6th East-Asia School and Workshop on Laboratory, Space, Astrophysical Plasmas

July 11 (Mon) – July 16 (Sat), 2016

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6th East-Asia School and Workshop on Laboratory, Space, Astrophysical Plasmas
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MONDAY, July 11		
8:50 - 9:10	**Registration**	
9:10 - 9:15	**Opening**	
Chair: H. Ji		
9:15 - 10:45	Yoon, P.	Nonlinear Kinetic Turbulence Theory
10:45 - 11:15	**Coffee Break**	
11:15 - 11:45	Kishimoto, Y.	Magnetic turbulence and self-organization via magnetic reconnection in laser produced non-equilibrium extreme radiation plasma
11:45 - 12:15	Lazarian, A.	Turbulent reconnection and its implications
12:15 - 13:50	**Lunch Break**	
Chair: R. Matsumoto		
13:50 - 14:20	Kang, H.	Injection Problems in Diffusive Shock Acceleration Theory
14:20 - 14:50	Amano, T.	Particle Acceleration and Transport at Collisionless Shocks
14:50 - 15:10	Seough, J.	Proton temperature-anisotropy-driven instability: Quasi-linear kinetic theory
15:10 - 15:40	**Coffee Break**	
15:40 - 16:10	Matsukiyo, S.	Roles of microinstabilities in collisionless shocks
16:10 - 16:40	Ji, H.	Frontiers for laboratory study of magnetic reconnection relevant to helio and astrophysics

TUESDAY, July 12		
9:00 - 9:15	**Registration**	
Chair: S. Matsukiyo		
9:15 - 10:45	Melrose, D.	Magnetic reconnection in solar flares and pulsar magnetosphere
10:45 - 11:15	**Coffee Break**	
11:15 - 11:45	Kusano, K.	The Onset Mechanism of Solar Eruption
11:45 - 12:15	Song, H. Q.	Magnetic Reconnection and Instability in Solar Eruption
12:15 - 13:50	**Lunch Break**	
Chair: K. Kusano		
13:50 - 14:20	Hotta, H.	Large-scale MHD simulation of solar convection zone and dynamo
14:20 - 14:40	Yamasaki, K.	Experimental study of electron acceleration mechanism during high guide field reconnection
14:40 - 15:00	Mao, A.	Conceptual Design of the Asymmetric Reconnection EXperiment (AREX)
15:00 - 15:30	**Coffee Break**	
15:30 - 16:00	Matsumoto, Y.	Three-dimensional structures of high-Mach-number shocks and associated electron accelerations
16:00 - 16:30	Cai, D.	Parallel 3D Electromagnetic Particle-In-Cell Simulation for Relativistic Jets
16:30 - 16:50	Kaothekar, S.	Jeans Instability of a Self-Gravitating Thermally Conducting Viscoelastic Fluid with Radiative Effects

WEDNESDAY, July 13		
9:00 - 9:15	**Registration**	
Chair: T. Amano		
9:15 - 10:45	Watanabe, T.-H.	Gyrokinetic simulation of fusion and space plasmas
10:45 - 11:15	**Coffee Break**	
11:15 - 11:45	Kwon, J.-M.	Bounce-averaged gyrokinetic simulations of tokamak micro-turbulence
11:45 - 12:15	Kim, S. S.	Gyrofluid Simulation of Tokamak Plasma
12:15 - 13:50	**Lunch Break**	

Parallel Student Session

Student Session A (Room 403) Chair: Song, H. Q.		
13:50-14:05	Shibayama, T.	Fast magnetic reconnection supported by sporadic small-scale Petschek-type shocks
14:05-14:20	Takeshige, S.	The effects of an optically-thin synchrotron radiation cooling in the Petscheck type reconnection process
14:20-14:35	Zhou, X.	Electron acceleration by cascading reconnection in the solar corona
14:35:-14:50	Muhamad, J.	Simulation Study of Solar Flare Trigger Mechanism
14:50-15:20	**Coffee Break**	
15:20-15:35	Ishiguro, N.	Double Arc Instability in the solar corona
15:35-15:50	Arai, S.	Solar energy transport with significantly suppressed velocity
15:50-16:05	Choi, G.J.	Role of ExB Shear and Precession Shear in Electron Thermal Internal Transport Barrier Formation

Student Session B (Room 404) Chair: Y. Matsumoto		
13:50-14:05	Ha, S.	Toward the Development of a New MHD Code for Fusion Plasma
14:05-14:20	Hirabayashi, K.	Stratified simulation of collisionless accretion disks by kinetic MHD with anisotropic pressure
14:20-14:35	Peng, C.-H.	Magnetohydrodynamic Simulations of Galactic Prominence with Cooling/Heating processes
14:35:-14:50	Xie, W.	Numerical solutions of Neutrino-Dominated Accretion Flows with a Non-Zero Torque Boundary Condition and its applications in Gamma-ray Bursts
14:50-15:20	**Coffee Break**	
15:20-15:35	Iwamoto,M.	A large-amplitude electromagnetic wave excited in relativistic shocks
15:35-15:50	Tomita, S.	Particle in Cell Simulation of the Weibel Instability Driven by Spatially Anisotropic Structures
15:50-16:05	Kawahito, D.	Characteristics of radiation in non-equilibrium plasma produced by high intensity laser

THURSDAY, July 14		
9:00 - 9:15	**Registration**	
Chair: K. Ida		
9:15 - 10:45	Kawazura, Y.	Particle acceleration in laboratory magnetosphere
10:45 - 11:15	**Coffee Break**	
11:15 - 11:45	Xiao, C.	Plasma rotation in the PKU Plasma Test Device
11:45 - 12:15	Saitoh, H.	Toward creation of electron-positron plasmas in a laboratory
12:15 - 13:50	**Lunch Break**	
Chair: C. Xiao		
13:50 - 14:20	Ida, K.	Explore of magnetic topology by heat pulse propagation method
14:20 - 14:40	Ido, T.	Abrupt excitation of a subcritical instability in magnetically confined plasmas in the LHD
14:40 - 15:00	Nagaoka, K.	Experimental Study of Turbulent Transport and the Effect of Rotation in an Eelectro-Convection
15:00 - 15:30	**Coffee Break**	
15:30 - 16:00	Kuramitsu, Y.	Turbulent wakefield acceleration of relativistic particles
16:00 - 16:20	Sano, T.	High Power Laser-Plasma Interaction under a Strong Magnetic Field
16:20 - 16:40	Iwata, N.	Radiation reaction in interactions between ultrahigh intensity laser fields and cluster media

FRIDAY, July 15		
9:00 - 9:15	**Registration**	
Chair: M. Hoshino		
9:15 - 10:45	Lu, Q.	Electron Acceleration in Collisionless Reconnection
10:45 - 11:15	**Coffee Break**	
11:15 - 11:45	Ryu, D.	Magnetic Fields in the Large-Scale Structure of the Universe
11:45 - 12:15	Lei, W.-H.	Tidal disruption events with a relativistic jet
12:15 - 13:50	**Lunch Break**	
Chair: D. Ryu		
13:50 - 14:20	Matsumoto, R.	Plasma Dynamics in Accretion Disks
14:20 - 14:50	Li, Z.	High Energy Neutrino Astronomy
14:50 - 15:10	Tanaka, S. J.	Induced Compton Scattering off Anisotropic Radiation
15:10 - 15:40	**Coffee Break**	
15:40 - 16:10	Shibata, K.	Magnetic Reconnection in Solar and Astrophysical Plasmas
16:10 - 16:30	Hoshino, M.	Particle Acceleration of Driven Magnetic Reconnection

Poster Session (MONDAY afternoon to THURSDAY morning)		
P-01	Choi, J.	Transient time scale of poloidal Alfven waves in dipole geometry
P-02	Kaneda, K.	Polarization Characteristics and Depolarization Processes of Zebra Pattern in Type IV Solar Radio Bursts
P-03	Kato, Y.	X-ray observation of shocks within the plasma in clusters of galaxies
P-04	Kumthekar, B. K.	The Role of Diffusivity and Viscosity in Solar Plasma
P-05	Lee, K. P.	Gyro-kinetic Study of Residual Zonal Flow for Slowing down Distribution Function
P-06	Ozawa, N.	Observation of Azimuthal Doppler Effect by Optical Vortex
P-07	Shibayama, T.	Fast magnetic reconnection supported by sporadic small-scale Petschek-type shocks
P-08	Shimoda, J.	Importance of Richtmyer-Meshkov Instability on measurements of Cosmic-Ray acceleration efficiency at Supernova Remnants
P-09	Tanaka, S. J.	A Stochastic Acceleration Model of Radio Emission from Pulsar Wind Nebulae
P-10	Xie, W.	Numerical solutions of Neutrino-Dominated Accretion Flows with a Non-Zero Torque Boundary Condition and its applications in Gamma-ray Bursts
P-11	Zaitsev, I.	Numerical investigation of slow-mode shock waves in 1D simulations of thin current layer decay
P-12	Zhang, P.	Radio emission processes and magnetic field measurement of an M-class flare on August 27 2015
P-13	Kin, F.	Phase relation between Density and Potential fluctuations in Streamer

Abstract for Oral Presentations

Nonlinear Kinetic Turbulence Theory

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Abstract

Plasmas may be considered collisionless if one is interested in phenomena that evolve in time scales much shorter than time scales of binary collisions. For such cases, the Vlasov-Maxwell system of equations may be employed, which is a nonlinear partial differential equation, customarily solved under different degrees of approximation. Under the linear approximation one obtains the dispersion relations, but for time evolution of the system one needs to nonlinear effects. The lowest order approach is the quasilinear theory. The next step in this chain of approximations is the weak turbulence theory, which incorporates nonlinear effects of lowest order, that is, the quadratic nonlinearity. The weak turbulence theory was largely developed between the late 1950s and the decade of 1970s. In more recent years the present author resumed further development of the weak turbulence theory. However, until recently, the formal developments and numerical analyses thereof have not taken into account the collisional interaction between plasma particles. The reason had been that the time scale of collective processes should be shorter than the time scale associated with binary collisional processes. However, in some of the applications that have been made, it was shown that nonlinear effects continue to operate far beyond the time scale of the instability saturation and nonlinear mode coupling, to the extent that an asymptotically steady state, or quasi-equilibrium state, of the turbulent system becomes of relevance. Specifically, it was demonstrated that the plasma in such a “turbulent equilibrium” state is associated with a background of electromagnetic radiation and the inverse power-law velocity distribution function called the “kappa” distribution. It is therefore pertinent to raise the question of whether collisional processes can play a role in these processes of long-time evolution or not, even in tenuous turbulent systems. In addition, there are space plasma phenomena whose explanation requires the presence of beams of particles under the influence of collisional processes. The prime example may be the emission of X rays via bremsstrahlung, by electrons traveling in the solar chromosphere. There is evidence that suggests that the generation of Langmuir waves due to the presence of a beam may affect the velocity distribution of the X ray generating electrons. It is therefore deemed necessary that the long time evolution of the beam-plasma system, and possibly other physical systems, may have to be reconsidered by taking into account not only the wave-particle and wave-wave interactions, but also the collisional interactions as well. In the present lecture, the generalized theory of plasma kinetic theory in the context of weak turbulence ordering that includes both collective and collisional effects will be outlined.

Magnetic turbulence and self-organization via magnetic reconnection in laser produced non-equilibrium extreme radiation plasma

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Abstract

We study a plasma produced by the interaction between high power laser and high-Z structured medium, which we refer it as "*non-equilibrium extreme radiation plasmas*", and discuss the characteristics. Such a plasma is highly non-stationary and non-thermodynamic equilibrium, and consists of multiply charged high-Z ions, high energy relativize electrons, quasi-static and/or low frequency electromagnetic fields, high energy X-rays and [redacted]-rays resulting from Bremsstrahlung and also from radiation damping [1]. The nonlinear response of such plasma leading to various kinds of structure formation and their thermodynamics property are of specific interest to understand the extreme state in universe and to explore applications such as heavy ion acceleration.

We have developed a comprehensive particle based integrated simulation code, EPIC3D, which includes key elements to reproduce such interaction between high power lasers and high-Z structured medium, e.g. various atomic process and relaxation process, radiation process such as Bremsstrahlung and radiation damping, and their transport [2,3].

Here, we introduce a lattice-like assembly consisting of 2-dimensional sub-micron Au-rod embedded in strong magnetic field in the order of 10kT, which is irradiated with high intensity short pulse laser in the range of $10^{20\text{-}22}$ W/cm^2. The high absorption of laser energy is realized causing ionization of Au-rods to high charge state and expansion leading to high energy density plasma. The applied ambient magnetic field is scrambled by the complex plasma motion leading to *magnetic turbulence* exhibiting power-law spectrum. The magnetic turbulence is then self-organized to coherent strong magnetic vortex around the rods, which field strength is the order of magnitude higher than that of initially applied magnetic field. The structure is similar to that of z-pinch, so that high energy density plasma is confined in longer time scale, which emits high intensity x-rays.

The generation mechanism of the magnetic vortex results from the successive reconnection between closed magnetic field-line around the rod and open magnetic field-line advected by the background plasma flows, which is similar to the collision between the Earth's magnetic field and that of solar wind. Furthermore, collision and marge of different magnetic vortexes take place with slower time scale through reconnection, which play a role in thermalizing and/or accelerating ions. Various kind of electromagnetic radiation including Alfven wave are observed.

The present scheme can be a tool in studying magnetic turbulence and associated self-organization through reconnection in plasmas with various magnetization level, e.g. fully kinetic, electron MHD, or near ideal MHD, in non-equilibrium extreme plasma.

[1] Y. Kishimoto et al., High Energy Density Science 2016, May 17, 2016, Yokohama.

[2] D. Kawahito, Y. Kishimoto, *et al.*, IFSA. Mo.Po.24, 339(2015)

[3] N. Iwata et al., accepted for publication in Physics of Plasma (2016)

Turbulent reconnection and its implications

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Abstract

I shall cover several topics related to magnetic reconnection in turbulent media. I shall discuss the model of turbulent reconnection and show non-relativistic and relativistic simulations supporting the model. I shall show that the model implies the violation of flux freezing in turbulent media and show numerical and observational evidence supporting this claim. Finally, I shall discuss particle acceleration in turbulent reconnection.

Injection Problems in Diffusive Shock Acceleration Theory

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Abstract

Injection of electrons into the Fermi 1st-order process has been one of long-standing problems in the Diffusive Shock Acceleration (DSA) theory for astrophysical shocks, because it involves complex plasma kinetic processes that can be studied only through full Particle-in-Cell (PIC) simulations. It is thought that electrons must be pre-accelerated from their thermal momentum to several times the postshock thermal proton momentum to take part in the DSA process, and electron injection is much less efficient than proton injection due to smaller rigidity of electrons.

Several recent studies using PIC simulations have shown that some of incoming protons and electrons gain energies via shock drift acceleration (SDA) while drifting along the shock surface, and then the particles are reflected toward the upstream region. Those reflected particles can be scattered back to the shock by plasma waves excited in the foreshock region, and then undergo multiple cycles of SDA, resulting in power-law suprathermal populations. In these PIC simulations, however, subsequent acceleration of suprathermal electrons into full DSA regime has not been explored yet, because extreme computational resources are required to follow the simulations for a large dynamic range of particle energy.

Non-Maxwellian tails of high energy particles have been widely observed in space and laboratory plasmas. Such particle distributions can be described by the combination of a Maxwellian-like core and a suprathermal tail of power-law form, which is known as the kappa-distribution. The existence of kappa-like suprathermal tails in the electron distribution would alleviate the problem of extremely low injection fractions for weak quasi-perpendicular shocks such as those widely thought to power radio relics found in the outskirts of galaxy clusters.

Particle Acceleration and Transport at Collisionless Shocks

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Abstract

The collisionless shock has been a primary candidate for the production of nonthermal particles in space. The diffusive shock acceleration (DSA) has been considered as the standard shock-acceleration theory that predicts a power-law spectrum, whose index is sorely determined by the shock compression ratio. The theory assumes (1) injection or pre-acceleration providing a seed population for subsequent acceleration, (2) nearly isotropic distribution in momentum space via efficient pitch-angle scattering, leading to diffusive transport of energetic particles, (3) energetic particles are test particles that do not affect the dynamics of the thermal plasma. Validity of these assumptions has been extensively studied over the decades, as they provide the key ingredients of the acceleration process. Indeed, these issues are intimately linked with each other, making it extremely difficult to understand the overall picture of the whole nonlinear system.

We will present recent theoretical and numerical effort toward understanding the key issues in the shock acceleration theory. In particular, the electron injection processes involving a variety of nonlinear and kinetic plasma waves in the shock transition layer is discussed. In addition, we also present results of kinetic simulations on turbulence driven by energetic particles streaming in the precursor region of the shock. Implications of the result will be discussed in relation to the transport of solar energetic particles in the interplanetary space.

Proton temperature-anisotropy-driven instability: Quasi-linear kinetic theory

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Abstract

The proton temperature-anisotropy-driven instabilities have received attention because they may be applicable to a variety of space plasma environments. For instance, in-situ measurements of the solar wind and the Earth's magnetosheath have shown that these instabilities could play an important role in regulating the unlimited growth of the temperature anisotropy. Indeed, it has been shown that the solar wind proton temperature anisotropies are regulated by the marginal stability conditions obtained from linear Vlasov analysis of the kinetic instabilities [1]. In the literature [2-4], numerical simulations have been carried out to study the fundamental properties and investigate how the instabilities affect the solar wind dynamics. Recently, a series of papers [5-7], which employed the quasi-linear kinetic theory for several kinetic instabilities, successfully have explained the observed temperature anisotropy upper bound in the solar wind. In the present study, we will discuss the validity and limitation of the quasi-linear treatment for various kinetic instabilities and show some recent results that describe the expanding box model of quasi-linear theory as an application to a kinetic model of the solar wind.

References

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Roles of microinstabilities in collisionless shocks

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Abstract

In a collisionless shock microinstabilities play important roles. They heat an incoming plasma to provide necessary dissipation in a transition region. They are sometimes able to directly produce non-thermal particles. Furthermore, they produce a scatterer of the non-thermal particles in the context of diffusive shock acceleration (DSA). We review the above mentioned roles of microinstabilities in some cases of quasi-perpendicular shocks from the viewpoint of full particle-in-cell simulation.

First, we focus on the instabilities generated in the so-called foot region, which is produced by the ions specularly reflected at the shock (ramp). The reflected ions become a beam in terms of the incoming plasma so that some microinstabilities get excited. Depending on the shock parameters a variety of instabilities are generated. Here, we introduce electron thermal Mach number, M_{te}, defined as the upstream flow velocity normalized to electron thermal velocity, which is proportional to Alfven Mach number divided by the square root of electron beta. When the Mach number is low, $M_{te} \lesssim 1$, as in the Earth's bow shock, electron cyclotron-drift instability, and modified two-stream instability are dominantly generated. These instabilities contribute to electron as well as ion heating. For higher Mach numbers, $M_{te} >> 1$, Buneman instability gets excited. The resultant large amplitude waves trap some electrons which are accelerated by the convection electric field to non-thermal energy while being trapped.

On the other hand, when $M_{te} < \cos\Theta_{Bn} (B_2/B_1)^{1/2}$, non-negligible amount of electrons are mirror reflected at a shock. The reflected electrons form a foreshock. In the foreshock resonant and non-resonant instabilities are generated. The latter is also called electron firehose instability and efficiently scatter the reflected electrons. The waves play crucial roles in injection of non-thermal electrons into DSA.

Frontiers for Laboratory Study of Magnetic Reconnection Relevant to Heliophysics and Astrophysics

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Abstract

Frontiers of magnetic reconnection research will be discussed by highlighting a few recent achievements primarily from laboratory experiments but also from theory and numerical simulations. Of particular importance among these achievements is the development of a reconnection "phase diagram", in which different coupling mechanisms from the global system scale to the local dissipation scale are classified into different reconnection phases [H. Ji & W. Daughton, Phys. Plasmas 18, 111207 (2011)]. This progress motivated the major next-step laboratory device, called the Facility for Laboratory Reconnection Experiments or FLARE (flare.pppl.gov), which is currently under construction at Princeton. The goal of the FLARE project is to access reconnection regimes directly relevant to heliophysical and astrophysical plasmas. The currently existing small-scale experiments have been focusing on the single X-line reconnection process in plasmas either with small effective sizes or at low Lundquist numbers, both of which are typically very large in natural plasmas. The new regimes involve multiple X-lines are illustrated in the reconnection phase diagram. The design of the FLARE device is based on the existing Magnetic Reconnection Experiment (MRX) (mrx.pppl.gov). After a brief summary of recent laboratory results on the topic of magnetic reconnection, the motivating major physics questions, the construction status, and the planned collaborative research especially with heliophysics and astrophysical communities will be discussed.

Magnetic reconnection in solar flares and pulsar magnetospheres

D.B. Melrose [1)]

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Abstract

In this lecture, I review early ideas on magnetic reconnection, and discuss the present-day status of the application of reconnection to astrophysical and space plasmas.
The need for magnetic reconnection at magnetic nulls was first recognized in connection with solar flares in the 1940s and 1950s. By the 1960s this had led to models involving X-type neutral points for flares, and also for the Earth's magnetosphere. The related concept of tearing modes was developed in connection with laboratory plasmas around the same time. These early models assumed two-dimensional magnetic nulls and it was not until the 1990s that the generalization to three-dimensional nulls and to reconnection in the absence of a null were explored.
I discuss the present-day status of the application of reconnection to solar flares, emphasizing the enormous mismatch between the scales relevant to existing reconnection models and the scales relevant to flares. Some form of turbulent reconnection, or related concept, is needed to bridge this gap. I also explain why three-dimensional models for reconnection that include pre-existing currents are essential. A global model for a flare requires both null-point and non-null-point reconnection in widely separated locations. Although non-null-point reconnection is usually ignored in flares, I explain why it has been an ingredient in models for pulsar electrodynamics since the 1970s.

The Onset Mechanism of Solar Eruption

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Abstract

Solar eruptions, such as solar flares and coronal mass ejections, are the most catastrophic eruptions in our solar system, and have been known to affect terrestrial environments and infrastructure. Because their onset mechanism is still not sufficiently understood, our capacity to predict the occurrence of solar eruptions is substantially hindered. Recently, however, the systematic simulation of solar eruptions for a wide variety of magnetic structures and the comparative study between the high resolution satellite observations and the realistic numerical simulations of three-dimensional magnetic field improve our understanding of solar eruptions. In this paper, we show the most widely acceptable picture of solar eruptions, in which the nonlinear interaction between an ideal magnetohydrodynamics (MHD) instability and magnetic reconnection play a crucial role. Magnetic reconnection works for transporting magnetic helicity from sheared magnetic loops into a flux rope, and a flux rope becomes more unstable. The growth of instability of flux rope further drives magnetic reconnection. We also propose that a small scale magnetic field of specific structures is capable of triggering this nonlinear feedback process, and discuss about the predictability of flares based on the high-resolution magnetic field observation.

Magnetic Reconnection and Instability in Solar Eruption

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Abstract

Coronal Mass Ejections (CMEs) are the most energetic eruptions in the solar system and can cause strong geomagnetic storms and other space-weather catastrophic effects when they interact with the geo-space at high speeds ranging from several hundred to even more than three thousand kilometres per second. Therefore, it is important to investigate their acceleration mechanisms in space/solar physics and space-weather studies. It is generally believed that the accumulated magnetic free energy serves as the main energy source for CME accelerations (Forbes 2000), but it remains open regarding how the magnetic energy is released.

Two mechanisms have been proposed (Song et al. 2015 and references therein): one is the resistive magnetic reconnection process and the other is the ideal global magnetohydrodynamic (MHD) magnetic flux rope (MFR) instability. Both mechanisms are supported by observations. For example, good correlations exist between the CME speed (acceleration) and the associated soft X-ray (hard X-ray and microwave) profiles (Zhang et al. 2001; Qiu et al. 2004; Maričić et al. 2007). In addition, studies showed that the extrapolated magnetic flux in the flaring region was comparable with the magnetic flux of the MFR reconstructed from in-situ data (Qiu et al. 2007). These CME-flare association studies, among others, support that the reconnection plays an important role in accelerating CMEs. On the other hand, statistical studies showed that the projected speed in the sky plane and kinetic energy of CMEs only had weak correlations with the peak X-ray fluxes of their associated flares (Yashiro et al. 2002; Vršnak et al. 2005). There also exist some fast front side CMEs without accompanying flares (Song et al. 2013). These observations support that the ideal MHD instability also plays an important role in the CME dynamics. Simulations demonstrate that both mechanisms can make comparable contributions to the CME acceleration (Chen et al. 2007), which is supported by latest observation with a case study (Song et al. 2015).

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Large-scale MHD simulation of solar convection zone and dynamo

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Abstract

In the talk, I review recent development of the solar dynamo study.

The sun has the sunspots, i.e., cool and strong magnetic region, on the surface. The number of the sunspot varies with 11-year cycle period. This is one of the most important unresolved problems in the astrophysics. Since the sunspot has strong magnetic field, the sunspot cycle is thought as a magnetic activity cycle. We need to understand the magnetic field generation, i.e. dynamo, to understand this mystery. The solar convection zone is filled with ionized plasma and this plasm move turbulently, since the solar convection zone is thermal convectively unstable due to the energy flux from the radiation zone. We need to understand this turbulence and its interaction with the magnetic field. This issue involves a lot of processes 1. Excitation of the thermal convection. 2. Anisotropic angular momentum transport. 3. Generation of the large-scale flow patterns. 4. Global stretching and transport of large-scale magnetic field. 5. Anisotropic magnetic field generation with turbulent electromotive force. 6. Small-scale magnetic field generation without any anisotropy. We need to understand all these processes. In the talk, these processes are reviewed and I introduce recent development of the understanding of these ideas.

In the final part of the talk, I introduce our 5-year plan to advance the solar dynamo study.

Experimental study of electron acceleration mechanism during high guide field reconnection

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Electron energization mechanism during merging startup is experimentally investigated in the University of Tokyo Spherical Tokamak (UTST). Magnetic probe and Langmuir probe measurements indicate that the diffusion region extends in the downstream direction. Trajectory calculation using the measured magnetic field and electric field indicates that the electrons are energized by field-aligned electric field within the diffusion region. Under the condition of same initial plasma current, the electron energy gain inside the diffusion region increases with the toroidal magnetic field.

Floating potential profile around the X-point was measured using Langmuir probe array during merging startup. Right after transition to the fast reconnection phase, the measured potential profile abruptly shows a quadrupole structure around the X-point, whose polarity changes with guide field direction. Its diffusion region profile was estimated using the potential profile and magnetic field profile, which was measured by 2D magnetic probe array. According to the Ohm's law, field-aligned electric field (E||) must have a finite value in diffusion region, while inductive E|| and electrostatic E|| must cancel out with each other in ideal MHD region. Therefore, the region where inductive E|| is much greater than electrostatic E|| was adopted as the diffusion region. The diffusion region was observed to extend in downstream region, which is quite different from the VTF result [1]. Particle trajectory calculation was performed using the obtained electric field and magnetic field profile. The trajectory analysis indicates that electrons gain energy from E|| inside the diffusion region and the obtained energy increases with stronger guide field. Also, soft X-ray measurement exhibits similar trend. Trajectory analysis also indicates that the electrons which gain significant kinetic energy inside the diffusion region are localized along the separatrices as shown in figure 1. The CIII emission profile obtained by fast camera also indicates the increase in the number of energetic electrons along the separatrices during fast reconnection phase.

Using the trajectory calculation results, inertia term was estimated and was compared with other non-ideal term in Ohm's law. It was found that resistivity term and inertia term are 3-5 order smaller than the reconnection electric field, which indicates that electron pressure term or fluctuation might play the key role in high guide field reconnection where Bg/Brec > 10.

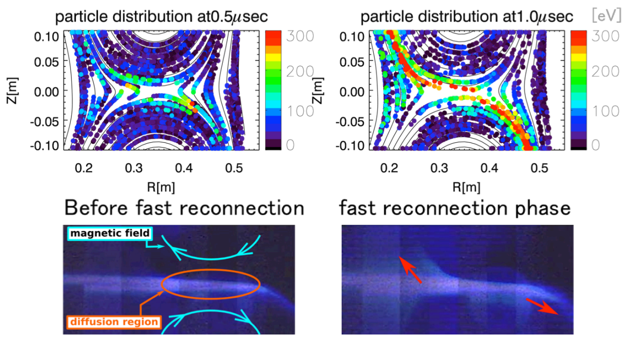

fig 1 Test particle locations and their kinetic energy at 0.5 and 1.0 μ sec from calculation start (upper left and right panel). Fast camera image of CIII emission before fast reconnection phase and during fast reconnection phase are shown in lower left and right panel, respectively.

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Conceptual Design of the Asymmetric Reconnection EXperiment (AREX)

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Abstract

A new terrella device, the Space Plasma Environment Research Facility (SPERF), is designed and under construction at Harbin Institute of Technology (China), with Asymmetric Reconnection EXperiment (AREX) as one of the experiment components to simulate interaction between the interplanetary and magnetosphere plasmas. Different from existing reconnection experiments with both axisymmetry and symmetry about the neutral line, the aim of AREX is to provide a unique platform for simulating asymmetric magnetic reconnection such as that at magnetopause. The new AREX regime explores reconnection dynamics by driving reconnection with a set of coils and flux cores for simulating "solar-wind-side" magnetosheath field to reconnect with a dipole field generated by the Dipole Research EXperiment (DREX) coil on the "magnetosphere-side". Thus it will be able to investigate a range of important reconnection issues in magnetosphere geometry, such as the electron and ion-scale dynamics in the current sheet, particle and energy transfer from magnetosheath to magnetosphere, particle energization/heating mechanisms during magnetic reconnection, 3D and asymmetric effects in fast reconnection and so on. The design of AREX device approximately follows the Vlasov scaling laws between the laboratory plasma of the device and the magnetosphere plasma to reproduce local reconnection dynamics. The plasma is generated by the flux cores at the "solar-wind-side" and an electron cyclotron resonance (ECR) source at the "magnetosphere-side" to achieve a wide range of plasma parameters. Different kinds of coils with specific current driven functions, as well as advanced diagnostics are designed to be equipped for the facility. Motivation, design criteria for AREX experiments and reconnection scenarios will also be discussed.

Three-dimensional structures of high-Mach-number shocks and associated electron accelerations

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Abstract

Astrophysical shock waves have been a candidate for the origin of cosmic-rays. In particular, X-ray emissions from supernova remnant shocks have provided great opportunities to examine how high-energy electrons are produced at collision-less shocks. Numerical simulations have revealed that electrons can be efficiently heated and accelerated via resonant interactions with plasma kinetic waves, such as the electron shock surfing acceleration mechanism in which electron-scale Buneman instability played key roles. Recently, Matsumoto et al. [2015] proposed a new acceleration mechanism by turbulent reconnection in the shock transition region through excitation of the ion-beam Weibel instability.

In order to deal with the two different acceleration mechanisms in a self-consistent system, we examined 3D PIC simulations of quasi-perpendicular, high-Mach-number shocks. With the help of the high computational capability of the K computer, we successfully followed a long time evolution in which the two different acceleration mechanisms coexist in the 3D shock structure. The Buneman instability was strongly excited ahead of the shock front in the same manner as have been found in 2D simulations. In the transition region, the ion-beam Weibel instability generated strong magnetic field turbulence in 3D space. The turbulence was much stronger than those found in 2D simulations. Plasma blobs found in the turbulent region indicated magnetic reconnection took place in 3D magnetic field structures. As a result, electron energy spectrum in the downstream region exhibited a high energy tail following a power-law distribution. In this talk, we present how such relativistic electrons are produced during traveling in the 3D shock structure.

Parallel 3D Electromagnetic Particle-In-Cell Simulation for Relativistic Jets

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Abstract

The radiation from afterglows of gamma-ray bursts is generated in collisionless plasma shocks between a relativistic out flow and an ambient medium. The two main ingredients responsible for the radiation are high-energy, non-thermal electrons and a strong magnetic field. First-order Fermi acceleration (or diffusive shock acceleration, DSA) is normally believed to be responsible for the acceleration of the particles. In DSA, particles diffuse back and forth across the shock front and gain energy by scattering from the magnetohydrodynamics (MHD) waves. However, DSA needs a seed population of particles with energies well in excess of the thermal ones, because only these particles are capable for multiple crossing the shock front and effective scattering by magnetic turbulences. However, it is not apparent how the electrons can reach the threshold energy of DSA. It demands their kinetic energies be comparable to those of the ions. This is known as the electron injection problem. In the case of magnetized upstream, the injection of electrons is thought to be directly associated with the background motional electric field $E_0 = -\beta_0 \times B_0$. They may gain energy from the motional electric field while they gyrate surf around the shock front. Based on the barrier that reflects the electrons toward the upstream, thus capable them for repeatedly energizations, this process is known with distinct names. If the reflecting barrier has a magnetic source, the acceleration mechanism is named shock drift acceleration or SDA. If the barrier has an electrostatic source, the process is called shock surfing acceleration or SSA. Basically, the SSA process acts only in the electron-ion shocks, because electrostatic barrier would not be generated if the species have the same inertia. Magnetization parameter, obliquity angle of the upstream magnetic field with respect to the shock direction of propagation, and bulk Lorentz factor of the incoming stream may also play significant role in determining the responsible process for particle acceleration. The main question in report is: how does the electron ejection operate in unmagnetized electron-ion shocks?" Here, on the basis of a three-dimensional relativistic electromagnetic particle-in-cell code, we have analysed the Weibel-like instabilities, collisionless external shocks, and the electron injection acceleration associated with the unmagnetized relativistic jet propagating into an unmagnetized ambient plasma. The results of simulations demonstrate that the Weibel-like instabilities are responsible for generating and amplifying the dominantly transversal electromagnetic fields. In accordance with hydrodynamic shock systems, the shock consists of a reverse shock and forward shock separated by a contact discontinuity. The development and structure are controlled by the ion Weibel-like instabilities. The ion filaments are sources of strong transverse electromagnetic fields at both sides of the double shock structure over a length of 30 -100 ion skin depths. Electrons are heated up to a maximum energy $\epsilon_0 \sim \sqrt{\epsilon_B}$, where ϵ is the energy normalized to the total incoming energy. The shock-reflected ambient ions generate a double layer in the reverse shock transition region which evolves consequently into an electrostatic shock. In addition, a double layer is formed in the forward shock transition region because of the decelerated jet ions and ambient electrons. The simulations show strong electron acceleration that is required

for injecting the electrons into the DSA. The large energy stored in the jet ions causes the extreme electron acceleration. The double layers convert directed ion energy into directed electron energy, without heating up the plasma. Electrons can thus be accelerated by the double layers to much higher speeds than by a shock because the latter also transfers flow energy into heat. The electron distribution functions in the reverse shock and forward shock transition regions show power-law distributions with index $p = 1.8 - 2.6$.

Jeans Instability of a Self-Gravitating Thermally Conducting Viscoelastic Fluid with Radiative Effects

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The linear self-gravitational instability of magnetized finitely conducting viscoelastic fluid with radiative effects is investigated using the modified generalized hydrodynamic (GH) model. A general dispersion relation is derived with the help of linearized perturbation equations using the normal mode analysis method and it is discussed for longitudinal and transverse mode of propagation. In longitudinal mode of propagation, we find that Alfven mode is uncoupled with the gravitating mode. The fundamental Jeans criterion of gravitational instability is determined which depends up on thermal conductivity, radiative heat-loss function, shear viscosity and bulk viscosity while it is independent of magnetic field. The viscoelastic effect modifies the fundamental Jeans criterion of gravitational instability. Numerical calculations have been performed to see the effect of different parameters on the growth rate of the Jeans instability.

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Gyrokinetic simulation of fusion and space plasmas

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Abstract

The gyrokinetics provides a theoretical basis for analytical and numerical studies on low-frequency drift waves and turbulence, or magnetohydrodynamic (MHD) phenomena, in fusion and space plasmas with a mean magnetic field. After development of the nonlinear gyrokinetic formulation in 1980's, computer simulations based on the gyrokinetic theory have largely been advanced in fusion plasma research. In this lecture, after introduction of the basic concept of the gyrokinetics, we discuss numerical simulation models and their applications to fusion and space plasmas.

The gyrokinetic equations consist of the kinetic and field equations. The Vlasov equation is averaged over the gyro-motion of charged particles so that high-frequency fluctuations are eliminated by construction. Electromagnetic fields are given by the quasi-neutrality condition and the Ampere's law. In the derivation of the gyrokinetic equation, one needs to assume the gyrokinetic ordering, where a smallness parameter ε is introduced, such that

$$\varepsilon \sim \omega/\Omega \sim \rho/L \sim k_{\parallel}/k_{\perp} \sim \delta f/f_0 \sim e\phi/T$$

where Ω, ρ and L mean the gyrofrequency, thermal gyroradius, and an equilibrium scale-length. Frequency, ω, and the parallel and perpendicular wavenumbers, $k_{\parallel}$ and $k_{\perp}$, are defined for fluctuations. Distribution functions of equilibrium and perturbed parts are denoted by f_0 and δf, respectively. Potential energy of fluctuations normalized by the background temperature, $e\phi/T$, also obeys the ordering. Since the gyrokinetic ordering is consistent to nature of drift waves and the shear Alfven law, applications to the drift wave turbulence, the shear Alfven wave turbulence, and the ballooning-type instabilities are quite straightforward. By using the gyrokinetic equations, the theoretical and numerical analysis can be free from the closure problem of fluid equations as well as the high-frequency plasma oscillations and cyclotron motions, while keeping effects of the finite gyroradius and the drift orbits.

The gyrokinetic simulation model is designed to resolve the low amplitude of fluctuations, $e\phi/T \sim \varepsilon$, where the conventional particle-in-cell method is inefficient. Thus, the Vlasov (continuum) simulation approach and/or the δf-formulation are widely employed. The distribution function is discretized on the five-dimensional phase space in the former. Only the perturbed part of the distribution function, δf, is handled in the latter. High phase-space resolution achieved in the δf-Vlasov simulation is successfully applied to magnetized plasma turbulence, where transfer processes of entropy fluctuations on the phase space is clearly identified, extending a frontier of plasma turbulence theory.

Applications of the gyrokinetic simulation to the anomalous transport in fusion plasma have extensively been promoted in the last two decades. Discovery of turbulence regulation by zonal flows is a significant outcome of the gyrokinetic simulations which have also been applied to analysis of the fusion plasma experiments. State of the art of the gyrokinetic simulations of plasma turbulence reveals cross-scale interactions of ion- and electron-scale turbulence, where the peta-scale computing plays a key role in simultaneously resolving the electron and ion dynamics.

Bounce-averaged gyrokinetic simulations of tokamak micro-turbulence

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Abstract

For the prediction and optimization of tokamak performance, it is crucial to understand the thermodynamic properties of strongly magnetized plasma, which are mainly determined by relatively low frequency turbulence occurring in the magnetized plasma. The gyrokinetic theory provides an economic way to study such low frequency turbulence and dynamics of the magnetized plasma by removing the fast periodic gyro-motions from the system, thus significantly reducing the spatio-temporal scales to describe[1]. However, even with this reduced gyrokinetic model, it is still challenging to simulate global aspects of turbulence and transport in realistic tokamak geometry. This is mainly due to the large mass ratio of ion and electron constituting the tokamak plasma, and the resulting time scale disparities in their respective motions.

In this work, we introduce the bounce-averaged kinetic model[2], which is to remove the fast periodic bounce motions of electrons, and thereby to reduce the computational cost for simulation further. We show that the bounce-averaged kinetic model can be extended and applied to study key micro-instabilities such as ITG and TEM in realistic tokamak geometry[3]. As an example, we demonstrate that the bounce-averaged model can reproduce the shaping effects on ITG-TEM micro-instabilities in quantitatively correct ways. We also discuss possible future extension of the model for nonlinear simulation of ITG-TEM turbulence in tokamak plasma.

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Gyrofluid Simulation of Tokamak Plasmas

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Abstract

Development of a self-consistent, core-edge integrated simulation capability is a long standing problem in fusion simulation program. Such capability would yield insight into questions related to global profile dynamics originating from L→H and internal transport barrier (ITB) transitions, edge localized modes (ELM), and intrinsic rotation, to name just a few important problems in tokamak plasmas. Gyrofluid simulations are well-suited for this purpose owing to its fast computational time (capability of a long time simulation, e.g. adiabatic power ramp simulation), while keeping the relevant physics. In this talk, gyrofluid models and codes for tokamak turbulence simulation will be introduced. Recent gyrofluid studies of intrinsic rotation, hysteresis in ITB, role of external torque in ITB formation/profile de-stiffening will be presented and discussed.

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

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Abstract

Magnetic reconnection is a process of changing the connectivity of magnetic field lines, and thought to play a core role in explosive energy conversion of solar flares. According to the Sweet-Parker theory, it is, however, difficult to conduct magnetic reconnection efficiently in highly conductive plasma of the solar corona. Petschek proposed another reconnection theory, in which small magnetic diffusion region realizes efficient reconnection with the energy conversion occurring in slow mode MHD shocks. However, recent numerical simulations suggest that Petschek reconnection is not stable in a system with spatially uniform resistivity. Some mechanism such as anomalous resistivity or kinetic physics is needed to sustain the localized diffusion region. It is, therefor, not clear yet how fast reconnection realizes in the actual parameter of the solar corona.

In order to answer to this question, we perform resistive 2D MHD simulation in a large system with a high spatial resolution, and find that slow mode MHD shocks predicted by Petschek spontaneously form even under a uniform resistivity (Shibayama et al. 2015, PoP). In this process, fast motion of large plasmoids in the current sheet play a role of localizing the diffusion region, and slow mode shocks form in front of the moving plasmoids. These plasmoids enhance magnetic reconnection intermittently and repeatedly. As a result, the reconnection rate increases up to 0.02, which is high enough to explain the time-scale of solar flares. Furthermore, our simulation suggests that the obtained reconnection rate doesn’t depend on the Lundquist number. This is due to a similarity in the evolution of plasmoid.

Reference : Shibayama et al., Physics of Plasmas, 22, 100706 (2015)

The effects of an optically-thin synchrotron radiation cooling in the Petscheck type reconnection process

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Abstract

In recent studies, relativistic magnetic reconnection processes are investigated by relativistic resistive magnetohydrodynamic (RRMHD) simulations. In the classical reconnection model, the inflow magnetic energies are converted to the outflow thermal and kinetic energies of outflow plasmas. For relativistic plasmas in a strong magnetic field, the synchrotron radiation has an important role for cooling plasmas. Therefore, in the steady reconnection processes, the balance between the reconnection heating and the radiation cooling can be important. In this study, we investigated effects of the radiation cooling in the Petscheck type reconnection process, using RRMHD simulations considering the radiation process. In our simulations, for simplicity, we assumed an optically-thin radiation and introduced a radiation cooling rate as source term. As a result, we found that the reconnection outflow is compressed and collimated, and that the larger cooling rate becomes, the larger reconnection rate becomes.

Electron acceleration by cascading reconnection in the solar corona

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Abstract

We investigate electron acceleration by electric field induced by cascading reconnections in current sheets trailing coronal mass ejections via a test particle approach in the framework of the guiding center approximation. Although the resistive electric field is much weaker than the inductive electric field, the electron acceleration is still dominated by the former. Anomalous resistivity ŋ is switched on only in regions where the current-carrier's drift velocity is large enough. As a consequence, electron acceleration is very sensitive to the spatial distribution of the resistive electric fields and electrons accelerated in different segments of the current sheet have different characteristics. Due to the geometry of the 2.5D electromagnetic fields and strong resistive electric field accelerations, accelerated high energy electrons can be trapped in the corona, precipitating into the chromosphere or escaping into the interplanetary space. The trapped and precipitating electrons can reach a few MeV within one second and have a very hard energy distribution. Spatial structure of the acceleration sites may also introduce breaks in the electron energy distribution. Most of the interplanetary electrons reach hundreds of keV with a softer distribution. To compare with observations of solar flares and electrons in solar energetic particle events, we derive hard X-ray spectra produced by the trapped and precipitating electrons, fluxes of the precipitating and interplanetary electrons as well as spatial distributions of all energetic electrons.

Simulation Study of Solar Flare Trigger Mechanism

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Abstract

Solar flare releases huge amount of energies from corona to the interplanetary space due to magnetic reconnection process. The releasing energy is initially stored in the corona as the magnetic energy contained within solar coronal magnetic structure. Due to some perturbations in the photosphere, solar coronal structure can be destabilized, which lead to the eruption. In this study, we performed MHD simulation with zero plasma beta to figure out what mechanism possible to trigger the flare. The coronal magnetic field was reconstructed by using MHD relaxation method to extrapolate coronal structure above active region NOAA 10930 in the state of Nonlinear Force-Free. We showed that this coronal model was stable against any instabilities before the perturbation was introduced. Various small bi-pole structures were then imposed onto the initial coronal structure to understand which configuration effective to trigger the flare. We confirmed that two kind of small bi-pole structures so called Opposite-Polarity (OP) and Reversed-Shear (RS) structures that imposed to the highly sheared magnetic fields were able to trigger the flare.

Double Arc Instability in the solar corona

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Abstract

Solar explosive phenomenon such as solar flare or coronal mass ejection impact the electromagnetic environment around the Earth. On the solar explosive phenomena, twisted flux rope was sometimes observed to be ejected. It suggests that the stability of flux rope is related to the occurrence of solar explosive phenomenon. To elucidate the stability, we modeled flux rope as current loop and analyzed its stability based on the theoretical framework developed by previous studies. Torus Instability (TI) was proposed by Kliem & Toeroek (2006) to explain the mechanism of solar eruption. Based on the results, they suggested that the stability is determined by "decay index", which is an index of attenuation of external magnetic field from torus axis. Although TI is often used as the criteria of explosive phenomenon recently, how the loop becomes unstable is still unclear. Although various scenarios have been suggested, the tether-cutting reconnection scenario suggested by Moore et al. (2001) is widely accepted. However, although the tether-cutting reconnection forms a double arc loop before eruption, the stability of double arc loop has not been analyzed yet.

Thus, the objectives of this study is to analyze the stability of double arc loop theoretically. We model a double arc loop as two circular tori connected each other. The equations of equilibrium state and the ideal MHD constraint, which is the conservation of magnetic flux below the double arc, are derived, and we solve them numerically. As the result of analysis, we found that double arc current loop can be destabilized for any type of external field, and the critical height of the instability is much lower than that of TI. We also found that the decay index is not relevant to the double arc instability (DAI). On the other hand, by calculating the criteria for DAI under force-free field, we found that necessary condition for DAI is that twist of magnetic field line is larger than one half. In addition, we demonstrate that the dynamics of DAI can reproduce the observational feature that fast eruption occurs after slow-rise phase. These results show that solar explosive phenomenon can occur as a result of destabilization of double-arc loop which is formed by tether-cutting reconnection before flux rope become torus shape. Thus, it suggests that the onset of solar explosive phenomena may be determined by the DAI.

Solar energy transport with significantly suppressed velocity

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Abstract

We carry out a series of 2D convection calculations with highly suppressed velocity. Thermal convection in the solar interior is thought to maintain differential rotation and meridional circulation. Although the solar equator is rotating faster than polar region, recent high-resolution calculations with solar parameters accelerate the pole. This problem can be attributed to over-excited thermal convection in numerical calculations. Local helioseismology also supports this finding. Recent MHD simulations suggest that the small-scale Lorentz force is able to suppress the convection velocity, but the suppression is not enough and has not been numerical converged, i.e., higher resolution shows stronger suppression.

In this study, we assume that the Lorentz feedback in extremely high resolution, i.e., the sun, becomes stronger enough to explain equator acceleration and the result of the local helioseismology. In order to investigate this extreme condition, we carry out series of 2D hydrodynamics simulations with high viscosity mimicking the strong Lorentz force. The purpose of our research is to investigate energy flux transported by the thermal convection. Even if the velocity is reduced, convection needs to transport imposed energy flux at the bottom boundary. Generally it is expected that upflow and downflow become hotter and cooler, respectively than those without viscosity. We also find that the efficiency of convective energy transport is maintained by increasing the correlation between vertical velocity and temperature fluctuation when the convective velocity is suppressed significantly.

Role of ExB Shear and Precession Shear in Electron Thermal Internal Transport Barrier Formation

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Abstract

In tokamaks, ExB shear induced turbulence suppression [1] is known to be an important mechanism in the formation of ion thermal internal transport barriers (ITBs) [2]. However, understanding different behaviour of electron thermal transport still remains a challenging problem in tokamak confinement physics. Trapped electron precession shear induced turbulence suppression was previously proposed [3] as a general nonlinear mechanism to explain electron thermal ITB formation in the presence of reversed magnetic shear configuration and local electron heating [4]. In this work, we confirm that ExB shear, as well as trapped electron precession shear, is naturally included in the two-point decorrelation theory on turbulence associated with trapped electrons by systematic derivation using modern bounce kinetic formalism [5]. We also study ExB shear and precession shear induced turbulence suppression, and synergism between ExB shear and precession shear. Relative sign between ExB shear and precession shear is found to be important as well as their magnitudes in suppressing turbulence. They can either reinforce or interfere with each other in reducing turbulence, depending on local plasma conditions. Our result provides explanations on broad range of experimental observations regarding electron thermal ITB observed in tokamaks such as TFTR and JT-60U [6, 7].

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Toward the Development of a New MHD Code for Fusion Plasma

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Abstract

Development of a new code for magnetohydrodynamic (MHD) phenomena in fusion plasma is under progress. The code implements the Finitie Volume Method (FVM) to follow conservative quantities such as the energy and momentum using a high-order scheme (WENO5). This approach is different from those of existing codes, such as NIMROD and M3D, which use the Finite Element Method. The boundary and geometry of tokamak are hard to be described in orthogonal coordinates. Therefore, it is non-trivial to implement FVM to codes for fusion plasma in tokamak. However, employing new numerical schemes and techniques to handle the geometry and boundary condition, we expect to resolve obstacles in codes with FVM. Here we introduce what we have done and a future plan for the code development.

Stratified simulation of collisionless accretion disks by kinetic MHD with anisotropic pressure

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Abstract

An accretion disk around a supermassive black hole is thought to consist of a collisionless plasma. 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 large deviation between the disk scale and the kinetic scale of particles makes it impossible to apply these simulation techniques directly. To study the large-scale dynamics of collisionless disks, therefore, the so-called kinetic magnetohydrodynamics (MHD), which can take into account some of kinetic effects, is required.

We, particularly, focus on the effect of anisotropic pressure. It can modify the nature of magnetorotational instabilities (MRIs), which play important roles for the angular momentum transport in accretion disks. We carried out series of kinetic MHD simulations using a *stratified* shearing box model, and found that, by inclusion of the pressure anisotropy, the magnetic energy in the saturated MRI-driven turbulence reduces to one third of that in the isotropic case, due to the anisotropy with $P_{\parallel} > P_{\perp}$ generated by the MRI itself. On the other hand, the magnetic energy 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.

Magnetohydrodynamic Simulations of Galactic Prominence with Cooling/Heating processes

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Abstract

We present two dimensional resistive MHD simulations to show the possible formation mechanism of molecular loops observed by Fukui et al. (2006) at Galactic central region. We speculate that formation process of molecular loops is similar to the solar prominence. Kaneko and Yokoyama (2014) demonstrated that prominence can be formed by imposing converge and shear motion at foot points of magnetic arch anchored to the solar surface and adapting radiative cooling. In our study, we adapted similar setting in Galactic center scale (~few hundreds pc) and applied cooling and heating function summarized by Inoue et al. (2006). We found that current sheets can formed inside the magnetic arch expanding by the imposed motion at foot points. Magnetic reconnection taking place in the current sheet forms rising dense plasmoids. In our simulation, thermal instability triggered within the plasmoids can form dense filaments floating at high Galactic latitude.

Numerical solutions of Neutrino-Dominated Accretion Flows with a Non-Zero Torque Boundary Condition and its applications in Gamma-ray Bursts

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Abstract

A stellar mass black hole (BH) surrounded by a neutrino-dominated accretion flow (NDAF) is widely considered as the central engine of gamma-ray bursts (GRBs). Previous studies on NDAF have been based on the assumption of "no torque" boundary condition, which is however invalid when the disk is magnetized. Recent general relativistic magnetohydrodynamic (GRMHD) simulations on magnetized disk show there is a significant magnetic stress at the inner edge. In this paper, we revise the NDAF model by introducing non-zero boundary stresses and general relativistic corrections. We present a numerical solution for such non-zero torque NDAF model. Their properties are significantly changed due to this non-zero boundary torque. As a consequence, we find that: (1) non-zero torque NDAF can account for those bright and powerful GRBs, which are hard to interpret with previous NDAF; (2) the variability of the prompt emission and the steep decay phase in the early X-ray afterglow are explained by the viscous instability in NDAF; (3) the strength of the gravitational waves radiated by a possible processing accretion disk is slightly enhanced due to the change of the material distribution caused by the existence of the magnetic torque.

A large-amplitude electromagnetic wave excited in relativistic shocks

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Abstract

The origin of cosmic rays has been a long-standing problem in astrophysics. Fermi shock acceleration in supernova remnants is considered a plausible model for the origin of galactic cosmic ray. On the other hand, the acceleration mechanism of high energy cosmic rays has not been understood yet. Recently Chen et al. (PRL, 2002) discussed the possibility of particle acceleration by the large-amplitude Alfvén waves and proposed that the ultra-high energy cosmic rays may be generated by the wakefield acceleration (Tajima and Dowson, PRL, 1979). Since then the acceleration mechanism attracts interests in astrophysical field. Lyubarsky (ApJ, 2006) suggested that a large-amplitude electromagnetic precursor waves, which is excited in the relativistic shock front by synchrotron maser instability (Hoshino and Arons, PoP, 1991), induces the electrostatic field and argued that it may be responsible for the particle acceleration. Hoshino (ApJ, 2008) extended the previous studies and demonstrated the efficient particle acceleration by the incoherent wakefield induced by the ponderomotive force of the precursor waves in the upstream region of the relativistic shock wave by using one-dimensional Particle-In-Cell (PIC) simulation.

In two-dimensional systems, however, several problems about the wakefield acceleration may arise due to the nature of the precursor wave. One is the problem of wave coherence of the precursor wave. The wave coherence is required for the ponderomotive force which induces the wakefield. Another problem is the generation of precursor wave under a competition between synchrotron maser instability and Weibel instability. The growth rate of the synchrotron instability might get smaller than that in one-dimensional systems due to the Weibel instability, and the amplitude of the precursor wave might be insufficient to cause the wakefield acceleration. As the previous one-dimensional simulations could not solve these problems, we investigate in this study the nature of the precursor waves in relativistic shocks by using the two-dimensional PIC simulation and argue the possibility of the wakefield acceleration in two-dimensional systems. In this presentation, we compare two-dimensional simulations to one-dimensional simulations, and discuss that the amplitude of the precursor wave in two-dimensional systems is large enough to induce the wakefiled acceleration even if Weibel instability occurs.

Particle in Cell Simulation of the Weibel Instability Driven by Spatially Anisotropic Structures

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Abstract

The Weibel instability occurs in collisionless plasma with the temperature anisotropy. It is thought to be important for particle acceleration and generation of magnetic fields in relativistic shocks. Observations of afterglows of gamma ray bursts (GRBs) suggest that magnetic fields are amplified in the large downstream regions of relativistic shocks. However the magnetic field produced by the Weibel Instability decays rapidly, which cannot explain observed properties of afterglows of GRBs. The nonlinear evolution of the Weibel instability has been studied in uniform plasma or shocks in uniform plasmas so far. However there are density fluctuations in the interstellar medium. For relativistic shocks propagating into the inhomogeneous plasmas, it is expected that anisotropic density structures are generated by the shock compression in the downstream regions of the shocks. We investigate the nonlinear evolution of the Weibel instability in inhomogeneous plasmas by means of two-dimensional PIC simulations. We find that spatially anisotropic density structures produce anisotropic velocity distributions. It causes that the magnetic fields are amplified by the Weibel instability. Furthermore we find that growth and damping timescales of the Weibel instability are proportional to the lengthscale of density structures. This means that magnetic fields produced by the Weibel instability can occupy larger regions than previously thought. Therefore our results can be important for the generation of magnetic fields in the afterglow of the GRBs.

Characteristics of radiation in non-equilibrium plasma produced by high intensity laser

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Abstract

The interaction between high power laser in the range of $10^{20\text{-}23}$W/cm^2 and high-Z structured material can lead to a high energy density plasma consisting of high energy relativistic electrons, multiply charged high-Z ions, strong fields with wide range of frequency from those of quasi-static and/or low-frequency electromagnetic fields, high intensity laser field including higher harmonics, strong X-rays and γ-rays resulting from various types of electronic transition from exotic atomic states, Bremsstrahlung, radiation reaction. Such a plasma, which we refer it as "*non-equilibrium extreme radiation plasma (NERP)*", is highly non-stationary and non-thermodynamic equilibrium and present a new class of material state where nonlinear process regulated by complex ionization and radiation process plays a key role. The exploration of such plasma, theoretically and experimentally, provide a new platform in studying extreme state in universe, e.g. magnetic turbulence, self-organization of magnetic field, particle acceleration, and also in exploring new application such as exotic nuclei acceleration and strong γ-ray source, etc.

In order to study such plasmas, it is of specifically importance to reproduce the interaction as precisely as possible by including both micros-scale physics, e.g. various kinds of ionization process and radiation process incorporated with quantum electrodynamics, and that of macro-scale, .e.g. long range kinetic dynamics of plasma over Debye length, but keeping self-consistency between them. For this purpose, we have developed a particle based integrated code, which includes key ingredients to reproduce the interaction between high power lasers and high-Z structured material specifically emphasizing on radiation model.

Here, we have introduced three kinds of radiation process to EPIC3D which are self-consistently incorporated with those of ionization and collisional relaxation. They are 1) K-α X-ray emission from radiative auger process associated with inner cell ionization of K-shell electrons and the generation of hole ion, 2) Bremsstrahlung resulting from collisional process between multiply charged ion and relativistic high energy electrons [1], 3) radiation reaction using classical and quantum models[2]. Incorporating with quasi-static and/or low-frequency component of electro-magnetic fields including those of laser and their higher harmonics, we can determine the spectrum of radiation in wide frequency range which is a key ingredient in studying the NERP. By using the code, we investigated the characteristics of NERP such as the emission energy and angle for each radiation process and the dependence of radiation efficiency coupled with the ionization process of high-Z target.

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Particle acceleration in laboratory magnetosphere

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Abstract

Magnetospheres are commonly seen objects in the universe that form natural plasma confinement devices. The study of magnetospheres has provided many insights for laboratory plasma. This talk will give overview of theoretical studies of magnetospheric plasma followed by recent results of magnetospheric plasma experiments.

One characteristic of magnetospheric plasma is a strongly inhomogeneous density distribution with planetward gradient. Such a self-organized structure is developed by an inward (or radial) diffusion process [1] which seemingly contradicts the maximum entropy principle. The key to understanding the inward diffusion is adiabatic invariants of magnetized particles: magnetic moment, bounce integral, and magnetic flux shell. Violation of the most fragile third invariant, while the other two invariants are kept constant, provokes the inward diffusion. One of the modern theoretical approaches to understanding the inward diffusion is regarding the adiabatic invariants as topological constraints in a phase space [2]. Following this approach, entropy is maximized on a topologically constrained (foliated) phase space instead of on Cartesian coordinates. The planetward density gradient on the Cartesian coordinate is equivalent to the uniform density on the foliated phase space [2, 3].

Experimental research has also advanced our understanding of magnetospheric plasma in recent years. The inward diffusion was observed in the ring trap 1 (RT-1) device [4, 5] and the Levitated Dipole Experiment (LDX) [6] that simulate laboratory magnetospheres via the levitated superconducting magnets. In these experiments the peaked density profile similar to the planetary magnetosphere was observed. Our most recent experiments observed the inward diffusion causing particle acceleration [7, 8]. A particle is energized when it is transported inward, with its first and second adiabatic invariants kept constant; conservation of the first adiabatic invariant increases the particle's perpendicular kinetic energy (betatron acceleration), and conservation of the second invariant increases its parallel energy (Fermi acceleration). These acceleration mechanisms are the primary generator of planetary radiation belts, and we proved that the former mechanism is responsible for ion heating in the RT-1.

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Plasma rotation in the PKU Plasma Test Device

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Abstract

Some preliminary results of plasma rotations in a linear plasma experiment device, PKU Plasma Test device (PPT), are shown in this paper. PPT has a cylindrical vacuum chamber with φ500 mm×1000 mm, and a pair of Helmholtz coils which can generate cylindrical or cusp magnetic geometry with magnitude from 0 to 2000 Gauss. Plasma was generated by a helicon source and the typical density is about 10^{13} cm^{-3} for the Argon plasma. Some Langmuir probes, magnetic probes, and one high-speed camera are setup to diagnostics. It's shown that the mode structures of rotational plasmas are typically as: the poloidal wavenumber m=1-10 (as shown in Figure 1), and the rotation frequency is about several kHz. Magnetic fluctuations exist during the plasma rotation processes with both cylindrical and cusp magnetic geometries, respectively. These preliminary results show that the plasma rotations might be related to some interesting electromagnetic processes.

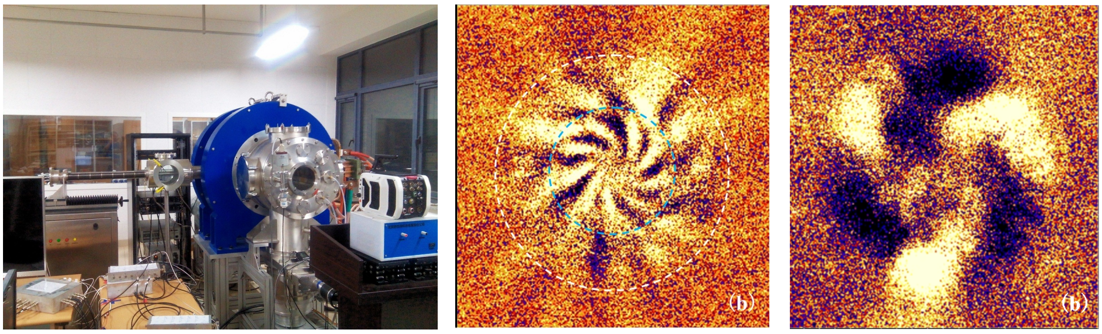

Figure 1: Overview of PPT divice and plasma rotations. left: a photo of PPT device; Middle: plasma rotation in the linear configuration; Right: Plasma rotation in the cusp configuration.

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Toward creation of electron-positron plasmas in a laboratory

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Abstract

Electron-positron plasmas own unique properties as one of pair-plasmas, plasmas consisting of equal-mass charged particles [1], which are fundamentally different from conventional ion-electron plasmas. Electron-positron plasmas have long been studied theoretically and numerically in relation to astrophysical phenomena observed for example in pulsar magnetospheres. Recently, remarkable stability properties of electron-positron plasmas have been predicted [2]. These studies on pair-plasmas are important for understanding fundamental properties of plasmas, as well as for providing insights into astrophysical phenomena. In order to create electron-positron plasmas in a laboratory, experiments in linear magnetic trapping configurations, such as Penning-Malmberg trap [3] and magnetic mirror [4] have been conducted. In the field of high-energy electron-positron plasmas, laser-based generation of dense electron-positron pairs was reported recently [5]. We, the PAX (Positron Accumulator eXperiment) and APEX (A Positron-Electron Experiment) teams [6], plan to create the first magnetically-confined electron-positron plasmas in a novel approach. We will operate toroidal traps (superconducting stellarator [7] and dipole [8] devices) in combination with a linear accumulator device at NEPOMUC [9], the world's strongest moderated positron source.

In this contribution, we present progress toward the creation of magnetically-confined electron-positron plasmas in IPP [10]. In the PAX accumulation experiment, we have conducted non-neutral (pure electron) plasma experiments with a 2.3 T Penning-Malmberg trap. More than one hour of confinement and observation of a collective mode of non-neutral plasmas were demonstrated. In the linear configuration, studies on remoderation and diagnostics of positron beams are also ongoing. In the APEX injection and confinement project, we have stated on-line experiments with intense positron beams at the NEPOMUC facility. We have characterized the positron beam for wide energy range including low energy range suitable for trapping in a dipole field configuration. In a prototype dipole trap, generated by a permanent magnet, efficient (40%) injection of the remoderated 5 eV positron beam from NEPOMUC was realized. After injection, we also observed relatively long confinement (~ 5 ms) of positrons in the prototype dipole field trap. Based on these results, we are conducting design and operation studies on a superconducting levitated dipole experiment suitable for the confinement of electron-positron pair-plasmas.

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Explore of magnetic topology by heat pulse propagation method

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Abstract

In the magnetized plasma, a heat pulse propagates both parallel and perpendicular magnetic field. The heat pulse propagates parallel to magnetic field in a time scale of thermal velocity of plasma, while it propagates perpendicular to magnetic field in the time scale of heat transport due to collisions and turbulences. Therefore the propagation speed parallel to magnetic field is much faster than that to perpendicular to magnetic field by more than one order of magnitude. By taking advantage of this characteristic, the magnetic topology can be explored by analyzing the propagation of heat pulse.

In laboratory plasmas, bifurcation physics of the magnetic topology has been investigated using the heat pulse propagation method produced by the modulation of electron cyclotron heating. There are two types of bifurcation phenomena observed in LHD and DIII-D. One is a bifurcation of the magnetic topology between nested and stochastic field[1, 2]. The nested state is characterized by the bi-directional (inward and outward) propagation of the heat pulse with slow propagation speed. The stochastic state is characterized by the fast propagation of the heat pulse with electron temperature flattening.

The other bifurcation is between magnetic island with larger thermal diffusivity and that with smaller thermal diffusivity[3]. The damping of toroidal flow is observed at the O-point of the magnetic island both in helical plasmas and in tokamak plasmas during a mode locking phase with strong flow shears at the boundary of the magnetic island[4]. Associated with the stochastization of the magnetic field, the abrupt damping of toroidal flow is observed in the large helical device [5]. The toroidal flow shear shows a linear decay, while the ion temperature gradient shows an exponential decay. This observation suggests that this flow damping is due to the change in the non-diffusive term of momentum transport.

In this method, a conditioning averaging technique is applied to improve a signal to noise ratio and the accuracy of the delay time measurements with small amplitude. The idea of heat pulse propagation method and the conditioning averaging technique could be applied to the research on magnetic field topology and to the visualization of the magnetic field in space and astrophysical plasmas. A feasibility of the application of this method to space and astrophysical plasmas will be discussed.

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Abrupt excitation of a subcritical instability in magnetically confined plasmas in the LHD

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Abstract

New phenomenon of an abrupt excitation of intense instability has been discovered in magnetically confined plasmas produced in the Large Helical Device (LHD) [1]. This instability is abruptly excited when the up-chirping frequency of an energetic-particle driven geodesic acoustic mode (EGAM), which is a kind of zonal flows with a finite frequency in torus plasmas, approaches twice the ordinary GAM frequency. Measurement of the electric potential fluctuation, density fluctuation, and magnetic field fluctuation indicates that the frequency and the spatial structures of the abrupt instability agree with the dispersion relation of the GAM. Therefore, the abrupt instability is also identified as a GAM.

The abruptly exited GAM has larger amplitude than the initially excited EGAM. The estimated growth rate of the abrupt GAM indicates that the GAM is excited through nonlinear processes. In addition, the observed specific phase relation between the GAM and the EGAM indicates the coupling between the GAM and the EGAM. The abrupt and intense excitation cannot be explained by well-known driving mechanisms such as nonlinear coupling of turbulence [2] and inverse Landau damping of energetic particles[3]. Thus, the observed phenomenon indicate the existence of a new excitation mechanism of the GAM.

A candidate mechanism of the abrupt excitation of the GAM is proposed in Refs. 4,5 and 6, in which it is shown that a subcritical instability of the GAM is driven by a cooperative collaboration of fluid parametric coupling and kinetic nonlinearity. The model can reproduce the observed phase relation, amplitude, and time scale of the abrupt excitation, quantitatively. Thus, this experiment would be the first demonstration of the existence of subcritical instability driven by a kinetic process in magnetically confined plasmas. Since a subcritical instability is one of working hypotheses of the onset of abrupt phenomena such as the sawtooth oscillation in laboratory plasmas and the solar flare in space plasmas, this study may suggest an experimental path to explore the abrupt phenomena.

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Experimental Study of Turbulent Transport and the Effect of Rotation in an Eelectro-Convection

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Abstract

Turbulent transport is a very general subject in a wide area of physics research. The phenomena that we are interested in are very complex ones associated with structure formations in turbulence. It is well known that the Kolmogorov scaling appears in three-dimensional isotropic turbulence. However, it is less interested because nothing happens. In many cases of our interest, some structures appear in turbulence due to “symmetry breaking” such as temperature gradient, density gradient, intensity gradient of turbulence, rotation, velocity shear, magnetic field, etc. In order to understand turbulent transport characteristics in complex systems, a simple experimental research of turbulent transport using ElectroHydro-Convection (EC) is in progress.

The EC is a convection motion driven by the electric field in a liquid crystal, where the gravity and the temperature gradient in a Rayleigh Bernard convection (RBC) system can be replaced by the electric field alone. When the electric field is increased, the EHC becomes turbulent, which is the same feature as RBC with stronger buoyant force. The advantage of the EC turbulence is controllability of the turbulence (Rayleigh number, Prandtl number), diagnostics of spatial structure of flow and evaluation of transport via particle tracing method. Experiments of EC turbulence to investigate the effect of rotation on the turbulence transport were carried out using a rotary stage. These experiments show that (1) nonlinear coupling of turbulent flow increases with rotation while the spatial power spectra of the flow velocity does not change and (2) the turbulent diffusivity decreases significantly with rotation (Rossby number < 1). These observations indicates the importance of the nonlinear coupling of the turbulent flow on the turbulent transport characteristics. The detailed of the EC turbulence and the experimental results will be presented in the workshop.

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Turbulent wakefield acceleration of relativistic particles

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Abstract

Ever since the discovery of cosmic rays, the origins of cosmic rays have been longstanding open question more than a century. While the galactic cosmic rays are considered to be accelerated by the diffusive shock acceleration at non-relativistic collisionless shocks, the extragalactic origins are not well understood. A possible candidate is wakefield acceleration in extreme astrophysical settings [1]. At relativistic perpendicular collisionless shocks, large amplitude light waves propagate in the upstream as precursor waves [2]. The strong ponderomotive force of the light excites the wakefield, and then, the wakefield nonthermally accelerates upstream particles [2]. The large-scale light waves are subject to self-modulation and filamentation instabilities, which make the wakefield turbulent. Numerical studies in an upstream system show the universal production of power law energy distribution functions of accelerated electrons with an index of -2 independent of the light and plasma conditions [3]. Astrophysical objects are inaccessible and there is no way to observe the plasma quantities to discuss these models. We have performed model experiments of the cosmic ray acceleration due to the turbulent wakefield. Preliminary results with Gekko PW laser show the power law tails with an index of -2 independent of the plasma density [4,5]. We have performed a relevant experiment with the 100 TW laser facility at National Central University [6], which is completely different scale from the Gekko PW laser. Our results show that the turbulent wakefield nonthermally accelerates particles and universally generates power law spectra with an index of -2.

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High Power Laser-Plasma Interaction under a Strong Magnetic Field

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Abstract

Existence of a magnetic field can largely affect the nature of laser (electromagnetic wave) propagation in plasmas. Recently, generation of an extremely strong magnetic field, which is of the order of kilo tesla, have been achieved in laboratory experiments by using high intensity lasers (Yoneda et al. 2012; Fujioka et al. 2013; Korneev et al. 2015). Because the laser wavelength is typically about 1 micron, the cyclotron frequency of electrons ω_{ce} for a kilo tesla field is comparable to the laser frequency ω_L. Interestingly, when $\omega_{ce} > \omega_L$, the cutoff frequency disappears for the whistler mode, and then the laser light can travel into overdense plasmas. Thus, the critical field strength defined as $B_c \equiv m_e \omega_L / e$, where m_e and e are the electron mass and the elementary charge, has a crucial meaning in laser-plasma interaction just like the critical density for non-magnetized plasmas. It can be expected that the direct interaction between a high intensity laser and overdense plasma could bring a new mechanism of efficient plasma heating and particle acceleration, and have various applications such as the inertial fusion science, laser-driven ion beams for cancer therapy, and astrophysical cosmic-ray acceleration.

We investigate laser-plasma interactions under a strong magnetic field by one-dimensional Particle-in-Cell (PIC) simulations. A simple setup is considered in our analysis, in which a thin foil of solid hydrogen is irradiated by a right-handed circularly polarized laser. A uniform magnetic field is assumed in the direction of the laser propagation. Then the whistler wave can penetrate the overdense hydrogen plasma when the external field is larger than the critical B_c. In this situation, key parameters are the plasma density and the size of the external field. We performed various models in the density-field strength diagram, which is actually the so-called CMA diagram, to evaluate the efficiency of the energy conversion from the laser to plasma and the reflectivity and transmittance of the laser.

It is found that there are two important processes in the interaction between the whistler wave and overdense plasma, which are the cyclotron resonance of relativistic electrons and the parametric (Brillouin) instability. The electron energy increases significantly through the resonant absorption, when the external field strength is near the critical value B_c. If the laser intensity is high enough, the electron velocity driven by the laser electric field can be relativistic. This fact should be considered in the cyclotron resonance condition, and which causes the realization of wider range of resonant field strength. Because of the high temperature of electrons, ions are accelerated dramatically by a large sheath field. The excitation of a large-amplitude ion acoustic wave by the stimulated Brillouin scattering is also very important for both the energy conversion and reflectivity. This could be an efficient mechanism for the ion heating directly from the laser energy.

Radiation reaction in interactions between ultrahigh intensity laser fields and cluster media

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Abstract

With the development of ultrashort high power lasers, the laser intensity reaches to the regime of $10^{19\text{-}21}$ W/cm^2 where electrons irradiated by such lasers are accelerated to relativistic energies within a few laser period. The high intensity laser-matter interaction has opened up various innovative applications such as compact particle accelerators [1], fast ignition-based laser fusion, strong magnetic field generation in the level of kilo-tesla [2], and intense radiation and neutron sources. Higher intensities of $10^{22\text{-}25}$ W/cm^2, which are expected in near future [3], lead to new fields of high energy density science including laboratory astrophysics and nonlinear quantum vacuum physics [4]. In this regime, plasmas consisting of relativistic electrons and ions, intense radiations, strong magnetic fields and electron-positron pairs can be expected to be generated depending on state, structure and species of target materials irradiated by lasers.

As the material state, besides gas and solid, clusters have been interested owing to its unique interaction features with laser fields such as high energy absorption due to the large ratio of surface to volume, efficient ion acceleration by Coulomb explosion and laser field propagation by the cluster mode [5], which have so far been studied for the regime below 10^{20} W/cm^2. Today, higher intensities of 10^{22} W/cm^2 are becoming feasible. In this intensity level, the energy of radiations from electrons accelerated by the laser fields reaches to the range of γ-ray, and accordingly, damping of electron motion by the radiation reaction, i.e., radiation damping, becomes not negligible [6]. Since clusters exhibit strong interactions with laser fields, the radiation damping can be specifically important, and the interaction properties will be different qualitatively from those in the lower intensity regime.

Here, we study the effects of radiation reaction in the interaction between laser fields and cluster mediums i.e., mediums compose of multi-clusters, in the intensity regime of $10^{22\text{-}23}$ W/cm^2 using the particle-in-cell (PIC) simulation that includes the radiation reaction [7]. Intense radiation emission is found in the cluster media where electrons suffer from strong accelerations by both the laser field and charge separation field of clusters. As a result, the clustered structure increases the energy conversion into high energy radiations significantly compared with a uniform plasma at the expense of the conversion into particles. The maximum ion energy achieved in the interaction with cluster media is found to decrease through the radiation reaction into the same level with that achieved in the interaction with the uniform plasma. The clustered structure thus enhances high energy radiation emission rather than the ion acceleration in the considered intensity regime.

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Electron Acceleration in Collisionless Reconnection

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Abstract

Magnetic reconnection is a fundamental plasma process which rapidly converts magnetic energy into plasma kinetic energy, and it is considered to be related to many explosive phenomena in space and laboratory plasma, such as solar flares in the corona, the heating of solar corona, substorms in the Earth's magnetosphere, and disruptions in laboratory fusion experiments. There is observational evidence that a significant portion of the magnetic energy released during reconnection is converted into kinetic energy of energetic electrons, and the electron acceleration is one of the important signatures in magnetic reconnection. In this talk, we will review the recent progresses on electron acceleration in magnetic reconnection, and discuss the mechanisms of electron acceleration in the vicinity of X line, the separatrix region of magnetic reconnection, as well as during the interactions between magnetic islands.

Magnetic Fields in the Large-Scale Structure of the Universe

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Abstract

Magnetic fields appear to be ubiquitous in astrophysical environments including the large-scale structure of the universe. The existence of magnetic fields in the cosmic web of clusters, filaments and voids has been established through observations of Faraday rotation, synchrotron emission, and gamma-ray. Yet, the nature and origin of the magnetic fields remains controversial and largely unknown. In this talk, I briefly summarize recent developments in our understanding of the nature and origin of the magnetic fields. I also describe a plausible scenario for the origin of the magnetic fields; seed fields were created in the early universe and subsequently amplified during the formation of the large-scale structure of the universe. I then discuss the prospect of studies of the magnetic fields in the cosmic web with the upcoming facilities.

Tidal disruption events with a relativistic jet

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Abstract

A star or sub-stellar object will be destroyed by tidal forces when it passes close enough by a supermassive black hole (SMBH). These events known as TDEs are expected to produce luminous flare emission in the UV to X-ray band. Recent observations of Sw J1644+57, in particular, suggest that at least some TDEs can launch a relativistic jet. A common speculation is that these rare events are related to rapidly spinning BHs. We constrained the BH spin parameter by using the available data, and found that the BH indeed carries a moderate to high spin, suggesting that BH spin is likely the crucial factor behind the Sw J1644+57-like events. Other observational properties include the rough 2.7 day periodicity in X-ray dips and 200s QPO, which we interpret as due to precession of the jet. In addition, Sw J2058+05 and Sw J1112.2-8238 are also thought to be a TDE with an on-beam relativistic jet. It is natural to expect that there should be some events with off-beam ones. We found that IGR J12580+0134 in the nucleus of NGC 4845 is likely such a case.

Plasma Dynamics in Accretion Disks

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Abstract

We review results of global magnetohydrodynamic (MHD) simulations of black hole accretion flows carried out by taking into account the radiative cooling. In differentially rotating, weakly magnetized disks, the magnetic field amplification by magneto-rotational instability (MRI) and the buoyant escape of the magnetic flux drive quasi-periodic dynamo, in which the direction of mean azimuthal magnetic fields reverses quasi-periodically. The buoyantly rising magnetic loops twisted by the rotation of the disk form current sheets inside the expanding magnetic loops. Magnetic reconnection taking place in the current sheet produce plasmoids and outflows. When the accretion rate is smaller than the threshold for the onset of the cooling instability, radiatively inefficient, optically thin, hot accretion flow is formed. This state corresponds to the X-ray hard state observed in galactic black hole candidates and in low luminosity active galactic nuclei (AGNs).

When the accretion rate exceeds the upper limit for the existence of radiatively inefficient accretion flow (RIAF), the disk shrinks in the vertical direction because the radiative cooling rate exceeds the heating rate. This transition corresponds to the hard-to-soft transition observed in black hole candidates. Machida et al. (2006) showed by three-dimensional global MHD simulations that magnetically supported disk is formed during the vertical contraction of the disk because the total azimuthal magnetic flux should be conserved. Since the magnetic pressure supports the disk, the disk stays in optically thin state. This state corresponds to the luminous hard state observed during the hard-to-soft transition. Machida et al. (2006), however, could not carry out longer time scale simulations because numerical oscillations appeared in magnetically supported region.

Here, we present numerical results of the hard-to-soft state transition obtained by applying CANS+ code, in which HLLD scheme (Miyoshi and Kusano 2005) is applied for MHD equations. In CANS+, 5^{th} order accuracy in space is achieved by applying MP5 scheme. We confirmed that magnetically supported disk is formed during the transition. We found that magnetic reconnection taking place in the interface between the magnetically supported, cool disk and ambient RIAF heats the cool disk and drive outflows. We discuss the observational signatures of the co-existence of the magnetically supported cool disk and hot RIAF. We also present preliminary results of MHD simulations taking into account the evaporation of the cool disk by thermal conduction.

High Energy Neutrino Astronomy

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Abstract

IceCube at the south pole had reported the discovery of TeV-PeV extraterrestrial neutrinos, which open a brand new window to observe the universe. I will briefly overview the history of the high energy neutrino detection, and then discuss the possible origins of these high energy neutrinos. I will emphasize that the multi-messenger approach may be the best way to diagnose the neutrino origin. By the photon-neutrino connection in the neutrino production processes, we can use the Fermi-LAT observations of various objects to constrain their neutrino flux, and test if they could be the sources of the IceCube detected neutrinos.

Induced Compton Scattering off Anisotropic Radiation

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Abstract

Induced Compton scattering (ICS) is an interaction between intense electromagnetic radiation and diffuse plasma. ICS is important when a brightness temperature of the radiation being larger than the rest-mass energy of an electron and also the density of the plasma being smaller than the critical density. In our past study [1], we deduced an equation that expresses a non-linear spectral evolution of the radiation spectrum by ICS on the assumption of the isotropy of the system. We found that the scattered photons rapidly lose their energy by ICS with continuously forming solitary structures in frequency space (see Figure 1). The characteristic solitary structures, which have the logarithmic width characterized by an electron temperature, have never been observed both in laboratories and space.

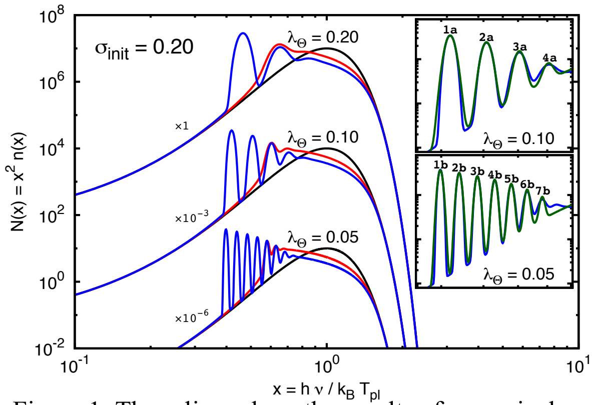

Figure 1. Three lines show the results of numerical calculations for spectral evolution by ICS [1], where the black lines are the initial spectra and blue lines are the final spectra. The temperature is larger for the upper curves. The solitary structures of blue curves have logarithmically width characterized by the electron temperature (T_{pl}).

Here, we extend the equation to the case for anisotropic radiation since such a intense radiation is highly directional in nature. We focus on the spectral evolution of scattered radiation because, in some situations, ICS does not simply isotropize the radiation. We find that the spectrum of the scattered radiation forms the solitary structure of logarithmic width that is characterized by both the electron temperature and the opening angle of the initial radiation. Figure 2 is the result of the calculation. Applying to a laser device whose energy of 3.3J, wavelength of 800nm, band-width of 36nm (duration of 33fs) and beam waist of 4.3um, we calculate the spectral evolution of scattered radiation by the plasma whose temperature of 1keV and density of 10^{18}cc^{-1}. The ICS signature would be observed for some present laser devises.

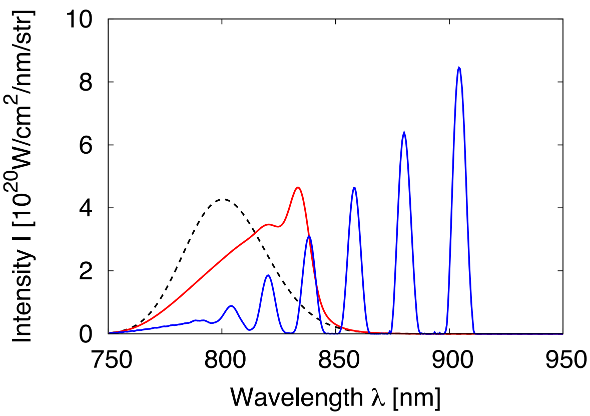

Figure 2. Spectral evolution for anisotropic radiation. The black line is the initial spectrum and the blue line is the final spectrum.

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Magnetic Reconnection in Solar and Astrophysical Plasmas

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Abstract

Recent space based observations of the Sun revealed that magnetic reconnection is ubiquitous in the solar atmosphere, ranging from small scale reconnection (observed as nanoflares) to large scale one (observed as long duration flares or giant arcades). Often magnetic reconnection events are associated with mass ejections or jets, which seem to be closely related to multiple plasmoid ejections from fractal current sheet. The bursty radio and hard X-ray emissions from flares also suggest the fractal reconnection and associated particle acceleration. We shall discuss recent observations and theories related to the plasmoid-induced-reconnection and the fractal reconnection in solar flares, and their implication to reconnection physics and particle acceleration. Recent finding of many superflares on solar type stars that has extended the applicability of fractal reconnection model of solar flares to much wider parameter space suitable for stellar flares are also discussed.

Particle Acceleration of Driven Magnetic Reconnection

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Abstract

Understanding of non-thermal particle acceleration in a current sheet is an important problem in space and astrophysical plasmas, and magnetic reconnection has been investigated as a key element of not only plasma heating but also nonthermal particle acceleration. Yet the acceleration efficiency of ions an electrons in reconnection is not clearly understood. For example, the satellite observations in the Earth's magneto-tail reported the relatively efficient electron acceleration event during the plasma sheet crossing in reconnection, but the ion acceleration events are few. The particle-in-cell (PIC) simulation studies also suggested less acceleration for ions and efficient acceleration for electrons. In this study, we investigate how and where the ions are acceleration during reconnection by using PIC simulation. Specifically, we focus on the effect of the so-called driven reconnection with an external Poynting flux injection into the plasma sheet, and discuss that the reconnection can generate quite a few nonthermal particles even if the driven Poynting flux is weak.

Abstract for Poster Presentations

Transient time scale of poloidal Alfven waves in dipole geometry

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Abstract

Standing poloidal Alfven waves with high azimuthal wave number (m >> 1) are of interest since they can be excited via bounce-drift resonance with ring current particles of the Earth's magnetosphere. However, the temporal behavior of these transient poloidal waves in realistic dipole geometry has not been demonstrated in detail. We have conducted 2.5-D MHD simulations in a dipole coordinate system that are suited to model high-m ULF waves with high grid resolution. To investigate the time-dependent behavior of local wave fields, we impose fundamental and second harmonic standing poloidal Alfven waves with different azimuthal wave number and follow their evolution in time at different locations. Our results show that the wave energy is initially poloidal and asymptotically transferred to the toroidal mode energy. Such transit time is dependent on the azimuthal wave number; the poloidal mode remains for a longer period of time when the wave has larger mode number. Although our results agree with the tendency from previous theoretical studies that the poloidal mode with higher azimuthal wave number has longer lifetime than that with lower wave number, it is shown that the transit time in dipole geometry is much shorter than that from box models. It suggests that the observations of prolonged poloidal mode waves are likely due to the continuous excitation via wave-particle interaction.

Polarization Characteristics and Depolarization Processes of Zebra Pattern in Type IV Solar Radio Bursts

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Abstract

Zebra pattern (ZP) is one of the spectral fine structures superimposed on the broadband type IV continuum, which has a characteristic spectral pattern with a number of parallel drifting stripes. Since these spectral fine structures reflect their emission mechanisms, we can obtain information from their characteristics about physical processes such as particle acceleration, excitation of electrostatic waves and their conversion to electromagnetic waves. Polarization of emission is important to know its emission mechanism. However, how these structures are generated is yet to be solved. In this study, we aim to reveal the generation mechanism of ZP by investigating their polarization characteristics.

In Kaneda et al. (2015, ApJL), we analyzed polarization characteristics of a ZP event and suggested from its frequency dependence that the ZP was originally generated polarized in the O-mode and was partly converted into the X-mode near the emission source. In order to examine these results, we analyzed totally 21 ZP events observed with AMATERAS, a solar radio telescope developed by Tohoku University in the frequency range of 100-500 MHz (Iwai et al., 2012). The analysis was made focused on three aspects: degree of circular polarization, temporal delay between the two polarization components and the wave mode of emission. We derived these three parameters using highly resolved spectral data from AMATERAS. As a result, we found the following characteristics; degree of polarization in the range of 5-70%, temporal delay of 0-70 ms and the dominance of O-mode emission (14 in 21 events), and that these characteristics of ZP were rather different from event to event. Furthermore, we found the positive correlation (R=0.66) between the degree of polarization and the delay. The dispersive character and the positive correlation between the degree of polarization and the delay implies the difference in physical mechanisms at a certain stage of the generation of ZP emission. Based on the obtained results, possible generation mechanisms of ZP will be discussed.

X-ray observation of shocks within the plasma in clusters of galaxies

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Abstract

A cluster of galaxies hosts up to thousands of galaxies trapped in a dark matter halo with a size of Mpc and total mass reaching 10^{14-15} times Solar mass. In its gravitational well, a large amount of plasma heated up to a temperature of several keV is trapped and emits X-rays via thermal process. With the evolution of large-scale structure of Universe, clusters of galaxies grow up by attracting one another and merging together. In these events, shocks with low Mach numbers (M~1-5) are produced in the plasma, and convert the huge gravitational energy into plasma thermal energy, and non-thermal energies such as particle acceleration and magnetic field amplification.

With recent X-ray observations, we found that the cluster candidate catalogued as CIZA J1358.9-4750, which has been poorly studied because of its location near the Galactic plane, is a textbook-case of a merging together pair, exhibiting various plasma physical phenomena activated by low-Mach-number shocks. This object consists of two X-ray clusters of galaxies separated by 1.2 Mpc. The two X-ray peaks are connected by an X-ray bright region, which can be a signature of their interaction. We analyzed the X-ray surface brightness with Chandra, which has superior spatial resolution, and discovered for the first time a pair of parallel brightness jumps that run perpendicular to the axis connecting the two clusters. We also studied the temperature distribution of this system, with the Japanese X-ray satellite Suzaku which has high spectroscopy performance. Then, the two closer cores were observed to have a temperature of 4.6±0.2 keV and 5.6±0.2 keV, whereas the region between the two Chandra-detected jumps to have a significantly higher temperature of 9.2±1.6 keV. The positional coincidence between the brightness jumps and the temperature increase allows us to interpret these structures as a pair of shocks propagating in the opposite direction. Since the shock fronts are vertical to the merging axis, the two clusters are suggested to have similar masses, and are in the course of an almost head-on collision. Compared to previously known shocks in merging clusters, the shocks we discovered are located in a region with a higher plasma density, and hence have a much higher brightness. As a result, we were able to derive the Mach number accurately as M=1.3±0.2, from the temperature transition and the Rankine-Hugoniot equations. From this Mach number, together with the sound velocity estimated from the unshocked temperature and symmetry assumption, the shocks propagation velocity is calculated to be 1200 km/s each. Further considering the separation between the two shocks, we conclude that they were formed only 70 Myr ago, which is very young compared to the cluster merging timescale (several Gyr). In contrast, assuming only the Coulomb scattering, the proton-to-electron heat transfer is calculated to take place on a much longer time scale of τ_c=210 Myr. Therefore, the electron heating is suggested to be taking place ~3 times faster than in the classical view.

The Role of Diffusivity and Viscosity in Solar Plasma

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Abstract

For diffusive and viscous plasma, the dispersion relation is applied for the North Polar Coronal Hole, where we assumed the angular frequency w to be a real quantity and the wave number k as a complex quantity. For ω we have chosen three values for τ. For each value of τ, we considered three situations: (i) where $\nu = 0$, (ii) where $\eta = 0$ and (iii) where both the diffusivity and viscosity are present. For the cases (i) and (ii), we get two solutions, $+(kr + iki)$ and $-(kr + iki)$. But for the case (iii), we get two pairs of solutions, $+(kr1 + iki1)$ & $-(kr1 + iki1)$ and $+(kr2 + iki2)$ & $-(kr2 + iki2)$. These two pairs correspond to the fast-mode and slow-mode waves.

Gyro-kinetic Study of Residual Zonal Flow for Slowing down Distribution Function

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Abstract

In toroidal plasma, zonal flow in bi-normal direction doesn't fully decay by collisionless process but remains with specific ratio of an initial level. This flow is called "Residual zonal flow" [1]. Since the residual flow regulates particle & heat transport in tokamak, it is important to know the exact level depending on its wavelength. In a burning plasma, fusion reaction produces fast alpha particles with an energy about 3.5 MeV. In the previous works, residual zonal flow level (and also zonal flow itself) is calculated in the Maxwellian equilibrium [1,2,3]. However, for alpha particle, the equilibrium distribution function is different from the Maxwellian distribution. In this study, we calculate the residual zonal flow level for slowing down distribution function. We use modern gyro-kinetic pull-back transformation method for residual zonal flow calculation [3]. The results of alpha particle contribution are compared with those obtained with the equivalent Maxwellian distribution function.

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Observation of Azimuthal Doppler Effect by Optical Vortex

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We have been developing a novel spectroscopic method to measure particle flow velocity using a Laguerre-Gaussian (LG) mode laser beam, which is called as an *optical vortex*. In contrast to a Hermite-Gaussian (HG) mode laser beam, which has planar phase fronts perpendicular to the beam axis, the optical vortex has helical phase fronts around the beam axis and an on-axis singularity. The wave vector of the optical vortex has a finite azimuthal component depending on the spatial structure of the phase. When the optical vortex is used in laser absorption spectroscopy measurement, the main terms of the Doppler shift in frequency is given by

$$\delta_{LG} \approx -kV_z - \left(\frac{m}{r}\right)V_\phi, \qquad (1)$$

where k, m, r, V_z, V_ϕ are the wave number, the topological charge characterizing the helical structure of the phase, the distance from the beam axis, the velocity components of a moving atom in the beam axis direction and that in the azimuthal direction, respectively [1]. The second term in the right-hand side of eq. (1) shows the contribution of the Doppler shift in the azimuthal direction, which depends on both the topological charge "m" and the distance from the beam axis "r". Therefore we can evaluate the particle velocity component perpendicular to the laser beam from this additional azimuthal Doppler shift.

The experiment to observe the azimuthal Doppler effect was carried out with the high density plasma experiment (HYPER-I) device at NIFS [2]. The plasma was generated by electron cyclotron resonance (ECR) heating with the microwave power of 40W and the Ar gas pressure of 10mTorr. The optical vortex was generated with the holographic method using a spatial light modulator (SLM). In order to evaluate the azimuthal Doppler shift of the absorption spectra of metastable argon neutrals in the plasma, laser absorption spectroscopy experiments were performed. The two-dimensional profile of the beam intensity transmitted through the plasma was measured by a beam profiler with a high spatial resolution. 1100 frames of two-dimensional data were obtained during the frequency sweeping from which the absorption spectra were reconstructed. The Doppler shifts of the absorption spectra were evaluated at points on the circumference of circles with three different radii. The results obtained in this experiment are summarized as follows:

i) The frequency shift of absorption spectra on the circumference of a circle centered at the singular point shows a sinusoidal dependence.
ii) The frequency shift decreases with the distance from the singular point.
iii) The sign of the frequency shift changes by changing the sign of the topological charge.

These experimental results are qualitatively consistent with the azimuthal Doppler effect of the optical vortex given by eq. (1). This is a promising achievement, and our next work is to calibrate the absolute particle flow velocity.

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

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Abstract

Magnetic reconnection is a process of changing the connectivity of magnetic field lines, and thought to play a core role in explosive energy conversion of solar flares. According to the Sweet-Parker theory, it is, however, difficult to conduct magnetic reconnection efficiently in highly conductive plasma of the solar corona. Petschek proposed another reconnection theory, in which small magnetic diffusion region realizes efficient reconnection with the energy conversion occurring in slow mode MHD shocks. However, recent numerical simulations suggest that Petschek reconnection is not stable in a system with spatially uniform resistivity. Some mechanism such as anomalous resistivity or kinetic physics is needed to sustain the localized diffusion region. It is, therefor, not clear yet how fast reconnection realizes in the actual parameter of the solar corona.

In order to answer to this question, we perform resistive 2D MHD simulation in a large system with a high spatial resolution, and find that slow mode MHD shocks predicted by Petschek spontaneously form even under a uniform resistivity (Shibayama et al. 2015, PoP). In this process, fast motion of large plasmoids in the current sheet play a role of localizing the diffusion region, and slow mode shocks form in front of the moving plasmoids. These plasmoids enhance magnetic reconnection intermittently and repeatedly. As a result, the reconnection rate increases up to 0.02, which is high enough to explain the time-scale of solar flares. Furthermore, our simulation suggests that the obtained reconnection rate doesn't depend on the Lundquist number. This is due to a similarity in the evolution of plasmoid.

Reference : Shibayama et al., Physics of Plasmas, 22, 100706 (2015)

Importance of Richtmyer-Meshkov Instability on measurements of Cosmic-Ray acceleration efficiency at Supernova Remnants

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Abstract

Using three-dimensional (3D) magnetohydrodynamics (MHD) simulations, we show that the efficiency of cosmic-ray (CR) acceleration in supernova remnants (SNRs) is over-predicted if it could be estimated based on proper motion measurements of Balmer filaments in combination with shock-jump conditions.

The CR acceleration efficiency at the SNR has been widely discussed, which seems to be ubiquitously so high that back reaction of CRs onto background shock structure is significant, with assuming that SNRs shock is plane parallel.

The role of the Richtmyer-Meshkov Instability (RMI) has recently been studied using MHD simulations that have shown that the forward shock of SNRs is rippled due to the interaction with interstellar medium, which has Kolmogorov-like density power spectrum. The kinetic energy of the shock wave is transferred into that of downstream turbulence as well as thermal energy that is related to the shock velocity component normal to the shock surface.

Our synthetic observation shows that the CR acceleration efficiency is overestimated by 10-40% despite of no CR acceleration. Furthermore, our simple analytical argument gives upper and lower bounds of apparent CR production efficiency, which is roughly consistent with our numerical results.

A Stochastic Acceleration Model of Radio Emission from Pulsar Wind Nebulae

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Abstract

Pulsar wind nebulae are a kind of supernova remnants (SNRs) shines from radio through TeV gamma-rays. The broadband emission is well described by non-thermal emissions (synchrotron radiation and inverse Compton scattering) from accelerated electrons and positrons injected from their central pulsars. However, the difference of spectral indices at radio and X-rays are not reproduced by the standard shock particle acceleration and cooling processes, and then, for example, the broken power-law spectrum for the particle energy distribution at the injection has been groundlessly adopted.

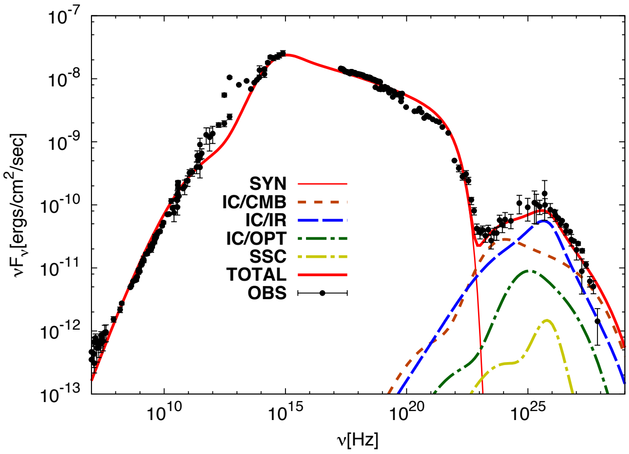

Figure 1. The broadband emission from the Crab Nebula. The Black points are observations. Synchrotron radiation reproduces the spectrum of < 10^{23}Hz and the inverse Compton scattering off the synchrotron radiation is dominate > 10^{23}Hz. The feature around infrared (~10^{13}Hz) is dominated by the blackbody radiation from the dust in the Crab Nebula, which is not added in this figure.

Here, we propose a possible resolution for the particle distribution; the radio emitting particles are not accelerated at the pulsar wind termination shock but are stochastically accelerated by turbulence inside PWNe. The turbulence may be induced by the interaction of the pulsar wind with the supernova ejecta. We upgrade our past one-zone spectral evolution model [Tanaka & Takahara, ApJ, 715, 1248 (2010)] including the stochastic acceleration and apply to the Crab Nebula. We consider the both continuous and impulsive injections of particles to the stochastic acceleration process. Figure 1 shows the calculated spectrum of the Crab Nebula from the particle spectrum in Figure 2. Our stochastic acceleration model reproduces the radio emission in the Crab Nebula. Figure 2 is the case for the continuous injection of the particle and the turbulent of Kolmogorov-like spectrum. The case of the impulsive injection also reproduces the spectrum but the decaying turbulence and also the very hard turbulent spectrum are required. Future radio observations distinguish the models.

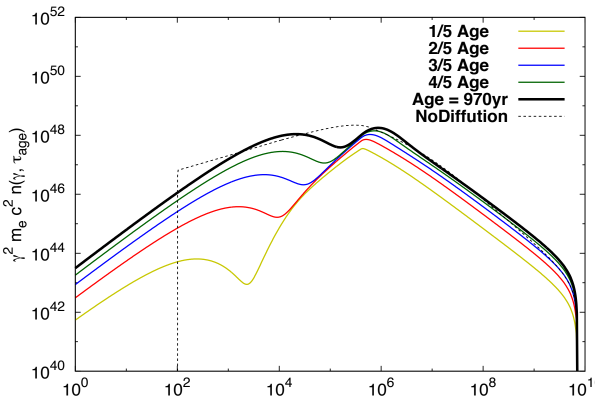

Figure 2. The evolution of the particle energy distribution inside the Crab Nebula. The particles of gamma > 10^6 accelerated at shock of the pulsar wind. For the particles of gamma < 10^6, we consider the stochastic acceleration of particles mixed from supernova ejecta.

Numerical solutions of Neutrino-Dominated Accretion Flows with a Non-Zero Torque Boundary Condition and its applications in Gamma-ray Bursts

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Abstract

A stellar mass black hole (BH) surrounded by a neutrino-dominated accretion flow (NDAF) is widely considered as the central engine of gamma-ray bursts (GRBs). Previous studies on NDAF have been based on the assumption of “no torque” boundary condition, which is however invalid when the disk is magnetized. Recent general relativistic magnetohydrodynamic (GRMHD) simulations on magnetized disk show there is a significant magnetic stress at the inner edge. In this paper, we revise the NDAF model by introducing non-zero boundary stresses and general relativistic corrections. We present a numerical solution for such non-zero torque NDAF model. Their properties are significantly changed due to this non-zero boundary torque. As a consequence, we find that: (1) non-zero torque NDAF can account for those bright and powerful GRBs, which are hard to interpret with previous NDAF; (2) the variability of the prompt emission and the steep decay phase in the early X-ray afterglow are explained by the viscous instability in NDAF; (3) the strength of the gravitational waves radiated by a possible processing accretion disk is slightly enhanced due to the change of the material distribution caused by the existence of the magnetic torque.

Numerical investigation of slow-mode shock waves in 1D simulations of thin current layer decay.

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Abstract

In this study we investigate one-dimensional decay of a thin plain current sheet which is perturbed by a weak magnetic field normal to the current sheet. Results of 1D Magnetohydrodynamic (MHD) and Particle-in-Cell (PIC) simulations are compared to the analytical MHD solution based on Rankine-Hugoniot relations. Such 1D formulation is suitable for studying dynamics of a single reconnected flux tube far from the diffusion region and resolves the shock waves generated by magnetic reconnection. MHD simulations are found to be in a good agreement with analytical solution. PIC simulations show the presence of pick up process in the exhaust which leads to mostly perpendicular acceleration of ions in the outflow region, with mostly parallel acceleration of ions at the edge of the exhaust region. Antiparallel case sees the formation of a wave train which we interpret as a slow mode shock wave. For guide field case (equal guide field/antiparallel components), the reconnection layer is a combination of Alfven discontinuity and slow mode shock. In antiparallel and weak guide-field case, the firehose instability is found to perturb the exhaust layer.

Radio emission processes and magnetic field measurement of an M-class flare on August 27 2015

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Abstract

In order to understand the radiation and particle acceleration processes during solar flares, we analyze a typical M-class flare observed on 2015 August 27. The radio light curves of this flare as observed by Nobeyama radio polarimeter (NoRP) and Nobeyama radio heliograph (NoRH) have two distinct components: an impulsive and a gradual component with the latter well correlated with the GOES SXR light curves. NoRH images show that the impulsive component is associated with a compact region with a high brightness temperature (>4.5e5K at 17GHz). The gradual component is mainly associated with an extended low-brightness temperature region. We show that the hot plasma responsible for the GOES SXR emission can reproduce the gradual component of the radio emission via the bremsstrahlung (free-free emission) process. Two patches of the extended gradual radio emission region show strong and variable polarization with opposite signs, which can be used to measure the magnetic field component along the line-of-sight. The field associated with a foot point is comparable to the photosphere field observed by the SDO/HMI. The magnetic field associated with the corona loop is much weaker, which is consistent with the B field structure in the solar atmosphere. Although the impulsive radio component does not show strong polarization, the high-brightness temperature suggests that it is produced by high energy electrons via the gyro-synchrotron process. The lack of radio polarization may be attributed to the compactness of the source, which is confirmed by RHESSI imaging observations up to 50 keV. These analyses also show that the gyro-synchrotron process produces a prominent pulse followed by a gradual decaying tail in the radio band. The above results and interpretations is further supported by the Hinode XRT and SDO/AIA imaging observations of the magnetic field structure during the flare.

Phase relation between Density and Potential fluctuations in Streamer

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Abstract

Streamer is a self-bunching of drift wave fluctuations in the azimuthal direction discovered in the linear plasma device, PANTA (Plasma Assembly for Nonlinear Turbulence Analysis). The streamer enhances radial transport and thus its formation is one of the important fundamental plasma turbulence processes [1]. Experimental results in PANTA have shown that the 3-wave coupling between drift-wave fluctuations and “mediator”, which is a wave propagating in the ion diamagnetic direction with azimuthal mode number of 1, plays an important role to form the streamer [2]. In the recent experiment, operational conditions in which the streamer is formed are clarified in PANTA. The streamer is formed in the condition (magnetic field (B) is 0.09 T, n_{e0} = 5×10^{18} m^{-3}, T_{e0} = 3 eV and neutral gas pressure of argon (P_n) is 1 mTorr). The B and P_n are the control parameter of turbulence state in the PANTA plasma and thus scanned systematically [3]. Streamer disappeared when the magnetic field/neutral pressure is above/below the critical values (B > 0.12 T, B < 0.08 T, P_n < 0.4 mTorr, P_n > 1.2 mTorr). In other words, there is a parameter window to form the streamer in the PANTA plasma. The changes of Fourier spectrum of turbulence are observed around the critical conditions. The role of the "mediator" is discussed by the bi-spectrum analysis. Fluctuation induced particle flux changes with magnetic field. Phase relation between density and potential fluctuations is also discussed.

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