Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

PEM35-01 Room:503 Time:May 2 15:00-15:25

Full PIC simulations on plasma electromagnetic disturbance in the vicinity of spacecraft

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Space exploration has been rapidly increasing, and a strong demand arises regarding comprehensive understanding of spacecraft-plasma (SP) interactions [1]. This is clearly required to ensure survivability and proper operations of space-based systems, and also for correct interpretation of measurements and other information collected in situ by scientific spacecraft.

In space environments, spacecraft are electrically charged due to plasma contact to spacecraft surface and its floating potential is basically determined by the current balance at spacecraft surface. The current consists of incident background plasma, emission of photoelectrons/secondary electrons from spacecraft surface as well as active emission of plasma beam in electric propulsion system such as ion engine. Due to the spacecraft charging, plasma environment near spacecraft is influenced. Non-uniform plasma distributions such as sheath and wake structures are formed near spacecraft surface and in the downstream region with respect to the solar wind, respectively. Field components near spacecraft can be also disturbed by the plasma response to spacecraft. Understanding of the SP interactions is important from a view point of spacecraft observation of plasma environment as well as its data analysis. To discriminate plasma phenomena artificially disturbed by spacecraft from observational data, quantitative understanding of SP interactions is necessary. In designing science instruments such as electric field sensor, plasma disturbance near spacecraft has to be minimized as much as possible to obtain reliable and valuable data. To obtain self-consistent solution of these plasma disturbances near spacecraft, we perform plasma simulations including spacecraft body in a simulation domain.

For solving SP problems, we have developed the EMSES plasma particle simulation code [2]. EMSES is based on the standard electromagnetic PIC method, and also has the capability to include the conducting bodies of a spacecraft, based on the capacitance matrix method. In addition, a number of crucial physics such as the photoelectron emission and the secondary emission are modeled numerically in the latest version of EMSES. The code has been applied so far to some specific spacecraft, e.g., Geotail, Cluster, BepiColombo/MMO, and Solar Probe Plus.

In this talk, first we will briefly explain the numerical treatment of spacecraft in EMSES. Then we will show a few examples of EMSES applications to scientific spacecraft. One of such applications is an enhanced wake formed behind the Cluster satellite in tenuous streaming plasma [3]. In the simulation we have included the conducting surfaces of very thin (in an order of mm) wire booms by using the fictitious surface technique. We found that even the extremely thin wire booms can contribute substantially to the formation of an electrostatic wake because of highly positive spacecraft charging in the tenuous plasma environment. We will also show a recent research topic on the SP interactions in the near-Sun environment. Large photoelectron emission current caused by an intense solar flux forms a negative potential barrier on the spacecraft surface, leading to negative charging of the spacecraft. Electromagnetic environments around these specific spacecraft will be presented in the talk.

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Keywords: Spacecraft plasma environment, Spacecraft-plasma interactions, Electromagnetic Particle simulation, Spacecraft charging, electromagnetic disturbance

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PEM35-02 Room:503 Time:May 2 15:25-15:45

General relativistic simulations of magnetized binary neutron star merger on K

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Binary neutron stars are a binary which is composed of two neutron stars and nine binaries have been observed so far. They gradually lose the orbital energy and angular momentum due to gravitation wave emission and merge in the end. Within the observed binaries, six of them will merger within the Hubble time. Gravitational waves emitted during the merger would be detectable with the ground-based gravitational wave detectors such as KAGRA, advanced LIGO, and advanced VIRGO at a frequency of about ten times per year. If we could observe the gravitational waves, they would tell us the validity of General Relativity in a strong gravitational field and the equation of state of neutron star matter which is poorly known to date as well.

This situation facilitates a theoretical study of binary neutron star mergers. During the merger, the density is as high as 10^{15} g/cc and the temperature rises as high as 10^{10} degrees. Therefore, any analytical approaches break down and we need a numerical modeling. Our group is approaching this problem in the framework of Numerical Relativity. It is a research field whose aim is figuring out phenomena in a strong gravitational field by solving the Einstein equation as well as the hydrodynamical equation and neutron radiation transfer.

The observations of the pulsars have revealed that the neutron stars are magnetized with about 10^{12} Gauss in general. Moreover, some of them could have 10^{14} Gauss. However, it is still unknown what the role of magnetic field during binary neutron star mergers is. There are several hydrodynamical instabilities which amplify the magnetic field and a short wavelength mode is essential in all cases. Therefore, it is mandatory to perform a high-resolution simulation. In the previous studies of this subject, it is hard to say that enough resolution is assigned to resolve these instabilities. Our group is performing a numerical simulation with the highest resolution on the supercomputer K and figuring out the role of the magnetic field during the merger of binary neutron stars. We summarize the result as follows.

When the two stars come into contact, the shear layer between the stellar surface becomes unstable against the Kelvin-Helmholts instability. The vortices are produce by this instability and the shorter the wavelength is, the larger the growth rate of the instability is. If there exists magnetic field lines, they are curled by these vortices and are expected to be amplified exponentially. By performing the convergence study against the numerical resolution, we have found the maximum magnetic field is amplified by the factor of about thirty at least at the merger.

After the merger, a hypermassive (HMNS) neutron star is transiently formed, which is supported by a rapid and strong differential rotation in addition to the thermal pressure. Although this star is unstable against the magnetorotational instability (MRI), it is difficult to resolve the MRI because the wavelength of the unstable mode is quite short due to the high density and high angular velocity of the HMNS neutron star. In our simulation, we have resolved this unstable mode and we have shown that the HMNS neutron star has the magnetic field as large as 10^{16}-10^{17} Gauss as a result.

In the HMNS neutron star, the angular momentum transport due to the non-axisymmetric structure as well as due to the MRI works. In addition, the star loses a significant amount of the angular momentum due to the gravitational wave emission. Then, the star collapses to a black hole which is surrounded by the accretion disk. Inside the accretion disk, the magnetohydrodynamical turbulence transports the angular momentum and its surface is unstable against the Kelvin-Helmoholts instability. Vortices produced by these two mechanisms transport the energy outwardly and the disk wind activates as a result. In this talk we will introduce the simulation result in details.

PEM35-03 Room:503 Time:May 2 15:45-16:00

Electromagnetic Vlasov simulations of magnetized plasma with a finite-volume multi-moment advection scheme

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The Vlasov simulation, which directly discretizes the Vlasov equation on grid points in phase space, has been proposed as an alternative method to the common Particle-In-Cell simulation, to improve the accuracy of kinetic plasma simulations. Although the electrostatic Vlasov simulations have been successfully carried out thus far, the electromagnetic Vlasov simulation of magnetized plasma is still limited, owing to numerical difficulty in solving the distribution function in velocity space.

To overcome the difficulty, we develop a new numerical scheme, specifically designed to solve the Vlasov equation in magnetized plasma. The scheme advances multiple piecewise moments of a physical profile based on their governing equations, to preserve the profile with high accuracy. The scheme allows us to perform a long-time calculation of the distribution function of magnetized plasma with small numerical diffusion.

In this talk, we first present the scheme and its performance. Then, we report the application of the scheme to two-dimensional (2D3V) electromagnetic Vlasov simulations. Long-time simulations of the linear wave propagation in magnetized plasma are conducted with quite small numerical errors. We also conduct the simulation of collisionless magnetic reconnection. The simulation resolves macroscopic structure without numerical noise, and is in good agreement with previous studies. Furthermore, the simulation resolves microscopic structure of the non-Maxwellian plasma velocity distribution around the reconnection site, e.g., acceleration by the reconnection electric field at the X-point, high energy beams around the boundary layer, and heating by the magnetic compression at the downstream. Since the simulations have been successfully carried out with the grid size much larger than the Debye length, the Vlasov simulation is a powerful technique to treat global-scale kinetic plasma phenomena.

Keywords: Advection equation, Vlasov simulations, Magnetic reconnection

PEM35-04 Room:503 Time:May 2 16:15-16:30

Generalization of Plasma Hybrid Simulation Model

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The hybrid simulation model has been widely used as one of the self-consistent simulation methods in investigating nonlinear space plasma phenomena, which treats ions as kinetic macro-particles whereas electrons are assumed to be an inertialess fluid. It can correctly simulate from magnetohydrodynamic to the ion inertia length scale. However, the assumption of the inertialess electron makes it sometimes numerically difficult to handle high-frequency whistler waves. We have recently shown that the problem may be resolved by appropriately including finite electron inertia effect, which also makes it possible to handle vacuum regions in a hybrid code. In this report, we discuss extension of the model which may be able to incorporate electron kinetic effect. Ignoring the displacement current and assuming charge neutrality, we adopt the Vlasov-Ampere system of equations. An equation to determine the electric field is derived from the basic equation without any approximations. We demonstrate that by using the equation, the electron cyclotron resonance can be properly included.

Keywords: plasma, numerical simulation

PEM35-05 Room:503 Time:May 2 16:30-16:45

Optimization of Magnetohydrodynamic Simulation Code for Planetary Magnetosphere to Xeon Phi

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For investigating the global structures of plasma, such as the planetary magnetospheres, the Magnetohydrodynamic (MHD) equations are often used, in which full kinetics of plasma are neglected by taking the moments of the Vlasov equations. The MHD equations are highly nonlinear and are very complex to solve by hand calculations. Thus computer simulations play essential roles in studies of global magnetosphere.

The numerical MHD code for the magnetosphere has been optimized for vector-type supercomputers for a long time because the MHD code is a kind of fluid code and most of supercomputers with vector processors have high performance to solve the fluid codes in 1990's. These codes often have achieved a very high computational efficiency (the ratio of the effective performance to the theoretical performance). However, almost 100% of the "Top 500" supercomputer systems in the world adopt the massively parallel scalar type processors and more than 85% of systems consist of the x86 processor architecture in these days. The other scalar type computers are POWER and SPARC architectures. Recently the new coprocessor Xeon Phi which has many cores (~60 cores) of X86 architecture is introduced to the supercomputer system and achieved good performance of the Linpack benchmark.

In this study I evaluate the performance of MHD code for the planetary magnetosphere on the single Xeon Phi coprocessor. For the performance evaluation, I use the three-dimensional domain decomposition method and a cache-hit type of three-dimensional domain decomposition method with the flat MPI and hybrid MPI. As the results, I found that normal three-dimensional decomposition of the MHD model with the hybrid MPI is suitable for Xeon Phi coprocessor and achieved computing performance efficiency of ~7%. Furthermore, I add the optimization to the MHD code based on the Xeon Phi architecture and obtained the computing performance efficiency of almost 10% which is the double performance of FX10 single node.

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A Study of Fluid Element Tracing in Global MHD Simulations via Parallel Data Processing on the NICT Science Cloud

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The NICT Science Cloud is a cloud system designed for scientific researches, and expected as a new infrastructure for big data sciences. Not only parallelization of CPU as in super-computers, but I/O and network throughput parallelization are crucial for the big data science. A high-performance visualization system is constructed on the NICT Science Cloud using Gfarm/Pwrake middleware. We examined performance of this parallel visualization environment for a set of computer simulation with 1000 files (2.3TB in all). After setting higher priority to access to local file on local disk, we finally achieved 124 times higher visualization using 192 core cpu.