PEM27-P01 Room:Convention Hall Time:May 24 16:15-17:30

Effects of turbulence in fast magnetic reconnection

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Since a magnetic Reynolds number R_m is very large in space, turbulence can be observed in many situations, e.g., in the solar wind and the Earth's magnetosphere. And turbulence is considered to play important roles in various situations such as magnetic reconnection and the diffusive acceleration in shocks. Here, we focus on the relationship between turbulence and magnetic reconnection.

The research on magnetic reconnection itself started around 1960, and it has attracted much attention because of the unique phenomenon that efficiently converts magnetic field energy to kinetic and thermal energy of plasmas. It is well known that the reconnection rate depends on a magnetic Reynolds number (propotional to ${R_m}^{-1/2}$) from a representative theory for reconnection [Sweet, 1958; Parker, 1957]. However, a major problem has been that their model can not explain the fast reconnection observed in space where the magnetic Reynolds number is sufficiently large. Recently, turbulence has been paid much attention as one of agents to solve this problem. For example, it is shown by large scale numerical simulations that a reconnection rate becomes independent of magnetic Reynolds number, R_m, as R_m increases, if turbulence exists [Loureiro+, 2009]. Another study addressed an importance of self-generation of turbulence in magnetic reconnection from the viewpoint of the theory of turbulence [Yokoi and Hoshino, 2011]. This theory predicts that the cross helicity (which is defined as a macroscopic value for turbulence) generated by the breaking of symmetry in magnetic reconnection would enhance the reconnection rate dramatically.

We have developed a new simulation code based on the MHD turbulence model [e.g., Yoshizawa, 1990] in order to clarify the relationship between turbulence and magnetic reconnection. In our simulation code, equations of time evolution for the cross helicity and turbulent kinetic energy are solved in addition to the ordinal MHD equations. Then, these quantities for turbulence interact with mean quantities, like the magnetic field and the velocity, through the turbulence electromotive term in the Ohm's law. Simulation results show the generation of the cross helicity along the reconnection exhaust as the theoretical prediction. It has also turned out the effective turbulent diffusion were localized around the reconnection point due to the spatial inhomogeneity of the cross helicity, and this results in a fast magnetic reconnection. In this presentation, from the result of our simulation, we present an overview of MHD turbulence model and discuss the importance of transport and localization of turbulence in the fast magnetic reconnection.

Keywords: magnetic reconnection, turbulence, cross-helicity, laminar flow, reconnection rate, simulation

PEM27-P02 Room:Convention Hall Time:May 24 16:15-17:30

Revisiting hybrid and Hall MHD models for space plasma simulations

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One of the outstanding difficulties for modeling space plasma phenomena is the huge gap between many different temporal and spatial scales. Accordingly, there exist several physical models suitable to describe phenomena occurring on a specific scale. The well-known magnetohydrodynamics (MHD) description gives an adequate view for macroscopic phenomena like global magnetospheric dynamics. On the other hand, key phenomena such as reconnection at the near earth neutral line is believed to be crucial even for the global dynamics of the magnetosphere. This calls for a more sophisticated model that is able to, at least in an approximate manner, describe kinetic effects controlling the key processes, while keeping the global dynamics yet computationally tractable. It is known that when the spatial scale becomes of the order of ion inertial length, the Hall term starts to play a role. Indeed, the importance of the Hall term in reconnection physics has been recognized for years. The Hall MHD model would therefore be the simplest model beyond ideal MHD. One may also includes kinetic effects by treating ions as an ensemble of macroscopic particles rather than a fluid. The hybrid model usually do so while approximating electrons as a massless charge-neutralizing fluid, thus ignoring their finite inertia and kinetic effects. Since these models do not include high frequency waves associated with electron scale physics, computational requirement is much less than the fully kinetic model in which both electron and ions are treated as kinetic particles. It appears that they are useful tools to describe physics beyond ideal MHD. In reality, however, they tend to be numerically unstable when dealing with the scale length smaller than the ion inertial length. Because of this, the applicability of the models have been severely limited to date.

Here, we look for the reason for the numerical difficulty and reconsider the formulation of these models. By analyzing the linearized magnetic field induction equation including the Hall current, we find that the problem seems to become ill-conditioned for the high frequency whistler mode branch. Namely, for whistler waves, even a small numerical error in the ion fluid velocity would be substantially amplified, implying a numerical instability. We suggest that the problem may be resolved by retaining an approximate non-zero electron inertial current term. Since the exact expression for the electron inertial current is not desirable for our purpose of describing waves with frequency much smaller than the electron cyclotron frequency, we assume that electrons are magnetized. Under this assumption, the electron inertial current may be approximated by a temporal derivative of the electric drift velocity, which makes the equation of motion of the electron fluid as essentially an equation describing time evolution for the electric field. In this model, the induction equation no longer involves explicit dependence on the ion fluid velocity. Linear analysis has been carried out to find that the present model gives an adequate description for scales larger than the electron inertial length. Comparisons with other models (MHD, Hall MHD, two fluid) as well as the applicability of the model will be addressed.

Keywords: space plasma, numerical simulation

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Simulation study on the hemispheric asymmetry of the solar dynamo cycle based on the flux transport dynamo model

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It is well known that the polarity of the solar magnetic fields on the poles periodically reverse at about 11 years. And it is also known that the reversal at one pole is followed by that on the other pole. The time difference of magnetic field reversal between the poles was first noted by Babcock (1959) from the very first observation of polar field. Svalgaard and Kamide (2013) recently indicated that there is a relation between the time difference of polarity reversal and the hemispheric asymmetry of the sunspot activity. However, the mechanisms for the hemispheric asymmetry are still open to be revealed.

In this paper, we study the asymmetric feature of solar dynamo based on the flux transport dynamo model (Chatterjee et al. 2004). We carried out the mean field dynamo simulations using the updated SURYA code which was originally developed by Choudhuri and his collaborators (2004). We analyzed the phase relation between the symmetric and asymmetric components, which correspond respectively to the quadrupole and dipole-like components, using the field decomposition technique proposed by Nishikawa and Kusano (2008). As a result, we found that the two components are mixed even if the dipole-like component is predominant and that the mixing of the two components causes the time lag of polar field reversals between the different hemispheres.

We will discuss also about the causal relationship between the time lag of polar field reversals and the asymmetric activity of sunspot focusing on the influence of nonlinear feedback processes driven by the magnetic buoyancy.

Keywords: solar dynamo, simulation

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Particle-In-Cell simulation on the interactions between the solar wind and a magnetic anomaly on the moon

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The objectives of the current research is to reveal the plasma environment in terms of plasma distribution and field enhancement caused by the interactions between the solar wind and magnetic anomaly found on the moon surface by considering the plasma kinetics. We perform plasma particle simulations for the current study. To increase the spatial resolution at the high density region of magnetic field as well as plasma, we utilize our new particle code called PARMER in which adaptive mesh refinement is incorporated. First, we analyzed simple cases where small-scale magnetic dipole is immersed in a plasma flow. Then we examined a case of magnetic anomaly found in Reiner Gamma on the moon and analyzed the solar wind interactions.

If we define the dipole size L as the distance between the dipole center and a position where the solar wind dynamic pressure balances the magnetic pressure, L of our interest is in the meso-scale which implies the size smaller than the ion's inertia length and sufficiently larger than the electron Larmor radius in the solar wind. Contrary to the Earth's magnetosphere, difference of dynamics between ions and electrons with respect to the local magnetic field play an important role in the magnetosphere formation. In other words, electron-ion coupling through a dipole field becomes important.

The simulation results obtained with the plasma particle simulations we performed so far show that electron interactions are important in the process of meso-scale magnetosphere formation. Around the distance of L from the dipole center, charge separation occurs because of the difference of dynamics between electrons and ions. Then intense electrostatic field is induced and ions, which can be assumed unmagnetized in the present dipole size, are eventually influenced by this electric field.

In the case of magnetic anomaly found in Reiner Gamma, the magnetic field is almost perpendicular to the solar wind. In such a situation, increase of plasma and magnetic field densities is found at the dayside region in the simulation results. When the direction of IMF changes, their increase fluctuates because of the magnetic field reconnection. One of the interesting findings is that the solar wind ions do not reach the moon surface in Reiner Gamma. We will discuss this point by considering the plasma dynamics as well as the electrostatic field observed over the Reiner Gamma region.

Keywords: Plasma particle simulation, magnetic anomaly, small-scale magnetic dipole, solar wind, Reiner Gamma

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Numerical study on particle acceleration in multi-shock system

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One of the plausible mechanisms producing cosmic rays is the first order Fermi acceleration in a collisionless shock wave. Most of the previous studies on this process are based on the assumption that charged particles interact with a single shock wave. However, a number of shock waves are ubiquitous in space. Two shocks frequently come close to or even collide with each other. For example, in the heliosphere, it is usual that an interplanetary shock collides with a terrestrial bow shock or the termination shock. In our research, we discuss particle acceleration processes in a system including two collisionless shock waves.

First, test particle simulations are performed to reproduce the particle acceleration process in a system including two motionless shocks. We find that power-law index of particle energy spectrum depends on particle energy, i.e., high energy particles show hard spectrum, while low energy particles denote soft one. We have extended the diffusion convection model to discuss the double shock system. The results are understood as follows: the high energy particles with a large diffusion coefficient are able to cross the two shocks within a typical scattering length scale and are efficiently accelerated as if they cross a single shock with a very large effective compression ratio. However, the low energy particles, associated with small diffusion coefficients, can cross only one shock within the same time scattering scale. The power-law index in the double shock system can be, then, harder than that of the strong shock limit (=2) in the single shock system.

Next, we investigate the process of particle acceleration when two collisionless shocks collide with each other by using one-dimensional full particle-in-cell (PIC) simulation. In the previous work [Cargill et al, 1986], they used a hybrid simulation and indicated that ions were efficiently accelerated when two supercritical shocks collided. However, electron dynamics are neglected in a hybrid simulation. Therefore, it cannot resolve the microstructures of the two colliding shocks. Here, we perform the PIC simulation to discuss detailed electromagnetic structures of the colliding shocks as well as the associated acceleration processes of ions and electrons.

Keywords: multi-shock waves, particle acceleration, numerical simulation

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The effect of magnetic field on cosmic ray modified shocks

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Galactic cosmic rays are believed to be accelerated by the supernova remnant shocks. When the acceleration process enters the nonlinear regime, the cosmic rays exert back reactions to the shocks (Drury & Falle 1981). Recent some observations of supernova remnants imply this back reactions actually occur (Helder et al. 2009; Hughes et al. 2000; Vink et al. 2006). These shocks whose structures change because of the existence of cosmic rays are called cosmic ray modified shocks.

On the other hand, there is the maximum energy problem as one of important subject in acceleration mechanism of galactic cosmic rays. To this issue, the solutions by magnetic amplification is proposed by many researches. Among them, Malkov & Diamond (2010) suggest that the instability due to back reactions of cosmic rays, particularly a gradient of cosmic ray pressure (Drury & Falle 1986), plays a dominant role in this matter.

In our research, we investigate the amplification effect of this instability and interaction of it with shocks. Drury & Downes (2012) conducted MHD simulation and showed magnetic amplification. But they treated only with the precursor region which is located in front of shocks without shocks. In out research, we conduct simulations including shocks in self-consistent form. We can discuss the whole system of back reactions of cosmic rays, shock structures and the structure of magnetic field. We also evaluate the relations between magnetic amplification and parameters of shocks.

Keywords: cosmic rays, shock

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1D PIC simulation of electromagnetic field penetration into magnetized plasmas for electrodeless electric thrusters

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We perform one-dimensional particle-in-cell (PIC) simulation of external electromagnetic field penetration into magnetized plasmas for development of electrodeless electric thrusters. The externally applied electromagnetic field near ion cyclotron frequency is assumed for the ponderomotive acceleration/ion cyclotron resonance (PA/ICR) scheme. We consider two schemes for the electromagnetic field excitation: electrostatic excitation by electrodes and electromagnetic excitation by current antenna. For both schemes we will evaluate a degree of the electromagnetic field penetration and discuss an energy conversion rate of the external field into plasmas in the PA/ICR scheme.

Keywords: external electromagnetic field, electric field penetration, electrodeless electric thruster, plasma acceleration, ponderomotive force, PIC simulation

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The relationship between the parameters plasma and penetration of magnetic fields due to the RMF acceleration

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Electric thrusters, characterized with high specific impulse, are considered to be useful for long-term space missions such as those to outer planets. On the other hand, the performance of many of the conventional electric thrusters (e.g., ion engine) is limited by electrode wastage. In order to overcome this difficulty, we have been engaging in the research and development of the next generation thrusters in which electrodes do not contact the plasma directly (the Helicon Electrodeless Advanced Thruster project) [1].

Among several different types of electrodeless plasma acceleration schemes we propose, in this presentation we discuss the acceleration concept utilizing the Rotating Magnetic Field (RMF), which has been developed primarily for an application to the plasma confinement in the field-reversed configuration [4]. In this scheme, a rotating external magnetic field is applied to the cylindrical helicon plasma [2], in such a way that the external magnetic field drives the azimuthal electron current. If the background magnetic field has a finite radial component, axial Lorentz force is generated, which can be used as a thruster power [5].

We will show the results of two dimensional numerical modeling of the RMF acceleration by Particle-in-Cell method. The axial thrust is generated by Lorentz force, so high azimuthal electric current is effective for electric thruster. We will show how the penetration of RMF depends on the parameters of plasma and RMF, and thus it is important to make a systematic parameter survey to determine the conditions that can yield the maximum thrust. Details of the computations will be given in the presentation.

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Keywords: Electric thruster, Electrodeless plasma acceleration, Rotating Magnetic Field, Numerical simulation

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Dispersion relation of helicon waves with dissipation

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Electric thrusters, characterized with high specific impulse, are considered to be useful for long term space missions such as those to outer planets. On the other hand, the performance of many of the conventional electric thrusters (e.g., ion engines) is limited by electrode wastage. In order to overcome this difficulty, we have initiated the HEAT (Helicon Electrodeless Advanced Thruster) project, in order to pursue research and development of completely electrodeless (i.e., no direct contact of electrodes with plasma) thrusters.

The electrodeless thrusters are composed of a plasma generation part and the plasma acceleration part. While efficient plasma production using a "helicon wave" is well established experimentally, there still remains a number of unsolved issues regarding how the plasma is generated using the helicon wave. This is due to the complexity of the problem: one needs to understand how the helicon waves propagate in the plasma, how electrons are accelerated by the waves, how neutrals are ionized, how the wave dispersion relation is modified as the ionization rate is increased, and how these processes interact with one another.

As a first step to solve this problem, we have invetsigated what kind of electric field can be generated when the helicon wave propagates into non-uniform plasma and how it accelerates the electrons. The dispersion relation of helicon waves is obtained in a non-uniform cylindrical plasma. The frequency range of helicon waves is w_{ci}(ion cyclotron frequency)$<<w<<w_{ce}$(electron cyclotron frequency). Thus, helicon waves are a kind of whistler waves propagating at some oblique angle with respect to the back ground axial magnetic field B_0. We assume a bounded cylindrical chamber and axial wave number is fixed by some boundary condition. From the dispersion relation, we obtain the helicon wave (long wavelength: propagating at nearly parallel angle for B_0) and the so-called TG wave (short wavelength: propagating at nearly perpendicular angle to B_0) as solutions. These waves can linearly couple in a non-uniform plasma. In particular, dispersion curves for these waves merge at a certain location, implying that an efficient mode conversion should take place. Previous studies show that an electrostatic TG wave is excited as the helicon wave propagates into the non-uniform plasma. Then, these TG waves efficiently accelerate the electrons and plays a crucial role in the plasma production. First, we discuss dispersion relation of helicon waves in a non-uniform plasma including dissipation using a fluid model. Then, we analyze the dispersion relation using a full PIC simulation.

Keywords: Electric thrusters, The electrodeless thrusters, Helicon wave, TG(Trivelpiece-Gould)wave

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An open boundary condition in the AMR-PIC simulations of magnetic reconnection

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One of the main issues on magnetic reconnection processes is the mechanism breaking the frozen-in condition around the x-line and providing the electric resistivity in collisionless plasmas. It has been recognized empirically in magnetohydrodynamic simulations that the Petschek-type fast reconnection can be achieved only when an intense resistivity arises locally near the x-line. However, the generation mechanism of the resistive effects in collisionless plasmas is poorly understood in the kinetic framework. In 2D reconnection, it has been demonstrated by kinetic simulations that the momentum transport due to the Speiser-type motion of the electrons around the x-line gives rise to the so-called inertia resisticity which results in the electron viscosity term in the generalized Ohm's law. Although the electron viscosity gives sufficient dissipation for supporting the reconnection electric field under the thin current layer on the order of the electron inertia length, such a thin current sheet has been observed neither in the laboratory experiments nor in the geomagnetosphere. Recent 3D particle-in-cell (PIC) simulations with the adaptive mesh refinement (AMR) have revealed that an electromagnetic turbulence in the current density direction gives rise to significant anomalous dissipation in association with plasmoid formations and enhances the effective width of the current sheet. However, the observations in space and laboratory have shown even wider current sheet during the fast reconnection, which implies the existence of more intense turbulence. It is reasonable to expect that, in a much larger system in the current density direction, the plasmoid formations are more three dimensional, which results in more turbulent current sheet.

The previous AMR-PIC simulations of magnetic reconnection have employed the periodic boundary condition in the outflow direction and the conducting wall condition in the upstream direction. These boundary conditions have an advantage that the implementation is easy, but they require very large system size for one to investigate the quasi-steady reconnection processes. Furthermore, the particles split around the x-line accumulate eventually in the downstream region, so that the number of the super-particles in the system increases as reconnection goes on. In order to achieve more efficient simulations of quasi-steady reconnection, we have developed an open boundary condition for the AMR-PIC model both in the downstream and upstream directions. The open boundary condition allows the particles and magnetic flux to leave the system in the downstream direction and to enter the system in the upstream direction. There are two advantages of using the open boundary condition: the first is to enable us to shrink the system size drastically in the reconnection plane, and the second is that the total number of the super-particles in the system is decreased. As a result, the redundant computer resources can be used to increase the system size in the out-of-plane direction. We expect that by using the open boundary condition one can obtain one order larger system size in the current density direction.

In this paper, we show initial results of the 2D AMR-PIC simulations of magnetic reconnection under the open boundary condition. It is described that the initial current sheet plasma is removed from the system and quasi-steady reconnection is achieved. By comparing to the results of the previous AMR-PIC simulations, we will discuss the efficiency by using the new boundary condition.

Keywords: magnetic reconnection, AMR-PIC model, open boundary, turbulence

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The effect of the ion gyro motion to the non-linear growth of the Kelvin-Helmholtz instability

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The Kelvin-Helmholtz instability (KHI) is one of fundamental hydrodynamic instabilities in plasma. The KHI takes place in a velocity shear layer and has been considered to occur at in the low-latitude boundary layer. In the present study, we examine the effect of the ion gyro motion to the nonlinear growth of the KHI via a full-kinetic two-dimensional Vlasov simulation. We perform two simulation runs. In Run A, the direction of the ion gyro motion is opposite to the rotation direction of the KH vortex. In Run B, on the other hand, the directions are same.

It is found that the growth rate of a wave mode at the ion gyro radius in Run B is smaller than in Run A. This is due to the stabilization effect of the ion gyro motion. In Run A, a secondary instability occurs at the outer edge of the KH vortex where the half thickness of the gradient of the ion density and secondary velocity shear is thinner than the ion gyro radius. On the other hand, the secondary instability does not develop in Run B because the half thickness becomes similar spatial scale as the ion gyro radius.

Keywords: Kelvin-Helmholtz instability, Vlasov simulation, space plasma, ion gyro motion

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Test-particle simulation of electron pitch angle scattering into the Saturn's atmosphere by neutral H2O from Enceladus

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Cassini observations revealed that Saturn's moon Enceladus (3.95Rs) ejects neutral H_2O from its southern pole with temporal variability [e.g., Hansen et al., 2006]. This volcanic activity, so-called 'plumes', leads to the electromagnetic coupling between Saturn's ionosphere and plasmas around Enceladus. The coupling causes auroral activities around the footprint of Enceladus [Pryor et al., 2011]. They discovered Enceladus footprint aurora with temporal variability and reported that observed field aligned fluxes of electrons and ions are sufficient to brighten the footprint aurora observed by EUV onboard Cassini. They interpreted that the variability of auroral brightness reflects variations of plume activities. In contrast, an electron precipitation into the atmosphere through pitch-angle scattering also causes auroral emissions. The dominant physical process controlling the activity of the footprint aurora is still controversial.

In the present study, for the quantitative evaluation of auroral emissions caused by the pitch-angle scattering through elastic collisions between magnetospheric electrons and H_2O particles, we have developed a spatially one dimensional test-particle simulation code with monoenergetic electron along a dipole magnetic field at Enceladus (L = 3.95). We assume that the initial velocity distribution of energetic electrons at the magnetic equator forms a velocity distribution with a loss-cone. It is assumed that the cross sections of elastic collisions are Born-dipole approximation [Khakoo et al., 2008]. An interaction between an electron and a background neutral cloud is solved by the Monte-Carlo method using the differential cross sections of elastic collisions for H_2O. We show a preliminary result of the variability of precipitating electrons with several hundred eV to several keV and estimation of the expected brightness of auroral emissions.

Keywords: electron pitch angle scattering, electron-neutral interactions, Enceladus, test-particle simulation, Saturn

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Study of the time evolution of magnetic turbulence induced by the magneto-rotational instability

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Magneto-rotational instability (MRI) is thought to be the generation mechanism of turbulence in accretion disks. Since the resultant turbulence stress causes the angular momentum transport and mass accretion, it is necessary to understand the processes determining the saturation level of the turbulent stress. Sai et al. (2013) suggested that the time variation of MRI turbulence is determined by the existence of the poloidal component of background magnetic field. In the nonzero net poloidal flux case, spike shape time variation of turbulent stress is observed and is suggested to contribute to large part of turbulent stress (e.g., Sano and Inutsuka, 2001). However, details of the physical processes have not been analyzed in the previous studies.

We investigate the processes occurring on the MRI turbulence by performing three-dimensional magnetohyrdodynamic simulations. Our study reveals the most part of processes in the nonlinear state of MRI. Specifically, our simulations reveal the existence of characteristic mode which has the largest amplitude in the nonlinear state of MRI. In this presentation, we report the characteristics of the largest amplitude mode and relaxation process in MRI turbulence.

Based on the results of analysis, we find that the observed dominant mode is expected to be the same wave mode which causes the channel flow reported in Sano and Inutsuka (2001). In previous studies, this mode is thought to be caused by the fastest growing mode which is lengthened by amplification of energy from poloidal magnetic field in turbulence (e.g., Sano and Inutsuka, 2001). However, from detailed analysis, although this mode is explained by the dispersion relation of MRI, we clarify that the wave pattern is determined by the disk thickness and the poloidal component of background field rather than the poloidal component of turbulence. This suggests that the determination process of the largest amplitude mode in the nonlinear state is different from the understanding of the previous studies. In saturation and relaxation phases of this mode, the generation of the parasitic instability (Goodman & Xu, 1994) is suggested even in the nonlinear state. From detailed estimation of each term in the MHD equation system, we also succeed to derive the condition for the occurrence of the relaxation. Using this relaxation condition, it is suggested that the amplification of the poloidal component of magnetic field is crucial to onset of turbulent relaxation. This amplification of the poloidal component of field is also expected to be caused by the growth of the parasitic instability. Moreover, the determination manner of the wave length of dominant mode can be explained by the relaxation condition.

Based on our findings, it is consistently explained that the energy ratio between the radial and azimuthal components of magnetic field, which has been reported in the previous simulations (e.g., Hawley et al., 1995) but has been unsolved. The obtained relation means that the field structure on the turbulence can be predicted when the poloidal flux of background field is given. We expect that the net flux dependence of the turbulent property revealed by the present study becomes a strong tool for considering the coagulation of dust particle and estimating the effect of MRI on disk turbulence.

Keywords: accretion disk, magnetohydrodynamics, turbulence, magneto-rotational instability

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Linear dispersion analyses on EMIC waves in oblique propagation in multi-component plasmas

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It is known that high energy particles in the radiation belt of the terrestrial magnetosphere make bad influence on artificial satellites. For example, relativistic electrons intrude artificial satellites, resulting in breakdown by charging. The high energy particles temporarily decrease when a magnetic storm takes place. Nowadays, it is pointed that electromagnetic ion cyclotron waves (EMIC waves), which are also observed in the magnetic storm, are regarded as a potential cause of the decrease by causing pitch angle diffusion of relativistic electrons and dissipation in polar regions. This study makes linear dispersion analyses on EMIC waves in multi-component plasmas. Especially, we study the growth rate and polarization property in oblique propagation.

We have made progress on Kyoto University Plasma Dispersion Analysis Package(KUPDAP) that has been developed at Research Institute for Sustainable Humanosphere of Kyoto University. We explain basic functions and additional functions of KUPDAP such as display of polarization, and demonstrate it.

Keywords: multi-component plasma, EMIC, oblique propagation, linear dispersion analysis