Full kinetic simulations on plasma and field disturbance in the vicinity of spacecraft

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Space exploration and utilization have been rapidly increasing, and a strong demand arises regarding comprehensive understanding of interactions between spacecraft system and its surrounding plasma environment. We have been studying plasma and field disturbance caused by the spacecraft-plasma interactions as well as active plasma emission from spacecraft by performing full kinetic simulations with the Particle-In-Cell (PIC) method. In this presentation, we introduce some of the simulation results on the interactions between spacecraft system and space plasma. We would particularly like to focus on plasma flow response to a meso-scale magnetic dipole in Magneto-Sail (MS) propulsion system. The MS system was proposed as one of the innovative interplanetary flight systems and its propulsion can be obtained through the solar wind plasma interactions with the artificially created magnetic dipole around spacecraft. The plasma flow response to a magnetic dipole and the resulting formation of a magnetosphere depends on the intensity of the magnetic moment of the artificial dipole field. When the size of the magnetic dipole is comparable to or somewhat smaller than the ion Larmor radius or the inertial length, we call it meso-scale and the plasma kinetics such as finite Larmor radius effect will play an important role to determine the plasma response to the magnetic dipole. Contrary to the case of the Earth's magnetosphere, we found that difference of dynamics between ions and electrons in the meso-scale dipole field plays an important role in the magnetosphere formation [1]. The width of the boundary current layer as well as the spatial gradient of the local magnetic field compression found at the dayside can be characterized by the electron Larmor radius. As an application, we also examined the solar wind interactions with a magnetic anomaly called Reiner Gamma found on the lunar surface. The simulation results show that some ions are reflected back to the sunward direction over Reiner Gamma even though the ion Larmor radius is larger than the scale of magnetic anomaly, which basically agrees with the KAGUYA spacecraft observation [2]. To investigate such multi-scale phenomena caused by the difference of dynamics between electrons and ions, we developed a new electromagnetic PIC code by incorporating the Adaptive Mesh Refinement (AMR) technique called PARMER [3]. The AMR technique is one of promising methods which can realize high-resolution analysis by making use of dynamically and locally refining calculation meshes when the phenomena are highly localized and involves coupled physical multi-scale. At the end of the presentation, we would like to touch upon PARMER development.

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