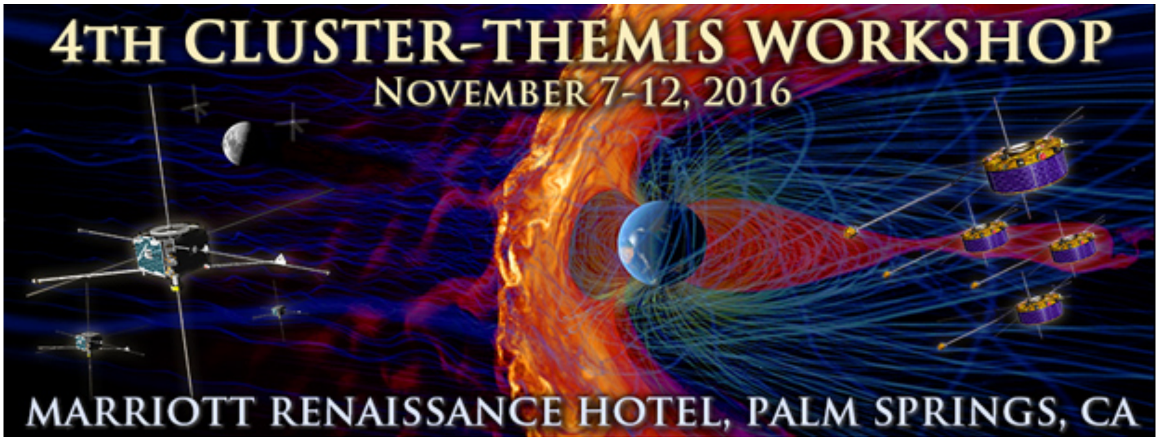

Book of abstracts

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Multipoint analysis of compressive fluctuations in the fast and slow solar wind

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Compressible turbulence in the solar wind is a topic of much recent debate. To understand the various compressive fluctuations at scales comparable to proton characteristic lengths we use multi-point magnetic field and density data (derived from spacecraft potential) from the Cluster spacecraft when they were in undisturbed intervals of slow and fast solar wind. Using the spacecraft potential allows much higher time resolution than is typically possible than with particle instruments. The spacecraft potential is subject to a strong spin effect due to changes in the illuminated surface of the spacecraft. To correct for this an empirical model of the spacecraft charging is derived as a function of spacecraft angle and is used to remove the effect. The application of the multipoint signal resonator technique is performed for the first time to a scalar time series with electron density and magnetic field fluctuations along the background magnetic field direction being used as inputs in addition to the traditional vector components of the magnetic field. This analysis is performed on two streams of solar wind, one which can be classed as a slow stream, and one which can be classed as a fast stream to investigate the difference in the compressible components in the two types of wind. The recovered plasma frame frequencies Omega for the incompressible component show low speed in the plasma frame consistent with previous applications
of the method while the compressible components are more scattered, some with very high phase speeds. We discuss the possible wave interpretations or coherent structure interpretations to explain these observations. Additionally the

three dimensional power spectrum in wave space is investigated.

Comparison of the bow shock and ICME shocks

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Collisionless shocks are ubiquitous in space. In addition to the bow sock, the heliosphere is pervaded by the termination shock at the heliopause. There are also transient interplanetary shocks produced by solar disturbances such as the CME (Coronal Mass Ejection) events. The ICME speeds relative to the ambient SW speed are faster than the local fast mode speed of the SW, hence the edges can compress and steepen into shock waves. ICME shock waves are traveling with speeds ranging from a few hundred km/s to more than a thousand km/s. ICME shocks are different from the bow shock which is a standing shock wave. ICME shocks are also of much larger spatial scales than the Earth's bow shock. Previous studies of ICME shocks from Voyager 2 have shown that they include reflected populations as in the bow shock but they can represent as much as 44% of the sheath population, much greater than the 20% observed in the Earth's bow shock. We have begun studies of ICME shocks using Cluster data and in this talk report similarities and differences of Earth's bow shock to those in ICME shocks including how the solar wind is heated across these two types of shocks.

Different types of foreshock and their connection with foreshock transients

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When the angle between the bow shock normal and the interplanetary magnetic field (IMF) in the upstream region is less than 45 degrees, the shock is called quasi-parallel. At such a shock a portion of solar wind ions is energized and reflected back upstream. The interaction between these reflected ions and the incoming solar wind results in the so called foreshock region in which the magnetic field is highly perturbed and different ion populations exist. There are also transient structures, such as foreshock cavitons, spontaneous hot flow anomalies and foreshock compressional boundaries, populating parts of the foreshock. Recently we

performed a multi-spacecraft analysis of foreshock observations by Themis and Cluster missions in order to show that two different types of foreshock may be detected in the data. There is a global foreshock that forms upstream of the quasi-parallel section of the bow-shock under steady or variable IMF. When the IMF changes its orientation, the foreshock changes its location with respect to the bow-shock. Another type is a traveling foreshock that forms when magnetic flux tubes connect with the nominally quasi-perpendicular section of the bow-shock in a quasi-parallel way. Traveling foreshocks propagate along the bow shock surface and appear in the spacecraft data delimited by rotational IMF discontinuities. The relations of the foreshock phenomena with such foreshocks will be discussed and also the implications for the downstream phenomena, such as magnetosheath jets.

A comparison of ion ramps of the bow shock and interplanetary shocks: Cluster, THEMIS and Spektr-R

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Collisionless shocks play a significant role in the solar wind interaction with the Earth. Fast forward shocks driven by coronal mass ejections or by interaction of fast and slow solar wind streams can be encountered in the interplanetary space, whereas the bow shock is a standing fast reverse shock formed by interaction of the supersonic solar wind with the Earth magnetic field. Both types of shocks are responsible for a transformation of a part of the energy of the directed solar wind motion to plasma heating and to acceleration of reflected particles to high energies. These processes are closely related to the shock front structure. The paper compares the structure of low-Mach number fast forward interplanetary shocks registered by Wind and ACE with observations of bow shock crossings observed by the Cluster, THEMIS, and Spektr-R spacecraft. Application of the high-time resolution data facilitates further discussion on formation mechanisms of both types of shocks.

Hot flow anomaly Generated ULF Waves in the Magnetosphere

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Hot flow anomalies (HFAs) are events observed near planetary bow shocks that are characterized by greatly heated solar wind plasmas and substantial flow deflection. HFAs are universal phenomena that have been observed near the bow shock of Earth, Venus, Mars, and Saturn. Several studies have demonstrated that transient phenomena near the bow shock (such as HFAs and Foreshock Bubbles) can generate ULF waves in the Earth's magnetosphere. (This is different from the low-latitude Pc3 waves that are driven by upstream waves in the ion foreshock.) The ULF waves generated by transient phenomena near the bow shock in both Pc3 and Pc5 ranges have been reported. In addition, there may be considerable variation between ULF waves resulting from different transient features (e.g., Hartinger et al. [2013] showed mostly compressional waves whereas Eastwood et al. [2011] showed standing Alfven waves). We report HFA generated Pc3 ULF waves observed by multiple spacecraft and ground stations. The ULF waves are standing Alfven waves. The wave power of poloidal mode is stronger than that of toroidal mode. The Pc3 ULF waves were observed at dawn, noon and dusk sectors, indicating the magnetospheric response to the HFA is global.

The source of backstreaming ions in a young Hot Flow Anomaly

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We analyze an event in front of the bow shock observed by Cluster spacecraft on 22.02.2006. This event has many attributes of Hot Flow Anomaly at early stage of development including strong upstream beam and disturbed magnetic profile with increased magnetic field at one or two sides as observed by 4 Cluster spacecraft. The angle between the magnetic field vectors at two sides of the current sheet was ~ 100. The minimum magnetic field magnitude within HFA was ~ 1 nT. The shock at two sides of the HFA was quasi-perpendicular. Upstream beam was observed on the leading side of the HFA. Parameters and velocity distributions of solar wind ions and of upstream ions observed on C1 and C3 spacecraft are analyzed separately in order to trace their changes across the event. The goal of this analysis was to get more information about the source of upstream beam. The beam evolved from the start of its observation till the HFA encounter being initially energetic and nearly mono-energetic. Its mean energy continuously decreased and energy spectrum widened as HFA approached spacecraft. First observation of particular energy that diminished with approaching the HFA varied linearly with gyro-radius of ions. Lowest energies in the beam were observed within HFA only. Highest density and pressure of upstream beam are found in the current sheet itself. The energy spectra of integrated beam and the energy spectrum of the beam observed just in front of HFA

are very similar to the energy spectrum upstream magnetosheath ions observed after bow shock crossing at ~ 1 hour after observation of the HFA. We suggest that the upstream beam is the result of the magnetosheath ions leakage through the region of HFA crossing with the bow shock front.

Relativistic electrons produced by foreshock disturbances

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Foreshock disturbances -- large-scale (~1000 km to >30,000 km), solitary (~5--10 per day, transient (lasting ~10s of seconds to several minutes)) structures -- generated by suprathermal (>100 eV to 100s of keV) ions arise upstream of Earth's bow shock formed by the solar wind colliding with the Earth's magnetosphere. They have recently been found to accelerate ions to energies of several keV. One type was found to have a distinct suprathermal electron population with energies >70 keV, which was attributed to a magnetospheric origin. Although electrons in Saturn's high Mach number (M > 40) bow shock can be accelerated to relativistic energies (nearly 1000 keV), it has hitherto been thought impossible to accelerate electrons at the much weaker (M < 20) Earth's bow shock beyond a few 10s of keV. Here we report observations of electrons energized by foreshock disturbances from 10s of eV up to at least ~300 keV. We observe a single isotropic power-law from 100s of eV to 100s of keV, unlike previous studies. All previous observations of energetic foreshock electrons have been attributed to escaping magnetospheric particles or solar events. We observe no solar activity and the single isotropic power-law cannot be explained by any magnetospheric source. Further, current theories of ion acceleration in foreshock disturbances cannot account for electrons accelerated to the observed relativistic energies. These electrons are clearly coming from the disturbances, leaving us with no explanation for the acceleration mechanism.

Reflected electrons and electrostatic waves observed by Cluster in the foreshock

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The foreshock region of the solar wind is populated with electrons reflected by the bow shock. The reflection process and propagation effects form electron beams which often drive the plasma distribution unstable. The presence of foreshock beams is typically identified in spacecraft data through observation of characteristic electrostatic waves around the local plasma frequency. Direct observations of the beams are more difficult due to their transient nature and low density. Only a few experimental studies on this topic exist, but the PEACE instrument of Cluster can consistently observe some of the denser field-aligned electron beams and the beam energy can be derived from the observations. At other times, a plateau in the electron distribution resulting from the dissipation of the beam by wave-particle interaction is observed. We analyzed a set of foreshock events where direct beam measurements were possible. We investigated a dependence of beam energy on the location within the foreshock and compared the results with an existing model. Beam observations were correlated with the qualitative character of the observed wave spectrum and for individual cases the observed electron distributions were used as an input for dispersion relation calculation.

Effects of Interplanetary Shocks on the Lunar Wake

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UCLA

As a nonconductive obstacle in the solar wind flow, the Moon creates a plasma void behind its body in the anti-sunward direction. This void, which has a low plasma density, high temperature and magnetic field strength, is called the lunar wake. There have been many observations and studies of the lunar wake. Using the extensive dataset now obtained by ARTEMIS, this paper studies the shock effects in the lunar wake. There have been several occasions during which one of the ARTEMIS spacecraft was located in the lunar wake at the time an interplanetary shock hit the Moon and compressed the wake. We discuss how the plasma and magnetic field reacted to the shock wave by comparing the observations inside the wake and in the nearby solar wind and by comparing the effects at different distances in the wake. We also investigate how such effects vary with the shock normal, ThetaBn, and the shock criticality.

Upstream transients and their influence on the bow shock and magnetosheath

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In this talk we will present preliminary results of the GI Cluster project Upstream transients and their influence on the bow shock and magnetosheath. Our aim is to study the main characteristics of upstream transients (cavitons and SHFA), and discuss how they can modify the solar wind, the bow shock structure, and the magnetosheath. The use of Cluster multi-spacecraft capabilities positioned at short separation distances will allow us to determine in detail the 3D morphology of structures such as cavitons, and determine how they evolve as they approach the shock and interact with other foreshock phenomena. We also want to study in more detail the formation of SHFA. Other point of interest is to determine how these transients can contribute to processes such as shock reformation and shock rippling.

On the importance of magnetosheath high-speed jets

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The dayside magnetosheath is often permeated by high-speed jets which are transient, localized, and coherent enhancements in dynamic pressure. These jets occur much more frequently downstream of the quasi-parallel bow shock, i.e., under quasi-radial (low cone angle) interplanetary magnetic field (IMF) conditions in the subsolar magnetosheath. Hence, they originate from processes in the foreshock or at the shock itself and provide long-range coupling between these regions and the downstream magnetopause. As jets are carriers of mass, momentum, and energy, the consequences of them impacting the magnetopause can be manifold: They may trigger local reconnection and/or cause localized, large amplitude indentations of the magnetopause. These may result in surface waves or inner-magnetospheric waves, may modify drift paths of radiation belt electrons, and may even cause enhancements in ionospheric convection and disturbances of the geomagnetic field, observable on ground. Naturally, the consequences will scale with the size of the jets. Scale size distributions are found to be well represented by exponential functions with characteristic sizes of 1.34 RE (perpendicular) and 0.71 RE (parallel to the jet flow direction), respectively. Therewith, impact rates of jets with cross-sectional diameters larger than 2 RE are obtained: These large scale jets hit the dayside magnetopause once every 20 minutes, on average, and once every 6 minutes under low IMF cone angle conditions. Hence, jets are the most common dayside transients.

Magnetic clouds in the Earth's magnetosheath: a statistical study

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Magnetic clouds (MCs) are highly geoeffective solar wind transients. In the interplanetary space, they possess a well-defined magnetic structure, characterised by an enhanced and smoothly rotating magnetic field. We examine here whether their magnetic structure is modified when they encounter the outer regions of the geospace, namely the bow shock and the magnetosheath. Significant changes in the magnetic structure of MCs could in turn affect the level of geomagnetic activity they induce in the near-Earth's space. We present here the results of a statistical study covering 15 years of data, from 2000 to 2014. We identify 82 MCs with simultaneous observations in the solar wind and in the magnetosheath. The magnetosheath measurements are obtained from Cluster, Themis, Geotail, Double-Star and Interball-Tail, while the solar wind data are provided by ACE or Wind. On each of these events, we run a magnetosheath model in order to relate the magnetosheath observations to the bow shock properties. For 66 events, the model yields reliable estimates of the bow shock parameters. Our results show a strong anti-correlation between the shock normal angle and the variation of the magnetic field direction from the solar wind to the magnetosheath. We investigate how this variation is distributed on the magnetic field cone angle and clock angle, and discuss its consequences for the different magnetic field components. We then go into detail analyzing the evolution of the Bz component from the solar wind to the magnetosheath, because of its salient role in terms of geoeffectivity. We find that the sign of Bz in the magnetosheath can differ from that in the solar wind. We investigate the conditions which lead to such a Bz reversal and show that it is generally related to specific upstream magnetic field orientations.

What Controls Dayside Reconnection

Joe Borovsky

Space Science Institute

Contrary to decades of accepted knowledge, the author has argued that the electric field of the solar wind has nothing to do with the dayside reconnection rate. (Although the solar-wind electric field or something similar can get into the magnetosphere post-reconnection and drive geomagnetic activity in an MHD-generator fashion.) To determine what drives dayside reconnection (1) we look at

the Cassak-Shay equation describing the two-plasma reconnection rate in terms of local plasma parameters and (2) determine what in the upstream solar wind controls those parameters. Five parameters appear in the Cassak-Shay equation: the magnetic-field strength in the dayside magnetosphere and in the sheath B_mag and B_sh, the number density in the dayside magnetosphere and in the sheath n_mag and n_sh, and the magnetic clock angle 'Clock'. B_mag is controlled by the ram pressure of the solar wind n_sw v_sw^2, B_sh is controlled by the ram pressure and the magnetosheath plasma-beta n_sw v_sw^2 and beta_sh, and beta_sh is controlled by the solar-wind Mach number M_A, n_sh is controlled by n_sw, and Clock is the solar wind Clock. So, n_sw v_sw^2, M_A, n_sw, n_mag, and Clock control dayside reconnection. Using differing approximations, a series of 'R' functions describing the reconnection rate have been derived, the simplest of which (which ignores n_sh) is R_quick = sin^2(Clock/2) n_sw^1/2 v_sw^2 M_A^-1.35 [1 + 680M_A^-3.30]^-1/4 . In the high-Mach-number and low-Mach-number limits, Rquick looks like variants of the solar wind electric field. The old logic was: the solar-wind electric field controls the electric field in the dayside reconnection line which controls the reconnection rate. A more-accurate logic is: the electric field in the dayside reconnection line is controlled by the rate of reconnection.

Electron Dissipation at the Dayside Magnetopause from MMS Measurements

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During its first of two scans of the dayside magnetopause, Magnetospheric Multiscale (MMS) encountered ten electron dissipation regions (EDRs). With spacecraft separations between 10 and 40 km, the four spacecraft all passed through or very close to each EDR but not all simulataneously. For the second dayside scan the separation has been reduced to 7 km to provide a better chance of all four spacecraft being in an EDR simultaneously. Such conjunctions become very important for analyzing magnetic and electric fields and electron distribution functions to determine the importance of possible sources of the reconnection electric field in the generalized Ohm's Law. This paper presents electron-scale dissipation derived from measured out-of-plane currents and reconnection electric fields for EDRs with various magnetic guide-field values. Disspation is observed at both in-plane magnetic nulls and flow stagnation points with their relative strengths varying with guide field. For example, very small guide fields lead to dissipation concentrated at the flow stagnation point while guide fields near unity show dissipation in both regions. The dissipation at the in-plane magnetic null appears to result from out-of-plane currents flowing along the guide field, which is not significant for very small guide field. In addition to the EDR events from the first dayside scan, any EDRs observed in the second scan, beginning in October 2016, will also be presented.

Cluster Observations of Magnetopause Reconnection Under High Flow-Shear Conditions

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When the IMF is northward, reconnection occurs in each hemisphere on lobe field lines, poleward of the cusp. We have identified a case where the Cluster spacecraft crossed the magnetopause and encountered a tailward-retreating x-line. The x-line is identified by the encounter of both a tailward and sunward jet, as well as Hall magnetic field signatures in the out-of-plane direction. Using two spacecraft we are able to resolve the velocity of the structure, which moves near the magnetosheath speed. The results are compared with theory and PIC simulations, and the speed of the x-line is found to be consistent with asymmetric reconnection theory. Additionally, we observe ion-distribution functions with counter-streaming populations, suggesting that a second x-line formed sunward of the original one, leading to a magnetic island.

Ion Larmor Radius Effects near a Reconnection X-line at the Magnetopause: THEMIS Observations and Simulation Comparison

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We report a THEMIS-D spacecraft crossing of a magnetopause reconnection exhaust ~9 ion skin depths (di) downstream of an X-line. The crossing was characterized by ion jetting at speeds substantially below the predicted reconnection outflow speed. In the magnetospheric inflow region THEMIS detected (a) penetration of magnetosheath ions and the resulting flows perpendicular to the reconnection plane, (b) ion outflow extending into the magnetosphere, and (c)

enhanced electron parallel temperature. Comparison with a simulation suggests that these signatures are associated with the gyration of magnetosheath ions onto magnetospheric field lines due to the shift of the flow stagnation-point toward the low-density magnetosphere. Our observations indicate that these effects, ~2-3 di in width, extend at least 9 di downstream of the X-line. The detection of these signatures could indicate large-scale proximity of the X-line, but do not imply that the spacecraft was upstream of the electron diffusion region.

Cluster observations of magnetopause as a rotational discontinuity: open issues on MHD reconnection tests

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When magnetic reconnection is ongoing, the magnetopause (MP) behaves like a rotational discontinuity (RD) outside the reconnection region. With in-situ satellite data, the RD character of the MP is usually checked by carrying out the Walen test, predicting that the plasma velocity observed in the deHoffmann-Teller frame equals the local Alfven velocity. Another relation, relying on the same MHD conservation laws, connects the variation in plasma mass density, rho, to variations in the pressure anisotropy factor, alpha, so that rho(1-alpha) is constant.

While the Walen relation has become a standard tool for classifying MP crossings as RDs, the rho(1-alpha) = const. condition has never been directly verified at the same time, largely due to problems with determining rho when no ion composition measurements were available. We exploit the availability of high time resolution composition measurements on Cluster to directly test the relation for several MP crossings, identified as RDs from application of the Walen relation to measurements of plasma ions and magnetic field by the CIS and FGM instruments, respectively. We find that in neither case the relation is fulfilled. Through comparisons of the measured ion densities with simultaneously measured total electron densities by the WHISPER instrument we were able to exclude the possibility that ion populations hidden to the CIS instrument because of their very low energies could have changed rho to match the rho(1-alpha) = const. condition. We also excluded the possibility that energetic ions above the CIS energy range could have sufficiently changed the true alpha. It thus appears that the rho(1-alpha) = const. condition, for reasons not presently understood, is not valid for the kind of RD-like structures we observed.

Another open issue relates to the fact that, in experimental context, the plasma flow velocity is typically just 0.6 - 0.8 of the Alfven velocity. This discrepancy might originate in a number of simplifying assumptions, two of which are examined in the

presentation. One simplification considers all the ions as protons, an approximation usually justified by the large prevalence of the protons in the MP environment. A Cluster event very rich in Oxygen ions is used to check the influence of this minor ion species by employing a formula based on the center-of-mass moments instead of the proton moments. Another simplifying assumption is to test for the Walen relation based on the ion velocities, although the magnetic field is more closely tied to the electron velocities, which differ from the ion velocities whenever electric currents are flowing. For a Cluster event with small inter-spacecraft separation distance, we have inferred the electron velocities from the measured currents and ion velocities, and performed the Walen test with the electron velocities. Although in both cases the corrected formulas brought an improvement in the result, the predicted values for the plasma flow velocity remains below the ideal value of local Alfven velocity.

Recent results about kinetics of electron holes in magnetopause reconnection observed by Cluster and MMS

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Electron holes (EHs) are characterized by localized bipolar electric fields parallel to the magnetic field. EHs are frequently observed at the magnetopause, and are often associated with magnetic reconnection. The unstable electron distributions produced by magnetic reconnection provide a source of EHs. In particular, EHs are generated in the separatrix regions of asymmetric reconnection, where large electron flows are observed. We investigate the properties of EHs associated with magnetic reconnection using Cluster and the Magnetospheric Multiscale (MMS) mission. Using these spacecraft we are able to characterize the properties of the waves, such as speed, length scale, and wave potential. We observe EHs with distinct speeds, indicating that multiple instabilities can occur during magnetic reconnection. This suggests that the waves can couple different electron populations and electrons with ions, heating the plasma and contributing to anomalous resistivity. We discuss the effects of EHs on magnetic reconnection at the magnetopause.

The Response Time of the Magnetopause Reconnection Location to changes in the Solar Wind: MMS Case Study

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Reconnection at the Earths magnetopause is the mechanism by which magnetic fields in different regions change topology to create open magnetic field lines that allow energy, mass and momentum to flow into the magnetosphere. It is the primary science goal of the recently launched MMS mission to unlock the mechanism of magnetic reconnection with a novel suite of plasma and field instruments. This study will investigate several magnetopause crossings in the general vicinity of the magnetopause reconnection location on September 19, 2015. These crossings occurred during rotations of the IMF and are used to determine the response time of the reconnection locations to such changes. The study shows that the reconnection location exhibits a tendency to remain at its current location despite significant rotations in the IMF and responds only minutes later to changes in the IMF

Flux Ropes Dynamics at the Subsolar Magnetopause: MMS Observations and Kinetic Simulations

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It is now well accepted that flux ropes are produced by magnetic reconnection and play a crucial role in the dynamics of the reconnection process. Sometimes, multiple flux ropes can be produced, which can coalesce sporadically into larger ropes, releasing large amount of energy. In this presentation, we report one of the first in-situ observations of the coalescence of macroscopic flux ropes by the Multiscale Magnetospheric (MMS) mission. Guided by results of 2-D kinetic simulations we identified the merging of two large-scale flux ropes with sizes of ~ 1 RE at the subsolar magnetopause. The coalescence process was characterized by the occurrence of a quadrupolar signature in the normal component of magnetic field measured by the MMS spacecraft when they were in the reconnection exhaust region after crossing the magnetopause. The inner bipolar field was weaker than the outer field indicating that magnetic energy had been dissipated by the two merging flux ropes. The reconnecting current sheet between the two flux ropes is characterized by intense current that was mainly carried by electrons, and a large guide field. An electron diffusion region embedded within the current sheet was marked by an intense parallel electric field, leading to significant energy dissipation in that layer. The enhancement of electron-driven waves (e.g., electromagnetic whistler and electron cyclotron harmonic waves) observed in the vicinity of the current sheet suggests that the coalescence involves multi-scale processes.

Locating dayside magnetopause reconnection with exhaust ion distributions

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Magnetic reconnection at Earth's dayside magnetopause is essential to magnetospheric dynamics. Determining where reconnection takes place is important to understanding the processes involved, and many questions about reconnection location remain unanswered. We present a method for locating magnetic reconnection at Earth's dayside magnetopause under southward IMF conditions using only ion velocity distribution measurements. Particle-in-cell simulations based on Cluster magnetopause crossings produce ion velocity distributions that we propagate through a model magnetosphere, allowing us to calculate the field-aligned distance between an exhaust observation and its associated reconnection location. We demonstrate this procedure and compare our results with those of the Maximum Magnetic Shear Model; we find good agreement

with its results, and show that when our method is applicable it produces more precise locations than the Maximum Shear Model.

**Low-energy ions in the magnetosphere:
Statistics and consequences**

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Magnetospheric ions with energies less than tens of eV originate from the ionosphere. The low energy indicates the origin of the plasma but also severely complicates detection of the positive ions onboard sunlit spacecraft at higher altitudes, which often become positively charged to several tens of volts. We discuss some methods to observe low-energy ions, including a technique based on the detection of the wake behind a charged spacecraft in a supersonic flow. Low-energy ions typically dominate the density and flux in large regions of the Terrestrial magnetosphere, also at high altitudes. This is true both on the nightside and the

dayside, during all parts of the solar cycle. The loss of this initially low-energy plasma to the solar wind is one of the primary pathways for atmospheric escape. Including low-energy ions in models of the magnetosphere will decrease the Alfven speed. Low-energy ions will also change the structure of magnetic reconnection separatrices and diffusion regions at the magnetopause. Low-energy ions are common just inside the magnetopause. During reconnection events, these low-energy ions remain magnetized down to smaller length-scales than the hot (keV) magnetospheric ions, introducing a new scale. When magnetized low-energy ions are present, the Hall currents carried by electrons can be partially cancelled by these ions. The electrons and the magnetized low-energy ions ExB drift together. This will reduce the Hall current. A mixture of lengths scales caused by a mixture of ion temperatures has significant effects on the Hall physics of magnetic reconnection.

Oxygen and cold ions in magnetic reconnection

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Magnetic reconnection occurs with a rate proportional to the inflow Alfven speed. In the Earth magnetosphere, oxygen ions are present near the reconnection site at magnetopause and magnetotail; cold ions with lower temperatures than ring current populations could also be involved in magnetopause reconnection. Such additional ion populations are likely to provide mass loading and affect the reconnection rate. With different thermal gyro-radii, the presence of oxygen and cold ions introduce additional scales of reconnection diffusion regions. By analyzing velocity distribution functions observed by Cluster during magnetopause reconnection, we will show that hot proton and oxygen ions from the magnetosphere join the reconnection outflow through a demagnetization-pickup process. Finite gyro-radius effect determines the penetration depth of these ions to the magnetosheath side of the current sheet. Cold ions are likely to experience a non-adiabatic motion close to the X-line, but if crossing the separatrix downstream, they convect with the magnetic field adiabatically. Observed mass densities from oxygen and cold ions during magnetopause reconnection are found to be up to about 30 percent, and measured reconnection rates closely follow the Cassak-Shay formula prediction. In order to provide an up-to-date introduction, we will review recent progresses in understanding oxygen and cold ion behaviors in simulations and MMS observations. Potential roles of these populations in exciting and dissipating waves and instabilities during reconnection will be discussed.

Kelvin-Helmholtz waves at Earth's magnetopause

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Magnetic reconnection is believed to be the dominant process by which solar wind plasma enters the magnetosphere. However, for periods of northward interplanetary magnetic field (IMF) reconnection is less likely at the dayside magnetopause, and Kelvin-Helmholtz (KH) waves may be important agents for plasma entry and for the excitation of ultra-low-frequency (ULF) waves. The relative importance of KH waves is controversial because no statistical data on their occurrence frequency exists. Our analysis, using 7 years of in situ data from the NASA THEMIS mission, has shown that KH waves at the Earth's magnetopause are ubiquitous and are present approximately 19% of the time regardless of the solar wind conditions. The occurrence rate increases with the IMF cone angle and maximizes at zero clock angle at about 35% for near northward IMF, and about 10% under southward IMF conditions. Although the occurrence rate under southward IMF is significantly higher than previously detected, it is still approximately four times less than the occurrence rate under northward IMF. The previous study suggested that the irregular and temporally intermittent structure of KH waves due to dynamically active sub solar behavior under southward IMF condition may explain the preferential in situ detection of KH waves under northward IMF. This explanation is also consistent with the KH waves under southward IMF in our database. To effectively isolate these differences, we performed OpenGGCM global simulations for both constant idealized solar wind and a THEMIS event and the simulation results show that the KH waves under southward IMF are irregular, higher frequency, and polychromatic in compared to northward IMF.

MMS Observations of Magnetic Reconnection Associated with Kelvin-Helmholtz Waves

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The four Magnetospheric Multiscale (MMS) spacecraft recorded the first direct evidence of reconnection exhausts associated with Kelvin-Helmholtz (KH) waves at the duskside magnetopause on 8 September 2015 which allows for local mass and energy transport across the flank magnetopause. Pressure anisotropy-weighted Walen analyses confirmed in-plane exhausts across 22 of 42 KH-related trailing magnetopause current sheets (CSs). Twenty-one jets were observed by all spacecraft, with small variations in ion velocity among the spacecraft, along the same sunward or antisunward direction with nearly equal probability. One exhaust was only observed by the MMS-1,2 pair, while MMS-3,4 traversed a narrow CS (1.5 ion inertial length) in the vicinity of an electron diffusion region. The exhausts were locally 2-D planar in nature as MMS-1,2 observed almost identical signatures separated along the guide-field. Asymmetric magnetic and electric Hall fields are reported in agreement with a strong guide-field and a weak plasma density asymmetry across the magnetopause CS.

A new view on drivers of magnetopause locations

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The solar wind dynamic pressure is the principal factor controlling the magnetopause location. Their mutual relation is usually considered in a power-law form and suggested indices vary from -1/4.8 to -1/6.6 in particular magnetopause models. The paper analyzes about ten thousands of THEMIS dayside magnetopause

crossings observed in a broad range of upstream pressures (0.2-20 nPa) and discusses the relationship between the dynamic pressure and magnetopause stand-off distance and flaring angle. We found that (1) the power-law form provides the best description of variations of the stand-off distance with upstream pressure for a full set of crossings as well as for subsets constrained by a sign of the interplanetary magnetic field (IMF) vertical component, IMF cone angle, and solar wind speed; (2) the most appropriate value of the power index resulting from the present study is -1/3.83 if only a dependence on the upstream solar wind pressure is considered; (3) the power index varies from -1/3.1 to -1/4.2 depending on the IMF direction and solar wind speed; and (4) the value of the power index increases to or above -1/6 if the orbital spacecraft limitations are not handled properly.

Science Objectives for Soft X-ray Missions to the Earth's Magnetosphere

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The soft X-rays emitted when high charge state solar wind ions exchange electrons with exospheric neutrals illuminate the Earth's dayside magnetosheath and cusps, outlining the positions of the bow shock, magnetopause, and cusps. Working in conjunction with in situ solar wind observations and far ultraviolet imagers of the auroral oval, wide field-of-view soft X-ray imagers can determine the nature of the global solar wind-magnetosphere interaction, including reconnection at the magnetopause, the nature of the substorm cycle, and the effects of the ring current upon both dayside and nightside processes. This presentation addresses some of the more salient topics suitable for any wide field-of-view soft X-ray mission.

New imaging of the Sun-Earth connection: the SMILE mission

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The interaction between the solar wind and the Earth's magnetosphere, and the geospace dynamics that result, comprise a fundamental driver of space weather. Understanding how this vast system works requires knowledge of energy and mass transport, and coupling between regions and between plasma and neutral populations. In situ instruments on a fleet of solar and solar wind observatories now provide unprecedented observations of the external Sun-Earth connection drivers. However, we are still unable to quantify the global effects of those drivers, including the conditions that prevail throughout geospace. This information is the key missing link for developing a complete understanding of how the Sun gives rise to and controls Earth's plasma environment and space weather.

Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) is a novel self-standing mission dedicated to observing the solar wind-magnetosphere coupling via simultaneous in situ solar wind/magnetosheath plasma and magnetic field measurements, X-Ray images of the magnetosheath and polar cusps, and UV images of global auroral distributions. Remote sensing of the cusps with X-ray imaging is now possible thanks to the relatively recent discovery of solar wind charge exchange (SWCX) X-ray emission, first observed at comets, and subsequently found to occur in the vicinity of the Earth's magnetosphere. SMILE is a collaborative mission between ESA and the Chinese Academy of Sciences (CAS) that was selected in November 2015 and is due for launch at the end of 2021. The SMILE science as well as the results of the on-going study undertaken jointly by ESA and CAS will be presented.

The role of turbulence in heating and accelerating particles: the THOR mission

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Turbulent fluctuations in astrophysical plasmas reach up to scales as large as stars, bubbles or 'clouds' blown out by stellar winds, or even entire galaxies. However, most of the irreversible dissipation of energy within turbulent fluctuations occurs at the very small scales - kinetic scales, where the plasma no longer behaves as a fluid and the properties of individual plasma species (electrons, protons, and other ions) become important. The energy transferred to different particle species, the acceleration of particles to high energies are strongly governed by kinetic processes that determine how the turbulent electromagnetic fluctuations dissipate. Thus, plasma processes at kinetic scales will directly affect the large-scale properties of plasma.

Turbulence Heating ObserveR (THOR) is the first mission ever flown in space dedicated to plasma turbulence. It will explore the kinetic plasma processes that determine the fundamental behavior of the majority of baryonic matter in the universe. THOR will lead to an understanding of the basic plasma heating and particle energization processes, of their effect on different plasma species and of their relative importance in different turbulent regimes. THOR will provide closure of these fundamental questions by making detailed in situ measurements of the closest available dilute and turbulent magnetized plasmas at unprecedented temporal and spatial resolution. THOR focuses on particular regions: pristine solar wind, Earth's bow shock and interplanetary shocks, and compressed solar wind regions downstream of shocks. These regions are selected because of their differing turbulent fluctuation characteristics, and reflect similar astrophysical environments. THOR is a candidate for selection as the next ESA M4 mission that will take place in June 2017 and the science as well as the results of the on-going study, currently undertaken at ESA, will be presented.

The MAARBLE project: investigating the properties of electromagnetic waves and their influence on the dynamic evolution of the Van Allen belts

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Solar variability drives, among other physical processes, the growth of low-frequency electromagnetic waves in the terrestrial magnetosphere. The resulting wave-particle interactions in the inner magnetosphere play a critical role in radiation belt dynamics. The MAARBLE (Monitoring, Analyzing and Assessing Radiation Belt Loss and Energization) project, which was implemented with support

from the European Community's Seventh Framework Programme, investigated in detail the properties of these waves and the particular the ways in which these waves may influence the energization and loss of radiation belt electrons. The MAARBLE project employed multi-spacecraft monitoring of the geospace environment, complemented by ground-based monitoring, in order to analyze and assess the physical mechanisms leading to radiation belt particle energisation and loss. MAARBLE created a database based on measurements from the Cluster, THEMIS and CHAMP missions and from the CARISMA and IMAGE ground magnetometer networks and containing properties of ULF and VLF waves. The database is available to the scientific community through the Cluster Science Archive as auxiliary content. Based on the wave database, statistical models of the wave activity dependent on the level of geomagnetic activity, solar wind forcing, and magnetospheric region have also been developed. Multi-spacecraft particle measurements have been incorporated into data assimilation tools, leading to a more accurate estimate of the state of the radiation belts. The synergy of wave and particle observations at the core of MAARBLE research studies of radiation belt dynamics enabled significant advances in understanding the nature of the physical processes responsible. In particular new understanding of the nature of ULF interactions, both coherent and diffusive, and better representations of multiple plasma wave-particle interactions lead to both new physical insights and thereby also to improved coupled models. Results and conclusions from these studies will be presented in this paper.

Understanding the radiation environment in the Earth's inner magnetosphere

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Earth's inner magnetosphere is the region where space weather effects are present. Even during quiet geomagnetic periods, it is full of dynamic processes. The number of satellites on orbit has grown significantly to more than 1000. Space weather events can increase radiation levels by five orders of magnitude in the Earth's radiation belts and trigger bursts of high energy particles which can disrupt satellite operations and sometimes cause a complete satellite loss. EU FP7 SPACESTORM project is for assessing and mitigating of the impact of space weather. We present the recent results from this project on data, models, and plasma theory studies to define the radiation environment for extreme space weather events with a specific focus on the radiation environment for medium Earth orbit and geostationary orbit. The driver for the space weather effects is the Sun. The overall goal of the EU H2020 PROGRESS project is to produce a set of forecast tools to accurately predict the occurrence and severity of space weather events. We demonstrate the recent

advances made for the development of such tools which include the forecast of the the solar wind parameters just upstream of the Earth's magnetosphere, geomagnetic indices, and the radiation environment in the radiation belts.

Interaction of ULF waves with different ion species: pitch angle and phase space density implications

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ULF waves can accelerate/decelerate the charged particles including the ring current ions via drift-bounce resonance, which play an important role in the dynamics of ring current during storm times. This study compares the different behaviors of oxygen ions (10.5-35.1keV) and protons (0.3-12.3keV) which simultaneously interact with Pc5 ULF waves observed by Cluster on June 03, 2003. The ULF waves are identified as the fundamental mode oscillations. Both oxygen ions and protons show periodic energy dispersion and pitch angle dispersion signatures, which satisfy the drift-bounce resonance condition of N=2. The different behaviors of oxygen ions and protons include: (1) the resonant energy of oxygen ions is higher than that of protons due to mass difference; (2) the phase space density (PSD) of oxygen ions show relative variations (3.6-6.3) that are much larger than that of protons (<0.4), which indicates a more efficient energy exchange between oxygen ions and ULF waves; (3) the PSD spectra show that oxygen ions are accelerated, while protons are decelerated, which depend on the radial gradient of their PSD; (4) the pitch angle distributions (PADs) of the oxygen ions and protons show negative slope and bidirectional field-aligned features, respectively, which is related to the preexisting state of ion PADs before the interaction with the ULF waves. In addition, the resonant ions with peakmfluxes tracing back to the magnetic equator are always collocated with the accelerating (westward) electric field, which indicate that the ions are mainly accelerated near the magnetic equator and the electric field intensity of ULF waves peaks there.

On the Elegant Dynamics of the Ultra-relativistic Van Allen Radiation Belt: How ULF Wave Transport Explains an Apparently Diverse Response to Solar Wind Forcing

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The NASA Van Allen Probes have opened a new window on the dynamics of ultra-relativistic electrons in the Van Allen radiation belts. Under different solar wind forcing the outer belt is seen to respond in a variety of apparently diverse and sometimes remarkable ways. For example, sometimes a third radiation belt is carved out (e.g., September 2012), or the belts can remain depleted for 10 days or more (September 2014). More usually there is a sequential response of a strong and sometimes rapid depletion followed by a re-energization, the latter increasing outer belt electron flux by orders of magnitude on hour timescales during some of the strongest storms of this solar cycle (e.g., March 2013, March 2015). Such dynamics also appear to be always bounded at low-L by an apparently impenetrable barrier below L~2.8 through which ultra-relativistic electrons do not penetrate. Many studies in the Van Allen Probes era have sought explanations for these apparently diverse features, often incorporating the effects from multiple plasma waves. In contrast, we show how this apparently diverse behaviour can instead be explained by one simple dominant process: ULF wave radial transport. Once ULF wave transport rates are accurately specified by observations, and coupled to the dynamical variation of the outer boundary condition at the edge of the outer belt, the observed diverse responses can all be explained. In order to get good agreement with observations, the modeling reveals the importance of still currently unexplained fast loss in the main phase which decouples pre- and post-storm ultra-relativistic electron flux on hour timescales. Similarly, varying plasmasheet source populations are seen to be of critical importance such that near-tail dynamics likely play a crucial role in Van Allen belt dynamics. Nonetheless, simple models incorporating accurate transport rates derived directly from ULF wave measurements are shown to provide a single natural, compelling, and at times elegant explanation for such previously unexplained and apparently diverse responses to solar wind forcing.

MMS Observations of Energetic Electron Microinjections

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The early MMS energetic electron data taken in the dusk to pre midnight regions above ~9 RE showed many clusters of electron injections we call microinjections because of their short duration signatures. These microinjections of 50-400 keV electrons have energy dispersion signatures indicating that they gradient and curvature drifted from earlier local times. A particular cluster of about 40 electron microinjections occurred in a 4.5-hour interval starting at 21:15 UT on 6 August 2015. We show detailed results from microinjections taken with burst mode data starting near 21:16 UT. These high temporal resolution data showed that the electrons in the microinjections were trapped and had bidirectional field-aligned angular distributions. Drift calculations constrained by the observed electron dispersion times indicate the electrons had drifted from near the magnetopause approximately two hours earlier in local time. Many multiple clusters of microinjections were observed as MMS apogee traversed the premidnight to dusk region. They were not observed as the MMS apogee passed from dusk through the dayside regions. Later, as the MMS apogee once again moved through the midnight to pre midnight region, during mission phase 1X, injections were once again observed. We provide statistics on the occurrence of the injections and discuss possible implications. These injection clusters are a new phenomenon in this region of the magnetosphere.

Cluster observations of magnetosonic waves in the inner magnetosphere.

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Observations of magnetosonic waves typically exhibit emissions at harmonics of the proton gyrofrequency that persist from several minutes to an hour or longer. Recent observations have shown the existence of non-time continuous examples of magnetosonic waves. In this paper we investigate the properties of these non-time continuous, reporting on a statistical study of the rate of frequency change for the rising tone emission features and the control more intermittent emissions appear to be controlled by the plasma density. The frequency structure of persistent magnetosonic waves shows evidence for emissions between the gyroharmonic frequencies. The source of these waves is investigated be examining their

propagation direction to determine if their generation is local or non-local.

Can EMIC triggered emissions be generated off the magnetic equatorial plane?

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ElectroMagnetic Ion Cyclotron (EMIC) triggered emissions (TEs) result from interaction between energetic protons (>1keV) and EMIC waves in the inner magnetosphere and in the dayside regions. The frequency with time dispersion and the high coherence level of the waves are characteristics of these emissions. They play a role in proton precipitations and their influence can be stronger in larger magnetospheres (at Saturn or Jupiter, for examples).

EMIC triggered emissions have been recently observed in situ by Cluster and THEMIS spacecraft. Up to our knowledge all events are observed close to magnetic equatorial plane, at magnetic latitudes (MLAT) lower than 15deg. The source region has been found in the vicinity of the equatorial plane for all these events.

In the present study we focus on three distinct Cluster events. In each of this event one or more EMIC triggered emissions are observed by one or more Cluster spacecraft off the magnetic equatorial plane (> 20deg MLAT). One of these events is of particular interest because many TEs occur at periodic time interval.

We first present a detailed polarization analysis of these waves. The magnetic waveform (STAFF instrument data) is transformed into the Fourier space for a study based on singular value decomposition (SVD) analysis. Unfortunately, the Poynting flux orientation could not be established. Then we compare our results to the observation of previous cases. In order to identify the source region we study two possibilities: a source region at higher latitudes than the observations (and particles orbiting in 'Shabansky' orbits) and a source region close to the magnetic equatorial plane, as reported in previous studies. The results are completed with a preliminary ray-tracing analysis.

Fine structure embedded in whistler mode chorus wave packets: observations of Cluster and Van Allen Probes in the inner magnetosphere

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Electromagnetic whistler-mode chorus waves are among the most intense naturally occurring emissions in the inner magnetosphere. Their amplitudes at hundreds of Hz to several kHz frequencies can reach 1% of the background magnetic field. These waves can play a significant role in the process of local acceleration of relativistic electrons and they can therefore strongly influence the dynamics of the outer Van Allen radiation belt.

Investigation of the nonlinear generation process of chorus is a subject of a significant effort in theoretical studies and numerical simulations, aiming at microphysics of wave-particle interactions. Assumptions of these studies need to be constrained by in situ observations. We use measurements of the Wide Band Data (WBD) instrument onboard Cluster spacecraft as well as measurements of the Waves instrument of the Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) onboard the Van Allen Probes to analyze intense chorus A large data base of multicomponent and multipoint waveform data has been collected by these instruments.

We use selected intervals of chorus and we determine the instantaneous amplitudes, phases, frequencies, and wave vector directions of chorus waveforms. Fine structure embedded in the chorus elements mainly reflects the simultaneous presence of waves at different frequencies (sidebands) although separate wave packets are also observed. The observed frequency differences (time scales of subpackets) do not seem to scale with amplitude as does the theoretical trapping frequency. Our results further show that peak values of the instantaneous amplitude decrease with the distance fro m the magnetic equator and with the time interval between peaks.

The inner magnetosphere ion composition

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The magnetospheric plasma is a multi-species plasma and it is known that during solar and geomagnetically active times, O+ ions of ionospheric origin can contribute significantly to, if not dominate, the density and pressure both in the magnetotail and in the inner magnetosphere. Adding O+, from the cusps and through the lobes, to the normally H+ dominated magnetotail plasma sheet, significantly changes the plasma sheet mass density. This isotropized hot population, through inward convection, becomes the main contributor of the storm time ring current pressure. The auroral outflow, which enters the plasma sheet closer to the earth, where the radius of curvature of the field line is larger, does not isotropize or become significantly energized, but remains a predominantly field aligned low energy population in the inner magnetosphere. Thus it appears that the O+ that enters the plasma sheet further down the tail has a greater impact on the storm-time ring current than ions that enter closer to the earth. The source population of the storm time ring current is the night side plasma sheet. However, the ring current responds differently to the different solar and interplanetary storm drivers such as coronal mass injections, (CME's), co-rotating interaction regions (CIR's), high-speed streamers and other structures. The resulting changes in the ring current particle pressure change the global magnetic field, which affects the transport of the radiation belts. In order to determine the field changes during a storm, it is necessary to understand the transport, sources and losses of the particles that contribute to the ring current.

Oblique Whistler-Mode Waves in the Earth's Inner Magnetosphere

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The recent spacecraft observations of oblique whistler-mode waves in the Earth inner magnetosphere, as well as the various consequences of the presence of such waves for electron scattering and acceleration, are presented. The statistics of occurrences and intensity of oblique chorus waves in the region of the outer radiation belt, comprised between the plasmapause and geostationary orbit is performed. We further examine how such oblique wave populations can be included into both quasi-linear diffusion models and fully nonlinear models of wave-particle interaction. On this basis, we demonstrate that varying amounts of oblique waves can significantly change the rates of particle scattering, acceleration, and precipitation into the atmosphere during quiet times as well as in the course of a storm. We demonstrate that oblique whistler-mode chorus waves can be considered as an important ingredient of the radiation belt system and can play a key role in many aspects of wave-particle resonant interactions.

Cof electric radial diffusion coefficient of radiation belt electrons with in situ electric field measurements by THEMIS

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Based on seven years' observations from THEMIS, we investigate the statistical distribution of electric field Pc5 ULF wave power under different geomagnetic activities and calculate the radial diffusion coefficient due to electric field, DLLE, for outer radiation belt electrons. A simple empirical expression of DLLE[THEMIS] is also derived. Subsequently we compare DLLE[THEMIS] to previous DLL models, and find similar Kp dependence with the DLLE[CRRES] model, which is also based on in-situ electric field measurements. The absolute value of DLLE[THEMIS] is constantly higher than DLLE[CRRES], probably due to the limited orbital coverage of CRRES. The differences between DLLE[THEMIS] and the commonly-used DLLB[B-A] and DLLE[Ozeke] models are significant, especially in Kp dependence and energy dependence. Possible reasons for these differences and their implications are discussed. The diffusion coefficient provided in this paper, which also has energy dependence, will be an important contributor to quantify the radial diffusion process of radiation belt electrons.

Plasmaspheric plume analysis during the 2013 Cluster close separation campaign, augmented with Van Allen Probes data and a plasmapause test particle simulation

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During the last Cluster close separation campaign (July-October 2013), two of the four Cluster satellites were only tens of kilometers apart, while the two others were located at a few hundreds of kilometers. This configuration offers an exceptional opportunity to analyze the plasmasphere with very high space and time resolution

around the time of perigee at about 4 RE. In particular, plasmaspheric plumes were crossed by the satellites on several occasions.

This contribution presents such an event on 13 July 2013 with electron density data obtained from the WHISPER instrument onboard Cluster. A plasmapause test particle simulation is used to provide a global view of the plasmasphere and plasmapause. Also, the electron density inside the plume is inferred from EMFISIS/Waves observations taken onboard the two Van Allen Probes, which crossed the same plume and provide another view. The initial formation and global evolution of the plume are studied using the general context and data from the satellites at their respective locations. Density irregularities are observed inside the plume. Some are very stable at only a few minutes scale, while others persist also at longer scales. Their spatial gradient is studied as well as their motion with the help of multi-spacecraft analysis. Recent results about waves observed during the plume crossings will be also presented.

Lightning whistlers triggering plasmaspheric hiss: multi-spacecraft observations and ray-tracing analysis

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Series of lightning whistlers were recorded by the Wide-Band Data (WBD) instruments onboard three Cluster spacecraft (C1, C3, and C4) during the Cluster Inner Magnetosphere close separation campaign on the 4th of July 2013. Our dataset is composed of high-resolution waveforms of lightning whistlers which occurred from 12:00 to 12:10 UT when the spacecraft were moving from the South to the North close to the equator at RE ~ 3.5. The satellite data were completed by the WWLLN and EUCLID lightning detection data.

The time-frequency spectrograms of the observed series of lightning whistlers exhibit two different specific patterns. In the first group of cases we observe intense bursts of plasmaspheric hiss at frequencies below 2 kHz which are clearly related to lightning whistlers. No such triggered hiss emissions are observed in the second group of cases.

Using multi-spacecraft analysis with estimation of the causative lightning stroke locations we investigate differences in propagation of these two groups of lightning whistlers. Results of our analysis lead us to a hypothesis that lightning whistlers penetrating the ionosphere at lower latitudes and propagating unducted may be one of the sources of plasmaspheric hiss below 2 kHz. We verify this hypothesis using a

ray tracing analysis based on the density profile derived from measurements of Electric and Magnetic Field Instrument Suite and Integrated Science instrument (EMFISIS) onboard Van Allen Probe spacecraft.

Erosion and refilling of the plasmasphere studied by neural network based three-dimensional plasmaspheric model

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We developed a time-dependent global plasma density model of the inner magnetosphere which uses a feedforward neural network schema with two hidden layers. As the model output, we used the electron density inferred from spacecraft potential from three THEMIS probes. As the model inputs, we took the spacecraft location (L, magnetic local time and latitude), and time series of the SYM-H, AL and F10.7 indices. The equatorial electron density is shown to be accurately reconstructed with a correlation of $r \sim 0.953$ between model output and observations. The model succeeded in reconstructing the distribution and dynamics of the density, including the quiet time plasmasphere, erosion and recovery of the plasmasphere, as well as the plume formation during a storm on February 04, 2011. The model also reproduced the contraction and recovery of the plasmapause for the same event.

The neural network based plasmaspheric model is then expanded to three dimensions by including more observations from both equatorial satellites and polar orbiting satellites (RBSP, CRRES, ISEE, CLUSTER, POLAR, IMAGE). We maintain the same architecture of the neural network model (two hidden layers)

and the model inputs (location and time series of SYM-H, AL and F10.7 indices). The three-dimensional plasmaspheric model can reproduce almost 90% of the variation in the plasma density with a correlation of r~0.943. Using the three-dimensional plasmaspheric model, we reconstruct a time-dependent three-dimensional plasmasphere. The latitudinal profile of the plasma density is compared with those profiles from previous study. In addition, we show the evolution (erosion and refilling and plume formation) of the plasmasphere during geomagnetic storms in a three-dimensional perspective.

The geospace exploration project: ERG

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The ERG (Exploration of energization and Radiation in Geospace) is Japanese geospace exploration project. The project focuses on the geospace dynamics in the context of the cross-energy coupling via wave-particle interactions. The project consists of the satellite observation team, the ground-based network observation team, and integrated-data analysis/simulation team. The development of the satellite is the final stage and will be launched in FY2016.

Comprehensive instruments for plasma/particles, and field/waves are installed in the ERG satellite to understand the cross-energy coupling system. In the ERG project, several ground-network teams join; magnetometer networks, radar networks, optical imager networks, etc. Moreover, the modeling/simulations play an important role for the quantitative understanding. For the data analysis environment, the ERG project has developed several plug-ins for SPEDAS in collaborations with the THEMIS mission. The ERG project data will be downloaded and analyzed using the SPEDAS. In this presentation, we will talk about an overview of the ERG project and possible collaborations with THEMIS and Cluster missions and other geospace projects.

Electric fields associated with 100s keV electron enhancements in the slot region

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The double-probe instruments onboard CRRES, THEMIS and the Van Allen Probes have shown that strong quasi-static electric fields can reach low L shells ($L < 3$) in the inner magnetosphere during geomagnetically active times. These electric fields can be related to a number of mechanisms including penetration of the convection electric field, subauroral polarization streams, substorm injections, interplanetary shocks and neutral winds. Quasi-static electric fields affect plasma through ExB drift and are usually associated with the dynamics of the low-energy plasmasphere. Higher-energy particles in the ring current and radiation belts are also influenced by large-scale electric fields, where inward radial transport through azimuthal electric fields can increase the energy of the particles. Recent observations by the Van Allen Probes show frequent enhancements of 100s keV electrons into the slot region and inner belt ($L < 3$), with lower energies reaching lower L shells more frequently. We explore in situ electric field measurements by THEMIS and the Van Allen Probes surrounding these enhancements to investigate the impact of quasi-static electric fields on 100s keV electron dynamics deep within the inner magnetosphere.

Particle Acceleration in Solar Flares and Terrestrial Substorms

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Particles are accelerated to very high, non-thermal energies during explosive energy-release phenomena such as solar flares and terrestrial substorms. While it has been established that magnetic reconnection plays a key role in these phenomena, the precise mechanism of particle acceleration via reconnection is still unclear. Here we show, based on a compilation of previously reported observations, that the power-law index d may have a lower-limit at $d \sim 4$ in both solar flares and terrestrial substorms (i.e., $d >\sim 4$), where d is defined in the flux density (differential flux) distribution. This is in stark contrast to the case of particle acceleration at shocks (such as interplanetary shocks and the terrestrial bow shock) whose power-law index often exceeds the limit (i.e., $d <\sim 4$). These results suggest the followings: (1) there may be a common but not-yet-identified physics in these entirely different environment, i.e. the corona and the magnetotail, and (2) explosive energy-release phenomena such as solar flares and terrestrial substorms are not as efficient as shocks in terms of converting upstream energies to non-thermal particle energies, at least in the heliospheric, non-relativistic environment of plasmas.

An Analysis of Magnetic Reconnection Events and their Associated Auroral Enhancements

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We present an analysis of simultaneous reconnection events in the earth's magnetotail and enhancements in the aurora. We exploit magnetospheric data from the Geotail, Cluster, and Double Star missions, along with auroral images of both hemispheres from the Image and Polar missions, to explore the relationship between a reconnection signature and its auroral counterpart. From a study of 46 suitable reconnection events, we find that 36 demonstrate a clear coincidence of reconnection and auroral enhancement. These 36 enhancements and reconnection sites are generally located within +/-1 hour MLT of each other and there is a good correlation between the MLTs of both (r=0.7). The enhancements are localized and often short lived (<10mins) and occur equally before and after the substorm onset. No significant dependence between the reconnection and auroral enhancement location is found with local By or Vy, or IMF By. Some small dependence is evident for solar wind Vy.

Magnetotail fast flows near lunar orbit

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We use five years (2011-2015) of ARTEMIS data to statistically investigate earthward and tailward flows at around 60 RE downtail. We find that a significant portion (~50%) of fast flows is directed earthward. This contribution reduces with increasing flow speed. As expected, earthward (tailward) flows are predominantly accompanied with positive (negative) Bz. A dawn-dusk asymmetry in the flow occurrence is seen for both earthward and tailward flows with about 50%-60% (60%-70%) of the earthward (tailward) flows occurring in the dusk sector. This asymmetry is more dominant for tailward than for earthward flows and increases slightly with higher flow speeds. Considering only the flow component perpendicular to the magnetic field, the portion of earthward flows reduces to about 30%-40%, depending on the flow speed. The dawn-dusk asymmetry is also seen in this perpendicular flows.

Magnetotail Current Sheet Structure from Cluster and THEMIS Observations

A. Artemyev, A. Runov, V. Angelopoulos

UCLA

Observations by two multi-probe missions, Cluster and THEMIS, provide unique opportunity to investigate both transverse (across the tail) and longitudinal (along the tail) current sheet structure. Studies of four-point magnetic field measurements by Cluster revealed many details of inner current sheet structure. Simultaneous observations by the tail-elongated THEMIS probes demonstrated how current sheet configuration varies along the tail. In this presentation, we review main current sheet properties derived from Cluster and THEMIS statistics.

Studying magnetic reconnection using the FOTE method: Cluster and MMS results

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FOTE is a method developed to find magnetic nulls and reconstruct field topology of linear magnetic structures; it is particularly useful to the four-spacecraft mission with small separation (e.g., Cluster in 2003 and the recent MMS mission). In this talk, we will show how we apply this method to the Cluster and MMS data and what results we can obtain from this method. Specifically, we study the magnetic islands in magnetotail, the flux transfer events (FTEs) at magnetopause, and the X-lines and flux ropes inside ion diffusion region at magnetopause. We reconstruct the topologies of all these structures (magnetic islands, FTEs, X-lines and flux ropes). Also, we reveal the particle dynamics around these structures. The new findings we obtain include: (1) sudden enhancement of oxygen inside the magnetic islands associated with dipolarization fronts; (2) significant increase of plasma density and O+ fluxes inside the FTE structures; (3) X-lines inside the electron diffusion region; (4) numerous kinetic-scale flux ropes inside the ion diffusion region; and (5) the strong quadrupolar Hall magnetic field in the guide-field asymmetric reconnection event.

Electric Fields at the Dipolarization Fronts: Cluster and MMS observations

Andris Vaivads, Andrey Divin, Daniel Graham, Mats Andre, Cluster Team, MMS Team

Swedish Institute of Space Physics, Uppsala

High speed plasma flows, commonly referred to as jets, are ubiquitous in plasma environments. Jets always accompany magnetic reconnection, which is one of the key energy conversion processes in magnetized plasmas. Jet fronts observed in the magnetotail, also called dipolarization fronts, are narrow regions with a typical transverse size of several ion inertial lengths, with large changes in magnetic field, density and temperature, and associated strong electromagnetic and electrostatic emissions in a broad frequency range. We present observations of electric fields at dipolarization fronts by Cluster and MMS and discuss their role in plasma heating and particle acceleration.

Electron Injections: A Study of Electron Acceleration by Multiple Dipolarizing Flux Bundles Using an Analytical Model

C.Gabrielse, C. Harris, V.Angelopoulos, A.Artemyev, A.Runov

UCLA

We study energetic electron injections using an analytical model that self-consistently describes electric and magnetic field perturbations of transient, localized dipolarizing flux bundles (DFBs). Previous studies using THEMIS, Van Allen Probes, and the Magnetospheric Multiscale Mission have shown that injections can occur on short (minutes) or long (10s of minutes) timescales. These studies suggest that the short timescale injections correspond to a single DFB, whereas long timescale injections are likely caused by an aggregate of multiple DFBs, each incrementally heating the particle population. We therefore model the effects of (1) a single DFB and (2) multiple DFBs on the electron population using multi-spacecraft observations of the fields and particle fluxes to constrain the model parameters. The analytical model is the first of its kind to model multiple dipolarization fronts in order to better understand the transport and acceleration process throughout the plasma sheet. It can reproduce most injection signatures at multiple locations simultaneously, reaffirming earlier findings that earthward-traveling DFBs can both transport and accelerate electrons to suprathermal energies, and can thus be considered the injections' primary driver.

Ion Heating and Anisotropy in Magnetotail Reconnection Jets

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Magnetic reconnection redistributes energy by releasing magnetic energy into particle energies---high-speed bulk flows, heating, and particle acceleration. With near-Earth in situ observations, we have access to different parameter regimes: the magnetotail, the magnetopause, and the solar wind. The energetics of magnetotail reconnection jets are particularly interesting as the available magnetic energy per particle (B_in^2/mu0*n_in = m_iVA,in^2) is typically orders of magnitude higher and the inflow (lobe) plasma beta much lower than in the solar wind and at the magnetopause. Furthermore, this separation of characteristic speeds (the Alfven speeds are high and the thermal speeds are low) allows us to better investigate the dynamics of the two mixing populations in the reconnection exhaust.

A significant portion of the energy released by magnetotail reconnection appears to go into ion heating, and the heating is anisotropic with the plasma temperature parallel to the magnetic field generally increasing more than the perpendicular temperature. Simulations and theory indicate that this temperature anisotropy can balance part of the magnetic tension force that accelerates the jet, and may even exceed it leading to firehose instability.

Here we present ARTEMIS dual-spacecraft observations of anti-parallel magnetic reconnection in the lunar distance magnetotail. We consider the spatial variations in the ion anisotropy across the outflow far downstream (>100 ion inertial lengths) of the X-line for both density symmetric and asymmetric boundary conditions. In the case of symmetric inflow conditions, plasma is well above the firehose threshold in portions of the exhaust, suggesting that the drive for the instability is strong and the instability is too weak to relax the anisotropy. The perpendicular temperature dominates at the mid-plane, indicating that particles undergo Speiser-like motion. In the case of asymmetric boundary conditions (an event where the north lobe had high-density mantle and boundary layer plasma while the south lobe had a much lower density) the plasma is mostly marginally firehose stable. The Hall magnetic field polarity corresponding to the high-density side is enhanced, consistent with theoretical expectations and stabilizing the plasma. We also analyze the characteristics of the particle distributions leading to these anisotropies at different distances from the mid-plane.

Electron field-aligned anisotropy and dawn-dusk magnetic field: nine years of Cluster observations in the Earth magnetotail.

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Processing nine years of Cluster observations in the Earth magnetotail, we investigate electron temperature anysotropy and it's dependence on By and Bz magnetic field components (in GSM coordinates). We characterise anysotropic electron population by temparature ratio Tpar/Tper and phase space density ratio Fpar/Fper for parallel (par) and transverse (per) directions to background mangnetic field. We show that electron anysotropic population identefied by large Fpar/Fper ratio can exist in plasma sheet with small Tpar/Tper. Thermal anysotropy Tpar/Tper increases significantly with Bz and By: By growth results in formation of strong Tpar/Tper peak near the magnetotail neutral plane Bx=0, whereas Bz growth results in Tpar/Tper increase for wide Bx range. Dependencies of Tpar/Tper on By and Bz have dawn-dusk asymmetry: Tpar/Tper growth corresponds to Bz increase at dusk flank and By increase at dawn flank. Using differences of electron anysotropy dependencies on By and Bz magnetic field components, we discuss possible mechanisms responsible for its formation.

CLUSTER view on PSBL ion beams in the Earth's magnetotail

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Plasma Sheet Boundary Layer (PSBL) is a very dynamic region playing an important role in the magnetosphere-ionosphere coupling. Field-aligned high-velocity ion beams transporting the energy from the distant tail to the inner magnetosphere are very frequently observed in the PSBL. In dependence on the global magnetotail dynamics the PSBL ion beams have different spatial and temporal scales. Multipoint CLUSTER observations allowed, for the first time, a precise estimation of the ion beam characteristics. It was shown that during different periods of the magnetotail activity the ion beams are generated by different regimes of the nonadiabatic acceleration. During quiet periods the PSBL may consist from multiple long-lasting (up to ~ 20 min) ion beams, which are localized both in velocity and physical space. On the contrary, the reconnection-associated sources of ion beam acceleration are transient and usually generate more energetic beams having a short (~ 1 - 3 min)

duration and a much broader range of parallel velocities. In this contribution the peculiarities of different mechanisms of ion beam acceleration and their PSBL manifestations are discussed and compared.

This work was supported by the Volskwagen Foundation (grant Az 90 312).

Does the cross-scale energy transport associated with asymmetric growth of Kelvin-Helmholtz Instability explain the origin of plasma sheet temperature asymmetry of cold-component ions?

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In the Earth's magnetosphere the specific entropy, which is a measure of non-adiabatic heating, increases by ~two orders of magnitude when transitioning from magnetosheath into the magnetosphere. However, the origin of this non-adiabatic heating has not been well understood. In addition, there exists a dawn-dusk temperature asymmetry in the flanks of the plasma sheet - the cold component ions are hotter by 30-40% at the dawnside plasma sheet compared to the duskside plasma sheet.

Our recent statistical study of magnetosheath temperatures using 7 years of THEMIS data indicates that ion magnetosheath temperatures downstream of quasi-parallel (dawn-flank for Parker-Spiral IMF) bow shock are only ~15 percent higher than downstream of the quasi-perpendicular shock. This seed magnetosheath temperature asymmetry existing in the magnetosheath is therefore inadequate to cause the observed level of the plasma sheet temperature asymmetry.

In this presentation we address the origin of non-adibatic heating from magnetosheath into plasma sheet by utilizing small Cluster spacecraft separations, statistical THEMIS data as well as simulations.

We show how fluid-scale Kelvin-Helmholtz waves can radiate ion-scale magnetosonic modes which in turn heat the ions thus transferring the kinetic energy of the shocked solar wind into heat energy of magnetospheric ions.

The statistical study of the Kelvin-Helmholtz waves and ion-scale wave activity shows also a dawn favored asymmetry which may explain the observed asymmetry in cold-component plasma sheet ions.

This same cross-scale heating mechanism may play role also elsewhere in the universe where significant flow shears are present such as in the solar corona and other astrophysical plasmas. The mechanism may also explain how the electrons 'know' when ions have been heated, a long standing mystery related to plasma sheet transport.

Kelvin-Helmholtz instability: lessons learned from Cluster & Themis and way forward

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Over more than 10 years, the Cluster and the Themis missions have shed a total new light on the Kelvin-Helmholtz Instability mechanism. To name a few, these missions have enabled the observation of KHI rolled-up vortices for the first with four spacecraft (Hasegawa et al., 2004). They revealed its presence under any IMF conditions (Hwang et al., 2011, 2012), previously underestimated (Kavosi and Raeder, 2015). Very recently, the presence of ion magnetosonic waves with sufficient energy to account for the observed level of ion heating within a KHI vortex may be evidence of cross-scale energy transport (Moore et al., 2016).

After presenting some the main highlights of Cluster and Themis on this phenomenon, we will present upcoming new observations with Cluster, Themis and MMS foreseen in 2019-2020 timeframe.

Now looking forward: how to go from a qualitative picture to a quantitative picture of this phenomenon? For instance, how to quantify the role of KHI in the formation of the cold dense plasmasheet? Which observations would be then needed? Two main concept of new observations will be evoked.

Conjugacy of Kelvin-Helmoltz Instability and Ps6 during the St. Patrick's Day 2013 Magnetic Storm Event

Martin Connors

Athabasca University Observatories

Ps6 perturbations are observed primarily in the Y and Z components of the ground magnetic field in the morning sector, and are sometimes associated with the auroral form known as omega bands. They drift sunward at a speed comparable to the

convection speed, and the perturbations are consistent with an equivalent current closing Region 1 and 2. The association with phase of the substorm remains contentious, but they appear to be more prevalent under strong driving by the solar wind. Here the St. Patrick's Day storm (March 17-18) of 2013 is examined for the relationship of Ps6 to Kelvin-Helmholtz waves present at the magnetopause as shown by spacecraft crossings and by MHD simulations. Cluster and THEMIS conjunctions with the ground establish a close connection between KHI on the magnetopause and Ps6 pulsations. KHI in space appears to last longer than corresponding Ps6, and amplitudes are not closely related. Interspacecraft comparison allows the wave speed to be found and compared to that in simulations and of the pulsations observed on the ground.

Characterization of energetic O+ and H+ ions in the plasma sheet

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The spatial distributions of different ion species are useful indicators for plasma sheet dynamics. Based on Cluster observations, we establish the spatial distributions of oxygen ions and protons at energies from 274 to 955 keV, depending on geomagnetic and solar wind (SW) conditions. Compared with protons, the distribution of energetic oxygen has stronger dawn-dusk asymmetry in response to changes in the geomagnetic activity. The strongest changes of the ion intensities are associated with AE index and not the change of the IMF direction or SW Pdyn. The high oxygen intensities during declining solar cycle phase associated with high substorm occurrence are observed despite the fact that ionospheric ion outflow is the strongest during the solar maximum. We relate it to the effective resonant acceleration by electro-magnetic fluctuations at oxygen gyrofrequencies in the magnetotail during substorms.

ARTEMIS observations of terrestrial ionospheric molecular ions at the Moon

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Recently, Poppe et al. [2016] reported on Acceleration, Reconnection, Turbulence, and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS) spacecraft observations of multiple instances of outflowing molecular ionospheric ions at lunar distances in the terrestrial magnetotail. The heavy ion fluxes are observed during geomagnetically disturbed times and consist of mainly molecular species (N2+, NO+, and O2+, approximately masses 28-32 amu) on the order of 1e5-1e6 /cm2/s at nearly identical velocities as concurrently present protons. By performing backwards particle tracing in time-dependent electromagnetic fields from the magnetohydrodynamic Open Global Geospace Circulation Model (OpenGGCM) of the terrestrial magnetosphere, they showed that the ions escape the inner magnetosphere through magnetopause shadowing near noon and are subsequently accelerated down-tail to lunar distances. Here, we expand upon these observations by investigating the spatial distribution of the molecular ion observations in the magnetotail and by correlating times of molecular ion observations with geomagnetic activity and solar wind drivers.

Plasma sheet drivers of currents and ionospheric conductivity effects

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Violent releases of space plasma energy from the Earth's magnetotail during substorms produce strong electric currents and bright aurora. But what modulates these currents and aurora and controls dissipation of the energy released in the ionosphere? Using data from the THEMIS fleet of satellites and ground-based imagers and magnetometers, we show that plasma energy dissipation is controlled by field-aligned currents (FACs) produced and modulated during magnetotail

topology change and oscillatory braking of fast plasma jets at 10-14 Earth radii in the nightside magnetosphere.

Distribution of Region 1 and 2 currents in the quiet and substorm time plasma sheet from THEMIS observations

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Although Earth's Region 1 and 2 currents are related to activities such as substorm initiation, their magnetospheric origin remains unclear. Utilizing the triangular configuration of THEMIS probes at 8-12 RE downtail, we seek the origin of nightside Region 1 and 2 currents. The triangular configuration allows a curlometer-like technique which do not rely on active-time boundary crossings, so we can examine the current distribution in quiet times as well as active times.

Our statistical study reveals that both Region 1 and 2 currents exist in the plasma sheet during quiet and active times. Especially, this is the first unequivocal, in-situ evidence of the existence of Region 2 currents in the plasma sheet. Farther away from the neutral sheet than the Region 2 currents lie the Region 1 currents which extend at least to the plasma sheet boundary layer. At geomagnetic quiet times, the separation between the two currents is located ~2.5 RE from the neutral sheet. These findings suggest that the plasma sheet is a source of Region 1 and 2 currents regardless of geomagnetic activity level.

During substorms, the separation between Region 1 and 2 currents migrates toward (away from) the neutral sheet as the plasma sheet thins (thickens). This migration indicates that the deformation of Region 1 and 2 currents is associated with redistribution of FAC sources in the magnetotail. In some substorms when the THEMIS probes encounter a dipolarization, a substorm current wedge (SCW) can be inferred from our technique, and it shows a distinctively larger current density than the pre-existing Region 1 currents. This difference suggests that the SCW is not just an enhancement of the pre-existing Region 1 current; the SCW and the Region 1 currents have different sources.

A case study on the FAC carriers in the magnetotail in substorm time

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The FAC variations indicate not only disturbances of the magetic field, but also dynamics of the charged particles those can be named the FAC carriers. In the polar region, it is well know that the FAC carriers are mainly the precipitation electrons. However, in the magnetotail, the FAC carriers have been poorly understood. Taking advantage of magnetic field and plasma multiinstrument onbaord the four Cluster spacecraft as they crossed the plasma sheet boundary layer in the magnetotail in storm time on 14 September 2006. We identified the species and energy range of the FAC carriers, and analyzed its characteristics. The results indicate that, in the substorm time, not only the electrons from 0.5 to 26 keV, but also the energetic keV ions were the main carriers for the FAC. The ions were originated from the ionosphere through outflow and were accelerated during transportation. This is the first time we found the ions also can be the main FAC carriers.

Multi-point studies of the aurora and associated cavity by Cluster, and of BBFs and magnetosheath jets by Cluster and MMS

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Results will be presented from multi-point studies of (1) the auroral acceleration region and associated density cavity, using Cluster data, and (2) of fast flows in the magnetotail and magnetosheath, using Cluster and MMS data. In part (1) the relative role of quasi-static and Alfvenic acceleration for producing large-scale auroral forms and surges, and characteristics of the auroral cavity are discussed based on new results from recent event and statistical studies. Part (2) focusses both on Bursty Bulk Flows in the magnetotail and on jets and plasmoids in the magnetosheath. Cluster and MMS data from different parts of the magnetotail are used to calculate the forces acting on the BBFs, to explore the fate of these as they approach Earth. For the magnetosheath jets and plasmoids, the forces acting on these are calculated and associated waves are studied, which may provide clues about the fate of the jets,

as well as of their origin.

Occurrence of auroral omega bands

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Omega band aurora has been described as a discrete wave form between the region-1 and region-2 boundary diffuse aurora boundary that resembles the Greek letter omega. These forms are generally related to auroral activity in the morning sector and during substorm recovery phase. A number of detailed multi-instrument case studies have been reported on omega bands but very few statistical studies are available, suggesting that omega forms are not common in auroral displays.

MIRACLE all-sky camera data from five Lapland stations over 1996-2007 have been searched for omega structures with an automated routine and by visual inspection. We required a clear discrete structure to be present for each omega band with a lifetime of more than a minute. We also required that the omega band to be taller than wider and that the omega band propagated eastward. We found 458 omega-like structures in total, most of them at the southern part of the auroral oval, in the field-of-view of Sodankyla camera. All the omegas occurred after a substorm onset and most of them during a recovery phase. The substorms with omega bands were found to be more intense than average substorms within the Lapland region. Furthermore, the omega occurrence rate peaked between 2002 and 2004 during the declining phase of the solar cycle. The omega band wave-like undulation was observed not only in the optical data but also in the equivalent current distribution. Omega forms occurred in between the Region 1 and 2 currents near the diffuse aurora boundary, and within a westward electrojet current, which appeared stronger than that of average substorm westward electrojet in the Lapland region. For a small fraction of the omega band events near conjugate spacecraft data were available and these data showed fast Earthward flows in the magnetotail except for one event that displayed no high speed flows. We discuss a possible scenario of omega formation and the relative occurrence of the omega bands.

Statistical properties of substorm auroral onset beads/rays

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Auroral substorms are often associated with optical ray or bead structures during initial brightening (substorm auroral onset waves). Occurrence probabilities and properties of substorm onset waves have been characterized using 112 substorm events identified in THEMIS all-sky imager data, and compared to Rice Convection Model-Equilibrium (RCM-E) and kinetic instability properties. Case studies were also performed with the conjugate THEMIS satellites in the plasma sheet. All substorm onsets were found to be associated with optical waves, and thus optical waves are a common feature of substorm onset. Eastward-propagating wave events are more frequent than westward-propagating wave events, and tend to occur during lower-latitude substorms (stronger solar wind driving). The wave propagation directions are organized by orientation of initial brightening arcs. We also identified notable differences in wave propagation speed, wavelength (wavenumber), period and duration between westward and eastward propagating waves. In contrast, the wave growth rate does not depend on the propagation direction or substorm strength but is inversely proportional to the wave duration. This suggests that the waves evolve to poleward expansion at a certain intensity threshold, and that the wave properties do not directly relate to substorm strengths. However, waves are still important for mediating the transition between the substorm growth phase and poleward expansion. The relation to arc orientation can be explained by magnetotail structures in the RCM-E, indicating that substorm onset location relative to the pressure peak determines the wave propagation direction. The measured wave properties agree well with kinetic ballooning interchange instability, while cross-field current instability and electromagnetic ion cyclotron instability give much larger propagation speed and smaller wave period.

The ionosphere as ginormous particle detector

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The formation of plasma beams is a ubiquitous consequence of energy propagation through a magnetized plasma. Within geospace, the beam energy is ultimately dissipated as heat, light, ionization, and turbulence in the outer atmosphere. Careful observation of the combined response provides a remarkably versatile remote sensing diagnostic for the location and mechanism of particle energization. This paper reviews recent research on beam-ionosphere interactions, with application to understanding space-time dynamics of the disturbed magnetosphere. Select case studies involving collaborative measurements from space (predominently using the THEMIS constellation) and ground (PFISR/RISR and collocated auroral imaging systems) have been used to investigate the partitioning of beam energization mechanisms during reconnection and substorm intervals. The results shed light on the nature of energy transfer in the geospace system.

TREx - an ASI and Riometer network designed to take THEMIS-ASI 'to the next level

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THEMIS-ASI has had a transformative impact on our understanding of geospace dynamics. With time sequences of mosaics stitched together from images from multiple ASIs with overlapping fields of view, used in coordination with in situ data from THEMIS and other missions, we have discovered new modes of coupling in geospace, brought ourselves tantalizingly close to understanding the substorm onset mechanism, and significantly advanced our understanding of the aurora. This has been a fantastic program, but there are limitations. Because the images are panchromatic (white light), and the cadence is 3 seconds, we lack information on the energy of the precipitating electrons, and things that happen on the second timescale are just out of our view.

TREx is a newly funded Canadian network designed to add new capabilities on top of THEMIS-ASI to address the lack of energy information and the 3 (6) second limit on temporal resolution. TREx is is being deployed over the next two years, and will consist of six optical imaging stations, each having four ASIs. These will be a full color equivalent to a THEMIS-ASI, and three narrow-band imagers targeting emissions in the near infrared (NIR), blueline (N2+), and redline (630 nm). The combined field of view will also be covered by ten imaging riometers. The riometers, NIR, and full-color ASIs and the imaging riometers will operate at 3 second cadence, timed with THEMIS-ASI, and the blueline ASIs will image at up to 30 Hz. The observational objective is to create two-D, time-evolving maps of characteristic energy, total energy flux, and time frequency domain information up to 15 Hz.

In this talk I will outline the scientific developments that led us to recognize the need for TREx, and outline some of the exciting science we believe this new facility will support.

Determination of dynamics of turbulence upstream and downstream of the Earth's Bow shock, using Cluster measurements

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Collisionless shocks (CS) are often accompanied by turbulence both upstream and downstream of the main ramp. This turbulence is closely related with the formation of the shock and therefore with the dissipation of solar wind flow to thermal energy. In order to understand the relation of these waves to to CS, we first need to determine their origin and dynamics.

Multi-spacecraft measurements can be used in combination with time and frequency techniques, in order to determine the propagation direction of these waves and their non-linear dynamics. The Cluster close separation campaign allows the investigation of waves with smaller wavelengths, using time and frequency domain techniques.

Magnetic field measurements will be examined in the two regions on each side of the main ramp of the Bow Shock. The propagation vector magnitude and direction will be determined along with the non-linear dynamics of the waves.

Rapid changes in the solar wind proton velocity distribution function observed with CIS

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The collisionless nature of the solar wind plasma, as well as the ability to support a number of waves and coherent structures, give rise to a number of non-Maxwellian features in the velocity distribution function. Using observations of the full three dimensional distributions from the Cluster Ion Spectrometer the VDF is seen to change significantly on timescales of minutes. In some instances double cores of the velocity distribution function can be seen. Using wavelet analysis the properties of the magnetic field fluctuations (coherency, phase, power) can be obtained at the instant the VDF is sampled. Additionally multi-spacecraft timing can also help characterise fluctuations and determine whether coherent structures contribute to the shape of the VDF.

Variability of the electron power spectrum in the solar wind

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At sub ion scales the slope and morphology of the turbulence power spectrum is a topic of open debate. A short interval of solar wind magnetic field data sampled at 450Hz by Cluster's Staff instrument when in burst mode show the presence of sporadic short duration energetic events, which last for a few seconds within a minute interval. Wavelet coherence and phase between components in the plane perpendicular to the magnetic field suggest that these fluctuations are whistler waves. Although they only cover make upt 10% of the time they are clearly visible in the global power spectral density. Electron distributions sampled show the presence of two beams during the most intense emission. The source of these fluctuations is unclear since the electron moments suggest the plasma is stable with respect to the whistler anisotropy instability and the electron heat flux instability.

Turbulence in the terrestrial foreshock: Multipoint observations

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Many linear and non-linear processes connected with a reflection of solar wind particles take place in a foreshock, the region upstream of the Earth bow shock.

When the bow shock is quasiparallel, this region can extend up to many Earth's radii. Under such condition, the incident solar wind is strongly disturbed and physical fields (velocity and magnetic fields), Q, fluctuate considerably, so that deltaQ/Q~1. These relative fluctuations of parameters are well localized, either in frequency or in space. Nevertheless, original background solar wind turbulence should be still present, maybe with a lower amplitude. Multipoint observations in the foreshock allow us to map foreshock structures from small to large spatial scales. We employ measurements of the BMSW instrument onboard the Spektr-R spacecraft with a 32 ms resolution of the ion flux, density, and bulk and thermal speeds and compare the results of their spectral analysis with a similar analysis in the pristine solar wind (Wind at ~ 1 AU) and with observations of the spacecraft orbiting near the Earth (Cluster, THEMIS).

Magnetic Curvature Analysis on Kelvin-Helmholtz Waves: a MHD Simulation Study

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Four-spacecraft missions are probing the Earth's magnetospheric environment with high potential for revealing spatial and temporal scales of a variety of in-situ phenomena. Magnetic curvatures are intrinsic to curved magnetic fields where the magnetic energy is stored in the form of magnetic tension. In-situ magnetic curvatures have been resolved by the four-spacecraft technique called 'magnetic curvature analysis' (MCA). The MCA technique has been used in various plasma structures identified as current sheets, plasmoids, and magnetic reconnection diffusion regions. We investigate the robustness of the method to interpret applications in the real data. Here, for the first time, we test the MCA on a 2.5D MHD simulation of curved magnetic structures induced by Kelvin-Helmholtz (KH) waves. Increasing (regular) tetrahedron sizes of virtual spacecraft are used to measure the curvatures of KH vortices. We investigate the magnetopause curvature for two main locations of KH vortex and we produce time series corresponding to these positions (for static spacecraft in the boundary layers). We have found variations of the curvature vectors both in radii and orientations depending on the sizes of the tetrahedron. This is helpful to better understand the MCA measures when the technique is applied to in-situ data without knowing the scale sizes of plasma structures under consideration. This study lends support for cross-scale

observations to better understand the nature of curvature and its role in plasma phenomena.

Kelvin-Helmholtz wave at the subsolar magnetopause boundary layer under radial IMF

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We present the first observation of the Kelvin-Helmholtz (KH) rolled-up vortex at the dayside magnetopause layers under a radial interplanetary magnetic field (IMF). The study uses measurements of four THEMIS probes aligned along the Y axis about 10 Re upstream of the Earth and located in different regions of the near-Earth environment. THEMIS C and A serve as monitors of the quiet solar wind and fluctuating magnetosheath conditions, respectively, and THEMIS D and E observe the magnetopause and low-latitude boundary layer (LLBL) crossings. The analysis shows: (1) a radial IMF changes to the southward pointing magnetosheath magnetic field; (2) dayside reconnection forms the thin but dense LLBL; (3) a large velocity shear at the LLBL inner edge excites a train of KH waves; and (4) in spite of a short path from the subsolar point (5 Re), one of KH waves exhibits all features of a fully developer rolled-up vortex.

Shape of the dayside equatorial magnetopause

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A magnetopause location is generally believed to be determined by the solar wind dynamic pressure and by a sign and value of the interplanetary magnetic field vertical (Bz) component. The contribution of other parameters is usually considered to be minor or negligible near the equatorial plane. A great majority of present magnetopause models describes the magnetopause shape with an ellipsoid or paraboloid of revolution. The axis of such surface usually reflects the Earth orbital motion around the Sun. Ten years of magnetopause observations near the

equatorial plane by the THEMIS spacecraft allow to tests of this description and facilitates search for a better approximation of the magnetopause shape. We present a statistical study based on more than 10.000 magnetopause crossings identified in the THEMIS data. The study accounts for the dependence of the magnetopause location on the upstream solar wind dynamic pressure and expects that all other effects can be averaged. The study suggests a very simple expression for the shape of the dayside magnetopause and examines the influence of interplanetary magnetic field and solar wind parameters on this shape. The effects of the magnetospheric current systems are discussed.

New tools for multi-mission data analysis with Cluster: SPEDAS, OVT and CSA 2.0

Helen Middleton, Arnaud Masson and the CSA Development Team

ESAC, Madrid

The Cluster Science Archive (CSA) is the long term data repository of all best-quality Cluster data for the scientific community. It is held and managed at ESAC, Madrid and is continuously updated (currently at ~100 TB). Two methods currently exist to access these data: through the command line (scripts, etc) and through a Java graphical user interface (GUI). While most data is downloaded via the command line, the GUI offers many extras to quickly browse data, like on-demand and pre-generated graphical products, particle distribution functions and data inventory plots. A substantial amount of documentation is available for the community to best use the various datasets offered (cosmos.esa.int/csa).

For data visualization, the Space Physics Environment Data Analysis Software (SPEDAS) enables Cluster data to be displayed alongside that of MMS, THEMIS, Van Allen Probes and soon, ERG. SPEDAS is a framework able to download and visualise in particular CDAWeb data which includes Cluster data in CDF for spin resolution (FGM data are available up to summer 2016) and WBD; prime parameters for all the other datasets. The inclusion of all best-resolution CSA data within CDAWeb is on-going.

A new version of the 3D Orbit Vizualisation Tool (OVT) was released in April 2016. Developed by IRF (Uppsala, Sweden), it now enables 3D visualisation of simultaneous orbits and magnetic footprints from various satellites, thanks to a direct link to the NASA's Satellite Situation Center. This allows users to find conjunctions and suitable overlapping datasets in context.

CSA 2.0 is currently in development, expected to be released to the public in 2017. It consists of a web interface which doesn't require a program to be downloaded anymore; it will work directly from any browser. This crisp, clean, new interface will offer all the currently available services plus more, including a Data Mining search tool. This tool will allow data to be found not only by time periods but also by physical parameters and region-specific criteria.

Correcting the RAPID Imaging Electron Spectrometer data set for long-term sensitivity decrease

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The Cluster mission has been operational for more than 16 years. Analysis of long-term data sets from the RAPID instrument show signs of degraded sensitivity over recent years in the 3D data from the Imaging Electron Spectrometer (IES). This degradation is a relative effect seen when comparing the 9 detectors of IES, each looking into different polar direction and covering an angle of 20 degrees. This effect is a nearly symmetric decrease of sensitivity as a function of detector number so that the middle detectors are affected the most. This long-term decay started in 2007 in all the four RAPID instruments with a drop in sensitivity of detectors 2-8 compared to detectors 1 and 9 (the latter two are looking almost parallel and anti-parallel to the spin axis). This decreasing trend stabilized in 2009-2010 followed by another drop in 2012.

Here we present the results of the process of determining correction factors for the relative long-term effect. Using burst mode data, the correction factors have been determined independently for each energy channel and detector (2-8) relative to the mean level of detectors 1 and 9 which are considered as a baseline. We have validated the corrected data set using a collection of all E2DD6 data (nominal mode, 9 polar directions and 6 energy channels) above the radiation belts (>7 Re), so that each data point in our analysis is the average differential flux over one orbit and one energy channel. The corrected data set will be available in the Cluster Science Archive in the near future.

Statistical survey of quasi-periodic VLF emissions observed in the inner magnetosphere conjugated with geomagnetic field fluctuations measured on the ground.

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We present a comparison between properties of quasiperiodic (QP) ELF/VLF emissions observed by the low-altitude DEMETER spacecraft and ULF geomagnetic field pulsations measured on the ground by the THEMIS/CARISMA (Canadian Array for Realtime Investigations of Magnetic Activity) system of flux-gate magnetometers and by the Sodankyla Geophysical Observatory (SGO) magnetometer. We have selected for analysis about 400 QP DEMETER events which were conjugated with ground-based stations. The analyzed QP events have modulation periods larger than 10 s and frequency bandwidths higher than 200 Hz.

A good agreement between modulation periods of QP emissions and frequencies of the most intense fluctuations of ULF pulsations has been found for QP events with modulation periods larger than 40 s. Such QP emissions which appear to be closely associated with coincident geomagnetic pulsations are called QP1, representing about 18 percents of the total number of analyzed QP events. No corresponding geomagnetic pulsations were identified in the remaining 82 percents of QP events, and these events are classified as QP2. The maximum spectral intensity of QP1 events does not seem to depend on the intensity of geomagnetic field fluctuations while QP2 events intensity is increasing with integral intensity of the geomagnetic field fluctuations at frequencies 10 - 500 mHz. The intensity of geomagnetic field disturbances gradually increases with invariant geomagnetic latitudes during QP emissions of both types. However, in the case of QP2 type, a rapid rise of geomagnetic field fluctuations was observed in the latitude range of 60 to 65 degrees.

Based on the observed association between QP emissions and geomagnetic field disturbances, we attempt to estimate the spatial extent of the QP emissions and we discuss the effect of ULF pulsations of different origin on QP1 emissions in the magnetosphere.

Multipoint observations of long-lasting Pc4 pulsations in the dayside magnetosphere

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We use magnetic field and plasma observations from the Van Allen Probes, THEMIS and GOES spacecraft to study the spatial and temporal characteristics of long-lasting poloidal Pc4 pulsations in the dayside magnetosphere. The most striking feature of the Pc4 pulsations was their occurrence at similar locations during successive orbits. We used this information to study the latitudinal nodal structure of the pulsations and demonstrated that the latitudinal extent of the magnetic field pulsations did not exceed 2 Earth radii (RE). We found no direct relationship between the plasmapause and the long-lasting Pc4 pulsations. We demonstrated that the latitudinal nodal extent of the magnetic field pulsations did not exceed 2 RE. We investigated the spectral structure of the Pc4 pulsations. We found that the dominant periods in the spectra depended on orbit and radial distance.

Influence of a guide BY field on the magnetotail current sheet structure and particle dynamics

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The magnetotail Current Sheet (CS) plays a key role in the dynamics of the Earth magnetosphere. Usually, the magnetic field lines, crossing the magnetotail equatorial plane, have a normal component BZ due to the Earth's dipole field and a smaller component along the dawn-dusk direction, BY. Sometimes, however, the BY component in the magnetotail CS becomes significant A strong BY field can shear the magnetic field of the CS making the CS thin and causing a cross-tail field-aligned current, influencing the adiabaticity and orbits of charged particles in the CS, that, in turn, may affect the CS structure and stability. Thus, it is important to know the spatial distribution of the BY field across the CS as well as the characteristic scale of the CS region where this component dominates. This knowledge is tightly connected with the understanding of mechanisms, which are responsible for the strong BY

field generation in the magnetotail CS.

The BY component in the magnetotail may exist due to the direct penetration of the interplanetary magnetic field (IMF). However, at some periods the strength of the BY component can be enhanced at the center of the CS relative to that in the CS boundaries, so that the spatial profiles of the BY component along the north-south direction have a 'bell-like' shape. The mechanism of the BY field enhancement in the center of the CS is still debated.

In this work we performed test ion simulations in a thin CS with the initially small guide BY field originated from the IMF BY penetration into the magnetotail. We show the possibility of the BY field enhancement in the center of the CS and formation of a 'bell-shaped' BY field profile due to the influence of the nonadiabatic ions on the CS structure. We also discuss the kinetic features of the nonadiabatic ion dynamics leading to the enhancement of the core BY field in the CS of plasmoids.

Substructures within a dipolarization front revealed by high-temporal resolution Cluster observations

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The Dipolarization Front (DF), usually observed near the leading edge of a Bursty Bulk Flow (BBF), is thought to carry an intense current sufficient to modify the large-scale near-Earth magnetotail current system. However, the physical mechanism of the current generation associated with DFs is poorly understood. This is primarily due to the limitations of conventional plasma instruments which are unable to provide a sufficient number of unaliased 3D distribution functions on the timescale of the DF, which usually travels past a spacecraft in only a few seconds. It is thus almost impossible to unambiguously determine the detailed plasma structure of the DF at the usual temporal resolution of such instruments. Here we present detailed plasma measurements using the Cluster PEACE electron and CIS-CODIF ion data for an event during which it was possible to observe the full pitch angle distribution at a cadence of 1/4 second. The observations clearly show details of plasma sub-structure within the DF, including the presence of field-aligned electron beams. In this event, the current density carried by the electron beam is much larger than the current obtained from the curlometer method. We also suggest that the field-aligned current around the DF obtained from the curlometer method may have been misinterpreted in previous studies. Our results imply that the nature

of the DF current system needs to be revisited using high resolution particle measurements, such as those observations shortly to be available from the Magnetospheric Multiscale (MMS) mission.

Temporal and spatial evolution of magnetotail dipolarization fronts in the near-Earth plasma sheet

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Dipolarization fronts (DFs) play a crucial role for the energy and magnetic flux transport in the magnetotail. They are characterized by a rapid increase in the northward magnetic field component perpendicular to the current sheet (Bz), which is typically preceded by a transient decrease, the Bz-dip. We present a statistical study on the temporal/spatial evolution of the DFs and their Bz-dips as they propagate Earthward. We use magnetotail observations from the Magnetospheric Multiscale (MMS) mission during the commissioning phase when MMS had a string-of-pearls configuration at radial distances within 12 Re and inter-spacecraft distances of 100 km. This particular spacecraft constellation enables us to study the temporal/spatial evolution of DFs on a small scale in the near-Earth plasma sheet. The main aim of this study is to reveal the evolution of DFs closer to the flow braking region, in order to better understand the magnetic flux transport in the magnetotail.

Comparing and contrasting dispersionless injections at geosynchronous orbit during a substorm event

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Particle injections in the magnetosphere transport electrons and ions from the magnetotail to the radiation belts. Here, we consider generation mechanisms of ``dispersionless'' injections, namely those with simultaneous increase of the particle flux over a wide energy range. In this study we take advantage of multi-satellite observations which simultaneously monitor Earth's magnetospheric dynamics from the tail towards the radiation belts

during a substorm event. Dispersionless injections occur at the substorm growth phase associated with instabilities in the plasma sheet and at the onset/expansion phase associated with multiple dipolarization fronts. They show different spatial spread and the propagation manner. At the distance for geosynchronous orbit (6.6 RE), the electron distributions do not have a classic power law fit but instead a bump-on-tail centered on ~120 keV during dispersionless electron injections. However, electron distributions of injections associated with dipolarizations in the magnetotail (13 RE) do not show such a signature. We surmise that an additional resonant acceleration occurs in-between these locations. We relate the acceleration mechanism to the electron drift resonance with ultralow frequency (ULF) waves localized in the inner magnetosphere.

IMF dependence of energetic oxygen and hydrogen ion distributions in the near-Earth plasma sheet

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Energetic ion distributions in the near-Earth plasma sheet can provide important information for understanding the entry of ions into the magnetosphere, and their transportation, acceleration, and losses in the near-Earth region. In this study, 11 years of energetic proton and oxygen observations (> ~100 keV) from Cluster/RAPID were used to statistically study the energetic ion distributions in the near-Earth plasma sheet. The dawn-dusk asymmetries of the distributions in three different regions (dayside plasma sheet, near-Earth nightside plasma sheet, and tail plasma sheet) are examined in northern and southern hemispheres. Results show that the ion distribution asymmetries in the plasma sheet are highly dependent on the IMF clock angle. The dawn-dusk asymmetries seem to be determined by location of magnetic reconnection at the magnetopause for both northern and southern hemispheres. The results give an implication that the source of energetic ions (higher than a few hundred keV) in the near Earth plasma sheet can be the cusp and/or quasi-parallel bow shock and not only the substorm-related processes in the

magnetotail. We show that the influence of the IMF clock angle on the distributions of the energetic protons and oxygen in the near-Earth plasma sheet should not be neglected in modeling.

A multi-satellite survey of convection in the terrestrial magnetotail

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We have collated over 20 years of magnetic field, electric field, and velocity data from the Geotail, Cluster, Double Star, and Themis spacecraft missions to elucidate large-scale patterns in the terrestrial magnetotail. We are specifically investigating the time-dependence of the convection on various IMF conditions. Investigations may lead to useful insights into magnetotail-ionsopheric coupling and the effect of convection on processes such as magnetic reconnection and substorm development.

The connection between small scale polar cap arcs and the LLBL

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High-latitude auroral arcs or polar cap arcs (PCA) consist in thin and elongated optical emission similar to discrete auroral arcs but located in the polar ionosphere. On November 10, 2005, high-latitude arcs were detected by an all-sky camera at Resolute Bay in Canada and by the TIMED/GUVI and DMSP/SUSSI space-based imagers. During this period, several PCAs were detached from the duskside oval and moved poleward while pointing in the cusp direction. On the same day, the Cluster spacecraft were flying in the dawn-dusk direction from the lobe region at altitudes around 5 RE to the duskside magnetopause. Cluster observations reveal the

presence of field-aligned acceleration regions above the polar ionosphere associated with the high-latitude arcs detected by the imagers.

We analyze Cluster particle observations from the lobe region to the duskside magnetopause. Above PCAs, Cluster detects upgoing ions and precipitating electrons accelerated by a quasi-static electric field. These accelerated particles coexist with a warm isotropic ion population embedded in the lobe region. The most equatorward arc is separated from the auroral oval by a transition region where weak fluxes of ions with plasmasheet-like temperatures are detected. Then the Cluster spacecraft cross the plasmasheet until they reach the low-latitude boundary layer (LLBL) characterized by a mixture of plasmasheet and magnetosheath plasma. The transition region and the LLBL are magnetically connected. Using Cluster observations we show that these two regions display many similar features which suggest that the origin of high-latitude auroral arcs may be related to processes occurring in the LLBL during periods of northward.

North-south asymmetries in cold ion outflow and lobe density.

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A significant fraction of the plasma in the terrestrial magnetosphere is supplied by the high latitude ionosphere. The transport path from the ionosphere to the magnetotail goes through the magnetotail. In this presentation, we show observations indicating a persistant interhemispheric asymmetry in ion outflow and lobe refilling: Around equinox, the cold plasma density in the northern hemisphere lobe is consistently higher than the southern lobe. We infer that differences in outflow from the polar cap ionosphere is the most likely explanation. Solar wind-magnetosphere interactions and daily and seasonal variations in the Earth's are known to set up asymmetries in ion outflow, but the persistent asymmetries reported here are probably related to non-dipolar terms in the Earth's internal magnetic field and/or time-lagged responses in thermospheric properties.

Solar zenith angle dependency, seasonal variations and N-S asymmetry of the polar wind

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The polar wind is an important process through which ions escape from the ionosphere and a significant source of plasma for the magnetospheric lobes and plasma sheet. Since solar illumination is the main driver of the polar wind, one would expect that the solar zenith angle of the ionospheric origin to have a strong control on the outflowing fluxes. Due to the inclination of Earth's rotational axis, and the offset of the magnetic dipole axis, the average solar zenith angle of the polar ionosphere varies on a daily and seasonal basis. Therefore the outflowing ion fluxes from the polar caps should exhibit similar variations. Moreover, Earth's magnetic field is asymmetric between the northern and southern hemisphere, which means the south magnetic pole has a larger offset from the rotational axis than the north magnetic pole.

The ions in the polar wind are difficult to measure at high altitudes, however, because they typically have too low energies to overcome the potential caused by the charge acquired by a satellite flying in these regions. An alternative method uses the two electric field experiments aboard the Cluster satellites to estimate the ion fluxes from the spacecraft potential and the wake formed behind the charged spacecraft. A dataset compiled by Andre et al. [2015], using this method and consisting of measurements over 10 years, is used in this study to investigate the solar zenith angle control of the ion outflow from the polar cap, as well as its seasonal variations and possible north-south asymmetries