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高粘性プラズマにおける磁気リコネクション
Magnetic reconnection in viscosity-dominated plasmas

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Magnetic reconnection is essentially multi-scale phenomenon. From fully kinetic to magnetohydrodynamic (MHD) scales, a wide variety of models are utilized to identify triggering mechanisms for fast reconnection. The so-called GEM reconnection challenge has compared numerical simulations with fully kinetic (Particle-In-Cell), partly kinetic (Hybrid and Hall-MHD), and conventional resistive MHD models under the same initial condition, and it has shown that only the MHD model cannot achieve fast reconnection (Birn et al. 2001). This result indicates that kinetic effects are the essential physics and the resistive MHD is insufficient to model fast reconnection.

There are several kinetic effects proposed for the candidate to trigger fast reconnection, such as the Hall effect, the dispersion of whistler waves, the electron inertia and pressure anisotropy. We particularly focus on a two-scale structure in the diffusion region. In the fully kinetic model of electron-ion plasmas, the diffusion region is composed of a thinner electron diffusion region embedded in a thicker ion diffusion region. We hypothesize that fast reconnection may be triggered even in the MHD model if it attains a two-scale diffusion region like the kinetic model. Since the ion and electron diffusion regions are respectively measured as the vortex and current sheet, the two-scale diffusion region may be observed in the visco-resistive MHD with the viscosity larger than the resistivity (i.e., magnetic Prandtl number is larger than unity). However, this is not expected in conventional MHD simulations because they often use only the resistivity and ignores the viscosity (i.e., magnetic Prandtl number is almost zero).

Then, we perform two-dimensional visco-resistive MHD simulations of magnetic reconnection in viscosity-dominated plasmas. A simple Harris sheet configuration with uniform viscosity and resistivity is assumed as an initial configuration. When the viscosity is sufficiently high, the two-scale structure of thicker vortex and thinner current sheet is observed in the diffusion region, and subsequently, the diffusion region begins to thin down. The thinning speed increases with decreasing the thickness, implying that the thinning is driven by the viscous vortex motion. The vortex originates from the viscous heating at the downstream. High viscosity immediately dissipates and opens the outflow jet, thus tends to localize the diffusion region. We observe the upstream propagation of rarefaction waves, which accelerate the plasma toward the diffusion region. As a result, the current sheet in the visco-resistive MHD model becomes much thinner than in the resistive MHD model. Explosive reconnection is expected in the visco-resistive MHD. Since the magnetic Prandtl number is estimated to be much larger than unity in hot and tenuous astrophysical plasmas (e.g., stellar corona and active galactic nuclei disks), our result indicates the importance of the visco-resistive MHD against the conventional resistive model.

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