ABSTRACTS

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Substorms from Dayside to Nightside and Back

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Substorms are a global phenomenon with signatures not only in the nightside magnetosphere but also in the dayside and inner magnetosphere. During the growth phase, the dayside magnetopause erodes earthward, the cusps move equatorward, the auroral ovals expand, ionospheric convection increases, Region 1 current strengths increase, and a duskward current appears in the dayside equatorial ionosphere. Onset and the release of energy stored within the magnetotail may be triggered by instabilities internal to the magnetotail, solar wind dynamic pressure increases, fluctuations in the interplanetary magnetic field, or localized plasma injections/auroral streamers; the latter remaining a topic of considerable and continued debate. Following onset, the expansion phase injects plasma deep into the magnetosphere and returns magnetic flux to the dayside magnetosphere. During the recovery phase, dayside and nightside reconnection cease, boundaries stop moving, and magnetic fluxes in each region stabilize. This presentation focusses on the dayside, nightside, steady, and intermittent processes that lead to and follow substorm onset.

Driving Magnetosphere Convection through the ionosphere: A key component in a proposed model of Strongly-Driven Substorms

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Dungey cycle explains that the convection within the closed part of the magnetosphere is primarily driven by magnetic reconnection in the nightside magnetospheric tail. Using global MHD simulations of an event study in strong solar wind, here we show that magnetospheric convection can also be driven solely by dayside magnetospheric reconnection through the ionosphere's two-cell convection. Specifically, dayside magnetic reconnection generates anti-sunward plasma flow over the geomagnetic poles, which in turn drives the ionosphere's two-cell convection during southward IMF. Through the FAC, the ionosphere's two-cell convection and associated convection electric fields are mapped to the magnetosphere, driving the convection within the closed-part of the magnetosphere. This sequential

process of enhanced convection progresses from the dayside to the nightside and responds rapidly, within 10-20 minutes, to a southward turning of the IMF. As a consequence, the dayside-driven magnetosphere convection produces a distinctive pattern of flow deflection in the azimuthal direction on the nightside at distances from 8 to 15 Re. These flow deflections are generally responsible for the formation of the substorm current wedge (SWC) system. In global MHD simulations, such flow deflection and SWC-like FAC are found in this event. Observational evidence from ionosphere and magnetosphere for this event are provided to support the proposed scenario.

Shock Induced Strong Substorms and Super Substorms: Preconditions and Associated Oxygen Ion Dynamics

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It is well known that the interaction between interplanetary (IP) shocks and the Earth's magnetosphere would generate/excite various types of geomagnetic phenomena. Progresses have been made on the Earth's magnetospheric response to solar wind forcing in recent years in the aspects associated with magnetospheric substorms. Strong substorms and super substorms could be triggered externally by sudden changes of solar wind dynamic pressures. When a strong substorms (AE > 1000 nT) or super substorms (AE > 2000 nT) occurs, singly charged oxygen ions escaped from the Earth's ionosphere are found to be a dominated ion population in the magnetotail and in the inner magnetosphere—ring current region. The products of a strong substorms or super substorms- plasmoid, burst bulk flows are also found to contain significant oxygen ions, even substorm injections can be dominated by oxygen ions. Thus, the magnetospheric dynamic must consider the contributions from the heavy oxygen ions. Also, the IP shock induced super substorms associated electromagnetic pulses (dB/dt) would shift the energetic particle (injections) inward and accelerate existing population significantly.

Extensive attempts have also been made to understand how the solar wind energy couples with the magnetosphere to excite magnetospheric substorms. The statistical analysis shows that strong substorms (AE > 1000 nT) and super substorms (AE > 2000 nT) triggered by interplanetary shocks are most likely to occur under the southward interplanetary magnetic field (IMF) and fast solar wind pre-conditions. In addition, strong substorms after the IP shock arrival are more likely to occur when IMF points toward (away from) the Sun around spring (autumn) equinox, which can be ascribed to the Russell-McPherron effect. Thus, the southward IMF precondition of an interplanetary shock and the Russell-McPherron effect can be considered as precursors of a strong substorm and/or super substorm triggered by IP shocks. Moreover, the average duration of CME sheath region which is just behind the interplanetary shock are found to be about 7 hours. This indicates that southward IMF compressed by shock could last at least 7 hours long in the downstream of the interplanetary shock (sheath region) if a southward IMF pre-condition is present, which explains why the largest substorm often occur in the CME sheath.

A Review of Supersubstorms (SSSs): Their Properties and Their Energetics

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Supersubstorms (SSSs) are defined as intense auroral zone geomagnetic (SML < -2500 nT) activity. They are obviously more intense than a normal substorm (by definition) and they can last for 5 hours or more. The nightside SSS onsets and auroral evolution (in two cases) were found to be substantially different than the Akasofu (1964) standard picture of auroral development for “typical” substorms. SSSs are the primary causes of geomagnetically induced currents (GICs) at the Mäntsälä gas pipeline, Finland, determined from a 21-year data study. Intense GIC events were sometimes found on the dayside. The amount of Joule heating on the dayside is found to be equal to that on the nightside. Cases will be shown where single SSS events caused major (SYM-H < -100 nT) magnetic storms, probably implying for these cases, the SSS events and the magnetic storms were perhaps the same thing? By studying interplanetary shock-related SSS events, we have gained new knowledge of the energetics of SSS events.

Effect of interplanetary shock on an ongoing substorm: Simultaneous satellite-ground auroral observations

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Substorm processes have been studied in detail, and it is well known that interplanetary (IP) shock encountering the terrestrial magnetosphere causes global responses. However, how IP shock compression to the magnetosphere affects the development of an ongoing substorm remains uninvestigated. Herein, the simultaneous satellite and ground-based auroral evolutions associated with an IP shock impact on the magnetopause during an ongoing substorm on May 7th, 2005, were examined. The IMAGE satellite over the Southern Hemisphere captured the global development

substorm, which was initiated at 17:38:47 UT. The poleward branch of the nightside auroral oval was fortuitously monitored by an all-sky camera at the Zhongshan Station (−74.5° magnetic latitude, ZHO) in Antarctica. The satellite imager observed continuous brightening and broadening of the nightside auroral oval after the IP shock arrival. The simultaneous ground-based optical aurora measurement displayed the intensification and expansion of a preexisting auroral surge poleward of the aurora oval. The geomagnetic field variations and the instantly increased PC indices indicated an elevated merging rate and enhanced the convection-related DP-2 currents. Therefore, this IP shock transient impact did not significantly change the ongoing development of the substorm, although it meets the magnetospheric precondition hypothesis.

The features of substorms on a contracted auroral oval

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Polar substorms include substorms observed at geomagnetic latitudes above 70° MLAT in the absence of simultaneous negative magnetic bays at lower latitudes. On the example of individual events registered on arch. Svalbard, the general morphological features of polar substorms are considered. It is shown that polar substorms, like “classical” substorms, are characterized by the formation of a substorm current wedge (SWC), an abrupt movement to the pole after the onset; generation of Pi2 geomagnetic pulsations, an increase in the PC- index of the polar cap before the onset. At the same time, there are certain differences between polar substorms and “classical” substorms, namely, development in the region of a compressed auroral oval, appearances at earlier pre-midnight hours, generation only at low solar wind velocity and weakly disturbed geomagnetic conditions. It has been suggested that polar substorms, apparently, represent a specific type of "classical" substorms developing in the evening sector under magnetically quiet or weakly disturbed conditions, when the auroral oval is compressed. The source of polar substorms can also be associated with a local intensification of previously existing substorms in the post-midnight sector.

The substorm effect on the ring current

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The dynamic of the ring current significantly affects the electromagnetic fields in the inner magnetosphere. An increase in the ring current can lead to a magnetic storm. Most of the previous works have studied the dynamics of the ring current during magnetic storms. Few studies have paid attention to the contribution of magnetospheric substorms to the ring current. This report will mainly discuss the dynamic process of the ring current during the substorm, and discuss the overall change of the ring current caused by the injection of the substorm.

Storm time substorms and outer radiation belt

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Storm time substorms are often considered as a distinct type of substorms, based on the assumption that tail reconnection plays a role in the development of an ordinary substorm in the absence of storms. However, the presence of high levels of tail turbulence allows for the identification of reconnection-type disturbances and bursty bulk flows (BBFs) even before the onset of any substorm, meanwhile not all BBFs can be linked to substorm development. Storm time substorms result in particle injection within the magnetosphere, the development of the ring current, and an increase in magnetospheric convection. However, a clear increase in SYM-H is also observed following strong ordinary substorms. Substorm dipolarizations lead to sharp increases in energetic electron fluxes. Recent studies have shown that substorm dipolarizations deep inside the magnetosphere towards Earth, in the region of magnetic field depression caused by the ring current, are the main mechanism for relativistic electron acceleration in the outer radiation belt (ORB), contrary to previous discussions on acceleration by chorus waves over many hours. These new findings require a re-analysis of the origins of magnetospheric substorms, suggesting that storm time substorms share the same nature as ordinary substorms and can be explained without assuming the dominant role of reconnection. Here we present the latest findings on the nature of substorms and the formation of the ORB, while identifying key directions that can contribute to achieving a self-consistent understanding of the processes leading to magnetic storm development and ORB formation. Our analysis is based on the study of magnetospheric pressure stability and the validity of Tverskaya's relation, which links the position of the ORB maximum after a storm with the magnitude of the Dst/SYM-H minimum after the storm. This relation holds true for the vast majority of storms analyzed.

Simulation of dynamic evolution of ring current ion flux by a lunar-base Energetic Neutral Atom (ENA) imaging

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The distribution of energetic ion flux in the ring current region, like a meteorological cumulonimbus cloud, stores up the particle energy for auroral substorm. It is helpful to study the auroral substorm mechanism by using lunar-base ENA imaging simulation of the dynamic evolution of ring current, and establishing the corresponding relationship between key node events of the substorm. Based on the previous observation experience and our simulation results of the dynamic evolution of the ring current, we propose a macroscopic model of auroral substorms which related to the dynamic evolution of ring currents, and present the possibility of confirming the causal sequence of some of those critical node events of substorms with lunar base ENA imaging measurements. IBEX, operating in the ecliptic plane, may even have given examples of telemetry of ring current ion fluxes through ENA measurements during substorms/quiets already.

Substorm-like Processes at Giant Planets

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Terrestrial substorms are among the most significant space weather events, capable of inducing strong perturbations on electromagnetic energy and energetic particles in near-Earth space environments. Similar perturbations have also been observed in giant planetary spaces, referred to as substorm-like processes to avoid confusion among distinct scientific communities. In this presentation, I will provide an overview of substorm-like processes at Saturn and Jupiter, focusing on energy circulation, particle acceleration, magnetic configuration, radio emission, and aurorae, among other related phenomena.

Global magnetospheric reconfigurations: Substorm-like behaviour at different planets explored with remote radio observations and in situ field and plasma measurements

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We explore the broad topic of “substorms” or “global magnetospheric reconfigurations” at different planets, drawing on decades of knowledge at Earth and considering the differences that come about due to varying planetary rotation rates, planetary field strengths, and internal magnetospheric plasma sources. When it comes to understanding reconnection effects, the study of multiple planets is worth much more than the sum of individual parts. In this talk we focus on two key aspects of the study of large-scale magnetospheric dynamics. (1) We build on work at Earth [Waters et al., 2021; Fogg et al., 2022] which has unlocked 10+ years of Auroral Kilometric Radiation data from Wind/WAVES and quantified the link to substorm onset. Similar radio phenomena – including intensifications and extensions of emission to lower frequency – are observed at Saturn and Jupiter, and can act as a remote diagnostic of intense magnetospheric dynamics. Examples from Cassini (Saturn) and Juno (Jupiter) can elucidate the utility of remote observations for tracking global dynamics. (2) We also use in situ field and particle data to identify transient reconnection products (e.g. plasmoids, Travelling Compression Regions), as well as using measurements in magnetotail lobes to track changes in flux content as a way of quantifying Dungey cycle timescales, and the loss of mass and closure of flux via tail reconnection. Examples at Mercury, Jupiter and Saturn reveal the diversity in timescales for reconnection activity as well as diverse drivers (external and internal) of magnetospheric activity.

Are Dawn Storms Jupiter's auroral substorms?: Clues from the Juno mission

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Identified as soon as we could acquire well resolved images of the UV auroras of Jupiter with the Hubble Space Telescope, Dawn Storms are among the brightest and most spectacular auroral events on Jupiter. Their name derives from the fact that the brightest part of the sequence always takes place on the dawn side of the main auroral oval. However, recent and unprecedented observations from the Juno spacecraft, which acquires views of the aurorae from the poles and has access to the night side of the aurorae, showed us the process actually starts on the night side and continues on the dusk side (and possibly even beyond) as the planet rotates. As the number of observations increases, a pattern starts to emerge, with an initiation with faint midnight spots, then beads on the main emissions, then an spectacular expansion and brightening of the dawn arc with an latitudinal emission void, followed the formation of a longitudinal gap the appearance of large scale injection signatures. We also noted that most dawn storms are non-isolated, meaning that they often occur in sequences separated by a few hours, and that some dawn storms do not fully develop (pseudo-dawn-storms). These morphological characteristics as well as in situ measurements carried out in the magnetosphere indicate that Dawn

Storms are the auroral signatures of large scale reconfigurations of the magnetotail. While the accumulation of mass an energy in the Jovian magnetotail is related to internal processes (essentially Io's volcanism and Jupiter's rotation), the explosive reconfigurations of the magnetosphere which follows it bears many similarities with the terrestrial substorms, indicating that similar physics is at play.

Trapped and Leaking Energetic Particles in Injection Flux Tubes of Saturn's Magnetosphere

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In Saturn's magnetosphere, the circulation of magnetic fluxes requires the inward motion of localized flux tubes with sharply enhanced equatorial magnetic fields. The flux tubes also carry energetic particles radially inward, of which the azimuthal drift motion is expected to produce energy-dispersive signatures. In this paper, we demonstrate that the drift motion can be significantly modified by the sharp magnetic gradient at the edge of the flux tube, which enables particle trapping at 90-degree pitch angles. The bouncing particles are hardly affected by the gradient, and therefore can still display energy-dispersive particle-leaking signatures. The distinct behavior corresponds to the observational diversity of energy-dispersive and/or dispersionless features depending on particle pitch angle, spacecraft traversal path, and the extent of the trapping region. The results improve our understanding of particle dynamics in Saturn's magnetosphere and indicate that caution should be applied in the observational data interpretation for flux tube properties.

Charge Separations and effects in the Geomagnetosphere

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Electromagnetic fields pervade the vastness of magnetospheres, playing a crucial role in regulating and influencing the behavior of magnetospheric plasmas. Electromagnetic fields emanate from electric charges and electric currents. The spatial distribution and mobility of these charges fundamentally determine the characteristics of the space electromagnetic field. By determining the distribution of space charge density, one can gain insight into the dynamic processes underlying the magnetospheric electromagnetic field, enabling a deeper understanding of the behavior and dynamics of magnetospheres. This study shows how to deduce the net charge density in electromagnetic structures by using the multiple point DC electric field measurements by multiple spacecraft constellations. The charge separations in the inner magnetosphere, the magnetopause boundary layer and magnetotail dipolarization fronts have been investigated accordingly. It has been found that there exists a positive

(negative) charge accumulates in the dusk (dawn) side inner magnetospheres, which can drive the region II field aligned currents. This study also discusses novel measurement principles for space charge density based on electric potential detection from multiple electric probes. It not only can observe the space net charge density but also enables high-precision measurements of electric field vectors.

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Substorm onset: An east-west aligned instability from spreading of flow channels driven by meso-scale polar-cap flows

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Substorm onset arc involves wave-like brightening along the onset auroral arc. Each wave is associated with intense electric fields, and the waves grow in amplitude following their initiation and then evolve into non-linear structures. These observations imply that substorms are initiated by an instability within the near-Earth plasma sheet, introducing the questions of what are conditions that lead to this instability and what is the physics of the instability. Direct observations of ionospheric flow, as well as using auroral imaging, support the idea that meso-scale flow channels intruding to the onset location are responsible for triggering the onset instability. But how can flow channels, which are not east-west aligned lead to onset, which is east-west aligned? The Rice Convection Model shows that, as a result of the energy dependent magnetic drift, the low entropy plasma of a flow burst spreads azimuthally within the inner plasma, which would lead to the east-west oriented onset. This is verified by ground-based radar and all sky imager observations showing subauroral polarization stream (SAPS) and dawnside auroral polarization stream (DAPS) enhancements at appropriate locations relative to onset.

The question then arises of what leads to the meso-scale flow channels within the plasma sheet? The answer may by in dynamic mesoscale flow channels that move across the open field line regions of the polar caps, and then enter the nightside plasma sheet via externally triggered localized reconnection. Within the plasma sheet, they can lead to other important space weather disturbances, such as streamers, and omega bands, as well as substorms. We find that the polar cap structures leading to disturbances can have long durations (at least ~1½ to 2 hours), and one flow structure can lead to more than one disturbance as it moves azimuthally within the polar cap. Examples using 630 nm auroral and radar observations indicate that the motion of flow channels within the polar cap may be significantly controlled by the IMF By. This motion appears to possibly be a critical factor in determining when and where a particular substorm will be triggered within the auroral oval. Also, potentially important is the occasional dramatic azimuthal turning of a flow channel, leading to azimuthal broadening of flow channel contact with the auroral oval and of a subsequent substorm onset.

Connection between substorm onset and expansion phase activity

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Dipolarization fronts and bursty bulk flows characterize energy transport in the magnetotail, and they are particularly intense during the substorm expansion phase. They originate in or around the near-Earth neutral line (NENL) at ~20-30 RE. To understand the behavior of the intense energy transport during substorms, it is important to understand how NENL is activated. The major issue about the connection between the two regions is the large (~10-20 RE) separation. Substorm onset is characterized by an intensification of auroral beads that corresponds to plasma instability in the near-Earth (~10 RE) plasma sheet at the first few minutes of the expansion phase. The region poleward (or tailward in the tail) of the onset arc is quiet except for faint growth-phase auroral streamers. On the other hand, NENL is located at ~20-30 RE and becomes active soon after the onset. It is not understood how the information of the substorm onset is sent to activate NENL. If near-Earth substorm onset sends information downtail, it is expected to illuminate the ionosphere right poleward of the onset arc. The present study examines this connection by investigating THEMIS all-sky imager observations. We found that a faint auroral arc forms a few tens of km poleward of the onset arc during substorm auroral onset before the poleward expansion begins. The onset beads grow faster within the longitude range of the poleward arc. The poleward arc moves poleward earlier than the poleward expansion of the onset arc, and then the fast-growing beads on the onset arc evolve to the auroral surge. The onset arc outside the local time range of the poleward arc grew much more slowly. This sequence suggests that the poleward arc maps to a narrow dawn-dusk region just tailward of the near-Earth onset instability. Its poleward motion would correspond to configuration changes of the magnetotail tailward of the onset region. We suggests that this tailward progression results in activation of NENL.

The role of incident post onset auroral streamers in driving the azimuthal expansion and duration of an auroral substorm

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The auroral substorm is the visible part of a magnetospheric substorm, and auroral streamers are the ionospheric footprint of plasma sheet flow bursts. All-sky imager observations show that substorms often have an initial onset that is followed by multiple expansion onsets at different longitudes, causing the formation of an azimuthally extended expansion phase and prolonged auroral activity. The larger the azimuthal extent and duration of a substorm expansion phase, the larger should be the disturbances in the Earth's ionosphere-thermosphere system; therefore, it is important to understand the factors that control the development of substorm expansion. Recent work suggests that pre-onset auroral streamers play a key role in the substorm onset by triggering near-Earth instability. However, the role of post-onset auroral streamers (hereafter referred to as the incident streamers) in controlling a substorm's azimuthal expansion and duration remains unknown. We used continent-scale ground-based Time History of Events and Macroscale Interactions (THEMIS) all-sky imager data to investigate the role of incident streamers in driving the azimuthal extent and duration of a substorm expansion phase. In addition to supporting the previous hypothesis that a pre-onset auroral streamer triggers a substorm onset at the pre-onset auroral arc, results reveal that repetitive incident streamers can trigger auroral onset at different longitudes, leading to an azimuthally expanded and prolonged substorm expansion phase. Furthermore, after onset, the auroral bulge can glide azimuthally along an incident streamer, suggesting that external streamers mark a channel for the continued expansion development. Occasionally, the onset aurora lifts poleward along an incident streamer. This usually occurred along bright onset-triggering streamers, and we have referred to such streamers as ‘straw streamers’. We identified some events where the incident streamer remained connected to the equatorward arc and appeared to feed the further auroral activity development. We refer to such streamers as 'pouring streamers'. These results suggest that the flow channels that occur after the substorm onset may be an important key to determining the duration and azimuthal expansion of the substorm expansion phase. We speculate that these auroral streamers (flow channels) likely originate from the polar cap, but more research is needed to confirm this hypothesis.

Plasmasheet Counterparts for Auroral Beads and Vortices in Advance of Fast Flows: New Evidence for near-Earth Substorm Onset

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The relationship between the signatures observed in the ionosphere, on the ground and in the plasmasheet during the transition to substorm onset is important for understanding the sequence of events that occur during a substorm event. The processes which occur at substorm expansion phase onset are of particular importance since they precede a large-scale morphological change in the magnetotail. Here, we present a case study of an event that occurred on September 18, 2021, between 04:45 and 05:00 UT, where the three Time History of Events and Macroscale Interactions during Substorms (THEMIS) probes were well-positioned to capture the signatures in the near-Earth plasmasheet region, at a location closely magnetically conjugate to Gillam (GILL) station. Four auroral activations were detected in the various GILL all-sky imagers (ASIs) all of which can be directly associated with plasmasheet disturbances observed in-situ at the three THEMIS satellites. An initial activation showed the brightening of an equatorward arc along with small vortices, well inside the cutoff of the 630 nm emissions, indicating initial activity in the inner magnetosphere on closed field lines well inside the open-closed field line boundary (OCFLB). This auroral activity gradually faded, and for this pseduo-onset a full substorm did not follow. During a second activation, auroral beads were observed on a brightening arc, again equatorward of the 630 nm cutoff at the OCFLB, followed by the transformation to vortices and then saturated mushroom-like auroral forms during the third activation. The tail current sheet was highly disturbed during the period of auroral vortex evolution, soon accompanied by pressure and Maxwell stress disturbances and an apparent broadening of a previously thin current sheet and a breakdown of the frozen-in condition. We attribute the plasmasheet disturbances to a kinetic scale ballooning instability, which interestingly is also associated with depolarization and an apparent diversion of the cross-tail current. Our observations clearly show late growth phase dynamics, including arc brightenings, the formation of auroral beads, and auroral vortex development, can occur well in advance of fast flows in the tail. Indeed, it is only during the later activity that strong Earthward flows, which we associate with magnetic reconnection further down the tail, auroral breakup and strong magnetic bays are observed on the ground. Here the observed sequence of events is consistent with a near-Earth shear-flow ballooning instability developing in advance of reconnection at a near-Earth neutral line, consistent with an inside-to-outside sequence of events at substorm expansion phase onset.

Auroral Beads in Conjunction With Kinetic Alfvén Waves in the Equatorial Inner-Magnetosphere

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Auroral beads are spatially wavy forms routinely seen before the onset of auroral substorms and are closely related to the onset-related instabilities. To date, the acceleration mechanism of electrons that create auroral beads is not fully determined. Here, we present a fortuitous event when the Van Allen Probe A (RBSP-A) was in magnetic conjunction with auroral beads. RBSP-A observed Alfvén waves, locally generated kinetic Alfvén waves (KAWs) and Alfvénic accelerated electrons at several 100 eV. The Alfvén waves and KAWs carried sufficient Poynting flux to power visible aurora and may control the beads' motion. These observations and previous simulations support that the Alfvénic acceleration is the acceleration mechanism of the auroral beads. Specifically, KAWs are generated around the equator and accelerate local cold electrons to several 100 eV. The waves are suggested to propagate to both hemispheres and accelerate electrons to several keV, which directly account for the auroral beads.

The Potential Role of Modified Electron Acoustic Wave and Nonlinear Mode Coupling in Mono-Energetic Aurora

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Results from a 1D kinetic simulation, for the first time, reveal the important role of modified electron acoustic wave (MEAW) in auroral electron acceleration. Parallel electric fields, generated due to the mode coupling between kinetic Alfven waves (KAWs) and MEAWs in the transition region from the magnetosphere and the ionosphere, can be sustained by continuous energy input carried by Alfven waves from the magnetosphere. Under the incidence of long-period Alfven waves carrying upward field-aligned currents, a parallel potential drop can be formed in the transition region, leading to mono-energetic electron acceleration. Such a mechanism provides a possible link between shear Alfven waves and the mesoscale mono-energetic auroral electron acceleration.

Ballooning-Interchange Heads from Midtail: In-Situ, Ground, Low-Altitude and Auroral Signatures

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Using ionospheric and low-altitude observations during an about 10hr long Magnetospheric MultiScale (MMS) radial outward passage in the plasma sheet after southward interplanetary magnetic field (IMF) turning, we track changes in the configuration and dynamics of the plasma sheet and identify the ionospheric response to these changes. MMS entered the magnetotail from the inner magnetosphere and moved radially outward more than 10 Re (Re – Earth's radius). We identify this period as stationary magnetospheric convection with weak magnetospheric activity (SML index was about 100 nT), fueled from the nightside, where MMS observed quasi-regular series of isolated bursty bulk flows and dipolarization fronts (BBF/DFs). The MMS data indicate a number of distinctive signatures, which attribute the series of the DFs to the kinetic ballooning-interchange heads at their non-linear stage of development. Among the signatures are the azimuthal DF propagation velocity component, the electromagnetic ion-cyclotron waves, as well as dawn-/duskside asymmetries in the ion temperature due to a finite ion Larmor radius effect. The ionospheric response to these activations was observed in both hemispheres near Greenland magnetic local time as a series of magnetic pulses. The ionospheric auroral observations indicated the presence of a structured azimuthal auroral arc and north-south injection prints. Inspecting energetic particles from conjugate low-altitude spacecraft we identify meridional spacecraft passages with isolated step-like increases of energetic proton flux, which manifest magnetotail flow channel boundaries. One azimuthal passage revealed quasi-periodical modulation of the flux, indicating simultaneous presence of up to ten azimuthally localized flow channels (each about 0.25h MLT wide). Using an adapted model and the identified locations of the particle isotropy boundaries, we also discuss the relation between the global configuration of the near-Earth magnetotail (Xgsm > -20 Earth's radii), the observed BBFs and the response to them in the conjugate ionosphere/high-latitude part of the auroral oval.

A Magnetosphere-Ionosphere Alfvén Wave Exchange Model for Substorm Onset

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Terrestrial substorms involve the explosive release of stored magnetic energy in the magnetotail at substorm expansion phase onset. However, the processes responsible for triggering the release of this stored energy are poorly understood and remain actively debated. Here we present a new model for substorm expansion phase onset based on the destabilization of the magnetotail arising from dynamical changes to the exchange of Alfvén waves between the ionosphere and the magnetosphere

on stretched field lines in the late growth phase. This new Alfvén wave exchange model for substorm onset incorporates the effects of field line stretching, changes to Alfvén wave propagation and reflection in the magnetosphere-ionosphere system, and a destruction of the pre-existing dynamical equilibrium, as its core tenets. We present the details of this new paradigm, and examine its predictions in comparison to the observational sequence of events in the late growth phase of the substorm cycle.

Gyrokinetic model of the Alfven wave parallel electic field generation in the dipole model of the magnetosphere

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One of the important features of ULF waves, including Alfven waves, is the ability to accelerate charged particles. This can be observed as a modulation of the luminosity of aurora arcs with Alfven wave frequencies on the corresponding magnetic shells in the auroral regions of the Earth's magnetosphere. Despite a large number of models of particle acceleration by Alfvén waves, a mechanism that satisfies all the observed facts has not yet been found. We suggest a mechanism for the generation of Alfven wave parallel electric field in the gyrokinetic approach for a dipole-like magnetosphere with trapped particles. The coupling with the compressional mode due to the magnetic field non-uniformity and finite plasma pressure provides the parallel magnetic field of Alfven wave. Further, the compressional and Alfven modes acquire the parallel electric field due to coupling with the electrostatic mode as required by the quasi-neutrality condition in kinetics. The parallel electric field acquired by the suggested mechanism is considerably larger than that due to the coupling between the Alfven and electrostatic modes in homogeneous plasmas. The parallel electric field is described by an integral equation arising from the averaging of the bounce-motion of electrons. This equation solution shows the change in the parallel potential of the Alfven wave electric field along the magnetic field line.

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Generation of field-aligned currents during substorm expansion: The latest updates

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Sudden intensification of field-aligned currents (FACs) is one of the manifestations of substorms. However, the generation of the substorm-associated FACs is a controversial issue, and not well understood. We incorporated a new method to search for the generation region and to investigate the generation mechanism of the substorm-associated FACs. Assuming that perturbation associated with the FACs propagates at the Alfvén velocity in the rest frame of moving plasma, we traced packets of the Alfvén wave backward in time from the onset position in the ionosphere in the global magnetohydrodynamics (MHD) simulation. The generation region is found in the near-Earth plasma sheet near the equatorial plane. We call this near-Earth FAC dynamo region. In the near-Earth FAC dynamo region, azimuthally moving plasma pulls the magnetic field line, and performs negative work against the magnetic tension force. The plasma involved originates in the tail lobe region. When near-Earth reconnection occurs in the plasma sheet, the plasma is accelerated earthward by the Lorentz force, and decelerated by the plasma pressure gradient force, followed by the Lorentz force. The flow is deflected to the west and east directions by the plasma pressure gradient force and the Lorentz force, resulting in the excitation of Alfvén waves and FACs. FACs are generated from the requirement of Ampère and Faraday laws. The Alfvén waves together with the FACs propagate along the magnetic field in the rest frame of the moving plasma. When it arrives at the ionosphere, the auroral electrojet starts developing and the substorm expansion phase begins. It takes ~0.7 minutes to travel from the near-Earth FAC dynamo to the Earth. Because of the finite velocity of plasma, the packet of the Alfvén waves was deflected by ~0.2 hours in MLT from the magnetic field line originating from the onset point in the ionosphere. After the arrival of the FACs from the magnetosphere, additional FACs could be generated from the requirement of the current continuity in the ionosphere, which may be related to the auroral surge traveling westward, poleward, and sometimes eastward. A series of processes from the near-Earth reconnection to the sudden intensification of the auroral electrojet becomes clearer than ever.

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Electron-scale current structures observed in the magnetotail plasma sheet during substorms

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We report MMS observations of intense electron-scale (e-scale) current structures in the magnetotail Plasma Sheet (PS) during the intervals of high-velocity bulk flows. The majority of these intervals corresponded to the substorm growth phase. The electric current density in these structures exceeds 30 nA/m2, which is several times larger than the typical current density observed in the undisturbed cross-tail current sheet. A thickness of the e-scale current structures was about a few electron gyroradii or less, so that the electric current was carried by unmagnetized thermal and/or suprathermal electron population. The epoch analysis has shown that the majority of e-scale structures were observed in the magnetic flux pile up region. Strong nonideal electric fields (E') with the amplitude up to tens mV/m were observed in many e-scale structures from our data base. The presence of these fields results in significant energy dissipation: in some events the value of j*E' was up to a few nW/m3 which is comparable or even larger than the value observed in other nonstationary structures (e.g. in dipolarization fronts, magnetic islands ets). Thus, the processes of energy transformation in the e-scale current structures formed in the PS can be important elements in energy transfer between electrons and fields, and can provide an additional energization of the ambient electron population in the PS.

This work is supported by Russian Science Foundation (grant # 23-12-00031).

Onset of magnetotail reconnection from an electron-only phase

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The onset mechanism of magnetotail reconnection has been controversial. Here by employing particle-in-cell simulations, we show that the magnetotail reconnection can start from an electron-only phase, in which only electrons couple with the reconnection process whereas the ions do not. We also provide direct evidence for the mechanism from the MMS spacecraft observations. The study helps better understand the onset of magnetotail reconnection and even the onset of substorms.

Dipolarization front and its role in substorm and particle acceleration

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Dipolarization front—a sharp boundary leading reconnection jets and producing colorful auroras—plays a crucial role in the magnetotail energy conversion. Behind this front, sometimes energetic electrons appear, whereas sometimes they vanish. The reason causing such uncertainty is still a mystery, owing to the lack of high-resolution measurements. Here we propose a new theory to uncover this mystery: we find that behind the front there exists a magnetic bottle with time-varying belly but steady neck. When the belly is expanding—like a man getting fat—the magnetic bottle is formed and energetic electrons are trapped; when the belly is contracting—like a man getting slim—the magnetic bottle disappears and energetic electrons are expelled. Our theory can explain both the presence and absence of energetic electrons behind dipolarization fronts.

Experimental Determination of the Dispersion Relation for Whistler Wave during Substorm

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Whistler waves that can produce anomalous resistivity by wave-particle interactions have been suggested as one of the mechanisms responsible for rapid magnetic reconnection. The dispersive property of whistler waves is the key to understanding why the reconnection rate is independent of any mechanism that breaks the frozen-in flux condition, inside the region where the electrons decouple from the magnetic field. However, there has been no direct determination of such property in spacecraft experiments, because the whistler wave usually propagates at a few-tenths of electron cyclotron frequency, which is relatively higher than the resolution of the fluxgate magnetometer for most satellites, thus making it difficult to resolve wave vectors. Here, we experimentally determine the dispersion relation of a low-frequency whistler wave in super-hot plasmas during substorm time, in good agreement with the theoretical predictions. These findings should provide new insights into the physics of magnetic reconnection, particularly in high-temperature plasmas (Te up to several keV).

Statistics of the high-speed electron flows in the magnetotail

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High-speed electron flows play an important role in the energy dissipation and conversion in the terrestrial magnetosphere and are widely observed in regions related to magnetic reconnection, e.g., the vicinity of electron diffusion regions (EDRs), and separatrix layers. NASA's Magnetospheric Multiscale mission was designed to resolve the electron-scale kinetic processes of Earth's magnetosphere. Here, we perform a systematic survey of high-speed electron flows in the terrestrial magnetotail using the MMS observations from 2017 to 2021. The high-speed electron flows are characterized by electron bulk speeds larger than 5000 km/s. We identified 642 events. Those events demonstrate unambiguous dawn-dusk asymmetry, and 73% of them locate in the dusk magnetotail. The selected events are found in EDRs, the reconnection separatrix boundary layer, and the lobe region. More than 70% of the events are identified in the separatrix boundary layer and the lobe region and are aligned with the ambient magnetic field. 29 cases, with magnetic field magnitude smaller than 5 nT, locate near the plasma-sheet neutral line. Approximately 20 cases among them have EDR signatures, and those high-speed electron flows are directed arbitrarily with respect to the ambient

magnetic field. We also show other statistical properties of the events, including the time of duration, electron bulk speed, and electron number density.

Wednesday, October 18, 2023

Alfvénic Aurora during Substorms

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The investigation of the global role and global impact of Alfvén waves in the dynamics of the terrestrial magnetosphere-ionosphere system has been the focus of several studies in the last decade. In this presentation, we review results related to substorms: (1) The Alfvén wave power over the nightside auroral zone grows linearly with increasing AE index; (2) 18–50% of the optical intensity in the substorm auroral bulge is driven by Alfvén waves; (3) During the substorm expansion phase, about 50% of the Alfvén wave power over the entire nightside auroral zone is collocated with the (substorm) auroral bulge region; (4) the total Alfven wave power shows three phases, growth, expansion and recovery, during substorms; (5) Alfven wave power is larger during storm-time substorms, compared to nonstorm-time substorms.

Electron-Scale Measurements of Antidipolarization Front

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Antidipolarization fronts (ADFs), usually formed at the leading edge of the tailward reconnection jets in the Earth's magnetotail, are characterized by sharp enhancements of southward magnetic field (negative Bz). The fine structures at electron scale of the ADFs have not been studied so far, due to instrumental limitations and large separation of previous spacecraft. Here, we use the Magnetospheric Multiscale mission to investigate the structure and dynamics of an ADF at electron scale. We find an intense current at the ADF, with the parallel current carried by a fast electron jet and the perpendicular current contributed by ion flow. Strong electric fields are found at the front and balanced by Hall term. The ion current leads to strong energy conversion, transforming the electromagnetic energy into particle energy. Our study makes essential steps toward understanding ADF dynamics in the magnetotail.

A Radial Standing Pc5-6 Wave and its Energy Coupling with Field Line Resonance within the Dusk-sector Magnetosphere

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Global ultra-low frequency (ULF) oscillations are believed to play a significant role in the mass, energy, and momentum transport within the Earth’s magnetosphere. In this letter, we observe a ~1.2 mHz radial standing wave in the dusk-sector magnetosphere accompanied by the field line resonance (FLR) on 16 July 2017. The frequency estimation from the simple box model also confirms the radial standing wave. The essential characteristics of FLR are concurrently identified at the dusk-sector magnetosphere and the conjugated ground location. Further, the radial standing wave dissipates energy into upper atmosphere to enhance the local aurora by coupling itself to the FLR. The magnetospheric dominant 1.2/1.1 mHz ULF waves plausibly correspond well with the discrete ~1 mHz magnetosheath ion dynamic pressure/velocity oscillation, suggesting this radial standing wave and FLR in the flank magnetosphere may be triggered by the solar-wind and/or magnetosheath dynamic pressure/velocity fluctuations.

A statistic study of Aurora evolution during Substorms: Boundaries, area and spanning

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In this work, using Polar/UVI data from 1996-2000, we proposed a new tool for aurora boundaries extraction based on deep-learning method SAG and Hr-seg. From the substorm onset lists provided by JHU/APL, we choose 596 independent substorm cases. The aurora boundary variations are extracted from the Polar/UVI images, using the tool given by deep learning. By analyzing the boundaries changes during the substorms, we conclude that the aurora latitude range and area is larger when the IMF By is positive than the negative cases. The longitude spanning duration is shorter than the latitude boundaries expansion. Also, the boundaries variation has an important seasonal control.

Revisit on the formation of trunk-like ion spectral structures in the inner magnetosphere

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The interplay between ion transport, acceleration and loss processes in the inner magnetosphere result in complicated patterns in ion spectra, known as ion spectral structures. An interesting type of such spectral structures, the trunk-like structures named after their shapes in the observed ion energy spectrum, is characterized by enhanced ion fluxes at decreasing energies towards Earth. An outstanding puzzle for these structures is that they appear almost exclusively during the inbound but not outbound passes of the observing spacecraft. To unravel this puzzle, we propose that the ions in the trunk-like structures are not dispersed radially as usually expected, but instead dispersed along the azimuthal direction due to the energy-dependent gradient/curvature drift speed. We build a dispersion model based on this hypothesis, and predict the trunk-like structures are accompanied with nose-like structures in the conjugated outbound pass, which is validated in a case study. Our study provides further insights into the rich dynamics deep inside the inner magnetosphere even during geomagnetic quiet intervals.

Magnetic Sandglass: A New Formation Mechanism for Electron Cigar-type Distribution during Substorm

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During substorm time, the cigar-type distribution of electrons, exhibiting pitch angles primarily at parallel/anti-parallel directions, is widely appearing inside the flux pile-up region or neutral sheet in the magnetotail and has long been attributed to the adiabatic Fermi acceleration or betatron cooling. However, all these classical mechanisms cannot explain the electron flux dropout in cigar distribution—especially in the perpendicular direction. Using the high-resolution data from the MMS (Magnetospheric Multiscale) mission, we propose a new theory to explain the formation of cigar-type distribution. In our theory, the extrusion of bursty bulk flow to a dipolarizing flux bundle resulted in the density-depleted neck of the magnetic sandglass. Analogous to sands in a sandglass, electrons could only partially pass through the neck along the parallel/anti-parallel directions by mirror effect, manifesting cigar distribution in the neck. Our theory can be crucial for understanding the microscale dynamics of the magnetotail during magnetospheric substorms.

Investigation of Kelvin–Helmholtz Instability on Mercury's Dawnside Magnetopause

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Kelvin–Helmholtz instability occurs on the surface between two fluids with velocity shears. It changes the pressure of the two sides of surface and can generate vortices in its non-linear stage. The Kelvin–Helmholtz instability is a common phenomenon in planetary magnetospheres, where it plays an important role in the transport of mass, momentum and energy between magnetospheric boundaries. Simulations and observational analyses have shown that Kelvin–Helmholtz instability can be developed at the magnetopause where solar wind and magnetospheric plasma corresponds a large velocity shear. Kelvin–Helmholtz instability related phenomena have been reported in Mercury's magnetosphere. However, previous studies have revealed a clear dawn-dusk asymmetry, with observations of the non-linear Kelvin–Helmholtz waves only on the duskside. Our study, based on five years of MESSENGER data, has identified a series of Kelvin–Helmholtz waves on Mercury's dawnside magnetopause. We have categorized these cases as either linear or nonlinear waves and conducting statistical analyses on each group. Linear waves are stable on the magnetopause and characterized by box-like structures in the magnetic field measurements. In contrast, nonlinear waves correspond to vortices and are associated with sawtooth-like structure in the magnetic field. Our study investigates the properties of Kelvin–Helmholtz waves on Mercury's dawnside magnetopause, including spatial distribution, frequency, IMF situation, etc. Our results provide significant references for research of the Kelvin–Helmholtz instability in Mercury's magnetosphere, particularly with regard to the mechanisms of asymmetry and the transport of momentum and energy.

Jets in Planetary Magnetosheath

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Magnetosheath jets are transient enhancements in plasma dynamic pressure which typically surpass the dynamic pressure of the upstream solar wind. Among other important effects, they can trigger magnetic reconnection upon impinging on the dayside magnetopause and cause magnetopause surface waves. It is widely considered that quasi-radial interplanetary magnetic fields and subsolar foreshocks are favorable conditions for jet formation. It is thus questioned whether or not jets can exist downstream of the subsolar sections of the Jovian and Kronian bow shocks where the shock geometry is most of the time quasi-perpendicular, a condition common to most astrophysical shocks. Here we report anti-sunward and sunward jets in the Jovian and Kronian magnetosheath for the first time and

provide observational evidence that although the parker's spiral is not ideal for subsolar foreshock at outer planets, the presence of discontinuities in solar wind allow these high Mach number shocks to potentially form jets. Finally, through a comparative analysis of jets observed at Earth, Mars, Jupiter, and Saturn, we show that the size of jets scales with the size of bow shock.

A phenomenological model of Strongly-Driven Substorms and Magnetosphere Convection: Perspectives for SMILE

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Using solar-wind-magnetosphere-ionosphere conjunction observations, we investigate the geomagnetic responses to fluctuating IMF Bz from interplanetary Alfven waves. Interplanetary Alfven waves transmit intensified IMF Bz to the magnetosheath, leading to intervals of large magnetic shear angles across the magnetopause and magnetopause reconnection. Such intervals are promptly followed by hundreds of nT increases in AE/AU index within 10-20 min. These observations are confirmed in multiple events in corotating interaction region (CIR)-driven geomagnetic storms. To put the observations into context, we propose a phenomenological model of strongly-driven magnetosphere convection/substorm. The substorm electrojet is linked to the enhanced magnetopause reconnection in the short timescale of re-establishing the ionosphere electric field and the two-cell convection. The ionosphere two-cell convection drives enhanced magnetosphere convection that may lead to substorm expansion. These results provide insights on the temporal patterns of the solar–wind–magnetosphere-ionosphere coupling.

Kelvin-Helmholtz Waves and Magnetic Reconnection at the Earth's Magnetopause under Southward Interplanetary Magnetic Field

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We present Magnetospheric Multiscale (MMS) observations of a K-H wave event under southward IMF conditions, accompanied by ongoing magnetic reconnection. The nonlinear K-H waves are characterized by quasi-periodic fluctuations, the presence of low-density and high-speed ions, and variations in the boundary normal vectors at both the leading and trailing edges. Our observations reveal clear evidence of on-going magnetic reconnection through the identification of

Alfvenic ion jets and the escape of energetic magnetospheric electrons. Among the 36 magnetopause current-sheet crossings in this event, 19 exhibit unambiguous signatures of reconnection at both the leading (7) and trailing (12) edges. Notably, the estimated current-sheet thicknesses at both edges are comparable to the ion-inertial scale, confirming the compression effect resulting from the large-scale evolution of the K-H waves. The reconnection jets potentially contribute to the suppression of K-H growth through boundary-layer broadening and the development of complex flow and magnetic field patterns.

Polar and equatorial Ionospheric electrodynamical coupling under a prolonged Northward Bz Interval

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The interplanetary magnetic field (IMF) significantly influences the global ionospheric electrodynamics, but it is still largely unknown the high- and low-latitude ionospheric electrodynamical coupling under long-duration northward IMF Bz (NBz) and By conditions. During the long-duration NBz and duskward By conditions (Kp<2, AE<100 nT, SYM-H>-25 nT) on 20 August 2014, six pairs of magnetometer data showed that daytime equatorial electrojet (EEJ) underwent strong decreases (reach up to 90%) at wide longitudes. TIE-GCM captured well the decrease and the control simulations revealed that both effects of the NBz and By significantly change the plasma convection, Joule heating, and thermospheric winds at high latitudes; and penetration electric field due to the NBz plays an important role in the decrease of the equatorial electric field. This study indicates the significant NBz effects on the equatorial ionospheric electrodynamics even during weak geomagnetic conditions, apart from the widely believed meteorological effects. Further study should be taken to disclose the relative contribution between geomagnetic and meteorological effects on the decrease of the equatorial electric field.

Solar Coronal Heating Fueled by Random Bursts of Fine-scale Magnetic Reconnection in Turbulent Plasma Regions

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Coronal heating is a longstanding issue in solar physics as well as plasma physics in general. In recent years, significant resolution improvements of satellite observations have contributed to a deeper understanding of small-scale physics, e.g., magnetic reconnection processes on fine scales inside the turbulent geo-magnetosheath. Coronal plasmas feature turbulent complexity of flows and magnetic fields with similar fine scales, and thus electron magnetic reconnection is very likely to be excited in the coronal region working as one of the ways to heat the solar corona, which offers a possible new mechanism for the nanoflare model proposed by Parker. We in this paper simulate and analyze the magnetic reconnection processes on a fine scale of the electron skin depth, with a particle-in-cell treatment, and estimate its contribution to coronal heating. The result shows that the electron magnetic reconnection can provide substantial heating efficiency for heating the corona to its observed temperature, once the reconnection events are reasonably spread.

Plasma and Field Variations in the Source Region of Substorm Auroral Brightening in the Inner Magnetosphere: Arase observations for three conjugate Events

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In this study we present conjugate observations of three substorm brightening aurora events observed by the Arase satellite and ground-base EMCCD cameras. In the first event, we performed the first comprehensive observations of source plasma and field variations of a substorm brightening aurora at L ~ 6 by a ground-based camera and the inner magnetospheric Arase satellite. Field-aligned bi-directional electrons with an energy range between 66-1800 eV were detected by the satellite’s data simultaneously with the appearance of the brightening of the auroral arc in the EMCCD camera, which was probably caused by ionospheric electrons from the auroral brightening region. In the second event, we report a substorm event where correspondences of Pi2 pulsations, aurora luminosity, and plasma flux fluctuation near a substorm brightening aurora were observed, suggesting that waves in the magnetosphere like ballooning instability controlled auroral intensity. In the third event, we made the first conjugate observation for a substorm onset aurora during the recovery phase of a geomagnetic

storm using the Arase satellite and an all-sky camera on the ground, where upward FAC and a steep increase of thermal pressure was observed when the satellite footprint was crossing the substorm auroral arc. In all three events, series of field-aligned Poynting flux and particle flux variations were found around the timing of the substorm auroral brightening started poleward expansion. Through these events we show the relationship between the ionospheric auroral arc at substorm onsets and the wave and particle features in the inner magnetosphere. Further event studies are under preparation to elucidate common features and generation mechanisms of substorm auroral arc.

Simultaneous observations of STEVE and bursts of intensity of ELF/VLF emissions during a substorm formation

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We considered 7 STEVE phenomena recorded using an "all-sky camera" at Maimaga (63 N, 130 E) station in the pre-midnight sector during the substorms formations observed in the interval from 2015 to 2022. For 5 of these 7 events the STEVE and the bursts of intensity of ELF/VLF emissions in the range from 1.1 kHz to 3.1 kHz were simultaneously observed. ELF/VLF emissions were registered by a magnetic vertical loop antenna at the Oibenkyol radiophysical station (62 N, 129 E), located 130 km from the Maymaga station. It is assumed that both the STEVE and the intensity burst of ELF/VLF subauroral emissions are generated by the same processes in the plasma of the magnetosphere during substorms formations. Obviously, the sources of the observed ELF/VLF emissions are associated with increased generation of whistling mode waves in magnetospheric plasma at subauroral latitudes during the substorm formation accompanied by a high-speed solar wind flow. Further more detailed researches of STEVE phenomena simultaneous both by the optical and the radio methods are required.
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The Effects of Substorms on Radiation Belt Dynamics: Current Understanding and Remaining Questions

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The Earth's radiation belts are characterized by large variations in electron fluxes, which are controlled by the competition between various source, transport, and loss processes. Understanding, quantitatively modeling, and eventually predicting the dynamics of energetic electrons in the radiation belts have been the research targets that space physicists have long pursued. Recent observational and modeling studies have shown that substorm activities in the magnetotail could have significant effects on the dynamics of radiation belt electrons, especially through the processes of wave particle interactions. For example, substorms could affect the generation of chorus and ULF waves in the outer radiation belt, as well as the direct interactions between these waves and energetic electrons. Substorm activities could also assist the deep injection of energetic electrons into the slot region and inner belt. These recent understandings are made possible by the extensive wave and particle measurements from multiple space and ground missions, especially the NASA Van Allen Probes Mission. In this talk I will briefly introduce the dynamics of radiation belt electrons, review some of our recent advances in revealing the effects of substorms on radiation belt dynamics, and finish with discussing the remaining questions and opportunities in understanding the radiation belt dynamics during substorms.

Ultra-Relativistic Electron Acceleration during High-Intensity Long-Duration Continuous Auroral Electrojet (AE) Activity (HILDCAA) Events

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Magnetospheric relativistic electrons are accelerated during high-intensity long-duration continuous auroral electrojet (AE) activity (HILDCAA) events. From an analysis of L-shell (~2–7) variations of ~2–20 MeV electrons measured by Van Allen Probes, electrons are found to be accelerated up to a maximum energy of ~7.2 MeV in the outer belt (L $\geqslant$ 4) during HILDCAAs. While ~3.4 – 4.1 days long HILDCAA events are characterized by ~7.2 MeV electron acceleration in the L ~4.0 – 6.0 region ~2.9 – 3.4 days after the HILDCAA onset, shorter (~2.2–2.5 days) HILDCAAs are associated with electron acceleration up to ~4.5–5.6 MeV in the L ~4.5–6.0 region ~2.1–2.3 days after the HILDCAA onset. Observed radial profiles of the electron phase space density and observations of electromagnetic chorus waves indicate competing roles of radial diffusion and in situ wave-particle interaction as the electron acceleration mechanisms and their case-to-case variation.

Localized Excitation of Electromagnetic Ion Cyclotron Waves from Anisotropic Protons Filtered by Magnetic Dips

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The excitation of electrostatic and/or electromagnetic waves in the plasma universe is often associated with anisotropic velocity distributions of charged particles. In Earth's inner magnetosphere, this anisotropy can gradually develop as particles injected from the magnetotail drift around the Earth at different speeds depending on their energy and pitch angle. Here, we show that the perpendicular-moving and bouncing ions can be separated more abruptly near the injection front. These pitch-angle filters are localized magnetic dip structures formed by the diamagnetic behavior of the injected particles, which can trap perpendicular-moving ions and allow bouncing ions to overtake. The resulting ion anisotropy facilitates the rapid generation of electromagnetic ion cyclotron (EMIC) waves, which in turn can largely reshape the Van Allen radiation belts. This scenario is examined by case and statistical observations, together with numerical simulations that reproduce most of the observational signatures, to support the causal relationship between magnetic dips, anisotropic ion distributions, and localized excitation of EMIC waves. Our study highlights the important roles of magnetic dips in the inner magnetospheric dynamics, as pitch-angle filters of the injected ions and traveling hotspots of EMIC wave activities.

High-latitude Magnetosphere-Ionosphere-Thermosphere Coupling During Substorms

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As one of the most spectacular geomagnetic disturbances of the magnetosphere, substorms are featured with explosive energy releases from the magnetosphere and can drastically alter the high-latitude ionosphere and thermosphere states. Ionospheric electrodynamic features, such as fast

convection flows and Harang flow reversal, often form during substorms, which are frequently used for remotely sensing their magnetospheric counterparts. We use multi-instrument observations and state-of-the-art two-way coupled MHD and PIC numerical simulations to study the evolution of these flow patterns and large-scale current systems during substorms. Also, we discuss the impact of these ionospheric electrodynamic features during substorms on the evolution of various ionospheric density structures, such as troughs and polar cap patches.

Unfolding the enigmas on the auroral spiral: Formation process and its relevance to solar wind-magnetosphere-ionosphere coupling system

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Auroras that locally exhibit a vortex structure are referred to as auroral spirals. They can frequently be seen under geomagnetic quiet conditions (Davis and Hallinan, 1976; Partamies et al., 2001a). However, the fundamental features of auroral spirals, such as their generation mechanism and source region in the magnetotail, are poorly understood. Recently, Nowada et al. (2023) followed the auroral morphological changes to the auroral spiral formation and revealed the intriguing features of the auroral spiral which occurred during the late substorm recovery phase, based on contemporaneous observations of ultraviolet imager (UVI) of Polar and an all-sky camera at Longyearbyen. The auroral spiral was formed while the substorm-associated auroral bulge was subsiding, and several poleward-elongated auroral streak-like structures appeared. Furthermore, the magnetotail region corresponding to the auroral spiral covered a region from Xgsm ~ -40 to -70 RE at Ygsm ~ 8 to 12 RE, according to the field-aligned auroral spiral UVI image projections onto the nightside magnetic equatorial plane using an empirical geomagnetic field model.

Nevertheless, it remains open how the auroral spiral is formed within a framework of solar wind-magnetosphere-ionosphere coupling system, although Hallinan (1976), Lysak and Song (1996), and Partamies et al. (2001b) explained the spiral formation using a model taken into account velocity and/or magnetic shears. We tried to reproduce the auroral spiral using the two different global Magnetohydrodynamics (MHD) simulation codes but could not form the spiral, suggesting that the

spiral formation may be closely relevant to some kinetic effect. In this presentation, we will discuss significant spiral features revealed by the recent studies and unraveled spiral problems. Unless spiral formation is addressed within the solar wind-magnetosphere-ionosphere coupling system, it cannot be elucidated why auroral spiral can frequently be seen during geomagnetically quiet times.

Signatures of ballooning instability and plasmoid formation processes in near-Earth magnetotail and auroral ionosphere

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The nonlinear development of ballooning instability and the subsequently induced plasmoid formation in the near-Earth magnetotail demonstrated in MHD simulations have been proposed as a potential trigger mechanism for substorm onset over the past decade, and their connections to the in-situ satellite and ground all-sky auroral optical observations have been a subject of continued research. In this work, a set of THEMIS substorm onset events with good conjunction of auroral observations have been selected for comparative simulation study, whose pre-onset magnetotail configuration and conditions are inferred from in-situ data and compared with the onset conditions of ballooning instability obtained in our MHD simulations. The evolution of the near-Earth magnetotail is followed, where the signatures of ballooning instability and the plasmoid formation are extracted from simulations and compared with the magnetic fields and flow patterns within the magnetotail region from observation data. The field-aligned current (FAC) density is evaluated at the Earth side boundary of the magnetotail domain of simulation, which is further mapped along magnetic field line to the auroral ionosphere and compared with the auroral pattern and evolution there in terms of growth rate, dominant wavenumber, and absolute auroral intensities. The ion flux variation in the magnetotail is also compared with the concurrent proton auroral measurement. Such validation efforts are also the first step towards the development of a self-consistent coupling model that includes the magnetotail-ionosphere interaction in the substorm onset process.

Introduction to a model of Throat Aurora

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The solar wind-magnetosphere-ionosphere coupling is a systematic process driven by the solar wind. It involves the buffering of the magnetosheath and the feedback of the magnetosphere and ionosphere. While previous observational studies have analyzed the driving effect of the solar wind, there is a lack of research on the contribution of the magnetosheath and the feedback effects of the ionosphere. Discrete and diffuse auroras, occurring near magnetic local noon, correspond to processes outside and inside the magnetosphere, respectively. Throat aurora, a specific form of discrete aurora, only occurs near local noon and is generally aligned with the direction of ionospheric convection. Throat aurora itself is also closely associated with the convection-aligned stripy diffuse aurora. These observations suggest that the magnetosphere internal factors may affect the generation of throat aurora. Additionally, the occurrence rate of throat aurora is related to radial interplanetary magnetic field (IMF) conditions, indicating that factors outside the magnetosphere also influence its generation. Moreover, observations have shown that throat auroras correspond to magnetopause cracks and are accompanied by clear magnetopause reconnection signatures. To comprehensively explain these observations, a conceptual model of throat aurora is proposed. The model suggests that the effect of ionospheric feedback on magnetopause reconnection is crucial for the generation of magnetopause cracks. The high-speed jets generated in the magnetosheath under radial IMF may only trigger the reconnection. This model considers the influence of factors inside and outside the magnetosphere on the solar wind-magnetosphere-ionosphere coupling, providing a new perspective for a comprehensive understanding of this process.

Mercury's dynamic magnetosphere and couplings between solar wind, magnetosphere, surface and core

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Mercury, the planet closest to the Sun, possesses a global intrinsic magnetic field that interacts with the solar wind to form a "mini" magnetosphere. Unlike other planets in the solar system, Mercury lacks a significant atmosphere and instead has a surface-bounded exosphere. Its large, highly-conducting core occupies approximately 0.8 of Mercury's radius. The magnetopause of Mercury's magnetosphere near the subsolar point is located approximately one thousand kilometers above the planet's surface. The solar wind near Mercury's orbit is the strongest among planetary magnetospheres, characterized by higher dynamic pressure and stronger interplanetary magnetic field (IMF) intensity.
In this presentation, we will discuss our current understanding of Mercury's magnetosphere based on the analysis of measurements from the MESSENGER spacecraft. Our focus will be on the processes of solar wind-magnetosphere-surface and solar wind-magnetosphere-core couplings. We will begin by examining the flux transfer event "showers" formed by multiple reconnection X-lines on the magnetopause. These FTE showers contain FTEs with high succession rates (about 10 FTEs per minute) and are a common feature on Mercury's magnetopause. They play a significant role in

transporting magnetic and particle flux in Mercury's magnetosphere. We will provide observational evidence of how magnetospheric dynamics influence the behavior of planetary ions in Mercury's magnetosphere.

Next, we will present Mercury's magnetosphere under extreme solar wind conditions. The magnetosphere can correspond to a deep cusp, indicating strong solar wind precipitation on the surface underneath the cusp. Magnetic reconnection erosion and induction due to the conducting core oppose each other. Under some extreme solar wind events, Mercury's dayside magnetosphere may disappear. We will also discuss intense magnetic reconnection in the magnetotail plasma sheet and lobe flux.

MESSENGER Observations of Multiple Magnetic Energy Releases During Mercury's Substorm

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Substorms are energy storage and dissipation processes that occur in planetary magnetospheres accompanied by numerous phenomena, such as magnetic dipolarizations, plasma sheet thinning and thickening, magnetic flux ropes, and plasmoid ejections. Recent MESSENGER observations have revealed substorm activity in Mercury's near magnetotail, with average durations of 2 to 3 minutes for both the growth and expansion phases. Herein, we report MESSENGER spacecraft observations of sporadic and short-term energy dissipation processes during the substorm expansion phase in Mercury's magnetotail. Three magnetic dipolarizations lasting for 4 min, were detected during the expansion phase and manifested as step-like enhancements in the northward component of the magnetic field. The magnetic field strength decreased during each dipolarization, indicating intermittent release of magnetic energy. They arise owing to multiple magnetic pileup effects caused by planetward bursty bulk flows ejected from distant magnetotail reconnections. Additionally, in close proximity to each dipolarization, we observed the occurrence of pulse-like fluctuations in the By component. These new MESSENGER observations suggest that during the expansion phase of Mercury's substorm, the energy dissipation can be caused by multiple local transient processes, although the duration is much shorter than that of Earth.

Numerical simulations on 3D asymmetric reconnection for SPERF experiments

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The Space Plasma Environment Research Facility (SPERF) has constructed at the Harbin Institute of Technology in China, which aims to provide a unique experimental platform, employing a unique

set of coils that are independently energized and the plasma sources, for ground simulation of magnetosphere plasma physics processes. There are three sub-systems in SPERF, Dipole Research EXperiment (DREX), Asymmetric Reconnection EXperiment (AREX), and Tail Reconnection EXperiment (TREX). DREX provides a laboratory platform to simulate radiation belt physics process, e.g., trapping, acceleration/loss, and transport of energetic charged particles, as well as wave excitation and configuration polarization, in a dipole magnetic field relevant to the inner magnetosphere. AREX provides a unique experimental platform to study the 3D asymmetric reconnection dynamics relevant to the interaction between the interplanetary and magnetospheric plasmas. TREX provides a research platform to understand the physics processes in magnetotail, e.g., the dipolarization front formation and the magnetotail reconnection. In AREX, the reconnection process is driven by a set of flux cores through coil-current-ramp-up to interact with a dipole magnetic field generated by the dipole coil. A wide range of plasma parameters can be achieved through inductive plasma generation with flux cores and electron cyclotron resonance (ECR) plasma source and cold cathode discharge plasma source around the dipole coil. The numerical simulations of the 3D reconnection process in AREX in a 3D magnetohydrodynamics (MHD) model are carried out for planned experiments. The typical 3D reconnection topology in AREX are discussed in detail.

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MFACE: A high-resolution model of field-aligned cur-rents through empirical orthogonal functions analysis

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Ten years of magnetic field measurements from the CHAMP satellite have been used to create MFACE, a model that represents field-aligned currents (FACs) using empirical orthogonal functions (EOFs). EOF1 primarily captures the Region-1/Region-2 pattern, which varies with changes in the interplanetary mag-netic field Bz component. On the other hand, EOF2 isolates the cusp current signature and variability related to By. In comparison to existing models, MFACE offers significantly improved spatial resolution, effectively replicates commonly observed FAC characteristics in terms of thickness and intensity, en-hances the distribution across magnetic local time (MLT), and depicts the seasonal variation in FAC latitudes and the NBZ current signature. MFACE also reveals systematic dependencies on By, such as modifications in the Region-1/Region-2 topology around noon, imbalances between upward and downward maximum current density, and the MLT location of the Harang discontinuity.

Additionally, our cross-correlation analysis enables the quantification of response times for FACs to solar wind influences at the bow shock nose. Specifically, we find lag times of 20 minutes and 35-40 minutes for FAC density and latitude, respectively. We further conduct the cross-correlation analysis within distinct MLT sectors. The results reveal that the FAC response time to changes in solar wind variables differs significantly between dayside and nightside FACs, with shorter response times observed on the dayside (15-25 minutes) as opposed to the nightside (35-95 minutes). Furthermore, we can more accurately parameterize dayside FACs, as evidenced by explained variance r-square values exceeding 0.7 for FAC latitude and greater than 0.3 for FAC intensity. In contrast, nightside FACs exhibit lower cor-responding r-square values, falling below 0.3 for FAC latitude and 0.15 for FAC intensity.

The MATLAB code of the model is open source and available at https://doi.org/10.7910/DVN/GA5ZTO. We are also working on translating and releasing the Python version.

Estimation of westward auroral electrojet current with magnetometer chain data

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This work presents the investigation of methods to determine the total electric current and location of the westward substorm electrojet, based on magnetic field observations along a meridian chain of observing stations.

We suggest original simple model for a case with small number of ground stations used. These model estimates of the total electrojet strength were compared with the estimates of substorm current wedge determined using the mid-latitude stations. Both estimates have similar magnitude and change in concert during development of substorm expansion phase. The differences in magnitude at specific time instants may reach factor of two, but are similar to the differences between competing ionospheric electrojet models. The geometry of electrojet was taken into account. The analysis is carried out for several substorms and several chains.

Empirical dynamical model of Energetic Electron precipitation based on drifting electron cloud concept

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Energetic electron precipitation (EEP, energies ~30-300 keV) is an important substorm manifestation which increases electron concentration in the D region, affects radio communications and navigation and, on long term, also affects ozone concentration and climate, making EEP diagnostic and forecast an actual problem. A remarkable EEP manifestation is Auroral Absorption (AA, subtype of Cosmic Noise Absorption) which provides an integral measure of surplus D-region ionization and is monitored by global riometer network. Though the AA morphology has been intensively studied since 1960-s, no dynamic EEP model yet exists reflecting extremely complicated evolution of trapped electron populations (both ambient and injected) and of their pitch-angle scattering into the ionosphere during substorms. We develop and investigate an empirical EEP model (here mostly based on observed AA) based on following assumptions:

(1) Energetic electrons are accelerated (primarily by betatron-like mechanism) and injected near midnight but then drift eastward, precipitating and creating auroral absorption. The EEP intensity at different MLTs is determined by initial conditions at midnight, the response being different for different MLTs, but stable in each MLT sector reflecting stability of drift delays in the Radiation Belt.

(2) As EE injection temporally/spatially coincides with magnetic dipolarization (which may be responsible for electron energization), the dipolarization magnitude, proportional to Substorm Current Wedge (SCW) intensity, can be used to initialize the injection strength. Here the intensity of elementary injection is estimated as the positive increment of the square root of MPB(t) at 5-min steps, where MPB is the mid-latitude positive bay index (after McPherron&Chu, Space Sci. Rev 2017) also related to SCW.

(3) Appreciating multiplicity of injections during substorms and suggesting 4-hour- long response of AA to each elementary (5-min scale) injection, we represent AA value as a sum of contributions of injections occurring during 4 preceding hours. Prediction filter-type response functions are then determined from AA and MPB time series (inputs) separately for each MLT using data sets, each including dozens of substorm events.

This approach was realized and investigated using Canadian NORSTAR riometer data as well as

EISCAT D-region electron densities Ne measured by EISCAT radar. (a) We found that in the same MLT sector at the same latitude the response functions are similar, justifying our approach and giving the opportunity to use several stations in common. Also for AA and Ne (at 90km altitude) the filters have similar shapes in different geographical zones. (b) Absorption values predicted by the model, were compared with Ne measured at different altitudes. Rather good correlation (up to CC~0.7-0.8) together with reasonable CC dependence on altitude and MLT justify our approach. (c) Comparison of filter dependence on MLT with RCM simulation of MLT variation of drifting cloud intensity during short injection event showed a nice agreement of precipitation front dynamics in the inner magnetosphere. (d) Surprisingly, the filters reconstructed for isolated and clustered substorm data sets appeared almost identical for riometers in the center of the actual auroral zone. "Universal" response functions for different substorm types probably point on similar processes acting inside those types.

We conclude that the approach based on drifting electron cloud energized by betatron-like mechanism is viable. Currently it provides a quantitative dynamical portrait of EE precipitation during substorm events of various complexity (excluding strong storms). The correlation of model predictions with observations has CC ~0.6-0.7, so a substantial part of energetic electron precipitation has a "short memory" of 3-4 hours and can be reconstructed based on magnetic variation data. Also, usefulness of MPB index is greatly supported by our study.

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Interhemispheric asymmetry in the distribution of electric currents of the magnetosphere–ionosphere system in the equinox pre-storm period

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We study the asymmetry of field-aligned current (FAC) intensity' dynamics during the stationary magnetospheric convection (SMC) event, which was observed during a long interval before an intense magnetospheric storm on 6 April 2000. From the data of the global network of ground-based magnetometers of the two hemispheres, on the basis of an extended version of the ISTP magnetogram inversion technique, time series of FAC distribution maps in the high-latitude ionosphere of the two hemispheres were obtained. During the event, stable negative non-radial components of the interplanetary magnetic field ($Bz < 0$, $By < 0$)) were observed. We also study the dynamics of the intensity and spectrum of the PiB type pulsations. It is shown that in the course of SMC there is an interhemispheric asymmetry, i.e., a change in the sign of dawn- dusk asymmetry in the FAC distribution at the transition to the southern hemisphere. Such asymmetry usually corresponds to the manifestation of the effect of the IMF By<0 component. However, during substorms at the beginning and the end of the event under study, the FAC intensity, as well as that of the westward electrojet intensity, prevails on the dawn side in the high-latitude ionosphere of both hemispheres. We discuss the influence of diurnal variations in the tilt angle of the geomagnetic dipole and the illumination of the polar ionosphere on the dynamics of the FACs and auroral electrojets.

Characterization of Magnetic Flux Contents for Flux Transfer Events and its Implications for Flux Rope Formation at the Earth's Magnetopause

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Flux transfer events (FTEs) are a type of magnetospheric phenomena that exhibit distinctive observational signatures from the in-situ spacecraft measurements across the Earth's magnetopause. They are generally believed to possess a magnetic field configuration of a magnetic flux rope and formed through magnetic reconnection at the dayside magnetopause. Such magnetic reconnection process may generate enhanced plasma convection in the ionosphere near the footpoints of the magnetic field lines connecting to the reconnection sites at the magnetopause. We examine two FTE events under the condition of southward interplanetary magnetic field (IMF) with a dawn-dusk component at the magnetopause by applying the Grad－Shafranov (GS) reconstruction method to the in-situ measurements by the Magnetospheric Multiscale (MMS) spacecraft to derive the magnetic flux contents associated with the FTE flux ropes. In particular，given a cylindrical magnetic flux rope configuration derived from the GS reconstruction method， the magnetic flux content can be characterized by both the toroidal (axial) and poloidal fluxes. We then estimate the amount of magnetic flux encompassed by the area in the ionosphere corresponding to the flux "opened" by the reconnection process (i.e.，the reconnection flux)，based on the ground-based Super Dual Auroral Radar Network (SuperDARN) observations. We find that for event 1，the FTE flux rope is oriented in the approximate dawn-dusk direction and is right-handed with the IMF possessing a dawn-dusk component. The amount of the reconnection flux agrees with the poloidal magnetic flux of the corresponding FTE flux rope. For event 2，the FTE flux rope's axis is nearly aligned with the North-South direction. The agreement among the estimates of the magnetic fluxes is uncertain. We then provide a detailed description about our interpretation for the topological features of the FTE flux ropes，based on a formation scenario of sequential magnetic field reconnection，consistent with our analysis results.

Friday, October 20, 2023

Field-Aligned Currents of Dipolarizing Flux Bundles and the Associated Plasma Disturbance: Understanding the Asymmetry of Wedgelets—Building Blocks of the Substorm Current Wedge

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The substorm current wedge (SCW), the characteristic current system of the expansion and recovery phases of Earth's substorms, has been suggested to be formed by 'wedgelets', mesoscale field-aligned currents (FACs) carried by dipolarizing flux bundles (DFBs). Each DFB is a 0.5-3 RE-wide magnetotail flux tube with a more dipolar magnetic field than the background; it propagates earthward in the form of bursty bulk flows. A DFB carries FACs in a similar configuration to an SCW but with much smaller current content, spatial scale, and lifetime. Thus, the FACs of a DFB have been recognized as a 'wedgelet'. Many coexisting wedgelets' collective effect may be equivalent to a classic SCW.

This collective formation scenario of an SCW requires ~10 wedgelets to coexist at most times during a substorm's expansion and recovery phases, which has been proven to be realistic by simulations and observations. Also, each wedgelet must contain an asymmetric pair of FACs so the net FAC of many wedgelets in each tail sector (dawn or dusk) can equal an SCW's net FAC in that sector. Such asymmetric wedgelets have been observed, but it is unclear how this asymmetry arises. To answer this question, we investigate how earthward-traveling DFBs interact with ambient plasma because this interaction leads to their FACs. The interaction is manifested as the pressure and magnetic field distributions around DFBs, which we examine statistically using THEMIS data. The statistical distributions are consistent with an interplay between the DFB-caused mesoscale perturbations and the global magnetotail configuration and favor the rise of wedgelets' asymmetric FACs. This result reveals the importance of cross-scale coupling in SCW formation.

Dipolarization Fronts and Magnetic Flux Transportation

Tony Lui

JHUAPL

An important feature intimately related to substorm process is the development of dipolarization in the near-Earth region. A common concept is that it arises from magnetic flux transported by dipolarization fronts or dipolarization flux bundles generated by magnetic reconnection in the mid-tail region. This concept is based on the assumption of validity of the frozen in-field condition for dipolarization fronts or dipolarization flux bundles. This frozen-in-field condition of these structures is critically evaluated from observations and by theoretical consideration. It is shown that both of these structures cannot transport sufficient magnetic flux to the near-Earth region that is revealed by observations for substorms.

Formation of Electron Butterfly Distribution by a Contracting Dipolarization Front

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Beihang University

The electron butterfly distribution, characterized by pitch angles (PA) primarily at 45° and 135°, was rarely observed in Earth's magnetotail. Here using the high-resolution measurements from Magnetospheric Multiscale mission, we present the observation of electron butterfly distribution in a contracting dipolarization front (DF), and propose a new physical mechanism to explain its formation. Specifically, we discover that the electron butterfly distribution only exhibited in the locally contracted DF and was observed above 1.7 keV. We infer that local contraction of the DF transformed its configuration from a magnetic bottle to an hourglass-shaped magnetic structure, and the butterfly distribution was formed by the magnetic mirror effect of this magnetic hourglass. Additionally, the theoretically estimated loss cone of the magnetic hourglass fits well with the observations of electrons, validating our inference about the formation mechanism. These findings can improve our understanding of electron dynamics in Earth's magnetosphere.

Investigating the kinetic dynamics of magnetospheric substorm onset

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Magnetospheric substorms are explosive disruptions of the magnetotail that are observed to be preceded by a slow growth phase of magnetic flux loading and current sheet thinning. While a variety of candidate mechanisms such as magnetic reconnection and ballooning instabilities are believed to be involved in substorm onset, their exact roles and interplay are not fully understood. Using three-dimensional particle-in-cell simulations initialized using an exact Vlasov magnetotail equilibrium, we model substorm onset while retaining the full kinetic dynamics of ions and electrons. Solar wind driving from the simulation boundaries leads to reconnection onset in the tail, producing tailward and earthward traveling plasma flows and magnetic islands. Dipolarization fronts are found to disrupt in the near-Earth dipole to tail transition region through a mechanism identified to the kinetic ballooning instability. Strong nonthermal particle acceleration exceeding the thermal energy by two orders of magnitude is produced, and using self-consistent particle tracking with a novel electric field analysis we separate the acceleration mechanisms into fluid and strictly kinetic effects. With its unprecedented resolution that allows measurements at electron spatial and temporal scales,

observations from the NASA MMS mission are ideally suited for comparisons with our fully kinetic simulations. Utilizing MMS electromagnetic field and particle distribution measurements from candidate substorm events, we compare simulated and observed nonthermal particle spectra and investigate the possibility of substorm onset through the kinetic ballooning instability.

Some aspects of electric field, IMF By influence and magnetic forces associated with fast earthward convection in the magnetotail plasma sheet: Recent studies using MMS observations

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Fast earthward flows are a major contributor to the plasma and magnetic flux transport in Earth's magnetotail plasma sheet. In the first part of the presentation, we discuss results of our recent statistical investigation of convective earthward fast flows in the tail plasma sheet using data measured by the Magnetospheric Multiscale (MMS) mission during 2017-2021. In this investigation, we focus on 'frozen in' fast flows and study the importance of different electric field components in the Sun-Earth (Vperpx) and dusk-dawn (Vperpy) velocity components perpendicular to the magnetic field. We find that a majority of the detected fast flow events (52% of 429 events) have the north-south electric field component (Ez) as the most relevant component (Ez category) whereas 26% have Ey and Ex as the relevant components (conventional category). We pursue the explanation for this distribution by investigating the flow events in relation to the distance to the neutral sheet and concurrent substorm phase. In addition, we explore how nonzero IMF By conditions influence the fast flow events. In the second part of the presentation, we discuss results of our other statistical investigation of fast earthward flows using MMS data. In this survey, we investigate the magnetic forces (the magnetic pressure gradient force, the curvature force, and their sum jxB-force) associated with fast flows, as estimated using multipoint analysis techniques (reciprocal vector method) applied to the MMS data.

Dusk displacement of plasmoids and reconnection in the magnetotail

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Magnetic reconnection in the near-Earth magnetotail is responsible for the explosive release of energy during auroral breakups. This near-tail reconnection had previously been recognized to occur near the midnight meridian in observations of earthward flows. The Geotail spacecraft mission discovered that the reconnection location is displaced toward dusk in observations of tailward-moving plasmoids. The dusk preference may be caused by the Hall electric field, as is the case in recent simulations with the Hall effect. In contrast, recent Messenger spacecraft observations indicated that the reconnection location was not displaced toward dusk but dawn in Mercury's magnetotail. This study reviews and unifies previous observational evidence of reconnection in the Earth's magnetotail to address the controversy surrounding the dawn-dusk displacement of the reconnection location. Consequently, the dusk preference is generally evident for tailward-moving structures but depends on studies for earthward-moving structures. This result suggests that statistical results of earthward flows are sensitive to selection criteria of events. No statistical studies have demonstrated the dusk displacement of eathward flows within a few minutes of substorm onsets. Accordingly, the reconnection may not occur on the meridian where planetward-moving structures were observed. Tailward-moving plasmoids may be predominantly located on the duskside of Mercury's magnetotail.

Thinning of the Magnetotail Current Sheet: near-equatorial and low-altitude observations

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The magnetospheric substorm is a key mode of flux and energy transport throughout the magnetosphere associated with distinct and repeatable magnetotail dynamical processes and plasma injections. The substorm growth phase is characterized by current sheet thinning and magnetic field reconfiguration around the equatorial plane. The global characteristics of current sheet thinning are important for understanding of magnetotail state right before the onset of magnetic reconnection and of the key substorm expansion phase. This presentation is devoted to investigation of this thinning at different radial distances using plasma sheet (PS) energetic (>50 keV) electrons that reach from the equator to low altitudes during their fast (~1 s) travel along magnetic field lines. We combine near-equatorial observations of the current sheet thinning by equatorial THEMIS and MMS missions and concurrent, latitudinal crossings of the ionospheric projection of the magnetotail by the low-altitude ELFIN CubeSats.

Configuration of magnetotail current sheet prior to magnetic reconnection onset

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The magnetotail current sheet configuration determines magnetic reconnection properties that control the substorm onset, one of the most energetic phenomena in the Earth's magnetosphere. The quiet-time current sheet is often approximated as a two-dimensional (2D) magnetic field configuration balanced by isotropic plasma pressure gradients. However, reconnection onset is preceded by the current sheet thinning and the formation of a nearly one-dimensional (1D) magnetic field configuration. In this study, using particle-in-cell simulations, we investigate the force balance of such thin current sheets when they are driven by plasma inflow. We demonstrate that the magnetic field configuration transitions from 2D to 1D thanks to the formation of plasma pressure nongyrotropy and reveal its origin in the nongyrotropic terms of the ion distributions. We show that substorm onset may be controlled by the instability and dynamics of such nongyrotropic current sheets, having properties much different from the most commonly investigated 2D isotropic configuration.

The Interaction of ULF Waves with Charged Particles in Earth's Magnetosphere

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In Earth's Van Allen radiation belts, ultralow frequency (ULF) waves in the frequency range between 2 and 22 mHz play a crucial role in accelerating charged particles via a resonant process named drift or drift-bounce resonance.In previous studies of drift(-bounce) resonance, a linearization approach is often applied with assumption of a weak wave-particle energy exchange.On the other hand, ring current particles can easily resonate with ULF waves via drift bounce resonance, providing free energy for the wave excitation. Considering the nonlinear effect in this process will be helpful to further discuss the wave evolution and dissipation. In this study, we develop the nonlinear drift bounce resonance theory by formulating nonlinear particle trapping in the ULF wave potential well with a pendulum equation and accordingly predict the observable signatures of nonlinear drift-bounce interactions. We also investigate the effects of magnetospheric convection on the nonlinear process, which provides an inhomogeneity factor S to externally drive the pendulum equation that describes the particle motion in the ULF wave field and determine the nonlinear wave excitation and growth.

ULF wave-electron drift resonance observed with the MMS spacecraft

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Ultra low frequency waves in the magnetosphere are known to interact both with energetic protons and electrons. However, electron—wave resonance is a relatively rare phenomenon in observations. In this study, we present a case of a wave event that includes two wave packets. The Magnetospheric Multiscale Mission spacecraft registered the oscillations in the postmidnight sector of the magnetosphere at a distance of about 11 RE. The first wave packet with amplitude of about 1.5 nT was registered during ~20 minutes. It features mixed polarization with considerable field-aligned component. The second one had predominantly azimuthal polarization and a lower amplitude. This complies with the theory of Alfvén wave transformation due to phase mixing. The wave was propagating to the east and had azimuthal wavenumber m=25.

Simultaneously, a cloud of substorm-injected energetic electrons was registered with the spacecraft. The flux was modulated with the wave frequency (~3 mHz). The oscillations were apparently induced via drift resonance, with the resonant electron energy of about 117 keV. However, an instability condition for a wave generation was not met. Emitting of Alfvén high-m waves by a cloud of drifting charged particles is proposed as a wave generation mechanism for this case.

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Multiple Auroras Induced by Interplanetary Shock: Plasma Wave Effects

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Aurora, as a visualized space weather phenomena, often occurs with the increasing space weather activity like storms and substorms. These auroras, no matter structured or structureless, are related to the depositions of energy electrons or ions which may result from the wave-particle interactions. In this study, we present an event in which different auroras corresponding to different frequency waves are induced by interplanetary (IP) shock. At dawn side, the brightness of diffuse auroras observed by Yellow River station enhances after IP shock, while both Van Allen Probe A and THEMIS-D nearby observe the enhancements of whistler waves (with frequency range from 0.1fce to 0.5fce). At dusk side, periodic aurora arcs of 8min period are observed by Kaktovik station, with similar frequency ULF waves observed by nearby groundbased magnetometers. It suggests that IP shock excited ULF waves and whistler waves which results in the depositions of electrons via wave-particle interactions and finally auroras occur.

The electron flux formation by kinetic Alfvén waves near a dissipative layer

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One of the visual manifestations of substorm activity in the Earth's magnetosphere are various auroras arising from the precipitation of charged particles. Their emission spectrum is affected by the energy of the precipitated particles. For example, electrons with energies of 2-5 eV are thought to give initiation to stable auroral red arcs (SAR arcs). There are several potential mechanisms to explain the acceleration of electrons to such energies. One of such mechanisms is their interaction with kinetic Alfvén waves (KAWs).

In this work the structure of KAWs is studied in the vicinity of the dissipative layer, where the type of dispersion of kinetic Alfvén waves changes. In this region, KAWs can effectively interact with the background plasma electrons through the mechanism of collisionless Landau damping. Absorption of the KAW energy in the dissipative layer can lead to the formation of a flow of suprathermal electrons (with energies of 2-5 eV) into the ionosphere. A formula is obtained for estimating the electron flux density directed to the ionosphere and the energy density transferred by them. This expression makes it possible to estimate the electron fluxes formed by KAWs excited by broadband sources. It is shown that the electron flux formed in the presence of a broadband source is an order of magnitude higher than that formed only by the fundamental harmonic of standing Alfvén waves, which is in better agreement with observations. It turns out that such flux is sufficient to form SAR arcs of medium intensity (~ 1-10 kR).

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Statistical Analysis of Geomagnetic Substorms with Different Time Durations

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Geomagnetic substorms are essential phenomena in the solar wind-magnetosphere coupling and play a significant role in the transport of energy and matter within the Earth's magnetosphere. We conducted a statistical analysis of the substorm durations from the onset of the expansion phase to the end of the recovery phase between 1982 and 2012. The results indicate that the duration of substorms does not correlate significantly with the minimum of the SML indices, but long-duration substorms tend to have higher SMU indices. During solar maximums and summers in the northern hemisphere, substorms tend to have longer durations, which should be related to differences in solar activities and ionospheric conductivities, respectively. Besides, stronger and longer-duration southward interplanetary magnetic fields and lower solar wind velocities are more likely to cause long-duration substorms. Additionally, the superposed epoch of geomagnetic indices with MLT dependence reveals that long-duration substorms are associated with stronger eastward electrojets located on the duskside, and westward electrojets also tend to shift toward the dawnside. Our findings provide a more comprehensive understanding of the temporal scale and overall processes of geomagnetic substorms.

STEVE phenomenon: association to a substorm formation

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We considered 7 STEVE events recorded at Maimaga (63 N, 130 E) and Zhigansk (66.8 N, 123 E) stations in the pre-midnight sector. According to the magnetic data of the global network SuperMag, STEVE events appeared during the expansion and/or recovery phases of a substorm. It can be noted that in most cases the STEVE registration took place during the recovery phase of a moderate magnetic storm. The solar wind at an occurrence of the STEVE phenomenon was quite strong (500-700 km/s), except for one event (April 10, 2021) Vsw ~ 340-350 km/s, and relatively unchanged within several previous and subsequent hours. The interplanetary magnetic field (IMF) also practically did not change in 5 cases, in 2 cases it varied on February 7, 2021 within 5-10 nT and on March 6, 2021 within 4-6 nT. At the beginning of STEVE occurrence, the Bz(GSM) component of the IMF changed direction from south to north in 5 cases out of 7; the By(GSM) component of the IMF was negative in 4 cases and positive in 3 cases.

The behavior of the parameter $/beta$ of the solar wind is interesting, which in most cases (in 5 out of 7) at the beginning of STEVE occurrence had large values $/beta$ > 1.5, i.e. the thermal pressure in the solar wind significantly exceeded the magnetic pressure. Possible mechanisms for STEVE generation are discussed.

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The growth of the GIC in power lines during 11 years of observations in the North of Russia

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It is considered influence of the substorms during different types of geomagnetic storm (CME, CIR) and without storms on a growth of GIC (geomagnetically induced currents) in electric power lines of Kola Peninsula and Karelia (Russia). The continuous registrations of GIC in this system are performed since 2011 year. So an analysis of the GIC data for the 11 years (2011-2022) was done. It is quasi solar cycle. This registration system includes 5 stations elongated in north-south direction. The IMAGE magnetometer data and 2D equivalent currents model was used. The analyses shows that extreme jumps of the GIC occur during substorm associated with the activation of the westward electrojet (negative magnetic bays). For the auroral station VKH (Vyhodnoy, geographic coordinates - [68.8°, 33°]) we select extreme values of I>30 A, for the subauroral station KND (Kondopoga, geographic coordinates - [62.2°, 34.2°]) we select extreme values of I>10 A.

It is found 85 extreme events for the VKH station. The analyses shows that for 50 events (59% of cases) growth of GIC occurs during CME storms, for 32 events (37% of cases) growth of GIC occurs during CIR storms and for 3 events (3.5% of cases) growth of GIC occurs even without magnetic storm. It is found 23 extreme events for the VKH station. The analyses shows that for 20 events (87% of cases) growth of GIC occurs during CME storms, for 3 events (12% of cases) growth of GIC occurs during CIR storms.

So it is important to take into account during forecast of space weather influence on technological systems not only more strong CME storms but also CIR storms and even events without magnetic storms. The analysis shows the important role of the vortex ionosphere current systems on the growth of GIC power lines elongated on North-South direction.