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Magnetospheric Physics in China: 2012–2014

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ABSTRACT

In the past two years, many progresses have been made in magnetospheric physics by using the data of Double Star Program, Cluster, THEMIS and RBSP missions, or by computer simulations. This paper briefly reviews these works based on papers selected from the 126 publications from March 2012 to March 2014. The subjects cover various sub-branches of magnetospheric physics, including geomagnetic storm, magnetospheric substorm and magnetic reconnection.

KEY WORDS

Magnetospheric physics, Cluster, Double Star, Themis

1 Geomagnetic Storms

To investigate the magnetospheric energetics during magnetic storms, Li *et al.*[1] performed a statistical survey of 307 geomagnetic storms between 1995 and 2009. For the purpose of getting a detailed understanding of the energy processes, they conducted study of storm-time energetics for three time durations: the main phase, the recovery phase, and the total storm period. They found that the partition of the energy dissipation via the ring current injection and high-latitude ionospheric dissipation is controlled by the storm intensity. The proportion of the ring current injection increases linearly as the storm intensity increases for all three time durations. For moderate storms, the high-latitude ionospheric dissipation is dominant, with only ~30% energy dissipated via the ring current; whereas for superstorms, the ring current injection becomes dominant, with ~70% energy dissipated via the ring current. They also confirmed the essential and crucial role of the total energy input into the magnetosphere during the main phase in controlling the storm intensity. The total energy input during the main phase is directly proportional to the storm intensity. Their correlation efficiency is as high as 0.85. The coupling efficiency indicates an exponential decay as the storm intensity increases, with the coupling efficiency during the main phase less than that during the recovery phase.

A substorm dispersionless injection event observed during the storm recovery phase on 11 March 1998 at geosynchronous orbit is carefully studied. The event shows the notable characteristics that for energetic ions the flux enhancement ratio before and after injection increases and remains elevated with increasing energy, while for energetic electrons it tends to decrease with increasing energy. In order to explain the unique injection feature, He *et al*.[2] proposed a possible mechanism that velocity space diffusion in common to electric acceleration adjusts the particle injection state. Spectral characteristics of four different phases (pregrowth phase, the growth phase, the substorm expansion phase, and the recovery phase) have been investigated. The differential fluxes of electrons from 50 keV to 1.5 MeV and ions from 50 keV to 1.2 MeV measured by Synchronous Orbit Plasma Analyzer (SOPA) instrument onboard LANL satellite 1991–080 are found to be best fitted with the three-parameter kappa distribution function. The evolutions of the three parameters in the above kappa distribution in different substorm phases have been depicted for both electrons and ions. The results indicate that the different species of particles exert different velocity space diffusion processes so that their flux enhancement ratios before and after injection are rather different. This implies that not only electric field acceleration, but also velocity space diffusion plays a very important role in the particle injection.

Using the data of the DEMTER satellite during the magnetic storm on 14 April 2006, Zhima *et al*.[3] study the storm time VLF electromagnetic waves, and find the first observational evidence of penetration of high-latitude chorus into the plasmasphere. During this geomagnetic storm, “banded” emissions of a few hertz to 20 kHz are observed to be intensified and to be organized in the frequency range of 0.1–0.5 f_{ce} (equatorial electron cyclotron frequency) in high-latitude region of magnetic latitude between ~40° and ~60°. The signatures in the wave power spectra suggest that these emissions are likely lower-band chorus. The observed chorus waves are generally outside the plasmasphere. However, interestingly, these waves are observed inside the plasmasphere at regions with low L value during the main phase and early recover phase, which has never been reported in previous studies of chorus in low-latitude regions.

Furthermore, Zhima *et al*. [4], staticsally investigated the storm-time variations of ELF/VLF waves during the intense CME-driven storms from 2005 to 2009. The results show that there is a good correlation between the enhancement of ELF/VLF waves and the CME events. Immidately following the enhanced wave activity driven by CMEs during the initial phase, the wave intensity decreases temporarily at the beginning of storm main phase. The strongest waves predominantly occur from the late main phase to early recovery phase. The ELF waves below 3 kHz are significantly intensified during the whole storm time, while the high-frequency waves above 3 kHz seem strengthened only during the late main and early recovery phase. The ELF waves below 3 kHz can exist in a wide L-shell range, with the intensity peaking at $L \approx 3$–4. High-frequency waves at $f > 9$ kHz exist mostly outside the plasmapause. The stronger ELF/VLF waves on the dayside can last longer time than those on the nightside.

Zhao *et al*. [5] investigated the magnetic local time distribution of the ring current during 879 geomagnetic storms (identified by SYMH < –30 nT) in the 23rd solar cycle (1996–2006) by using 23 mid-low latitude ground-based magnetometers. The storms are divided into eight different classes with a step of 20 nT for the statistical analysis. For each class, the dusk side events, for which the H component minimum located in the dusk sector is mostly corresponding to the UT of minimum SYMH index, are about 59.5% of the total events. Whereas the noon side events are about 20.0%, the night side events are about 18.7%, and the dawn side events are about1.8%. The H component distributions with MLT indicate that the magnetic field disturbance during the magnetic storm events is not only related to the symmetrical ring current, but also to the other current, mainly the partial current. A further statistical study of the dusk side events shows that both the symmetric and partial ring currents enhance accompanied by the increase in the storm class during the main phase. And the partial ring current makes a greater contribution to the main phase of the storm. Referring to the interplanetary parameters, the distinction of the solar wind velocity V_x is more obvious than the interplanetary magnetic field B_z for the dusk side events in different classes. The comparisons between dusk side and other side events in the same class indicate that besides the solar wind velocity V_x, the interplanetary magnetic field B_y also affects the disturbance of ring current on the ground in MLT.

2 Magnetospheric Substorms

Patches of ionization are common in the polar ionosphere where their motion and associated density gradients give variable disturbances to High Frequency (HF) radio communications, over-the-horizon radar location errors, and disruption and errors to satellite navigation and communication. Their formation and evolution are poorly understood, particularly under disturbed space weather conditions. Zhang *et al*.[6] reported direct observations of the full evolution of patches during a geomagnetic storm, including formation, polar cap entry, transpolar evolution, polar cap exit, and sunward return flow. Their observations show that modulation of nightside reconnection in the substorm cycle of the magnetosphere helps form the gaps between patches where steady convection would give a "Tongue" of Ionization (TOI).

It was recently noted that substorms can occur even under prolonged northward Interplanetary Magnetic Field (IMF) conditions. Based on the substorm list obtained from the IMAGE spacecraft, Peng *et al*. [7] performed a statistical study on the features of substorms during northward IMF interval. The strength of the substorm is represented by the *AL* index decrease and the total intensity of the auroral bulge. Four main features have been found as follows. (1) Most substorms occur soon after a southward IMF, and intense substorms are more likely to occur for short duration of northward IMF period (2–5 h), whereas no intense substorms occur after prolonged northward IMF condition. (2) There is a positive correlation between the strength of the substorm and the two solar wind parameters (the IMF $|B_y|$ and the solar wind dynamic pressure P_d). (3) The average strength of the substorms during the storm period is much larger than that of the substorms during the period without storm. Meanwhile, nearly all strong storm time substorms occur either during the intense storm period, or during the late main phase or the early recovery phase of the storm. (4) About half of substorms, with either an increase or a decrease in the solar wind dynamic pressure, are found within 30 min preceding each onset time. Such features indicate that the energy stored in the magnetotail during a previous southward IMF period is the main energy source for substorms under northward IMF condition, especially for intense substorms, and both the IMF $|B_y|$ and the solar wind dynamic pressure play an important role in the energy accumulation during the northward IMF period.

Liu *et al*.[8] presented four successive substorm events, which followed a super-long, as long as 9 h, growth phase on 5 December 2008, observed by the Time History of Events and Macroscale Interaction during Substorms (THEMIS) and the GOES 11 satellite with simultaneous coverage by the Alaska and THEMIS ground magnetometers. Several interesting and unique features were found for these cases. The interplanetary magnetic field was steadily southward and the solar wind speed was slow, less than 450 km·s^{-1}, which are thought to drive the long growth phase for the following onsets. At least four substorm expansion onsets occurred, including a double-onset event, which appears to be a challenge to the reconnection hypothesis for double-onset substorm and favors an instability mechanism for the onsets and could not be explained by the two neutral line models. For the onsets at 09:32 UT and 09:42 UT, the depolarization signature was observed by GOES 11, which was located earthward of THEMIS C and THEMIS B. THEMISC satellite caught a delayed and much weaker signature 1–3 min after GOES 11. THEMIS B observed no related signature. These observations provide us with direct evidence that these events initiated at the near-Earth region. The observations of THEMIS C and THEMIS B around the onsets favor the near-Earth instabilities model for substorm onset.

To investigate the global evolution of substorm phenomena, Ma *et al*.[9] examined a moderately intense substorm on 1 March 2008, from 08:30 UT to 10:00 UT, observed by THEMIS probes and the Ground Based Observatory (GBO). During this interval, all five THEMIS probes were closely aligned along the tail axis near midnight covering a radial range from 9 R_e to 18 R_e. After the substorm onset, plasma sheet expansions took place successively at multiple locations in the magnetotail as measured by different probes. The positions of the plasma sheet expansions had a tailward leap progression with an average velocity of ~36 km·s^{-1}. There are two types of dipolarization detected in this substorm. The first type is the dipolarization front which is associated with the Bursty Bulk Flow (BBF). While the second type, which they call global dipolarization, is associated with plasma sheet expansions. In the substorm studied, there are four intensifications as shown in the THEMIS *AE* index. They can detect the effects of localized and short-lived magnetic energy release processes occurring in the magnetotail corresponding to each of the four *AE* intensifications. Furthermore, the inner four probes can detect the global dipolarization signatures 4–15 min earlier than plasma sheet expansions, while the outermost probe (P1) cannot detect this before the plasma sheet expansion. These two phenomena are caused by the same process (magnetic energy release process) but the effects detected by probes locally appear delayed. The observations in this case are not sufficient to distinguish between the two competing substorm models.

Yao *et al*.[10] presented THEMIS measurements of two substorm events to show how the Substorm Current Wedge (SCW) is generated. In the late growth phase when an earthward flow burst in the near-Earth magnetotail brakes and is diverted azimuthally, pressure gradients in the X- and Y-directions are observed to increase in the pileup and diverting regions of the flow. The enhanced pressure gradient in the Y-direction is dawnward (duskward) on the dawnside (duskside) where a clockwise (counter-clockwise) vortex forms. This dawn-dusk pressure gradient drives downward (upward) Field-Aligned Current (FAC) on the dawnside (duskside) of the flow, which, when combined with the FACs generated by the clockwise (counter-clockwise) vortex, forms the SCW. Substorm auroral onset occurs when the vortices appear, Near-Earth dipolarization onset is observed by the THEMIS spacecraft (probes) when a rapid jump in the Y-component of pressure gradient is detected. The total FACs from the vortex and the azimuthal pressure gradient are found to be comparable to the DP-1 current in a typical substorm.

Understanding of sub-storm progression is essential for solar terrestrial physics and space weather research. Cao *et al*.[11] presented the auroral streamer and the bursty bulk flows (BBFs) that were simultaneously observed by the IMAGE/WIC and the Cluster in the midtail ($X \approx -16R_e$), whose footprint was near the auroral streamer, respectively, during a substorm on September 14, 2004. The Auroral Poleward Boundaries (APBs) were 2° – 3° MLAT lower than the Open-Closed field line Boundaries (OCBs) during the growth phase. After the expansion onset, streamer elongated poleward, and the location of APBs became coincident with OCBs. These observations are consistent with the scenario that substorm activations start from plasma sheet reconnection of closed field lines during growth phase; in the expansion phase the open field line in the lobes are involved in reconnection in tail.

Cao *et al*.[12] presented multi-point THEMIS observations of a reconnection event in the near-Earth magnetotail during substorm. In this event, THEMIS probes stayed in the near-Earth and midtail region aligning along the magnetotail. This allows reconnection evolution to be probed simultaneously from about $-10\,R_e$ to $-23\,R_e$ down tail. The Hall current related electron streams were observed at the same time by two probes far away from the reconnection site. Before near-Earth reconnection involved the tail lobe magnetic field, the reconnection site was restricted in earthward $-23\,R_e$. When reconnection involved into the tail lobe region, the reconnection site started to retreat gradually.

The energy transport of BBFs is very important to the understanding of substorm energy transport. Previous studies all use the MHD bulk parameters to calculate the energy flux density of BBFs. Cao *et al*.[13] used kinetic approach, i.e., ion velocity distribution function, to study the energy transport of an earthward bursty bulk flow observed by Cluster C1 on 30 July 2002. The earthward energy flux density calculated using kinetic approach Q_{Kx} is obviously larger than that calculated using MHD bulk parameters Q_{MHDx}. The mean ratio Q_{Kx}/Q_{MHDx} in the flow velocity range 200 – 800 km·s^{-1} is 2.7, implying that the previous energy transport of BBF estimated using MHD approach is much underestimated. The underestimation results from the deviation of ion velocity distribution from ideal Maxellian distribution. The energy transport of BBF is mainly provided by ions above 10 keV although their number density N_f is much smaller than the total ion number density N. The ratio Q_{Kx}/Q_{MHDx} is basically proportional to the ratio N/N_f. The flow velocity $v(E)$ increases with increasing energy. The ratio N_f/N is perfectly proportional to flow velocity V_x. A double ion component model is proposed to explain the above results. The increase of energy transport capability of BBF is important to understanding substorm energy transport. It is inferred that for a typical substorm, the ratio of the energy transport of BBF to the substorm energy consumption may increase from the previously estimated 5% to 34% or more.

3 Magnetic Reconnection

Magnetic separatrix is an important boundary layer separating the inflow and outflow regions in magnetic reconnection. Zhou *et al*.[14] investigated the sub-structures of the separatrix region by using two-and-half dimensional electromagnetic particle-in-cell simulation. The separatrix region can be divided into two sub-regions in terms of the ion and electron frozen-in conditions. Far from the neutral sheet, ions and electrons are magnetized in magnetic fields. Approaching the neutral sheet, ion frozen-in condition is broken in a narrow region (about c/ω_{pi}) at the edge of a density cavity, while electrons are frozen-in to magnetic fields. In this region, electric field E_z is around zero, and the convective term $v_i \times \boldsymbol{B}$ is balanced by the Hall term in the generalized Ohm's law because ions carry the perpendicular current. Inside the density cavity, both ion and electron frozen-in conditions are broken. The region consists of two sub-ion or electron-scale layers, which contain intense electric fields. Formation of the two sub-layers is due to the complex electron flow pattern around the separatrix region. In the layer, E_z is balanced by a combination of Hall term and the divergence of electron pressure tensor, with the Hall term being dominant. Their preliminary simulation result shows that the separatrix region in guide field reconnection also contains two sub-regions: the inner region and the outer region. However, the inner region contains only one current layer in contrast with the case without guide field.

Secondary islands have recently been intensively studied because of their essential role in dissipating energy during reconnection. Secondary islands generally form by tearing instability in a stretched current sheet, with or without guide field. Zhou *et al.*[15] studied the electric field structure inside a secondary island in the diffusion region using large-scale two-and-half dimensional Particle-in-Cell (PIC) simulation. Intense in-plane electric fields, which point toward the center of the island, form inside the secondary island. The magnitudes of the in-plane electric fields E_x and E_z inside the island are much larger than those outside the island in the surrounding diffusion region. The maximum magnitudes of the fields are about three times the B_0V_A, where B_0 is the asymptotic magnetic field strength and V_A is the Alfvén speed based on B_0 and the initial current sheet density. Their results could explain the intense electric field (~100 mV·m^{-1}) inside the secondary island observed in the Earth's magnetosphere. The electric field E_x inside the secondary island is primarily balanced by the Hall term $(j\times B)/n_e$, while E_z is balanced by a combination of $(j\times B)/n_e$, $-(v_i\times B)$, and the divergence of electron pressure tensor, with $(j\times B)/n_e$ term being dominant. That large Hall electric field is due to the large out-of-plane current density j_y inside the island, which consists mainly of accelerated electrons forming a strong bulk flow in the $-y$ direction. The electric field E_y shows a bipolar structure across the island, with negative E_y corresponding to negative E_z and positive E_y corresponding to positive E_z. It is balanced by $(j\times B)/n_e$ and the convective electric field. There are significant parallel electric fields, forming a quadrupolar structure inside the island, with maximum amplitude of about $0.3B_0V_A$.

Zhou *et al.*[16] calculated the Anomalous Resistivity (AR) due to electrostatic waves, including possibly the lower hybrid wave and electron beam mode, around the secondary islands in the reconnection region observed by the Cluster spacecraft. Their main findings are: AR is important on the reconnection separatrix layer but heavily suppressed at the central current sheet where $B_x\approx 0$. Moreover, there is a highly asymmetric pattern of AR across the island along the outflow direction, with much larger AR on one side of island than on the other side. Their results may be helpful in understanding the role of AR in reconnection.

Huang *et al.*[17] presented the first comprehensive observations of turbulence properties within high speed reconnection jet in the plasma sheet with moderate guide field. The power spectral density index is about ~1.73 in the inertial range, and follows the value of ~2.86 in the ion dissipation range. The turbulence is strongly anisotropic in the wave-vector space with the major power having its wave-vector highly oblique to the ambient magnetic field, suggesting that the turbulence is quasi-2D. The measured "dispersion relations" obtained using the k-filtering technique were compared with theory and were found to be consistent with the Alfvén-Whistler mode. In addition, both Probability Distribution Functions and flatness results show that the turbulence in the reconnection jet is intermittent (multifractal) at scales less than the proton gyroradius/inertial lengths. The estimated electric field provided by anomalous resistivity caused by turbulence is about 3 mV·m^{-1}, which is close to the typical reconnection electric field in the magnetotail.

Huang *et al.*[18] also presented one case study of magnetic islands and energetic electrons in the reconnection diffusion region observed by the Cluster spacecraft. The cores of the islands were characterized by strong core magnetic fields and density depletion. Intense currents, with the dominant component parallel to the ambient magnetic field, were detected inside the magnetic islands. A thin current sheet was observed in the close vicinity of one magnetic island. Energetic electron fluxes increased at the location of the thin current sheet, and further increased inside the magnetic island, with the highest fluxes located at the core region of the island. They suggested that these energetic electrons are firstly accelerated in the thin current sheet, and then trapped and further accelerated in the magnetic island by betatron and Fermi acceleration.

Magnetic reconnection is an important universal plasma dissipation process that converts magnetic energy into plasma thermal and kinetic energy, and simultaneously changes the magnetic field topology. Huang *et al.*[19] reported the first observation of energetic electrons associated with asymmetric reconnection in the sheath of an interplanetary coronal mass ejection. The magnetic field shear angle is about 151°, implying guide-field reconnection. The width of the exhaust is about 8×10^4 km. The reconnection rate is estimated as 0.044–0.08, which is consistent with fast reconnection theory and previous observations. They observed flux enhancements of energetic electrons with energy up to 400 keV in that reconnection exhaust. The region where energetic electron fluxes were enhanced is located at one pair of separatrices in the higher density hemisphere. They discussed these observation results, and compared with previous observations and recent kinetic simulations.

Zhang *et al*.[20] reported a clear transition through a reconnection layer at the low-latitude magnetopause which shows a complete traversal across all reconnected field lines during north-westward Interplanetary Magnetic Field (IMF) conditions. The associated plasma populations confirm details of the electron and ion mixing and the time history and acceleration through the current layer. That case has low magnetic shear with a strong guide field and the reconnection layer contains a single density depletion layer on the magnetosheath side which they suggested results from nearly field-aligned magnetosheath flows. Within the reconnection boundary layer, there are two plasma boundaries, close to the inferred separatrices on the magnetosphere and magnetosheath sides (S_{sp} and S_{sh}) and two boundaries associated with the Alfvén waves (or Rotational Discontinuities, R_{Dsp} and R_{Dsh}). The data are consistent with these being launched from the reconnection site and the plasma distributions are well ordered and suggestive of the time elapsed since reconnection of the field lines observed. In each sub-layer between the boundaries the plasma distribution is different and is centered around the current sheet, responsible for magnetosheath acceleration. They showed evidence for a velocity dispersion effect in the electron anisotropy that is consistent with the time elapsed since reconnection. In addition, new evidence was presented for the occurrence of partial reflection of magnetosheath electrons at the magnetopause current layer.

A number of backscatter power enhancement events with “equatorward-moving radar auroral forms” in the high-latitude ionosphere were studied by Zhang *et al*.[21]. These events were also associated with sunward flow enhancements at each location in the Northern Hemisphere which were shown in ionospheric convections measured by the Super DARN radars. These are typical features of high-latitude (lobe) magnetic reconnections. The durations of the velocity enhancements imply that the evolution time of the lobe reconnections is about 8-16 minutes from their origin at the reconnection site to their addition to the magnetotail lobe again. In additional, the Double Star TC-1 spacecraft was moving from magnetosheath into magnetosphere, and crossing the magnetopause near the subsolar region during that interval, and observed typical low-latitude magnetic reconnection signatures. This implies that the dayside high- and low-latitude reconnections may occur simultaneously.

Magnetic reconnection is one of the most important processes in astrophysical, space, and laboratory plasmas, and magnetic island is an important feature in reconnection. Therefore, identifying the structures of magnetic island is crucial to improving our understanding of magnetic reconnection. Using two-dimensional (2-D) Particle-in-Cell (PIC) simulations, Huang *et al*.[22] demonstrated that the out-of-plane magnetic field has a dip in the center of magnetic island, which is formed during multiple X line guide field reconnection. Such structures are considered to be produced by the current system in the magnetic island. At the edge of the magnetic island, there exists a current anti-parallel to the in-plane magnetic field, while the current is parallel to the in-plane magnetic field inside the magnetic island. Such a dual-ring current system, which is attributed to the electron dynamics in the magnetic island, leads to the dip of the out-of-plane magnetic field in the center of the island. The relevance between their simulations and crater flux transfer events (C-FTEs) was also discussed

Secondary islands are considered to play a crucial role in collisionless magnetic reconnection. Based on two-dimensional (2-D) Particle-in-Cell (PIC) simulations, Huang *et al*.[23] investigated the characteristics of the out-of-plane electron currents in magnetic islands formed during collisionless magnetic reconnection with an initial guide field. In a primary island (formed simultaneously with the appearance of the X lines), due to the acceleration of the trapped electrons, the direction of the formed out-of-plane electron current is reverse to it original one. In the secondary island (formed in the vicinity of the X line), the out-of-plane electron current is generated due to the accelerated electrons by the reconnection electric field in the vicinity of the X line. In such a way, the direction of the out-of-plane electron current in a secondary island is found to be opposite to that in a primary island. Such characteristic are found to be related to the evolution of the magnetic islands and then electron dynamics in the islands, which were proposed in their paper to be a possible criterion to identify a secondary island formed during collisionless magnetic reconnection, especially in the magntotail.

By performing two-dimensional (2-D) Particle-in-Cell (PIC) simulations, Lu *et al*.[24] investigated the transfer between electron bulk kinetic and electron thermal energy in collisionless magnetic reconnection. In the vicinity of the X line, the electron bulk kinetic energy density is much larger than the electron thermal energy density. The evolution of the electron bulk kinetic energy is mainly determined by the work done by the electric field force and electron pressure gradient force. The work done by the electron gradient pressure force in the vicinity of the X line is changed to the electron enthalpy flux. In the magnetic island, the electron enthalpy flux is transferred to the electron thermal energy due to the compressibility of the plasma in the magnetic island. The compression of the plasma in the magnetic island is a consequence of the electromagnetic force felt by the plasma as the magnetic field lines release their tension after being reconnected. Therefore, it can be observed that in the magnetic island the electron thermal energy density is much larger than the electron bulk kinetic energy density.

The onset of collisionless magnetic reconnection is considered to be controlled by electron dynamics in the electron diffusion region, where the reconnection electric field is balanced mainly by the off-diagonal electron pressure tensor term. Two-dimensional (2-D) particle-in-cell (PIC) simulations were employed by Lu *et al.*[25] to investigate the self-reinforcing process of the reconnection electric field in the electron diffusion region, which is found to grow exponentially. A theoretical model was proposed to demonstrate such a process in the electron diffusion region. In addition, the reconnection electric field in the pileup region, which is balanced mainly by the electromotive force term, was also found to grow exponentially, and its growth rate is twice that in the electron diffusion region.

Magnetic island plays an important role in magnetic reconnection. Using a series of two-dimensional (2-D) Particle-in-Cell (PIC) simulations, Huang *et al.*[26] investigated the magnetic structures of a magnetic island formed during multiple X-line magnetic reconnection, considering the effects of the guide field in symmetric and asymmetric current sheets. In a symmetric current sheet, the current in the x direction forms a tripolar structure inside a magnetic island during anti-parallel reconnection, which results in a quadrupole structure of the out-of-plane magnetic field. With the increase of the guide field, the symmetry of both the current system and out-of-plane magnetic field inside the magnetic island is distorted. When the guide field is sufficiently strong, the current forms a ring along the magnetic field lines inside magnetic island. At the same time, the current carried by the energetic electrons accelerated in the vicinity of the X lines forms another ring at the edge of the magnetic island. Such a dual-ring current system enhances the out-of-plane magnetic field inside the magnetic island with a dip in the center of the magnetic island. In an asymmetric current sheet, when there is no guide field, electrons flows toward the X lines along the separatrices from the side with a higher density, and are then directed away from the X lines along the separatrices to the side with a lower density. The formed current results in the enhancement of the out-of-plane magnetic field at one end of the magnetic island, and the attenuation at the other end. With the increase of the guide field, the structures of both the current system and the out-of-plane magnetic field are distorted.

Cao *et al.*[27] studied the ULF waves with a period of 30 s in the ion diffusion region of reconnection observed by Cluster satellites on 21 August 2002. The fast convective tailward ion flow accompanied with large southward magnetic field component, strong Hall magnetic field and Hall electric field demonstrate that Cluster satellites are located in the ion diffusion region of reconnection. The analyses of wave properties using MVA and timing method indicate that this wave is a obliquely propagating slow magnetosonic wave which is characterized by the anti phase relation between the magnitude of magnetic field and the ion number density, and a propagation angle of around 130° with respect to the ambient magnetic field. This wave is generated by periodic magnetic reconnection. The periodic oscillations in B_y and B_x components are driven by the periodic Hall current system, while the oscillation in B_z component is driven by quasi periodic convective tailward ion flows. The slow magnetosonic wave significantly influences the frequency of whistler waves and low hybrid waves excited by magnetic reconnection by changing the magnitude of local magnetic field and subsequently electron cyclotron frequency.

Dipolarization Fronts (DFs) are frequently detected in the Earth's magnetotail from $X_{GSM} = -30\ R_e$ to $X_{GSM} = -7\ R_e$. How these DFs are formed is still poorly understood. Three possible mechanisms have been suggested in previous simulations: (1) jet braking, (2) transient reconnection, and (3) spontaneous formation. Among these three mechanisms, the first has been verified by using spacecraft observation, while the second and third have not. Fu *et al.*[28] provided in situ evidence of the second mechanism: Transient reconnection can produce DFs. They suggested that the DFs detected in the near-Earth region ($X_{GSM} > -10\ R_e$) are primarily attributed to jet braking, while the DFs detected in the mid- or far-tail region ($X_{GSM} < -15\ R_e$) are primarily attributed to transient reconnection or spontaneous formation. In the jet braking mechanism, the high-speed flow "pushes" the preexisting plasmas to produce the DF so that there is causality between high-speed flow and DF. In the transient reconnection mechanism, there is no causality between high speed flow and DF, because the frozen-in condition is violated.

It is poorly understood how energetic electrons are produced during magnetic reconnection, which is a fundamental process responsible for stellar flares substorms, and disruptions in fusion experiments. Observations in the solar chromosphere and the Earth's magnetosphere indicate significant electron acceleration during reconnection, whereas in the solar wind, energetic electrons are absent. Fu *et al*.[29] showed that energetic electron acceleration is caused by unsteady reconnection. In the Earth's magnetosphere and the solar chromosphere, reconnection is unsteady, so energetic electrons are produced; in the solar wind, reconnection is steady, so energetic electrons are absent. The acceleration mechanism is quasi-adiabatic: betatron and Fermi acceleration in outflow jets are two processes contributing to electron energization during unsteady reconnection. The localized betatron acceleration in the outflow is responsible for at least half of the energy gain for the peak observed fluxes.

Wang *et al*.[30] investigated a direct south-north crossing of a reconnection ion diffusion region in the magnetotail. During this crossing, multiple electron density dips with a further density decrease within the cavity, called sub-cavities, adjacent to the northern separatrix were observed. The correlation between electron density sub-cavities and strong electric field fluctuations is obvious. Within one of the sub-cavities, a series of very strong oscillating perpendicular electric field and patchy parallel electric field were observed. The parallel electric field is nearly unipolar and directs away from X line. In the same region, inflow electrons with energy up to 100 keV are injected into the X line. Based on the observations, they concluded that the high energy inflowing electrons are accelerated by the patchy parallel electric field. Namely, electrons have been effectively accelerated while they are flowing into the X line along the separatrix. The observations indicate that the electron acceleration region is widely larger than the predicted electron diffusion region in the classical Hall magnetic reconnection model.

There exist two models of MR in the literatures, antiparallel and component, associated with intensive studies of their generation and applications. Guo *et al*.[31] reported an MR event observed by Cluster constellation in the geomagnetotail where both types of MR were detected. By reconstructing the three-dimensional (3-D) MR configuration, they found that a pair of A-B nulls existed in both types of MR cases with two fan surfaces intersecting each other to form a separator line connecting the nulls. A weak or sizable magnetic field exists along the separator in the antiparallel or component case, respectively. In the latter case, field strength is finite away from the two nulls and vanishes close to the nulls. Therefore, at least in the two cases observed, both antiparallel and component MR geometries are local presentation of the separator MR configuration. This result supports the expectation that 3-D nulls often occur as a crucial element of MR at least in the magnetotail and separator MR may play an important role in dynamics and reconfiguration of magnetic field in 3-D MR processes.

On 14 June 2007, four Time History of Events and Macroscale Interactions during Substorms spacecrafts observed a Flux Transfer Event (FTE) on the dayside magnetopause, which was previously proved to be generated by multiple, sequential X-line reconnection (MSXR) in a 2-D context. Zhong *et al*.[32] reported a further study of the MSXR event to show the 3-D viewpoint based on additional measurements. The 3-D structure of the FTE flux rope across the magnetospheric boundary was obtained on the basis of multipoint measurements taken on both sides of the magnetopause. The flux rope's azimuthally extended section was found to lie approximately on the magnetopause surface and parallel to the X line direction; while the axis of the magnetospheric branch is essentially along the local unperturbed magnetospheric field lines. In the central region of the flux rope, as distinct from the traditional viewpoint, they found from the electron distributions that two types of magnetic field topology coexist: opened magnetic field lines connecting the magnetosphere and the magnetosheath and closed field lines connecting the Southern and Northern hemispheres. They confirmed, therefore, for the first time, the characteristic feature of the 3-D reconnected magnetic flux rope, formed through MSXR, through a determination of the field topology and the plasma distributions within the flux rope. Knowledge of the complex geometry of FTE flux ropes will improve our understanding of solar wind-magnetosphere interaction.

4 Solar Wind-magnetosphere-ionosphere Interaction

The open magnetic flux (F_{pc}) is a key parameter to study magnetospheric dynamical process, which is closely related to magnetic reconnections in the dayside magnetopause and magnetotail. The dayside reconnection rate controls the amount of the open magnetic flux, which is affected by various solar wind parameters, among which the clock angle θ_c of the Interplanetary Magnetic Field (IMF) is an important factor that influence the dayside reconnection rate. Using global MHD simulations, Xia *et al.*[33] analyzed the relationship between θ_c and F_{pc}. The result shows that the open flux F_{pc} increases as the clock angle θ_c approaches 180° (due southward), and the open flux F_{pc} being proportional to $\sin 3/2(\theta_c/2)$. This reflects the physical connection between them, since the θ_c describes the magnitude of the shear between IMF and terrestrial magnetic field, and affects the dayside reconnection rate, thus controlling the open flux F_{pc}.

Sun *et al.*[34] performed global MHD simulations of the geosynchronous magnetic field in response to fast solar wind dynamic pressure (P_d) enhancements. Taking three P_d enhancement events in 2000 as examples, they found that the main features of the total field B and the dominant component B_z can be efficiently predicted by the MHD model. The predicted B and B_z varies with local time, with the highest level near noon and a slightly lower level around mid-night. However, it is more challenging to accurately predict the responses of the smaller component at the geosynchronous orbit *(i.e.*, B_x and B_y). In contrast, the limitations of T01 model in predicting responses to fast P_d enhancements were presented.

Sun *et al.*[35] presented different magnetic field changes in the nightside magnetosphere in response to the Interplanetary (IP) shock on 17 December 2007, using multiple spacecraft observations and global MHD simulations. The coexistence of two distinct B_z response regions in the nightside magnetosphere in a single event is observationally identified for the first time. From the inner magnetosphere to the tail, they are the positive response (B_z increase) and the negative response (B_z decrease). This scenario reasonably agrees with the MHD model prediction. Moreover, the analysis of the response delay time shows that, for the three satellites which observed the negative responses of B_z, the one closest to Earth was the last to respond. This phenomenon can also be understood based on the model prediction that the negative response region develops toward Earth after its formation. In addition, the temporarily enhanced earthward flows in the negative response region, which were suggested to be responsible for the formation of this region by previous model studies, were also supported by the observation. At last, a global view of the B_z response processes in the nightside magnetosphere was presented based on MHD simulations.

A statistical study of electron data observed within magnetosheath regions after Interplanetary (IP) shocks driven by magnetic clouds was performed by Xu *et al.*[36] to understand the constraints on temperature anisotropies of suprathermal electron component due to collective effects of electron wave-particle interactions with plasma micro-instabilities. Results show that although shock heating and acceleration, downstream selective reflection and leakage into upstream region, and wave-particle scattering all can contribute to suprathermal electron temperature anisotropy in downstream sheath regions of IP shocks, the consequent whistler anisotropy instabilities triggered by the sufficiently large temperature anisotropies can constrain temperature anisotropy increase to a more nearly isotropic distribution as plasma beta increases.

Fu *et al.*[37] studied the role of electrons during the shock-induced chorus intensification observed by THEMIS D on 19 November 2007. Firstly, the electrons are accelerated through the local betatron acceleration and radial diffusion, which are primarily in the perpendicular direction and result in the positive anisotropy ($T_{\perp}>T_{\parallel}$) of electrons; then they are scattered through the pitch-angle diffusion, during which the electron energies are partially transferred to amplify the chorus. In the case of interest, the energy loss is more efficient for the lower-energy (15 keV) electrons because they have larger density gradient along the diffusion curves. The energetic electrons act as the intermediate in this scenario. They transfer the energies carried by the interplanetary shock to the chorus. The energetic electrons injected from magnetotail were not observed; they have no contributions to the energy source in this event.

On 3 September 2009, the Time History of Events and Macroscale Interactions during Substorms (THEMIS) satellites observed a significant intensification of chorus in response to the interplanetary shock in the Earth's dayside plasma trough. Fu *et al.*[38] analyzed the wave-particle interaction and reveal that the chorus intensification can be caused by the gyroresonance between the chorus and the energetic electrons. When the electrons are scattered from resonance points to low-density regions along the diffusion curves, a part of their energy can be lost and then transferred to amplify the chorus. During the compression of the magnetosphere, the temperature anisotropy of electrons is enhanced. This makes the electron diffusion and chorus intensification very effective. The maximum growth rate after the shock is about 50% greater than that before the shock. The lower-energy (15–25 keV) electrons contribute more to the growth of chorus due to the larger density gradient along the diffusion curve. The <10 keV electrons are almost isotropic, so they contribute little to the amplification of chorus. They investigated the free energy for the chorus intensification and found that it can be generated through the local betatron acceleration and radial diffusion processes. The local betatron acceleration results from the shock-induced compression of the magnetosphere. The linear and nonlinear growth rates were also compared. They found that the linear diffusion process works well for the present case.

Using the data of solar wind recorded by WIND and geomagnetic activity index, Zou *et al*.[39] studied the influence of the variation of solar wind dynamical pressure on ring current index SYM-*H* and auroral electrojet indexes (*AU* and *AL*). The increase and decrease of solar wind dynamical pressure can produce simultaneous or delayed disturbances in geomagnetic activity indexes, which include the transient increase of ring current index SYM-*H*, increase of eastward electrojet index *AU* and decrease of westward electrojet index *AL*. The sudden large increase of solar wind dynamical pressure can trigger super substorm and large geomagnetic storm. The response of geomagnetic activity indexes to solar wind dynamical pressure impulse is complicated and various, indicating the geomagnetic effect of solar wind dynamical pressure impulse not only depends on the strength and duration of solar wind dynamical pressure impulse, but also on the state of magnetosphere. Large geomagnetic storm, which last long and consume more energy, can only be triggered by strong and long impulse of solar wind dynamical pressure.

Wang *et al*.[40] performed a statistical study by using two years of DMSP (Defense Meteorological Satellite Program) plasma observations to investigate the seasonal effect of SAPS (subauroral polarization stream) on the ion upflow in the duskside ionosphere of the Northern Hemisphere. There are obvious upflows occurring in the topside ionosphere around the SAPS region, exceeding 200 $m\cdot s^{-1}$ at winter solstice, indicating an important relationship between SAPS and the local plasma upward motion. Both SAPS and ion upward velocities show similar seasonal variations, largest in winter and smallest in summer, irrespective of geomagnetic activity. A good correlation is found and a linear relationship is derived between SAPS and the ion upflow velocities. During December solstice the average upflow flux can reach about 2×10^8 $cm^{-2}\cdot s^{-1}$ for more disturbed periods, which is comparable to the typical upflow flux in the dayside cusp region. The depression of the ion temperatures around the peak SAPS region can be understood in terms of the adiabatic cooling. The hot ion cools down when expanding into the low ion concentration region. The electron temperature elevates around the SAPS region because of the reduced Coulomb cooling in the low ion density region. Both the changes of ion and electron temperatures are larger in winter than in summer, however, for $Kp < 4$ the electron temperatures are almost seasonably independent. Their work highlights the important role of the SAPS-related frictional heating at mid-latitudes on the local formation of the strong upward flow, which might provide a direct ionospheric ion source for the ring current and plasmasphere in the duskside sector.

Li *et al*.[41] studied the foreshock turbulence evolution in high region via both Cluster observation on March 29, 2002 and 1-D hybrid simulation. The quasi-sinusoidal and the irregular wave trains were both detected in this event. The former one is believed to be generated by ion-ion right-hand non-resonant instability due to the right-hand polarization and anti-sunward propagation in the plasma frame. Since the ion distribution associated with the wave train is more “intermediate” rather than “diffused”, they suggested that the wave train reported in their paper can be viewed as a “mid-step” of “isolated” and “irregular”. From the quasi-sinusoidal to the irregular waveform, the corresponding polarizations appear to transit: right-hand wave of higher frequency (wave number) is substituted by a left-hand wave with lower frequency (wave number) in spacecraft frame. And the lower frequency left-hand wave is right-hand polarized in plasma rest frame. Then the 1-D hybrid simulation was applied for two cases with various velocities to study such polarization transition. By comparing observation results with the simulation, such polarization transition and “inversed cascade” (wave energy transferring from large wave number to small wave number) can be understood as the consequence of decay instability. Although decay instability cannot be initiated in high beta (>1) plasma in MHD (Magnetohydrodynamics) theory, such dependence can be modified by kinetic effect. Moreover, it is found that in simulation no matter which right-hand instability is dominant in early stage, left-hand wave (sunward propagating wave) will be the prime component of magnetic field disturbance in the final stage.

Interplanetary (IP) shocks, one of the important causes of the magnetosphere ionosphere disturbances, could affect the geomagnetic field by changing the current systems in the magnetosphere-ionosphere region. By using a global three dimensional MHD simulation code, Zhang *et al*.[42] analyzed the immediate responses of the Equivalent Current Systems (ECS) in the Earth's ionosphere to the impact of IP shocks. The model results show that after the shock arrival a pair of abnormal Field-Aligned Current (FAC) appears, flowing into and out of the ionosphere on the dusk and dawn side respectively. Also developed in the ionosphere is the two-cell ECS: an anticlockwise circulation in the dawn hemisphere and a clockwise one in the dusk hemisphere. The two ECS vortices shift poleward and tailward after their formation. In the meantime, their intensities increase at first and then decrease to virtually disappear within tens of seconds. At last the ECS pattern reaches a quasi steady state which is controlled by the interplanetary conditions downstream of the IP shock. The quantitative characteristics of such response processes depend on the intensity of the IP shock: for a stronger shock, the two-cell ECS becomes more intense, and its lifetime is shorter.

The plasma transport between the plasmasphere and the ionosphere in response to the interplanetary conditions is still not fully understood until now. Simultaneous observations of the plasmasphere and ionosphere from the newly developed Chinese Meridian Project provide a new opportunity for understanding the characteristic of the plasma transport and the coupling mechanism between these two regions. Zhang *et al*.[43] investigated the response of the plasmasphere ($L \approx 2$) and ionosphere to the solar wind dynamic pressure pulse during geomagnetically quiet period of 21–27 March 2011. The response of the plasmasphere shows a significant depletion. The plasmaspheric density nearly decreases by half in response to the solar wind dynamic pressure pulse, and subsequently recovers to the original level in 1–2 d. Meanwhile, the maximum electron density of the ionospheric F_2 layer (N_mF_2) and the total electron content (TEC) increase by 13% and 21%, respectively, and then gradually recover, which is opposite to the behavior during magnetic storms. Preliminary analysis shows that the plasmaspheric depletion may be mainly caused by the southward interplanetary magnetic field and changing dawn-dusk electric field. The plasmaspheric density variations seem to be controlled by both the IMF and ionospheric conditions.

Zhang *et al*.[44] employed a global Magnetohydrodynamics (MHD) model, namely the PPMLR-MHD model, to investigate the effect of the solar wind conditions, such as the Interplanetary Magnetic Field (IMF) clock angle, southward IMF magnitude and solar wind speed, on the average pattern of the ionospheric Equivalent Current Systems (ECS). A new method to derive ECS from the MHD model was proposed and applied, which takes account of the oblique magnetic field line effects. The model results indicate that when the IMF is due northward, the ECS are very weak while the current over polar region is stronger than the lower latitude; when the IMF rotates southward, the two-cell current system dominates, the eastward electrojet on the afternoon sector and the westward electrojet on the dawn sector increase rapidly while the westward electrojet is stronger than the eastward electrojet. Under southward IMF, the intensity of the westward electrojet and eastward electrojet both increase with the increase of the southward IMF magnitude and solar wind speed, and the increase is very sharp for the westward electrojet. Furthermore, they compared the geomagnetic perturbations on the ground represented by the simulated average ECS with the observation-based statistical results under similar solar wind conditions. It was found that the model results generally match with the observations, but the underestimation of the eastward equivalent current on the dusk sector is the main limitation of the present model.

The open magnetic flux (F_{pc}) is a key parameter to study magnetospheric dynamical process, which is closely related to magnetic reconnections in the dayside magnetopause and magnetotail. Using global MHD simulations, Wang *et al*.[45] found that the open magnetic flux F_{pc} can be estimated through a combined parameter f by $F_{pc} = 0.89 f / (f + 0.20) + 0.52$, where the parameter $f = v_{sw} B_s n_{sw}^{1/5} \sum p^{1/3}$ is a function of the solar wind velocity v_{sw}, the solar wind number density n_{sw}, the southern Interplanetary Magnetic Field (IMF) strength B_s, and the ionospheric Pederson conductance Σp. The comparison with the limited observational F_{pc} data available in the literature shows its promise in estimating the open magnetic flux from the interplanetary and ionospheric conditions. The open magnetic flux F_{pc} may be served as a key space weather forecast element in the future.

The plasma transport between the plasmasphere and ionosphere during magnetic storms is a long-standing problem and is still not fully understood. Simultaneous observations of the plasmasphere and ionosphere are vital to understand the coupling between the two regions. Using the measurements from the newly developed Chinese ground-based space weather monitoring network (Meridian Project), Wang *et al*.[46] investigated the plasmaspheric density at $L = 2$ inferred from ground magnetometers and the ionospheric electron density inferred by digital ionosondes and GPS signals during magnetic storms in 2011. Five moderate magnetic storms with minimum *Dst* index between ~ 47 and ~103 nT during this period have been investigated. The observations show that the plasmaspheric density drops significantly by more than half of the prestorm value. The ionospheric F_2 layer electron density N_mF_2 and the Total Electron Content (TEC) show 20% – 50% decreases, and the N_mF_2 and TEC reductions take place before the plasmaspheric density reaches its minimum. These findings suggest that the plasmaspheric depletion is very likely due to the reduced plasma supply from the ionosphere for the five moderate magnetic storms in 2011. Therefore, the plasmasphere dynamics seems to be controlled by the ionosphere during magnetic storms.

A statistical survey of 379 IMF southward turning events during the time period from 1995 to 2011 was performed by Li *et al*.[47] to study the impact of solar wind conditions on the substorm growth phase duration and intensity. Substorm growth phase persists from several minutes up to 2–3 h, and its duration is mainly controlled by solar wind conditions. The larger dayside reconnection E-field and solar wind speed are, the shorter the growth phase will be. The lower limits of solar wind reconnection E-field and bulk speed for substorm occurrence are found to be 0.6 $mV{\cdot}m^{-1}$ and 280 $km{\cdot}s^{-1}$, respectively. Similarly, the substorm intensity is linearly correlated to the dayside reconnection *E*-field. However, it seems to be independent of the amount of dayside geomagnetic flux reconnected and solar wind energy entered into the magnetosphere during the growth phase. Furthermore, all the events are divided into three groups for different averages of dayside reconnection *E*-field during the growth phase (E_{kl}): (1) $0.0 \leqslant E_{kl} < 1.5$ $mV{\cdot}m^{-1}$; (2) $1.5 \leqslant E_{kl} < 2.5$ $mV{\cdot}m^{-1}$; and (3) $E_{kl} \leqslant 2.5$ $mV{\cdot}m^{-1}$, and the geometric means of growth phase duration and auroral power maximum for these three groups are 91 min, 62 min, 32 min, and 35 GW, 51 GW, 74 GW, respectively.

Li *et al*.[48] studied statistically the joint responses of magnetic field and relativistic (> 0.5MeV) electrons at geosynchronous orbit to 201 interplanetary perturbations during 6 years from 2003 (solar maximum) to 2008 (solar minimum). The statistical results indicate that during geomagnetically quiet times ($H_{SYM} > -30$nT, and $AE < 200$nT) ~47.3% changes in the geosynchronous magnetic field and relativistic electron fluxes are caused by the combined actions of the enhancement of solar wind dynamic pressure (P_d) and the southward turning of Interplanetary Magnetic Field (IMF) ($\Delta P_d > 0.4$ nPa, and IMF $B_z < 0$nT), and only ~18.4% changes are due to single dynamic pressure increase ($\Delta P_d > 0.4$nPa, but IMF $B_z > 0$nT), and ~34.3% changes are due to single southward turning of IMF (IMF $B_z < 0$ nT, but $|\Delta P_d| < 0.4$ nPa). Although the responses of magnetic field and relativistic electrons to the southward turning of IMF are weaker than their responses to the dynamic pressure increase, the southward turning of IMF can cause significant dawn-dusk asymmetric perturbations that the magnetic field and relativistic electron fluxes increase on the dawnside (00:00 LT–12:00 LT) but decrease on the duskside (13:00 LT– 23:00 LT) during the quiet times. Furthermore, the variation of relativistic electron fluxes is adiabatically controlled by the magnitude and elevation angle changes of magnetic field during the single IMF southward turnings. However, the variation of relativistic electron fluxes is independent of the change in magnetic field in some magentospheric compression regions during the solar wind dynamic pressure enhancements (including the single pressure increases and the combined external perturbations), indicating that nonadiabatic dynamic processes of relativistic electrons occur there.

The interaction between interplanetary shocks and the Earth's magnetosphere manifests in many important space physics phenomena including particle acceleration. Zong *et al*.[49] investigated the response of the inner magnetospheric hydrogen and oxygen ions to a strong interplanetary shock impinging on the Earth's magnetosphere. Both hydrogen and oxygen ions were found to be heated/accelerated significantly with their temperature enhanced by a factor of two and three immediately after similar to 1 min and similar to 12 min of the shock arrival respectively. Multiple energy dispersion signatures of ions were found in the parallel and anti-parallel direction to the magnetic field immediately after the interplanetary shock impact. The energy dispersions in the anti-parallel direction preceded those in the parallel direction. Multiple dispersion signatures can be explained by the flux modulations of local ions (rather than the ions from the Earth's ionosphere) by ULF waves. It is found that the energy spectrum from 10 eV to similar to 40 keV are highly correlated with the cross product of observed ULF wave electric and magnetic field ($V = (E_x B)/B^2$), which indicate that both cold plasmaspheric plasma and hot thermal ions (10 eV to similar to 40 keV) are accelerated and decelerated with the various phases of ULF wave electric field. They then demonstrated that ion acceleration due to the interplanetary shock compression on the Earth's magnetic field is rather limited, whereas the major contribution to acceleration comes from the electric field carried by ULF waves via drift-bounce resonance for both the hydrogen and oxygen ions. The integrated hydrogen and oxygen ion flux with the poloidal mode ULF waves are highly coherent (> 0.9) whereas the coherence with the toroidal mode ULF waves is negligible, implying that the poloidal mode ULF waves are much more efficient in accelerating hydrogen and oxygen ions in the inner magnetosphere than the toroidal mode ULF waves. The duration of high coherence for oxygen ions with the poloidal mode ULF wave is longer than that for hydrogen ions, indicating that oxygen ions can be heated/accelerated more efficiently by the poloidal mode ULF wave induced by the interplanetary shock.

Detailed features of the near-Moon pickup ions under different Interplanetary Magnetic Field (IMF) conditions were investigated by Zong *et al.*[50] using data obtained from the solar wind ion detector (SWID-B) onboard Chang'E-1. In the event studied, Chang'E-1 was on a noon-midnight meridian orbit and the field-of-view of the SWID-B was in the satellite orbital plane. The observations show that the pickup energy detected depends not only on where these particles are detected but also on their incident angles. As the spacecraft moved into the wake from the South Pole along the midnight meridian, wider incident angle distributions were measured. When IMF B_x was significant, the pickup ions had a strong velocity component parallel to the magnetic field, and the efficiency of acceleration was reduced when the IMF B_y decreased. The back tracking calculations show that the possible source of the pickup ions is solar wind ions scattered/reflected on the lunar surface in a wide area over the dayside of the Moon, from both magnetic and nonmagnetic anomaly regions. A three dimensional analysis performed on the asymmetric properties of the pick-up ions can explain most of the particle behavior observed near the Moon under different IMF conditions.

Luo *et al.*[51] statistically studied the solar wind dependence of the magnetospheric activities during intense northward Interplanetary Magnetic Fields (IMFs) events ($B_z > 10$ nT, last over 3 h). It was found that the energy coupling between the solar wind and magnetosphere during intense northward IMFs is mainly controlled by solar wind velocity and IMF clock angle θ. A northward IMF coupling function is derived based on the dimensional analysis and quantitative analysis of the solar wind parameters and the geomagnetic indices. It is shown that when $\theta > 45°$, the energy input increases obviously as θ increases. Most importantly, it is also found that the relative importance between the viscous interaction and the IMF $|B_y|$ effect in controlling the energy input into the magnetosphere during intense northward IMFs mainly depends on IMF clock angle. The viscous interaction will outweigh the IMF $|B_y|$ effect in the northward IMF events with $\theta > 75°$. In contrast, for those northward IMF events with $\theta < 75°$, the IMF $|B_y|$ effect may be more important than the viscous interaction.

The rapid change in the Earth’s magnetosphere caused by solar wind disturbances has been an important part of the solar wind-magnetosphere interaction. However most of the previous studies were focused on the perturbation of the Earth’s magnetic field caused by solar wind dynamic pressure changes. Dong *et al.*[52] studied the response of geosynchronous magnetic field and the magnetic field to the rapid southward turning of interplanetary magnetic field during the interval 13:50 UT–14:20 UT on 7 May 2007. During this event, B_z component of the interplanetary magnetic field decreased from 15 nT to –10 nT within 3 min (14:03 UT–14:06 UT). The geosynchronous magnetic field measured by three geosynchronous satellites (GOES 10–12) first increased and then decreased. The variations of magnetic field strength in the morning sector (09:00 LT–10:00 LT) were much larger than those in the dawn sector (05:00 LT). Meanwhile, the H components of geomagnetic field on the ground had similar response features but exhibit latitude and LT dependent variations. Compared with H components, the D components did not have regular variations. Although the solar wind dynamical pressure encountered small variations, the magnetic field both in space and on the ground did not display similar variations. Therefore, the increase of geomagnetic field in the dawn sector is caused by the southward turning of IMF (interplanetary magnetic field) B_z. These results will help to better understand the coupling process of geomagnetic filed and interplanetary magnetic field.

An understanding of the transport of solar wind plasma into and throughout the terrestrial magnetosphere is crucial to space science and space weather. For non-active periods, there is little agreement on where and how plasma entry into the magnetosphere might occur. Moreover, behavior in the high-latitude region behind the magnetospheric cusps, for example, the lobes, is poorly understood, partly because of lack of coverage by previous space missions. Using Cluster multi-spacecraft data, Shi *et al*.[53] reported an unexpected discovery of regions of solar wind entry into the Earth's high-latitude magnetosphere tailward of the cusps. From statistical observational facts and simulation analysis they suggested that these regions are most likely produced by magnetic reconnection at the high-latitude magneto-pause, although other processes, such as impulsive penetration, may not be ruled out entirely. They found that the degree of entry can be significant for solar wind transport into the magnetosphere during such quiet times.

Hot Flow Anomalies (HFAs) are phenomena that frequently appear in the vicinity of the Earth's bow shock. Wang *et al*.[54] studied the plasma and magnetic field variations during typical HFAs. They identified 765 HFA events with Cluster spacecraft data from 2003 to 2009. Then they studied the average structure of HFAs using the superposed epoch method during a 200 s time interval, with the HFA onset time as the epoch time. The results show that HFAs can be classified into four classes based on variations of the dynamic pressure over time, namely "– +" (down-up), "+–" (up-down), M (up-down-up) and W (up-down-up-down-up), where the letters represent similar shapes with the variation trends of the dynamic pressure. Trends of other parameters are highly related to those of the dynamic pressure with obvious characteristics of the classification. Moreover, statistical results suggest that the number of HFA events varies in years. Compared with the speed of solar wind and sunspot number, the number of HFA events in each year has positive correlation with the former, while it has little relation with the latter. The result of their paper will provide data base for further studies on the mechanisms of the formation, the structural evolution and other relative questions of HFAs.

Case and statistical studies have been performed to investigate hot flow anomalies (HFAs) with large flow deflections using data from the Cluster-C1 spacecraft from 2003 to 2009. Wang *et al*.[55] selected 87 events with V_y or V_z in GSE coordinates larger than 200 km·s^{-1}. Observations of these HFAs indicate a "location-dependent deflection": V_y or V_z deflects to a positive value when the event is located in the positive Y or Z side relative to the subsolar point and to a negative value when it is located in the negative Y or Z side relative to the subsolar point. The amplitude of the deflection increases with increasing distance in Y or Z direction. The decrease in V_x at the event center is larger when the location is closer to the Sun-Earth line. The location-dependent deflection might be due to a near-specular reflection of ions at the Earth's bow shock. The HFAs studied in their paper are close to the bow shock with the distance of the event location to the bow shock ranging from 0.03 to 3.51 R_e, which might cause the reflected ions to remain as a coherent near-specular reflected beam.

Wang *et al*.[56] used the same database to further studied the bow shock geometry at Hot Flow Anomaly (HFA) edges. The results suggest that HFAs can be formed at both quasi-parallel and quasi-perpendicular shocks. In the paper, they showed that the ions might be near-specularly reflected at the bow shock and interact with the solar wind to form HFAs. The guiding center of specularly reflected ions will typically be swept downstream to the bow shock at quasi-perpendicular shocks. However, this study shows that in at least 13 of these 87 (15%) HFAs, both the leading and trailing edges are at quasi-perpendicular shocks. These HFAs show a high gyration velocity and a high fast magneto-sonic Mach number, increasing the gyro-radius and the possibility of pitch angle scattering, which might help the ions escape from the bow shock and move upstream. In addition, HFAs with both edges at quasi-perpendicular shocks are closer to the bow shock than those with both edges at quasi-parallel shocks. This might help the reflected ions at a quasi-perpendicular shock interact with the incident solar wind immediately after the reflection and increase the possibility of HFA formation

5 Radiation Belt, Ring Current and Plasmasphere

The resonance regions for resonant interactions of radiation belt electrons with obliquely propagating whistler-mode chorus waves were investigated in detail by Shi *et al*.[57] in the Dungey magnetic fields that are parameterized by the intensity of uniform southward IMF B_z or, equivalently, by the values of $D=(M/B_{z,0})^{1/3}$ (where M is the magnetic moment of the dipole and $B_{z,0}$ is the uniform southward IMF normal to the dipole's equatorial plane). Adoption of background magnetic field model can considerably modify the determination of resonance regions. Compared to the results for the case of D = 50 (very close to the dipole field), the latitudinal coverage of resonance regions for 200 keV electrons interacting with chorus waves tends to become narrower for smaller D-values, regardless of equatorial pitch angle, resonance harmonics, and wave normal angle. In contrast, resonance regions for 1 MeV electrons tend to have very similar spatial lengths along the field line for various Dungey magnetic field models but cover different magnetic field intervals, indicative of a strong dependence on electron energy. For any given magnetic field line, the resonance regions where chorus-electron resonant interactions can take place rely closely on equatorial pitch angle, resonance harmonics, and kinetic energy. The resonance regions tend to cover broader latitudinal ranges for smaller equatorial pitch angles, higher resonance harmonics, and lower electron energies. Calculations of quasi-linear bounce-averaged diffusion coefficients for radiation belt electrons due to nightside chorus waves indicate that the resultant scattering rates differ from using different Dungey magnetic field models, demonstrating a strong dependence of wave-induced electron scattering effect on the adoption of magnetic field model. Their results suggest that resonant wave-particle interaction processes should be implemented into a sophisticated, accurate global magnetic field model to pursue comprehensive and complete models of radiation belt electron dynamics.

Xiao *et al*.[58] reported correlated observations of enhanced whistler waves and energetic electron acceleration collected by multiple satellites specifically near the geostationary orbit during the 7–10 November 2004 superstorms, together with multi-site observations of ULF wave power measured on the ground. Energetic (> 0.6 MeV) electron fluxes are found to increase significantly during the recovery phase, reaching a peak value by similar to 100 higher than the prestorm level. In particular, such high electron flux corresponds to intensified whistler wave activities but to the weak ULF wave power. This result suggests that wave-particle interaction appears to be more important than inward radial diffusion in acceleration of outer radiation belt energetic electrons in this event, assisting to better understand the acceleration mechanism.

The Electromagnetic Ion Cyclotron (EMIC) wave has long been suggested to be responsible for the rapid loss of radiation belt relativistic electrons. Su *et al*.[59] performed test-particle simulations to calculate the bounce-averaged pitch angle advection and diffusion coefficients for parallel-propagating monochromatic EMIC waves. The comparison between Test-Particle (TP) and Quasi-Linear (QL) transport coefficients is further made to quantify the influence of nonlinear processes. For typical EMIC waves, four nonlinear physical processes, *i.e.*, the boundary reflection effect, finite perturbation effect, phase bunching and phase trapping, are found to occur sequentially from small to large equatorial pitch angles. The pitch angle averaged finite perturbation effect yields slight differences between the transport coefficients of TP and QL models. The boundary reflection effect and phase bunching produce an average reduction of > 80% in the diffusion coefficients but a small change in the corresponding average advection coefficients, tending to lower the loss rate predicted by QL theory. In contrast, the phase trapping causes continuous negative advection toward the loss cone and a minor change in the corresponding diffusion coefficients, tending to increase the loss rate predicted by QL theory. For small amplitude EMIC waves, the transport coefficients grow linearly with the square of wave amplitude. As the amplitude increases, the boundary reflection effect, phase bunching and phase trapping start to occur. Consequently, the TP advection coefficients deviate from the linear growth with the square of wave amplitude, and the TP diffusion coefficients become saturated with the amplitude approaching 1 nT or above. The current results suggest that these nonlinear processes can cause significant deviation of transport coefficients from the prediction of QL theory, which should be taken into account in the future simulations of radiation belt dynamics driven by the EMIC waves.

Su *et al*.[60] performed both theoretical analysis and numerical simulation to comprehensively investigate the nonlinear interaction between EMIC wave and relativistic electrons. In particular, they emphasize the dependence of nonlinear processes on the electron initial latitude. The nonlinear phase trapping yields negative equatorial pitch angle transport, with efficiency varying over the electron initial latitude, implying that it can increase the loss rate predicted by quasilinear theory. The nonlinear channel effect phase bunching produces positive equatorial pitch angle transport, less dependent on the electron initial latitude, suggesting that it can decrease the loss rate predicted by quasilinear theory. The nonlinear cluster effect phase bunching alternately causes positive and negative equatorial pitch angle transport, quasi-periodically dependent on the electron initial latitude, suggesting that it can either decrease or increase the loss rate predicted by the quasilinear theory. Such latitudinal dependence of nonlinear processes should be taken into account in the evaluation of radiation belt electron loss rate driven by EMIC waves.

Storm time electron radiation belt dynamics have been widely investigated for many years. Su *et al*.[61] presented a rarely reported nonstorm time event of electron radiation belt evolution observed by the Van Allen Probes during 21–24 February 2013. Within 2 days, a new belt centering around $L = 5.8$ formed and gradually merged with the original outer belt, with the enhancement of relativistic electron fluxes by a factor of up to 50. Strong chorus waves occurred in the region $L > 5$. Taking into account the local acceleration driven by these chorus waves, the two-dimensional STEERB can approximately reproduce the observed energy spectrums at the center of the new belt. These results clearly illustrate the complexity of electron radiation belt behaviors and the importance of chorus driven local acceleration even during the nonstorm times.

As an essential concept of resonant wave-particle interactions, the strong diffusion limit DSD is an important variable to explore the efficiency of wave-induced pitch angle scattering for particle precipitation loss to the atmosphere. Determined by the size of equatorial loss cone on a given field line and the bounce period at a given energy, the value of DSD sets a lower limit to the precipitation timescale for loss cone filling, regardless of the strength of wave-particle interactions. However, no efforts have ever been made to evaluate DSD in the realistic magnetosphere considering the impact of various geomagnetic activities. To perform a systematic exploration of the dependence of DSD on geomagnetic condition, spatial location, and global magnetic field model, Zhou *et al.*[61] numerically computed DSD using the dipolar and non-dipolar Tsyganenko magnetic field models under three representative (quiet, moderate, and active) geomagnetic conditions. Use of more realistic Tsyganenko magnetic field models introduces non-negligible or considerable differences in DSD magnitude from that obtained using a dipolar field. The difference can be over an order of magnitude at the field lines with equatorial crossings ≥6Re during geomagnetically disturbed times. They also reported that in the realistic magnetosphere both DSD magnitude and its variations have a strong dependence on the spatial location. Computed DSD shows the maximum tending to occur on the dayside (MLT = 12:00 and 16:00) and the minimum DSD more likely to occur at MLT= 00:00. Compared to the dipolar results, largest deviation in DSD occurs for MLT= 00:00, 04:00, and 20:00, while DSD variations on the dayside are relatively small. Their results demonstrate that accurate evaluation of DSD besides scattering rates in the realistic magnetosphere, especially at high spatial locations and under geomagnetically disturbed conditions for which a dipolar approximation fails, can make an important contribution to quantifying the wave effect on particle resonant diffusion, which should be incorporated into future modeling efforts for comprehending the role of resonant wave-particle interactions and the dynamics of magnetospheric electrons under a variety of geomagnetic conditions.

Electromagnetic Ion Cyclotron (EMIC) waves have long been suggested to account for the rapid decay of ring current, which is usually described by the quasi-linear theory. Zhu *et al.*[62] demonstrated that the interactions between ring current protons and typical EMIC waves can be highly nonlinear. A dimensionless parameter R was derived to identify the nonlinear interaction region, and a test-particle simulation was performed to analyze the motions of typical (kinetic energy E_k = 50 keV) ring current protons in detail. Nonlinear phase bunching occurs widely in the region $R<1$, whereas nonlinear phase trapping is confined in the region $R \approx 1$. The former produces the non-stochastic pitch angle decrease, probably increasing the overall loss rate predicted by the quasi-linear theory. In contrast, the latter causes the significant pitch angle increase, probably reducing the overall loss rate estimated from the quasi-linear theory. These two nonlinear mechanisms lead to complex advection and diffusion processes, and an advection-diffusion modeling is required to more accurately simulate the ring current decay induced by EMIC waves.

Yuan and Zong[63] quantitatively investigated the radiation belt dynamic variations of 1.5–6.0 MeV electrons during 54 Coronal Mass Ejection (CME)-driven storms from 1993 to 2003 and 26 Corotating Interaction Region (CIR)-driven recurrent storms in 1995 by utilizing case and statistical studies based on the data from the SAMPEX satellite. It was found that the boundaries determined by fitting an exponential to the flux as a function of L shell obtained in this study agree with the observed outer and inner boundaries of the outer radiation belt. Furthermore, they constructed the Radiation Belt Content (RBC) index by integrating the number density of electrons between those inner and outer boundaries. According to the ratio of the maximum RBC index during the recovery phase to the prestorm average RBC index, they concluded that CME-driven storms produce more relativistic electrons than CIR-driven storms in the entire outer radiation belt, although the relativistic electron fluxes during CIR-related storms are much higher than those during CME-related storms at geosynchronous orbit.

Yuan and Zong [64] further applied superposed epoch analysis to the 1.5–6.0 MeV electron flux dropout events for 110 magnetic storms related to Coronal Mass Ejections (CMEs) associated with interplanetary shocks during 1998–2003, which can help to study one of the scientific objectives of the recently launched Van Allen Probe, to determine and quantify the mechanisms of the losses in the outer radiation belt. The results obtained in their paper show that the impact of high solar wind dynamic pressure (P_{dy}) on the magnetosphere would lead to much larger electron flux dropout than low dynamic pressure. Furthermore, it is shown that southward Interplanetary Magnetic Field (IMF) condition can result in more significant dropout compared with northward IMF condition. In addition, the largest local dropout is caused by high P_{dy} with northward IMF at $L \approx 5.1$. Dropouts under high P_{dy} and southward IMF conditions are the largest, whereas dropouts under low P_{dy} and northward IMF conditions are the smallest. Their study tackles the problem of quantifying the dropouts of electrons by calculating the radiation belt content index and finding the spatial distribution of dropout and the location of maximum dropout. Another finding is that P_{dy} and IMF affect the dropouts in CME-driven storms. These new findings provide insight into which mechanisms play a more important role in different dropout events.

Yuan *et al.*[65] identified eight events with double-belt structure in the outer radiation belt from 110 Coronal Mass Ejection (CME) driven magnetic storms and 223 Corotating Interaction Regions (CIR) driven storms during 1994 to 2003 based on the SAMPEX data sets. Among them, three cases are related to CME-driven magnetic storms and five cases are related CIR-driven storms. All double-belt structure events in the outer radiation belt are found during the recovery phase of a magnetic storm for both CME- and CIR-related events—they usually start to form within 3–4 days after the onset of the magnetic storm. The preconditions needed to form a double-belt structure, for all the CME-related events, are found to be high solar wind dynamic pressure (P_{dy}) and southward interplanetary magnetic field B_z; nevertheless, for the CIR-related events, they are found to be associated with high-speed stream with southward interplanetary magnetic field, which is enhanced by a suitably orientated B_y component. It is further found that the flux distributions of the double-belt structure can be fitted well with a simply exponential decay function of L^*. Based on the radiation belt content index, the proportion of the total number of 1.5–6.0 MeV electrons inside the position of maximum fluxes to that outside the maximum fluxes keeps rising during the double-belt period, which implies that the acceleration mainly occurs at regions inside the location of maximum fluxes. They suggested that the plasmapause and the strong wave-particle interactions with VLF and ULF waves near it play an important role in the development of the double-belt structures.

Zong *et al.*[66] quantitatively investigated the radiation belt's dynamic variations of 1.5–6.0 MeV electrons during 54 CME (coronal mass ejection)-driven storms from 1993 to 2003 and 26 CIR (corotating interaction region)-driven recurrent storms in 1995 by utilizing case and statistical studies based on the data from the SAMPEX satellite. It is found that the boundaries determined by fitting an exponential to the flux as a function of L shell obtained in this study agree with the observed outer and inner boundaries of the outer radiation belt. Furthermore, they have constructed the Radiation Belt Content (RBC) index by integrating the number density of electrons between those inner and outer boundaries. According to the ratio of the maximum RBC index during the recovery phase to the pre-storm average RBC index, they conclude that CME-driven storms produce more relativistic electrons than CIR-driven storms in the entire outer radiation belt, although the relativistic electron fluxes during CIR-related storms are much higher than those during CME-related storms at geosynchronous orbit. The physical radiation belt model STEERB is based on the three-dimensional Fokker-Planck equation and includes the physical processes of local wave-particle interactions, radial diffusion, and adiabatic transport. Due to the limitation of numerical schemes, formal radiation belt models do not include the cross diffusion term of local wave-particle interactions. The numerical experiments of STEERB have shown that the energetic electron fluxes can be overestimated by a factor of 5 or even several orders (depending on the pitch angle) if the cross diffusion term is ignored. This implies that the cross diffusion term is indispensable for the evaluation of radiation belt electron fluxes. Formal radiation belt models often adopt dipole magnetic field; the time varying Hilmer-Voigt geomagnetic field was adopted by the STEERB model, which self-consistently included the adiabatic transport process. The test simulations clearly indicate that the adiabatic process can significantly affect the evolution of radiation belt electrons. The interactions between interplanetary shocks and magnetosphere can excite ULF waves in the inner magnetosphere; the excited polodial mode ULF wave can cause the fast acceleration of "killer electrons". The acceleration mechanism of energetic electrons by poloidal and toroidal mode ULF wave is different at different L shells. The acceleration of energetic electrons by the toroidal mode ULF waves becomes important in the region with a larger L shell (the outer magnetosphere); in smaller L shell regions (the inner magnetosphere), the poloidal mode ULF becomes responsible for the acceleration of energetic electrons.

6 Outer Magnetosphere

With the approaching of the 24th solar cycle peak year (2012–2014), the impacts of super solar storms on the geospace environment have drawn attentions. Based on the geomagnetic field observations during Carrington event in 1859, Wang *et al*.[67] estimated the interplanetary solar wind conditions at that time, and investigated the response of the magnetosphere-ionosphere system to this extreme solar wind conditions using global 3D MHD simulations. The main findings include: (1) The dayside magnetopause and bow shock are compressed to 4.3 and 6.0 R_e (Earth radius), and their flanks are also strongly compressed. The magnetopause shifts inside the geosynchronous orbit, exposing geosynchronous satellites in the solar wind in the magnetosheath. (2) During the storm, the region-1 current increases by about 60 times, and the cross polar potential drop increases by about 80 times; the connection voltage is about 5 to 6 times larger than the average storms, which means a larger amount of the solar wind energy enters the magnetosphere, resulting in strong space weather phenomena.

Tang *et al*.[68] performed a statistical study of the surface current at the High-Latitude Magnetopause (HLMP) and the bow shock under different southward Interplanetary Magnetic Field (IMF) conditions, taking advantage of the crossing events of these discontinuities by the Cluster spacecraft. With an enhancement of southward IMF B_z, the surface current at HLMP reduces, while increasing at the bow shock. Since the amount of the magnetospheric current increases with the increase of southward IMF B_z, a synthesis analysis based on the Cluster observations suggests the bow shock and HLMP together contribute to the magnetospheric current system, and the bow shock would become an important current generator when the southward IMF B_z becoming large. This scenario accords with the previous global Magnetohydrodynamic (MHD) simulations.

Li *et al*.[69] investigated the global features of Kelvin-Helmholtz Waves (KHW) at the low-latitude magnetopause for constant northward interplanetary magnetic field conditions, using global magnetohydrodynamic simulations. The Root-Integrated Power (RIP) of X component of bulk velocity is employed to analyze the magnetopause mode of KHW along the boundary layer. The RIP distribution of the outer KHW is much broader than that of the inner one, and the maximum amplitude of global KHW occurs near the dawn/dusk terminator regions. In the dayside magnetopause, the phase of the waveform at middle latitudes leads to that at low latitudes, while the situation reversed in the nightside. The global evolution of KHW phases is a representation of an interesting feature that the axis of the Kelvin-Helmholtz vortex aligns with the geomagnetic field lines. They suggested that the reported features may also exist in other KHW active regions with flow-sheared plasma.

It is generally accepted that Electromagnetic Ion Cyclotron (EMIC) waves are generated around the equatorial regions and propagate toward the high latitude ionospheres in both hemispheres. Liu *et al*.[70] described a prolonged EMIC wave event in the Pc2 (0.1–0.2 Hz) frequency band above the He^+ cyclotron frequency detected by the four Cluster satellites as they traversed sunward from $L \approx 13$ in the outer magnetosphere to the magnetopause, over 13° – 20° magnetic latitude north of the equator and across the high latitude cusp region near local magnetic noon. Wave packet energy propagated dominantly along the geomagnetic field direction, confirming this was a traveling EMIC wave rather than a toroidal field line resonance. The energy packets propagated in alternating directions rather than uni-directionally from the equator, implying the wave source was located in a high latitude region away from the equator, where a minimum in the B field is located. The CIS-CODIF H^+ ion data provided evidence that the waves were generated locally via the ion cyclotron instability. They believed the off-equatorial minimum magnetic field regions may be important source regions for these waves in the outer magnetosphere.

Two types of Poleward-Moving Plasma Concentration Enhancements (PMPCEs) during a sequence of pulsed reconnection events were identified by Zhang *et al*.[71], both in the morning convection cell: Type L (Low density) was associated with a cusp flow channel and seems likely to have been produced by ionization associated with particle precipitation, while Type H (High density) appeared to originate from the segmentation of the Tongue of Ionization (TOI) by the processes which produced the Type L events. As a result, the Type L and Type H PMPCEs were interspersed, producing a complex density structure which underlines the importance of cusp flow channels as a mechanism for segmenting and structuring electron density in the cusp, and shows the necessity of differentiating between at least two classes of electron density patches.

7 Magnetotail

Pang *et al*.[72] studied multiple plasma bubbles detected by Cluster satellites on August 15th 2001 in midtail

(~18 R_e). Those bubbles can be classified into two types. Type-I bubbles are similar to those bubbles in previous studies. Unlike type-I bubbles, the trailing parts/tails of type-II bubbles are much more dynamic than their leading parts/heads and have larger the flux transfer rate. The leading parts of type-II bubbles were suffering a deceleration process and the interaction between the leading and trailing parts will lead to the intensification of $|B|$ and B_z and also a flow shear layer at the trailing parts. Those shear flows cause the twist of magnetic field line, the enhancement of x and y components magnetic field and the generation of field aligned current system. Enhancement of electric field fluctuations also can be found at the trailing parts of type-II bubbles. The corresponding ionospheric signatures were also detected by ground geomagnetic stations. They suggested that the type-II bubbles are bubbles in their late evolution stage and their results are important in understanding the evolution of plasma bubble or fast flow and the transportation of energy from magnetotail to ionosphere.

Fast plasma flows are believed to play important roles in transporting mass, momentum, and energy in the magnetotail during active periods, such as the magnetospheric substorms. Zhou *et al*.[73] presented Cluster observations of a plasma depleted flux tube, *i.e.*, a plasma bubble associated with fast plasma flow before the onset of a substorm in the near-Earth tail around $X \approx 18\ R_e$. The bubble is bounded by both sharp leading ($\partial B_z/\partial x<0$) and trailing ($\partial B_z/\partial x>0$) edges. The two edges are thin current layers (approximately ion inertial length) that carry not only intense perpendicular current but also field-aligned current. The leading edge is a Dipolarization Front (DF) within a slow plasma flow, while the trailing edge is embedded in a super-Alfvénic convective ion jet. The electron jet speed exceeds the ion flow speed thus producing a large tangential current at the trailing edge. The electron drift is primarily given by the $\boldsymbol{E}\times\boldsymbol{B}$ drift. Interestingly, the trailing edge moves faster than the leading edge, which causes shrinking of the bubble and local flux pileup inside the bubble. This results in a further intensification of B_z, or a secondary dipolarization. Both the leading and trailing edges are tangential discontinuities that confine the electrons inside the bubble. Strong electron acceleration occurrs corresponding to the secondary dipolarization, with perpendicular fluxes dominating the field-aligned fluxes. They suggested that betatron acceleration is responsible for the electron energization. Whistler waves and lower hybrid drift waves were identified inside the bubble. Their generation mechanisms and potential roles in electron dynamics were discussed.

Huang *et al*.[74] studied multiple Dipolarization Fronts (DFs) observed by Cluster spacecraft in the magnetotail during a substorm. These DFs were kinetic structures, embedded in the bursty plasma flow, and moved earthward (mainly) and dawnward. Intense electric field, parallel and perpendicular currents were detected in the DF layer. These front layers were energy dissipation region (load region) where the energy of electromagnetic fields were transferred to the plasma thermal and kinetic energy. This dissipation was dominated by electrons. There were enhancements of plasma waves around the DF region: wavelet results show that wave activities around the ion cyclotron frequency in the front layer were generated by Alfvén ion cyclotron instability; whistler waves were also detected before, during and after the DFs, which are triggered by electron temperature anisotropy and coincident with enhancement of energetic electron fluxes. The observation of these waves could be important for the understanding of evolution of DF and electron energization during the substorm. They discussed the generation mechanism of the DFs and suggested that these DFs were generated in the process of transient reconnection, and then traveled toward the Earth.

Using a newly modified global Magnetohydrodynamics (MHD) simulation model and test-particle method, Guo *et al*.[75] investigated the mechanism of plasma transfer into the near-tail plasma sheet under different Interplanetary Magnetic Field (IMF) conditions (northward and southward). The results explain some well-known observations and clearly reveal the physical nature of the plasma transfer: particles mainly originate from the solar wind under a northward IMF and from the Earth under a southward IMF. They found solar wind particles transfer into the plasma sheet through dusk and dawn flanks under a northward IMF, and the transfer paths are consistent with merging sites on the magnetopause. When the IMF is southward, the solar-wind plasma transferring into the plasma sheet is mainly from the northern and southern sides. The average energy of the injected ions is much higher when the IMF is southward, which would result in a shorter stay-time in the plasma sheet. The tail terrestrial magnetic field lines are more open in the north–south direction when the IMF is southward, and this pattern makes it easier for terrestrial particles with higher energies to be ejected into the plasma sheet.

The strong magnetic field B_y component (in GSM coordinates) has been increasingly noticed to play an important role in the dynamics of tail Current Sheet (CS). The distribution profile of strong B_y components in the tail CS (*i.e.*, those with guide field), however, is not well known. Using the simultaneous multipoint observations of Cluster satellites, Rong *et al*.[76] studied the profile of a strong B_y component in tail current sheets, through detailed case studies, as well as by a statistical study. It was discovered that around the midnight meridian, the strength of the strong B_y component, *i.e.*, $|B_y|$, is basically enhanced at the center of the CS relative to that in the CS boundaries and lobes and forms a north-south symmetric distribution about the center of CS. Generally, however, for strong guide field cases in the non-midnight meridian, the profile of B_y strength basically becomes north-south asymmetric, the strength of the B_y component in the northern side of the CS was found to be either stronger or weaker than that in the counterpart southern side. B_y considering the modulation of the tail flaring magnetic field with magnetic local time, they proposed an interpretation to account for the variation of the B_y-profile, which is supported by the statistical survey. These results offer an observation basis for further studies.

Shen *et al*.[77] presented a generalized multipoint analysis of physical quantities, such as magnetic field and plasma flow, based on spatial gradient properties, where the multipoint data may be taken by irregular (distorted) configurations of any number of spacecraft. The methodology was modified from a previous, fully 3-D gradient analysis technique, designed to apply strictly to 4-point measurements and to be stable for regular spacecraft configurations. Here, they adapted the method to be tolerant against distorted configurations and to return a partial result when fewer spacecraft measurements are available. They applied the method to a variety of important physical quantities, such as the electric current density and the vorticity of plasma flows based on Cluster and THEMIS multiple-point measurements. The method may also have valuable applications on the coming Swarm mission.

It was revealed for the first time by Shen *et al*.[78] that the full magnetic field gradient and current density distribution can be derived from two spacecraft magnetic field measurements under the assumptions that the magnetic field is approximately stationary and force-free, conditions which are particularly relevant to low altitude regions of the Earth's magnetosphere and in the regions containing the field aligned current systems. The magnetic field gradients along the spacecraft line, spacecraft velocity direction and the normal direction can be defined so that the full magnetic field gradient tensor is determined, projected into any coordinate system. One test for an ideal situation has been made, which confirms the validity of this approach with very high accuracy. This method can be applied to the determination of the magnetic field gradient tensor and current density for the forthcoming multi spacecraft Swarm mission.

Electrons streaming along the magnetic field direction are frequently observed in the plasma sheet of Earth's geomagnetic tail. The impact of these field-aligned electrons on the dynamics of the geomagnetic tail is however not well understood. Zheng *et al*.[79] reported the first detection of field-aligned electrons with fluxes increasing at ~1 keV forming a "cool" beam just prior to the dissipation of energy in the current sheet. These field-aligned beams at ~15 R_e in the plasma sheet are nearly identical to those commonly observed at auroral altitudes, suggesting the beams are auroral electrons accelerated upward by electric fields parallel ($E_{\|}$) to the geomagnetic field. The density of the beams relative to the ambient electron density is $\delta\ n_b/n_e$ similar to 5%–13% and the current carried by the beams is about 10^{-8}–10^{-7} A·m^{-2}. These beams in high beta plasmas with large density and temperature gradients appear to satisfy the Bohm criteria to initiate current driven instabilities.

The fine magnetic field structure of two successive plasmoids previously reported is investigated by Zhang *et al*.[80] by means of magnetic rotation analysis using four Cluster satellite data. Between these two plasmoids, opposite trends of curvature radius (R_c) variations of the magnetic field lines from the boundary to the inner part are found. The different variations of R_c reflect that the two plasmoids have different magnetic configurations. The electric current density distributions for both plasmoids are found distinct. The B_y increase and abundant field-aligned currents in the narrow core region of the first plasmoid indicate that a possible Magnetic Flux Rope (MFR) core exists inside. The results indicate that the first observed plasmoid is of a Magnetic Loop (ML) type (with possible MFR core) and the second plasmoid is of a MFR type. The coexistence of ML and MFR in the near-Earth plasma sheet may imply that multiple X line reconnection can occur by either an antiparallel or a component-parallel way.

Wu *et al*.[81] studied the development of the proton temperature anisotropy $T_\perp/T_\|$ in bursty bulk flows, as observed by THEMIS Mission. For a set of 10 selected events, during which at least 3 spacecrafts were aligned in the same flow, they coule sample the plasma parameters along the Earth's magnetotail. The temperature anisotropy in the quiescent tail was negligible. However, as soon as the Bursty Bulk Flow (BBF) passed over the spacecraft a strong anisotropy was measured. They analyzed $T_{\perp}/T_{\parallel}$ as a function of parallel plasma beta-$\beta_{\parallel}(=nkT_{\parallel}/(B^2/2\mu_0))$ for the different THEMIS satellites and compare the spread of the data points with various instability thresholds over ion-scales that can reduce the temperature anisotropy: for $T_{\perp}/T_{\parallel}<1$ the parallel and oblique firehose; for $T_{\perp}/T_{\parallel}>1$ the proton cyclotron and mirror mode. It is shown that the anisotropy reduces whilst the BBF is moving Earthward, and the strongest fluctuations are enhanced along the instability thresholds, indicating that these instabilities reduce the proton temperature anisotropy.

Wu *et al.*[82] also investigated the electron acceleration behind dipolarization fronts (DFs) in the magnetotail from $-25\ R_e$ to $-10\ R_e$ through the examination of the energetic electron energy flux (>30 keV) with the observations from THEMIS satellites. Statistical results of 133 DF events were presented based on the dataset from January to April of the years 2008 and 2009. As the DFs propagate earthward, the acceleration of energetic electrons behind the DFs was found to take place over several Re along the tail. The increase in energetic electron energy flux can reach 2~4 orders of magnitude. The dominant acceleration mechanisms are different in the mid-tail ($X_{GSM}\leqslant -15\ R_e$) and the near-Earth region ($-15< X_{GSM}\leqslant -10\ R_e$). In the mid-tail, the majority of DF events show that the dominant electron acceleration mechanism is betatron acceleration. In the near-Earth region, betatron acceleration is dominant in ~46% DF events while Fermi acceleration is dominant in ~39% DF events.

In August 2001, Cluster satellites observed that the mid-tail Current Sheet (CS) moves southward continuously for almost seven hours. Meanwhile, Cluster crosses back and forth the CS repeatedly. This means that the large-scale southward movement of the CS is accompanied by a small-scale CS flapping during this period. Using the Minimum-Variation-Analysis (MVA) method and the multi-spacecraft data, Duan *et al.* [83] calculated the normal vector, current density and the magnetic curvature of the CS, which show that the CS alternates between flattened CS and tilted CS for several times. Strong dawn-dusk oscillations were found for the tilted CS, which caused the repeated crossings of the center of CS by the satellites. This feature is obviously different from the previous observations of the vertical flapping of the CS induced by the kink instability. Two types of flapping were observed: one of them is accompanied with Bursty Bulk Flows (BBFs) and the other is not. This suggests that in this event there is no direct relationship between the CS flapping and BBFs.

Based on the magnetic field and plasma data obtained by GEOTAIL in 1992–1995 and WIND in 1994–2009, Tian *et al.*[84] studied statistically the magnetic field and plasma properties in the magnetotail near lunar orbit using the superposed epoch analysis. The results showed that near the 0 degrees sector the plasma density was negatively correlated with *Dst* index while the temperature was positively correlated with *Dst* index. The plasma velocity and magnetic field strength had little correlation with *Dst* index. Around the current sheet near the lunar orbit, the B_x varied between –15 and 15 nT, the plasma density was less than 0.4 cm^{-3}, the median of plasma density for all events was less than 0.1 cm^{-3}, the temperature varied from 0.016 to 8.98 keV, the median of the plasma temperature for all the events was similar to 3 keV, the median of speed was about 200 km·s^{-1} and the maximum speed was up to 1500 km·s^{-1}. The tailward and earthward flows could be observed accompanied with the current sheet. For the current sheet cases with tailward flow, the B_x varied from –15 to 15 nT, the upper quartile of plasma velocity was more than 400 km·s^{-1}, the maximum speed was up to 1500 km·s^{-1}. For the current sheet cases with tailward flow, the B_x varied from 10 to 10 nT, the upper quartile of plasma velocity was less than 400 km·s^{-1}, the maximum speed was up to 1200 km·s^{-1}. The median of plasma density, temperature and velocity were similar for the two categories. Their paper discussed the relationship between above results and magnetic reconnection at magnetic tail, compared the above results with the observation in the far magnetotail. They fitted the statistical results according to the Harris current sheet model, and the observation was consistent with Harris current sheet model. The above results can provide useful information for the design and protection of lunar-orbiting spacecraft and can be used as the background magnetic field and plasma parameters in the numerical simulation of mid-magnetotail reconnection.

Tian *et al.*[85] studied the compressional wave event in Pc5 frequency range observed in the dawn-side magnetic equator on 9 March 1998 by Grad-Shafranov (GS) reconstruction method for the first time. To test the effectiveness of application of GS method on Pc5 compressional wave, they benchmarked their procedure by applying it to a one-dimensional current sheet model first. Excluding the left-hand corners, the average error magnitude was less than 10%. The reconstruction of actual data showed that they obtained the 2-D map of compressional wave without suffering model constraints for the first time. The magnetic filed lines density cyclical changed, and the wavelength was about 2–4 times earth radius. The reconstructed magnetic topology had a shape very similar to the empirical 2-dimensional standing wave model proposed by the former workers. Besides, they also recovered the plasma thermal pressure and current density of the wave quantitatively.

Spacecraft and ground-based observations were used by Tian *et al*.[86] to study characteristics of ultralow frequency waves in the plasma sheet from the postmidnight to morning local time sectors in the terrestrial magnetosphere. Field line resonance (FLR) type oscillations with discrete and latitude-dependent frequencies in the ranges of 1.7–2.0 and 3.0–3.2 mHz were observed in situ by the Time History of Events and Macroscale Interactions during Substorms C (THEMIS C), THEMIS D, THEMIS E, and GOES 12 spacecraft. The ground resonant oscillations in the two mentioned frequency bands were also observed at corresponding spacecraft footprints. Spectral peaks at these frequencies were observed by nearly all ground stations from premidnight to noon, with the larger-amplitude oscillations occurring in a narrow range of latitudes (3 degrees-6 degrees). The largest wave activity occurred in the magnetic local time of similar to 05:00. The ground observations indicate westward propagation for the 1.8 mHz wave activity with an azimuthal wave number of about –2.6. The Poynting vectors from the THEMIS spacecraft show weak net energy flow (anti field aligned) toward the ionosphere of the southern hemisphere. They also showed notable net energy flow toward the west. A possible interpretation is that the observed FLRs are driven by cavity and waveguide modes in the nightside outer magnetosphere after a period of long-lasting northward interplanetary magnetic field.

Nose event, which names after the nose-like shape of structures in ion spectrograms observed by satellite in the inner magnetosphere, refers to the deep inward penetration of ions from magnetotail at discrete energy bands. Wang and Zong[87] used the UBK method to model the different L-shell penetration characteristics for a multi-band nose event observed by Cluster/CODIF on April 11, 2002. The modeled open-closed orbit separatrices are generally smaller than the observed L-shell penetrations for outbound crossing; the difference varies from –2.02 to –0.62 R_e for different energy channels of H^+ bands and from –1.88 to –1.10 R_e for O^+ band. The average difference is –1.46 R_e. The separatrices for the inbound crossing are generally larger than those of outbound crossing and are more consistent with the observed L-shell penetration depths. The modeled open-closed orbit separatrices are smaller than the observed L-shell penetrations for 6.5–17.1 keV energy channels of H+ bands but larger for 4.0–5.1 keV (due to closed banana orbits region) and 21.7–35.2 keV (due to energy increasing) energy channels of H^+ bands. For O^+ band, the difference between the modeled open-closed orbit separatrix and observed L-shell penetrations of 4.6 keV energy channel is larger (due to closed banana orbits region), the difference of 7.4 keV energy channel is smaller. The overall average difference is 0.043 R_e for nose structures of inbound crossing. The discrepancies between the model and observation may come from the magnetic field and electric potential models they used. The formation of multi nose event and relations to the observed plasma flow vortices were discussed, the local intense $E(Y)$ may relate to the formation of the observed multi nose structures.

The electric structure of Dipolarization Fronts (DFs) is very important to both DF dynamics and particle acceleration. Lu *et al*.[88] performed two-dimensional Hall MHD simulation to study the electric structure of DF produced by interchange instability on the scale of ion inertial length in the flow braking region of near-Earth tail. The results indicate that the Hall effect makes the structures of plasma density and magnetic field deformed in the dawn-dusk direction. This deformation is caused by the induced Lorentz force along the tangent plane of DF, which is associated with the outward moving of demagnetized ions driven by the ion-scale Earthward electric field on DF. In addition, the x component of electric field contributed jointly by Hall and electron pressure gradient terms along with B_z can produce a dawnward $\boldsymbol{E} \times \boldsymbol{B}$ drift to the whole “mushroom” structure. Inside the DF, the electric field is mainly produced by Hall term, and the contributions from the convectional and electron pressure gradient electric fields are very small. This indicates that the ion frozen-in condition of magnetic field is violated inside the DF. Therefore, it is the electric field contributed by Hall term inside the DF that changes the overall MHD “mushroom” pattern. The comparison between the simulation results and the observations of THEMIS satellites demonstrates that the model of Hall MHD simulation can reproduce the plasma and electric field observed at DF.

Using nine years of Cluster data, Cao *et al.*[89] statistically investigated the relations of central plasma sheet energetic proton fluxes, about 30–380 keV, with the solar wind parameters and geomagnetic indexes. The energetic proton fluxes increase with increasing solar wind dynamical pressure and solar wind speed. The energetic proton fluxes are more correlated with solar wind dynamical pressure than with solar wind speed. During northward IMF B_z, energetic proton fluxes are independent of northward IMF B_z while during southward IMF B_z, energetic proton fluxes are highly correlated with southward IMF B_z and increase with increasing IMF $|B_z|$. The response time of energetic proton flux to southward IMF B_z is around 80 min. The energetic proton fluxes are correlated with plasma sheet ion temperature. The energetic proton fluxes increase with increasing indexes of *Kp*, *AE* and $|Dst|$. Among three geomagnetic indexes, the CPS energetic proton fluxes are most correlated with *Kp* index with the largest correlation coefficient being 0.82. The energetic proton fluxes are large during positive *Dst* index, suggesting that the sharp jump of solar wind dynamical pressure can enhance the plasma sheet energetic proton fluxes. The enhanced plasma sheet energetic proton fluxes may be important for geomagnetic storms and substorms since they can possibly directly become the source of ring current and substorm injected energetic particles without the need of additional acceleration process in the inner magnetosphere.

Li *et al.*[90] studied rapid loss of the plasma sheet energetic electrons associated with the growth of whistler mode waves inside the bursty bulk flows. During the interval about 07:45:36 UT–07:54:24 UT on 24 August 2005, Cluster satellites (C1 and C3) observed an obvious loss of energetic electrons (~3.2–95 keV) associated with the growth of whistler mode waves inside some bursty bulk flows (BBFs) in the midtail plasma sheet ($x_{GSM}\approx -17.25\ R_e$). However, the fluxes of the higher-energy electrons ($\geqslant$128 keV) and energetic ions (10–160 keV) were relatively stable in the BBF-impacted regions. The energy-dependent electron loss inside the BBFs is mainly due to the energy-selective pitch angle scatterings by whistler mode waves within the time scales from several seconds to several minutes, and the electron scatterings in different pitch angle distributions are different in the wave growth regions. The plasma sheet energetic electrons have mainly a quasi-perpendicular pitch angle distribution ($30° < \alpha < 150°$) during the expansion-to-recovery development of a substorm (*AE* index decreases from 1677 nT to 1271 nT), and their loss can occur at almost all pitch angles in the wave growth regions inside the BBFs. Unlike the energetic electrons, the low-energy electrons (~0.073–2.1 keV) have initially a field-aligned pitch angle distribution ($0°\leqslant \alpha \leqslant 30°$ and $150°\leqslant \alpha \leqslant 180°$) in the absence of whistler mode waves, and their loss in field-aligned directions is accompanied by their increase in quasi-perpendicular directions in the wave growth regions, but the loss of the low-energy electrons inside the BBFs is not obvious in the presence of their large background fluxes. These observations indicate that the resonant electrons in an anisotropic pitch angle distribution mainly undergo the rapid pitch angle scattering loss during the wave-particle resonances.

Magnetic holes with relatively small scale sizes, detected by Cluster and TC-1 in the magnetotail plasma sheet, were studied by Sun *et al.*[91]. It was found that these magnetic holes are spatial structures and they are not magnetic depressions generated by the flapping movement of the magnetotail current sheet. Most of the magnetic holes (93%) were observed during intervals with B_z larger than B_x, *i.e.* they are more likely to occur in a dipolarized magnetic field topology. Their results also suggest that the occurrence of these magnetic holes might have a close relationship with the dipolarization process. The magnetic holes typically have a scale size comparable to the local proton Larmor radius and are accompanied by an electron energy flux enhancement at a 90° pitch angle, which is quite different from the previously observed isotropic electron distributions inside magnetic holes in the plasma sheet. It is also shown that most of the magnetic holes occur in marginally mirror-stable environments. Whether the plasma sheet magnetic holes are generated by the mirror instability related to ions or not, however, is unknown. Comparison of ratios, scale sizes and propagation direction of magnetic holes detected by Cluster and TC-1, suggests that magnetic holes observed in the vicinity of the TC-1 orbit (~7–12 R_e) are likely to be further developed than those observed by Cluster (~7–18 R_e).

Current densities associated with Dipolarization Fronts (DFs) have been calculated in the geomagnetic tail using the curlometer technique applied to high-resolution magnetic field $\vec{\boldsymbol{B}}$ data obtained by the four Cluster spacecraft. Sun *et al.*[92] then use the relation $\langle b\rangle\cdot(\nabla\times\vec{\boldsymbol{B}})$ to characterize the behavior of Field-Aligned Current (FAC) during 25 DF events. Their results show that the magnitude of FAC density ($J_{//}$) ranges from 5 to 20 nA·m^{-2}, and they are observed in Northern and Southern Hemispheres flowing along both directions of the $\vec{\boldsymbol{B}}$-field. The FACs have dimensions characteristic of the DFs and with region-1 current sense flowing inside the DFs and region-2 sense just in front of DF (in the B_z dips). Most of their observations come from 15 to 20 R_e in the tail, different from previous statistical studies based mainly on observations made around 9–12 R_e. They suggested that DFs can sustain significant FACs and appear as “wedgelets” in the early stage.

Zheng *et al*.[93] studied downward current electron beams observed at the dipolarization front. The strong field-aligned pitch angle distribution of electrons was observed right at the Dipolarization Front (DF) before the arriving of a high speed flow when the four Cluster satellites are traveling in the magnetotail around 15 R_e on July 22, 2001. The increased electron fluxes only lasted for a short time period at the DF, corresponding to just a few bouncing periods for 1 keV electrons. The field-aligned current contributed by these electrons agrees well with that calculated by the magnetic field observations by four satellites at the front. These electron streams are found in the energy range of 0.2–2 keV, peak around 1 keV. It is suggested that these downward current electrons may be originated near the aurora region by some kinds of potential structure. The occurrence of these electrons implies that the formation of the dipolarization front and the associated field-aligned current play an important role in the magnetosphere-ionosphere coupling.

Rong *et al*.[94] developed a new simple method for inferring the orientation of a magnetic flux rope, which is assumed to be a time-independent cylindrically symmetric structure *via* the direct single-point analysis of magnetic field structure. The model tests demonstrate that, for the cylindrical flux rope regardless of whether it is force-free or not, the method can consistently yield the axis orientation of the flux rope with higher accuracy and stability than the minimum variance analysis of the magnetic field and the Grad-Shafranov reconstruction technique. Moreover, the radial distance to the axis center and the current density can also be estimated consistently. Application to two actual flux transfer events observed by the four satellites of the Cluster mission demonstrates that the method is more appropriate to be used for the inner part of flux rope, which might be closer to the cylindrical structure, showing good agreement with the results obtained from the optimal Grad-Shafranov reconstruction and the least squares technique of Faraday's law, but fails to produce such agreement for the outer satellite that grazes the flux rope. Therefore, the method must be used with caution

Cao *et al*.[95], using the dataset of Bursty Bulk Flows (BBFs) observed by two Cluster satellites C1 and C4, studied the difference between onset times of BBFs observed by C1 and C4. It is found that the onset time differences of most of BBFs observed by C1 and C4 are smaller than 60s. The average onset time difference of BBFs of C1 and C4 is 68.5 s. The probabilities of onset time difference of BBFs of C1 and C4 larger than 30 s, 60 s, 90 s and 120 s are respectively 55%, 35%, 27% and 23%. The largest onset time difference of BBFs of C1 and C4 decreases with the increase of earthward component of maximum velocities of BBFs. The onset time difference of BBFs of C1 and C4 results from the velocity inhomogeneity inside the flow channel of BBF, which may be produced in propagation path and/or in source region of BBFs. Such a wide range of onset time difference of BBFs suggests that the velocity inhomogeneity inside the flow channel of BBF is various. These results are very important to the current study of substorm research based on THEMIS data because they indicate that it is impossible to determine the onset time of BBF with a single satellite.

Recently, observational results on currents around the Dipolarization Fronts (DFs) of earthward flow bursts have attracted much research attention. These currents are found to have close association with substorm intensifications. Yao *et al*.[96] studied the current system ahead and within the DFs with high-resolution magnetic field measurements from Cluster constellation in 2003. The separation of four spacecraft is much smaller than the scales of spatial structures ahead and within the DF layer so that the currents can be reliably obtained. Based on features of the magnetic field variations prior to the fronts, they categorized the DFs into two types: DFs with magnetic dips immediate ahead of the fronts (type I) and DFs without magnetic dips (type II). For type I DFs, it is found that dawnward currents along the DFs exist in the dip region; duskward currents exist within the fronts. Furthermore, the dawnward currents in the dip region are found to be mainly parallel to the local magnetic field with a spatial scale of similar to 1000 km, whereas the duskward currents within the fronts have both significant parallel and perpendicular components. On the other hand, for type II DFs, only significant duskward and mainly perpendicular currents show up within the fronts; no dawnward currents exist ahead of DFs. The dawnward and mainly parallel current in the type I DFs is important in the current coupling process between magnetosphere and ionosphere and may lead to local current disruptions for substorm initiations.

On the basis of the plasma, electric and magnetic fields jointly observed by Cluster and the Double Star TC-1 spacecraft in the Earth's magnetotail, Ma *et al.*[97] investigated the earthward flow bursts by introducing the momentum equation in the *X*-direction in the ideal conditions of Magneto Hydrodynamics (MHD). One earthward flow burst with a peak in excess of 500 km·s^{-1} was selected, when the four spacecraft of Cluster were located around 16 R_e and TC-1 was located around 10 R_e in the *X*-direction. The inter-spacecraft distances in *Y* and *Z* directions were smaller than the statistical spatial scales of the bursty bulk flows. When the *Y* components of $\boldsymbol{E}$ and $\boldsymbol{V}\times\boldsymbol{B}$ were compared, there was no clear breakdown of the frozen-in condition during the earthward flow burst. With the measured plasma and magnetic parameters from two spacecraft at different positions in the magnetotail, the *X* component of the pressure gradient was calculated. Magnetic tension was calculated using the magnetic field measured at four points, which could be compared with the assumed constant in the past research with single satellite. When the pressure gradient and the magnetic tension were put into the MHD momentum equation, some samples of the earthward flow bursts were accelerated and some were decelerated. The braking process of the earthward flow burst was more complicated than what the past results had shown. The accelerated samples accounted for about one third of the whole earthward flow bursts and discontinuously located among the decelerated elements. The original single earthward flow burst event might be split into several short flow bursts when it was moving to the Earth. Their results may partly illustrate that the duration of fast flows during three phases of substorm becomes short near the Earth. The results are consistent with the past results that fast flows intrude to places earthward the typical braking region.

A flapping wave was observed by THEMIS-B (P1) and THEMIS-C (P2) probes on the dawn side of the magnetotail, while the solar wind was generally stable. The magnetic activity was quite weak, suggesting that this flapping wave was generated by an internal instability, which normally occurs during magnetic quiet times. Sun *et al.*[98] showed that the flapping wave was propagating downward with a tail-aligned scale of at least 3.7 R_e and did not show much change in shape during its propagation from P1 to P2. Correlation analysis employed to estimate the time lag between the corresponding half waveforms of P1 and P2 shows that the propagating velocities along the current sheet normal directions were close to each other in the beginning, but increased linearly later on. The average wavelength of the flapping wave is approximately 4 R_e. Theoretical analysis suggests that the ballooning type wave model may not be the mechanism for the observed flapping wave, but that the magnetic double-gradient instability model is a more plausible candidate.

The motion and deceleration processes of plasma sheet high-speed flows have great significance to magnetospheric particle acceleration, magnetic field perturbation, magnetic flux transport, triggering of substorm, and the current system formation in the magnetotail. From February to April 2009, two satellites of the THEMIS during Substorms mission, THA and THE, were often separated largely in *Z* direction, but had small *X* and *Y* separations. Such special configuration allows simultaneous observations of high-speed flows at the center and boundary of the plasma sheet. Based on selected case study and statistical analysis, Shang *et al.*[99] found that for about 89% of the events they selected, the probe further away from the neutral sheet observed the high-speed flow earlier than the one close to the center, and the flow is mainly field aligned. And for about 95% events the probe further away from the neutral sheet observed higher *X* component of the plasma flow. With the hypothesis that parallel flow keeps the same speed during its earthward propagation while central plasma sheet stream uniformly or suddenly brakes on its way to the earth, they deduced the position where the deceleration begins to be between 13 R_e and 17 R_e downtail, where the near-Earth reconnection is supposed to occur. In addition, their statistical results show that dipolarization fronts observed in the central plasma sheet are more prominent than those observed in the plasma sheet boundary layer ahead of the high-speed flow.

8 Geomagnetic Field and Auroras

Poleward Moving Auroral Forms (PMAFs) are statistically investigated by using continuous, high-quality, optical observations for six winters obtained from three-wavelength all-sky imagers at the Chinese Yellow River Station (78.92° N, 11.93° E), Svalbard, in the Arctic. Xing *et al.*[100] examined the dependence of the PMAF occurrence on solar wind conditions in the Magnetic Local Time (MLT) range of 09:00 MLT–15:00 MLT. Comparing to the previous studies, their larger PMAFs data base enables us to examine how the PMAFs' occurrence depends on each Interplanetary Magnetic Field (IMF) component in different MLT sectors. It was found that 59%, 60%, and 57% of the PMAF events occurred under IMF conditions of negative B_z, positive B_y, and negative B_x, respectively. They also found that the

PMAFs show a tendency to occur preferentially under large IMF $|B_x|$ conditions. The MLT dependence of PMAFs presents a remarkable tendency of decreasing in the midday sector, showing a clear IMF By-related prenoon-postnoon asymmetry, which is consistent with the motion of reconnected flux tubes due to the release of magnetic field tension. For the first time, they found, however, that the asymmetry is more evident during conditions of $B_z > 0$ than $B_z < 0$, suggesting the importance of the effect of the lobe reconnection. Their statistical results suggest that the PMAFs are not caused by the solar wind pressure pulses, but by bursts of magnetic reconnection.

Using high temporal resolution optical data obtained from three-wavelength all-sky imagers over six winters continuously at Yellow River Station (78.92° N, 11.93° E) in Arctic, Xing *et al*.[101] statistically investigated the dependence of location of Poleward Moving Auroral Forms (PMAFs) on the Interplanetary Magnetic Field (IMF) B_z and B_y components as a function of MLT and MLAT under stable IMF conditions. It is found that more PMAFs occurred in lower latitude for $B_z < 0$ and there was less evident IMF B_y-related prenoon-postnoon asymmetry for $B_z < 0$ than for $B_z > 0$. They found that the PMAFs distributed over a wide range of MLT when $B_z < 0$, which indicates that the reconnection X-line might spread like an S shape. However, during northward IMF, PMAFs were observed predominantly prenoon for IMF $B_y > 0$ and postnoon for IMF $B_y < 0$ associating with the effect of the high-latitude reconnection, which is largely consistent with the theoretical model of the convection flow.

The aurora is one of the most significant visible manifestations of the dynamic processes associated with the precipitation of particles into the polar ionosphere generated by the solar-terrestial interactions, which has played an important role in understanding our Earth's environment and predicting the space weather. Using high temporal resolution optical data obtained from the three-wavelength all-sky imagers at Yellow River Station (YSR) in the Arctic, together with the particle precipitation data measured by the DMSP satellites, Xing *et al*.[102] investigated the quantitative relationship between the auroral intensities and the energy features of the precipitated particles near magnetic noon. The statistical results indicated that the soft auroral electron precipitation was dominated near magnetic noon during 10:00–13:00 MLT with 630.0 nm auroral emissions. The I (630.0 nm) / I (427.8nm) ratio decreased as the intensity of 427.8nm increased in the 13:00 MLT–14:00 MLT sector, suggesting the energy of the precipitated particles was getting higher. In addition, the intensity of 427.8 nm was dependent on the total energy flux of the precipitating electrons and the I(630.0 nm)/I(427.8 nm) ratio was related to the average energy. They have built a parameter model of auroral emissions and particle precipitation near magnetic noon at YSR, which will serve to monitor the space weather in the future.

Due to the altitudinal extent of an auroral arc, its observed width is different at different zenith angle even when its real width is the same. For that reason, former measurements of arc widths were obtained only for arcs located close to the geomagnetic zenith direction. A method to correct arc width was proposed by Qiu *et al*.[103], which considers the altitudinal extent of auroral arc. Then, they apply this method to the auroral arcs observed at the Chinese Yellow River Station, and analyze the widths of 17571 dayside auroral arcs. The distributions of the widths are almost the same at different zenith angles with an average width of 18.5 km. Arc widths are narrower as MLT is close to midday.

Interaction between interplanetary shock and magnetosphere frequently induces dayside enhancements of auroral activity, and subsequent enhancement of auroral precipitation referred as shock aurora propagating dawnward and duskward from noon to the night sector. In some cases, these interplanetary shocks also induce enhanced activity during which the power precipitated into the night sector may reach values as high as observed during typical magnetospheric substorms. Liu *et al*.[104] analyzed the nightside auroral responses to the interplanetary shock sudden compression based-on the ground optical auroral observations from Chinese Antarctic Zhongshan and Arctic Yellow River stations for the first time. 18 shock associated aurora cases indicated that nightside auroral responses can be classified into auroral breakup and weak intensification or null events. Epoch time analysis showed that both the solar wind-magnetosphere coupling efficiency and electro-magnetic environment inside magnetosphere determine the nightside auroral responses.

Compared to the recently improved understanding of nightside diffuse aurora, the mechanisms responsible for dayside diffuse aurora remains poorly understood. While dayside chorus has been thought as a potential major contributor to dayside diffuse auroral precipitation, quantitative analyses of the role of chorus wave scattering have not been carefully performed. Shi *et al*.[105] investigated a dayside diffuse auroral intensification event observed by the Chinese Arctic Yellow River Station (YRS) All-Sky Imagers (ASI) on January 7, 2005 and captured a substantial increase in diffuse auroral intensity at the 557.7 nm wavelength that occurred over almost the entire ASI field-of-view near 09:24 UT, *i.e.*, 12:24 MLT. Computation of bounce-averaged resonant scattering rates by dayside chorus emissions using realistic magnetic field models demonstrates that dayside chorus scattering can produce intense precipitation losses of plasma sheet electrons on timescales of hours (even approaching the strong diffusion limit) over a broad range of both energy and pitch angle, specifically, from ~1 keV to 50 keV with equatorial pitch angles from the loss cone to up to ~85° depending on electron energy. Subsequent estimate of loss cone filling index indicates that the loss cone can be substantially filled, due to dayside chorus driven pitch angle scattering, at a rate of ⩾0.8 for electrons from ~500 eV to 50 keV that exactly covers the precipitating electrons for the excitation of green-line diffuse aurora. Estimate of electron precipitation flux at different energy levels, based on loss cone filling index profile and typical dayside electron distribution observed by THEMIS spacecraft under similar conditions gives a total precipitation electron energy flux of the order of 0.1 $\mathrm{erg \cdot cm^{-2} \cdot s^{-1}}$ with ~1 keV characteristic energy (especially when using T01s), which can be very likely to cause intense green-line diffuse aurora activity on the dayside. Therefore, dayside chorus scattering in the realistic magnetic field can greatly contribute to the YRS ASI observed intensification of dayside green-line aurora. Besides wave induced scattering and changes in the ambient magnetic field, variations in associated electron flux can also contribute to enhanced diffuse aurora emissions, the possibility of which they cannot exactly rule out due to lack of simultaneous observations of magnetospheric particles. Since the geomagnetic activity level was rather low during the period of interest, it is reasonable to infer that changes in the associated electron flux in the magnetosphere should be small, and consequently its contribution to the observed enhanced diffuse auroral activity should be small as well. Their results support the scenario that dayside chorus could play a major role in the production of dayside diffuse aurora, and also demonstrate that changes in magnetospheric magnetic field should be considered to reasonably interpret observations of dayside diffuse aurora.

Using the Polar Ultraviolet Imager (UVI) above the Arctic and the All-Sky Camera (ASC) at Chinese Zhongshan Station (ZHS) in Antarctica, an outstanding hemispheric conjugate observation of postnoon “bright spots” in the Arctic and auroral spirals in Antarctica is presented. Multiple bright auroral spirals, which are counterclockwise rotation viewed along the direction of the magnetic field, in postnoon auroral arcs are seen on the Field of View (FOV) of ASC at ZHS in the Southern Hemisphere, while multiple bright spots are seen at the conjugate FOV of ASC on postnoon auroral oval in the Northern Hemisphere by Polar UVI. Hu *et al*.[106] considered that the auroral spirals in postnoon arcs are the visible characteristic of postnoon UV bright spots on ground-based observation and suggest that the current sheet instability above the parallel electric field region, which could produce the arcs, is the origin for bright spots occurring at the ionosphere, and the hemispheric symmetry/asymmetry of postnoon upward field-aligned currents, which is affected by the IMF BY and season, can control the conjugacy/nonconjugacy of postnoon bright spots/auroral spirals between the two hemispheres.

Zhang *et al*.[107] performed a statistical study of the surface current at the High-Latitude Magnetopause (HLMP) and the bow shock under different southward Interplanetary Magnetic Field (IMF) conditions, taking advantage of the crossing events of these discontinuities by the Cluster spacecraft. With an enhancement of southward IMF B_z, the surface current at HLMP reduces, while increasing at the bow shock. Since the amount of the magnetospheric current increases with the increase of southward IMF B_z, a synthesis analysis based on the Cluster observations suggests the bow shock and HLMP together contribute to the magnetospheric current system, and the bow shock would become an important current generator when the southward IMF B_z becoming large. This scenario accords with the previous global Magnetohydrodynamic (MHD) simulations.

The Russell-McPherron (R-M) effect is one of the most prevailing hypotheses accounting for semiannual variation of geomagnetic activity. To validate the R-M effect and investigate the difference of geomagnetic activity variation under different Interplanetary Magnetic Field (IMF) polarity and during extreme solar wind conditions (interplanetary shock), Zhao *et al*.[108] analyzed 42 years interplanetary magnetic field and geomagnetic indices data and 1270 SSC (storm sudden commencement) events from the year 1968 to 2010 by defining the R-M effect with positive/negative IMF polarity (IMF away/toward the Sun). The results obtained in their study have shown that the response of geomagnetic activity to the R-M effect with positive/negative IMF polarity are rather profound: the geomagnetic activity is much more intense around fall equinox when the direction of IMF is away the Sun, while much more intense around spring equinox when the direction of IMF is toward the Sun. The seasonal and diurnal variation of geomagnetic activity after SSCs can be attributed to both R-M effect and the equinoctial hypothesis; the R-M effect explains most part of variance of southward IMF, while the equinoctial hypothesis explains similar variance of ring current injection and geomagnetic indices as the R-M effect. However, the R-M effect with positive/negative IMF polarity explains the difference between SSCs with positive/negative IMF B_y accurately, while the equinoctial hypothesis cannot explain such difference at the spring and fall equinoxes. Thus, the R-M effect with positive/negative IMF polarity is more reasonable to explain seasonal and diurnal variation of geomagnetic activity under extreme solar wind conditions.

On 3 March 2007, five THEMIS satellites on the dusk side of the magnetic layer, three geosynchronous GOES satellites on the downside and morning and ground geomagnetic stations all observed Pc5 ULF waves for almost four hours. Wu *et al*.[109] used cross wavelet correlation analysis to calculate the pulse′s propagation speed and MVA to determine the propagation direction. Then they combine the speed and the direction to obtain the information of the Pc5 phase velocity vectors. THEMIS satellite observed that Pc5 waves were of compression, propagating sunward at a speed about 6–20 $km{\cdot}s^{-1}$. Compared to the magnetic layer Alfvén speed (1000 $km{\cdot}s^{-1}$), this velocity is relatively low. They may come from the magneto tail or inner magnetosphere instability. Three GOES satellites observed different Pc5 ULF pulsations dominated by the poloidal mode and have the wave packet structure which means that Pc5 waves have the Alfvén wave feature, likely originated from K-H instability. The ULF disturbance amplitude observed by ground stations strengthened with increasing latitudes. Pc5 waves reached the highest level at 60 degree latitude. There is good similarity in waveforms between the pulses observed by the Dumont Durville station and the waves observed by THEMIS.

Derivation of Equivalent Current Systems (ECS) from a global magnetospheric Magnetohydrodynamics (MHD) model is very useful in studying magneto-sphere-ionosphere coupling, ground induction effects, and space weather forecast. Zhang *et al*.[110] introduced an improved method to derive the ECS from a global MHD model, which takes account of the obliqueness of the magnetic field lines. B_y comparing the ECS derived from this improved method and the previous method, they find that the main characteristics of the ECS derived from the two methods are generally consistent with each other, but the eastward- westward component of the geomagnetic perturbation calculated from the ECS derived from the improved method is much stronger than that from the previous method. They then compared the geomagnetic perturbation as a function of the Interplanetary Magnetic Field (IMF) clock angle calculated from the ECS derived from both methods with the observations. The comparison indicates that the improved method can improve the performance of the simulation. Furthermore, it is found that the incomplete counterbalance of the geomagnetic effect produced by the ionospheric poloidal current and Field-Aligned Current (FAC) contributes to most of the eastward-westward component of geomagnetic perturbation.

Du *et al*.[111] , using the magnetic field data observed by Venus Express (VEX) from April 2006 to December 2009, analyzed the magnetic configuration around Venus. All the magnetic observations are organized in a coordinate system which is determined by the Solar Wind (SW) flow and the interplanetary magnetic field. By averaging and compiling the VEX data, they compiled a global picture of the magnetic field for the SW interaction with Venus. The magnetic field around the planet displays a clear asymmetry on both field strength and pattern. The magnetic field is stronger on the $+E$ hemisphere where the convective electric field E_{sw} points away from the planet, and is wrapped around the planet more tightly on the $–E$ hemisphere where E_{sw} points toward the planet. The underlying physics of this E_{sw} asymmetry is still under debate. Except in ideal single-fluid MHD simulation, the E_{sw} asymmetry can be observed in both multi-fluid MHD and hybrid simulations.

Although much has been done on the hemispheric asymmetry (or seasonal variations) of auroral Hemispheric Power (HP), the dependence of HP hemispheric asymmetry on solar cycle has not yet been studied. Zheng *et al*.[112] analyzed data during 1979–2010 and investigated the dependence of HP hemispheric asymmetry/seasonal variation for the whole solar cycle. Here they show that (1) the hemispheric asymmetry of HP is positively correlated to the value of solar $F_{10.7}$ with some time delay; (2) it is closely related to the coupling function between the solar wind and magnetosphere; and (3) the winter hemisphere receives more auroral power than the summer hemisphere for Kp being 0 to 6. The statistic results can be partly understood in the framework of the ionospheric conductivity feedback model. The similarity and differences between their results and previous results were discussed in the paper.

Using simultaneous measurements from THEMIS spacecraft, GOES-11 and ground stations (Canadian Array for Realtime Investigations of Magnetic Activity or CARISMA, and 210° magnetic meridian or MM) on March 18, 2009, Luo *et al*.[113] studied the dynamic processes in the near-Earth magnetotail and corresponding Pi2 pulsations on the ground in great detail. Fast earthward flows along with traveling Alfvén waves and fast mode waves in the Pi2 band were observed by three Time History of Events and Macroscale Interactions during Substorms (THEMIS) probes (P3, P4 and P5) in the near-Earth plasma sheet. At the mid- to high-latitude nightside, the CARISMA stations located near the foot points of the three probes recorded Pi2s with two periods, about 80 s after the earthward fast flows observed by the P4 probe. The long-period Pi2 (140–150 s) belongs to the transient response Pi2 (TR Pi2), since the travel time of the Alfvén waves between the plasma sheet and CARISMA stations is very close to half the period of the long-period Pi2. The short-period Pi2 (60–80 s) has the same period band as the perpendicular velocity of the fast flows, which indicates that it may relate to the inertial current caused by periodic braking of the earthward fast flows. The 210° MM stations located at the low-latitude duskside also observed Pi2s with the same start time, waveform and frequency, about ~120 s after the earthward fast flows. Strong poloidal oscillations are shown by GOES-11 (~23:00 MLT) and the compressional component (B_b) is highly correlated with H components of the 210° MM stations, whereas the other two components (B_r and B_e) are not. These results confirm that the low-latitude Pi2s are generated by cavity mode resonance, which is driven by an impulsive broadband source in the near-Earth magnetotail.

Earth's cusp proton aurora occurs near the prenoon and is primarily produced by the precipitation of solar energetic (2–10 keV) protons. Cusp auroral precipitation provides a direct source of energy for the high-latitude dayside upper atmosphere, contributing to chemical composition change and global climate variability. Previous studies have indicated that magnetic reconnection allows solar energetic protons to cross the magnetopause and enter the cusp region, producing cusp auroral precipitation. However, energetic protons are easily trapped in the cusp region due to a minimum magnetic field existing there. Hence, the mechanism of cusp proton aurora has remained a significant challenge for tens of years. Based on the satellite data and calculations of diffusion equation, Xiao *et al*.[114] demonstrated that EMIC waves can yield the trapped proton scattering that causes cusp proton aurora. This moves forward a step toward identifying the generation mechanism of cusp proton aurora.

9 Plasmasphere

Liu *et al*.[115] reported on a rare Ultra-Low-Frequency (ULF) wave generation event associated with the formation of a Plasmasphere Boundary Layer (PBL), which was well observed by one of the THEMIS satellites, TH-D, during subsequent outbound passes. On 13 September 2011, TH-D observed a sharp plasmapause at $L = 3.4$. The plasmasphere started to expand and continued to be refilled on 14 September. On 15 September, a PBL was formed with two density gradients at $L = 4.4$ and 6.5, respectively. Within the two density gradients, strong radial magnetic field and azimuthal electric field oscillations were observed, suggesting poloidal ULF waves. Based on the phase delay between magnetic and electric field signals, as well as the comparison between the observed wave frequency and predicted harmonic eigen frequency, they find that the observed oscillations are second harmonic poloidal waves. Further investigation shows that the observed waves are likely generated by drift-bounce resonance with "bump-on-tail" plasma distributions at ~10 keV. They demonstrated that the waves are excited within the PBL where the eigen frequency is close to the bounce frequency of these hot protons, but not outside the PBL where the eigen frequency deviates from the bounce frequency. Finally, they suggested that cold plasma density seems to be a controlling factor for ULF wave generation as well, in addition to the bump-on-tail energy source, by altering eigen frequency of the local field lines.

The wave-particle interaction is a possible candidate for the energy coupling between the ring current and plasmaspheric plumes. Yuan *et al*.[116] presented wave and particle observations made by Cluster C1 satellite in a plasmaspheric plume in the recovery phase of the geomagnetic storm on July 18, 2005. Cluster C1 simultaneously observed Pc1-2 waves and Extremely Low Frequency (ELF) hiss in the plasmaspheric plume. Through an analysis of power spectral density and polarization of the perturbed magnetic field, they identify that the observed Pc1-2 waves are linear polarized Electromagnetic Ion Cyclotron (EMIC) waves and show that the ELF hiss propagates in the direction of the ambient magnetic field in whistler mode. In the region where the EMIC waves were observed, the pitch angle distribution of ions becomes more isotropic, likely due to the pitch angle scattering by the EMIC waves. It is shown that the ELF hiss and EMIC waves are spatially separated: the ELF hiss is located in the vicinity of the electron density peak within the plume while the EMIC waves are detected in the outer boundary of the plume because of the different propagation characteristics of the ELF hiss and EMIC waves.

Yuan *et al*.[117] presented characteristics of precipitating energetic ions/electrons associated with the wave-particle interaction in the plasmaspheric plume during the geomagnetic storm on July 18, 2005 with observations of the NOAA 15 NOAA 16, IMAGE satellites and Finnish network of search coil magnetometers. Conjugate observations of the NOAA 15 satellite and the Finnish network of search coil magnetometers have demonstrated that a sharp enhancement of the precipitating ion flux is a result of Ring Current (RC) ions scattered into the loss cone by EMIC waves. Those precipitating RC ions lead to a detached subauroral proton arc observed by the IMAGE FUV. In addition, with observations of NOAA 15 and NOAA 16, the peak of precipitating electron flux was equatorward to that of precipitating proton flux, which is in agreement with the region separation of ELF hiss and EMIC waves observed by the Cluster C1 in the companion paper. In combination with the result of the companion paper, they demonstrate the link between the wave activities (ELF hiss, EMIC waves) in plasmaspheric plumes and energetic ion/electron precipitation at ionospheric altitudes. Therefore, it is an important characteristic of plasmaspheric plumes-RC-ionosphere interaction during a geomagnetic storm that the precipitation of energetic protons is latitudinally separated from that of energetic electrons.

Yuan *et al*.[118] reported some interesting ionospheric characteristics associated with wave-particle interactions with observations of the ionosonde and co-located Incoherent Scatter Radar (ISR) at Millstone Hill in a Storm-Enhanced Density (SED) plume identified from two-dimensional GPS TEC maps during a super geomagnetic storm on Nov. 20, 2003. Firstly, the digisonde ionogram only contained echoes for scanning frequencies from 6.2 MHz to 9.3 MHz. The lack of echoes at frequencies below 6.2 MHz is attributed to enhancements of sub-ionospheric absorption caused by precipitating RC electrons in the SED plume. Secondly, there was an obvious F_1 layer, as well as an Es layer, appearing on the ISR profile, that was not observed by the digisonde due to strong sub-ionospheric absorption. For echoes at frequencies from 6.2 MHz to 9.3 MHz, a comparison of the virtual height obtained from the digisonde ionogram and that derived from the ISR electron density profile, demonstrated that an Es layer appeared with a peak altitude of 123 km. The occurrence of the Es layer is attributed to enhancements of precipitating energetic ion fluxes in the SED plume. Their result suggests that the ionospheric behavior in the SED plume is controlled not only by ionospheric dynamical process but also by precipitating energetic RC ions/ electrons as a consequence of wave-particle interactions in the plasmaspheric plume.

The wave-particle interactions and associated precipitation of energetic ions/electrons play an important role in the coupling between the inner magnetosphere and the ionosphere. Yuan *et al*.[119] presented characteristics of precipitating Ring Current (RC) ions/electrons and precipitating radiation belt electrons associated with wave-particle interactions in the plasmaspheric plume in the main phase of a geomagnetic storm during 8–9 May 2001. With observations of the NOAA 16 satellite, within the anisotropic zone, the peak of precipitating RC electron flux was equatorward to that of precipitating RC proton flux in a plasmaspheric plume recognized by the IMAGE and LANL-91/94 satellites. An enhancement of precipitating flux for >3 MeV electrons was simultaneously observed by NOAA 16 with the increase of precipitating RC proton flux within the anisotropic zone. Theoretical calculations of pitch angle diffusion coefficients for RC protons and for radiation belt electrons caused by Electromagnetic Ion Cyclotron (EMIC) waves demonstrated that precipitating flux enhancements of RC protons and >3 MeV radiation belt electrons are a result of EMIC wave-particle interactions in the plasmaspheric plume. Their result suggests that EMIC waves in the plasmaspheric plume can scatter not only RC ions but also radiation belt electrons into the loss cone, which cause the loss of the RC ions and radiation belt electrons.

Yuna *et al*.[120] reported in situ observations by the Cluster spacecraft of plasmaspheric electron heating in the plasmaspheric plume. Electron heating events were accompanied by enhancements of Electromagnetic Ion Cyclotron (EMIC) waves in the increased density ducts on the negative density gradient side for two substructures of the plasmaspheric plume. Electron heating is much stronger for the pitch angle of 0° and 180° than for the pitch angle of 90°. Theoretical calculations of the Landau resonant interaction between electrons and observed EMIC waves demonstrate that Landau damping of oblique EMIC waves is a reasonable candidate to heat cold electrons in the presence of O^+ ions in the outer boundary of the plasmaspheric plume. Therefore, this observation is considered in-situ evidence of plasmaspheric electron heating through Landau damping of EMIC waves in plasmaspheric plumes.

The EUV imager on board the Chang'E-3 lunar lander will image the Earth's plasmasphere from a lunar perspective to focus on some of the open questions in plasmaspheric researches (*i.e.*, global structures, erosion, and refilling of plasmasphere). In order to achieve the understanding of the plasmaspheric dynamics in relation to these EUV images in lunar perspective, He *et al.*[121] investigated the He^+ 30.4 nm emission intensities and global structures of the plasmasphere viewed from the moon by using a dynamic global core plasma model embedded with TS07 magnetic field model and W05 electric field model. Two typical storms observed by the IMAGE EUV imager are systematically simulated from the perspectives of the moon. It is found from the simulations that the maximum emission intensity of the plasmasphere is ~12.3 *R* which is greater than that detected from polar orbit, and the global shapes and temporal evolutions of large-scale plasmaspheric structures (plasmapause, shoulder, and plume) also have different patterns in moon-based simulated images. It is also shown that the plasmaspheric structures extracted from moon-based EUV images are in agreement with those from IMAGE EUV images. Systematic simulations demonstrate that specific latitudinal distribution of the plasmaspheric structures can only be imaged at specific positions in lunar orbit. It is expected that this investigation provides us with an overall understanding on moon-based EUV images and helps to identify the plasmaspheric structures and evolution patterns in future moon-based EUV imaging. Spatial distribution of Kelvin-Helmholtz instability at low-latitude boundary layer under different solar wind speed conditions

Using the PPMLR-MHD global simulation model, Li *et al.*[122] examined the Kelvin-Helmholtz (K-H) instability at the Low-Latitude Boundary Layer (LLBL) under northward Interplanetary Magnetic Field (IMF) conditions with various solar wind speeds (400, 600, and 800 $km\cdot s^{-1}$). The spatial distribution of the K-H wave power in the equatorial plane shows two distinct power populations, referring to the two modes of K-H surface waves. The spatial evolution of K-H instability at the boundary layer is classified into four phases: quasi-stable, exponential growth, linear growth, and nonlinear phases. The boundary layer is quasi-stable near the subsolar point region. The K-H instability starts at about 30° longitude, and grows exponentially with a spatial growth rate of 0.28–0.87 R_e until ~45° longitude where the vortices fully develop. At larger longitudes, the instability grows linearly, while the vortices grow in size. From ~80° longitude to the distant magnetotail, the K-H instability develops nonlinearly and the vortices roll up. The wave frequency, wavelength, and phase speed are given at various spatial points. Model results show that the higher solar wind speed generates K-H waves with higher frequency under the northward IMF, and the wavelengths and the phase speeds increase with the increase of the longitude. Moreover, they made a comparison of the K-H wave periods on Earth's, Mercury's and Saturn's magnetopauses by a proposed prediction method.

Liu *et al.*[123] analyzed a long-duration Electromagnetic Ion Cyclotron (EMIC) ion wave event seen in the inner magnetosphere in order to understand the propagation characteristics of these waves in the vicinity of the plasmapause. The study takes advantage of the south to north orbit of the four-satellite Cluster constellation as it passed through perigee at $L \approx 4.2$ at ~08:00 magnetic local time on 2 November 2001. Cluster traversed from a low-density magnetosphere ($< 20\ cm^{-3}$) through a gradual plasmapause into a high-density plasmasphere (~80 cm^{-3}) where the waves were seen over about 50 min and ceased on exiting the plasmapause in the Northern Hemisphere. The waves were observed over 1.8–3.5 Hz, above the local helium cyclotron frequency, between magnetic latitudes ±18°, and confined to a radial source region size estimated at 0.77 R_e. Wave polarization appeared to be associated with plasma density, with left hand in the equatorial region, right hand at higher latitudes nearer the plasmapause, and a mixture between. Wave normal angles were typically <60°, and Poynting flux measurements show that wave energy was predominantly directed along the geomagnetic field toward high latitudes in both hemispheres. These results suggest that the plasma density and its gradient play a significant role in confining the wave source region and affecting the wave properties, which will help understand wave generation and propagation mechanisms in the magnetosphere plasma environment.

The whistler-mode waves and electron temperature anisotropy play a key role prior to and during magnetic reconnection. Wei *et al.*[124] studied Generation mechanism of the whistler-mode waves in the plasma sheet prior to magnetic reconnection. On August 21, 2002, the Cluster spacecrafts encountered a quasi-collisionless magnetic reconnection event when they crossed the plasma sheet.

Prior to the southward turning of magnetospheric magnetic field and high speed ion flow, the whistler-mode waves and positive electron temperature anisotropy are simultaneously observed. Theoretic analysis shows that the electrons with positive temperature anisotropy can excite the whistler-mode waves via cyclotron resonances. Using the data of particles and magnetic field, they estimated the whistler-mode wave growth rate and the ratio of whistler-mode growth rate to wave frequency. They are 0.0016 f_{ce} (Electron cyclotron frequency) and 0.0086 f_{ce}, respectively. Therefore the whistler-mode waves can grow quickly in the current sheet. The combined observations of energetic electron beams and waves show that after the southward turning of magnetic field, energetic electrons in the reconnection process are accelerated by the whistler-mode waves.

Low frequency electromagnetic fluctuations in the vicinity of a magnetospheric substorm onset were investigated by Duan *et al.*[125] using simultaneous observations by THEMIS multiple probes in the near-Earth plasma sheet in the magnetotail. The observations indicate that in the vicinity of a substorm onset, kinetic Alfvén waves can be excited in the high-β plasma sheet ($\beta = 2\mu_0 nT/B^2$, the ratio of plasma thermal pressure to magnetic pressure) within the near-Earth magnetotail. The kinetic Alfvén wave has a small spatial scale in the high-β plasma. The parallel electric field accompanying kinetic Alfvén waves accelerates the charged particles along the magnetic field. The kinetic Alfvén waves play an important role in the substorm trigger process, and possibly in the formation of a substorm current wedge.

Sudden Impulses (SIs) are an important source of Ultra Low Frequency (ULF) wave activity throughout the Earth's magnetosphere. Most SI-induced ULF wave events have been reported in the dayside magnetosphere; it is not clear when and how SIs drive ULF wave activity in the nightside plasma sheet. Shi *et al.*[126] examined the ULF response of the nightside plasma sheet to SIs using an ensemble of 13 SI events observed by THEMIS (Timed History of Events and Macroscale Interactions during Substorms) satellites (probes). Only three of these events resulted in ULF wave activity. The periods of the waves are found to be 3.3, 6.0, and 7.6 min. East-west magnetic and radial electric field perturbations, which typically indicate the toroidal mode, are found to be stronger and can have phase relationships consistent with standing waves. Their results suggest that the two largest-amplitude ULF responses to SIs in the nightside plasma sheet are tailward-moving vortices, which have previously been reported, and the dynamic response of cross-tail currents in the magnetotail to maintain force balance with the solar wind, which has not previously been reported as a ULF wave driver. Both mechanisms could potentially drive standing Alfvén waves (toroidal modes) observed via the field-line resonance mechanism. Furthermore, both involve frequency selection and a preference for certain driving conditions that can explain the small number of ULF wave events associated with SIs in the nightside plasma sheet.

REFERENCES

[1] Li H, Wang C, Xu W Y, *et al*. Characteristics of magnetospheric energetics during geomagnetic storms [J]. *J. Geophys. Res*., 2012, **117**, A04225, doi: 10.1029/2012JA017584

[2] He Z H, Chen T, Liu Z X, *et al*. Spectral characteristics of the plasma dispersionless injection during the storm recovery phase on 11 March 1998 [J]. *J. Geophys. Res*., 2012, **117**, A11210, doi: 10.1029/2012JA017760

[3] Zhima Zeren, Cao Jinbin, Liu Wenlong, *et al*. DEMETER observations of high-latitude chorus waves penetrating the plasmasphere during a geomagnetic storm [J]. *Geophys. Res. Lett*., 2013, **40**(22): 5827-5832

[4] Zeren Zhima, Cao Jinbin, Liu Wenlong, *et al*. Storm-time evolution of ELF/VLF waves observed by DEMETER satellite [J]. *J. Geophys. Res*., 2014, doi: 10.1002/2013JA019237

[5] Zhao X D, Du A M, Xu W Y. The magnetic local time distribution of ring current during the geomagnetic storm [J]. *Planet. Space Sci*., 2013, **78**: 52-63

[6] Zhang Qinghe, Zhang Beichen, Lockwood Michael, *et al*. Direct observations of the evolution of polar cap ionization patches [J]. *Science*, 2013, **339**(6127):1597-1600

[7] Peng Z, Wang C, Yang Y F, *et al*. Substorms under northward interplanetary magnetic field: Statistical study [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 364-374

[8] Liu J M, Kamide Y, Zhang B C, *et al*. THEMIS and ground-based observations of successive substorm onsets following a super-long growth phase [J]. *Ann. Geophys*., 2013, **31**: 835-843

[9] Ma Yonghui, Shen Chao, Angelopoulos Vassilis, *et al*. Tailward leap of multiple expansions of the plasma sheet during a moderately intense substorm: THEMIS observations [J]. *J. Geophys. Res*., 2012, **117**, A07219, doi: 10.1029/2012JA017768

[10] Yao Z H, Pu Z Y, Fu S Y, *et al*. Mechanism of substorm current wedge formation: THEMIS observations [J]. *Geophys. Res. Lett*., 2012, **39**(13), L13102, doi: 10.1029/2012GL052055

[11] Cao X, Pu Z Y, Du A M, *et al*. Auroral streamers implication for the substorm progression on September 14, 2004 [J]. *Planet. Space Sci*., 2012, **71**: 119-124

[12] Cao X, Pu Z Y, Du A M, *et al.* On the retreat of near-Earth neutral line during substorm expansion phase: a THEMIS case study during the 9 January 2008 substorm [J]. *Ann. Geophys*., 2012, **30**: 143-151

[13] Cao Jinbin, Ma Yuduan. Parks George, *et al*. Kinetic analysis of the energy transport of bursty bulk flows in the plasma sheet [J]. *J. Geophys. Res. Space Phys.*, 2013, 118: 313-320

[14] Zhou M, Deng X H, Huang S Y. Electric field structure inside the secondary island in the reconnection diffusion region [J]. *Phys.*

Plasmas, 2012, **19**, 042902, doi: 10.1063/1.3700194
[15] Zhou M, Deng X H, Pang Y, *et al*. Revealing the sub-structures of the magnetic reconnection separatrix via particle-in-cell simulation [J]. *Phys. Plasmas,* 2012, **19**, 072907, doi: 10.1063/1.4739283
[16] Zhou Meng, Su Wei, Deng Xiaohua, *et al*. Anomalous resistivity associated with secondary islands in the reconnection region [J]. *Chin. Phys. Lett*., 2012, **29**, 089401, doi: 10.1088/0256-307X/29/8/089401
[17] Huang S Y, Zhou M, Sahraoui F, *et al*. Observations of turbulence within reconnection jet in the presence of guide field [J]. *Geophys. Res. Lett*., 2012, **39**, L11104, doi: 10.1029/2012GL052210
[18] Huang S Y, Vaivads A, Khotyaintsev Y V, *et al*. Electron acceleration in the reconnection diffusion region: Cluster observations [J]. *Geophys. Res. Lett*., 2012, **39**, L11103, doi: 10.1029/2012GL051946
[19] Huang Shiyong, Deng Xiaohua, Zhou Meng, *et al*. Energetic electrons associated with magnetic reconnection in the sheath of interplanetary coronal mass ejection [J]. *Chin. Sci. Bull*., 2012, **57**(12): 1455-1460
[20] Zhang Q H, Dunlop M W, Lockwood M, *et al*. Inner plasma structure of the low-latitude reconnection layer [J]. *J. Geophys. Res*., 2012, **117**, A08205, doi: 10.1029/2012JA017622
[21] Zhang Qinghe, Liu Ruiyuan, Yang Huigen, *et al*. SuperDARN CUTLASS Finland radar observations of high-latitude magnetic reconnections under northward Interplanetary Magnetic Field (IMF) conditions [J]. *Sci. China: Tech. Sci*., 2012, **55**(5): 1207-1216
[22] Huang Can, Lu Quan [0] ming, Zhang Hui, *et al*. Kinetic simulations of the structures of magnetic island in multiple X line guide field reconnection [J]. *Phys. Plasmas*, 2012, **19**, 042111; doi: 10.1063/1.4704799
[23] Huang C, Quanming Lu, Wu M Y, Lu S, Wang S. Out-of-plane electron currents in magnetic island formed during collisionless magnetic reconnection [J]. *J. Geophys. Res*., 2013, 118: 991-996
[24] Lu San, Lu Quanming, Huang Can, *et al.* The transfer between electron bulk kinetic energy and thermal energy in collisionless magnetic reconnection [J]. *Phys. Plasmas*, 2013, **20**, 061203, doi: 10.1063/1.4811119
[25] Lu Quanming, Lu San, Huang Can, *et al*. Self-reinforcing process of the reconnection electric field in the electron diffusion region and onset of collisionless magnetic reconnection [J]. *Plasma Phys. Control. Fusion*, 2013, **55**, 085019 doi: 10.1088/0741-3335/55/8/085019
[26] Huang Can, Lu Quanming, Lu San, *et al*. The effect of a guide field on the structures of magnetic islands formed during multiple X line reconnections: Two-dimensional particle-in-cell simulations [J]. *J. Geophys. Res.*: *Space Phys.*, 2014, **119**: 798-807
[27] Cao J B, Wei X H, Duan A Y, *et al*. Slow magnetosonic waves detected in reconnection diffusion region in the Earth's magnetotail [J]. *J. Geophys. Res. Space Phys.*, 2013, **118**: 1659-1666
[28] Fu H S, Cao J B, Khotyaintsev Yu V, et al. Dipolarization fronts as a consequence of transient reconnection: In situ evidence [J]. *Geophys. Res. Lett.*, 2013, 40, 6023-6027
[29] Fu H S, Khotyaintsev Yu V, Vaivads A, *et al*. Energetic electron acceleration by unsteady magnetic reconnection [J]. *Nature Phys.*, 2012, **9:** 426-430
[30] Wang Rongsheng, Du Aimin, Nakamura Rumi, *et al*. Observation of multiple sub-cavities adjacent to single separatrix [J]. *Geophys. Res. Lett*., 2013, **40**: 2511-2517
[31] Guo Ruilong, Pu Zuyin, Xiao Chijie, *et al*. Separator reconnection with antiparallel/component features observed in magnetotail plasmas [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 6116-6126
[32] Zhong J, Pu Z Y, Dunlop M W, *et al.* Three-dimensional magnetic flux rope structure formed by multiple sequential X-line reconnection at the magnetopause [J]. *J. Geophys. Res. Space Phys.*, 2013, **118**: 1904-1911
[33] Xia Zhiyang, Wang Chi, Peng zhong, *et al.* Relationship between interplanetary magnetic field clock angle and magnetosphere open magnetic flux [J]. *Chin. J. Space Sci.,* 2014, **34**(1): 24-28
[34] Sun T R, Wang C, Borodkova N L, *et al*. Geosynchronous magnetic field responses to fast solar wind dynamic pressure enhancements: MHD field model [J]. *Ann. Geophys*., 2012, **30**: 1285-1295
[35] Sun T R, Wang C, Wang Y. Different B_z response regions in the nightside magnetosphere after the arrival of an interplanetary shock: Multipoint observations compared with MHD simulations [J]. *J. Geophys. Res*., 2012, **117,** A05227, doi: 10.1029/2011JA017303
[36] Xu Dan, Chen Tao. Constraints on electron temperature anisotropies in sheath regions of interplanetary shocks [J]. *Planet. Space Sci*., 2012, **62**(1): 100-103
[37] Fu H S, Cao J B, Zong Q G, *et al*. The role of electrons during chorus intensification: Energy source and energy loss [J]. *J. Atmos. Sol. Terr. Phys*., 2012, **80**: 37-47
[38] Fu H S, Cao J B, Mozer F S, *et al*. Chorus intensification in response to interplanetary shock [J]. *J. Geophys. Res. Space Phys.,* 2012, **117**, A01203, doi: 10.1029/2011JA016913
[39] Zou Z M, Cao J B, Li Y. Influence of solar wind disturbance on ring current and auroral electrojet indexes [J]. *Chin. J. Space Sci.*, 2012, **32**(1): 14-19
[40] Wang H, Lühr H. Seasonal variation of the ion upflow in the topside ionosphere during SAPS (Subauroral Polarization Stream) periods [J]. *Ann. Geophys*., 2013, **31**: 1521-1534
[41] Li Huimin, Pang Ye, Huang Shiyong, *et al.* The turbulence evolution in the high β region of the Earth's foreshock [J]. *J. Geophys. Res. Space Phys.*, 2013, **118**: 7151-7159
[42] Zhang Qingmei, Sun Tianran, Zhang Jiaojiao, *et al*. Response of the ionospheric equivalent current systems to interplanetary shocks [J]. *Chin. J. Space Sci.*, 2013, **33**(5): 486-493
[43] Zhang QingMei, Wang Chi, Li Hui, *et al*. Plasma transport between the ionosphere and plasmasphere in response to solar wind dynamic pressure pulsation [J]. *Chin. Sci. Bull*., 2013, **58**(33): 4126-4132
[44] Zhang J J, Wang C, Tang B B, *et al*. Effect of the solar wind conditions on the ionospheric equivalent current systems [J]. *Ann. Geophys*., 2013, **31**, 489-501
[45] Wang C, Xia Z Y, Peng Z, *et al*. Estimating the open magnetic flux from the interplanetary and ionospheric conditions [J]. *J. Geophys. Res. Space Phys.*, 2013, **118**: 1899-1903
[46] Wang Chi, Zhang Qingmei, Chi P J, *et al*., Simultaneous observations of plasmaspheric and ionospheric variations during magnetic storms in 2011: First result from Chinese Meridian Project [J]. *J. Geophys. Res. Space Phys.*, 2013, **118**: 99-104
[47] Li H, Wang C, Peng Z. Solar wind impacts on growth phase duration and substorm intensity: A statistical approach [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 4270-4278
[48] Li L Y, Cao J B, Yang J Y, *et al*. Joint responses of geosynchronous magnetic field and relativistic electrons to external changes in solar wind dynamic pressure and interplanetary magnetic field [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 1472-1482
[49] Zong Q G, Wang Y F, Zhang H, *et al*. Fast acceleration of inner magnetospheric hydrogen and oxygen ions by shock induced ULF

waves [J]. *J. Geophys. Res.*, 2012, **117**, A11206, doi: 10.1029/2012JA018024
[50] Zhong J, Xie L, Zhang H, *et al*. Chang'E-1 observations of pickup ions near the Moon under different interplanetary magnetic field conditions [J]. *Planet. Space Sci*., 2013, **79/80**: 56-63
[51] Luo H, Chen G X, Du A M, *et al*. Solar wind dependence of energy coupling between solar wind and magnetosphere during intense northward IMFs [J]. *Planet. Space Sci*., 2013, **79/80**: 82-89
[52] Dong YiXuan, Cao JinBin, Liu WenLong, et al. Response of magnetic fields at geosynchronous orbit and on the ground to the sudden changes of IMF B_z [J]. *Sci. China: Tech. Sci.*, 2014, **57**(2): 360-367
[53] Shi Q Q, Zong Q G, Fu S Y, *et al.* Solar wind entry into the high-latitude terrestrial magnetosphere during geomagnetically quiet times [J]. *Nature Commun.*, 2013, 1466, doi: 10.1038/ncomms2476
[54] Wang Shan, Zong Qiugang, Zhang Hui, Cases and statistical study on Hot Flow Anomalies with Cluster spacecraft data [J]. *Sci. China: Tech. Sci.*, 2012, **55**(5): 1402-1418
[55] Wang Shan, Zong QiuGang and Zhang Hui. Cluster observations of hot flow anomalies with large flow deflections: 1. Velocity deflections [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 732-743
[56] Wang Shan, Zong Qiugang, Zhang Hui. Cluster observations of hot flow anomalies with large flow deflections: 2. Bow shock geometry at HFA edges [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 418-433
[57] Shi Run, Ni Binbin, Gu Xudong, et al. Resonance zones and quasi-linear diffusion coefficients for radiation belt energetic electron interaction with oblique chorus waves in the Dungey magnetosphere [J]. *Phys. Plasmas,* 2012, **19**(7): 072904, doi: 10.1063/1.4737105
[58] Xiao Fuliang, Zhang Sai, Su Zhenpeng, *et al*. Rapid acceleration of radiation belt energetic electrons by Z-mode waves [J]. *Geophys. Res. Lett.*, 2012, **39**, L03103, doi: 10.1029/2011GL050625
[59] Su Zhenpeng, Zhu Hui, Xiao Fuliang, *et al*. Bounce-averaged advection and diffusion coefficients for monochromatic electromagnetic ion cyclotron wave: Comparison between test-particle and quasi-linear models [J]. *J. Geophys. Res*., 2012, **117**, A09222, doi: 10.1029/2012JA017917
[60] Su Zhenpeng, Xiao Fuliang, Zheng Huinan, et al. Nonstorm time dynamics of electron radiation belts observed by the Van Allen Probes [J]. *Geophys. Res. Lett*., 2014, **41**: 229-235
[61] Zhou Chen, Yang Guobin, Ni Binbin, *et al*. Strong diffusion limit in the realistic magnetosphere: Dependence on geomagnetic condition and spatial location [J]. *J. Geophys. Res. Space Phys.*, 2013, **118**: 118-131
[62] Zhu Hui, Su Zhenpeng, Xiao Fuliang, *et al*. Nonlinear interaction between ring current protons and electromagnetic ion cyclotron waves [J]. *J. Geophys. Res*., **117**, A12217, doi: 10.1029/2012JA018088
[63] Yuan C J, Zong Q G. Quantitative aspects of variations of 1.5–6.0 MeV electrons in the outer radiation belt during magnetic storms [J]. *J. Geophys. Res*., 2012, **117**, A11208, doi: 10.1029/2011JA017346
[64] Yuan Chongjing, Zong Qiugang. Relativistic electron fluxes dropout in the outer radiation belt under different solar wind conditions [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 7545-7556
[65] Yuan Chongjing, Zong Qiugang. The double-belt outer radiation belt during CME- and CIR-driven geomagnetic storms [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 6291-6301
[66] Zong Qiugang, Yuan Chongjing, Wang Yongfu, *et al*. Dynamic variation and the fast acceleration of particles in Earth's radiation belt [J]. *Sci. China Earth Sci.*, 2013, **56**(7): 1118-1140
[67] Wang Chi, Li Hui, Guo Xiaocheng, *et al*. Numerical study on the response of the Earth's magnetosphere-ionosphere system to a super solar storm [J]. *Sci. China: Earth Sci*., 2012, **55**(6): 1037-1042
[68] Tang B B, Wang C, Guo X C. Bow shock and magnetopause contributions to the magnetospheric current system: Hints from the Cluster observations [J]. *J. Geophys. Res*., 2012, **117**, A01214, doi: 10.1029/2011JA016681
[69] Li Wenya, Wang Chi, Tang Binbin, *et al*. Global features of Kelvin-Helmholtz waves at the magnetopause for northward interplanetary magnetic field [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 5118-5126
[70] Liu Y H, Fraser B J, Menk F W. Pc2 EMIC waves generated high off the equator in the dayside outer magnetosphere [J]. *Geophys. Res. Lett*., 2012, **39**, L17102, doi: 10.1029/2012GL053082
[71] Zhang Q H, Zhang B C, Moen J, *et al*. Polar cap patch segmentation of the tongue of ionization in the morning convection cell [J]. *Geophys. Res. Lett*., 2013, **40:** 2918-2922
[72] Pang Y, Lin M H, Deng X H, *et al*. Deformation of plasma bubbles and the associated field aligned current system during substorm recovery phase [J]. *J. Geophys. Res*., 2012, **117**, A09223, doi: 10.1029/2011JA017410
[73] Zhou Meng, Deng Xiaohua, Ashour-Abdalla Maha, *et al*. Cluster observations of kinetic structures and electron acceleration within a dynamic plasma bubble [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 674-684
[74] Huang S Y, Zhou M, Deng X H, *et al*. Kinetic structure and wave properties associated with sharp dipolarization front observed by Cluster [J]. *Ann. Geophys*., 2012, **30**: 97-107
[75] Guo Jiuling, Shen Chao, Liu Zhenxing. Simulation and comparison of particles entering the plasma sheet under northward and southward IMF conditions [J]. *Chin. Sci. Bull*., 2012, **57**(34): 3295-3300
[76] Rong Z J, Wan W X, Shen C, *et al*. Profile of strong magnetic field B_y component in magnetotail current sheets [J]. *J. Geophys. Res*., 2012, **117**, A06216, doi: 10.1029/2011JA017402
[77] Shen C, Rong Z J, Dunlop M W, *et al*. Spatial gradients from irregular, multiple-point spacecraft configurations [J]. *J. Geophys. Res*., 2012, **117**, A11207, doi: 10.1029/2012JA018075
[78] Shen C, Rong Z J, Dunlop M. Determining the full magnetic field gradient from two spacecraft measurements under special constraints [J]. *J. Geophys. Res*., 2012, **117**, A10217, doi: 10.1029/2012JA018063.
[79] Zheng H, Fu S Y, Zong Q G, *et al*. Observations of ionospheric electron beams in the plasma sheet [J]. *Phys. Rev. Lett*., 2012, **109**, 205001, doi: 10.1103/PhysRevLett.109.205001
[80] Zhang Y C, Shen C, Liu Z X, *et al*. Two different types of plasmoids in the plasma sheet: Cluster multisatellite analysis application [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 5437-5444
[81] Wu Mingyu, Volwerk Martin, Lu Quanming, *et al*. The proton temperature anisotropy associated with bursty bulk flows in the magnetotail [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 4875-4883
[82] Wu Mingyu, Lu Quanming, Volwerk Martin, *et al*. A statistical study of electron acceleration behind the dipolarization fronts in the magnetotail [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 4804-4810
[83] Duan Aiying, Cao Jinbin, Ma Yuduan, *et al*. Cluster observations of large-scale southward movement and dawnward-duskward flapping of Earth's magnetotail current sheet [J]. *Sci. China: Tech.*

Sci., 2013, **56**(1): 194-204

[84] Tian Tian, Zong Qiugang, Wang Yongfu, *et al*. Statistical study of the properties of the magnetic field and plasma in the Earth's magnetotail near lunar orbit [J]. *Sci. China: Tech. Sci.*, 2012, **55**(9): 2570-2577

[85] Tian Anmin, Zong Qiugang, Shi Quanqi. Reconstruction of morningside plasma sheet compressional ULF Pc5 wave [J]. *Sci. China: Tech. Sci*., 2012, **55**(4): 1092-1100

[86] Tian A M, Zong Q G, Zhang T L, *et al*. Dynamics of long-period ULF waves in the plasma sheet: Coordinated space and ground observations [J]. *J. Geophys. Res*., 2012, 117, A03211, doi: 10.1029/2011JA016551

[87] Wang Yongfu, Zong Qiugang. Study of the nose event on 11 April 2002 with UBK method [J]. *Sci. China: Tech. Sci*., 2012, **55**(7): 1929-1942

[88] Lu H Y, Cao J B, Zhou M, *et al*. Electric structure of dipolarization fronts associated with interchange instability in the magnetotail [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 6019-6025

[89] Cao Jinbin, Duan Aiying, Reme Henri, *et al*. Relations of the energetic proton fluxes in the central plasma sheet with solar wind and geomagnetic activities [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 7226-7236

[90] Li L Y, Yu J, Cao J B, *et al*. Rapid loss of the plasma sheet energetic electrons associated with the growth of whistler mode waves inside the bursty bulk flows [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 7200-7210

[91] Sun W J, Shi Q Q, Fu S Y, *et al*. Cluster and TC-1 observation of magnetic holes in the plasma sheet [J]. *Ann. Geophys*., 2012, **30**: 583-595

[92] Sun W J, Fu S Y, Parks G K, *et al*. Field-aligned currents associated with dipolarization fronts [J]. *Geophys. Res. Lett*., 2013, 40, 4503–4508, doi: 10.1002/grl.50902

[93] Zheng Hao, Fu Suiyan, Zong Quigang, *et al*. Downward current electron beams observed at the dipolarization front [J]. *Chin. Sci. Bull.*, 2013, **58**(8): 913-919

[94] Rong Z J, Wan W X, Shen C, *et al*. Method for inferring the axis orientation of cylindrical magnetic flux rope based on single-point measurement [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 271-283

[95] Cao Jinbin, Wang Zhiqiang, Ma Yuduan, *et al*. Differences between onset times of Bursty Bulk Flows (BBFs) of two Cluster satellites in the magnetotail [J]. *Sci. China: Tech. Sci.,* 2012, **55**(5): 1178-1183

[96] Yao Zhonghua, Sun W J, Fu S Y, *et al*. Current structures associated with dipolarization fronts [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 6980-6985

[97] Ma Yuduan, Cao Jinbin, Fu Huishan, *et al*. MHD and kinetic analysis of flow bursts in the Earth's plasma sheet [J]. *Sci. China: Tech. Sci*., 2014, **57**(1): 55-66

[98] Sun Weijie, Fu Suiyan, Shi Quanqi, *et al*. THEMIS observation of a magnetotail current sheet flapping wave [J]. *Chin. Sci. Bull*., 2014, **59**(2): 154-161

[99] Shang Wensai, Yao Zhonghua, Shi Quanqi, *et al*. Braking of high-speed flows in the magnetotail: THEMIS joint observations [J]. *Chin. Sci. Bull.*, 2014, **59**(3): 326-334

[100] Xing Z Y, Yang H G, Han D S, *et al*. Poleward Moving Auroral Forms (PMAFs) observed at the Yellow River Station: A statistical study of its dependence on the solar wind conditions [J]. *J. Atmos. Sol. Terr. Phys*., 2012, **86**: 25-33

[101] Xing Zanyang, Yang Huigen, Han Desheng, *et al*. Dayside poleward moving auroral forms and ionospheric convection under stable Interplanetary Magnetic Field (IMF) conditions [J]. *Sci. China: Tech. Sci*., 2013, **56**(4): 910-916

[102] Xing Zanyang, Yang Huigen, Wu Zhensen, *et al*. A parameter model of auroral emissions and particle precipitation near magnetic noon [J]. *Chin. J. Geophys*., 2013, **56**(7): 2163-2170

[103] Qiu Qi, Yang Huigen, Lu Quanming, *et al*. Widths of dayside auroral arcs observed at the Chinese Yellow River Station [J]. *J. Atmos. Solar Terr. Phys*., 2013, **102**: 222-227

[104] Liu Jianjun, Hu Hongqiao, Han Desheng, *et al.* Response of nightside aurora to interplanetary shock from ground optical observation [J]. *Chin. J. Geophys*., 2013, **56**(5): 598-611

[105] Shi R, Han D, Ni B, *et al*. Intensification of dayside diffuse auroral precipitation: contribution of dayside Whistler-mode chorus waves in realistic magnetic fields [J]. *Ann. Geophys*., 2012, **30**: 1297-1307

[106] Hu Zejun, Yang Huigen, Hu Hongqiao, *et al*. The hemispheric conjugate observation of postnoon "bright spots"/auroral spirals [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 1428-1434

[107] Zhang J J, Wang C, Tang B B. Modeling geomagnetically induced electric field and currents by combining a global MHD model with a local one-dimensional method [J]. *Space Weather*, 2012, **10**, S05005, doi: 10.1029/2012SW000772

[108] Zhao H, Zong Q G. Seasonal and diurnal variation of geomagnetic activity: Russell-McPherron effect during different IMF polarity and/or extreme solar wind conditions [J]. *J. Geophys. Res.*, 2012, **117**, A11222, doi: 10.1029/2012JA017845

[109] Wu Qi, Hong Minghua, Du Aimin, *et al*. Multi-point joint observations of long-time continual Pc5 ULF waves on 3 March 2007 [J]. *Chin. J. Geophys*., 2012, **55**(11): 3568-3575

[110] Zhang Jiaojiao, Wang Chi, Tang Binbin. Improved method to derive equivalent current systems from global MHD simulations [J]. *Sci. China: Earth Sci.*, 2014, **57**(1): 167-173

[111] Du J, Wang C, Zhang T L, *et al*. Asymmetries of the magnetic field line draping shape around Venus [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 6915-6920

[112] Zheng Ling, Fu Suiyan, Zong Quigang, *et al*. Solar cycle dependence of the seasonal variation of auroral hemispheric power [J]. *Chin. Sci. Bull.*, 2013, **58**(4-5): 525-530

[113] Luo Hao, Chen Gengxiong, Du Aimin. Multipoint observations of Pi2 pulsations and correlation with dynamic processes in the near-Earth magnetotail on March 18, 2009 [J]. *Sci. China: Earth Sci*., 2014, **57**(2): 359-371

[114] Xiao Fuliang, Zong Qiugang, Su Zhenpeng. Determining the mechanism of cusp proton aurora [J]. *Sci. Rep.*, 2013, **3:** 1654

[115] Liu W, Cao J B, Li X, *et al*. Poloidal ULF wave observed in the plasmasphere boundary layer [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 4298-4307

[116] Yuan Zhigang, Xiong Ying, Pang Ye, *et al*. Wave-particle interaction in a plasmaspheric plume observed by a Cluster satellite [J]. *J. Geophys. Res*., 2012, **117**, A03205, doi: 10.1029/2011JA017152

[117] Yuan Zhigang, Xiong Ying, Wang Dedong, *et al*. Characteristics of precipitating energetic ions/electrons associated with the wave-particle interaction in the plasmaspheric plume [J]. *J. Geophys. Res.*, 2012, **117**, A08324, doi: 10.1029/2012JA017783

[118] Yuan Zhigang, Xiong Ying, Zhang Shunrong, *et al*. Ionospheric characteristics associated with wave–particle interactions in a SED plume during a super geomagnetic storm [J]. *J. Atmos. Sol-Terr. Phys.,* 2013, 95/96: 96-101

[119] Yuan Zhigang, Li Ming, Xiong Ying, *et al*. Simultaneous observations of precipitating radiation belt electrons and ring current ions associated with the plasmaspheric plume [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 4391-4399

[120] Yuan Zhigang, Xiong Ying, Huang Shiyong, *et al*. Cold electron heating by EMIC waves in the plasmaspheric plume with observations of the Cluster satellite [J]. *Geophys. Res. Lett*., 2014, **41**, doi: 10.1002/2014GL059241

[121] He Fei, Zhang Xiaoxin, Chen Bo, *et al*. Moon-based EUV imaging of the Earth's plasmasphere: Model simulations [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 7085-7103

[122] Li W Y, Guo X C, Wang C. Spatial distribution of Kelvin-Helmholtz instability at low-latitude boundary layer under different solar wind speed conditions [J]. *J. Geophys. Res*., 2012, **117**, A08230, doi: 10.1029/2012JA017780

[123] Liu Y H, Fraser B J, Menk F W. EMIC waves observed by Cluster near the plasmapause [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 5603-5615

[124] Wei X H, Cao J B, Zhou G C, *et al*. Generation mechanism of the whistler-mode waves in the plasma sheet prior to magnetic reconnection [J]. *Adv. Space Res.*, 2013, **52**(1): 205-210

[125] Duan Suping, Liu Zhenxing, Angelopoulos Vassilis. Observations of kinetic Alfvén waves by THEMIS near a substorm onset [J]. *Chin. Sci. Bull*., 2012, **57**(12): 1429-1435

[126] Shi Q Q, Hartinger M, Angelopoulos V, *et al*. THEMIS observations of ULF wave excitation in the nightside plasma sheet during sudden impulse events [J]. *J. Geophys. Res. Space Phys*., 2013, **118**: 284-298