MHD simulation of the magnetorotational instability using the compact difference scheme and LAD method with the shearing box model

Kenichiro Hirai[1]; Yuto Katoh[1]; Naoki Terada[2]
[1] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [2] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.

The magnetorotational instability (MRI) is one of the most important phenomena in the accretion disk. Turbulence generated by MRI causes the turbulent viscosity in the disk and is a strong candidate of the driver of mass accretion. Recent study suggested that the turbulence induced by MRI also plays an important role in the planetesimal formation in the protoplanetary disk. In the planetesimal formation process, both the ionized gas and dust coexist in the disk and the motion of dusts is strongly affected by the motion of gas through the collisional and/or frictional effects. Kato et al. (2010;2012) showed the result of the local MHD + dust simulation with the inhomogeneous MRI occurrence region and meter-sized dusts treated as test particles in the simulation system. They showed the possibility that meter-sized dusts are gathered locally due to the modification of the disk gas distribution through the evolution of MRI and that the situations favored for the planetesimal formation are created in the localized region. On the other hand, the computational domain used in this simulation corresponds to the spatially limited region in the disk. In order to study the dust motion in the disk globally, we should take into account the effects of the Kelvin-Helmholtz instability (Sekiya, 1998; Barranco, 2009) and the streaming instability (Youdin & Goodman, 2005) generated by the dust-gas interaction and the effect of the time evolution of the global disc structure (Suzuki et al., 2010). In order to carry out the MHD simulation considering these effects, we need to develop the scheme that can accurately resolve both waves of short wavelength in turbulence and discontinuity appeared in the evolution of instabilities.

In the present study, we develop the MHD simulation code using an 8th-order compact difference scheme with the local artificial diffusivity (LAD) method (Kawai, 2013). The compact difference scheme proposed by Lele (1992) has an advantage for solving turbulent flow because it has the property for resolving short wavelength. The LAD method for MHD simulation proposed by Kawai (2013) enables us to reduce unphysical oscillations generated in the compact difference scheme. We carry out a series of standard test problems for MHD simulations and clarify pros and cons of the developed MHD code for the study of MRI. In spatially 2-dimentional test problems, we find that the maximum value of the numerical error appeared in the computation of the divergence of the magnetic field is the order of 10^{-12}, which is approximately consistent with the results of Kawai (2013).

We then carry out the 2-dimensional MHD simulation of MRI by the developed code. We initially set the uniform vertical magnetic field and assume the perturbation of the radial magnetic field whose amplitude is 1% of the background magnetic field and wavelength corresponds to that of the maximum growth rate of MRI. We perform simulations with the different spatial resolution. In the linear growth phase, we find that the maximum growing mode of MRI is resolved in all simulation runs. By comparing the simulation results, we find that the saturation level of MRI increases as we increase the spatial resolution. We show the results of detailed analysis of the 2D-MRI growth and discuss the obtained dependence of the saturation process. In addition to the characteristics of the developed code, we report the current status of the development of 3-dimentional MHD simulation code and its first results.