Irreversibility of Landau damping

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Landau damping is one of the most important elementary process in the plasma kinetics and widely known to plasma physicists. However, its detailed understanding is somewhat controversial and several misconceptions are found in textbooks. One misconception found in most of textbooks is reversibility of collisionless plasmas. Explanation given there is that phenomena in collisionless plasmas are reversible since the Vlasov equation is time symmetric. Experiments on the plasma echo is often referred as an example of this reversibility, saying that the plasma holds the information of its initial state even after the wave dies out by Landau damping.
The plasma echo is, however, not reversible if we interpret the word "reversible" by its literal meaning, which is "the time reversal process actually takes place in the real world." There will never be a process in which the echo occurs first and then the system returns to its initial state. Landau damping is a time irreversible process when we view it from the point of view that tries to derive macroscopic irreversibility from reversible basic equations in statistical physics. In this point of view plasma echo can occur after the wave damped out because the dissipation takes place in velocity space in the same time scale as in real space. This interpretation can be generalized to phenomena incollisionless plasmas, and we can say they are essentially irreversible in the same sense as in ordinary dissipative matters.

Keywords: Landau damping, Plasma waves, Collisionless plasma

Stratified Simulations of Collisionless Accretion Disks by Kinetic MHD with Anisotropic Pressure

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An accretion disk is one of the most ubiquitous astrophysical structure in the universe. In particular, the accretion disk around a supermassive black hole, such as Sgr A* in our galactic center, is thought to consist of a collisionless plasma, in which the gas is so hot and dilute that the mean free path of charged particles become larger than a scale size of the accretion disk. Particle-in-cell and Vlasov simulations are typical numerical approaches to investigate such a collisionless system. In the case of the accretion disk, however, the fact that the scale size of the disk and the kinetic scale of particles are different by orders of magnitude makes it impossible to apply the kinetic simulation techniques to this problem directly due to the limit of computational resources. To study the large-scale dynamics of collisionless accretion disks, therefore, the so-called kinetic magnetohydrodynamics (MHD), which can take into account some of kinetic effects, is required.

In this study, we pay attention to the effect of anisotropy of the thermal pressure. Including an anisotropic pressure tensor can modify the nature of the magnetorotational instability (MRI), which has been considered to play an important role for the angular momentum transport in accretion disks. We carried out series of kinetic MHD simulations using a *stratified* shearing box model, for the purpose of investigating the impact of pressure anisotropy on large scale dynamics of collisionless disks.

In the case of the standard MHD simulations with an isotropic pressure in a stratified domain, it is known that the disk threaded by a weak magnetic field is eventually filled with MRI-driven turbulence, which provides a sufficient rate of the angular momentum transport. This MRI-driven turbulence is considered to be responsible for production of a large-scale toroidal magnetic field observed in the stratified simulations, through some underlying disk dynamo process. We found that, once the effect of the anisotropic pressure is included, the resultant saturation level of the small-scale MRI-driven turbulence reduces to one third of that in the isotropic case with respect to the magnetic energy, due to the anisotropy with $P_{\perp}>P_{||}$ generated by the MRI itself. On the other hand, the magnetic energy contained in large-scale structure gets much smaller roughly by one order of magnitude, which implies that the dynamo action might not work efficiently in the collisionless disks. In our talk, we will discuss the dynamical behavior in more detail and try to give a theoretical explanation to the reduction of the turbulence and suppression of the disk dynamo.

Keywords: accretion disk, collisionless plasma, MHD simulation

Anisotropic wave number spectra of turbulence driven by parasitic instability in the nonlinear stage of MRI

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The magneto-rotational instability (MRI) (Balbus & Hawley, 1991) is one of the most important phenomena in accretion disks and causes turbulence driving the mass accretion in the disks. Goodman & Xu (1994) suggested that the magnetic field structure cased by the MRI cascades into turbulence through the evolution of the parasitic instability, which is related to the Kelvin-Helmholtz instability and magnetic reconnection. Pessah (2010) suggested the wave vector and growth rate of parasitic instability are strongly related to both magnetic diffusivity and fluid viscosity. These facts indicate that the artificial diffusivity, which is necessary in an MHD simulation scheme for treating the discontinuity and shock, should be as low as possible in the ideal MHD simulation of MRI-driven turbulence.

We have originally developed the MHD simulation code by employing the MHD scheme suggested by Kawai (2013). This scheme focuses on resolving the turbulence much accurately, and treats the discontinuity by adding the artificial diffusivity only to the vicinity of discontinuity (Localized Artificial Diffusivity method). We carry out the three-dimensional ideal MHD simulation by the developed code with net vertical magnetic field in the local shearing box disk model. We use 256x256x128 grids in the simulation system. We analyze the simulation results for the evolution of the MRI and the simultaneous enhancement of the parasitic instability.

Simulation results in the present study show that the MRI grows in the time scale of a few orbital periods and saturates at 2.8 orbital period. We find that a channel flow is formed through the evolution MRI and that the parasitic instability grows concurrent with the MRI, resulting in the turbulence spectra of both magnetic field and velocity in the simulation system. We confirm the strong enhancement of the parasitic instability at the timing of the saturation of the MRI and its anisotropic wave number spectra of turbulence appeared when the first channel flow is broken down. The anisotropic wave number spectra observed in the simulation result are consistent to the previous analytical studies. Additionally, we reveal that the magnetic field and velocity vectors enhanced by the MRI do not change in time from the same specific angle in the horizontal plane, but the waves enhanced by the parasitic instability in the subsequent channel break down does not show such a clear anisotropic wave number spectra as we find in the first channel flow. It could be because the turbulent flow breaks the laminar channel flow in the subsequent channels as Latter et al. (2009) suggested. We study the formation process of the anisotropic turbulence by analyzing the simulation results in detail.

Keywords: Magneto-rotational instability, Parasitic instability, MHD simulation

MHD Relaxation with Flow in a unit Sphere

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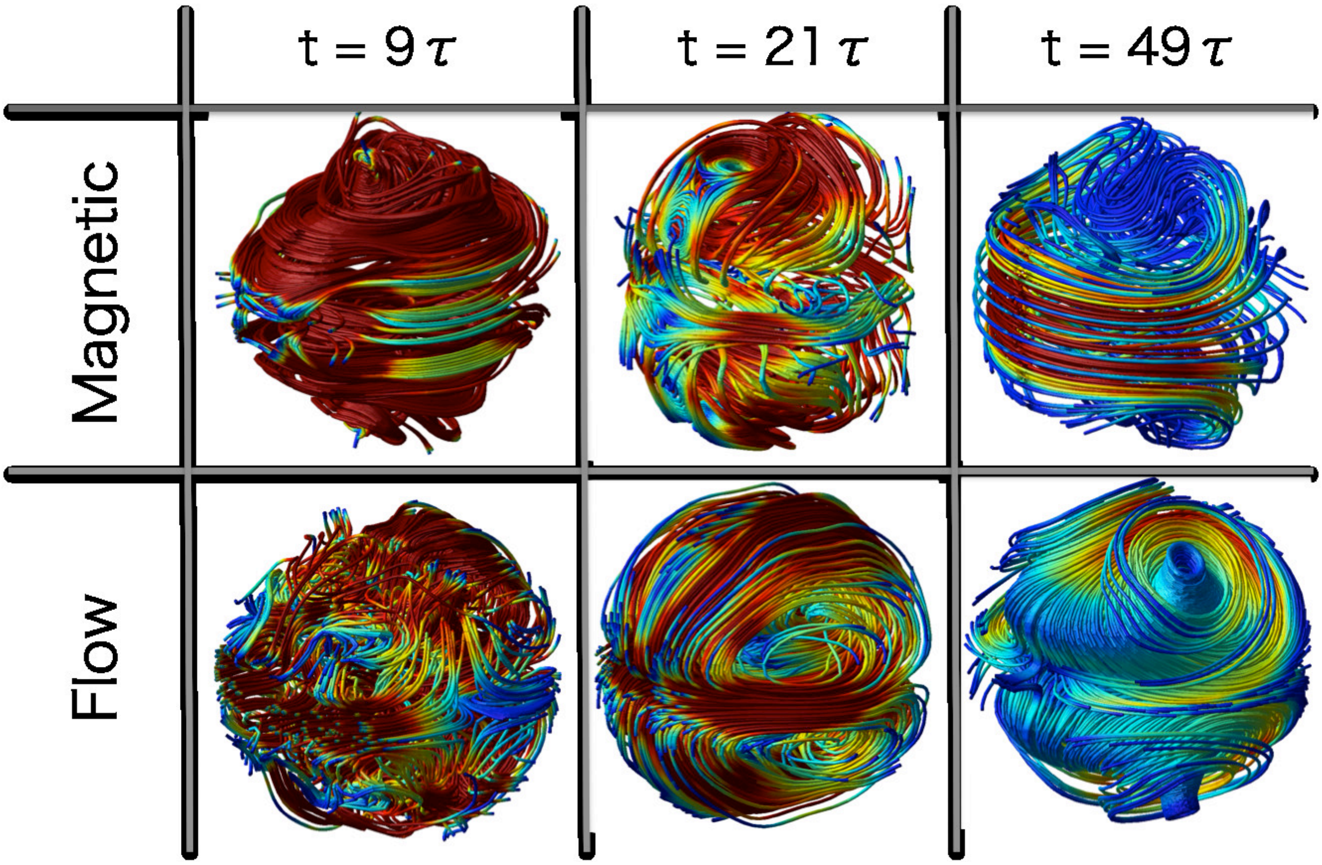
We investigate a relaxation process in a unit sphere of an electrically conducting fluid by computer simulation. We solve the magnetohydrodynamics(MHD) equations in a full sphere, including the origin at the radius r = 0, with a newly developed spherical grid system, Yin-Yang-Zhong grid (Hayashi and Kageyama, J.Comput.Phys., 2016). In the classical theory of the MHD relaxation by Woltjer and Taylor, flow in a relaxed state is supposed to be absent. On the other hand, we study relaxed states with flow. The boundary is a perfectly conducting, stress-free, and thermally insulating spherical wall. Under these conditions, the angular momentum is conserved as well as the total energy. Starting from a simple and symmetric state in which a ring-shaped magnetic flux without flow, a dynamical relaxation process of the magnetic energy is numerically integrated. The relaxed state has a characteristic structure of the flow field with four vortices. The Reynolds number Re and the magnetic Reynolds number Rm is the same: Re = Rm = 8600.

Keywords: magnetohydrodynamics, self-organization, plasma relaxation, Yin-Yang-Zhong grid



The simulation of helicon plasma discharge

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Helicon plasma is a high-density and low-temperature plasma generated by the electromagnetic helicon wave (i.e., bounded whistler wave) excited in the plasma. It is considered useful for various applications. The helicon plasma discharge is a very complex system that involves many physical processes: the wave propagation and mode conversion to the electrostatic TG wave (determined by the wave dispersion relation), collisional and non-collisional wave damping, plasma heating, and ionization/recombination of neutral particles which in turn renews the dispersion relation. While the steady state of the helicon plasma is relatively well understood, there remain some important unsolved questions, such as how the discharge grows, how the helicon and the TG waves influence the plasma density and the electron temperature, and how their spatial profiles are determined. We have constructed a self-consistent model of the discharge growth that takes into account the wave excitation, electron heat transfer, and diffusion of particles. We discuss some quantitatively different states arising due to different choices of plasma parameters.

Keywords: Helicon plasma, Helicon wave, TG wave, Self-consistent discharge model

Confirmation of the proposal of five sets of binary of super massive black holes in the central region of our Galaxy

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Through out the current studies of the present research of the observation of the decameter radio waves from the center part of our Galaxy, we have proposed the existence of the five sets of binaries of super massive black holes which show periods of orbital motions, 2300 sec, 1200 sec, 810sec, 528sec, 450sec and 410sec respectively for Gaa-Gab system, Gac-Gae system, Gad-Gaf system, Gag-Gah system, and Gai-Gaj system. The element BH’ s show the spin periods as 171.6 sec, 119.6 sec, 100.8 sec 72.4 sec, 62.8 sec, 54.0 sec, 46.0 sec 44.,0 sec, 26.0 sec and 23.6 sec , respectively for Gaa, Gab, Gac, Gad, Gae, Gaf, Gag, Gah, Gai, and Gaj. To deduce these periods two steps of data analyses have been employed. The first is application of FFT method to find coarse periods of pulses and orbital motions considering the Doppler effects. The second is the application of the box-car methods to detect the pulse forms and precise spin periods from which we can estimate the size and mass of the objects based on the theory of the Ker black hole ; spin periods of 1 sec roughly corresponds to .5000 solar mass.
The present studies are purposed to make rigorous confirmation of the approach of the present research work by giving proof for the following three subjects of questions.
Those are 1) to confirm the significance of the side bands of spectra as signature of the orbital motion of the black hole binary, 2) to find one to one correspondence between appearance of the Galaxy center and occurrence of FFT codes that verify the existence of BH binaries, and 3) to find identity between FFT results of observations and results of FFT of the simulation model that is constructed being based on observation periods.
The results of the works for subject 1),have indicated that there is clear difference between the observed FFT results which are characterized by many series of sidebands and the random array of noise spectra. The results of the works for subject 2), indicated that the FFT codes from the observed data appear even in the periods when the center of Galaxy center is not observable. For this confusing situation, however, the occurrence of the mirage effects due to earth surface and ionosphere reflections of the decameter radio waves is verified. By the simulation work of the subject 3) it is confirmed that FFT results for the constructed model of the 5 BH binary systems with deduced periods show good coincidence with the results of FFT for the observed data. We can, therefore, conclude that our approach to propose the BH binary systems in the center part of our Galaxy is not erroneous

Keywords: Black Hole Binary, Galaxy Center, Decameter Radio Wave

Numerical simulation of collective Thomson scattering in laboratory astrophysics

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We have performed the laboratory experiment on collisionless shocks by using high power laser in collaboration with the Institute of Laser Engineering (ILE) at Osaka university for the past few years. 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.

The CTS measurement has been widely used so far to measure experimental as well as space plasmas. However, details of the scattering theory are complex. In particular the theory of the CTS in a non-equilibrium plasma has not been established. In this study we build the numerical simulation system of virtual CTS applicable to the measurement system in the ILE experiment. A local non-equilibrium plasma near a shock is reproduced by using standard full particle-in-cell (PIC) simulation. The time-series data of electron density obtained from the PIC simulation is used to solve a wave equation of the scattered waves separately. Since the frequencies of the scattered waves as well as the incident probe light are much higher than the plasma frequency, the wave equation should be solved with the temporal resolution much higher than that in the PIC simulation. Furthermore, the measurement system at ILE is essentially two dimensional. We will report preliminary results of the virtual CTS simulation with realistic parameters in the ILE experiment.

Keywords: collective Thomson scattering, laboratory astrophysics, numerical simulation

Long-term PIC simulations of relativistic shocks using the magic CFL method

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Mitigating so-called the numerical Cherenkov instability (NCI) has been a critical issue in studying particle accelerations at relativistic collision-less shocks by means of the particle-in-cell simulation. We have studied the stability property of the NCI in relativistic plasma flows employing particle-in-cell simulations. Using the implicit finite-difference time-domain method to solve Maxwell equations, we found that the nonphysical instability was greatly inhibited with a Courant-Friedrichs-Lewy (CFL) number of 1.0 (Ikeya and Matsumoto, 2015). The present result contrasts with recently reported results (Vay et al., 2011; Godfrey and Vay, 2013; Xu et al., 2013) in which magical CFL numbers in the range 0.5–0.7 were obtained with explicit field solvers.

Using the newly found stability property of the NCI, we successfully solved long-term evolutions of relativistic collision-less shocks. For relativistic, un-magnetized shocks in pair plasmas, we found that magnetic field turbulence generated by the Weibel instability saturated at much larger levels than those found in the previous studies. As results, particles' maximum energy increased linearly in time with the energy spectral slope $\gamma^{-1.8}$, which compares with the previously-reported relation as $\gamma_{max} \propto \sqrt{t}$ with $\gamma^{-2.4}$.

Keywords: PIC simulation, relativistic shocks, particle acceleration

Evaluating gyro-viscosity in the Kelvin-Helmholtz instability by kinetic simulations

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In the present paper, the gyro-viscous term[W. B. Thompson, Pep. Prog. Phys. 24, 363-424 (1961)] is evaluated by using a full kinetic Vlasov simulation result of the Kelvin-Helmholtz instability (KHI). The average velocity (velocity field) and the pressure tensor are calculated from a high-resolution data of the velocity distribution functions obtained by the Vlasov simulation, which used to approximate the gyro-viscous term according to Thompson (1961). The direct comparison between the pressure tensor and the gyro-viscous term shows a good agreement. It is also shown that the off-diagonal pressure gradient enhanced the linear growth of the KHI when the inner product between the vorticity of the primary velocity shear layer and the magnetic field is negative, which is consistent with the previous Finite-Larmor-Radius(FLR)-MHD simulation result, but not with the previous kinetic simulation results. This result suggest that it is not enough for reproducing the kinetic simulation result to include the gyro-viscous term only in the equation of motion in fluid simulations.

Keywords: Computer simulation, Kelvin-Helmholtz instability, Non-MHD effect

Compressible fluid effects in plasmoid-dominated turbulent reconnection

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Traditionally, two basic models of magnetic reconnection have been discussed in the framework of resistive magnetohydrodynamics (MHD): Fast Petschek reconnection and slow Sweet--Parker reconnection. However, the former requires a localized profile of the electric resistivity. The latter is free from such an assumption, but it is too slow to explain reconnection events in the plasma universe.

Recently, it has been found that Sweet--Parker reconnection switches to plasmoid-dominated turbulent reconnection due to the generation of secondary plasmoids. As a result, the reconnection rate remains moderately fast (R ~ 0.01) in realistic parameters, in which the conventional Sweet--Parker reconnection is too slow. This transition is analogious to a transition from a laminar flow to a turbulent flow in fluid dynamics.

Both Sweet--Parker and plasmoid-dominated models usually assume the incompressibility as a first step to understand the mechanism. At present, the role of the compressibility in these systems remains unclear.

The compressible fluid effects are pronounced in a low-beta plasma, in which the typical speed of the system or the typical Alfven speed exceeds the local sound speed. As extreme examples of compressible effects, recent MHD simulations revealed various shock-structures in low-beta reconnection (Zenitani & Miyoshi 2011, Zenitani 2015).

In this contribution, we will report our initial results on the basic properties of plasmoid-dominated turbulent reconnection in a low plasma beta. We discuss the role of the compressible parameters on the global reconnection rate and fine structures around the plasmoid islands. We will also discuss numerical issues in our HLLD/HLLC type MHD code.

Keywords: Magnetic reconnection, MHD, Turbulence

The role of Hall magnetic field in large-scale magnetic reconnection dynamics and structure

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A Hall magnetic field of magnetic reconnection is generated by the electron-ion dynamics in the diffusion region. There are many studies on the effect of the Hall magnetic field for the reconnection rate around the diffusion region. However, in this study, we investigate the roles of the Hall magnetic in the dynamics and structures of reconnection jets and plasma sheet boundary layers, along which the Hall magnetic field propagate away from the diffusion region in large-scale magnetic reconnection systems. That makes it possible to discuss the Hall magnetic field strength generated in various conditions of magnetic reconnection.

Keywords: magnetic reconnection, Hall magnetic field

Impact of diffusion processes on magnetic reconnection

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Magnetic reconnection intrinsically contains a hierarchical structure ranging from the fully kinetic scale to the magnetohydrodynamic (MHD) scale. In order to identify the essential physics necessary to model the reconnection, numerical simulations have been conducted with a variety of codes from kinetic codes to conventional resistive MHD codes (Birn et al. 2001). They have shown that only the MHD simulation with uniform resistivity fails to trigger fast reconnection, indicating that resistive MHD would be insufficient to model it.
The role of resistive dissipation on the reconnection has been extensively investigated in the framework of MHD. Recent theoretical and numerical studies have proposed a dynamic model dominated by plasmoids for sufficiently small resistivity beyond a classical static model. The resulting reconnection rate seems to be independent of the resistivity that may account for actual phenomena, although it does not necessarily settle the difference from the kinetic model. Meanwhile, the impact of other dissipation processes should be discussed. This study especially focuses on viscosity and heat transfer.
Viscosity controls the dissipation scale of vortex. Resistive MHD assumes it to be zero, meaning that the vortex dissipation scale is negligible small compared with the current dissipation scale. However, the ratio of the scale of vortex to current can be much larger than unity in actual environments, and it affects the dynamics. Finite heat transfer is frequently observed in association with the reconnection. It can also affect the dynamics through increasing compressibility.
In order to investigate the effect of viscosity and heat transfer on the nonlinear evolution of the reconnection, we conduct two-dimensional fully-compressible visco-resistive MHD simulations coupled with thermal conduction. We discuss that viscosity and thermal conduction considerably modify the dynamics from a resistive model. Large viscosity excites a broad vortex that enables the efficient transfer of upstream magnetic field to the reconnection region. The resulting reconnection rate increases with viscosity provided that thermal conduction is fast enough to take away the viscous heating energy. This is indicative of the importance of viscosity and heat transfer to model the reconnection against the conventional resistive MHD. We also investigate the dependence on resistivity to determine key parameters (specifically, Reynolds numbers and Prandtl numbers) governing the visco-resistive reconnection coupled with thermal conduction. Comparison with the kinetic model will be discussed.

Keywords: Magnetic reconnection, MHD simulation, Diffusion

Enhancement of kinetic scale electrostatic fluctuations in decaying whistler turbulence: Particle-In-Cell simulations

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Solar wind observations show that larger cascade rates of turbulence lead to steeper power-law magnetic spectra at kinetic scales. This suggests that larger fluctuation amplitudes at kinetic scales lead to some nonlinear properties more efficiently. Our previous research showed that the modified two stream instability in a monochromatic finite amplitude whistler wave contributes the nonlinear dissipation of the wave at kinetic scales. This result suggests that kinetic instabilities can enhance the dissipation at electron and ion scales. The wave driven instability occurs with larger wave amplitudes more efficiently, so this process could be a contributor for the steep power-law spectrum at kinetic scales. Here two-dimensional electromagnetic particle-in-cell simulations in magnetized, homogeneous, collisionless electron-ion plasma demonstrate the forward cascade of whistler turbulence at ion scales. The simulation show that whistler turbulence cascades into electron scales, and show a spectrum break around the scale of the electron inertial length. Around the scale related to the break point, electrostatic fluctuations appear at several points intermittently. The electrostatic fluctuations are expected to be driven by ion acoustic instability driven by localized electric current in whistler turbulence. We will discuss the instability driven dissipation of whistler turbulence at kinetic scales and heating of both electrons and ions.

Keywords: plasma turbulence, whistler wave, Particle-In-Cell simulation

Precursor Waves in Relativistic Shocks

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The origin of high energy cosmic rays has been a long-standing problem in astrophysics. Many particle acceleration mechanisms such as Fermi shock acceleration in relativistic jets and magnetic reconnection in pulsar/magnetor magnetosphere have been proposed so far, however, there is no plausible model to explain such energetic particles. Recently Chen et al. (2002) proposed the particle acceleration by the ponderomotive force of a large amplitude Alfvén wave as a model of ultra-high energy cosmic rays, based on the wakefield acceleration process (Tajima and Dowson 1979). Since then the mechanism attracts interests in astrophysical field. In relativistic shocks, the generation of large-amplitude precursor electromagnetic waves is discussed by synchrotron maser instability (Hoshino and Arons 1991). Lyubarsky (2006) suggested the precursor waves excited in the relativistic shock front induces the electrostatic field, and argued that it may be responsible to the particle acceleration. Hoshino (2008) extended the previous studies and demonstrated the efficient particle acceleration by the incoherent wakefields induced by the large-amplitude precursor electromagnetic waves in the upstream region of a relativistic shock wave by using one-dimensional Particle-In-Cell (PIC) simulation.

However, the efficiency of the particle acceleration by the wakefield mechanism is sensitive to the nature of the precursor electromagnetic waves, because the ponderomotive force is known to strongly depend on the wave amplitude and the wave coherence. In this study, we argue the precursor waves in relativistic shocks by using the two-dimensional PIC simulation. Since relativistic shocks are mainly controlled by “sigma parameter” which is the ratio of the Poynting flux and plasma flow energies, the amplitude of the precursor wave depends on sigma parameter. For instance, in our simulations, the amplitude of the precursor wave gets smaller and the wave coherency of the precursor wave gets lower as sigma parameter decreases, and the amplitude dependence on sigma parameter in two-dimensional simulations is different from that in one-dimensional simulations. Furthermore, the previous one-dimensional simulations could not investigate the wave coherency of the precursor wave. We must take account of the wave coherency when considering the wakefield acceleration because the wave coherency of the precursor wave, which is required for the ponderomotive force, is essential to the wakefield acceleration. In this presentation, we compare two-dimensional simulations to one-dimensional simulations and report our results.

Keywords: plasma, shock, particle acceleration

Moment extracted method for solving kinetic Alfven wave dynamics

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Kinetic Alfven waves (KAW), which play crucial roles in a variety of phenomena in space plasmas, involve multiple space- and time-scales. For example, the wavelength along the field line may extend to the system size, while the perpendicular wave numbers are characterized by the ion gyro-radius or the electron skin depth. The characteristic time is given the wave frequency or the electron transit time. Thus, drift kinetic or gyrokinetic simulations of low-frequency plasma dynamics including the KAWs often suffer from a sever Courant condition for explicit time-integrators or a poor convergence of iteration in implicit methods.
To overcome the numerical inefficiency, we have developed a new scheme for solving the KAW dynamics including drift kinetic electrons. In the new scheme, the low-order moments of electron distribution function are calculated separately from the drift kinetic equation for electrons. It enables us to easily implement implicit time-integrators and/or the semi-Lagrangian scheme while keeping the numerical stability and the conservation property. Some applications of the moment extracted formulation will be discussed.

Keywords: Alfven waves, simulation, gyrokinetics

Effects of the equilibrium velocity distribution function with the apparent temperature on nonlinear evolution of Alfven waves

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Finite amplitude Alfvenic fluctuations are ubiquitously observed in the solar wind plasma. When we model the low-frequency phenomena of the solar wind plasma using one-fluid magnetohydro-dynamic (MHD) system, the fluctuations and the non-equilibrium components of ions are mixed into the pressure tensor (e.g., Chen et al, 770, 125 (2013); Nariyuki et al, POP, 22, 124502 (2015)). It is noteworthy that the local equilibrium velocity distribution function in the one-fluid MHD system can include the effects of the fluctuations as the apparent temperature. In the present study, nonlinear evolution of Alfven waves with the background (equilibrium) VDF including the apparent temperature is discussed by using the classical theoretical method such as the reductive perturbation method. If the isotropic equilibrium VDF is assumed, the apparent temperature can appear as the linear term in the triple-degenerated derivative nonlinear Schrodinger (TDNLS) system. The relationship between the apparent temperature and the Reynolds stress is also discussed.

Keywords: Alfven waves, solar wind, MHD

Expanding box model of quasilinear theory including the anisotropy-driven instabilities and collisional dissipation

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Measurements in situ of proton temperature anisotropy were found to be bounded by the marginal stability conditions of the kinetic instabilities driven by proton temperature anisotropies. This implies that these instabilities are indeed active and play an important role in limiting the range of temperature anisotropies observed in the expanding solar wind. However, the vast majority of the observed data distribution in the parameter space, denoted by proton temperature anisotropy and parallel beta, are found near isotropic state instead of being near the instability thresholds, so that they could not be explained by the local kinetic instability alone. Since the solar wind itself expands in inhomogeneous interplanetary space, the solar wind expansion would lead to a development of excessive parallel temperature anisotropy. Moreover, the binary particle collisions are thought to contribute to the temperature isotropization of the solar wind plasma. In order to understand the measured proton properties in the solar wind, various kinetic processes responsible for the global dynamics, such as the solar wind expansion and binary collisions, and the local kinetic instabilities should be taken into account. In the present work, we employ quasilinear theory of the expanding box model to investigate how the solar wind expansion and the instability driven collisionless dissipation as well as the collisional dissipation affect the dynamic evolution of the solar wind proton.

Keywords: solar wind proton, temperature anisotropy-driven kinetic instability, expanding box model of quasilinear theory, collisional dissipation

Cosmic ray transport in a turbulence field

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Transport of cosmic rays (energetic particles) in a turbulence field remains to be an important issue, both from astrophysical and nonlinear science points of view. In particular, it is known that the transport in a plasma with large amplitude MHD turbulence can exhibit properties of non-gaussian statistics. In this presentation, we show some results on numerical integration of the so-called fractal diffusion/transport equation, which is known to model time evolution of such a dynamical system. Applications to the diffusive shock acceleration will also be discussed.

Keywords: cosmic rays, transport, non-gaussian process

On the kinetic nature of Dipolarization fronts

*Haoyu Lu

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

