On the kinetic nature of Dipolarization fronts

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A non-ideal MHD model including Hall and finite Larmor radius (FLR) effects was used to reproduce the dipolarization fronts(DFs) produced by the interchange instability in the magnetotail. Numerical results indicate that Hall effect on the scale of inertial length determines the distributions of electric field and its ingredients at DFs. The inclusion of FLR effect would cause a clear asymmetry and dawnward drifting of the DF structure, which is attributed to the ion diamagnetic velocity. In addition, it also causes to alter the direction of the high-speed flow nearby the DF.

Keywords: dipolarization fronts, interchange instability, Hall effect, FLR effect, simulation

Landau resonant acceleration of relativistic electrons by whistler mode waves at oblique angles

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We perform test particle simulations of relativistic electrons interacting with whistler-mode waves propagating from magnetic equator at oblique angles in this study to reveal the acceleration processes of electrons in radiation belt. First we demonstrated the validity of gyro-averaging method, which solved the equations of motion of relativistic electrons with oblique propagated whistler-mode waves. In a simulation, initial distribution of kinetic energy and equatorial pitch angle are set to be a delta function, and the location of electrons are set to be different along a magnetic field line. Following the trajectories of electrons, we obtain the numerical Green's function of evolution of kinetic energy and equatorial pitch angle. We have computed several cases with energy ranges from 50 keV –2 MeV, and equatorial pitch angle ranges from 20°-70° for both parallel and oblique propagating waves. By analyzing the trajectories and Green's functions of electrons, we understand that the accelerated mechanism under Landau resonance, which appear in oblique whistler-mode wave-particle interactions but not in parallel waves, is very different from n=1 cyclotron resonance. Furthermore, by comparing the efficiency of acceleration in parallel propagating cases and oblique propagating cases at different energy ranges covering the MeV electrons, we found that MeV electrons are accelerated with remarkable efficiency through n=0 resonance.

Keywords: whistler-mode waves, oblique propagation, relativistic electrons

3D Electromagnetic Particle Simulations about the Lowe Frequency Component of BEN based on statistical analysis of EFD data

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PIC simulations revealed that ESW (Electrostatic Solitary Waves) are generated from electron beam instabilities. ESW correspond the upper frequency component of BEN (Broadband Electrostatic Noise) which is frequently observed in space plasma. The generation mechanism of the low frequency component of BEN, however, is still unexplained. To clarify whether such low frequency waves are generated, we made statistical analysis on generation conditions of low frequency component of BEN observed by Electric Field Detector (EFD) onboard Geotail spacecraft. We detected low frequency component of BEN automatically from EFD data, and made an occurrence frequency distribution of these waves. Low frequency component of BEN are observed in PS and PSBL region in the magnetosphere.

According to our statistical analysis, the low frequency component of BEN have two different types of spectrum. These two types of waves are observed in the different region and plasma conditions, therefore, we assumed that there exist two different waves as the low frequency component of BEN. Based on this assumption, we are going to make further analysis on generation conditions of these two types of low frequency component of BEN, and perform a series of three-dimensional electromagnetic particle simulations with different parameters to clarify the generation process of the low frequency component of BEN.

Virtual collective Thomson scattering measurement of foreshock instabilities in collisionless shock experiment at ILE

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In space collisionless shocks are ubiquitously observed. Dissipation mechanism at a collisionless shock is highly complex and has not been well understood. Recently, collisionless shocks have been successfully reproduced in a laboratory by using high power laser facilities. We have performed the laboratory experiment on collisionless shocks by using Gekko XII high power laser in collaboration with the Institute of Laser Engineering (ILE) at Osaka University. To measure the local plasma quantities in the shock transition region, collective Thomson scattering (CTS) measurement is utilized. The CTS is the scattering of low frequency incident electromagnetic waves by collective oscillations of plasma electrons. The spectrum of the scattered waves enables us to infer the local plasma quantities like electron density, electron and ion temperature, valence of ions, etc, as a function of local position along the path of the incident probe laser light. If a plasma is nearly in equilibrium, scattered wave spectrum typically has two types of peaks called electron and ion features. The electron (ion) feature is produced when the incident waves are scattered by Langmuir (ion acoustic) waves.

On the other hand, the CTS theory in a non-equilibrium plasma has not been established. In the foreshock region a back streaming plasma is often observed as a beam by which beam instability is easily generated. Although the electron feature is usually too weak to be detected in an equilibrium plasma, it is possibly enhanced by the beam instability in the foreshock. Therefore, electron feature measurement is planned in the ILE experiment.

Numerical simulation greatly helps to interpret the experimental results. PIC (Particle-In-Cell) simulation is regarded as a first principle simulation of a collisionless plasma. It can reproduce a variety of non-equilibrium plasma phenomena in a self-consistent manner. However, the time resolution usually assumed in a PIC simulation is not enough to reproduce the CTS with realistic parameters. In this study we construct a simulation system of virtual CTS for realistic parameters in the ILE experiment. A foreshock beam instability is reproduced by using a PIC simulation. Then, the time-series data of electron density obtained from the PIC simulation is used to solve a wave equation of the scattered waves separately with much higher temporal resolutions. We performed this virtual CTS simulation for a parameter set typical in the ILE experiment and confirmed that electron feature is strongly enhanced through an electron-beam instability in a foreshock. In the meeting we will discuss characteristics of virtual CTS spectra for a variety of beam-plasma systems.

Keywords: Collisionless shock, Non-equilibrium plasma, Collective Thomson scattering

Simulation study of whistler-mode chorus in planetary magnetospheres

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We study the generation process of whistler-mode chorus emissions in planetary magnetospheres based on results of electron hybrid and MHD simulations. Chorus emissions are electromagnetic plasma waves commonly observed in planetary magnetospheres and are a group of coherent wave elements showing a variety of frequency shifts in time; typically rising tones, occasionally falling tones, and sometimes observed as hiss-like broadband emissions. While the generation process of chorus has been reproduced by numerical experiments [e.g., Katoh and Omura, GRL 2007a] and has been explained by the nonlinear wave growth theory [Omura et al., JGR 2008, 2009], numerical experiments have revealed that nonlinear wave-particle interactions between chorus and energetic electrons play essential roles not only in generating chorus but in energizing relativistic electrons. Since the nonlinear trapping of resonant electrons by chorus results in very efficient acceleration of trapped particles, chorus should play significant roles in the energization process of radiation belt electrons in planetary magnetospheres. On the other hand, previous studies revealed similarities and differences of the spectral characteristics of chorus in planetary magnetospheres, which has not been understood yet.

In the present study, by carrying out cross-reference simulations by electron hybrid and MHD codes, we investigate physical processes which differentiate the spectral characteristics of chorus emissions in planetary magnetospheres. Our previous simulations have revealed that the spectral characteristics of chorus vary depending on both the inhomogeneity of the background magnetic field and the velocity distribution function of energetic electrons in the equatorial region of the magnetosphere. We use the MHD code for the investigation of the range of variation of the spatial scale of the Jovian magnetosphere in the region from 5 to 20 Rj, where Rj is the radius of Jupiter, corresponding to the region where intense chorus emissions are identified by the Galileo spacecraft observations [Katoh et al., JGR 2011]. By referring the results of the MHD simulations, we conduct a series of electron hybrid simulations for the condition required for the chorus generation and resultant spectral characteristics of chorus in the Jovian magnetosphere. Our simulation results should provide important clues in understanding similarities and differences of chorus emissions in planetary magnetosphere and also the energization process of relativistic electrons.

Keywords: whistler-mode chorus, planetary magnetosphere, numerical experiments

Vlasov simulation of the Rayleigh-Taylor instability

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The Rayleigh-Taylor instability (RTI) develops at an interface between two fluids with different densities when an external force is applied from a heavy fluid to a light fluid. The RTI is seen as a secondary instability of the Kelvin-Helmholtz instability taking place at the magnetopause. The spatial scale of the secondary RTI is on the ion inertial scale or ion gyro scale where non-MHD effects are important. In the previous studies of ideal MHD simulations, the RTI develops symmetrically in the horizontal axis. On the other hand, previous hall-MHD and Finite-Larmor-Radius (FLR)-MHD simulations have shown that the RTI develops asymmetrically in the horizontal axis. In this study, basic processes of non-MHD scale RTI are of interest. We perform four-dimensional Vlasov simulations of the RTI with two spatial dimensions and two velocity dimensions. We vary the ratio of the ion inertial length and/or the ion gyro radius to the spatial scale of the density gradient layer, and discuss the effect of the non-MHD effects on the linear growth and nonlinear development of the RTI.

Keywords: Space Plasma, Rayleigh-Taylor instability, Vlasov simulation

Fast magnetic reconnection supported by sporadic small-scale Petschek-type shocks

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Magnetic reconnection is a process to change the connectivity of magnetic fields and works as a mechanism of explosive energy conversion from magnetic to kinetic and thermal energy of plasma and particles. Energy conversion during solar flare, magnetospheric substorm and Tokamak disruption is thought to be caused by magnetic reconnection. Furthermore, magnetic reconnection is considered to play an important role also on many astrophysical phenomena.

One of the largest problems of theories on magnetic reconnection using magnetohydrodynamic (MHD) approximation is that the efficiency of energy conversion is far smaller than that of observations in space or laboratory plasma. A recent outstanding theory of MHD magnetic reconnection that may solve this "fast reconnection problem" is plasmoid reconnection theory. In plasmoid reconnection, reconnection is accelerated accompanied with a formation of plasmoids (magnetic islands). The reason of the acceleration, however, is not yet understood enough.

In this study, we conducted large-scale numerical simulations to elucidate the mechanism of fast reconnection supported by plasmoids. We used MHD equations with spatially uniform resistivity. At first, "global model" numerical simulation that includes a large system of whole current sheet exhibiting magnetic reconnection is performed. We revealed that reconnection region structure with shock planes, which is called Petschek-type structure, repeatedly appears together with plasmoids and reconnection is accelerated.

Next, we conducted "local model" numerical simulation, which models the region where Petschek-type structure appeared in the global model numerical simulation. Using this simulation, we revealed the condition that Petschek-type structure is reproduced. The condition is existence of plasma flow along the interface of antiparallel magnetic fields. Because of the growth of plasmoids in this plasma flow, the structure of magnetic diffusion region is restricted and fast reconnection with Petschek-type structure realizes.

According to these numerical simulations, "Dynamical Petschek Reconnection" model is proposed in this presentation. The flow along the interface, which is necessary to realize Petschek-type structure, spontaneously forms as out-flow of reconnection before the formation of plasmoids. This model, accordingly, can explain the fast reconnection as a result of self-consistent evolution of reconnecting current sheet. Petschek-type reconnection regions form repeatedly with the formation and coalescence of plasmoids, and the reconnection in this model shows highly dynamic temporal evolution. Observation of solar flare also suggests such a short-time variation, which is consistent with our Dynamical Petschek Reconnection theory. Furthermore, according to our theory, shock plane will appear around reconnection region, which is a candidate of acceleration process of high energy particle accompanied by solar flare.

A part of this study is already published in Physics of Plasmas (Shibayama et al. (2015), Physics of Plasmas, 22, 10, 100706).

Keywords: Magnetic reconnection, MHD simulation, Solar flare

Higher-order weighted compact nonlinear scheme for magnetohydrodynamics

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Complex interactions between a magnetohydrodynamic (MHD) shock and turbulence play an important role in various space and astrophysical plasmas. For the last several decades, a number of approximate Riemann solvers for MHD have been developed. The HLLD approximate Riemann solver proposed by Miyoshi and Kusano [1] is adopted as a standard solver in many MHD software packages. In addition, the Riemann solver which is first-order accurate must be extended to higher-order in order to numerically solve the turbulence. A higher-order finite-volume method in which the numerical fluxes are evaluated using a nonlinear variable interpolation method such as MUSCL, WENO, or MP5 is often constructed as a higher-order MHD method [2,3,4]. However, it is difficult in general to construct higher-order finite-volume method in multidimensions and realize higher-order for multidimensional physics simulations.

In this study, we construct a higher-order MHD scheme by applying a finite-difference method which can simply be extended to multidimensions. Particularly, a shock capturing finite-difference method, so-called weighted compact nonlinear scheme (WCNS) [5,6], is adopted. The WCNS is composed of higher-order numerical fluxes evaluating from a weighted variable interpolation method and higher-order central finite-difference method. Combinations of 5th-order numerical fluxes and 4th or 6th-order central finite-difference method are applied for and comparatively investigated. We also discuss a divergence-free WCNS for multidimensinoal MHD in this report.

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Keywords: MHD, WCNS, approximate Riemann solver