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Electron heating mechanism in the plasma sheet-lobe boundary region associated with magnetic reconnection

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Magnetic reconnection is widely believed to play an important role in the magnetospheric substorm and solar flares as a fast conversion process of the magnetic energy to kinetic and thermal energies of ions and electrons. Plasma heating and acceleration processes associated with magnetic reconnection are very important for understanding energy transport processes and have been discussed over the last decades. However, our understanding on the energization mechanisms of electrons still remains poor.

It is well known that non-Maxwellian electrons selectively heated parallel to the ambient magnetic field, having an velocity distribution of the flat-topped form, have been often observed in the plasma sheet-lobe boundary region located between the magnetotail lobe and the plasma sheet in association with magnetic reconnection. Some mechanisms responsible for the anomalous heating have been suggested: the slow-mode shocks formed near the separatrices associated with magnetic reconnection, the lower hybrid drift instability (LHDI) excited in the boundary region, and the Buneman instability and/or the bump-on-tail instability resulting from the high-energy electrons accelerated near the X-line. However, it has been difficult to specify the mechanism because of the ambiguity of observational data or limited computer resources. In fact, it is inevitable to perform full particle simulations in order to describe electron heating processes. However, it is still hard to conduct conventional particle-in-cell simulations in a large system.

To overcome this difficulty, we have developed a new electromagnetic particle code with adaptive mesh refinement (AMR) technique and the particle splitting algorithm, and achieved full particle simulations of magnetic reconnection in a large system. The AMR technique dynamically subdivides the cells that satisfy a refinement criterion and enables locally high-resolution simulations.

In this study, we investigate a generation mechanism of high energy electrons in the plasma sheet-lobe boundary region associated with magnetic reconnection, using the full particle simulations in a large system. It is found that the electron two-stream instability arising between cold background electrons and strong beam electrons with high perpendicular temperature is responsible for the formation of the flat-topped electrons. Electrons are quickly heated along the ambient magnetic field due to the trapping effect in the electrostatic potential wells. The shoulder energy of the flat-topped electron distribution reaches a few keV consistent with satellite observations. The strong beam electrons consist of hot and cold components. The former electrons come from the lobe region passing through the vicinity of the X-line, while the latter are originating from the opposite boundary region of the plasma sheet. The electron two-stream instability in association with magnetic reconnection is also responsible for the generation of the Electrostatic Solitary Waves (ESW) that have been frequently observed in the boundary region. This indicates that the electrostatic turbulence should play an important role in strong electron energization in the plasma sheet-lobe boundary region during magnetic reconnection.

In this paper, we will show the simulation results in a large system, and demonstrate the detailed processes of the electron heating due to the electron two-stream instability and the subsequent generation of ESW.