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Nonlinear evolution of MRI studied by an MHD code with the compact difference scheme and the LAD method

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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 dusts coexist in the disk and the motion of dusts is strongly affected by the motion of gas through collisional and/or frictional effects. Kato et al. (2010;2012) 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 situations favored for the planetesimal formation are created in the localized region. In addition to the effect pointed out by this simulation, we should take into account effects through the Kelvin-Helmholtz instability (Sekiya, 1998; Barranco, 2009) and the streaming instability (Youdin & Goodman, 2005) generated by the dust-gas interaction as well as 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 short wavelength waves in turbulence and discontinuity appeared in the evolution of instabilities.

In the present study, we develop an 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) enables us to solve turbulent flow accurately up to the wavenumber range corresponding to a few grid points. The LAD method for MHD simulation proposed by Kawai (2013) enables us to reduce unphysical oscillations generated in central difference type scheme like the compact difference scheme. We have also applied parallelization by MPI using the pipeline algorithm to the code in order to increase the box size with keeping the high spatial resolution. By using the pipeline algorithm, we have applied the domain decomposition to the code with maintaining the accuracy of 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. By conducting spatially 2-dimensional 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 3-dimensional MHD simulation of MRI by the developed code. In order to realize the differential rotation, we use the shearing box boundary condition (Hawley et al., 1995) and the 9-wave method (Dedner et al, 2010) so as to suppress the divergence error caused by the interpolation in the shearing box boundary. We initially set the uniform vertical magnetic field and assume the perturbation in the three-components of the velocity vector whose amplitude is 1% of the sound speed. Our developed simulation code can solve the linear growth and nonlinear evolution of MRI. Our newly developed code enables us to solve the MRI driven turbulence accurately, which is important in solving not only a wide range of the evolution of the disk but also the fine structure of the saturation and nonlinear evolution mechanism of MRI. We show the characteristics of the developed code and study results of the 3-dimensional MHD simulation of the nonlinear evolution of MRI.