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磁気回転不安定性が駆動する磁気流体乱流計算の収束性について

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On the convergence of numerical simulations of magnetohydrodynamic turbulence induced by the magnetorotational instability

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Magnetohydrodynamic (MHD) turbulence plays an important role in space and astrophysical plasmas. For example, weakly magnetized accretion disks are subjected to the magnetic turbulence induced by the magnetorotational instability (MRI; Balbus & Hawley 1991, 1998). The MRI-induced turbulence is believed to contribute to the outward angular momentum and subsequent mass accretion toward a central star (Hawley et al. 1995, 1996). Nonlinear stage of the magnetic turbulence has been extensively studied by means of MHD simulations.

When the (magnetic) Reynolds number in space and astrophysical plasmas is expected to be very high, ideal MHD equations are often adopted to study their dynamics. In ideal MHD simulations, the viscous and resistive dissipation scales are numerically determined, and are not necessarily identical. Kritsuk et al. (2011) have carried out turbulence decay simulations to compare the numerical resolution of MHD simulation codes, and have shown that a code with high velocity spectral bandwidth does not necessarily have high magnetic spectral bandwidth, and vice verse. Therefore, the numerical convergence of MHD turbulence simulations is no longer guaranteed among simulation codes.

In this study, we examine the numerical convergence of the MHD turbulence to assess the effect of numerical dissipation scales on a practical problem. To this end, we conduct a large set of numerical simulations of the MRI with various schemes. Our ideal MHD simulations do not achieve the numerical convergence. We show that the nonlinear saturation level is very sensitive to the numerical magnetic Prandtl number, indicating the importance to use explicit viscosity and resistivity to control the magnetic Prandtl number in MRI-induced turbulence simulations. Viscoresistive MHD simulations of the MRI are then carried out to examine the parameter dependence of the saturation level. The saturation level is found to intricately depend on the viscosity, resistivity, and gas pressure.