論文内容の要旨

Study on turbulent magnetic reconnection by Reynolds-averaged MHD model and kinetic viewpoint

（レイノルズ平均 MHD モデルと運動論的視点による乱流磁気リコネクション研究）

東森一晃

For many active phenomena in space plasmas, such as the substorm in the Earth's magnetosphere, the solar flare, and the dynamics in pulsar magnetosphere, it has been suggested that ``*magnetic reconnection*'' often plays an important role in their energy release. In general consensus of magnetic reconnection, the topological change of magnetic field lines leads to the release of magnetic field energy and results in the dynamical plasma processes. From previous theoretical and observational studies, it is suggested that the mechanism of magnetic reconnection may not be understood by only a single solution and highly depends on the scale and the plasma behavior on which we are focusing. For this reason, the dynamics has been studied by both the collisionless kinetic and the magneto-hydro-dynamic (MHD) approaches, so far. In either cases, reconnection dynamics has been mainly studied in a laminar equilibrium, and the efficient mechanism to convert the magnetic field energy into kinetic and internal energy of plasmas has been suggested. On the other hand, the effect of turbulence, which seems to be natural and essential in high magnetic Reynolds number plasmas, has not been established yet. This dissertation aims to address some suggestions on the relationship between turbulence and reconnection dynamics from collisionless kinetic and MHD reconnections with different viewpoints.

As for the collisionless kinetic reconnection, we consider the reconnection as the source of turbulence. In the kinetic scale, there exists plenty of free energies, such as non-uniformity and the pressure anisotropy, and we may expect a lot of plasma instabilities compared to the MHD system. Along with such a way of thinking, Chapter 2--3 focused on the self-generated fluctuations in magnetic reconnection. In Chapter 2, we considered the condition when magnetic reconnection becomes turbulent based on the nonlinear kinetic simulations and the local linear analysis. The results showed that whether the reconnection exhausts become turbulent or not strongly depends on the ion plasma beta in the initial inflow regions, β_{i0}: the reconnection jet becomes turbulent in the low beta condition, $\beta_{i0} < 0.1$--0.2. On this issue, the excitation and suppression of Alfvenic modes in the plasma sheet boundary layer (PSBL) is discussed. The local analysis for the PSBL suggests that as the ion beta increases, the damping rate of ion-scale Alfven waves becomes larger and suppresses the ion-scale fluctuations. In addition to the PSBL dynamics, we tried to explain global unstable mode observed in reconnection jets. This unstable mode appears across the current sheet and cannot be explained by only the PSBL dynamics shown in Chapter 2. Then, in Chapter 3, in order to discuss the nature of the global mode in jets, we presented a linear eigenmode analysis including both non-uniformity and pressure anisotropy effects. The analysis suggests that the global mode observed in the reconnection jet is the slow Alfven type mode, where the globally-appearing magnetic pressure gradient force weakens the magnetic tension force, and is very sensitive to the pressure anisotropy. As a result, the mode has efficient growth rate and could contribute to the generation of fluctuations in the anisotropic ion-scale reconnection jet.

In Chapter 4, the macroscopic MHD reconnection dynamics is focused. We considered the effect of pre-existing turbulence in the MHD scale current sheet, and how turbulence affects the current sheet dynamics is investigated using a Reynolds-averaged MHD model. In the model, equations of time evolution for turbulent quantities (such as cross-helicity and turbulent energy) are solved in addition to the mean MHD equations, and the coarse-grained effect was considered. Namely, the effect is included in Ohm's law as a turbulent electromotive force term, and mean and fluctuating field quantities develop with interacting each other through it. The results suggest that the initial current sheet develops in three ways, depending on the strength of turbulence: slow laminar reconnection, turbulent reconnection, and turbulent diffusion without magnetic reconnection. In the second turbulent-mediated reconnection case, the turbulent energy and cross-helicity develop near the magnetic neutral point through the interaction between mean and the fluctuating field, and the localized turbulent diffusion leads the fast magnetic reconnection. Because turbulence takes the central role in magnetic field diffusion instead of the kinetic-originated resistivity, the current sheet may not necessarily be as thin as the kinetic scale.