高速磁気リコネクションにともなう電流層シア不安定性

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A current sheet shear instability during fast reconnection

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One of the main issues on magnetic reconnection processes is the mechanism breaking the frozen-in condition around the x-line and providing the electric resistivity in collisionless plasmas. In 2D reconnection, it has been demonstrated that the momentum transport due to the Speiser-type motion of the electrons gives rise to the electron viscosity around the magnetic x-line which leads to an effective resistivity. Although the electron viscosity gives sufficient dissipation for supporting the reconnection electric field under the thin current layer on the order of the electron inertia length, such a thin current sheet has not been observed neither in the laboratory experiments nor in the geomagnetosphere. Recent 3D kinetic simulations have revealed that, in 3D reconnection, a kink-type electromagnetic (EM) mode with a frequency ranging from w$_{ci}$ to w$_{LH}$ has a significant impact on the dissipation processes around the x-line, where w$_{ci}$ and w$_{LH}$ are the ion cyclotron frequency and the lower hybrid frequency, respectively. However, the generation mechanism of the EM mode in the thin current layer is poorly understood yet.

The linear properties of the EM mode have been investigated intensively for the Harris-type current sheet. However, the current sheet profile during the fast reconnection is far from the Harris sheet. The density profile is almost uniform, so that the pressure and current density profiles are maintained through the temperature and bulk velocity gradients, respectively. Furthermore, the current sheet develops a two-scale structure consisting of the electron and ion current sheets. Therefore, it is very questionable that the previous results for the Harris sheet are still applicable during the fast reconnection.

The present study introduces a more realistic equilibrium with the two-scale structure based on the two-fluid equations. The wave dispersion is obtained by solving the linearized two-fluid equations numerically with an initial value approach starting with small random noise. We find that the growth rate decreases as the ion current sheet width increases, although the relative drift velocity between the ions and electrons remains fixed at the x-line. This result indicates that the mode is driven by the ion flow shear rather than the relative drift velocity, so that it is termed here as the current sheet shear instability (CSSI). We also find that this mode differs from the ion-ion kink mode because the spatio-temporal scale has a dependency of the ion-to-electron mass ratio, implying some coupling between the electrons and ions.

In this paper, we show the detailed results of the linear wave analyses based on the tow-fluid equations and compare with 3D simulation results. The generation mechanism of the CSSI will be discussed.