Obesrvations of strong plasma enhancement at the dawn terminator by the MMS

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At the dawn terminator (~6 am MLT) the four MMS spacecraft detected several significant plasma enhancements accompanied by strong plasma acceleration. The strongest event was captured by MMS in burst mode (30 ms for electron and 150 ms for ions). The number density abruptly increased from typical magnetospheric background values, ~1 cm^{-3}, up to 50-60 cm^{-3}. The solar wind parameters corresponding to these observations are quite stable without any sharp changes, therefore there is no apparent solar wind driver that is responsible for these injections. The estimated distance from the nominal magnetopause to the spacecraft was ~3 R_E and the data does not show characteristics of multiple magnetopause crossings. We combine the MMS observations with results of global MHD simulations to understand which one of several possible scenarios might explain MMS observations: either set of the Flux Transfer Events (FTE) resulting from the dayside reconnection or earthward-propagating dipolarization fronts caused by the tail reconnection.

Keywords: Reconnection, FTE

CLUSTER and MMS missions : Estimation of the gradient of a field with a flattening tetrahedron

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The ESA mission CLUSTER, successfully launched in 2000 has been the first one to involve four identical spacecraft orbiting simultaneously around the Earth in order to provide a three dimensional view of plasma processes with inter-spacecraft distances varying from a few tens to a few thousands of kilometers. CLUSTER is going on and has already demonstrated the impressive benefit of simultaneous multipoint observations; its success has triggered new projects like the NASA MMS mission, launched in 2014, which is currently investing shorter scales than CLUSTER. For not too large inter-spacecraft distances, multi-spacecraft data analysis methods have been developed to estimate gradients of fields : see the detailed presentations in two ISSI books [1,2]. It has been demonstrated by Chanteur [3] that estimated gradients are spoiled by large errors when the tetrahedron of spacecraft flattens, which occurs twice per orbit and sometimes during “interesting” time intervals. Shen et al. [4] proposed to estimate gradients under such difficult configurations by making use of the principal axes of the inertia tensor of the configuration of the cluster : that solves the problem only partially, but the divergence remains along the normal to the plane of the singular “flat” tetrahedron. We have designed a rigorous analysis of the flattening tetrahedron by making use of a frame of reference attached to the tetrahedron which allows to estimate all components of the gradient, avoiding any divergence but nonetheless the estimated gradient is affected by the geometrical amplification of errors due to the flattening.

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Keywords: magnetospheric physics, multi-spacecraft data analysis, reciprocal vectors of a tetrahedron

Investigation of the magnetic neutral line region with the frame of two-fluid equations: A possibility of anomalous resistivity inferred from MMS observations

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Magnetic reconnection is a basic physical process by which energy of magnetic field is converted into the kinetic energy of plasmas. In recent years, MMS mission consisting of four spacecraft has been conducted aiming at elucidating the physical mechanism of merging the magnetic fields in the vicinity of the magnetic neutral line that exists in the central part of the structure. In this paper, we examine the magnetic field frozen-in relation near the magnetic neutral line as well as the causal relationship between electron and ion dynamics in the frame of two fluid equations.

It is thought that the electron dissipation region with the thickness of about the electron inertial length surrounds the magnetic neutral line, and the ion dissipation region with the thickness of about the ion inertia length further surrounds them. Theoretically, it is shown that electrons are frozen-in to the magnetic fields while ion’s frozen-in relation is broken in the ion dissipation region. However, when we examined the observational data around 1307 UT on October 16, 2015 when MMS spacecraft passed through the vicinity of the magnetic neutral line [Burch et al., Science 2016] , it was confirmed that the frozen-ion relation was not established for electrons in the ion dissipation region. In addition, we found that intense wave electric fields in this region. From the spectral analysis of the waves, it turned out that their characteristic frequencies are the lower-hybrid and electron cyclotron frequencies.

In the framework of the two-fluid equation, we can evaluate the values of each term of the equations of motion for both ions and electrons except for the collision term from MMS spacecraft data. Therefore, it is possible to obtain collision terms for both species. Since magnetospheric plasma is basically collisionless, it is considered that the collision term is due to anomalous resistivity associated with the excited waves . On the other hand, in the usual two-fluid equation system, the two vectors corresponding to the collision terms of ions and electrons have the same absolute value. Because the force exerted between the two is the internal force, they should face exactly in the opposite direction. However, the vectors corresponding to the collision terms obtained by using the actual data did not satisfy such a condition. One of the possible reasons is that the momentum carried by the waves cannot be neglected. Another possibility is that, such a discrepancy is caused by measurement error of each physical quantity.
After careful examination, we conclude that the effect of the anomalous resistivity in the ion dissipation region acts to some degree that cannot be ignored in the equation of motion of the two-fluid system.

Keywords: MMS mission , two fluid equation, magnetic reconnection, plasma waves, anomalous resistivity

Currents and associated electron scattering and bouncing near the diffusion region at Earth’ s magnetopause

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Based on high-resolution measurements from NASA’ s Magnetospheric Multiscale mission, we present the dynamics of electrons associated with current systems observed near the diffusion region of magnetic reconnection at Earth’ s magnetopause. Using pitch angle distributions (PAD) and magnetic curvature analysis we demonstrate the occurrence of electron scattering in the curved magnetic field of the diffusion region down to energies of 20 eV. We show that scattering occurs closer to the current sheet as the electron energy decreases. The scattering of inflowing electrons, associated with field-aligned electrostatic potentials and Hall currents, produces a new population of scattered electrons with broader PAD which bounce back and forth in the exhaust. Except at the center of the diffusion region the two populations are collocated and behave adiabatically: the PAD of inflowing electrons focuses inward (towards lower magnetic field), while the bouncing population gradually peaks at 90° away from the center (where it mirrors owing to higher magnetic field and probable field-aligned potentials).

Keywords: Reconnection, Electrons, Plasma

Inverse Energy Dispersion of Energetic Ions Observed in the Magnetosheath

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We present a case study of energetic ions observed by the Energetic Particle Detector (EPD) on the Magnetospheric Multiscale (MMS) spacecraft in the magnetosheath just outside the subsolar magnetopause that occurred at 1000 UT on December 8, 2015. As the magnetopause receded inward, the EPD observed a burst of energetic (~50-1000 keV) proton, helium, and oxygen ions that exhibited an inverse dispersion, with the lowest energy ions appearing first.
The prolonged interval of fast antisunward flow observed in the magnetosheath and transient increases in the *H* components of global ground magnetograms demonstrate that the burst appeared at a time when the magnetosphere was rapidly compressed.
We attribute the inverse energy dispersion to the leakage along reconnected magnetic field lines of betatron-accelerated energetic ions in the magnetosheath and a burst of reconnection has an extent of about 1.5 R_E using combined Super Dual Auroral Radar Network (SuperDARN) radar and EPD observations.

Electron crescent distributions as a manifestation of diamagnetic drift in an electron scale current sheet: Magnetospheric Multiscale observations using new 7.5 ms Fast Plasma Investigation moments

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We report Magnetospheric Multiscale spacecraft observations of electron pressure gradient electric fields near a magnetic reconnection diffusion region using a new technique for extracting 7.5 ms electron and 37.5 ms ion moments from the Fast Plasma Investigation (FPI) data. Comparing our results to previously reported 30 ms electron and 150 ms ion FPI moments (e.g., Burch et al. Science 2016, Torbert et al. GRL 2016), we find a significant improvement in the agreement between the FPI perpendicular electron bulk velocity and the ExB drift as measured by the Electric Field Double Probes (EDP) and Flux Gate Magnetometer (FGM) instruments (averaged to the FPI data). While the 7.5 ms moments recover significant additional structure in the electron bulk velocity, no significant additional structure is observed in the 7.5 ms electron parallel or perpendicular pressure. The violation of the electron frozen flux constraint in the vicinity of the stagnation point (where electron crescent shaped velocity distributions have been previously reported by Burch et al. Science 2016) can be explained largely by the gradient of the perpendicular electron pressure perpendicular to the magnetic field. These results suggest that the electron crescent distributions are a manifestation of the electron diamagnetic drift and do not in themselves contribute to the dissipation of magnetic energy.

Keywords: diamagnetic drift, plasma moments, crescent distributions

Calibration of wave vector analysis techniques for low frequency waves detected by MMS in the terrestrial magnetosphere and magnetosheath regions

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There are certain difficulties in determining wavelengths using in-situ single-spacecraft data without assuming the dispersion relation of the waves. Wave vector analysis techniques using multi-spacecraft data have been developed after the 1990s in space science [*Neubauer and Glassmeier*, 1990; *Narita et al*., 2011]. Recent MMS mission enables us to resolve smaller wavelength in the ion kinetic range [*Narita et al*., 2016]. While the developed techniques provide the wave energy distribution in the frequency-wave vector domain with high resolution, some parameters can affect significantly on the distribution. We perform the wave vector analyses using synthetic multi-spacecraft data and investigate two parameters: the noise tolerance parameter n and degree of freedom for ensemble averaging m. The synthetic data are constructed assuming low frequency waves detected by MMS in the terrestrial magnetosphere and magnetosheath regions. We compare the results obtained by beam former projection, Capon's minimum variance projection, extended MUSIC, and MSR technique quantitatively to identify adequate parameters n and m for the target waves.

Walen and Slow-mode shock analysis of magnetopause crossings by MMS

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Magnetic reconnection is the main driving process behind phenomena like solar flares, magnetic storms and astrophysical plasma jets. The fast rate of reconnection as seen in observations was explained by Petschek’s model [1964] in MHD regime. In this model, X-line geometry with a narrow diffusion region and two pairs of slow-mode shocks helps to achieve faster reconnection than Sweet-Parker’s model [Sweet, 1958 and Parker, 1957]. On one hand, resistive Hall MHD simulations show that the quadrupole magnetic fields formed by inclusion of the Hall term achieve the X-line geometry in scale of the ion inertial length and thus fast reconnection [e.g., Drake et al., 2008].

Laboratory experiments support the importance of the Hall physics, while they have not observed the slow-mode shocks till date [Zweibel and Yamada, 2016]. However, in-situ observations in space show the existence of slow shocks on MHD scale [Feldman et al., 1987, Saito et al., 1995]. Recent studies on presence of slow-mode shocks in Earth’s magnetotail have been carried out extensively using THEMIS and Cluster data [e.g., Erikson et al., 2004]. Also, in the asymmetric reconnection at the Earth’s magnetopause, the combination of slow-mode shock and other discontinuity such as the rotational discontinuity is theoretically predicted [Levy et al., 1965, Hau and Wang, 2016] and observed [Walthour et al., 1994]. Thus, the structure and presence of slow-mode shocks seems to established on MHD scale but on ion inertial scale, it still remains controversial.

We aim to study the inside structure (on ion inertial length scale) of the slow-mode shocks. As a first step towards our final aim, we investigated the presence of slow-mode shocks and other discontinuities in Earth’s magnetopause by using Magnetospheric Multiscale (MMS) data. High time resolution of MMS data enables us to observe reconnection structure from the ion diffusion to MHD scales. The results of the Walen test and slow-mode shock analysis (Rankine-Hugoniot conditions) of magnetopause crossings by MMS are presented.

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(2016).

Keywords: MMS, Slow shock, Reconnection, Magnetopause

MMS observations of sub-ion scale magnetic holes in the magnetosheath

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Magnetic holes (MHs), structure of an observable magnetic field magnitude decrease, have been widely observed in space plasma. Spatial size of the MHs ranged from tens to thousands of proton gyroradius (ρ_i). In previous studies, these large magnetohydrodynamics (MHD) MHs were associated with mirror instabilities. In this study, we report a series of sub-ion scale magnetic holes in the terrestrial magnetosheath. The main characteristics are summarized below. 1. These structures have been observed in a scale of 10 ~ 20 ρ_e (electron gyroradii) and lasted 0.1 ~ 0.3 s. 2. The magnetic field magnitude decreases along the background direction; distinctive electron dynamics features are observed, while no substantial deviations in ion data are seen. 3. An electron flow vortex is found perpendicular to the background magnetic field. 4. Electron diamagnetic drift contributes the calculated current density. 5. For the 90° pitch angle electrons, the flux is decreases between 34 eV to 66 eV and significantly increases between 109 eV to 1024 eV. 6. Electron magnetohydrodynamics (EMHD) soliton theory is considered as a possible generation mechanism.

Keywords: magnetic hole, sub-ion scale, vortex, diamagnetic drift , MMS, soliton

