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FORESHOCK, BOWSHOCK, MAGNETOSHEATH (FBM) FOCUS GROUP (FG3) – FINAL REPORT

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The GEM FBM Focus Group was formed with the following objectives in mind.

1. Understand the origin and properties of ULF waves in the foreshock.
2. Understand the structure and dynamics of the bow shock.
3. Understand the nature of ULF turbulence in the magnetosheath and their magnetospheric impacts.
4. Understand the interaction of solar wind discontinuities with the bow shock and the magnetospheric consequences.

In the following we summarize the major advances made towards each of these objectives and the current state of our knowledge.

ULF Waves in the Foreshock

ULF waves in the foreshock are generated by the interaction between ion beams reflected or leaked from the bow shock and the solar wind. Through nonlinear wave particle interactions they modify solar wind properties such as density, velocity, temperature and the interplanetary magnetic field (IMF). Until recently, the most likely ULF waves to modify the solar wind and ion beam properties were thought to be the 30 second sinusoidal waves and the so-called shocklets. The former propagate primarily along the magnetic field and are transverse in nature, i.e. density and magnetic field variations associated with these waves are relatively small. On the other hand, shocklets propagate at angles of ~20^o-40^o and are associated with local enhancements of density and magnetic field and deceleration of the solar wind. One outstanding question regarding ULF waves in the foreshock was the connection between these two types of waves and whether shocklets are the outcome of further evolution of the sinusoidal waves. Global hybrid simulations by *Omidi et al.* [2005] showed independent generation of sinusoidal and shocklet waves by field aligned and gyrating ion beams respectively. The gyrating beams are present near and upstream of the quasi-parallel shock and so are the shocklets. *Blanco-Cano et al.* [2006] compared the properties of the observed and simulated ULF waves and their co-relations with the ion beams and found a good agreement between the two.

Global hybrid simulations by *Lin* [2003] and *Omidi* [2007] during radial IMF geometries showed the formation of density cavities in the foreshock that are associated with correlated drops in the magnetic field strength (by ~50%). *Omidi* [2007] showed that the formation of these density cavities is tied to the simultaneous generation and nonlinear evolution of parallel propagating ULF waves similar to the 30 second sinusoidal waves and highly oblique, fast magnetosonic waves. Using linear theory, it has been shown that for a wide range of ion beam and solar wind properties the two modes have comparable growth rates and can grow together. *Blanco-Cano et al.* [2009] reported on the detection of similar structures in the Cluster data and named them *foreshock cavitons* to distinguish them from structures called foreshock cavities. **Figure 1** from *Blanco-Cano et al.* [2009] shows an example of a foreshock caviton in the blue shaded area. *Blanco-Cano et al.* [2009] compared the properties of the observed cavitons with the structure present in the hybrid simulations and found good agreement. Examination of the Cluster data set has established the presence of numerous foreshock cavitons over a wide range of solar wind conditions and cone angles as large as 50^o [*Kajdic et al.*, 2009]. Foreshock cavitons are generated with a size of about 1 R_E, however, simulations and data show that they merge into larger structures as they are convected by the solar wind. As we describe below, formation of foreshock cavitons has significant implications for the global structure and properties of the foreshock.

Global Structure and Dynamics

Global hybrid simulations show that strong wave particle interactions associated with the ULF waves in the foreshock such as the generation of cavitons, results in the formation of a new boundary that is associated with correlated enhancements in density and magnetic field. This

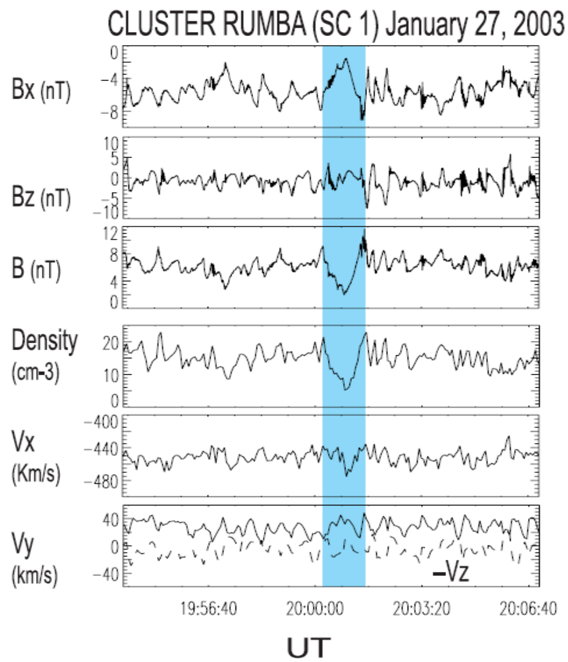

Figure 1

boundary has been named the foreshock compressional boundary (FCB) and is illustrated in **Figure 2** that shows density from four runs with Alfven Mach numbers ranging between 6 and 15 during radial IMF [*Sibeck et al.*, 2008; *Omidi et al.*, 2009a]. As can be seen, FCB becomes stronger with increasing Mach number so that at low Mach numbers it corresponds to a fast magnetosonic pulse while at higher Mach numbers it becomes a fast shock and a true extension of the bow shock surface. Formation of the foreshock compressional boundary is tied to the lateral expansion of the foreshock due to strong wave particle interactions and is associated with drops in the average density and magnetic field strength in the foreshock to below solar wind levels. *Sibeck et al.* [2008] used data from a global hybrid simulation and the Cluster

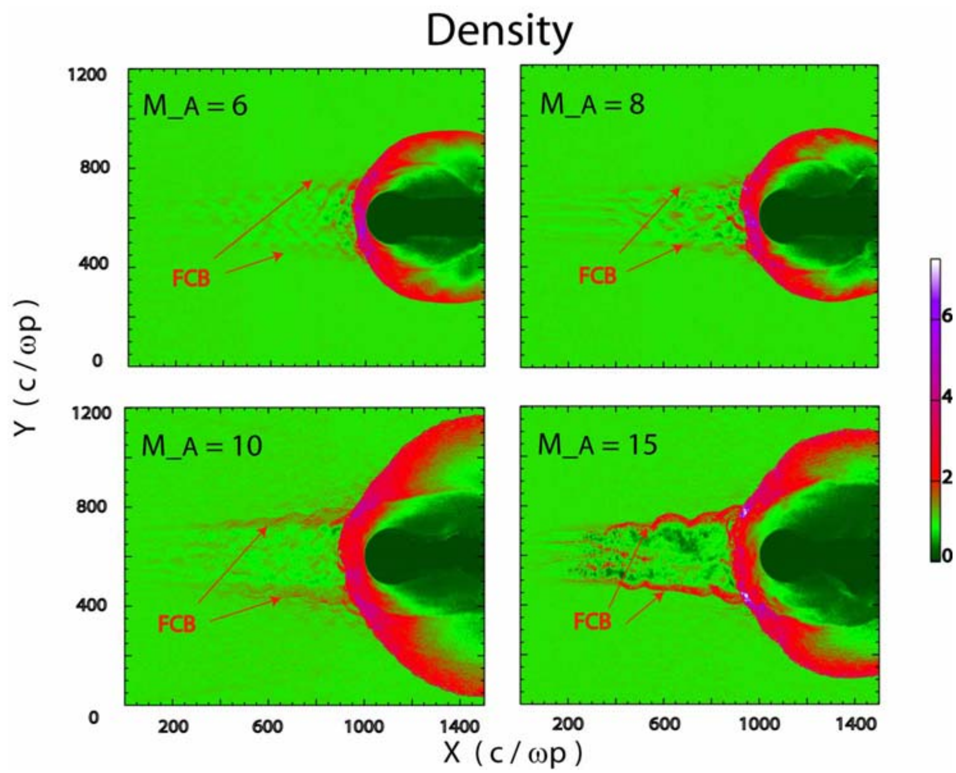

Figure 2

spacecraft to show that passage of a spacecraft from the solar wind through the FCB and back into the solar wind results in a signature in time series data similar to foreshock cavities. Comparing the changes in density, velocity, ion temperature and magnetic field strength across the FCB in simulation and Cluster data showed a good agreement between the two. *Omidi et al.* [2009a] have demonstrated that FCBs form over a wide range of cone angles and compared the detailed structure of an observed FCB with simulations and found good agreement between the two. More comparisons between model predictions and the observed properties of FCBs are currently underway. However, the results have already established the fact that solar wind properties are greatly (by 25% or more) affected by strong ULF wave activity in the foreshock on a global scale. During small and intermediate cone angles when the foreshock falls upstream of the magnetosphere, such drastic changes in the solar wind properties impact its interaction with the magnetosphere.

Impacts of Waves and Turbulence in the Magnetosheath

Convection of ULF waves and nonlinear structures such as foreshock cavitons by the solar wind brings them into the magnetosheath during small and intermediate cone angles and results in large fluctuations in density, velocity, temperature and magnetic field strength and direction. Given that these fluctuations are the byproduct of nonlinear processes in the upstream and their passage through the bow shock, it is not clear that they can be described in terms of linear plasma modes. For example, foreshock cavitons start as highly nonlinear structures and as they cross the quasi-parallel bow shock experience considerably different levels of compression in density and magnetic field strength. The resulting fluctuations in plasma and fields in the magnetosheath are therefore, not describable in terms of a single plasma mode. The extent to which this turbulence can be classified and described in a systematic manner remains to be determined. Similarly, while the large fluctuations in the magnetosheath are bound to impact transport processes such as magnetic reconnection at the magnetopause, the details remain to be understood.

During large cone angles, the dayside magnetosphere is exposed to the sheath fluctuations generated at and downstream of the quasi-perpendicular bow shock. Both Alfven ion cyclotron and mirror mode waves are generated by the temperature anisotropy of the ions going through the shock. The former propagates through the sheath while the latter is non-propagating and is carried by the magnetosheath flow. Both types of waves are observed near the magnetopause, however, ion cyclotron waves are favored during northward IMF when a strong plasma depletion layer forms while mirror mode waves are favored during southward IMF. The drastic change in the nature of the ULF waves in the magnetosheath with the cone angle is illustrated in **Figure 3**. It is clear from the figure that the IMF rotates from high cone angle at the start of the interval to a low cone angle at the end. THEMIS-A sees an abrupt transition between smaller amplitude fluctuations in the dayside magnetosheath before 2240 UT to bigger fluctuations after that. Figure 3 also shows two snapshots of the fluctuations in expanded view below the survey plots. It can be seen that mirror mode waves, associated with anti-correlated oscillations in density and magnetic field, are present on the left in the quieter magnetosheath from 2000 to 2005 UT. This period corresponds to large cone angles when dayside magnetosheath lies downstream from the quasi-perpendicular bow shock. The relationship between the magnetic field strength and density is less clear in the disturbed magnetosheath on the right, from 2300 to 2305 UT where the waves look noisier and density and magnetic field perturbations are larger. This period corresponds to small cone angles when the dayside magnetosheath falls downstream of the quasi-parallel bow shock.

Global hybrid simulations [*Omidi and Sibeck*, 2007] show that during southward IMF

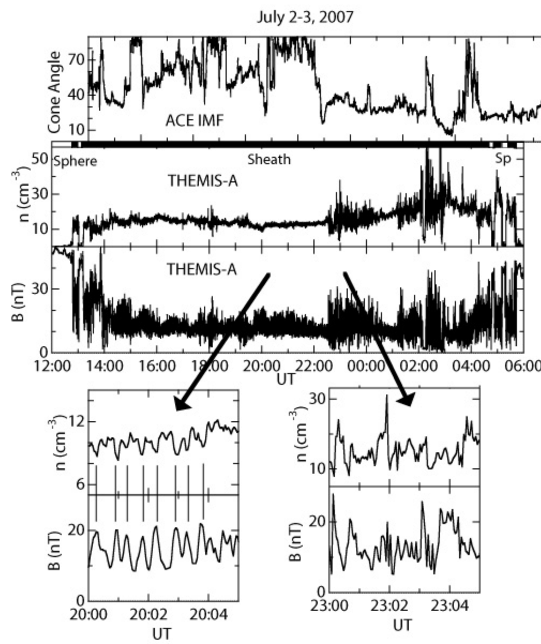

Figure 3

time dependent reconnection at the magnetopause results in the generation of FTEs at lower latitudes that subsequently travel to higher latitudes. As they encounter the cusps a secondary magnetic reconnection starts which results in plasma injection into the cusps with signatures that resemble Poleward Moving Auroral Forms (PMAFs). By performing numerical tests that damp out the ULF waves in the sheath, upstream of the magnetopause we find that the rate of FTE formation drops by more than 50%. This demonstrates that the mirror mode waves in the sheath contribute to the time dependency of reconnection at the magnetopause. Recent analysis of the Cluster data near the subsolar magnetopause, during southward IMF, shows the presence of strong mirror mode waves and time dependent reconnection [*Laitinen et al.*, 2009]. This study provides strong indications that mirror mode waves are responsible for the time dependent reconnection.

Impacts of Solar Wind Discontinuities

It has been known for a couple of decades that the interaction of a class of solar wind discontinuities, with certain characteristics, with the bow shock results in the formation of hot flow anomalies (HFAs). Evidence for the gross deformation of the magnetopause surface due to HFAs was presented in this decade. However, the THEMIS multi-spacecraft and ground based observations have provided a unique opportunity to study these structures and their magnetospheric impacts from upstream all the way to the ground level. *Eastwood et al.* [2008] showed that HFAs have a complex structure in the magnetosheath and are associated with pressure pulses that upon encountering the magnetopause initiate a series of processes which result in the observed magnetic perturbations on the ground. *Jacobsen et al.* [2009] have examined an event that shows the formation of an HFA at the bow shock is associated with the outward displacement of the magnetopause by 4.8 R_E in 59 seconds corresponding to a normal velocity of 800 km/s. They also found a large bulge on the magnetopause travelling tailward at a speed of 355 km/s. This in turn, resulted in the generation of field aligned currents and travelling convection vortices which were detected by the ground magnetometers. **Figure 4** is from *Jacobsen et al.* [2009] and shows THEMIS ground magnetometer data. Stations are sorted by magnetic longitude from low to high. For each station, the *X* (North-South) component of the magnetic field is plotted. The long-term average magnetic field has been subtracted. To the right of the plot the positions of the stations in magnetic latitude and longitude are shown. A Magnetic Impulse Event (MIE) in the form of a positive peak in the *X*-component is seen moving westward.

Recently, *Omidi et al.* [2009b] have shown results from a global hybrid simulation that demonstrate the formation of a new structure called the foreshock bubble (FB). This structure

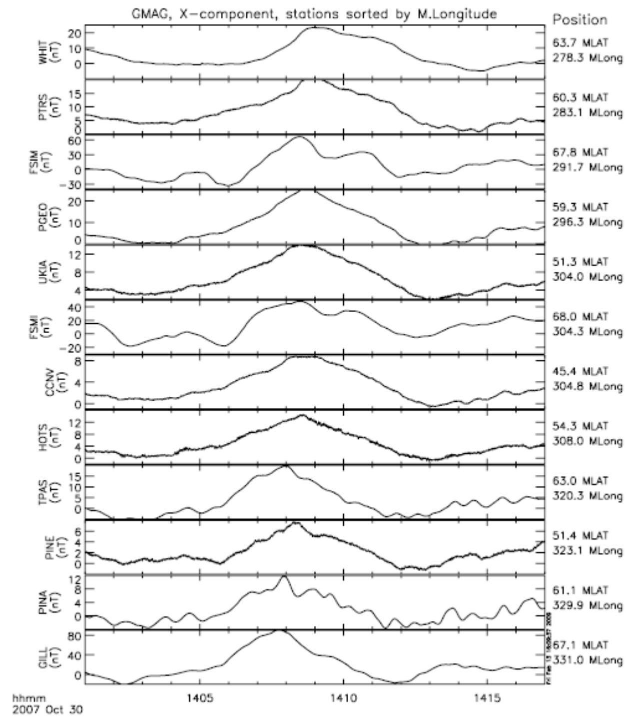

Figure 4

initially forms in the ion foreshock, upstream of the bow shock, due to changes in the IMF associated with solar wind discontinuities and its interaction with the backstreaming ions. The leading edge of the foreshock bubble consists of a fast magnetosonic shock and the compressed and heated plasma downstream of the shock. The leading edge surrounds the core which consists of a less dense and hotter plasma and lower magnetic field strength. The size of the foreshock bubble transverse to the flow direction scales with the width of the backstreaming ion beam and at Earth corresponds to 10s of R_E. The size along the flow depends on the age of the bubble and grows with time. Although they expand sunward, foreshock bubbles are carried anti-sunward by the solar wind and for small IMF cone angles they collide with the bow shock. This collision was shown to have significant magnetospheric impacts. Upon encountering the bow shock, the low pressures within the core of the bubble result in the reversal of the magnetosheath flow from anti-sunward to sunward direction. This in turn results in the outward motion of the magnetopause and expansion of the dayside magnetosphere. The interaction is found to noticeably impact the density and energy of trapped radiation belt ions and plasma injection into the cusp. Foreshock bubbles are found to be highly effective sites for ion reflection and acceleration to high energies via first and second order Fermi acceleration. The interaction also results in the release of energetic ions into the magnetosheath, some of which are injected into the cusps. These results illustrate that in addition to HFAs whose major magnetospheric impacts are well established, other structures with similar global impacts may form due to the presence of solar wind discontinuities.

Deliverables

The following three deliverables were promised by the FBM focus group:

1. Enhanced understanding of the fundamental bow shock processes.
2. Understanding the impacts of the bow shock on dayside transport.
3. Improved global and local kinetic models that will contribute to future GGCM models

In regards to our fundamental understanding of the bow shock and its magnetospheric impacts we note that the launch of the ISEE spacecraft and advances in kinetic simulations led to an explosion of knowledge of collisionless shocks in general and the bow shock in particular. A perception that arose among some was that these advancements had brought about a full knowledge of the bow shock and its minor to non-existent impact on the magnetosphere. Accordingly, except for the deceleration and deflection of the solar wind, the bow shock was assumed to be a passive component of the magnetospheric system. The activities and findings of the FBM focus group have resulted in new discoveries and major shifts in our views and paradigms of the complex bow shock system. However, perhaps the biggest contribution of the focus group has been to establish beyond a doubt that much more remains to be learned about the bow shock and that it impacts the magnetosphere in many ways some of which are known and others remain to be discovered and understood. Much of the advances made by the FBM focus group are based on model predictions and comparisons with spacecraft observations. In particular, global hybrid simulations have demonstrated that ion kinetics determine not only the structure of the shock layer but also the global structure of the foreshock, bow shock and the magnetosheath. These simulations have made a number of predictions some of which have already been verified by spacecraft data. They also show global interactions that inspire future missions with a large number of spacecraft or the capability to image the bow shock and the magnetopause on a global scale. One possibility, currently being advocated by M. Collier at NASA/GSFC invokes the soft X-rays emitted when high charge state solar wind ions interact with exospheric neutrals in the foreshock and magnetosheath to image the global interaction from a nominal vantage point on a spacecraft with a high apogee. The proposed mission, named 'STORM', would provide both snapshots and films of the foreshock and magnetosheath suitable for direct comparison with output from global numerical simulations.

During the 2009 GEM Summer Workshop, the FBM focus group organized a session on future directions. It was overwhelmingly agreed that the next natural and needed focus group to be formed is on the topic of the magnetosheath. Katariina Nykyri and Steve Petrinec will lead a proposal on this topic for the upcoming meeting of the GEM steering committee prior to the Fall AGU meeting. Please contact them if you are interested in participating and contributing to the list of objectives for this focus group.

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Reconnection Processes at the Dayside Magnetopause 2004-2009 (FG5) – Final Report

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1. INTRODUCTION

The Global Interaction Campaign started its first workshops at the annual GEM meeting in Snowmass, Colorado on June 22 and June 23, 2004. The campaign originated from the fusion of two separate proposals to study the "solar wind interaction with the magnetosphere" and "geospace transport." The scope of the new campaign was to follow fields and particles from the solar wind to the plasma sheet, with an emphasis on processes that mediate their transport. Substorms, although important for the plasma sheet and magnetosphere, were left outside the scope of the campaign. Similarly, the role of the ionosphere was left to the M-I coupling campaign. The dayside component of the campaign consisted of two closely-linked working groups: Reconnection Dynamics, Cusp, and LLBL (RDCL or Dayside GI) and Plasma Acceleration and Transport within the Magnetotail (PATM). The Dayside Campaign coordinators were *D. Sibeck* and *T. Phan* and the RDCL chairmen were *J. Berchem*, *N. Omidi*, and *K. Trattner*. In 2006, following the reorganization of the GEM activities into focus groups, the RDCL was divided into three focus groups: 1) Foreshock, bow shock and magnetosheath, 2) Dayside magnetopause reconnection and 3) Cusp physics.

2. SCIENTIFIC OBJECTIVES

The scientific objectives of the focus group on Reconnection Processes at the Dayside Magnetopause was to bring together people interested in both modeling and observing reconnection processes at the dayside magnetopause to examine the following outstanding topics:

1. Large-scale properties of reconnection at the magnetopause
2. The physics of magnetic reconnection at the dayside magnetopause
3. Quasi-steady versus time dependent reconnection at the dayside magnetopause
4. Plasma transport including particle entry and energization through reconnection and diffusive processes at the dayside magnetospheric boundary
5. Impacts of the bow shock/magnetosheath and the cusp/ionosphere systems on dayside magnetopause reconnection

3. ACTIVITY

The "Dayside Reconnection" group met between 2004 and 2009 at Fall AGU meetings in San Francisco (CA) and the GEM meetings in Snowmass (CO) and Zermatt, Midway (UT). About 75 talks were presented over the 5 summer and winter sessions of the focus group. Sessions were very lively and stimulating. The presentations were very well attended; between 30 and 50 people regularly took part in these sessions. Below, we report the highlights of the sessions.

1) Large-scale properties of reconnection at the magnetopause

GEM 2005

Dorelli reported that both component and antiparallel merging can occur within global MHD simulations [see *Dorelli et al*., 2007], while *Berchem* reinterpreted observations previously taken as evidence for component merging in terms of antiparallel merging [see *Berchem et al*., 2008a]. *Wendel and Reiff* used Cluster observations to define reconnection topology at the magnetopause, while *Maynard* used Cluster observations of the separatrices to remotely sense reconnection and determine its location on the magnetopause [see *Maynard et al*., 2004; 2005, 2006].

GEM 2006

Berchem presented results from global models by showing results from global MHD simulations using idealized inputs. He showed that for a 135° shear angle, the simulation indicated simultaneous antiparallel merging at high latitudes and component merging in the subsolar region. However he pointed out that isosurfaces of non-vanishing parallel electric field indicated that the component reconnection was patchy and limited to a relatively small region of the subsolar magnetopause, and that he could not identify a clear merging line as predicted by simple geometrical constructions [see *Berchem et al*., 2008a]. *Dorelli* investigated the dependence of dayside magnetopause reconnection topology on the IMF clock angle. He considered two cases: a) clock angle = 45° and b) clock angle 135°. For case a), he found that the reconnection topology was consistent with steady state separator reconnection; for case b) that reconnection was time dependent, with flux ropes forming at the subsolar magnetopause and propagating into the cusps [see *Dorelli and Bhattacharjee*, 2008]. *Wiltberger et al.* used LFM simulations of the magnetosphere to study the reconnection configuration during IMF clock angles of 45°, 90°, 135°, 180°. By combining path line traces with magnetic field lines they were able to track the motion of flux tubes into reconnection sites. While the analysis is still ongoing it is clear that the reconfiguration of the magnetic field is significantly more complicated than the classic 2D pictures of X-lines.

Ridley showed BATS-R-US MHD results for conditions on October 24-25, 2003, when the IMF pointed strongly northward. The model results compared quite well with observations by many different spacecraft, implying that the model had captured the essential physics. The model predicts the times and characteristics of magnetopause crossings well, and the trends but not the magnitude of *Dst* (pressure variations), but did not predict the degree of stretching that was observed in the magnetotail. Wind missed seeing the magnetotail, perhaps because it was short and torqued or compressed and deflected. There was a strong indication that the reconnection site was poleward from the cusp, with no reconnection occurring in the equatorial region. This indicated that the model favored anti-parallel rather than component reconnection. Because the only resistivity in the model is numerical resistivity, there is a need to examine how results might change for different resistivity models. *Moore* explored simulations of steady NBz, EBy, and SBz conditions, examining flow streamlines that would radiate from the subsolar point in the absence of Maxwell stresses produced by reconnection. *Moore* concluded that the LFM simulations contain an extended Z or S shaped “X curve” that crosses the subsolar equator (with active component reconnection) and loops up around each cusp as it crosses the antiparallel reconnection region [see *Moore et al.,* 2008].

GEM 2007

Berchem described test particle simulations in MHD magnetic fields indicating that a small percent of particles can become greatly energized (up to 60 keV) during encounters with the magnetopause. Particles pick up energy by scooting along the reconnection separator. Reconnection often follows the predictions of the antiparallel models, but enhanced resistivities move reconnection to the subsolar region [see *Berchem et al*., 2008b]. *Trattner* continued his determinations of the location of the dayside reconnection line. The survey contains now 130 events. In each case he examines the ion dispersion features seen by TIMAS on Polar. In particular, 3-D cuts of the distribution functions can be used to map back to entry points along an X-line on the magnetopause. The results are compared with the predicted locations of reconnection on the magnetopause for component merging and the anti-parallel reconnection scenario. The locations for these two models can be obtained using the Cooling model for draped magnetosheath and magnetospheric magnetic fields together with the *Sibeck* model for magnetopause location. Both reconnection scenarios are observed at the magnetopause depending on the IMF clock angle. In case of nearly radial or strongly southward (within 20° of the -Z axis) IMF orientations, the reconnection line is located where the merging fields are exactly anti-parallel. For all other IMF clock angles the reconnection line follows a tilted X-line across the dayside magnetopause along a region where the shear angle reaches a maximum. However, the region of maximum magnetic shear lies off the equator due to the dipole tilt.

Kuznetsova used the BATS-R-US model to simulate two events [1996/06/03 05:00-6:30 and 1997/11/06 14:00-15:30; results were posted on the CCMC website]. She found that B_y piles up near the reconnection site. Shear angles differ from those expected qualitatively. *Berchem* ran an MHD simulation for the stable IMF observed during the June 3, 1996 case. He found antiparallel merging on the northern pre-noon and southern post-noon magnetopause. The model predicts the line of maximum shear in the vicinity of the locations where *Trattner* infers merging to occur. *Dorelli* reviewed what 3D reconnection looks like. He found the nulls and showed that different reconnection signatures occur at different points along the X-line connecting the two nulls. He demonstrated the existence of strong JxB flows at high latitudes, but the strongest electric fields occurred in the subsolar region. He therefore concluded that reconnection proceeds at the subsolar point even during periods of very strongly northward IMF, although the results of this reconnection may not be very dynamically exciting. *Trattner* noted the absence of any cusp signatures indicating that this can happen.

GEM 2008

Ouellette presented results from the LFM code. He has run a series of simulations for constant solar wind conditions and different IMF clock angles. He found that reconnection is predominantly an anti-parallel process. For 45° and 90° IMF clock angles, reconnection occurs in two small regions on the upper dusk and lower dawn sides, whereas for 135° and 180° angles it extends across the subsolar region. Reconnection rates at the magnetopause grow linearly with IMF clock angle from 45° to 135°and then saturate, increasing only slightly from 135° to 180° clock angles. Cross-polar potential drops increase linearly from 50 to 225 kV, where they saturate.

GEM 2009

Trattner presented the results of a study that uses THEMIS magnetopause crossings to test the reconnection location model derived from Polar/TIMAS observations in the cusp. He found a remarkable good agreement with the prediction of reconnection occurring along the line of maximum magnetic shear across the dayside. However, the study showed that a better description for the transition between the line of maximum magnetic shear and the anti-parallel solution is needed around local noon. 2008 *Omidi* reported the results of a study showing the influence of magnetosheath turbulence on magnetic reconnection at the magnetopause. He presented two global hybrid simulations in which the dayside magnetosheath exhibited waves associated with dissipation at the quasi-perpendicular shock (e.g., mirror and ion cyclotron waves). Both runs had the same solar wind plasma and southward IMF conditions. However, the resistivity was increased in the second run to damp magnetosheath waves. Comparison of the results showed that the number of FTEs formed at the magnetopause was reduced from 20 to 9 in the second run, indicating that the presence of turbulence in the magnetosheath enhances considerably time dependent reconnection.

2) The physics of magnetic reconnection at the dayside magnetopause

GEM 2004

The 2004 session on reconnection at the dayside magnetopause started with several presentations focused on local processes at the magnetopause. *Hesse* discussed results of kinetic models of reconnection at the dayside magnetopause highlighting the physics of guide-field magnetic reconnection. *Phan et al.* examined Cluster observations of the magnetopause and boundary layer during steady southward IMF conditions. Even during intervals of steady solar wind parameters, plasma blobs generated on the low latitude magnetopause move poleward to high latitudes. Accelerated flows in the boundary layer exhibit the characteristics expected for steady state reconnection at the magnetopause. *Phan et al*. suggested that the plasma blobs result from time-dependent reconnection rates.

Drake and colleagues have used full particle 2-D simulations to examine the nature of time-dependent reconnection. They find that when a guide field is not present both the location of the X-line and the reconnection rate remain steady. However, when a guide field is present the location of the original X-line no longer remains steady and secondary magnetic islands form. According to these results, antiparallel reconnection should be steady, but component reconnection should be time dependent [see *Drake et al*., 2006]. *Huba* obtained results from the first fully three-dimensional Hall MHD simulation of forced magnetic reconnection. In the absence of a guide field, reconnection extended along the current direction with asymmetric accelerated flows. Although the current layer shows some dynamic behavior, the overall reconnection process seems steady state with no FTE formation.

GEM 2006

Reiff showed results from Cluster observations of an X-line at the high latitude magnetopause. Using data from the 4 Cluster spacecraft, the inflow and outflow of electrons and ions at the X-line was examined and compared to the currents calculated from the magnetometer data. The X-line seems to be in a steady state, however, some of the flow patterns observed at the X-line seem more complex than expected for simple inflow and outflow. The y-component was enhanced at the X-line, and the derived current sheet was thicker than that drawn by *Birn*. *Singh* showed results from 3-D, full particle, electromagnetic simulations that examined the stability of a current sheet. The magnetic field geometry corresponded to antiparallel configuration, i.e. no guide field. No initial perturbations were introduced to generate an X-line. The results of the simulations show that current sheet evolution is associated with the formation of substructures (many islands) in the current sheet profile. Similarly, spiky electric fields with length scales of the order of electron Debye length are generated which were compared to *Mozer*'s observations of electric field by Cluster. The results also show electron acceleration associated with the reconnection process.

Hesse showed that the presence of a guide field (or component merging) slightly favors the formation of islands; however he noted results from *Huba* indicating that the guide field reduces the reconnection rate because it makes the system less compressible. He also presented recent results from *Swisdak* showing that pressure asymmetries result in diamagnetic drifts on the magnetopause, which suppress reconnection. *Borovsky* showed that the reconnection rate depends on a hybrid Alfven speed when such asymmetries are present. He also pointed out studies by *Horiuchi*, which indicate that kinetic reconnection can be highly time dependent for a wide range of driver profiles. *Karimabadi* presented some results of kinetic simulations showing the linear and nonlinear evolution of the tearing mode as a function of the guide field. He found that guide field tearing is competitive with anti-parallel merging at the magnetopause. There is a continuum of solutions ranging from component to antiparallel. He showed also some results from a related study that indicate that a new regime, which he called the intermediate regime, forms with mode properties that are a mixture between antiparallel and strong guide field. This regime occurs at relatively small values of guide field (~7%). From these results, he suggested that one should expect to observe reconnection at various guide field strengths at the magnetopause, and that this would generally take the form of component reconnection for most conditions. *Karimabadi* criticized the concept of a single stable X line, noted that multiple lines eventually become unstable, and remarked that the electron diffusion region is small and doesn't control the overall configuration. He was examining island coalescence and jets perpendicular to the current sheet [see *Karimabadi et al*., 2005a; 2005b].

Borovsky discussed the effects of plasma from plasmaspheric drainage plumes reaching the dayside magnetopause. He argued that this plasma could reduce the rate of reconnection at the subsolar magnetopause. The reason for this reduction is due to changes in the local Alfven speed caused by the presence of heavier magnetospheric ions. MHD simulations indicate rate reductions up to 50%. The effect can only occur following abrupt and then prolonged southward IMF turnings. *Birn* used local MHD simulations to examine the effects of asymmetries on the reconnection rate. The asymmetry considered was due to the presence of heavier plasma (reduced Alfven speed) on one side of the current layer. This is similar to the effect discussed by *Borovsky* due the presence of plasmaspheric plumes at the magnetopause. The results of the simulations show a reduction in the reconnection rate. The high-speed flows occur on the low-density side [see *Birn et al*., 2008; *Borovsky et al*., 2008].

GEM 2008

Cassak started by presenting results from a generalized Sweet- Parker type scaling analysis of 2D anti-parallel asymmetric reconnection. He showed that the outflow speed scales like the Alfven speed based on the geometric means of upstream fields and density of the outflow and that the reconnection rate is a product of the aspect ratio of the dissipation region, the outflow speed, and an effective magnetic field strength given by the "reduced" field. These results are independent of dissipation mechanism. Results from numerical simulations agree with the theory for collisional and collisionless (Hall) reconnection. The location of the X-line differs from the location of the stagnation line [see *Cassak and Shay*, 2008; 2009]. Subsequently, *Birn* presented some results for asymmetric reconnection in resistive MHD. He showed that the scaling was similar to that for fast reconnection (*Cassak-Shay* model) when using the outflow density from the X-line. Fast flows occur preferentially into the high Alfven speed region and the flow stagnation line was displaced toward the high-field side. An investigation of the energy flow and conversion in the vicinity of the reconnection site revealed the significant role of enthalpy flux generation (compressional heating) in addition to the expected conversion of Poynting flux to kinetic energy flux [see *Birn et al*., 2008]. Pritchett showed that regions associated with electron physics in asymmetric magnetic field reconnection with a guide magnetic field do not completely overlap, are not confined in all dimensions to sizes the order of the electron skin depth, do not surround the X-line, and are not embedded in a larger region where the ion ideal MHD is violated [see *Mozer and Pritchett*, 2009].

Roytershteyn gave a presentation about the influence of sheared parallel flows on the onset of reconnection. He has built several equilibrium models of a jet embedded ($k \parallel B_0$) in a Harris-type current sheet. Results from the kinetic studies differ significantly from those for fluid treatments. The kinetic studies show that the instability persists in super-Alfvenic flows and produces reconnection. The thickness of the sheet was found to be one of the factors determining the transition to a fluid-like behavior. For thin sheets ($<\rho_i$) kinetic effects (ion anisotropy in their model) determines the mode behavior, whereas the qualitative features appear to be independent of the details of the equilibrium distribution for thicker sheets.

3) Quasi-steady versus time dependent reconnection at the dayside magnetopause

GEM 2006

Omidi showed results from 2.5-D global hybrid simulations during periods of steadily (and purely) southward IMF. FTEs marked by density enhancements and considerable variations in size and speed form on the low latitude dayside magnetopause and move poleward. When they reach the cusp, the density enhancements diminish and the events ultimately disappear. The interaction of FTEs with the cusp involves secondary reconnection and is quite complex. It may be an important means by which solar wind plasma enters the magnetosphere. The reasons for time-dependent reconnection at the simulated magnetopause remain to be established [see *Omidi and Sibeck*, 2007].

Russell discussed the motion of FTEs along the magnetopause surface and how multiple spacecraft observations can be used to determine the nature of this motion. Observations indicate that FTEs generally move away from local noon. *Russell* concluded that neutral points and not current sheets are the key to understanding reconnection. Reconnection enables (but does not guarantee) rapid energy release. Reconnection through topology changes enables momentum coupling between flowing plasma and obstacles. Coupling is not necessarily steady: flux transfer events and bursty bulk flows recur without obvious triggers. Geometry is important in determining event size and occurrence frequency. A large statistical scatter and the strength of B_y effects suggest that an interpretation in terms of a single subsolar merging line is not correct. The guide field appears to control onset of collisionless reconnection. This controls where reconnection occurs, results in a half-wave rectifier effect and dipole tilt control, and enhances the semi-annual variation of geomagnetic activity. *Fear* used Cluster observations to present an analysis of FTE motion during northward IMF. The emphasis was on post-terminator FTEs, which can result from a tilted equatorial X-line or from magnetic reconnection near the cusp. The observations were more consistent with reconnection near the cusp. Observed velocities generally agree with the model of *Cooling et al.,* [2001]. It was also suggested that the locations, polarities and velocities of the observed FTEs are in general agreement with a long, component merging X-line originating from a region of high magnetic shear on the lobe. Although the events could be mapped back to high shear regions, not all the observed velocities were consistent with a near 180^o shear.

Wang used Cluster observations and global MHD simulations to study the dependence of FTEs on geophysical parameters and solar wind conditions. He reported that FTE occurrence may depend upon dipole tilt, that FTE amplitudes may increase with magnetic latitude, that there is a solar wind trigger (e.g. north/south fluctuations), and that more events occur for IMF *Bx* > 0. Combining the *Kawano* and *Wang* databases may provide more statistically significant information about FTEs and transient magnetopause reconnection. Without simultaneous observations in the magnetosheath, it is hard to identify the effects (if any) of magnetosheath fluctuations on FTEs. *Raeder* used a global MHD model to simulate an event in which both Cluster and Double Star 1 observed FTEs during an interval of strongly dawnward IMF orientation. Cluster observed nearly monopolar magnetic field signatures normal to the magnetopause and density pulses deep within the magnetosphere. *Raeder* noted that global MHD simulations do not predict FTE formation unless the resolution suffices to suppress diffusion. The objective of the study was to establish model limits and parameter dependencies and to investigate FTE formation and evolution. The simulation generally predicted the characteristics of the observed FTEs, suggested a subsolar origin, but more detailed analysis of the simulation data and comparisons with spacecraft data is planned for future (in particular speed, size, origin, recurrence times).

Dorelli used the same global MHD simulation than *Raeder* to look at FTE formation. He also stressed the need for sufficient grid resolution in order to see FTEs to form, and noted that there was no dependence of occurrence rates on dipole tilt. His results indicate the formation of FTEs moving poleward into both hemispheres away from points of origin at low latitudes during periods of steady southward IMF orientation [*Dorelli and Bhattacharjee*, 2009]. When they encounter the exterior cusps, the FTEs generate pressure enhancements that move along field lines into the interior cusp. This suggests that FTE interaction with the cusp is important for solar wind plasma transport into the magnetosphere. During periods of northward IMF orientation, the simulation provided evidence for steady reconnection. *Kuznetsova* showed results from the BATS-R-US MHD code during southward IMF. She demonstrated that when the resolution of the simulations is high enough, FTEs form at the low latitude magnetopause and travel to high latitudes. The FTEs are associated with enhancements in pressure similar to the results shown by *Dorelli*. Upon encountering the cusp, the pressure enhancements travel into the interior cusp. On the flanks, she found tailward-propagating vortices and both strong velocity and magnetic shears.

GEM 2007

Sibeck showed results from *Korotova's* survey of Interball FTEs. For southward IMF they are surely generated on the dayside equatorial magnetopause. On the high latitude magnetopause, she definitely sees events for both strongly antiparallel and parallel magnetic fields. The ones observed for antiparallel magnetosheath and magnetospheric magnetic fields may be locally generated. But they are often seen at high latitudes for southward IMF orientations, which do not favor local reconnection. It was suggested that better models of magnetosheath magnetic field draping would help clear up the problem [see *Korotova et al*., 2009]. *Winglee* presented results from a multifluid global simulation for southward IMF. He showed that localized flux ropes with a thickness of a few hundred to a few thousand kilometers develop and can expand laterally due to current sheet acceleration of ions that have a gyroradius comparable to the current sheet thickness [see *Winglee et al*., 2008].

GEM 2008

Kuznetsova reported results from a global MHD simulation (BATSRUS) with high grid and temporal resolution run at CCMC to explain the occurrence of the flux transfer events (FTEs) observed by THEMIS near the flank of the magnetosphere. She found that individual extended flux ropes formed by component reconnection near the subsolar region (strong core field), but antiparallel reconnection at the flanks (weak core field). The flux rope had bends and elbows reminiscent of those invoked by *Russell and Elphic* to explain the occurrence of FTEs at the dayside magnetopause. The simulation showed also the formation of plasma wakes (field-strength cavities) as the ropes move over the magnetopause and that different parts of the flux rope moved in different directions.

GEM 2009

Sibeck used the Cooling model to understand why FTEs observed on the dayside magnetopause tend to occur for southward IMF orientations whereas they don't show such a tendency on the flanks. His method was to generate series of FTEs along the subsolar component reconnection curves parallel to magnetopause current vector and then to use the Cooling model to track their subsequent motion. He found that FTEs generally retain the original reconnection line orientation, and as a consequence the velocities obtained from multispacecraft timing must differ from (and be less than) those of the plasma parcels within the events. FTEs for southward IMF orientations exhibit stronger signatures than those for northward IMF orientations, but never reach the flanks. Consequently events for IMF $B_z < 0$ dominate statistical studies of the dayside magnetopause, but not those of the flanks [see *Sibeck and Lin*, 2009].

4) Plasma transport including particle entry and energization through reconnection and diffusive processes

GEM 2004

Fritz presented Polar observations of particle entry and energization in the cusps [*Fritz et al*., 2003; *Fritz*, 2009]. *Phan* reported the results of a Cluster survey of reconnection tailward of the cusp indicating that cusp-region merging only occurs for strongly northward IMF Bz, but neither he nor *Fritz* noted any evidence for its location to depend upon the sign of IMF By. *Phan* noted that the depletion layer observed for northward IMF orientations was required to enable steady merging on the high-latitude magnetopause. Although *Phan* had not found a depletion layer at high latitudes for southward IMF orientations, *Moretto* reported observing one during an interval of greatly enhanced solar wind dynamic pressure [see *Moretto et al*., 2005].

The origin of the LLBL was one of the topics also discussed during the magnetopause session. *Russell* noted that leakage, acceleration, and heating are common at boundary layers (and in the foreshock). He noted that the presence of sharp transitions excludes an explanation in terms of diffusion, although *Cheng* argued forcefully that wave-particle interactions at the magnetopause were important. Results from 2- and 3-D hybrid code simulation runs were presented. *Omidi* focused on the boundary layer while *Blanco-Cano* examined the influences of the quasi-parallel shock on the magnetopause. The hybrid simulations indicated a density peak at the magnetopause, a possible magnetic field pile-up in the inner magnetosheath, and slow mode waves in the quasi-parallel sheath [see *Omidi et al.,* 2006]. The magnetopause was most easily interpreted as an intermediate shock for some IMF orientations.

Fuselier used results from global MHD simulations to interpret Polar's observations of counterstreaming O+ on field lines that connect the high latitude to the flank magnetopause for northward IMF. He explained that successive reconnection near the southern cusp and then in the northern hemisphere provides a viable mechanism to capture energetic ions generated in the foreshock on closed field lines and populate the flank plasma sheet. The second reconnection closes off the flank field line solar wind and quasi-parallel bow shock source but opens the other hemisphere ionospheric source. *Fuselier* also reported that the flank plasma sheet is colder and less dense than the magnetosheath during periods of $Bz > 0$. Whereas O+ is not correlated with H+, He2+ is. Density ratios change across the magnetopause [see *Fuselier et al*., 2007].

During the course of a study of sawtooth Kelvin-Helmholtz waves (period ~3 min, wavelength ~ 6 R_E), *Don Fairfield* estimated the thickness of the flank LLBL as greater than 0.5 R_E during an interval of northward IMF orientation [see *Fairfield et al*., 2003]. *Lavraud* reported that unidirectional, heated magnetosheath electrons are often observed outside the magnetopause under northward IMF and that a preliminary survey of Cluster Data indicates that when reconnection occurs in both cusp regions, the dipole tilt is the major factor controlling which hemisphere may reconnect first [see *Lavraud et al*., 2005; 2006]. *Kessel* presented the results of a study of vortices near the magnetopause using MHD simulations along with Geotail and Cluster observations during periods of high-speed solar wind streams and northward IMF.

GEM 2005

Wenhui Li reported that models that invoke double reconnection poleward of the cusps successfully account for Cluster boundary layer observations during prolonged periods of northward IMF. *Lavraud* reported work by *Seki*, which also invokes the Kelvin-Helmholtz instability to explain the boundary layer properties under the same conditions. *Antonius Otto* explored the generation of a sequence of bipolar magnetic field signatures normal to the magnetopause by the Kelvin-Helmholtz instability.

GEM 2006

Winglee showed results from global multi-fluid simulations during southward IMF. Concentrating on the dayside magnetopause, he demonstrated the ability of the model to produce current layer thicknesses as low as about ion skin depth. The results show no evidence for time-dependent reconnection or the formation of FTEs, while the accelerated flows are consistent with steady state reconnection. Only a small amount of the plasma entering the dayside LLBL enters via the cusp.

5) Impacts of the bow shock/ magnetosheath and the cusp/ionosphere systems on dayside magnetopause reconnection

GEM 2004

Lavraud reported the results of a statistical study of Cluster plasma flows in the cusp as a function of IMF orientation. Flows on the equatorward edge of the cusp are poleward and Earthward during intervals of southward IMF. They are stagnant and Earthward on the poleward edge of the cusp for northward IMF. Dawnward flows were seen for duskward IMF orientations, but the situation was not so clear for dawnward IMF orientations. Field strengths were weaker than those predicted by the Tsyganenko model.

Double and even triple cusps were a topic of interest. *Berchem* presented results of a global MHD case study showing that for strong IMF *By* multiple successive reconnection events occurring in the flanks can explain some of the multiple proton injections observed simultaneously by Cluster CIS in the cusp and by Image FUV in the dayside auroral region. *Wing* presented observations and discussed a model for the double cusp. He argued that it could be a spatial or a temporal feature, and noted that observationally it is most common for large B_y and small B_z [see *Wing et al*., 2001; 2005]. *Zong* reported a triple cusp encounter in Cluster observations on April 18, 2002 from 1600 to 1900 UT. He attributed the repeated encounters to variations in the solar wind flow direction, although there were also substantial fluctuations in the solar wind dynamic pressure. *Berchem* has simulated this event. Despite the low solar wind pressure, he found reconnection jets and crossings near the standard magnetopause location, not far out as suggested by *Zong*.

GEM 2006

Using local hybrid simulations, *Omidi* showed that the interaction of a magnetosonic pulse with a current sheet can initiate reconnection and therefore it is conceivable that some of the time dependency is tied to magnetosheath turbulence [see *Omidi et al.,* 2009].

GEM 2009

Trattner reported the results of a study related to the formation of magnetic islands at the dayside magnetopause. Motivated by results from *Omidi*'s hybrid simulation, he searched Polar/TIMAS observations in the cusp to identify remote signatures of their occurrence. In particular, he looked for double reconnection events since the reconnection of an already opened flux tube could create a magnetic island. He showed several examples of overlapping parallel ion beams observed in the cusp that suggest that magnetic islands do occur at the magnetopause.

Berchem used an actual Cluster event to discuss the effects of a rapid northward turning of the IMF on the topology of magnetic reconnection at the magnetopause. He ran a global MHD simulation of the event and traced the motion of solar wind ions launched upstream of the shock in the time-dependent MHD simulation electric and magnetic fields. Ion dispersions calculated from particles collected at Cluster's location in the simulation were found to be in very good agreement with those measured by Cluster in the cusp. In particular, the simulation reproduced the change in the slope of the ion dispersions observed by the spacecraft very well. Analysis of the simulation results indicates that reconnection occurs mostly in the subsolar region as the discontinuity interacts with the magnetopause, and then moves tailward and poleward as the field completes the rotation. As shown by the results of the particle computation, the evolution of the reconnection topology implies that different plasma sources contribute to the formation of discrete structures in the ion dispersions observed by the spacecraft as they cross the cusp.

Omidi investigated time-dependent and patchy reconnection using planar hybrid simulations for southward IMF. His main goal is to measure the impact of magnetosheath waves on reconnection at the magnetopause. Simulation results indicate that the presence of magnetosheath waves results in time-dependent reconnection and the formations of FTEs that move along the magnetopause surface and coalesce into larger FTEs. However, time-stationary magnetic islands are formed in some cases. This different regime could correspond to patchy reconnection at the dayside magnetopause near the nose where sheath velocities are small and phase-standing waves may exist.

4. SUMMARY

1) Large-scale properties of reconnection at the magnetopause

A significant amount of the group's activity focused on the large-scale properties and dynamics of merging at the dayside magnetopause. One of the main conclusions of the different studies presented is that merging at the magnetopause should not be viewed as a component versus antiparallel reconnection problem, though it is sometimes easier to discuss observations in these terms. Global models and indirect observations of merging sites show clearly that reconnection occur at the subsolar magnetopause for a large variety of southward IMF directions. These results invalidate one of the fundamental premises of the antiparallel model, which predicts no subsolar reconnection when the IMF has a significant B_y component. On the other hand, there is plenty of evidence for merging at locations other than the tilted merging line predicted by the component-merging model. Results from studies of Polar/TIMAS cusp observations and THEMIS magnetopause crossings indicate that reconnection has a tendency to occur along the line of maximum magnetic shear across the low-latitude region and near the anti-parallel locations at high latitudes. However, a better description for the transition between the line of maximum magnetic shear and the anti-parallel solution is needed around local noon.

The present consensus from global MHD models is that merging at the dayside magnetopause follows the reconnection separator predicted by 3D reconnection theories. However, numerous questions remain; for example, some simulations for steady IMF clock angle 135° show that reconnection can be time dependent, with flux ropes forming at the subsolar magnetopause and propagating into the cusps. Also an interesting consequence of the reconnection separator model is that reconnection should proceed in the subsolar region even during periods of very strongly northward IMF, which left some observers concerned during the sessions. More data-simulation comparisons are required to verify these predictions; results from other global models (e.g. hybrid) should also be examined. More work is also needed to determine whether there is a relation between the reconnection separator and the line of maximum magnetic shear across the dayside magnetopause. The latter appears to organize merging regions determined from observations.

2) The physics of magnetic reconnection at the dayside magnetopause

Two major issues dominated the discussions of the physics of reconnection at the dayside magnetopause: the role of the guide field and the effects of asymmetries. Most of the studies used kinetic simulations to investigate the linear and nonlinear evolution of reconnection as a function of the guide field. Results from the majority of studies indicate that both the location of the X-line and the reconnection rate remain steady when a guide field is not present. However, when a guide field was present the location of the original X-line no longer remained steady and secondary magnetic islands formed. Guide field tearing appeared to compete with anti-parallel merging at the magnetopause. There is a continuum of solutions ranging from component to antiparallel, with a relatively small range of guide field values that have a mixture of antiparallel and strong guide field properties.

Strongly motivated by the interaction of plasmaspheric plumes with the dayside magnetopause, the group spent some time discussing the properties of asymmetric reconnection when the magnetic field strengths and densities on either sides of the dissipation region differ. The results presented showed that outflow speeds and reconnection rates found using different modeling approaches did not differ significantly. It was found that the results were independent of the dissipation mechanisms invoked in the models and that numerical simulations agree with the theory for collisional and collisionless (Hall) reconnection. Asymmetric reconnection in guide field geometries was also examined using two-dimensional PIC simulations. Results indicate that regions associated with electron physics are not confined in all dimensions to sizes the order of the electron skin depth and that the large-scale perpendicular electric field is the source of most of the total particle energization during reconnection.

Although microprocesses were examined during the sessions, no real advance was made in bridging results from local and global simulations. This is one topic that will need to be examined in the future.

3) Quasi-steady versus time dependent reconnection at the dayside magnetopause

Numerous FTE studies were presented during the five-year lifetime of the group. Observational studies suggest that geometry is important in determining FTEs event size and occurrence frequency and that an interpretation in terms of a single subsolar merging line is unlikely. Recent surveys including Cluster data indicate that FTE occurrence may depend on dipole tilt, that FTE amplitudes may increase with magnetic latitude, that there is a solar wind trigger (e.g. north/south fluctuations), and that more events occur for IMF $Bx > 0$. Also, FTEs for southward IMF orientations exhibit stronger signatures than those for northward IMF orientations, but never seem to reach the flanks. Consequently events for IMF $B_z < 0$ dominate statistical studies of the dayside magnetopause, but not those of the flanks. Some of the highlights of the sessions were presentations of the first FTE studies carried out using hybrid and multifluid global simulation codes. In fact, almost all the results of global models (MHD, hybrid and multifluid) presented during the sessions involved the formation of magnetic flux ropes for southward IMF conditions. In general, good agreement was found between FTE observations and local predictions of global models, and new features, such as the formation of plasma wakes as the ropes move over the magnetopause were examined. However, no consensus was reached in determining what are the physical processes that trigger the occurrence of FTEs at the dayside magnetopause, and how they evolve as they move tailward. It is clear that future focus groups will have to reinvestigate these issues.

4) Plasma transport including particle entry and energization through reconnection and diffusive processes at the dayside magnetospheric boundary

Discussions about the formation of the magnetopause boundary layer, the role of the depletion layer, and the transport of plasma toward the tail were particularly active at the beginning of the GI campaign. In particular, the group focused on modeling the properties of the boundary layer observed during prolonged periods of northward IMF. Several models based on double reconnection poleward of the cusps and studies based on the Kelvin-Helmholtz instability were used to investigate plasma entry and the population of the plasma sheet. Conflicting results indicated that more work was needed to determine the mechanisms for the entry of plasma at the magnetopause. After the reorganization of the GI campaign, plasma entry studies were addressed by the Plasma Entry and Transport focus group and cusp studies by the Cusp focus group. Though several cusp studies presented in the "Dayside Reconnection" sessions after the reorganization, they focused more on using cusp observations to test large-scale models of reconnection, than debating where and how high-energy particles observed in the cusp gain energy.

5) Impacts of the bow shock/magnetosheath and the cusp/ionosphere systems on dayside magnetopause reconnection

Another area explored by the group was the impacts of the bow shock/magnetosheath and the cusp/ionosphere systems on dayside magnetopause reconnection. Results from hybrid simulations showed that the interaction of a magnetosonic pulse with a current sheet can initiate reconnection and that the presence of magnetosheath waves results in time-dependent reconnection and the formations of FTEs. In some cases simulations predict the formation of stationary magnetic islands. Though particle measurements suggest that such islands occur at the magnetopause, the question is now how common they are and what the controlling factors are for their formation.

In conclusion, the focus group made substantial progress in the understanding of reconnection processes at the dayside magnetopause. As we reported above, the activities of the focus group greatly enhanced our knowledge of the large-scale properties of reconnection at the magnetopause, the effects of the guide field and asymmetries on dayside reconnection, and the occurrence of flux transfer events at the magnetopause. These achievements were made possible by bringing together people from different backgrounds to share their views of the reconnection processes at the dayside magnetopause. We would like to thank all the contributors to the focus group.

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- Ilie, Raluca (2009 - 2010)

Research Areas

Research Area Coordinators
- Dayside, including boundary layers and plasma/energy entry. (Dayside)
  - Berchem, Jean (2009 - 2012)
  - Trattner, Karl-Heinz (2009 - 2015)
- Inner magnetosphere and storms. (IMS)
  - Friedel, Reiner (2006 - 2012)
  - Chan, Anthony (2009 - 2015)
- Tail, including plasma sheet and substorms. (Tail)
  - Henderson, Mike (2006 - 2012)
  - Kepko, Larry (2009 - 2015)
- Magnetosphere - ionosphere coupling, aurora. (MIC)
  - Murr, David (2006 - 2012)
  - Lysak, Bob (2009 - 2015)
- GGCM
  - Sazykin, Stan (2006 - 2012)
  - Merkin, Slava (2009 - 2015)

Focus Groups

Focus Groups and Their Research Areas (RA)
1. GGCM Metrics and Validation (2005 - 2010, M. Kusnetzova & A. Ridley, RA: GGCM)
2. GGCM Modules and Methods (2005 - 2010, J. Dorelli, M. Shay, B. Sullivan, RA: GGCM)
3. Foreshock, bowshock, magnetosheath (2004 - 2009, N. Omidi, RA: Dayside)
4. Plasma Entry and Transport into and within the Magnetotail (2006-2011, S. Wing, J. Johnson, and A. Otto, RA: Tail)
5. Component versus Anti-parallel Reconnection (2004 - 2009, J. Berchem, RA: Dayside)
6. Cusp Physics (2006 - 2010, K-H. Trattner, RA: Dayside)
7. MIC Electrodynamics (2003 - 2008, J. Semeter & B. Lotko, RA: MIC)
8. Near Earth Magnetosphere: plasma, fields, and coupling (2007 - 2012, S. Zaharia, S. Sazykin, B. Lavraud, RA: IMS, Tail)
9. Space Radiation Climatology (2006 - 2011, P. O'Brien and G. Reeves, RA: IMS)
10. Diffuse Auroral Precipitation (2006 - 2011, R. Thorne and J. Borovsky, RA: MIC, IMS)
11. Plasmasphere-Magnetosphere Interactions (2008 - 2013, J. Goldstein and J. Borovsky, RA:IMS)
12. Substorm Expansion Onset (2008 - 2013, V. Angelopoulos, S. Ohtani, K. Shiokawa, RA:Tail)
13. Modes of Magnetospheric Response (2008 - 2013, B. McPherron, L. Kepko, RA:Tail)

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