R-CIP 法とベクトルポテンシャルを用いた磁場のソレノイダル性を保証する３次元 MHD コードの開発

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Development of the 3-D MHD code with the vector potential formulation to guarantee the divB=0 property using R-CIP algorithm

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From the past observations by Mariner 10, it was suggested that the Mercury's magnetosphere may be analogous to the geomagnetosphere. The temporal and spatial scales of the Mercury's magnetosphere is, however, much smaller than those in the geomagnetosphere because of its week intrinsic magnetic field. One of the most important subject in studying the Mercury's magnetosphere is kinetic effects of the plasma due to the small scales. For example, the hybrid simulation by Kallio and Janhunen [2003] showed the dawn-dusk asymmetry caused by finite ion gyroradius effects in the Mercury's magnetosphere. A start point to investigate particle dynamics in the Mercury's magnetosphere is to use an analogy to the geomagnetosphere. Recent studies by Delcourt et al. [2003, 2005] used the analytical models of electric and magnetic fields that are obtained by rescaling the geomagnetosphere. And it is noted that the resultant properties largely depend on the field models. In order to verify the rescaling magnetospheric models and particle dynamics in the more realistic global configuration of the Mercury's magnetosphere, a self-consistent electric and magnetic field configuration such as obtained from MHD simulations is required. For studies of kinetic effects it is important that the resultant magnetic field (B) satisfies solenoidal condition i.e., divB=0, to avoid artificial acceleration/deceleration.

Aiming at global simulation of the Mercury's magnetosphere, we developed a MHD simulation code that automatically satisfies solenoidal condition for B. To implement the condition, we used vector potential (A) instead of magnetic field itself in the MHD equation. The usage of A automatically guaranteed div(rotA)=divB=0. For accurate simulation of high Reynolds number magnetofluid (low numerical viscosity), we adopted R-CIP algorithm [Yabe et al., 1991; Xiao et al., 1996] to solve the advection term in the simulation code. Time evolution of not only physical quantities but also their first derivatives are solved in the CIP method. The non-advection terms are solved by 3rd order Adams-Moulton predictor-corrector method. The code assessment by comparison with previous simulations with TVD algorithm or analytical solutions shows reasonably good ability of energy and mass conservation, and description of MHD discontinuities of the newly developed code. A remarkable feature of the new code with A is the precise description of Alfven wave propagation compared to the code with B even for high wave number regime near the Nyquist wavelength. The two-dimensional feature of the code is tested by simulation of 2-D K-H instability: The linear growth rate got good reconciliation and energy conservation fulfilled enough not to change results. As for the 3-D global simulation of the Mercury's magnetosphere, we adopted initial and boundary conditions similar to those used in a previous simulation study by Walker and Ogino [1989]. In the presentation, the status of ongoing tests of 3-D global simulation of the Mercury's magnetosphere will be also presented in addition to the basic characteristics of the new code.