## SM61A MCC: Hall D Saturday 0830h

### Magnetic Reconnection: Theory and Observation Posters *(joint with NG, SH)*

***Presiding:*** **T Phan,** University of California, Berkeley**; M Yamada,** Princeton University

#### SM61A-0443 0830h POSTER

### Flux Transfer Events (FTEs) Produced by the Patcht Reconnection and Pressure Pulses

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We present MHD predictions for the 3-D signatures of flux transfer events (FTEs) produced by patchy reconnection on the dayside magnetopause with and without background flows transverse magnetic shears. We also predict the 2-D signatures associated with subsonic magnetosheath density/pressure pulses. We trigger reconnection triggered with a spherical spot of locally enhanced resistivity. We treat the pressure pulse model as a localized (3000 $km$) region of enhanced plasma pressure and density propagating at subsonic (90 $km/s$) velocities along the magnetopause. In the case of 3-D patchy reconnection, the X-line bifurcates in the $yz$ plane to form an X that spreads steadily dawnward and duskward away from the subsolar point for $B_y = 0$. The trajectory of X-line in the $yz$ plane forms a nearly straight line (positive slope) within a short period of time for $B_y < 0$. With magnetosheath background flow, the trajectory of X-line is formed as a distorted "curly X type (only symmetric in the $y$ direction) and a straight line with different slopes at the dawn and dusk side of the magnetopause for $B_y = 0$ and $B_y < 0$, respectively. All the signatures of $B_x$ tend to be asymmetric bipolar mainly in the magnetosheath.

The 2-D pressure pulse drives wavy magnetopause motion. Time histories of plasma and magnetic field parameters on both sides of the magnetopause indicate the presence of bipolar magnetic field signatures normal to the nominal magnetopause.

#### SM61A-0444 0830h POSTER

### Magnetic Reconnection in the Presence of Flow Shear and Hall Physics

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Magnetic reconnection is a fundamental process in many space plasma systems where plasma of different origin interact. A typical situation is reconnection at the Earth's magnetopause. Observationally reconnection has been identified through accelerated flows and the occurrence of magnetic flux transfer events at the dayside magnetopause. Characteristic for the plasma at the magnetopause are the different plasma properties on the two sides of the magnetic boundary and the presence of a velocity tangential to the magnetopause on the magnetosheath side. We have investigated magnetic reconnection for such configurations in the framework of MHD and Hall MHD. The presence of velocity shear has a number of interesting properties some of which are present both for the MHD and Hall MHD approximations such as the generation of a By magnetic field component even if such a component is not present in the initial configuration. However, there are also specific differences one of which is a pronounced difference of the structure of the diffusion region. The diffusion region in the case of Hall dynamics is also very different from previously reported results for cases without such flow shear. In a three-dimensional system the presence of flow shear can also generate Kelvin Helmholtz modes in addition to magnetic reconnection. We will discuss the physics of reconnection in the presence of flow shear and present a systematic comparison between MHD and Hall MHD results.

#### SM61A-0445 0830h POSTER

### Magnetic Reconnection at Neutral Points: Role in Magnetospheric Dynamics

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Magnetic reconnection is a key process in magnetospheric dynamics. Much theoretical progress has been made on the nature of magnetic reconnection in ideal geometries with long neutral lines and with or without guiding magnetic field component. In the presence of significant IMF By components, magnetic neutral points are formed at the flanks. This can also take place if the magnetic field is sheared near the subsolar region. The relative role of neutral point magnetic reconnection vs. component reconnection at the subsolar point in magnetospheric dynamics is a matter of on-going discussions. We will employ 3D Global MHD simulations using the BATRSUS simulation code with Adaptive Mesh Refinement and critical point analysis to determine the location of magnetic neutral points for different IMF orientations. We will analyze the local magnetic field and plasma structure in the vicinity of the magnetic neutral points. We will estimate the contribution from neutral point reconnection relative to those from all reconnection sites. Results from our modeling will be compared with observations for selected events, as a means of model validation.

#### SM61A-0446 0830h POSTER

### Evidence for Electron Acceleration up to $\sim 300$ keV in the Magnetic Reconnection Diffusion Region of the Earth's Magnetotail

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We report direct measurements of high energy particles in a rare crossing of the diffusion region in the Earth's magnetotail by the Wind spacecraft. The fluxes of energetic electrons up to $\sim$ 300 keV peak near the center of the diffusion region and decrease monotonically away from this region. The electron flux spectrum obeys a power law with an index of -3.8 above $\sim$ 2 keV, and the electron angular distribution displays strong field-aligned bi-directional anisotropy at energies below $\sim$ 2 keV, becoming isotropic above $\sim$ 6 keV. These observations indicate significant electron acceleration inside the diffusion region. Ions show no such energization.

#### SM61A-0447 0830h POSTER

### The structure of the fast plasma flow in the plasma sheet: Comparison between observations and two-fluid simulations

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The fast plasma flow in the plasma sheet is one of the most important features of tail dynamics. The present study examines how magnetic field and plasma parameters change in association with the fast plasma flow. A superposed epoch analysis is conducted for 818 earthward flow events and 290 tailward flow events observed by the Geotail satellite in the near-Earth (X > -31 RE) region. The results are summarized as follows: (1) The average magnetic field becomes more dipolar in the course of the fast earthward flow; (2) Sharp dipolarization tends to be preceded by the initiation of fast flows, a transient decrease in Bz, and a transient increase in the plasma density; (3) The corresponding signatures can also be found for the tailward flow, although they are less clear; (4) Whereas the average plasma density decreases in association with the fast flow irrespective of the flow direction, the average ion temperature increases for the earthward flow and decreases for the tailward flow; (5) The average plasma and total pressures decrease in the course of the fast flow, suggesting the reduction of the lobe field strength. These results are compared with the fast plasma flow modeled by a two-fluid simulation with a focus on (2). The results of the simulation reveal that the initial fragmenting of the current sheet into multiple neutral lines develops into a larger-scale structure as one neutral line dominates others, and the signatures of these dominated neutral lines are convected along with the fast reconnection outflow. The present study will address similarities and difference between the associated internal structure of the simulated fast flow and the result of the superposed epoch analysis.

#### SM61A-0448 0830h POSTER

### Estimates of magnetotail reconnection rate based on IMAGE FUV and EISCAT measurements

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Dayside reconnection between the interplanetary and the terrestrial magnetic field couples the solar wind electric field to the Earth's magnetosphere, increases the magnetospheric convection and results in efficient transport of solar wind energy into the magnetosphere. Subsequent reconnection of the lobe magnetic field transports energy into the closed magnetic field region. Combining global imaging and ground based radar measurements we estimate the reconnection rate in the magnetotail during a substorm event that occurred November 28, 2000. Global images from the IMAGE FUV system guide us to identify ionospheric signatures of the open-closed field line boundary observed by EISCAT VHF. Continuous radar and optical monitoring of the open-closed field line boundary are used to determine the location and velocity of the open-closed boundary and the ion flow velocity normal to this boundary. Estimates of the reconnection electric field in the ionosphere are compared with variations in the auroral intensity and the solar wind electric field.



#### SM61A-0449 0830h POSTER

### Slowing of the Solar Wind by Current Closure in the Polar Cap Ionosphere

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A simple formula is derived which explains how the solar wind drives the earth's magnetospheric circulation, the aurora and many other high latitude phenomena. The conductivity of the polar ionosphere determines how much the solar wind slows down as mechanical energy is converted into electrical energy. For the Earth this magnetohydrodynamic generator has sufficient energy to drive even the electrical load presented by the sunlit hemisphere. The calculation is not based on energy conservation, but rather on current continuity.

## SM61A-0450 0830h POSTER

### Spreading Critical Dynamics in POLAR UVI Image Sequences as Evidence for Self-Organized Criticality in the Plasma Sheet

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A recent analysis due to Uritsky et al. [JGR, in press] of auroral emission bright spots in POLAR UVI images has revealed a remarkable set of scale-free power-law avalanche distributions for several of the spots' physical characteristics. The most straightforward and, at present, sole explanation for these distributions is that localized reconnection in the plasma sheet leads to a self-organized critical avalanching system that is scale-free over a broad range of scales.

The scale-free UVI distributions due to Uritsky et al. were constructed under the assumption that the auroral bright spots are a direct image of the plasma sheet avalanches; i.e., the bright spots were treated as though they were the avalanches. If this assumption is valid, and if it is correct that the distributions imply self-organized criticality (SOC) in the plasma sheet, then the bright spots should exhibit other known properties of avalanching systems in SOC.

We investigate the spreading dynamics of the auroral bright spots. We demonstrate that, on average, the bright spot evolution is consistent with the behavior known as spreading critical behavior in the general context of critical phenomena in many-body systems; it is a typical mean-field signature of SOC dynamics. We show that the so-called dynamical critical exponents controlling the spreading dynamics are consistent with the statistical exponents obtained earlier by Uritsky et al., thus providing further evidence of SOC dynamics in the plasma sheet.

## SM61A-0451 0830h POSTER

### Scaling of Solar Wind Epsilon and the AU, AL and AE Indices

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Magnetic reconnection mediates the coupling of the solar wind to the ionospheric currents gauged by the AE indices. To study this coupling we here apply the finite size scaling technique to quantify the statistical properties of fluctuations both in AU, AL and AE indices and in the epsilon parameter that represents energy input from the solar wind into the magnetosphere. We find that the exponents needed to rescale the probability density functions (PDF) of the fluctuations are the same to within experimental error for all four quantities. This self-similarity persists for time scales up to 4 hours for AU, AL and epsilon and up to 2 hours for AE.

On shorter time scales than these, the fluctuations are found to have similar long-tailed (leptokurtic) PDF, the form of which is consistent with an underlying turbulent process. Thus epsilon and the geomagnetic indices, at least under this measure, share the same statistical properties in their fluctuations.

These quantitative and model-independent results provide important constraints to modellers of the coupled solar wind-magnetosphere system.

URL: http://xxx.lanl.gov/abs/physics/0208021

## SM61A-0452 0830h POSTER

### On the Lévy-Nature of Magnetic Field Fluctuations During Magnetospheric Tail Current Disruption

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One of the most relevant phenomena occurring at the substorm onset is the development of a current wedge, which is responsible for the magnetosphere-ionosphere coupling during magnetic substorms. This current wedge is generally associated with the diversion or disruption of the near cross-tail current system [*Lui*, 1996]. In the last years this near-Earth dipolarization phenomenon has been the subject of several observation, as well as, simulation studies, which suggested a multiscale and a non-MHD nature of the phenomenon [*Sitnov et al.*, 2000; *Malova et al.*, 2000; *Zelenyi et al.*, 2000; *Miura*, 2000].

Here, using magnetic field data relative to 3 current disruption (CD) events as observed by AMPTEE/CCE spacecraft, we investigate the statistical features of magnetic field fluctuations. In the kinetic domain (i.e. above the ion cyclotron frequency during CD) the distribution function of magnetic field fluctuations shows non Gaussian tails and the probability of return $P_t(0)$ scales as $t^{-\alpha}$ with $\alpha \neq 1/2$ which is compatible with a Lévy-statistics. Conversely, in the magnetohydrodynamic (MHD) region CD magnetic fluctuations are compatible with a classical Brownian motion. These findings seem to indicate that the near-Earth dipolarization process, associated with CD, is a non-MHD phenomenon, during which fast kinetic processes in collisionless plasmas take place.

## SM61A-0453 0830h POSTER

### Thin current sheet instabilities relevant to the onset of reconnection in the geomagnetotail: Theory and observations

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Two basic families of thin current sheet instabilities responsible for the onset of X- and Y-line reconnection in the tail current sheet of Earths magnetosphere are discussed. The X-line reconnection onset becomes possible due to the growth of the tearing mode. Its stability is shown to crucially depend on the presence of a transient electron population and as a result the X-line can be formed only far enough from the Earth. Earthward of this critical distance the tail current sheet is tearing-stable and evolves into a thin current sheet (TCS). These results are fully consistent with recent Geotail observations [Asano, 2001], which show that the X-line is initially formed near the tailward edge of the evolved TCS. On the other hand, the formation of TCS creates the free energy source for current-driven instabilities that are not significant in the case of the conventional Harris equilibrium [Daughton, 1999]. This arises due to the bulk flow velocity shear provided by the nonadiabatic motion of ions. We provide the new results of the nonlocal stability analysis of TCS taking into account the effect of bulk flow velocity shear. In contrast to recent results [Shinohara et al., 2001; Daughton, 2002], where the shear appeared as a nonlinear effect resulting from the lower-hybrid turbulence in the pure Harris sheet with zero normal component of the magnetic field, we explore the stability of more realistic self-consistent TCS models with nonzero normal magnetic field that already have the velocity shear [Sitnov et al., 2000]. A distinctive feature of these models is the bean-shaped ion distribution at the center of the sheet. It is consistent with the characteristic ion distributions prior to the onset of the current disruption in the magnetotail [Lui, 2002].

## SM61A-0454 0830h POSTER

### Properties of the Drift Kink Instabilities and Their Effect on the Tearing Mode

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There is ample observational evidence for thin current structures in the magnetotail during the growth phase of substorms and at the magnetopause. The existence of such thin current sheets with thickness on the order of the ion gyroradius greatly augments the growth rate of various current sheet instabilites. This work investigates the properties of kink instabilities driven by relative electron-ion and ion-ion cross field drifts. A linear Vlasov code is used to examine the relative importance of the two kink modes as well as the collisionless tearing instability as a function of mass ratio, current sheet thickness, velocity shear, and the guide field strength. The nonlinear evolution of the instabilities is studied by means of hybrid (fluid electron, kinetic ions) and full particle-in-cell simulations. The electron-ion and lower hybrid drift instabilities are not present in the massless electron fluid model utilized in the hybrid code, and the tearing instability can be eliminated by setting the resistivity to zero. The hybrid model can thus be used to study the ion-ion mode both in isolation from other instabilities as well as in conjunction with the tearing instability. Comparison of the hybrid results with those from the full particle code can then document the influence of the lower hybrid and electron-ion instabilities on the ion-ion mode. The full particle code is also used to determine the role of the ion-ion kink mode in triggering reconnection in cases where the current sheet is stable to the linear tearing mode.

## SM61A-0455 0830h POSTER

### Current Disruption and Reconnection in a Harris Current Sheet

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Fully 3-D particle-in-cell simulations were performed for thin current sheets (CS). The Harris equilibrium was self-consistently established at an early stage with electrons as the major current carrier. In the simulated thin CS the relative drift between electrons and ions is large enough to drive Buneman instability. For the early time during the evolution of the instability, the antiparallel magnetic field lines bounding the CS remain unconnected. However, at certain stages of the evolution, the field lines begin to connect suddenly. During this stage significant acceleration of both electrons and ions occur in the CS. The CS itself undergoes a great deal of modification. The electron current disrupts locally in the midst of the CS. The CS expands, and ions begin to carry a significant part of the current. Our simulations reveal that current disruptions and reconnections are mutually intertwined phenomena and both play important roles in determining the electrodynamics in current sheets.

## SM61A-0456 0830h POSTER

### Three-Dimensional Collisionless Magnetic Reconnection: Simulation With a Particle Electromagnetic Code

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We have investigated the onset of reconnection in thin current sheets by means of three-dimensional full particle (PIC) simulations. Instead of imposing reconnection ab initio, reconnection is allowed to develop out of the numerical noise. We do not impose symmetry about the midplane, so that the drift kink instability, the Kelvin-Helmholtz instability, and the sausage instability are allowed for, and we use a high mass ratio of $m_i/m_e = 160$. The system is double periodic with two current sheets, which limits the time reconnection can proceed, but simplifies the boundary conditions. Two cases are investigated: (1) a thin current sheet with exactly antiparallel fields, and (2) a thin current sheet with a guide field of the same order as the antiparallel field. In case (1) the lower hybrid drift instability (LHDI) is excited and leads to current sheet thinning. Subsequently, patchy reconnection sets in, and arranges itself within a few ion times into a single neutral line. In case (2) the onset of reconnection is delayed, but eventually a single neutral line emerges. No sausage mode or kink mode, respectively, preceed in either case the onset of reconnection. After a single neutral line has evolved it kinks in the current direction.

## SM61A-0457 0830h POSTER

### Formation of thin-current layer embedded in an ion scale current sheet

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We have recently found that a quick triggering of magnetic reconnection in an ion-scale current sheet is possible. For the quick triggering of magnetic reconnection, the lower-hybrid drift waves excited at the edges of the current sheet is indispensable. This wave excitation brings about formation of a thin magnetic neutral layer sustained by accelerated electrons, and this thin layer is subject to the quick reconnection. As such, the electron acceleration within the curent sheet is playing a crucial role in making the quick triggering available. We found that the electron acceleration process is strongly coupled with the non-linear evolution of the lower-hybrid drift instability. The inductive electric field, which is generated through change of the current profile, can efficiently accelerate meandering electrons around the magnetic neutral layer. As a result, elctric current in the thin layer is mostly carried by non-adiabatic electrons. We will show results of detailed analyses of this key process for the quick reonnection triggering.

## SM61A-0458 0830h POSTER

### Quick reconnection triggering and development of islands to larger scales

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We have recently found that a quick triggering of magnetic reconnection in an ion-scale current sheet is possible. While it is impossible in two-dimensional cases, the quick triggering is enabled when the lower-hybrid drift waves is allowed to be excited at the edges of the current sheet. We carried out a series of three-dimensional full particle simulation runs, changing the simulation box size in the X directrion, and found that the wavelength of the fastest growing mode is abouth 12 times of the initial thickness of the current sheet. After the growth of the mode saturates, coalescence of tearing islands starts. Evolution of the coalescence process is rather slower, but, still faster than in two-dimensional cases. Eventually, MHD-scale reconnection geometry appears within a few tens of ion-gyro periods. We will discuss about dynamics of islands observed in the coalescence stage.

## SM61A-0459 0830h POSTER

### Instability at the edge of reconnection jets

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When the reconnection process has fully developed, the leading part of a reconnection jet pushes and compresses the plasma standing ahead of it, and steep pressure gradient threaded by curved field lines develops in front of the jet. It implies that the leading edge of the jet wil be unstable to an interchange instability. We have studied this situation by three dimensional MHD simulations. As soon as the pressure gradient develops adequately, the jet front becomes wavy and subsequently grows into a bubble-like pattern. The growth rate of this mode depends on the wavelength, with the shorter wavelength mode growing faster. It is also revealed that the magnetic pressure and plasma pressure are out of phase on the equatorial plane, which makes us identify the mode at the edge of jets as the ballooning mode instability.

We have found that the shape of the jet are further modified in the late growth phase of a short wavelength mode. As the bubble-like pattern is elongated in time, a velocity shear is produced between the parts that leads ahead and that is left behind.The Kelvin-Helmholtz(K-H) instability grows in the velocity shear layer, which undulate the already complex bubble-like pattern into a turbulent state. As a whole, our three dimensional MHD simulations tell that the leading edge of reconnection jets should be highly turbulent. We will discuss the consequences of this jet-driven turbulence in the magnetospheric physics context as well as in the astrophysical context.

## SM61A-0460 0830h POSTER

### Why current-carrying magnetic flux tubes gobble up plasma and become thin as a result

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Magnetic reconnection often involves currents flowing along a guide field; this situation can be construed as a twisted magnetic flux tube. It is shown here that when a current is made to flow along an axially non-uniform magnetic flux tube, then non-linear, non-conservative $\mathbf{J} \times \mathbf{B}$ forces develop which pump plasma axially from regions where the flux tube has small cross-section to where it has large cross section. Thus if a flux tube is bulged in the middle, plasma is pumped from both ends towards the middle.

The combination of plasma compressibility, flux-conservation in the frame of the moving plasma, the guiding effect of the axial field, and stagnation where the opposing flows meet cause the flux tube volume to decrease in such a manner that the flux tube develops an axially uniform cross-section (e.g., as observed in solar coronal loops). This result is the opposite of the prediction of the sausage instability and occurs because at the stagnation layer convected azimuthal flux accumulates and so enhances the pinch force there. The pumping process produces counter-rotating, counter-streaming bulk plasma motion consistent with solar observations. A small number of tail particles trapped between approaching axially conterstreaming fluid elements can be Fermi accelerated to very high energies.

An analytic solution of the Grad-Shafranov equation shows that a flux tube becomes axially uniform when $(\mu_0 Ia/\psi)^2 = 2\beta$ where $I$ is the current flowing along the flux tube, $\psi$ is the flux in the flux tube, and $a$ is the flux tube radius. This prediction is in good agreement with coronal measurements of $\alpha = \mu_0 I/\psi$, $a$, and $\beta$.

## SM61A-0461 0830h POSTER

### EMHD Plasma Dynamics in a Reconnection Experiment

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An experiment in which a Helmholtz coil is pulsed in opposition to a uniform background field ($B_0 = 5$ G) in an Argon plasma ($n_e \simeq 5{\times}10^{11}$ cm$^{-3}$) is used to study magnetic reconnection in the electron magnetohydrodynamic regime. The pulse length is long enough ($t \approx 50\ \mu$s) to allow for the Helmholtz coil field to diffuse through the ambient plasma and establish a vacuum-like field configuration. Driven reconnection at a 2-D $X$-type null line located between the coils is observed during turn on. The reconnection rate is observed to be roughly 10% slower than the vacuum rate. In steady state, the magnetic field topology consists of two 3-D cusp type null points on axis and an elongated 2-D $O$-line near the coils. Non-driven magnetic field annihilation occurs at the 2-D $O$-line during the free relaxation. However, no reconnection is observed at the two cusp-type 3-D null points because flux cannot be transferred across the separatrix. A broad current sheet ($\Delta y \simeq 7$ cm $> c/\omega_{pe} \approx 1$ cm) forms adjacent to the magnetic null layer during annihilation, which consists of Hall currents that flow perpendicular to the field lines. The evolution of magnetic flux contours and plasma currents will be presented. For comparison, data obtained with the Helmholtz coil field parallel to $B_0$ will be included.

## SM61A-0462 0830h POSTER

### A new mechanism to break the frozen-in condition in an EMHD plasma

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A Helmholtz coil is inserted into a large weakly magnetized ($B_0 = 5$ G) laboratory plasma. Its magnetic field ($B = 50$ G) is pulsed with rise and fall times fast compared to an ion cyclotron period. Thus the plasma and field dynamics are governed by Electron MHD (EMHD). During the rise of the field the electrons experience a $\mathbf{J} \times \mathbf{B}$ force away from the coils while the ions are initially at rest. A space charge electric field is set up which accelerates the ions away from the coils, producing in time a vacuum region around the coils. When the Helmholtz coil is rapidly switched off a large inductive electric field develops at the plasma boundary. The electrons should convect toward the coils at the $\mathbf{E} \times \mathbf{B}$ velocity but are bound by space charge electric fields to the slow ions. Thus, the electrons become decoupled from the field lines, i.e., the frozen-in condition is broken. The space charge electric field causes an electrons drift across strong field lines in the direction opposite to the inductive electric field. Theis leads to strong electron heating but no electron runaway. The electron energization occurs in the absence of magnetic null points, reconnection processes or turbulence.

## SM61A-0463 0830h POSTER

### Electron Heating During Magnetic Field Annihilation in an Electron MHD Plasma

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The conversion of magnetic energy into particle heating during the free relaxation of a magnetic topology that includes three-dimensional magnetic null points is studied. The topology, a field-reversed configuration (FRC), is created by pulsing a Helmholtz coil against the weak ambient field present in an afterglow plasma (see *Strohmaier et al*'s poster in this session). During the establishment of the topology, driven reconnection and annhilation leads to localized particle heating. This occurs at an $X$ and an $O$-line, respectively. During the free relaxation phase, the energy deposited in the plasma cannot freely convect away via whistlers because of null points located at both ends of the FRC's separatrix. Instead, it is dissipated locally via magnetic field annihilation, where strong electron heating is observed. Simultaneously, inductive electric fields near the individual coils create highly energetic electrons. No particle heating is observed in the null points because no flux transfer takes place across the separatrix. These processes are compared with the case where the Helmholtz coil field is in the same direction as the ambient background field, where the energy deposited by the coil in the plasma simply convects away via whistlers.

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## SM61A-0464 0830h POSTER

### Microinstabilities in an EMHD reconnection experiment

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A magnetic null point geometry has been established in a large laboratory plasma with a dipole field opposing a weak uniform magnetic field. The field and plasma parameters fall into the regime of Electron MHD (EMHD). Magnetic nulls are formed in two cusp points and a toroidally closed *O*-type layer, which carries a toroidal current sheet. The behavior of this field topology is studied during its free relaxation without boundary effects. Magnetic flux is annihilated in the *O*-type null layer. Magnetic energy is converted into electron heat. Current-driven ion sound turbulence is created in the current sheet. The associated anomalous resistivity explains the rate of energy conversion which is two orders of magnitude faster than predicted by classical diffusion. The temperature rise of the electrons is limited by heat conduction, emission of light, and electromagnetic waves above the plasma frequency. Ion acceleration is negligible during EMHD reconnection. The observed phenomena should be relevant to reconnection in the solar photosphere which has similar parameters as the laboratory plasma.

## SM61A-0465 0830h POSTER

### Energy conversion and transport in magnetotail reconnection

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Magnetic reconnection is the crucial process in the release of magnetic energy previously stored in the magnetotail. We discuss the energy release, transport, and conversion on small and large scales, based on large-scale resistive MHD simulations of magnetotail dynamics and full particle simulations of reconnection. We address in particular, where the energy is released, how it propagates and where and how it is converted from one form into another. The matching of the energy transport is also of crucial importance for the embedding of small-scale models or simulations into a large-scale transport code.

## SM61A-0466 0830h POSTER

### Signatures of Collisionless Magnetic Reconnection

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Recent numerical studies of collisionless magnetic reconnection, associated for example with the GEM Reconnection Challenge project, have stimulated widespread efforts to compare the predictions of reconnection simulations to observations in the magnetosphere and laboratory reconnection experiments. In addition to the reconnection rate, the simulations predict the structure of the magnetic field, plasma flows, and other profiles across the reconnection zone. In the case of a reversed-field configuration (no out-of-plane guide field prior to reconnection), for example, a now well-known theoretical prediction is the formation of a localized, spatially antisymmetric (ie, quadrupole) structure in the out-of-plane magnetic field. Evidence supporting this prediction was recently obtained through spacecraft observations of reversed-field configurations in the magnetotail [Oieroset et. al. 2001] and at the subsolar magnetopause [Mozer et. al. 2002], which linked the plasma flows generated by a reconnection event with the expected quadrupole signature in the magnetic field. Such quadrupole structures have now come to be viewed as a hallmark signature of reconnection in collisionless plasmas, and have become a target for studies of other reconnecting systems seeking to test the predictions of the reconnection simulations. The main point of this paper is to show that a quadrupole magnetic field signature is not in fact a generic feature of collisionless reconnecting systems. Across the wide range of configurations found in the Earth's magnetopause or laboratory reconnection experiments, for example, in which a significant guide field component (comparable to or exceeding the reconnecting component) is often present, the symmetry of the profiles exhibited by the simulations can be very different from the reversed-field case. The perturbation in the out-of-plane magnetic field generated by nonlinear reconnection, for example, becomes fully symmetric (rather than antisymmetric) across the reconnection zone in the strong guide-field limit. The spatial symmetry of the plasma pressure, which is symmetric in the absence of a guide field, also reverses in the presence of a strong guide field. The physical processes and important parameters that govern this transition will be discussed.

## SM61A-0467 0830h POSTER

### The Role of Hall Electric Fields in Two-dimensional Forced Magnetic Reconnection

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Magnetic reconnection is thought to be the mechanism by which magnetic energy is converted into plasma energy in such astrophysical dissipative events as solar flares and magnetospheric substorms. While many solar-terrestrial physicists now routinely invoke reconnection in models of such dissipative events, a self-consistent theory yielding realistic dissipation time scales does not yet exist. Recent computational work suggests that Hall electric fields (which are normally neglected in the usual resistive MHD treatment) play an essential role in allowing reconnection to occur on Alfvenic time scales (as required by observations). In this talk, we critically review this recent work, demonstrating the following: 1) Hall electric fields only play a direct role in driving fast reconnection when the scale sizes of the merging magnetic structures are comparable to the ion inertial scale; 2) Magnetic flux pile-up, an ideal MHD effect, seems to be the key physical effect which allows fast reconnection to occur for large systems; 3) For large, two-dimensional merging structures, Hall electric fields seem to play a more passive role than previously suggested, merely preventing the flux pile-up saturation (and consequent reduction in reconnection rate) which occurs in resistive MHD. We discuss the implications of this effect for the possibility of Alfvenic reconnection in astrophysical systems.

## SM61A-0468 0830h POSTER

### Three Dimensional Mesoscale Reconnection and its Relation to Magnetotail Dynamics

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The mesoscale structure of reconnection is explored using a two-fluid code with the Hall effect and electron inertia. Previous full particle simulation studies of 3-D reconnection have shown that the system self-organizes into a quasi 2-D x-line configuration. However, these kinetic models were limited to relatively small systems. In a mesoscale systems (with scale length around $20R_e$) we show that reconnection becomes intrinsically 3-D. In relatively thick current sheets we find that reconnection occurs in widely separated localized patches whose intrinsic scale length is of the order of $10c/\omega_{pi}$ or $1-4R_e$ in the Earth's magnetotail. There is no tendency for magnetic x-lines to spread and become quasi 2-D. The spatial scale of these patches are consistent with cross tail length scales of bursty bulk flows (BBFs), as inferred from multiple satellite observations. In thinner current sheets multiple finite length x-lines form in the cross tail direction which lead to a global release of magnetic energy. The implications for these results on the conditions under which the magnetotail releases magnetic energy in localized regions (BBFs) or through more global processes (substorms) are discussed.

## SM61A-0469 0830h POSTER

### Key Signatures of Hall Mediated Reconnection at the Magnetopause

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Currently, we are at a very exciting time when observations of reconnection in the magnetosphere are becoming more and more commonplace due to higher time resolution and multiple spacecraft studies. In order to provide clear signatures of Hall mediated reconnection, we simulate reconnection in several possible magnetopause equilibrium with two fluid and hybrid simulations of reconnection. Specifically, we focus on those features most easily compared with satellite data, such as the density depletion layer which forms due to Hall physics near the separatrix of the reconnection process. Comparisons with multiple previously published magnetopause crossings will be performed.

## SM61A-0470 0830h POSTER

### Particle heating and energization in intense reconnection current layers

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Magnetic reconnection generates intense current layers near the X-line which become turbulent in 3-D simulations as a result of the development of Buneman instabilities. To more fully explore the dynamics of this turbulence and associated particle scattering and heating, we have carried out 2-D electromagnetic PIC simulations of the current sheet which forms at the x-line during reconnection (in a plane defined by the inflow and out-of-plane current in a 2-D reconnection simulation). The electron beams are unstable to the Buneman instability which rapidly evolves into electron holes, localized regions of bipolar parallel electric field. The strong scattering of electrons by these intense parallel electric fields scatter the electrons, producing extended tails on the electron distribution functions. At late time the ion perturbation becomes so large that the holes self-destruct, forming a jet-like structure within the current sheet which has the form of a double layer. Both electrons and ions are strongly accelerated by the intense fields at the head of the jets. We discuss the expected signatures of these structures at the magnetopause and the broader implications for understanding particle energization in space and astrophysical plasmas.

## SM61A-0471 0830h POSTER

### 3D Hall MHD Reconnection Dynamics in a Strongly Sheared System

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A 3D Hall MHD simulation code (VooDoo) has recently been developed at the Naval Research Laboratory. Recent results have demonstrated that magnetic shock-like structures [*Rudakov and Huba*, 2002] and a 'reconnection wave' [*Huba and Rudakov*, 2002] can propagate in three dimensional, reversed field plasma layers. In this talk we present preliminary results of a fully 3D magnetic reconnection process in a reversed field plasma that includes a strong guide field, i.e., no magnetic nulls. The initial configuration of the plasma system is as follows. The ambient, reversed magnetic field is in the $x-$direction with $B_x = B_0 \tanh(y/L_y)$ where $L_y$ is the scale length of the current sheet. The ambient guide field is in the $z-$direction with $B_z = B_0$. Perturbation fields $\delta B_x$ and $\delta B_y$ are introduced to initiate the reconnection process. This initial configuration is similar to that used in the 2D GEM reconnection study. However, the perturbation fields are localized in the $z-$direction. We find that the magnetic topology of the system is reconfigured via a process akin to 'magnetic flipping' described by Priest and Forbes (1992). A high-density, magnetic flux-rope forms in the center of the plasma sheet. Magnetic flipping occurs between the center of the flux-tube and the boundaries in the $x-$direction. Associated with

this magnetic flipping geometry, the reconnected magnetic field component $B_y$ reverses sign 3 times in the $x-$direction, in contrast to only once in the no-guide field case. As in previous Hall MHD reconnection simulation studies, the system evolves asymmetrically along the current.

Huba, J.D. and L.I. Rudakov, to be published in *Phys. Plasmas*, 2002.
Priest, E.R. and T.G. Forbes, *J. Geophys. Res. 97*, 1521, 1992.
Rudakov, L.I. and J.D. Huba, *Phys. Rev. Lett. 89*, 095002, 2002.

Research supported by NASA and ONR.

## SM61A-0472 0830h POSTER

### Collisionless Hall MHD Reconnection Dynamics: Is the Nonlinear Reconnection Rate Independent of the Mechanism that Breaks Field Lines?

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There has been considerable interest in recent years in collisionless reconnection dynamics governed by the generalized Ohm's law in which electron inertia provides the mechanism for breaking field lines. It has been suggested in several theoretical studies that the nonlinear reconnection dynamics, to leading order, is independent of the mechanism that breaks field lines (that is, electron inertia). We test this suggestion carefully using the new Magnetic Reconnection Code (MRC) developed at the Center for Magnetic Reconnection Studies. The MRC is a new massively parallel code with Adaptive Mesh Refinement (AMR) that integrates the equations of Hall MHD. The use of AMR enables unprecedented levels of resolution of the current and vorticity layers and uncovers interesting secondary dynamics not seen in previous studies. We apply the MRC to the study of two problems, one involving free reconnection caused by a spontaneous and fast collisionless instability, the other involving forced reconnection induced by boundary perturbations on a stable plasma. In the case of free reconnection, over the range of parameters covered by our simulations, it is shown that the nonlinear reconnection rate is near-explosive, and furthermore, that the nonlinear magnetic island width is an invariant function of a dimensionless variable which is the product of the linear growth rate and time. Now, since the linear growth rate is a function of the ion sound radius as well as the electron skin depth, we conclude that the nonlinear reconnection rate is not independent of electron inertia. In the case of forced reconnection, after a slow growth phase, the dynamics exhibits an impulsive growth in the amplitude of the thin current sheet, and a subsequent current disruption mediated by secondary instabilities. These results, in which electron inertia provides the mechanism for breaking field lines, are contrasted with resistive Hall MHD simulations in which resistivity provides the mechanism for breaking field lines.

## SM61A-0473 0830h POSTER

### Magnetic Reconnection in the Tail at Global and Meso-Scale Lengths

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There has always been a dichotomy between the reconnection seen in global MHD simulations and local kinetic simulations. This dichotomy includes the trigger mechanism for reconnection, i.e. external solar wind conditions versus internal particle processes, to scale size, i.e. several $R_e$ for MHD versus localized flux ropes in particle treatments. These different processes are studies through multi-fluid simulations that includes ion-cyclotron effects in the fluid dynamics as well as the in the Ohms law. This new approach thereby incorporates both internal and external drives at both global and meso-scale lengths. It is shown that tail reconnection has different forms during substorm growth phase, onset and expansion phase. These forms are very distinct in terms of size, particle populations and spatial distribution, which could easily be distinguished by insitu observations. The recognition that reconnection in the tail has different forms represents a shift in the paradigm but could be important in understanding substorm and storm development as seen by both global and local treatments.

## SM61A-0474 0830h POSTER

### Particle-in-cell simulations of magnetic reconnection in three-dimensional force-free plasmas

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Recent observations and theoretical considerations have pointed to a dynamic intergalactic medium, a sizable part of which is filled with magnetic fields (e.g., Kronberg et al. 2001, ApJ, 560, 178). Magnetic reconnection is an important mechanism of converting magnetic energy into heating and accelerating particles. Astrophysical plasmas often store their magnetic energy in the twists of magnetic fields and with low plasma beta (ratio of thermal to magnetic pressure), in which case it can be assumed that currents flow nearly parallel to the background magnetic field (i.e., force-free). We are investigating the onset of magnetic reconnection in such a plasma using 3-D fully kinetic particle-in-cell simulations. We use a sheet pinch, kinetic equilibrium as an initial force-free configuration (Bobrova et al. 2001, Phys. Plasmas, 8, 759). In our previous 2-D simulations concerning the same problem, we see that the magnetic field configuration has completely changed through magnetic reconnection process. And, the initial magnetic field energy is converted into the flow and thermal energy of particles in the vicinity of X-points. The main purpose of our 3-D simulations is to examine how the physics of magnetic reconnection in force-free plasmas changes when we remove a spatial restriction from 2-D simulations.

## SM61A-0475 0830h POSTER

### Influence of a Guide Field on the Tearing Mode

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The influence of a guide field on the linear and nonlinear dynamics of the tearing mode is examined for a thin current sheet in which the thickness is comparable to a thermal ion gyroradius. The linear Vlasov stability of a Harris sheet with an arbitrary guide field is calculated using a recently developed technique in which the orbit integrals are treated numerically using the exact unperturbed particle orbits and including the global structure of the perturbation inside the integral[1]. Both electromagnetic and electrostatic contributions to the field perturbation are included and the eigenvalue problem for the resulting system of integro-differential equations is solved using a finite element representation of the eigenfunction. The addition of a guide field causes the eigenfunction for the tearing instability to be of mixed parity (i.e. a superposition of even and odd parity functions) and strongly alters the quadrupole magnetic field structure in the reconnection region. The influence of the guide field on the mode structure is confirmed using fully kinetic particle-in-cell (PIC) simulations and the resulting reconnection rates in the linear and nonlinear regimes are compared with the growth rates from linear theory for a range of parameters.

[1] W. Daughton, *Physics of Plasmas* **6**, 1329 (1999)

## SM61A-0476 0830h POSTER

### Reconnection in presence of guide fields

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Many physical systems observed in laboratory experiments, in space and astrophysics plasmas can be modeled as simple current sheet with a magnetic field reversal (Harris sheet). However, often additional components of the magnetic field need to be considered. In the Earth's magnetopause, there is an out of plane magnetic field (referred to as guide field) of strength comparable to the lobe field on either side of the Harris sheet. In astrophysical systems, such as jets from accretion disks, the magnetic field is believed to be primarily aligned with the current and can be represented by a Harris sheet with a very strong guide field, much larger than the lobe field. In magnetic confinement fusion devices, reconnection develops in presence of strong toroidal fields and the configuration can be represented by a Harris sheet in the poloidal plane with a strong guide field in the toroidal direction.

To understand better the role of the guide field the implicit PIC code CELESTE has been applied. The advantage of the implicit formulation in the present case is to allow one to exceed the time step limitation imposed by the rapid gyromotion in the guide field. Normal explicit codes are limited to weak guide fields to respect this stringent time step limitation. Furthermore, a linear theory [1] for the stability of current sheets has been extended to include the additional processes caused by the guide field.

Our results show that the reconnection rate is adversely affected by the guide field and that the structure of the reconnection region is altered dramatically. The dissipation layer still breaks up into two layers as without a guide field but the physics in each layer is modified. To understand the physics of the dissipation layer we compare the results of the PIC simulations with linear theory. The agreement is remarkable and several features of the simulations can be explained by linear effects alone.

[1] Daughton W.S., PHYSICS OF PLASMAS , 6, 1329 (1999)

## SM61A-0477 0830h POSTER

### 3-D Collisionless Magnetic Reconnection in the Presence of a Guide Field

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Recently, considerable progress has been made in understanding collisionless magnetic reconnection for the case of a standard Harris neutral sheet configuration. In many geophysical applications, however, such as the dayside magnetopause, auroral arc models, and even at times the magnetotail, this configuration is modified by the presence of a "guide field" component $B_{0y}$ of the magnetic field. 3-D particle-in-cell simulations with an open geometry are used to investigate the changes in the reconnection physics produced by the guide field. With $B_{0y} \leq B_0$, the nonlinear reconnection rate is not substantially modified from that for the pure Harris case. The properties of the reconnection fields and particle dynamics, however, are strongly altered. The familiar quadrupole $B_y$ pattern is replaced by an enhancement of $|B_y|$ between the separatrices. The enhanced parallel electric field and parallel electron velocity are confined to one pair of separatrix arms (which are positively charged), while the electron current peaks on the other pair (which are negatively charged). The electrons are accelerated to form a beam structure with temperature less than the initial value, but this structure is partially smeared out due to turbulence. The peak parallel velocity is limited by the electron Alfvén speed. No significant $y$ dependent structures are observed in the magnetic field, but some localized electron holes are produced by a Buneman instability. For $B_{0y} \gg B_0$, the growth rate is reduced and the parallel fields and velocities are somewhat smaller. Observational implications will be discussed.

## SM61A-0478 0830h POSTER

### On the Possibility of an Analytic Kinetic Treatment of Simple Reconnection Geometries

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Previous work obtained an exact 2-D, self-consistent X-point structure which contained no reconnection electric field but suggested the possibility of extension by adding small perturbing electric and magnetic fields. We have explored this possibility by adding such perturbing fields to both the previous X-point result, and also to simple shock models where the magnetic field changes discontinuously at a boundary. In both cases the calculation of particle trajectories in these fields shows that the first adiabatic invariant can be well-preserved in spite of large changes in the fields over a particle gyro-radius. This opens the possibility of finding analytic relations between the parallel and perpendicular energies in an accelerating field. These relations can be exploited to obtain moments of the distribution functions.

We describe preliminary results from these studies and indicate how they might be further extended to help understand reconnection processes in the magnetosphere.

### SM61A-0479 0830h POSTER

## FULL PARTICLE SIMULATION OF SLOW WAVESFULL PARTICLE SIMULATION OF SLOW WAVES

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Magnetohydrodynamic theory predicts that the slow shock pairs should be generated by magnetic reconnection in the Earth magnetotail. One question is focussed on conditions/mechanisms responsible for the survival time of such waves. For this purpose, kinetic and nonlinear effects of the slow waves dynamics are analyzed with the help of a 1-2/2-dimensional electromagnetic full particle code (1-D in x-space and 3-D in velocity space) with periodic boundary conditions. At the initial time of the simulation, the particles are loaded with sinusoidal density perturbation (30% of its background value) in x-space with consistent sinusoidal magnetic field in z; these pertubations are provided by results issued from MHD equations. Magnetic field and density profiles have opposite phase as a slow wave nature. The simulations are performed for one long slow wave period that is considered to be enough for the wave steepening. Results show that kinetic effects speed up the slow wave steepening process so that $T_{steepening,PIC} << T_{steepening,MHD}$. Main difference between MHD theory and full particle simulation is that a strong competition between steepening and damping processes are observed. The wave steepening time is much less than the wave damping time ($T_{steepening,PIC} << T_{damping,PIC}$). In addition, both processes (i) have characteristic times less than one ion gyroperiod ($T_{steepening,PIC}$ , $T_{damping,PIC} < T_{ci} << T_{slow}$), (ii) may complete in the initial stage of the simulation; this cause the linear growth of the longitudinal electrostatic field energy of the wave. After the wave is fully steepened, both processes may balance and cause the saturation in the growth of the longitudinal electrostatic field energy. Thus after the saturation, electrostatic field energy is mainly transferred to the ion kinetic energy; at the same time, a strong change in the magnetic field polarization is also observed.

### SM61A-0480 0830h POSTER

## Hall MHD and hybrid simulations of the magnetic reconnection: A comparative study

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Using hybrid simulations, it has been established that the sequence of discontinuities formed during the magnetic reconnection process do not match those predicted by single fluid MHD. It has also become clear that the Hall term plays a significant role in the reconnection process. So the natural question is whether the inclusion of Hall term alone will be sufficient to resolve the discrepancies observed between kinetic and MHD simulations of the reconnection process. To this end, we have made Hall MHD and hybrid (electron fluid, kinetic ions) simulations of both symmetric and asymmetric current sheets for anti-parallel as well as non-coplanar configurations. The Hall MHD simulations are made using two different models of constant as well as variable temperature. We specially focus on the detailed structure of the resulting core field (out- of-the-plane field component corresponding to BM component in boundary normal coordinates) in the two simulation methodologies. Hybrid simulations show (i) large-scale core fields that can extend to tens of ion inertial length across the current layer, (ii) current sheet instabilities in certain parameter regimes that lead to modulation of the current layer, and (iii) magnetic and plasma asymmetries about the neutral line for non-coplanar configurations. The extent and the level to which these features are captured in the Hall MHD regime will be examined in detail. Such a comparison will also help distinguish between kinetic and Hall MHD effects in the reconnection process.

### SM61A-0481 0830h POSTER

## Magnetic reconnection in symmetric and asymmetric configurations

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Magnetic flux ropes or plasmoids are observed both at the Earths magnetopause as well as in the magnetotail. The flux ropes are typically observed to have large out-of-the-plane component (the so-called core field). Such large core fields drastically change the mobility of the ions as well as the topology of the plasmoid/flux ropes. A number of explanations have been put forward to explain this core field. We have tested each concept, as well as several new possibilities in various domains. Our main tools of investigation were 2D and 3D hybrid codes (fluid electron, kinetic ions) running on parallel machines. The proper study of the core field required extending the simulations to much larger system lengths than before and running them for much longer times. Our findings regarding the validity of the various concepts for core field generation will be presented. The presence of an asymmetry in the current layer can have profound effects on the stability of the current sheet as well as the formation of the core field. This dependency will be explored in detail. Finally, we will show results on the possibility of the intermittent reconnection in 3D geometries.

# SM61B MCC: 123 Saturday 0830h

## ULF Waves and Their Role in Diagnosing the Plasmasphere II *(joint with SA)*

***Presiding:*** **P Chi,** University of California, Los Angeles**; K Takahashi,** Applied Physics Laboratory**; R E Denton,** Dartmouth College

### SM61B-01 0830h

## Ground-based ULF Wave Studies of the Plasmapause

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More than 25 years ago a major research effort was undertaken to examine the possibility of diagnosing the Earth's plasmapause through the use of ground-based magnetic field measurements of ULF waves. While the spatial resolution of the measurements was more broad than is desirable today, the program at that time, using an instrumented array of latitudinally-spaced stations in the northern hemisphere and a conjugate station at Siple Station, Antarctica, was a significant success by any measure. In addition to providing the first diagnostics of the plasmapause by ULF waves, the research also carried out joint "calibrations" of the technique using complementary and contemporaneous measurements by VLF waves, by total electron content (TEC), and by spacecraft. This talk reviews some of the intellectual background for the 1970's research program, presents a number of the central discoveries and understandings from the research, and provides a perspective on what might be used from that program to advance contemporary research in this field.

### SM61B-02 0845h INVITED

## Remote Sensing Plasma Dynamics of the Inner Magnetosphere Using ULF Waves

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Ground-based observations of ultra low frequency (ULF) magnetic field line resonant (FLR) oscillations may be used to remote sense cold plasma number densities in the magnetosphere. Detecting FLRs on the ground can be achieved in a number of ways. Several of these experimental methods will be illustrated.

For mid to high latitudes, the plasma mass density remote sensing techniques based on simple exponential plasma density models give reasonable agreement with spacecraft electron density measurements. For the inner magnetosphere, the Alfven speed varies along the magnetic field direction in such a way that the lower altitude plasma population becomes important. Techniques for freeing the estimates of plasma mass density from density models can be devised if harmonics of the resonant oscillations can be obtained. The development of these methods is important for remote sensing the inner magnetosphere. The few techniqes developed so far will be discussed.

### SM61B-03 0905h

## Theory and Data Analysis of ULF Field Line Resonances : Comparisons with Global MHD models

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ULF Alfven waves, propagating inside closed flux tubes of Earth's magnetic field, can form standing waves in the magnetosphere. These standing waves are known as field line resonances (FLRs) and are commonly detected by ground-based instruments and by satellites. The properties of FLRs are related to global magnetospheric topology and to the plasma density along their path. Therefore, their study can provide three-dimensional information about the structure of the magnetosphere, and of the processes driving large scale magnetospheric dynamics. We use magnetic field lines and ion densities generated by the BATS-R-US global MHD model to estimate FLR frequencies for several characteristic sets of solar wind parameters, as well as for several specific dates when FLRs were observed. We find that despite numerous approximations of the MHD model, and our simple technique for the frequency calculation using a WKB and full-wave approximation, we get reasonable estimates for observed FLR frequencies. We present results for discrete FLRs, and for the Alfven continuum.

### SM61B-04 0920h INVITED

## The Role of the Plasmapause in Magnetospheric MHD Waves

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The plasmapause as the boundary region between the inner and outer magnetosphere provides a complex