§23. Suppression of Hall Term Effects by Gyroviscous Cancellation in Collisionless Magnetic Reconnection

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Collisionless magnetic reconnection is a fundamental mechanism for the rapid release of magnetic energy in space plasmas and laboratory plasmas. Recent computer simulation studies have revealed that the rate of reconnection by collisionless processes is very large compared to those obtained by using resistive MHD. Rapid reconnection is demonstrated to occur when the motions of electrons and ions decouple in a narrow region around the reconnection point. This decoupling is explained in terms of two-fluid effects and particle orbit effects, which are not included in the MHD model, and which form an ion-dissipation region. In this region the ion frozen-in condition is broken, while the electrons are tied to the field. This difference between the ion flow and electron flow causes fast magnetic reconnection.

We demonstrate the formation of an ion-dissipation region, in which motions of electrons and ions decouple and fast magnetic reconnection occurs during a steady state of two-dimensional collisionless driven reconnection without guide field by means of full-particle simulations. The Hall term effect is suppressed due to the gyroviscous cancellation at scales between the ion-skin depth and ion-meandering-orbit scale, and thus ions are tied to the magnetic field. The ion-frozen-in constraint is strongly broken by nongyrotropic pressure tensor effects due to ion-meandering motion, and thus the ion-dissipation region is formed at scales below the ion-meandering-orbit scale. A similar process is observed in the formation of an electron-dissipation region.

Figure 1 shows the spatial profiles of various terms measuring the violation of the frozen-in condition along the vertical line passing through the X-point in the steady state. Figure 1 (a) shows that the ions are tied to the field at the outside of the region indicated by ion scales. The ion frozen-in condition is strongly broken within the ion meandering orbit scale lmi. On the other hand the ions are almost tied to the field and correspondingly the Hall term is small between ion skin depth and ion meandering orbit scale (lmi<y<di). Figure 1 (b) shows that the electrons are still tied to the field in the ion-dissipation region where the ion frozen-in condition is broken. This electron frozen-in condition implies the violation of the ion frozen-in condition within ion skin depth. Figures 1 (c) and (d) show the spatial profiles of out-of-plane component of the terms in the ion and electron momentum equations. The ion pressure tensor term cancels out the ion inertia term in the two-fluid region (lmi < y < di) where the ion inertia term is large and works toward breaking the frozen-in condition as shown in Fig. 1 (c). Therefore, this cancellation leads to the suppression of the Hall term effects and to the maintenance of the ion frozen-in constraint within di. The ion frozen-in condition is strongly broken in the full kinetic region within lmi where the pressure tensor term is dominant. This large pressure tensor term is originated from the nongyrotropic ion-meandering motion. Figure 1 (d) shows that the electron pressure tensor term and the electron inertia term break the electron frozen-in constraint near the X-point. The electron inertia term vanishes at the X-point, while the electron pressure tensor term has a sharp peak and it balances the electric field there. Thus, the reconnection electric field is generated by the nongyrotropic pressure tensor originating from the electron-meandering motion at the X-point. The electron pressure tensor seems to cancel out the electron inertia effect in the region between de and lme.

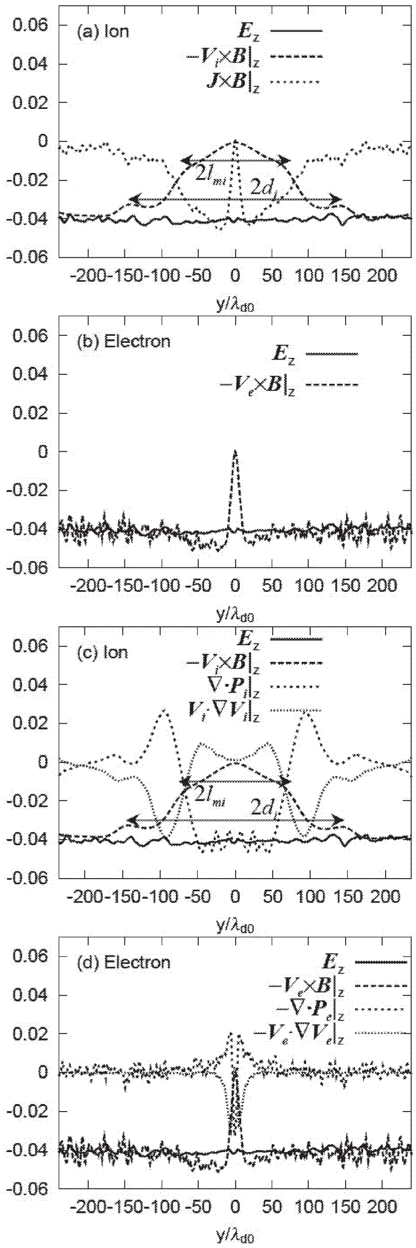

Fig. 1. The spatial profile of each term in the out-of-plane component of the ion momentum equation and of the electron momentum equation along the vertical line passing the X-point in the steady state

Reference

1) Ishizawa, A. and Horiuchi, R: to be published in Physical Review Letters (2005).