluctuation is responsible for the enhancement of reconnection rate and the ion anomalous heating in the plasma merging experiment with a guide field.

This work was supported by JSPS Grants-in-Aid for Scientific Research 22246119, 22686085, and JSPS Core-to-Core Program 22001.

Impact of Density and Gas Pressure on the Rate of Magnetic Reconnection

Jun Lin, Chengcai Shen, & Nicholas A. Murphy

Solar flares occur when magnetic energy is quickly converted into heat and kinetic energy by magnetic reconnection in a current sheet (CS). We briefly discuss previous works on the CS thickness estimated from observations by the UVCS and the LASCO experiments on SOHO. Based on these results, we perform 2D MHD simulations of the development of instabilities and turbulence in a long CS and study various properties of the energy conversion in the reconnection region. We noticed that the energy conversion process depends not only on Rm of the CS, but also on the density and plasma pressure inside the CS. The high plasma density and pressure inside the sheet prevents reconnection from taking place quickly. In reality, on the other hand, the CS forms in the disrupting magnetic field and either density or pressure inside may not be high, and this guarantees the fast reconnection process to occur in solar flares. We also studied the formation of the plasmoid in the environment of different values of Rm.

The tearing instability and reconnection with force-free Harris geometry in 3D PIC simulations

Yi-Hsin Liu, W. Daughton and Hui Li
Los Alamos National Laboratory

While most studies of magnetic reconnection have focused on Harris-type equilibrium, which is relevant to the Earth's magnetosphere, there has been growing interest in force-free current sheets. This type of initial condition is thought to be more relevant when the energy density in the magnetic field greatly exceeds the thermal energy of the plasma. This is clearly the case in hot solar corona of our Sun, and it is also thought to be true within the relativistic jets emerging from AGN.

In force-free layers, the current flows parallel to the strong local magnetic field while the density is uniform. This is very different from the Harris sheet initial condition. However, there has been limited work on kinetic studies of magnetic reconnection in such force-free configurations. One important first step is to understand the 3D evolution of tearing modes (or magnetic flux ropes in 3D simulations). It has been hypothesized that a spectrum of these interacting islands may play a crucial role in accelerating energetic particles, either though coalescence or through Fermi acceleration inside contracting islands. Thus, it is very important to understand how many magnetic flux ropes are produced within a given large-scale current sheet that goes unstable to reconnection. Accordingly, we have completed a detailed linear stability analysis of the tearing mode for the force-free configuration and verified the mode properties using 2D full particle simulations and 3D Fourier spectrum. This theory shows that the tearing modes are unstable over a wide range of oblique angles. Recently, the interaction of oblique modes in a Harris current sheet leads to turbulent magnetic reconnection is demonstrated [1]. In the force-free configuration, our linear theory predicts much more power in oblique modes than in the Harris equilibrium. These results suggest that force-free current sheets may be even more susceptible to the generation of turbulent flux ropes during magnetic reconnection in large 3D systems. [1] Daughton *et al*. Role of electron physics in the development of turbulent magnetic reconnection in collisionless plasmas. *Nature Physics*, **7**, 539, 2011.

MHD simulation of solar chromospheric evaporation jets in the oblique coronal magnetic field

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ABSTRACT

We reproduce the solar chromospheric evaporation jet in the oblique coronal magnetic field based on a magnetic reconnection model by two-dimensional MHD simulations. Magnetic reconnection occurs between the oblique coronal magnetic field and emerged flux from the convection zone. In our simulations, two types of jets occur simultaneously caused by the magnetic reconnection. One of the reproduced jets has the characteristics of the reconnection jet which is accelerated by the magnetic force caused by the magnetic reconnection. The other jet is the evaporation jet which is accelerated by the high pressure caused through the thermal energy input from the magnetic reconnection site. This result is consistent with the magnetic reconnection model. The reconnection jet and evaporation jet occur continuously. The continuous occurrence of the reconnection and evaporation jet is consistent with the interpretation of our previous observed jet presented in MR2010. This simulation includes the effect of heat conduction, radiation and coronal heating and keeps the corona stable.

Solar-relevant magnetic flux ropes in the laboratory: initial results and experimental plans

C. E. Myers, M. Yamada, E. E. Lawrence, H. Ji, J. Yoo, and T. D. Tharp
Princeton Plasma Physics Laboratory, Princeton, NJ 08543

Abstract

Solar eruptive events such as coronal mass ejections (CMEs) are thought to be driven by a sudden release of magnetic energy stored in the solar corona. In many cases, the pre-eruptive configuration is a non-potential magnetic structure that can be modeled as a line-tied magnetic flux rope. In spite of ever-improving observational capabilities, directly studying the evolution of coronal flux ropes remains a significant challenge. Thus, in order to further explore the mechanisms that drive solar eruptions, we must find ways to simulate the relevant physical system. To this end, we have designed a laboratory experiment to produce magnetic flux ropes in a low-β environment that is similar to the solar corona. The flux ropes studied here have an arched topology and are formed as an arc discharge between two magnetically linked electrodes. They evolve quasi-statically over many Alfvén times and have footpoints that are line-tied to the electrodes. In this paper, we present results from proof-of-principle experiments that demonstrate the equilibrium and stability properties of these laboratory flux ropes. The primary focus will be on magnetic measurements of radial force balance and the external kink instability. We then present plans for a new set of experiments that will include a background potential field configuration whose structure mimics that of a solar active region. The new experiments are expected to access a regime where a slowly evolving flux rope can suddenly undergo a dynamic eruption that is driven by a loss of equilibrium or the torus instability. This would represent the first observation of such a transition in the laboratory and allow us to directly study this type of event using extensive magnetic measurements from within the plasma.

Fluctuation signatures of reconnection sites

Vadim Roytershteyn[1], Homa Karimabadi[1], William Daughton[2]

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Large-amplitude electromagnetic fluctuations are routinely observed in the vicinity of reconnection sites in both laboratory and space plasmas. Based on the results of large-scale fully kinetic 3D simulations, we discuss the "fluctuation portrait" of reconnection sites and the role of various instabilities in generating such fluctuations. Specifically, lower-hybrid drift instabilities, ion-ion cross-field instability, and whistler modes arise self-consistently at various spatial locations depending on such parameters as degree of asymmetry and plasma beta. The role played by these instabilities in controlling reconnection dynamics is discussed.

Particle Acceleration at Reconnecting 3D Null Points

Author: Adam Stanier (University of Manchester, stanier@jb.man.ac.uk)
Co-Authors: P. K. Browning (University of Manchester);
S. Dalla (University of Central Lancashire)

Hard X-ray observations from the RHESSI spacecraft indicate that a significant fraction of solar flare energy release is in non-thermal energetic particles. One plausible acceleration mechanism for these is the strong electric field associated with reconnection, a process that can be particularly efficient when particles become unmagnetised near to null points. This mechanism has been well studied in 2D, at X-points within reconnecting current sheets; however, 3D reconnection models show significant qualitative differences and it is not known whether these new models are efficient for particle acceleration.

We place test particles in electromagnetic fields that are exact solutions to the steady, incompressible and resistive MHD equations near reconnecting 3D nulls (eg. Craig and Fabling 1996). We compare the resistive spine and fan reconnection models with previous results for acceleration in ideal models (Dalla and Browning 2005). We find that the fan model is very efficient due to an increasing "guide field" that stabilises particles against ejection from the current sheet. However, the spine model, which was the most promising in the ideal case, gives weak acceleration as the reconnection electric field is localised to a narrow cylinder about the spine axis.

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Quantitative Study of Guide Field Effects on Hall Reconnection in a Laboratory Plasma

Tim Tharp,
M. Yamada, H. Ji, E. Lawrence, S. Dorfman, C. Myers, J. Yoo

The effect of guide field on magnetic reconnection has been quantitatively studied by systematically varying an applied guide field in the Magnetic Reconnection Experiment (MRX). The quadrupole field, a signature of two-fluid reconnection at zero guide field, is significantly altered by a finite guide field. It is shown that the reconnection rate is significantly reduced with increasing guide field, and this dependence is explained by a combination of local and global physics: locally, the in-plane Hall currents are modified, while globally guide field compression produces an increased pressure both within and downstream of the reconnection region.

Multi-Hierarchy Simulation with Domain Dynamic Conversion for Magnetic Reconnection Studies

Shunsuke Usami[1], Hiroaki Ohtani[1,2], Ritoku Horiuchi[1,2] and Mitsue Den[3]

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Magnetic reconnection is one of the important and fundamental processes in plasmas. It plays an essential role in the rapid energy release in fusion plasmas and astrophysical plasmas such as solar flare. Furthermore, magnetic reconnection attracts considerable attention as a multi-hierarchy phenomenon. In magnetic reconnection, the field topology changes globally, while electrical resistivity controlled by microscopic process is needed as trigger in the vicinity of reconnection points. In order to understand its multi-hierarchy structure completely, we develop a multi-hierarchy simulation model, which deals with both microscopic and macroscopic physics consistently and simultaneously.

The multi-hierarchy structure of reconnection in the upstream direction has a special feature that dynamics near the neutral sheet are controlled by kinetic physics, while plasma behaviors away from the neutral sheet can be expressed as one-fluid. Them our multi-hierarchy model is based on the domain decomposition method [1, 2]. Physics in the domain where some microscopic dissipation mechanisms are required is solved by particle-in-cell (PIC) algorithm (PIC domain). On the other hand, dynamics outside the PIC domain is expressed by magnetohydrodynamics (MHD) algorithm (MHD domain). Between the PIC and MHD domains, an interface domain with a finite width is inserted in order to interlock two domains smoothly and exchange data each other. Physics in the interface domain is solved by both PIC and MHD algorithms.

In the current model, PIC, MHD and interface domains are fixed. However, reconnection point would move with time and kinetic region also would move. Therefore, we are extending our model to develope a method to convert calculation domains dynamically. We tentatively refer to this method as “domain dynamic conversion method”. As the first step of the domain dynamic conversion method, we perform simulation as shown in Fig.1. Initially, whole domain is taken to be the MHD domain. At the conversion time, a part of MHD domain, which is close to the neutral sheet is converted to the PIC domain. The quasi-interface at the conversion time means that only MHD data are sent to the PIC algorithm one-sidely unlike the “ordianry” interface. In presentation, we would like to explain this method in detail and demonstrat simulations results.

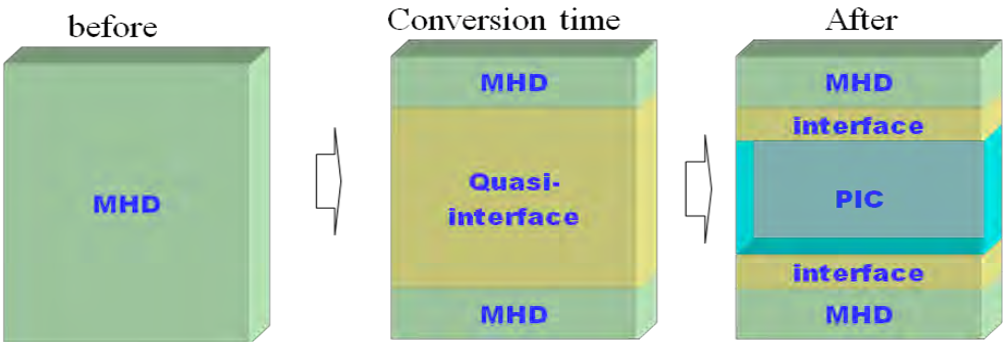

Fig.1: Conceptual diagram of doman dynamic convertion method.

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Magnetic Reconnection with Optically Thin Radiative Cooling

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and

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Stanford/KIPAC

Both magnetic reconnection dynamics and also reconnection-powered particle acceleration in various high-energy-density astrophysical environments (e.g., magnetar flares; gamma-ray bursts; pulsar magnetospheres, winds, and nebulae; and black-hole accretion-disk coronae), and also, perhaps, some laboratory experiments (e.g., laser-produced plasmas) may be strongly affected by radiation via, e.g., radiative cooling, radiation pressure, and Compton drag resistivity. Traditional, non-radiative reconnection models are not applicable to such systems, and hence there is a need for the development of a new theory of radiative magnetic reconnection. As a first step, here we present a Sweet–Parker-like theory of resistive magnetic reconnection with strong optically thin radiative cooling. We find that, intense radiative cooling accelerates reconnection by two complimentary mechanisms: (1) a lower temperature of a radiatively-cooled layer leads to a higher Spitzer resistivity and hence a higher reconnection rate; and (2) in the absence of a strong guide field, intense cooling leads to a strong plasma compression, which also increases the reconnection rate. In general, the compression ratio and the reconnection layer temperature are governed by the balance between ohmic heating and radiative cooling. We then analyze several specific radiative processes (bremsstrahlung, cyclotron, and inverse Compton) in the optically thin regime for both the zero- and strong-guide-field cases, and also derive the applicability conditions of our theory. *This work is supported by NSF grant PHY-0903851.*

Cluster observations of non-ideal behavior at three-dimensional magnetic nulls in the turbulent magnetosheath

Deirdre Wendel and Mark L. Adrian

NASA Goddard Space Flight Center

In a turbulent layer of the magnetosheath, the Poincare index indicates the Cluster spacecraft entrap a number of magnetic nulls. Previous researchers have found evidence for reconnection at one of the many filamentary current sheets observed by Cluster in this layer. Many of the entrained nulls are also associated with strong currents. We dissect the current structure of a pair of spiral nulls that may be topologically connected. In both cases, we find a strong current along the spine, accompanied by a modest current perpendicular to the spine that tilts the axis of the spine toward the fan plane. At least one of the nulls manifests a non---ideal rotational flow pattern consistent with torsional spine reconnection as predicted by theory. These results emphasize the importance of examining the magnetic topology in understanding the nature of current sheets and reconnection in three---dimensional turbulence.

Measurement of the Hall electric field and its effects on ion dynamics

J. Yoo, M. Yamada, H. Ji, C. Myers, T. Tharp, and E. Lawrence, Princeton Plasma Physics Lab

Numerical simulations and space observations have demonstrated that an electrostatic potential well can develop during two-fluid magnetic reconnection along the direction normal to the current sheet. Utilizing Langmuir probes and a floating potential probe array, the in-plane potential profile is measured in the Magnetic Reconnection Experiment (MRX). The radial potential well is observed to be deeper and broader further downstream. The magnitude of the potential drop is 10-15V at the center and 15-35V downstream, which is significant compared to the typical upstream electron temperature of 5eV. This Hall electric field is believed to accelerate and heat ions. The ion flow profile measured in two dimensions supports a picture where ions are accelerated by the Hall electric field. The ion outflow can reach 35km/s which is about the half of the upstream Alfven velocity. Preliminary results on ion temperature measurements are also presented.

Magnetohydrodynamic structure of a plasmoid in fast reconnection in low-beta plasmas

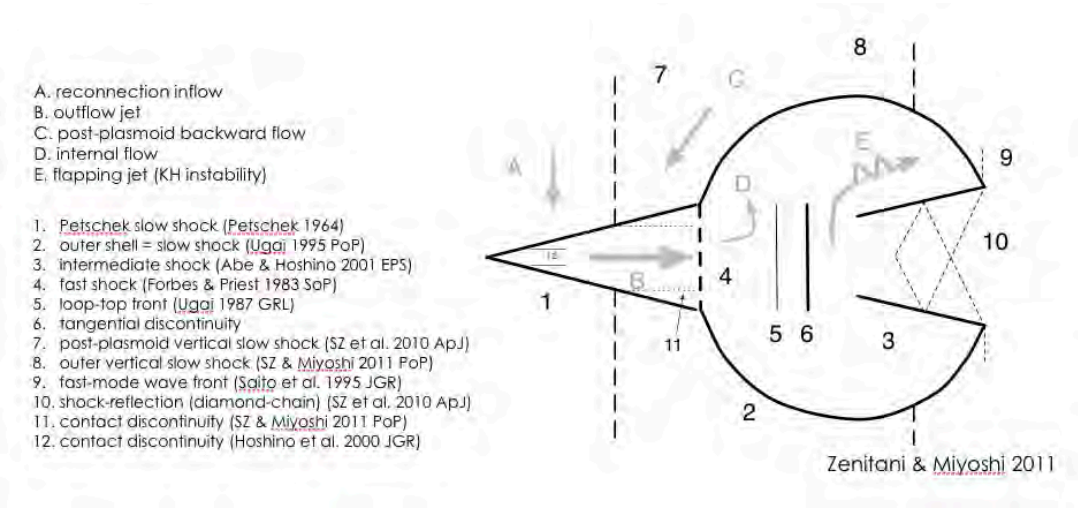
Seiji Zenitani (NAOJ)

Takahiro Miyoshi (Hiroshima U)

Michael Hesse, and Alex Klimas (NASA/GSFC)

Plasmoid structures in fast reconnection in low-beta plasmas are investigated by 2D magnetohydrodynamic (MHD) simulations. A high-resolution shock-capturing code enables us to explore a variety of shock structures: vertical slow shocks behind the plasmoid, another slow shock in the outer-region, and the shock-reflection in the front side. The Kelvin–Helmholtz-like turbulence is also found inside the plasmoid. It is concluded that these shocks are rigorous features in reconnection in low-beta plasmas, where the reconnection jet speed or the upstream Alfvén speed exceeds the sound speed.

These signatures are found in the relativistic plasmas as well, in which relativistic Alfvén speed exceeds the sound speed (≤ c/sqrt{3}). A sufficient magnetization parameter for these new shocks is $\sigma_E = 1/2$.



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Magnetic Reconnection in the Near Venusian Magnetotail

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Observations with the Venus Express magnetometer and low-energy particle detector revealed magnetic field and plasma behavior in the near-Venus wake symptomatic of magnetic reconnection, a process that occurs in the Earth's magnetotail but is not expected in the magnetotail of a non-magnetized planet like Venus. On 15 May 2006, the plasma flow in this region was toward the planet and the magnetic field component transverse to the flow was reversed. Magnetic reconnection is a plasma process that changes the topology of the magnetic field and results in energy exchange between the magnetic field and the plasma. Thus, the energetics of the Venus magnetotail resembles that of the terrestrial tail where energy is stored and later released from the magnetic field to the plasma.

THURSDAY, MAY 24, 2012

8:00am Registration

8:25am Announcements

Reconnection Theory and Reconnection in Space (M. Hoshino, U. Tokyo)

8:30am **M. Hesse** (NASA-GSFC): The impact of geometrical constraints on collisionless magnetic reconnection

8:55am **S. Zenitani** (NAOJ): A new measure of the dissipation region in collisionless magnetic reconnection: Theory, simulation, and observation

9:20am **L.-N. Hau** (National Central U.): Theory of ideal MHD wave propagation in Harris type current sheet

9:35am **Q. Lu** (USTC): Kinetic simulations of the structures of magnetic island in multiple X line reconnection

9:50am **Y.-H. Liu** (LANL): The structure of the magnetic reconnection exhaust boundary

10:05am Break

Solar Reconnection (S. Antiochos, NASA-GSFC)

10:25am **H. Isobe** (Kyoto U.): Magnetic Reconnection in Solar Atmosphere

10:50am **J. Edmondson** (U. Michigan): Reconnection in the Solar Corona

11:15am **T. Shimizu** (JAXA): Hinode observations of microflares and plasma ejections in the solar chromosphere and corona

11:30am **C. Shen** (YAO): Numerical Simulations of Fine Structures within Reconnecting Current Sheets in Solar Flares

11:45am **N. Murphy** (CfA): Asymmetric Magnetic Reconnection in the Solar Atmosphere

12:00pm Lunch

Reconnection in Lab (H. Ji, PPPL)

1:30pm **Y. Ono** (U. Tokyo): Impulsively Fast Magnetic Reconnection by Acceleration of Ejecting Plasmoid Motion

1:45pm **M. Inomoto** (U. Tokyo): Excitation of Large-amplitude Magnetic Fluctuation in Plasma Merging Experiment

2:10pm **S. Dorfman** (PPPL): Three-dimensional, impulsive reconnection events in the Magnetic Reconnection Experiment (MRX)

2:35pm **J. Sarff** (U. Wisconsin): Ion Heating and Acceleration in the Reversed Field Pinch

3:00pm **Discussion (M. Hoshino, U. Tokyo)**

3:15am Break

Special Session (R. Kulsrud, PPPL)

3:30pm **S. Tsuneta** (NAOJ): Quadruple solar poloidal fields as observed with Hinode

3:55pm **J. Drake** (U. Maryland): A magnetic reconnection mechanism for ion acceleration and abundance enhancements in impulsive flares

4:20pm **K. Shibata** (Kyoto U.): Super flares on Solar Type Stars

4:40pm **A. Bhattacharjee** (U. New Hampshire): The Plasmoid Instability in High-Lundquist-Number Plasmas: Dynamics and Statistics

5:05pm **M. Yamada** (PPPL): Reflection on MRX research in the context of reconnection phenomena in space- astrophysics

5:45pm Adjourn

The impact of geometrical constraints on collisionless magnetic reconnection

Michael Hesse, Nico Aunai, Masha Kuznetsova, Rebekah Frolov, Carrie Black
(all at: Heliophysics Science Division, NASA Goddard Space Flight Center)

One of the most often cited features associated with collisionless magnetic reconnection is a Hall-type magnetic field, which leads, in antiparallel geometries, to a quadrupolar magnetic field signature. The combination of this out of plane magnetic field with the reconnection in-plane magnetic field leads to angling of magnetic flux tubes out of the plane defined by the incoming magnetic flux. Because it is propagated by Whistler waves, the quadrupolar field can extend over large distances in relatively short amounts of time – in fact, it will extend to the boundary of any modeling domain. In reality, however, the surrounding plasma and magnetic field geometry, defined, for example, by the overall solar wind flow, will in practice limit the extend over which a flux tube can be angled out of the main plain. This poses the question to what extent geometric constraints limit or control the reconnection process and this is the question investigated in this presentation. The investigation will involve a comparison of calculations, where open boundary conditions are set up to mimic either free or constrained geometries. We will compare momentum transport, the geometry of the reconnection regions, and the acceleration if ions and electrons to provide the current sheet in the outflow jet.

A new measure of the dissipation region in collisionless magnetic reconnection: Theory, simulation, and observation

Seiji Zenitani (NAOJ)

Michael Hesse, Alex Klimas, Carrie Black, Masha Kuznetsova (NASA/GSFC), Iku Shinohara (JAXA/ISAS), Tsugunobu Nagai (Tokyo Tech), Hiroyuki Takahashi (NAOJ), Makoto Takamoto (Nagoya U), Naoki Bessho (UNH)

We discuss a new measure to identify a small-scale dissipation region in collisionless magnetic reconnection. Traditionally, the dissipation region has been identified by the electron's nonidealness ($E + v_e \times B \neq 0$). However, recent numerical results suggest that it may not accurately locate the reconnection site.

In this work, we propose an "electron-frame dissipation measure" to identify the dissipation region. This is the energy transfer from the electromagnetic fields to plasmas in the rest frame of the electron's bulk motion. The measure is formulated as a Lorentz invariant quantity. Since it is related to the nonideal dissipation, it excellently locates a compact dissipation region surrounding the X-point in various configurations: symmetric and asymmetric reconnection, with and without a guide field.

Carrying out large-scale PIC simulations, we apply our theory to the structure of symmetric antiparallel reconnection. From the electron-scale dissipation region, a narrow electron jet extends in the outflow direction. The jet region is often referred to as the "outer electron diffusion region," but it turns out to be anti-dissipative. It is also found that the electrons get magnetized at the jet front and that electron shock-heating is relevant to the local magnetic structure.

Next we apply the theory to the satellite observation in the magnetotail. Evaluating an approximate dissipation measure from Geotail data on 15 May 2003, we detect a signature of a compact dissipation region around the possible X-line. This and other signatures are discussed in relevance to PIC simulations.

Finally, we preview another application to reconnection in high-energy astrophysics.

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Theory of ideal MHD wave propagation in Harris type current sheet

L.-N. Hau[1,2] and Y.-T. Lai[1]
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In the context of MHD theory magnetic reconnection requires the breakdown of frozen-in-flux condition. Studies of magnetic reconnection in Harris current sheet are mostly based on the resistive MHD, resistive Hall-MHD and particle simulations. In these models field line reconnection occurs as a consequence of nonideal MHD effects such as resistivity etc. which however have no corresponding physics in the context of MHD or fluid theory. In this talk we present an overview of the physics of ideal MHD waves in Harris type current sheet and discuss its implications for magnetic reconnection.

Kinetic simulations of the structures of magnetic island in multiple X line reconnection

Quanming Lu, Can Huang, San Lu

Department of Geophysics and Planetary Science, University of Science and Technology of China, Hefei 230026, China

Magnetic reconnection is one of the most important processes in astrophysical, space and laboratory plasmas, and magnetic island is an important feature in reconnection. Therefore, identifying the structures of magnetic island is crucial to improving our understanding of magnetic reconnection. Using two-dimensional (2-D) particle-in-cell (PIC) simulations, we investigate the structures of magnetic island in multiple X line reconnection. In anti-parallel reconnection, due to the Weibel instability excited by the temperature anisotropy, Regular structures with alternate positive and negative values of the out-of-plane magnetic field along the x direction are formed in magnetic island. In guide field reconnection, the out-of-plane magnetic field has a dip in the center of magnetic island. Such structures are considered to be produced by the current system in the magnetic island. At the edge of the magnetic island, there exists a current anti-parallel to the in-plane magnetic field, while the current is parallel to the in-plane magnetic field inside the magnetic island. Such a dual-ring current system, which is attributed to the electron dynamics in the magnetic island, leads to the dip of the out-of-plane magnetic field in the center of the island.

The structure of the magnetic reconnection exhaust boundary

Yi-Hsin Liu[1,2], J. F. Drake[2] and M. Swisdak[2]
[1]Los Alamos National Laboratory
[2]University of Maryland

Switch-off slow shocks (SSS) are the key structure of driving the outflow in Petschek's reconnection model. Observations of reconnection in the solar wind in particular seem to suggest that reconnection X-lines and associated exhausts grow to very large scales and resemble the open outflow geometry predicted by Petschek. However, direct observations of SSSs in the Earth's magnetosphere and the solar wind are infrequent. Since it is the release of magnetic energy downstream from the X-line that ultimately drives the outflow rather than the dynamics close to the X-line, the absence of the SSS in observations and kinetic simulations calls into question the conjecture that fast collisionless reconnection actually can scale to very large systems. Thus, a key requirement for demonstrating the fast energy release of reconnection that takes place in large systems is to pin down the specific mechanism driving the Alfvenic outflow.

We present a large 2-D reconnection simulation and its companion Riemann problem using a Particle-In-Cell code. The self-generated firehose-sense temperature anisotropy (i.e., T_parallel > T_perpendicular) by counterstreaming ions is found to be important in determining the structure of reconnection exhausts. This temperature anisotropy slows down the intermediate mode while speeds up the slow mode, and consequently prevents the formation of classical Switch-off Slow shocks in Petschek's model. Instead, the nonlinear coupling between the slow and intermediate waves constitutes the shock transition. A plateau of the firehose stability parameter 1-(beta_parallel-beta_perpendicular)/2 at value 0.25 is observed inside these hybrid waves, which should also be observable in Earth's magnetotail and the solar wind. This special value is significant because it is the degeneracy point of slow and intermediate waves in anisotropic MHD system. The anisotropic Rankine-Hugoniot jump conditions are derived and compared with our simulations, while the pseudo-potentials of shocks are analyzed to explain the dynamics of forming these transition structures. The Walen relation is shown to fail at the core of reconnection exhausts, where the firehose is unstable. (Ref: Yi-Hsin Liu, J. F. Drake and M. Swisdak, The structure of the magnetic reconnection exhaust boundary, *Phys. of Plasmas,* **19**, 022110, 2012)

Magnetic Reconnection in Solar Atmosphere

Hiroaki Isobe[1]

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Observations in 1990s have shown that magnetic reconnection do occur in the solar corona and driving solar flares and coronal mass ejections. The evidence for reconnection includes cusp-shaped flare loops, loop-top hard X-ray source, direct detection of reconnection inflow etc. Recent development in space observations, such as those by Hinode and SDO, allow us to study the morphology and dynamics of reconnection region with better spatial/temporal resolution and plasma diagnostics. Observational studies of magnetic reconnection in the sun are shifting from search for reconnection evidence to investigation of the reconnection physics itself, such as role of plasmoids, and slow shocks and kinetic effects.

Another recent development in the study of reconnection in the sun is the findings of more and more evidence for reconnection in the lower atmosphere, namely in the photosphere and chromosphere. Careful study of morphology and dynamics of chromospheric jets indicates that reconnection occurs in an intermittent and bursty way, though we still have poor estimation of the reconnection rate because of lack in direct magnetic field measurements. This invokes an interesting question: how such bursty reconnection is realized in a fully collisional, weakly ionized plasma? What are the roles of Hall effect and ambipolar (Pedersen) diffusion expected in such weakly ionized plasmas?

I will review these recent progresses in the study of magnetic reconnection in the solar atmosphere.

Reconnection in the Solar Corona; J.K. Edmondson, University of Michigan

The solar corona is a low-beta, highly-conductive environment in which the assumptions of MHD are valid. Observations of coronal structures, such as the coronal-hole pattern, the streamer belt, and active regions, constrain the magnetic field over the majority of spatial and temporal scales to a force-free (and on the very-largest spatial scales, nearly-potential) character. The corona is constantly being driven away from equilibrium by the inertial forces at the lower-boundary (usually taken as the photosphere). These driving-flows are typically three orders of magnitude slower than coronal Alfven speeds, and thus global structures generally evolve over nearly quasi-static timescales, equilibrating the injected stresses with the existing coronal structures effectively instantaneously. However, the transient phenomena that occur on much shorter timescales require relatively fast stress redistribution, and accompanying energy release, within the coronal magnetic field. Therefore, a major factor of the dynamic time scales in the solar corona is the ability of the magnetic field structure to retain and release stress.

Reconnection in MHD is a process that serves to relieve stress, and therefore lower the energy state of the magnetic field structure. Reconnection in MHD requires the formation of strongly dissipative current systems. In the highly-conductive, low-beta, MHD environment of the solar corona, separatrix (quasi-separatrix) structures in the magnetic field and strong gradients in the boundary flows are favorable sites for the formation of strongly dissipative current systems, and therefore reconnection. These structures are defined by discontinuities (strong gradients) in the field connectivity, and owing to this, even in equilibrium, the pressure-tension stress distribution within the global field is discontinuous (contains a strong gradient) across these structures. Physically, these stress discontinuities manifest as strong non-zero curls, thus are the origin of strongly dissipative, reconnecting current sheets in otherwise highly-conductive MHD plasma.

This talk will review the generally complex, nested, multipolar flux structure of the global coronal magnetic field, in which the magnetic domains, defined by a smooth connectivity structure, are bounded by separatrics. This talk will discuss (1) how the global coronal magnetic field structure evolves in response to the stress-energy injection at the lower-boundary and (2) how regions of low field strength (e.g., null points) offer the least resistance to deformation and, therefore, the formation of reconnecting current discontinuities. Low-beta MHD simulations show, in general reconnecting current sheets typically form along the separatrices in the magnetic field, relieving the injected stresses by transferring magnetic flux between domains, thereby lowering the global magnetic energy state. In addition, this talk will discuss the role of reconnection at the largest spatial scales, where the coronal magnetic field structure and evolution is governed by solar-heliospheric conditions, such as the solar wind and the helisopheric current sheet. Reconnecting current sheets that may form in the absence of separatrix structures, due to strong, highly transient dynamics, and/or strong gradients in the boundary flows (those responsible for the braiding structure of the Parker heating model) are outside the scope of this talk.

Hinode observations of microflares and plasma ejections in the solar chromosphere and corona

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This talk will discuss some *Hinode* observations of microflares, plasma ejections and flares, in which magnetic reconnection play central role in converting the magnetic energy to thermal and kinetic energy in a short period. High-resolution photospheric magnetic-field measurements and chromospheric Ca II H imaging observations from Hinode Solar Optical Telescope (SOT) will be used with simultaneous coronal measurements from Hinode X-ray Telescope (XRT). One example is chromospheric plasma ejections observed recurrently and intermittently in sunspot light bridges. A complicated sunspot observed in 24 January 2012 will be examined to discuss the magnetic topology of the site where chromospheric ejections are recurrently produced. Also, a similar light-bridge-like magnetic configuration temporarily formed in a developing sunspot due to emergence will be discussed; X-ray microflares in addition to chromospheric ejections were produced from this site. If the time is permitted, we may briefly discuss larger flares observed with the Hinode observatory in 2011-2012.

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Title:

Numerical Simulations of Fine Structures within Reconnecting Current Sheets in Solar Flares

Authors:

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Abstract:

Solar flares occur when magnetic energy is quickly converted into heat and kinetic energy by magnetic reconnection in a current sheet (CS). Based on 2D MHD experiments, we simulate the development of instabilities and turbulence in a long CS. The simulations start with a vertical current sheet that is in mechanical equilibrium and line-tied at the lower boundary. Reconnection commences gradually due to an initially imposed perturbation, but becomes faster when plasmoids form and produce small-scale structures inside the current sheet. These structures include magnetic islands or plasma blobs flowing in both directions along the sheet, and X-points between pairs of adjacent islands. The various properties of the energy conversion in the reconnection region are studied through performing a 1D Fourier analysis. The results display a power law distribution for the energy versus the scale of small structures inside the CS, suggesting that the reconnection process is turbulent.

Asymmetric Magnetic Reconnection in the Solar Atmosphere

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ABSTRACT

Flux rope models of coronal mass ejections (CMEs) predict the formation of an elongated current sheet in the wake behind the rising plasmoid. Magnetic reconnection in these current sheets is highly asymmetric. Sunward outflow impacts the post-flare loops and regions of high density and plasma pressure, whereas antisunward outflow is directed toward the rising flux rope. After reviewing observations of features identified as current sheets in white light, EUV, and X-ray observations, we will present a series of simulations designed to investigate the basic physics of asymmetric magnetic reconnection in the solar atmosphere. Resistive MHD simulations of asymmetric outflow reconnection suggest that the majority of the kinetic and thermal energy released in the flare is directed upward. Diffusion of the normal component of the magnetic field allows the X-line to retreat against strong plasma flow. Simulations of asymmetric inflow reconnection where the initial X-line perturbation is placed near a lower line-tied boundary display the consequences of asymmetric reconnecting magnetic field strengths during solar eruptions. The observational signatures of line-tied asymmetric reconnection include skewed candle flame shaped loops, asymmetries in the footpoint motion and emissions, and vorticity in the rising flux rope. Last, we will present initial simulations of the plasmoid instability and the interaction of multiple X-lines during asymmetric inflow reconnection.

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Impulsively Fast Magnetic Reconnection by Acceleration of Ejecting Plasmoid Motion

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Magnetic reconnection, a major mechanism for converting magnetic energy into plasma energy and restructuring the plasma and magnetic field configurations, has been studied mostly by the conventional steady-state models. However, most reconnection phenomena reveal signatures of "impulsive" behaviors. Our two-torus plasma merging experiments performed at the University of Tokyo TS-4 device demonstrated for the first time that the reconnection rate and reconnection electric field in the current sheet impulsively increase and decrease in temporal correlation with the acceleration of plasmoid ejection velocity. This clear relationship indicates a new mechanism that impulsively fast magnetic reconnection is induced by the acceleration of plasmoid ejection velocity. The laboratory experimental result explains the simultaneous occurrence of plasmoid acceleration and enhanced magnetic reconnection rate observed during the impulsive non-thermal energy release of solar flares.

Excitation of Large-amplitude Magnetic Fluctuation in Plasma Merging Experiment

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Waves are universally observed in magnetosphere or solar atmosphere associated with magnetic reconnection and are believed to play important roles in reconnection physics, e.g. enhancement of reconnection rate, energy conversion and energy transport. In laboratory experiment, large-amplitude magnetic fluctuation with ion's cyclotron range of frequency was observed in the vicinity of the X-point of the strongly driven magnetic reconnection in the TS-3 plasma merging experiment, in which two toroidally confined plasmas were merged through magnetic reconnection with guide magnetic field comparable to the reconnection field. The amplitude of the fluctuating field reached no less than 20% of the reconnecting field and the spectrum was highly monochromatic ($\omega \sim 2\omega_{ci}$). The averaged reconnection rate (inflow velocity normalized to Alfvén velocity) increased from 0.05 to 0.15 when large amplitude magnetic fluctuation arose in the current sheet region. Electrostatic fluctuation with lower hybrid frequency range (~40MHz) was observed near the X-point prior to the large-amplitude magnetic fluctuation, suggesting that the lower hybrid drift instability might trigger the secondary instability with lower frequency, which provided large dissipation in the current sheet.

On the other hand, magnetic reconnection without guide field was accompanied by magnetic fluctuation near the end of and after the reconnection. The observed fluctuation frequency of 200-400kHz was close to that estimated from the motion of the reconnected field lines with m=1 and 2 deformation. This low frequency fluctuation may account for the significant ion heating in the reconnection without guide field observed in detail by a two-dimensional Doppler spectroscopy.

This work was supported by JSPS Grants-in-Aid for Scientific Research 22246119, 22686085, and JSPS Core-to-Core Program 22001.

Three-dimensional, impulsive reconnection events in the Magnetic Reconnection Experiment (MRX)

S. Dorfman, H. Ji, M. Yamada, J. Yoo, E. Lawrence, C. Myers, and T. D. Tharp
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Fast, impulsive reconnection is commonly observed in laboratory, space and astrophysical plasmas. Many existing models of reconnection attempt to explain this behaviour without including variation in the third direction. However, the impulsive reconnection events observed on the Magnetic Reconnection Experiment (MRX) are characterized by large local gradients in the third direction and cannot be explained by 2-D models. Signatures of flux rope dynamics in the two-fluid regime are identified and found to play a key role in these events. The observed drop in the reconnection current and spike in the reconnection rate during the event are due to ejection of these "flux rope" structures from the layer. By contrast, even though electromagnetic fluctuations in the Lower Hybrid frequency range consistent with [1] are also observed concurrently with the impulsive behaviour [2], they are not the key physics responsible. A qualitative, 3-D, two-fluid model consistent with [3] is proposed to explain the observations.

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Ion Heating and Acceleration in the Reversed Field Pinch

J. Sarff, A.F. Almagri, J.K. Anderson, D.J. Den Hartog, G. Fiksel, S.T.A. Kumar, R.M. Magee, V.V. Mirnov, M.D. Nornberg, J.A. Reusch

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Quasi-periodic magnetic reconnection events (sawteeth) associated with tearing instability in RFP plasmas liberate a substantial amount of magnetic energy that reappears as ion thermal energy. In the thermal portion of the ion distribution, the heating mechanism appears to act dominantly perpendicular to the mean-field direction, with collisional relaxation on a time scale similar to the duration of the reconnection event, as determined by charge exchange recombination measurements of minority ions such as carbon. Measurements of neutron emission from d-d fusion events reveal an energetic ion tail characterized by a power-law distribution. New charge exchange diagnostics are able to resolve this tail up to 30 keV. The bath of tearing modes causes the magnetic field to become stochastic, yet these energetic ions remain well confined. Good energetic ion confinement is also confirmed by injection of mono-energetic 20 keV protons using a 1 MW neutral beam injection system. The NBI-created protons are observed to be accelerated to higher energy during the intense reconnection process.

Quadruple solar poloidal fields as observed with *Hinode*

Saku Tsuneta

National Astronomical Observatory of Japan

Masaaki Yamada and his collaborators published a historical paper on magnetic reconnection in laboratory environment in 1990. Fortunately, I happened to see the paper. This paper, which was not much known then in astrophysics community, fascinated me, and I sent a personal letter to Dr. Yamada, who was obscure to us at that time. In return, I got a friendly letter from Yamada-san, and I dare to say that this is the start of the fruitful collaboration between solar physics and laboratory plasma physics. The interaction resulted in one remarkable achievement; decision of NASA Headquarters to support the construction of the Princeton MRX experiment. In the following year, Yohkoh was launched. The mission was supposed to solve the solar flare problem. At that time, magnetic reconnection was mere possibility, and there is a feeling not to accept the concept in solar physics community. It needed certain courage to propose that magnetic reconnection do play a role in solar flares based on Yohkoh results at that time. But, I was confident partly because of the laboratory experiment. As the time went on, magnetic reconnection becomes, by its own and from the point of application to various astrophysical phenomena, one of the central topics in plasma astrophysics including solar physics. I will here talk about the latest *Hinode* observations related to solar dynamo where magnetic reconnection would play a role to commemorate Masaaki's 70th birthday.

We reported earlier that strong magnetic patches with size smaller or comparable to small sunspots (pores) were scattered in the whole polar regions. Before the observation results by the *Hinode* became clear, it was believed that there were only broad, weak magnetic fields in the polar region. Since then, we have been monitoring yearly variation in the Sun's polar magnetic fields with the Solar Optical Telescope aboard *Hinode* to record their evolution and expected reversal near the solar maximum. The detected magnetic flux per patch ranges over four orders of magnitude (10^{15}–10^{20} Mx). The higher end of the magnetic flux in the polar regions is about one order of magnitude larger than that of the quiet Sun, and nearly that of pores. Almost all large patches ($>10^{18}$Mx) have the same polarity, while smaller patches have a fair balance of both polarities. The polarity of the polar region as a whole is consequently determined only by the large magnetic concentrations. A clear decrease in the net flux of the polar region is detected in the slow rising phase of the current solar cycle. The decrease is more rapid in the north polar region than in the south. This has been taking place with few active regions in lower latitudes in the minimum phase of the sunspot cycle. The decrease in the net flux is caused by a decrease in the number and size of the large flux concentrations as well as the appearance of patches with opposite polarity at lower latitudes. In contrast, we do not see temporal change in the magnetic flux associated with the smaller patches ($< 10^{18}$ Mx) and that of the horizontal magnetic fields during the years 2008–2012. We expect based on the *Hinode* data that both poles have the same plus polarity until now. We will discuss implications to solar dynamo based on these results.

A magnetic reconnection mechanism for ion acceleration and abundance enhancements in impulsive flares

J. F. Drake, K. Knizhnik and M. Swisdak, University of Maryland
P. Gary, LANL

The acceleration of ions during magnetic reconnection in solar flares is explored with PIC simulations with multiple ion species and analytic analysis. Ions crossing into Alfvenic reconnection outflows can behave like pickup particles and gain an effective thermal velocity equal to the Alfven speed. An ambient guide magnetic field, which is the relevant configuration for flares, significantly impacts both how and whether ions gain significant non-convective energy. With a sufficiently strong guide field ions can become adiabatic and their heating is then dramatically reduced. The threshold for non-adiabatic behavior, where ions are strongly heated, becomes a condition on the ion mass-to-charge-ratio. Thus, during flares high mass-to-charge particles gain energy more easily than protons and a simple model reveals that their abundances are enhanced consistent with observations. This model, however, does not explain the abundance enhancement of He3. On the other hand, the energy gain of particles that are strongly heated during reconnection with a guide field is dominantly perpendicular to the ambient magnetic field, which is in contrast with the dominantly parallel heating that takes place during reconnection of anti-parallel fields. Perpendicular ion heating from reconnection will drive ion-cyclotron waves, which will preferentially heat He3 and possibly produce the He3 abundance enhancements. Strong perpendicular heating of both protons and minority species is consistent with recent SOHO observations.

Supeflares on Solar Type Stars

Kazunari Shibata

Kwasan and Hida Observatories, Kyoto Univeristy

Superflares are very big flares that release total energy much greater than that of the biggest solar flares ever observed (~ 3 x 10^32 erg). The famous Carrington flare in 1859 may correspond to the biggest solar flare. If such superflares will occur on our Sun, we would have extreme space weather events, which might lead to big hazards of terrestrial environments and our civilization. Astronomical observations revealed that young stars or fast rotating stars often show superflares (10^34 ~ 10^38 erg). Hence it has been thought that our Sun would have produced superflares when it was young and rotating faster (> 10 km/s). However it was not clear whether superflares would occur on the present Sun or not, since the present Sun is not young and is now slowly rotating (at 2 km/s). Recent observations of solar type stars with Kepler satellite have revealed existence of superflares (with energy of 10^34-10^35 erg) on solar twins which are quite similar to our Sun on surface temperature (5600 K ~ 6000 K) and slow rotation (< 10 km/s). From the statistical analysis of these superflare observations, it is suggested that superflares with energy 10^34 erg occur once in 500 years and superflares with 10^35 erg occur once in 5000 years on solar twins and/or our present Sun. Finally, we will also give theoretical arguments whether superflares will occur on the present Sun or not on the basis of modern theories of flares and dynamo.

The Plasmoid Instability in High-Lundquist-Number Plasmas: Dynamics and Statistics

A. Bhattacharjee
Center for Integrated Computation and Analysis of Reconnection and Turbulence
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This talk is dedicated to Masaaki Yamada on the occasion of his 70th birthday. Through a broad range of experiments in spheromaks, tokamaks, and basic laboratory facilities (such as the Magnetic Reconnection Experiment), Masaaki's work has done much to illuminate the twin concepts of magnetic relaxation and reconnection in plasmas. As we consider new developments in the theory of magnetic reconnection in high-Lundquist-number plasmas, we look forward to Masaaki's continued involvement and leadership, his penetrating questions to theorists who he treats with a healthy combination of skepticism and grudging respect, and definitive experimental results that rule out theories and inspire new ones.

In this talk, I will review some recent developments in the theory of the plasmoid instability, which begins from the realization that there is a basic flaw in the canonical Sweet-Parker model, studied and tested extensively by Masaaki and his co-workers in the laboratory. The basic flaw in the Sweet-Parker model is the assumption that the system-size current sheet mediating reconnection in resistive plasmas is stable. Recent work has shown that above a critical threshold in Lundquist number, the Sweet-Parker current sheet is violently unstable to a secondary, super-Alfvenic tearing instability (the plasmoid instability) that produces, rather remarkably, a nonlinear regime in which the reconnection rate becomes independent of the Lundquist number. Inclusion of Hall MHD effects changes qualitatively the nonlinear regimes accessible to the plasma. One of the regimes is X-point like, seen by Masaaki and coworkers in the laboratory, but when the system size becomes sufficiently large, there is a novel regime in which the current sheet geometry alternates dynamically between two meta-stable states: an X-point and an extended thin current sheet unstable to the plasmoid instability. Recently, we have developed a theoretical model for the statistical distribution of plasmoids in quasi-steady state. A new kinetic equation has been developed for the plasmoid distribution function $f(\psi)$ (where ψ is the flux trapped in a plasmoid), which predicts a power-law $f(\psi) \sim \psi^{-1}$, consistent with simulation results.

This is work carried out primarily in collaboration with Yi-Min Huang, and supported by DOE, NSF, and NASA.

Reflection on MRX research in the context of reconnection phenomena in space-astrophysics

M. Yamada
In collaboration with H. Ji, R. Kulsrud, J. Jara-Almonte, E. Lawrence, C. Myers, T. Tharp, J. Yoo, Center of Magnetic Self-Organization, PPPL, Princeton University, Princeton NJ 08543

I will present my reflection on past and present MRX [Magnetic Reconnection Experiment] research and its relationship to space-astrophysical phenomena. Magnetic reconnection occurs because magnetic field lines are driven towards a magnetic shear region localized in a 3-D geometry. Magnetic energy is stored for a long period of time and then suddenly released, globally driving the plasma system to a relaxed state. By observing how it happens, the relationship between the local reconnection dynamics and the buildup of global stored energy is found to be key. The physics understanding of a reconnection layer has moved forward through collaboration between numerical simulations, space observations, and lab experiments. Two-fluid dynamics have been verified through experimental identification of both the ion and electron diffusion layers. The reconnection rate increases significantly when the ratio of the electron mean free path to the scale length approaches unity. A new scaling of reconnection resistivity with respect to this ratio has been obtained from the laboratory results. Comparison of these lab results with recent space satellite observations has been made.

Our research has reached to a critical juncture where we focus on the conversion of magnetic field to particle kinetic energy during reconnection. An MRX-Upgrade device is being designed to address the outstanding key issues. This talk will include results from the very recent experimental campaigns carried out in the past year on MRX: (1) Detailed measurements of electron dynamics in the two-scale diffusion layer using plasma jogging, (2) Documentation of neutral sheet disruption (impulsive reconnection), (3) Reconnection in partially ionized plasmas, (4) Quantitative study of the effects of guide field on collisionless reconnection, and (5) Study of the equilibrium and stability properties of solar-relevant flux-ropes.

FRIDAY, MAY 25, 2012

8:25am Announcement

Solar Reconnection (K. Shibata, Kyoto U.)

8:30am **S. Antiochos** (NASA-GSFC): Integrating Kinetic effects into Global Models for Reconnection

8:55am **S. Takasao** (Kyoto U.): Slow Shock Acceleration Mechanism of Chromospheric Jets on the Sun

9:10am **S. Nishida** (Kyoto U.): The relation between a flux rope eruption and magnetic reconnection in solar flares

9:25am **N. Nishizuka** (JAXA): A Laboratory Experiment of Magnetic Reconnection: Outflows, Heating and Waves in Chromospheric Jets

9:40am **D. Pontin** (U. Dundee): Dynamics of braided coronal loops

9:55am **J. Leake** (George Mason U.): Multi-fluid simulations of magnetic reconnection in the weakly ionized solar chromosphere

10:10am Break

Reconnection Theory and Reconnection in Space (J. Drake, U. Maryland)

10:25am **R. Horiuchi** (NIFS): Multi-Hierarchy Simulation Bridging Gap between Macro and Micro Physics of Magnetic Reconnection

10:50am **J. Egedal** (MIT): Large-scale electron acceleration by parallel electric fields during magnetic reconnection

11:15am **N. Loureiro** (IST): Fast Collisionless Reconnection and Electron Heating in Strongly Magnetised Plasmas

11:30am **Y. Khotyaintsev** (SISP): Production of Energetic Electrons by Magnetic Reconnection

11:45am **M. Ashou-Abdalla** (UCLA): On the Acceleration of Electrons During Magnetospheric Substorms

12:00pm Lunch

Astrophysical Reconnection (R. Matsumoto, Chiba U.)

1:30pm **A. Harding** (NASA-GSFC): Crab Flares and Magnetic Reconnection in Pulsar Winds

1:55pm **D. Uzdensky** (Colorado U.): Anisotropy of Particle Acceleration and Associated Radiation in Relativistic Pair Reconnection

2:20pm **S. Imada** (NAOJ): Self-Organization of Reconnecting Plasmas to a Marginally Collisionless State in the Solar Corona

2:45pm **H. Ji** (PPPL): Survey of Astrophysical Plasma Conditions for Magnetic Reconnection and a Phase Diagram

3:00pm Break

Reconnection Theory and Reconnection in Space (R. Horiuchi, NIFS)

3:15pm **N. Yokoi** (U. Tokyo): Turbulent transport and magnetic reconnection

3:40pm **A. Lazarian** (U. Wisconsin): 3D reconnection of magnetic field in the presence of turbulence and the acceleration of energetic particles

3:55pm **E. Zweibel** (U. Wisconsin): Magnetic Reconnection with Instabilities and Flow: A Workshop Report

4:10pm **N. Aunai** (NASA-GSFC): Does the rate of collisionless magnetic reconnection depend on the dissipation mechanism?

4:25pm **P. Wu** (U. Delaware): Magnetotail dipolization front and associated ion reflection via Particle-in-Cell simulations

4:40pm **N. Buzulukava** (NASA-GSFC): Reconnection and dipolarization fronts: Full-particle simulations with open boundary conditions in 2D current sheet

4:55pm **Discussion (K. Shibata, Kyoto U.)**

5:10pm Adjourn

ABSTRACT FOR: MR2012

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Integrating Kinetic effects into Global Models for Reconnection

Magnetic reconnection is the most striking example of how the coupling between global and kinetic scales can lead to fast energy release. Explosive solar activity, such as coronal mass ejections and flares for example, is widely believed to be due to the release of magnetic energy stored on global scales by magnetic reconnection operating on kinetic scales. 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 the Sun's activity. Consequently, the NASA Living With a Star Program selected a Focused Science Team to attack the problem of cross-scale coupling in reconnection. In this talk I will present some of the results of the Team and review our latest theories and methods for modeling the global-local coupling in solar reconnection.

This work was supported by the NASA TR&T program.

Slow Shock Acceleration Mechanism of Chromospheric Jets on the Sun

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Magnetic reconnection generates waves or shocks in various forms. The waves could easily become shocks in a gravitationally stratified atmosphere like the solar atmosphere. There is the transition region, where the density drastically changes, between the chromosphere and the corona. Slow shocks can launch the transition region when passing through it. Such a launched transition region is believed to be the chromospheric jet. This is one of the most promising mechanism to explain the ubiquitous chromospheric jets. Recent observations have showed that many of the jets are supersonic and related to magnetic reconnection between the emerging flux and the pre-existing ambient field. Those supersonic jets might not be the reconnection outflows because the plasma beta in the chromosphere is close to unity and the maximum velocity would be the sound speed. This makes it difficult to understand the connection between magnetic reconnection and jets. Shibata et al. (2007) focused on that the slow shock acceleration can explain the supersonic jets. Then they proposed one possible scenario in which the energy released by magnetic reconnection is carried by shocks and they generate the jets. By using two-dimensional MHD simulation, we investigate this mechanism and try to explain the relation among magnetic reconnection, shocks and jets.

The relation between a flux rope eruption and magnetic reconnection in solar flares

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Solar flares are often associated with flux rope (plasmoid) eruptions. Positive correlations between flux rope velocity and reconnection rate were found in various observations of solar flares. These results suggest that a flux rope eruption plays a key role in causing fast magnetic reconnection. This is also known as the plasmoid-induced reconnection model (Shibata and Tanuma 2001). In our previous work two-dimensional (2D) magnetohydrodynamic simulation was performed to examine the plasmoid-induced reconnection model which reproduces the correlation between the plasmoid velocity and the reconnection rate (Nishida et al. 2009). However, this model has not been confirmed yet in three-dimensional (3D) simulations.

In this study, we investigated the dynamical evolution of a 3D flux rope eruption and associated magnetic reconnection in a solar flare, extending 2D magnetohydrodynamic simulation model of solar flares (Chen and Shibata 2000, Nishida et al. 2009) to 3D. We succeeded in reproducing a bursty magnetic reconnection and dynamic bi-directional reconnection outflows just below the flux rope during the eruption in our 3D simulations. To examine the relation between a flux rope eruption and magnetic reconnection, we calculated four cases of a strongly twisted flux rope and a weakly twisted flux rope in 2D and 3D simulations. The time evolution of a weakly twisted flux rope in 3D plane shows similar behaviors to 2D simulation, while a strongly twisted flux rope shows clearly different time evolution from 2D simulation except for the initial phase evolution. The ejection speeds of both strongly and weakly twisted flux ropes in 3D simulation are larger than those in 3D simulation, and the reconnection rates in 2D cases are also larger than those in 2D cases. Especially, in the case of a strongly twisted flux rope, both ejection speed and reconnection rate are much larger than those in 2D cases. This indicates that there exists a positive feedback between the ejection speed of a flux rope and the reconnection rate even in the 3D simulation, and that the plasmoid-induced reconnection model can be applied to 3D.

A Laboratory Experiment of Magnetic Reconnection: Outflows, Heating and Waves in Chromospheric Jets

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Hinode observations have revealed intermittent recurrent plasma ejections/jets in the chromosphere. They are interpreted as a result of non-perfectly anti-parallel magnetic reconnection, i.e. component reconnection, between a twisted magnetic flux tube and the pre-existing coronal/chromospheric magnetic field, though the fundamental physics of component reconnection is unrevealed.

In this paper, we experimentally reproduced the magnetic configuration and investigated the dynamics of plasma ejections, heating and wave generation triggered by component reconnection in the chromosphere. We set plasma parameters as in the chromosphere (density 10^{14} cm^{-3}, temperature 5-10 eV, i.e. (5-10)×10^4 K, and reconnection magnetic field 200 G) using argon plasma. Our experiment shows bi-directional outflows with the speed of 5 km s^{-1} at maximum, ion heating in the downstream area over 30 eV and magnetic fluctuations mainly at 5-10 μs period.

We succeeded in qualitatively reproducing chromospheric jets, but quantitatively we still have some differences between observations and experiments such as jet velocity, total energy and wave frequency. Some of them can be explained by the scale gap between solar and laboratory plasma, while the others probably by the difference of microscopy and macroscopy, collisionality and the degree of ionization, which have not been achieved in our experiment.

Dynamics of braided coronal loops

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We investigate the resistive relaxation of a magnetic loop that contains braided magnetic flux, as a model for a solar coronal loop. The loop is subject to line-tied boundary conditions. We investigate the dynamical processes that occur during this relaxation, in particular the magnetic reconnection that occurs, and discuss the nature of the final equilibrium. It is found that, following an instability within the loop, a myriad of thin current layers forms, via a cascade-like process. This cascade becomes more developed and continues for a longer period of time for higher magnetic Reynolds number. During the cascade magnetic flux is reconnected multiple times, with the level of this “multiple reconnection” positively correlated with the magnetic Reynolds number. Eventually the system evolves into a state with no more small-scale current layers. This final state is found to approximate a non-linear force-free field consisting of two flux tubes of oppositely-signed twist embedded in a uniform background field.

Multi-fluid simulations of magnetic reconnection in the weakly ionized solar chromosphere

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We present the first self-consistent *ab initio* multi-fluid simulations of magnetic reconnection in the solar chromosphere, where the ionized and neutral fluids are treated as coupled but distinct. Recent observations of EUV jets in the chromosphere and flux cancellation events on the solar surface have been interpreted as observational signatures of magnetic reconnection in the solar chromosphere. Unlike the corona, the dense chromosphere is highly collisional. On average, the collision rate between ionized plasma and neutrals is larger than the inverse of the typical time-scale of the system, and so the two fluids are strongly coupled. However, our multi-fluid simulations show that for chromospheric conditions there is a decoupling of ionized plasma and neutral gas in reconnection inflows, as plasma is pulled in by the magnetic field. This decoupling creates an ionization/recombination imbalance, and provides a way to increase the rate of reconnection by rapid recombination of inflowing plasma within the reconnection current sheet. We combine the intuition developed through numerical simulations with simple analytic arguments to predict the expected reconnection rate as a function of plasma parameters. The prediction is verified against the fully nonlinear simulation results and used to draw conclusions about the nature of magnetic reconnection in the chromosphere.

Multi-Hierarchy Simulation Bridging Gap between Macro and Micro Physics of Magnetic Reconnection

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Two different types of simulation models are developed in order to bridge huge gap between macro and micro physics of magnetic reconnection. An effective resistivity model is constructed based on the PIC simulation results that reconnection electric field generated by microscopic physics evolves inside ion meandering scale so as to balance the flux inflow rate at the inflow boundary [1]. This model is applied to global MHD phenomena controlled by magnetic reconnection in the earth magnetosphere. It is found that, although this model does not include any adjustable parameters, global phenomena such as onset of magnetic substorm and formation of plasmoids are well reproduced and consistent with the observations [2].

On the other hand, in order to investigate magnetic reconnection phenomena more comprehensively, we have developed a multi-hierarchy simulation model in which MHD and PIC models are interconnected through the interface region. The model is applied to a few numerical test programs [3,4] and collisionless driven reconnection [5] in a simple geometry. Recently, this multi-hierarchy model is extended to more realistic model with non-uniform space grids [2]. By comparing the simulation results with large-scale PIC simulation results, it is confirmed that reconnection physics is described correctly in the extended multi-hierarchy model.

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Large-scale electron acceleration by parallel electric fields during magnetic reconnection

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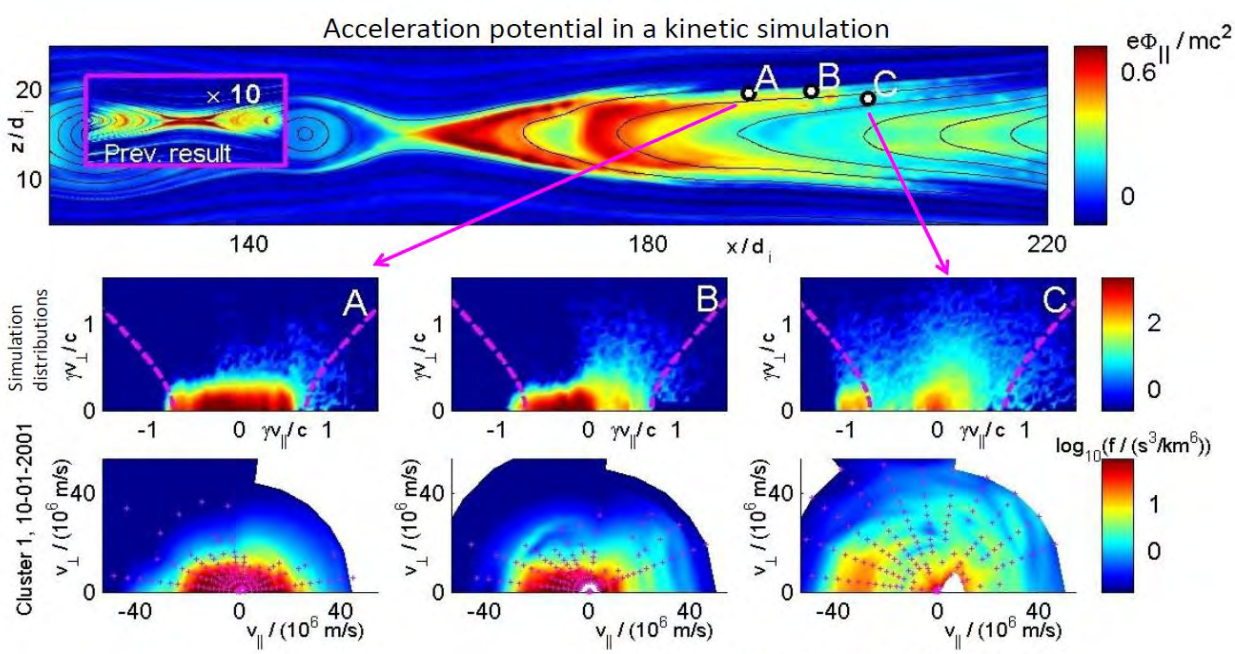
During reconnection in magnetized plasma stress in the magnetic field is reduced through changes in the field line topology. The process is often accompanied by an explosive release of magnetic energy and is implicated in a range of astrophysical phenomena. In the Earth's magnetotail, reconnection energizes electrons up to hundreds of keV and solar flares events can channel up to 50% of the magnetic energy into the electrons resulting in superthermal populations in the MeV range. Electron energization is also fundamentally important to astrophysical applications yielding a window into the extreme environments. Here we show that during reconnection powerful energization of electrons by magnetic-field-aligned electric field ($E_{||}$) can occur over spatial scales which hugely exceed previous theories and simulations. We find that $E_{||}$ is supported by non-thermal and strongly anisotropic features in the electron distributions not permitted in standard fluid formulations, but routinely observed by spacecraft in the Earth's magnetosphere. This allows for electron energization in spatial regions that exceed the regular d_e scale electron diffusion region by at least three orders of magnitude.



Fast Collisionless Reconnection and Electron Heating in Strongly Magnetised Plasmas

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The nonlinear tearing mode evolution is studied numerically using a novel hybrid fluid/kinetic model [Zocco & Schekochihin, Phys. Plasmas **18** 102309 (2011)] which retains non-isothermal electron kinetics.

We find that a large fraction of the initial (magnetic) energy is converted into electron heating: up to 60% for the largest system studied. Importantly, we demonstrate that electron heating mainly occurs via energy cascade in phase-space: the smaller the collision frequency (ν_{ei}), the larger the real and velocity-space gradients that form. The amount of energy transferred is independent of ν_{ei}, but the role of finite collisions is critical.

For sufficiently large systems, the peak reconnection rate is similar to that of the no guide-field limit, $cE_{max} \approx 0.2 v_A B_{y,0}$, where v_A is the Alfvén speed based on the reconnecting field $B_{y,0}$.

The saturation amplitude of the tearing mode is well described by a fluid approximation except for small systems, when it becomes comparable to the kinetic scales.

Production of Energetic Electrons by Magnetic Reconnection

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Swedish Institute of Space Physics, Uppsala

We present *in situ* Cluster observations of energetic electrons in relation to magnetic reconnection in the Earth's magnetotail. Initial acceleration is happening in the diffusion region, where the electrons are accelerated in thin current sheets and magnetic islands. The electrons are then further accelerated in the outflow region by the adiabatic betatron and Fermi mechanisms. This acceleration is related to the dipolarization fronts – ions scale discontinuities located at fronts of the reconnection jets being a characteristic feature of unsteady reconnection. We suggest that production of the most energetic electrons is happening when the reconnection is unsteady, as it enables, in addition to the X-line acceleration, efficient acceleration mechanisms operating in the outflow region.

On the Acceleration of Electrons During Magnetospheric Substorms

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It has long been observed that electrons in the near-Earth (r < 20RE) magnetotail can be accelerated to 100s of keV during magnetospheric substorms. There is debate over whether this acceleration occurs near the reconnection site in the tail or as the electrons propagate earthward from the reconnection site. In particular the energy flux of energetic electrons are frequently observed in association with earthward propagating dipolarization fronts. Dipolarization fronts are rapid (minutes) increases in the BZ component of the magnetic field accompanied by rapid (100s of km/s) flows. We have been using a combination of global magnetohydrodynamic and large scale kinetic simulations (LSK) to investigate where and how the electrons are accelerated. First, we investigated a substorm on February 15, 2008 during which the energetic electron increases were observed by three THEMIS spacecraft located in the near Earth (r~10RE) tail. For this event we found that the increases in the electrons could be understood by as resulting from betatron acceleration associated with the earthward propagating dipolarization front. While the electrons were accelerated to ~100 keV by the betatron acceleration they gained only about 10 keV near the neutral line. Next, we studied a substorm on March 11, 2008. This time in addition to two THEMIS spacecraft (P3 and P4) at r~10RE the THEMIS P2 spacecraft was at r ~15RE. We developed both a simple analytic model to study the acceleration and carried out a large scale kinetic simulation. Again we found that most of the acceleration was associated with the dipolarization fronts. In the simple model we assumed that the particle distribution observed at P2 was propagated to P3 and P4. In both the simple model and the LSK simulation the electrons were accelerated by a combination of betatron and Fermi acceleration. As before the acceleration near the neutral line was less than that associated with adiabatic motion associated with the dipolarization front.

Crab Flares and Magnetic Reconnection in Pulsar Winds

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The striped winds of rotation-powered pulsars are ideal sites for magnetic reconnection. The magnetic fields of the wind near the current sheet outside the light cylinder alternate polarity every pulsar period and eventually encounter a termination shock. Magnetic reconnection in the wind has been proposed as a mechanism for transferring energy from electromagnetic fields to particles upstream of the shock (the "sigma" problem), but it is not clear if, where and how this occurs. Fermi and AGILE have recently observed powerful gamma-ray flares from the Crab nebula, which challenge traditional models of acceleration at the termination shock. New simulations are revealing that magnetic reconnection may be instrumental in understanding the Crab flares and in resolving the "sigma" problem in pulsar wind nebulae.

Anisotropy of Particle Acceleration and Associated Radiation in Relativistic Pair Reconnection

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I will report on our recent advances in theoretical analysis and PIC simulations of relativistic pair magnetic reconnection, with a special emphasis on nonthermal particle acceleration and on the resulting radiation by the highest-energy particles. In contrast to previous studies that focussed only on the particles' *energy* distribution, we are also analyzing in detail the *angular distribution* of the accelerated particles. Our main new result is the discovery of a strong energy-dependent particle anisotropy. The effect is most pronounced for the highest-energy particles, with the effective beaming solid angle Ω declining rapidly with energy. In particular, we find that the highest energy particles are focused in two beams with opening solid angle of less than 1% of the full sphere. Next, since the particles are ultra-relativistic, this particle anisotropy translates directly into a strong *anisotropy of the radiation* they emit (both synchrotron and inverse-Compton). This effect is of great importance for the interpretation of high-energy astrophysical observations. It leads to an effective *kinetic beaming*, greatly boosting the high-energy part of the emitted spectrum along a couple of special lines of sight. It may also provide a natural mechanism for the ultra-rapid temporal variability of the very high energy gamma-ray emission observed in some systems. Finally, focusing of the highest-energy particles in a tight beam deep inside the reconnection layer, where the perpendicular magnetic field is weak, may suppress the synchrotron radiation reaction, enabling the particles to exceed the standard radiation-reaction energy limit, and thus explain the puzzling GeV-flares recently discovered in the Crab Nebula. *This work is supported by NSF grant PHY-0903851.*

SELF-ORGANIZATION OF RECONNECTING PLASMAS TO A MARGINALLY COLLISIONLESS STATE IN THE SOLAR CORONA

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We explore the suggestions by Uzdensky (2007) and Cassak et al. (2008) that coronal loops heated by magnetic reconnection should self-organize to a state of marginal collisionality. We have discussed coronal loop hydrodynamics with one-dimensional hydrodynamic calculation. We assume that many current sheets are present in solar corona, with a distribution of thicknesses, but that only current sheets thinner than the ion skin depth can rapidly reconnect. This assumption naturally causes a density dependent heating rate which is actively decided by the plasma. We report 9 numerical simulation results of coronal loop hydrodynamics in which the absolute value of heating rates are different but their density dependence are the same. We find two regimes of behavior, depending on the amplitude of the heating rate. In the case that the amplitude of heating is below a threshold value, the loop is in stable equilibrium. Typically the upper and less dense part of coronal loop is collisionlessly heated and conductively cooled. When the amplitude of heating is above the threshold, the conductive flux to the lower atmosphere required to balance collsionless heating drives an evaporative flow which quenches fast reconnection, ultimately cooling and draining the loop until the cycle begins again. The key elements of this cycle are gravity and the density dependence of the heating function. Some additional factors are present, including large enthalpy flux and pressure driven flows from the loop top, which play an important role in reducing the density. We find that on average the density of the system is close to the marginal value.

Survey of Astrophysical Plasma Conditions for Magnetic Reconnection and a Phase Diagram

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A large number of heliophysical and astrophysical plasmas where magnetic reconnection might occur have been surveyed based on published observations, commonly used models, and sometimes private communications. This talk is to summarize this survey and to present the survey results in a phase diagram [1] for magnetic reconnection in two key dimensionless parameters: the Lundquist number and the macrosopic system size in units of the ion sound gyroradius. In addition to the conventional single X-line collisional and collisionless phases, multiple X-line reconnection phases arise due to the presence of the plasmoid instability either in collisional and collisionless current sheets. In particular, there exists a unique phase termed "multiple X-line hybrid phase" where a hierarchy of collisional islands or plasmoids is terminated by a collisionless current sheet, resulting in a rapid coupling between the macroscopic and kinetic scales and a mixture of collisional and collisionless dynamics. Status of a next step experiment [2] intended to study these new phases, supported by the state-of-the-art numerical simulations, will be discussed.

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Turbulent transport and magnetic reconnection

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Effects of turbulence are examined in the context of magnetic reconnection. Primary effect of turbulence is enhancing the effective transport. In addition to this primary effect, under some circumstances, turbulence give rise to the suppression of transport. A typical example is turbulent dynamo, where the turbulent magnetic diffusivity is balanced by some field-generation mechanisms associated with pseudo-scalars in turbulence. In inhomogeneous turbulence, unlike homogeneous isotropic turbulence, statistical properties of turbulence are subject to the mean-field configurations. In the presence of breakage of symmetry due to the mean-field configurations, some pseudoscalars are present in turbulence, which will affect the transport properties much. We consider magnetic reconnection in this context. The following points are presented: (i) Positive and negative turbulent cross helicity (velocity–magnetic-field correlation in fluctuation) is spatially distributed surrounding the magnetic reconnection region; (ii) The mean velocity and magnetic fields are analytically solved with the turbulent effects incorporated through the Reynolds stress and mean Lorentz force. (iii) Field generation due to the turbulent cross helicity modulates the mean-field configurations, leading to the field configuration preferable for the fast reconnection; (iv) Spatial distribution of the turbulent cross helicity leads to the localization of enhanced magnetic resistivity; (v) Numerical tests are performed to confirm these theoretical notions; (vi) Proposal on experiment and observation of magnetic reconnection is also advanced.

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3D Reconnection of Magnetic Field in the Presence of Turbulence and the Acceleration of Energetic Particles

Alex Lazarian
University of Wisconsin - Madison

I shall show new tests of 3D magnetic reconnection in the presence of turbulence and discuss the influence of different types of turbulence driving. I shall show that test particles experience first order Fermi acceleration in zones of such a reconnection. The properties of the acceleration depend whether the system is 2D or 3D, which testifies that correct results on particle acceleration can be obtained only in 3D reconnection configurations.

Magnetic Reconnection with Instabilities and Flow: A Workshop Report

Ellen G. Zweibel

University of Wisconsin - Madison

The Center for Magnetic Self-Organization recently sponsored a small workshop on magnetic reconnection with instabilities and flow. Talks were presented on reconnection in the presence of small-scale driven turbulence, formation of reconnecting current sheets by turbulence, reconnection of an unstable current sheet, and reconnection induced by shear flow instability. This talk will briefly summarize some of the main results.

Does the rate of collisionless magnetic reconnection depend on the dissipation mechanism ?

Nicolas Aunai, *Michael Hesse, Carrie Black, Rebekah Evans, Maria Kuznetsova*
NASA / Goddard Space Flight Center

The importance of the electron dissipation effect on the reconnection rate is investigated in the general case of asymmetric collisionless magnetic reconnection. Contrary to the standard collisionless reconnection model, it is found that the reconnection rate, and the macroscopic evolution of the reconnecting system, crucially depend on the nature of the dissipation mechanism and that the Hall effect alone is not able to sustain fast reconnection.

Magnetotail dipolization front and associated ion reflection via Particle-in-Cell simulations

Pin Wu and Michael Shay
University of Delaware

For the Earth magnetotail, the [Svenes et al., 2008] statistical study infers the lobe density to be highly variable, in the range of 0.007–0.092 cm^{-3}. Such lobe density variation modifies reconnection diffusion region physical processes and reconnection rate drastically [Wu et al., 2011]. This presentation addresses observable reconnection signatures in the vicinity of the X-line that are to be affected by the dynamic changes of reconnection. Using a 2.5D particle-in-cell (PIC) code, we find the dipolarization front (DF) a moving ram that pushes the initial equilibrium plasma sheet in front of it. The DF propagation velocity scales with the upstream Alfven speed, leading to faster, steeper, and more compressed DFs with stronger Bz at low lobe densities. These DFs reflect plasma sheet ions in a streaming manner. The streaming ions create a bipolar magnetic field straddling the central plasma sheet and can excite various instabilities.

Reconnection and dipolarization fronts: Full-particle simulations with open boundary conditions in 2D current sheet equilibria and multi-spacecraft observations

N. Buzulukova[1,2], M. Sitnov[3], T. Moore[1], M. Swisdak[2]

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(2) University of Maryland College Park
(3) JHU APL

We discuss results from 2D PIC simulations (P3D code) with open boundary conditions and 2D current sheet equilibria. Sitnov&Swisdak (2011) showed that reconnection onset and its further dynamics strongly depend on the type of the initial equilibrium. We extend their analysis and study in detail the evolution of out-of-plane electric and magnetic fields, electron currents, parallel electric field and dissipation regions for runs starting from two different types of 2D equilibria. We also discuss the formation of dipolarization fronts (DFs) and their relation to reconnection process. It is shown that multiple DFs can be found for runs starting from an equilibrium with accumulated magnetic flux. DFs profiles from virtual spacecraft in simulations are found to be consistent with their characteristics observed by THEMIS and Cluster missions.

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FINAL MR2012 ORAL PROGRAM

May 23 Wednesday

8:00 Registration
8:25 announcement

Astro (Zweibel)
8:30 Hoshino
8:55 Matsumoto
9:10 McKinney
9:35 Takahashi

10:00 break

Lab (Ono)
10:20 Bellan
10:45 Brown
11:00 Gray
11:15 Tanabe
11:30 Gryaznevich
11:45 Brookhart

12:00 lunch

Theory/Space (Hesse)
1:30 Daughton
1:55 Pritchett
2:10 Cassak
2:25 Nakamura
2:40 Che
2:55 Goldstein
3:10 Wyper

3:25 Discussion (Zweibel)

3:45 break

4:00 **Poster session**

5:30 end

May 24 Thursday

8:00 Registration
8:25 announcement

Theory/Space (Hoshino)
8:30 Hesse
8:55 Zenitani
9:20 Hau
9:35 Lu
9:50 Liu

10:05 break

Solar (Antiochos)
10:25 Isobe
10:50 Edmondson
11:15 Shimizu
11:30 Shen
11:45 Murphy

12:00 lunch

Lab (Ji)
1:30 Ono
1:45 Inomoto
2:10 Dorfman
2:35 Sarff

3:00 Discussion (Hoshino)

3:15 break

Special Session (Kulsrud)
3:30 Tsuneta
3:55 Drake
4:20 Shibata
4:40 Bhattacharjee
5:05 Yamada
5:45 end

Banquet
6:30 Prospect House
9:30 end

May 25 Friday

8:00 Registration
8:25 announcement

Solar (Shibata)
8:30 Antiochos
8:55 Takasao
9:10 Nishida
9:25 Nishizuka
9:40 Pontin
9:55 Leake

10:10 break

Theory/Space (Drake)
10:25 Horiuchi
10:50 Egedal
11:15 Loureiro
11:30 Khotyaintsev
11:45 Ashour-Abdalla

12:00 Lunch

Astro (Matsumoto)
1:30 Harding
1:55 Uzdensky
2:20 Imada
2:45 Ji

3:00 break

Theory/Space (Horiuchi)
3:15 Yokoi
3:40 Lazarian
3:55 Zweibel
4:10 Aunai
4:25 Wu
4:40 Buzulukava

4:55 Discussion (Shibata)
5:10 end