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

*Levon A Avanov[1,2], David A Mackler[3], Natalia Y Buzulukova[1,2], Danial J Gershman[1,2], Barbara L. Giles[1], John C Dorelli[1], Craig C Pollock[5], Victoria N Coffey[4], Michael O Chandler[4]

1. NASA Goddard Space Flight Center, 2. University of Maryland, College Park, MD, USA, 3. The Catholic University of America, Washington DC, USA, 4. NASA Marshall Space Flight Center, 5. Scientific Denali, Healy AK

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

*Gerard Marcel CHANTEUR[1,2,3]

1. CNRS, 2. Ecole Polytechnique, 3. UPMC

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

二流体方程式を用いた磁気中性線領域の調査：MMS衛星の観測結果による異常抵抗の可能性
Investigation of the magnetic neutral line region with the frame of two-fluid equations: A possibility of anomalous resistivity inferred from MMS observations

*小林 勇貴[1]、町田 忍[1]、北村 成寿[2]、斎藤 義文[2]、家田 章正[1]
*yuki kobayashi[1], Shinobu Machida[1], Naritoshi Kitamura[2], Yoshifumi Saito[2], Akimasa Ieda[1]

1. 名古屋大学大学院工学研究科、2. 宇宙航空開発機構　宇宙科学研究所
1. nagoya university graduate school of engineer, 2. Institute of space astronautical science, Japan Aerospace exploration agency

磁気リコネクションは、磁場のエネルギーがプラズマのエネルギーに変換される基礎的な物理過程である。近年、その中心部分に存在する磁気中性線近傍において磁場を融合させる物理メカニズムの解明を目指して、4機の衛星で構成されるMMS計画が展開されている。本研究においては、磁気中性線近傍における磁場凍結則の検証と、二流体方程式を用いた電子とイオンの動力学に関する因果関係について調べた。

運動論的な取り扱いを行うと、磁気中性線の周囲には、厚みが電子の慣性長程度の電子の散逸領域と、さらにそれを取り囲むように、イオンの慣性長程度の厚みのイオン散逸領域が存在していると考えられている。理論的には、イオンの慣性領域においてイオンの磁場凍結則が破れる一方で、電子は磁場に凍結されていることが、粒子シミュレーション等の手法によって示されている。しかし、今回、MMSが磁気中性線近傍を通過したとされる2015年10月16日1307UT付近のデータ[Burch et al., Science 2016]について調べた所、イオン散逸領域において、イオンだけでなく電子についても磁場の凍結則が成り立っていないことが確認された。また、電場、磁場の波動成分についても調べたところ、当該の領域で強い波動電場の存在が確認された。波動のスペクトル解析から、低域混成波および電子のサイクロトロン周波数を特性周波数とするものであることが判明した。

二流体方程式の枠組みでは、イオン、電子ともに、衝突項以外の項についてMMS衛星の観測から値を求めることができる。その性質を用いると、両者の衝突項をそれぞれ求めることができ、磁気圏のプラズマは基本的に無衝突プラズマであるので、その衝突項は励起された波動による異常抵抗に起因するものであると考えられる。一方、通常の二流体方程式系においては、イオンと電子の衝突項に対応する２つのベクトルは、両者の間で及ぼしあう力が内力であるために、大きさが同じで、丁度反対方向を向いているとされるが、実際のデータを用いて求めた衝突項に対応するベクトは、そのような条件を満たしていなかった。その理由としては、波動によって持ち去られる運動量が無視出来ない可能性が挙げられる。また、別の可能性として、各物理量の計測上の誤差に起因することも考えられ、それらについて検討を行い、イオン散逸領域において異常抵抗の効果が二流体運動方程式において無視出来ない程度作用していることを示唆する結論が得られた。

キーワード：MMS衛星、二流体方程式、磁気リコネクション、プラズマ波動、異常抵抗
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

*Benoit Lavraud[1], Yongcun Zhang[2], Yoann Vernisse[1], Daniel Gershman[3], John Dorelli[3,4], Paul Cassak[5], Jérémy Dargent[1], Craig Pollock[3], Barbara Giles[3], Nicolas Aunai[6], Matthew Argall[7], Levon Avanov[3], Alexander Barrie[3,8], James Burch[9], Michael Chandler[3], Li-Jen Chen[3], Ian Cohen[11], Victoria Coffey[10], Jonathan Eastwood[12], Jan Egedal[13], Stefan Eriksson[14], Robert Ergun[14], Charlie Farrugia[7], Stephen Fuselier[9], Vincent Génot[1], Daniel Graham[15], Elena Grigorenko[16], Hiroshi Hasegawa[17], Christian Jacquey[1], Issaad Kacem[1], Yuri Khotyaintsev[15], Olivier Le Contel[6], Elisabeth MacDonald[3], Werner Magnes[18], Barry Mauk[11], Thomas Moore[3], Toshifumi Mukai[17], Rumi Nakamura[18], William Paterson[3], Emmanuel Penou[1], Tai Phan[19], Amy Rager[3,20], Alessandro Retino[6], Z. Rong[21], Christopher Russell[22], Yoshifumi Saito[17], Jean-André Sauvaud[1], Stephen Schwartz[12], C. Shen[23], Suzanne Smith[4]

1. IRAP-CNRS, Toulouse, France, 2. State Key Laboratory of Space Weather, NSSC/CAS, Beijing, China, 3. NASA Goddard Space Flight Center, Greenbelt, MD, 4. University of Maryland, College Park, MD, 5. West Virginia University, WV, 6. Laboratoire de Physique des Plasmas, Palaiseau, France, 7. University of New Hampshire, Durham, NH, 8. Millenium Engineering, Arlington, VA, 9. Southwest Research Institute, San Antonio, TX, 10. NASA Marshall Space Flight Center, Huntsville, AL, 11. Johns Hopkins University Applied Physics Laboratory, Laurel, MD, 12. The Blackett Laboratory, Imperial College, London, UK, 13. University of Wisconsin, Madison, WI, 14. University of Colorado / Laboratory for Atmospheric & Space Physics, Boulder, CO, 15. Swedish Institute of Space Physics, Uppsala, Sweden, 16. Space Research Institute of the Russian Academy of Sciences, Moscow, Russia, 17. Institute of Space and Astronautical Science, JAXA, Sagamihara, Japan, 18. Space Research Institute, Austrian Academy of Sciences, Graz, Austria, 19. Space Sciences Laboratory, Berkeley, CA, 20. Catholic University of America, Washington, DC, 21. Key Laboratory of Earth and Planetary Physics, IGG/CAS, Beijing, China, 22. University of California, Los Angeles, CA, 23. Harbin Institute of Technology, Shenzhen, China

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

*Sun Hee Lee[1], David G. Sibeck[1], Kyoung-Joo Hwang[1,2], Yongfu Wang[3], Marcos V. D. Silveira[1], Mei-Ching Fok[1], Barry Mauk[4], Cohen J. Ian[4], Mike Ruohoniemi[5], Naritoshi Kitamura[6], Jim Burch[7], Barbara Giles[1], Roy Torbert[8], Christopher T. Russell[9], Mark Lester[10]

1. NASA Goddard Space Flight Center, 2. Goddard Planetary and Heliophysics Institute, University of Maryland, Baltimore County, Baltimore, MD 21228, USA., 3. Institute of Space Physics and Applied Technology School of Earth and Space Sciences, Peking University, Beijing 100871, China, 4. The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723, USA., 5. Bradley Department of Electrical and Computer Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA., 6. Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA) 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, Japan., 7. Southwest Research Institute, San Antonio, TX, USA., 8. University of New Hampshire, Durham, NH, USA., 9. University of California, Los Angeles, CA, USA., 10. Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH, United Kingdom.

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

*Amy Catherine Rager[1], John Dorelli[2], Daniel J Gershman[2,3], Jan Egedal[4], Roy Torbert[5], James L Burch[6], Robert Ergun[7], Levon A Avanov[2,3], Conrad Schiff[2], Barbara L Giles[2], William R Paterson[2], Craig J Pollock[8], Robert Strangeway[9], Christopher T Russell[9], Benoit Lavraud[10], Victoria Coffey[11], Yoshifumi Saito[12]

1. Catholic University of America, 2. NASA Goddard Space Flight Center, 3. University of Maryland, 4. University of Wisconsin, 5. University of New Hampshire, 6. Southwest Research Institute, 7. University of Colorado Boulder, 8. Denali Scientific, 9. University of California, 10. Research Institute in Astrophysics and Planetology, 11. NASA Marshall Space Flight Center, 12. Institute for Space and Astronomical Science

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

*津川 靖基[1]、加藤 雄人[2]、寺田 直樹[2]、町田 忍[1]
*Yasunori Tsugawa[1], Yuto Katoh[2], Naoki Terada[2], Shinobu Machida[1]

1. 名古屋大学宇宙地球環境研究所、2. 東北大学大学院理学研究科
1. Institute for Space-Earth Environmental Research, Nagoya University, 2. Department of Geophysics, Tohoku University

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

*Nehpreet Kaur Walia[1], Kanako Seki[1], Masahiro Hoshino[1], Naritoshi Kitamura[2], Yoshifumi Saito[2], Shoichiro Yokota[2], Craig J Pollock[3,4], Barbara L Giles[4], Thomas Earle Moore[4], Roy B Torbert[5], Christopher T Russell[6], James L Burch[7]

1. UTokyo, 2. ISAS/JAXA, 3. Denali Sci., 4. NASA GSFC, 5. UNH, 6. UCLA, 7. SwRI

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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Keywords: MMS, Slow shock, Reconnection, Magnetopause

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

*Shutao Yao[1], Quanqi Shi[1]

1. Shandong Provincial Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, Institute of Space Sciences, Shandong University, Weihai, China

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