Electron dynamics surrounding the X-line in magnetopause-type asymmetric reconnection

*Seiji Zenitani[1], Hiroshi Hasegawa[2], Tsugunobu Nagai[3]

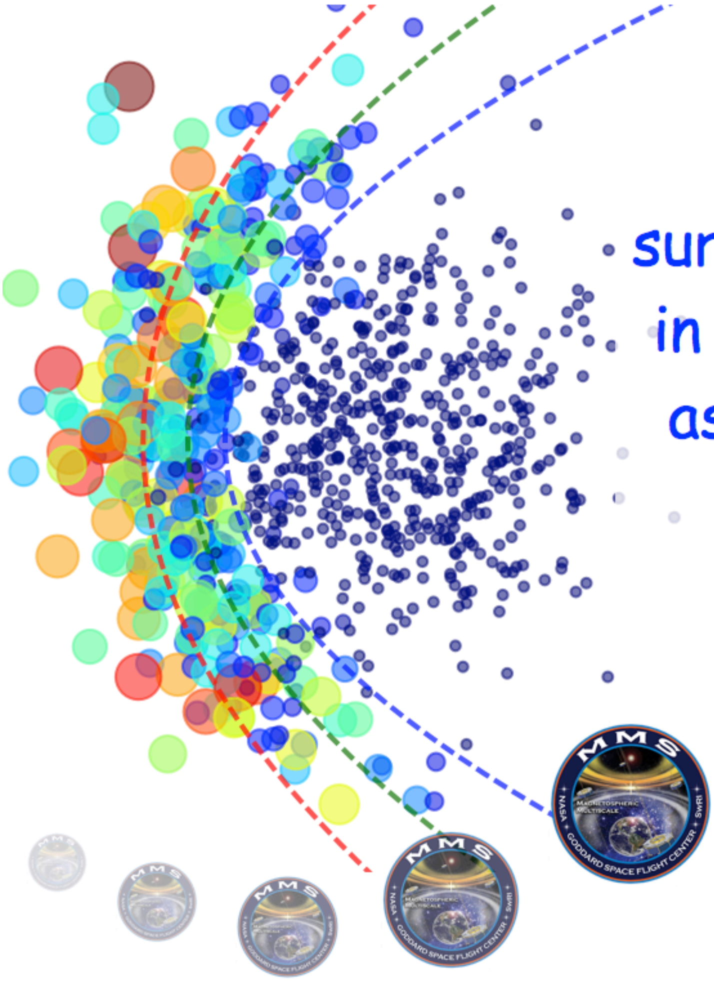
1. NAOJ National Astronomical Observatory of Japan, 2. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3. Department of Earth and Planetary Sciences, Tokyo Institute of Technology

Electron dynamics surrounding the X-line in magnetopause-type asymmetric reconnection is investigated using a two-dimensional particle-in-cell (PIC) simulation. We study electron properties of three characteristic regions in the vicinity of the X-line. The fluid properties, velocity distribution functions (VDFs), and orbits are studied and cross-compared. In the low-beta side of the X-line, the normal electric field enhances the electron meandering motion from the high-beta side. The motion leads to a crescent-shaped component in the electron VDF, in agreement with recent studies. In the high-beta side of the X-line, the magnetic field line is highly stretched in the third dimension. As a result, its curvature radius is comparable with a typical electron Larmor radius. The electron motion becomes chaotic, and therefore the electron idealness is no longer expected to hold. Around the middle of the outflow regions, the electron nonidealness is coincident with the region of the nonadiabatic motion.

Reference:

- Zenitani, S., H. Hasegawa, and T. Nagai, submitted to *J. Geophys. Res.* (MMS special issue)

Keywords: magnetic reconnection, magnetopause, particle dynamics



Electron dynamics surrounding the X-line in magnetopause-type asymmetric magnetic reconnection

Seiji ZENITANI

with H. Hasegawa, T. Nagai

Triggering fast tearing: from MHD to kinetic effects

*Marco C M Velli[1], Fulvia Pucci[2], Anna Tenerani[1]

1. University of California Los Angeles, 2. NIFS-Princeton

One of the main questions about magnetic reconnection concerns how this mechanism may account for fast magnetic energy conversion to kinetic and thermal energies, resulting in explosive events in astrophysical and laboratory plasmas. Over the past decade progress has been made on the initiation of fast reconnection via the plasmoid instability and what has been called ``ideal" tearing, which sets in once current sheets thin to a critical aspect ratio: as shown by Pucci and Velli (2014) once the thickness reaches a scaling a/L ~ S^-1/3, the time scale for the instability to develop becomes of the order of the Alfvén time and independent of the Lundquist number. However, given the large values of the Lundquist number in natural plasmas, this transition might occur for thicknesses of the inner, singular layer, approaching the ion inertial length. When this occurs, Hall currents produce a three-dimensional quadrupole structure of magnetic field, and the dispersive waves introduced by the Hall effect accelerate the instability. Here we present a linear study showing how an "ideal tearing mode" is achieved when Hall effects are taken into account, including scaling laws for sheet aspect ratios and growth rates. We show that for an appropriate scaling of the aspect ratio in the parameter space (S, d_i/L), the instability develops on ideal timescales and the associated growth rate does not depend on the parameters, suggesting a revision of the phase diagrams describing different regimes for magnetic reconnection in space and laboratory plasmas.

Keywords: Plasma, Magnetic Reconnection, Heliosphere

Macroscopic quasilinear kinetic model for electrons and protons instabilities in homogeneous and in inhomogeneous solar wind plasmas

*Muhammad Sarfraz[1], Peter H. Yoon[2,3]

1. Department of Physics, GC University Lahore, Katchery Road, Lahore 54000, Pakistan, 2. University of Maryland, College Park, Maryland 20742, USA, 3. School of Space Research, Kyung Hee University, Yongin, Gyeonggi 446-701, Korea

Solar wind species like electrons, protons and alpha particles are detected to possess temperature anisotropies with respect to ambient magnetic field. Microinstabilities driven by these anisotropies are responsible for an upper check of higher values of temperatures at different radial distances of solar wind. For a homogeneous and non-collisional medium, we employed a macroscopic quasilinear kinetic model to display asymptotic variations and saturations of temperature anisotropies and wave energy densities for electromagnetic electron cyclotron (EMEC) and electron firehose (EFH) instabilities. A bi-Maxwellian form of particles distribution adopted all the time except that temperatures may vary in time t. We showed that, in ($\beta_{\parallel}$, $T_{\perp}/T_{\parallel}$) phase space, the saturations stages of anisotropies associated with core and halo electrons lined up on their marginal stability curves for EMEC instability. For case of EFH instability, the electrons and protons dynamics saturated at firehose and proton cyclotron marginal stability curves, respectively. Next, we interpreted the outstanding issue that most of observed proton data resides in nearly isotropic state in phase space. Here, in quasilinear frame-work of inhomogeneous solar wind system, we formulated a set of self-consistent quasilinear equations to show a dynamical variations of temperatures with spatial distributions. On choice of different initial parameters, we showed that, interplay of electron and proton instabilities provided an counter-balancing force to slow down the protons away from marginal stability states. Our present approach may eventually be incorporated in global-kinetic models of the solar wind electrons and ions.

Keywords: solar wind, instabilities

Propertime Path Integral for Relativistic Diffusion

*Tadas Nakamura[1]

1. Fukui Prefectural University

It is well known that there exist infinite speed components in a solution of a simple diffusion equation with the first order time derivative. This does not cause serious problems if that part is small enough in non-relativistic regime, however, it may cause spurious growing solution in relativity. The reason is that propagation faster than the speed of light means backward propagation in time in some reference frame, and time reversal diffusion equations may have growing component.

This difficulty is inevitable for equations with first order time derivative, and hence, equations with second order have been proposed by Israel and Stewart (1970) for relativistic thermodynamics. Theories in this line are called "causal thermodynamics" and have been extensively studied since then. Second or higher order time derivative can make the propagation speed under a certain finite value to avoid the non-causal propagation. However, these higher order terms are not based on some physical reasoning of underlying mechanism; they are mathematical device to avoid infinite speed. Solutions of these equations do not violate causality, but it does not mean they are physically reasonable. For example, when we apply the theory of Israel and Stewart to thermal diffusion, we obtain so called telegraph equation. A telegraph equation is reduced to wave equation in high speed (highly relativistic) limit; it does not violate causality but wave equation does not represent diffusion.

A method proposed here is to solve the evolution of the particle distribution function, which is defined on the spacetime (x,t), along the proper time. The evolution cannot be formulated in the form of diffusion equation along propertime because the direction of time is forward only. To avoid this problem the method of path integrals with the constraint of energy shell is introduced in the present study.

Keywords: Relativistic Diffusion, Path Integral, Proper time

Cyclic self-reformation of perpendicular shocks in two-dimensional particle-in-cell simulation

*Takayuki Umeda[1], Yuki Daicho[1]

1. Institute for Space-Earth Environmental Research, Nagoya University

The cyclic self-reformation of perpendicular collisionless shocks was first identified in one-dimensional (1D) kinetic particle-in-cell simulations. In early studies, the reformation was defined as the cyclic accumulation and release of ions. The release ions toward upstream (ion reflection) takes place periodically at the ion gyro period of the downstream, which forms the shock foot region. Later, the cyclic self-reformation of perpendicular shocks was also identified in two-dimensional (2D) full particle-in-cell simulations with a simulation domain shorter than the ion inertial length in the shock tangential direction. However, some of recent 2D full particle-in-cell simulations with a large simulation domain argued against the evidence of the cyclic self-reformation of perpendicular shocks due to rippled structures at the shock front. In the previous studies, the cyclic self-reformation was identified from the cyclic oscillation of the magnetic field at overshoot, since the magnetic field and the ion density are well correlated in 1D simulations and 2D simulations with a small simulation domain. In the present study, we analyze ion particle data obtained from large-scale 2D full particle-in-cell simulations with different ion-to-electron mass ratio, and discuss the effect of the mass ratio to the evidence of the cyclic self-reformation of perpendicular shocks.

Keywords: collisonless shock wave, particle-in-cell simulation

Anomalous convection diffusion model of cosmic rays

*Tohru Hada[1]

1. Earth System Science and Technology, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Transport of cosmic rays (energetic particles) in a turbulence field remains to be an important issue, both from astrophysical and nonlinear science points of view. In particular, it is known that the transport in a plasma with large amplitude MHD turbulence can exhibit properties of non-gaussian statistics. A natural formalism to model such anomalous transport processes is the fractional diffusion equation, in which the time and/or spatial derivative contain fractional differentiation operators. After briefly introducing the idea of the fractional differentiation/integration operators and numerical methods, we discuss the diffusive shock acceleration process by solving numerically the fractional convection diffusion equation. The results will be compared with those obtained by test particle simulations using sub- and super- diffusive particles. Possible applications of the present model to other high-energy astrophysical phenomena will be discussed as well.

Keywords: cosmic rays, diffusion

MHD relaxation with flow inside a sphere

*Kohei Yamamoto[1], Akira Kageyama[1]

1. Kobe University

We have studied MHD (magnetohydrodynamics) relaxation processes inside a spherical vessel with a perfectly conducting boundary. According to the classical theory of the MHD relaxation--Woltjer-Taylor theory--the relaxed state is force-free and its magnetic field configuration is called spheromak. The formation and stability of spheromaks were not only confirmed by plasma experiments, but also used in various experiments such as magnetic reconnections. The Woltjer-Taylor theory assumes, however, that the flow energy in the relaxed state is negligibly small. Here in this study, we investigate MHD relaxations with flow in a ball region by computer simulation. We have numerically solved compressible MHD equations in all ball region including the origin ($r=0$) by making use of recently developed Yin-Yang-Zhong grid [Hayashi & Kageyama, JCP, 2016]. Since we can perform high resolution simulations, incorporated viscosity is much lower than those in previous MHD relaxation simulations. Since general spheromak solutions are composed of the spherical bessel function (in the radial direction r) and the spherical harmonics (in the latitude θ and longitude ϕ directions), they are characterized by eigenvalue n (in r) and l and m (in θ and ϕ). As for the initial conditions, we employed higher modes $l,m>1$ with weak perturbations. Pressure and mass density were uniform. The flow velocity is zero. Due to the instability of the spheromaks with higher modes, flows are driven when simulations start. After some transient time, the flows arrives at quasi-stationary states that retain in the dissipation time (i.e., long) scale, because the simulated viscosity is low enough. Although the flow energies E_K in the quasi-steady states are relatively small compared with the magnetic energies E_M ($E_K/E_M=O(10^{-3})$), the existence of the flow is not negligible. We have found, in particular, the quasi-steady states are not force-free; the electric current and the magnetic field are not in parallel.

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

Simulation study of transition from steady Petschek reconnection to dynamical Petschek reconnection

*yonaha hiroyasu[1], Kanya Kusano[1], Takuya Shibayama[1]

1. Institute for Space-Earth Environmental Research

Magnetic reconnection is a process of converting magnetic energy into thermal energy and kinetic energy. However, classical steady reconnection model (Sweet-Parker model) cannot explain the high speed of reconnection (reconnection rate) observed in the solar corona. Fast magnetic reconnection model has developed to solve this problem. Although the steady Petschek model reconnection can explain the fast reconnection, it requires the localized anomalous resistivity in current sheet. On the other hand, when the resistivity is uniform in space, so-called plasmoid reconnection occurs as the result of instability of a thin current sheet, and reconnection is accelerated. Recently, Shibayama et al. (2015) showed that the plasmoid-type reconnection in uniform resistivity can produce a new-type of fast reconnection with non-steady slow mode shocks, called “dynamical Petschek reconnection.” In this study we have performed two-dimensional magnetohydrodynamics (MHD) simulation to investigate a holistic picture from the steady Petschek reconnection to the dynamic Petschek reconnection. We focused on the dependency of reconnection on the intensity of anomalous resistivity localized in space. As a result of that, we found that there is an oscillating Petschek-type reconnection between the steady Petschek reconnection and the Dynamical Petschek reconnection. We analyze magnetic field in the oscillating Petschek reconnection by decomposing two components of the different parities for mirror symmetry with respective to the current sheet, and discuss the picture of transition from the steady Petschek reconnection to the dynamical Petschek reconnection.

Keywords: magnetic reconnection, Petschek reconnection, simulation, slow shock

Persistence of Precursor Waves in Two-dimensional Relativistic Shocks

*Masanori Iwamoto[1], Takanobu Amano[1], Masahiro Hoshino[1], Yosuke Matsumoto[2]

1. Graduate School of Science, The University of Tokyo, 2. Graduate School of Science, Chiba University

The origin of high energy cosmic rays (>$10^{15.5}$eV) has not been fully understood, and the acceleration mechanism is still controversial. Recently Chen et al. (PRL, 2002) proposed the particle acceleration by the large-amplitude Alfvén waves at gamma-ray bursts as a model of the generation of ultra-high energy cosmic rays (>10^{18}eV), based on the wakefield acceleration mechanism which was initially proposed by Tajima and Dowson (PRL, 1979) in the context of laser-plasma interactions in the laboratory. The wakefield acceleration in laboratory is induced by an intense laser pulse (or transverse electromagnetic waves) propagating in a plasma. The mechanism may also operate in relativistic shocks in nature because it is known that large-amplitude electromagnetic precursor waves are excited by synchrotron maser instability driven by the particles reflected off the shock-compressed magnetic field in relativistic shocks (Hoshino and Arons, PoP, 1991). In fact, Hoshino (ApJ, 2008) demonstrated the generation of the non-thermal electrons by the wakefield induced by the ponderomotive force of the electromagnetic precursor waves in relativistic magnetized shocks by means of one-dimensional Particle-In-Cell (PIC) simulation.

The wakefield acceleration has been discussed only in one-dimensional shocks so far. It is not known very well whether or not the same mechanism can operate in more realistic multi-dimensional systems. In multi-dimensional shocks, the inhomogeneity may appear in the transverse direction of the shock, and the waves emitted from different positions at the shock may overlap with each other. Consequently, the wave coherency which is essential for the ponderomotive force may be broken and the wakefield acceleration may not occur. Another possible problem is the competition between the synchrotron maser and Weibel instability. The Weibel instability occurs near the shock front due to effective temperature anisotropy generated by the reflected particles in the shock transition region. Since both the instabilities are excited from the same free energy source, the efficiency of the precursor wave emission may be affected or even completely shut off.

To solve these subjects, we investigated in this study the properties of the precursor wave emission in relativistic shocks by using the two-dimensional PIC simulation. Since the growth rate of the synchrotron maser instability at high harmonics are significantly large, the precursor waves are high-frequency electromagnetic waves and thus may easily be damped. Therefore, our simulations were performed with high spatial resolution to resolve the precursor waves well. We observed that large-amplitude, coherent precursor waves were excited in two-dimensional shocks, and found that the amplitude of the precursor waves was large enough to induce the wakefield acceleration even if the Weibel instability occurs. In addition, the amplitude of the precursor wave remains finite and has reached a quasi-steady state by the end of the simulation. In this presentation, we quantitatively evaluate the efficiency of the precursor wave emission in both one-dimensional and two-dimensional shocks, and then discuss the possibility of the wakefield acceleration model for the production of non-thermal electrons in an astrophysical shock.

Keywords: acceleration of particles, collisionless shock, cosmic rays

Verification of Super Massive Black Hole Binaries Discovered at the Center of Our Galaxy by Observations of Decameter Radio Wave Pulses

*Hiroshi Oya[1]

1. Department of Geophysics Graduate School for Science Tohoku University

1. Introduction Based on the observations of decameter radio wave pulses from the center part of our Galaxy by using ,mainly, decameter radio wave interferometer at Tohoku University, search for super massive black holes has currently been carried out starting from 1984. In 1999, it had tentatively reported that there were at least 23 black holes which could be origins of the decameter radio wave pulses. From 2016, new observations to verify the proposed black hole hypothesis were started and further development of the observations had been realized by introducing digital system to obtain the interferometer data. New analyses provide evolutional progress correcting the previous results of the present study.

2. Observations In 2016, observations of the decameter radio wave pulses had been made from February 2 to February 28, for non Galaxy center condition, and from March 15 to June 30 aiming at the Galaxy center. The utilized decameter long baseline interferometer at Tohoku University consist of three observation stations at Kawatabi, Zao and Yoneyama which provide three interferometer base lines with the length ranges from 44km to 83km. At each station, signals at 21.860MHz were observed and converted down to 1kHz with bandwidth of 500Hz which were sent to the Sendai station ,through the telemeter system. The signals at the backend of the telemetry system were converted into digital signals by AD converter with sampling rate of 3000 data points per sec.

3. FFT analyses and Confirmation by Simulation For the obtained digital data from each observation point of the interferometer system, interferometry correlation functions were calculated by digital computer to find interferometry fringe function to which the template fringe to detect the arrival directions of the signal were applied culculating the correlation. To these direction correlated data, FFT analyses are carried out so as to pick up the source signals of a few percent level compared with large background noises by averaging 6000 times trial of independent FFT operations. The results had definitely indicated that the purposing spectra are arriving from the center part of our Galaxy with allowance angle range of +-0.5 degree. The resulted spectra are characterized by two fundamental periods at 156.6sec corresponding to the source Gaa and 130.8 sec corresponding to Gab. These two fundamental spectra are associated with 2nd and 3ird harmonics; furthermore all spectra are associated with 3 to 5 sideband spectra both in the upper side and lower side of the principal spectra. All sidebands have a frequency gap of 1/2200 Hz :that is, all spectra are manifestation of the frequency modulation caused by orbital motions of Gaa and Gab with orbiting period of 2200sec.

4. Confirmation by FFT simulation Based on the characteristic parameters deduced by the FFT analyses, possible signals from spinning Gaa and Gab which are moving along two orbits with a common period of 2200sec with speeds respectively of 0.16c and 0.19c are constructed as simulation function to understand the observed FFT results: it is concluded that FFT results for this constructed function revealed coincidence with observation case. That is, current results in which 5 set of black hole binary have been proposed should be corrected so as to be one set of principal black hole binary consisting of

Gaa and Gab .

5. Box Car Analyses Accurate feature of the Gaa and Gab black hole binary system has been investigated applying period correlation analyses (Box Car analyses) to find pulse forms with search of the orbit period and orbiting speeds together. The results has indicated that orbiting period of Gaa and Gab is 2205 sec ; two black holes have two separated visible sources of radio wave as manifestation of curving effect of the ray paths due to the space rotation of the ergo-sphere.

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

Fast magnetic reconnection onset for different equilibrium configurations: from analytical results to 3D simulations

*Fulvia Pucci[1], Marco Velli [2], Ganapati Sahoo[3], Anna Tenerani[2], Luca Biferale[3]

1. National Institute for Fusion Science (NIFS), 2. UCLA , 3. UNITOV

We investigate the onset of fast magnetic reconnection starting from equilibrium configurations relevant for astrophysical as well as for laboratory plasmas, that differ from the simple Harris current sheet configuration. In particular we present an analytical as well as a numerical study of the linear instability for equilibrium magnetic fields which go to zero at the boundary of the domain and of a double current sheet system, the latter previously studied as a proxy for the m=1 kink mode in cylindrical plasma. We show how the "ideal" tearing trigger condition is changed by assuming such different equilibrium profiles. Finally we present results for incompressible 3D MHD simulations of a double current sheet, in triperiodic geometry. We examine and contrast the destabilization and transition to turbulence describing the evolution of the magnetic energy and dissipation, and possible application to heliospheric phenomena, in particular CME evolution and relaxation.

Keywords: plasma physics, space plasma, magnetic reconnection

High-order leapfrog scheme of the Vlasov-Ampère system for the electrostatic plasma

*Tsung-Che Tsai[1], Ling-Hsiao Lyu[2], Wen-Chieh Hsieh[2]

1. National Center for High-performance Computing, National Applied Research Laboratories, 2. Graduate Institute of Space Science, National Central University

The simulation result of Vlasov code has high signal-to-noise ratio, in comparison to PIC (particle-in-cell) code. In the past, due to the scarcity of computing power, most researchers use PIC code as a tool toward novel explorations and investigations. With the rapidly enhancement in computing power of supercomputers, the high resource-demanding Vlasov simulation of potency has become wildly adoptable and efficiently achievable. In this study, we adopt grid-base Eulerian solver, instead of the customary semi-Lagrangian method, to solve Vlasov-Ampère equations for electrostatic plasma. We use three-step high-order leapfrog scheme for the solutions of energy-conserving Vlasov-Ampère equations. We use fifth-order central finite difference method to calculate the first derivative in Vlasov equation along the real space. We use cubic spline method to calculate the first derivative and integration along velocity space in the Vlasov equation and Ampère law without magnetic field, respectively. We use forth-order leapfrog method for time stepping. Subsequently, we examine the correctness of grid-base Eulerian solver in solving Vlasov-Ampère equations for electrostatic plasma by linear Landau damping test.

Keywords: Vlasov simulation, electrostatic plasma

Evaluation of Numerical Properties of Constrained-Transport-Type Schemes for Hybrid Simulations

*Takanobu Amano[1]

1. Department of Earth and Planetary Science, University of Tokyo

Numerical simulations of space and astrophysical plasmas need an accurate method for solving Maxwell's equations. The divergence-free property of the magnetic field is the fundamental constraint in the system that must be satisfied in a numerical solution because otherwise, the simulation will become unstable. The Constrained-Transport (CT) scheme, which exactly preserves the discrete divergence-free property, has been quite successful in numerical Magnetohydrodynamics (MHD). In recent years, the CT scheme for Maxwell's equations has been ingeniously combined with an HLL-type (Harten-Lax-Van Leer) Riemann solver for the hydrodynamics part in a consistent fashion. The scheme known as the HLL-UCT shows excellent performance in numerical MHD as well as two-fluid plasma simulations.

It is straightforward to apply the same technique to kinetic Particle-in-Cell (PIC) type simulation method. However, the numerical properties of the scheme as applied to kinetic simulations are not known very well. In fact, artifacts arising from numerical noise inherent in the PIC method (which is absent in a grid-based fluid code) should carefully be analyzed.

In this study, we apply the HLL-UCT scheme to a quasi-neutral plasma hybrid code in which ions are treated as kinetic macroparticles whereas electrons are assumed to be a fluid. We found that naive application of HLL-UCT to a hybrid code may lead to artificial heating and/or cooling of ions, presumably because of excessive dissipation in the HLL-UCT scheme. We thus quantify the numerical artifact by extensive numerical experiments with varying mesh size, the number of particles per cell, plasma beta, etc. We found that the numerical heating/cooling may be explained by absorption (or dissipation) of spontaneous emission of waves arising from a discrete particle effect. Practical workarounds to minimize the numerical artifact for long time simulations will be discussed.

Keywords: Maxwell's equations, numerical simulation, plasmas

Designing high-order finite difference scheme for magnetohydrodynamics: shock capturing and divergence-free conditions.

*Takashi Minoshima[1], Takahiro Miyoshi[2]

1. Department of Mathematical Science and Advanced Technology, Japan Agency for Marine-Earth Science and Technology, 2. Graduate School of Science, Hiroshima University

Space and astrophysical plasmas are rich in dynamic phenomena such as convection, eruption, shock, accretion, and so on. Their macroscopic dynamics is well described by magnetohydrodynamics (MHD). Since the system of MHD equations are highly nonlinear, a numerical simulation is an indispensable tool to reveal its complicated physics.
The plasma is frequently associated with supersonic flows such as the coronal mass ejection, supernova, and jet, which yield various shocks and discontinuities. Furthermore, these flows are almost inviscid, thus will become turbulent. Reliable MHD simulations need to resolve these phenomena simultaneously, which is a contradictory issue for computational fluid dynamics and thus is challenging. Moreover, the MHD simulation should carefully handle errors of the divergence for magnetic field, which is not necessarily free in numerical simulations.
Many works have been devoted to develop exact or approximate Riemann solvers (upwind schemes) for (M)HD to accurately capture shocks and discontinuities. Nowadays, such shock capturing schemes are adopted as a standard method for MHD simulations (Kritsuk et al. 2011). On the other hand, various high-order interpolation techniques are proposed to improve the resolution of small scale structure (e.g., turbulence), and they can be incorporated into shock capturing schemes.
Shock capturing schemes are based on the finite volume method, which automatically satisfies the conservation laws but has a difficulty in achieving high order of accuracy in multi-dimension. The finite difference method is rather convenient for designing multidimensional high-order scheme. Conservative finite difference schemes have been proposed by approximating fluxes to high order, and succeeded in high resolution MHD simulations (Jiang et al. 1999; Mignone et al. 2010).
We consider another type of the conservative finite difference scheme for MHD, which interpolates physical variables to high order and utilize a variety of Riemann solvers to capture shocks. We also take special care of the divergence-free condition for magnetic field. Combination of the upwind scheme and the constrained transport (UCT) method, which satisfies divergence-free condition within machine accuracy without violating upwind property (via Riemann solvers), is thought to be a powerful strategy especially for low beta plasmas. We test various type of the UCT method. In this paper, we will present details of our code design and its performance, especially focusing on the comparison among different interpolation techniques, Riemann solvers, and UCT methods.

Keywords: MHD simulation, Numerical method

Study of anisotropic electrons distributed around the wake of an ionospheric sounding rocket by a 1D Vlasov-Poisson simulation

*Ken Endo[1], Atsushi Kumamoto[1], Yuto Katoh[1]

1. Department of Geophysics, Graduate School of Science, Tohoku University

Ionospheric sounding rockets travel in plasma at supersonic velocity with rarefied regions called 'plasma wakes'. In a rocket wake, plasma waves with frequencies near the upper hybrid resonance (UHR) frequency, plasma frequency, and Z-mode cutoff frequency in the wake are observed as reported by Yamamoto [PhD. thesis, Tohoku University, 2001]. From the results of the S-520-26 rocket experiment, Endo et al. [JGR, 2015] suggested that the waves observed in the wake were electrostatic waves such as electrostatic electron cyclotron harmonic (ESCH) waves and UHR mode waves because plasma waves with long wavelengths cannot be generated in a narrow region like the rocket wake. The intensities of these waves, as well as of whistler mode waves observed in the same experiment, had spin-phase dependence, which is different depending on kinds of plasma waves. These results indicate that there was inhomogeneous spatial distribution of hot electrons with some anisotropic velocity distribution functions around the rocket wake.

In order to investigate inhomogeneity of hot electrons around the rocket wake, we are now developing a Vlasov-Poisson code. In the simulation with this code, we can calculate wake filling process of ambient ions and electrons in one-dimensional space along the X-axis, which is parallel to the ambient magnetic field. The grid spacings of the space and of the velocity spaces of electrons and ions are $\Delta X = \lambda_D$ (λ_D: Debye length), $\Delta V_e = 0.1V_{the}$ (V_{the}: thermal velocity of electrons), and $\Delta V_i = 0.0025V_{the}$, respectively. The range of the space is $-600\lambda_D X 600\lambda_D$, and a void is set at $-25\lambda_D X 25\lambda_D$ at the initial time. The ranges of the velocity spaces of electrons and ions are $-10V_{the} V_e 10V_{the}$, and $-15V_{thi} V_i 15V_{thi}$ (V_{thi}: thermal velocity of ions), respectively. The time step Δt is $\Delta t=0.1\omega_p^{-1}$ (ω_p: plasma frequency). Accordingly, the CFL (Courant-Friedrichs-Lewy) condition, which should be satisfied to carry out numerical simulations stably, is $E/E_0 1$ ($E_0 = \lambda_D \omega_p^2 m_e / e$), where E is the electric field, m_e is the electron mass, and e is the elementary charge. The rational CIP method [Xiao et al., CPC, 1996] is applied to solve the Vlasov equations, and Fourier transform [Birdsall and Langton, Taylor & Francis Group, 2008] is used to obtain electric fields through the Poisson's equation. If we assume that the plasma is also flown in the y direction, the plasma distribution along the X-axis as a function of time can be understood as that as a function of distance in the y direction.

In our current code, electric oscillations whose amplitudes increase with time are observed outside the wake near the wake boundaries, which makes the CFL condition be unsatisfied at $t=469\Delta t$ (corresponding to 3.4 mm downstream). However, the calculation has to be proceeded until at least t˜$60000\Delta t$ because we are going to check the velocity distribution functions in the region including the tail of the wake (about 0.4 m downstream) to discuss plasma waves observed in the S-520-26 rocket experiment. Therefore, the electric oscillations must be damped such as by selectively and artificially attenuating the electric fields or by making the density gradients at the wake boundaries be shallower. Even in the calculation before $t=469\Delta t$ with our current code, we can see several hot electrons such as multi-stream electrons on the wake axis, and a single beam component outside the wake. The multi-stream electrons are considered to be composed of electrons periodically coming into the wake from the outside, and the single electron beam may be owing to the reflection of electrons by the polarized electric field at the wake boundaries.

In this presentation, we will describe the configuration and schemes of our simulation first, and then will show the calculation results. We will especially discuss the spatial distribution of anisotropic electrons and their generation process.

Keywords: wake, sounding rocket, Vlasov-Poisson simulation, velocity distribution function, ionosphere

Particle Simulations on Near-Spacecraft Plasma Perturbations in Polar Ionospheric Environment

*Yohei Miyake[1], Yukari Sasaki[2], Hideyuki Usui[2]

1. Education Center on Computational Science and Engineering, Kobe University, 2. Graduate School of System Informatics, Kobe University

This paper reports the international collaborative project on spacecraft-plasma interactions in the Polar Ionospheric environment, which is initiated by Kobe University and University of Oslo. It is widely known that plasma density irregularities with various spatial scales are generated frequently in the Ionospheric environment. A series of ICI rockets have been launched from Norway for studying such ionospheric phenomena. One of the outstanding issues regarding the rocket experiments is near-spacecraft plasma perturbations, possibly influencing the in-situ observations. We applied the 3-dimensional plasma particle simulations to the problem, in order to have better understanding of such processes.

Our preliminary results confirmed 1. rocket surface potential depending on an angle between the geomagnetic field and the rocket axis and 2. asymmetric wake structure due to strong magnetization of plasma electrons. We analyzed their associated electron dynamics around the rocket and found that electron motion creates a circular current center at the body, which may be attributed to the ExB drift as well as the diamagnetic effect. We have also started a numerical study on frequency spectra of potential fluctuations and their relevance to plasma wave modes near a spacecraft/rocket.

Keywords: Polar Ionospheric plasma, sounding rocket, spacecraft charging, wake, PIC simulation

Numerical Modeling of Plasma Wave Electric Field Effects on Spacecraft Charging

*Yohei Miyake[1], Takeshi Kiriyama[3], Yuto Katoh[2], Hideyuki Usui[3]

1. Education Center on Computational Science and Engineering, Kobe University, 2. Graduate School of Science, Tohoku University, 3. Graduate School of System Informatics, Kobe University

Based on the particle-in-cell (PIC) method, we numerically model the modulation of a spacecraft potential in the presence of time-varying electric fields of plasma waves. Recent observations by Van Allen Probes showed apparent spacecraft potential fluctuations associated with chorus wave detection [e.g., Malaspina et al., 2014], and a major physical factor of the effect was speculated as photoelectron-escape current modulations due to wave electric field. Although its dependencies on wave frequency and magnetic field strength have been examined experimentally [Wang et al., 2014a; 2014b], there are a number of remaining issues such as effects of wave polarization or configuration of spacecraft chassis and probes. In particular, in-space spacecraft potential measurements are conducted by seeing a potential difference between spacecraft chassis and electrostatic probes, and thus it is necessary to consider the difference of their responses to external wave electric fields.

In this paper, we perform plasma particle simulations to address such unresolved issues. Our original PIC simulation code EMSES has a capability of reproducing plasma wave excitation/propagation as well as spacecraft charging in a self-consistent manner. Meanwhile, such analysis with realistic physical parameters requires too large computational resources, because the typical spatial scale of plasma wave lengths is much greater than that of the near-spacecraft environment. Thus, we propose another modeling of the phenomena by applying a spatially-uniform and time-varying electric field to the whole simulation domain as an external force term. We have confirmed that this model can reproduce the photoelectron-driven spacecraft potential fluctuations in case of a circular-polarized wave electric field. We have also constructed a theoretical model to explain the simulated potential fluctuations in consideration of a photoelectron escaping current though an RF sheath around the spacecraft [Boehm et al., 1994].

Keywords: plasma wave, spacecraft charging, wave electric field, chorus waves, photoelectron emission, particle-in-cell simulation

3D Electromagnetic Particle Simulations about the Low Frequency Component of BEN

*Taketoshi Miyake[1], Masaya Saji[1], Masaki Okada[2], Yoshiharu Omura[3]

1. Department of Informatic system, Faculty of Engineering, Toyama Prefectural University, 2. National Institute of Polar Research, 3. Research Institute of Sustainable Humanosphere, Kyoto University

According to PIC simulations, ESW (Electrostatic Solitary Waves) are generated from electron beam instabilities. ESW correspond the upper frequency component of BEN (Broadband Electrostatic Noise) which is frequently observed in space plasma. The generation mechanism of the low frequency component of BEN, however, is still unexplained. We went statistical analyses of the low-frequency component of the BEN observed by EFD onboard Geotail spacecraft, and investigated the relation between magnetic field strength, ion density and ion temperature. According to the spctrum analysee of the low frequency component of BEN, there are two different types of spectrum. We performed the 3-dimensional electromagnetic particle simulations about these two types of the low frequency component of BEN, and found low frequency waves are excited in both cases.We are going to further simulations with sufficient scale in time and space, and make clear the generation mechanism of the low frequency componet of BEN.

Keywords: Broadband Electrostatic Noise, 3-dimensional Electromagnetic Particle Simulations, Geotail Spacecraft

