Waves and Electron Heating in the Reconnection Separatrix Regions

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Magnetic reconnection is a natural energy converter, releasing explosively the magnetic field energy into plasma kinetic energy. It is a typical multi-scale phenomenon where the magnetic dissipation takes place predominantly in a microscopic region formed around the x-line, while the topological change of the field lines causes large-scale plasma convection. Magnetic reconnection is universal process in space plasma leading to explosive phenomena such as geomagnetic substorms and solar flares. The purpose of this research is to understand the fundamental processes of magnetic reconnection and to establish the universal model applicable to real phenomena under complicated initial/boundary conditions. In particular, this paper focuses on the roles of microscopic waves in the reconnection processes.

Recent satellite observations in the geomagnetotail have shown that the wave activities are significantly enhanced in a broad range of frequency around the separatrices of anti-parallel magnetic reconnection where the guide-field is negligibly small [1]. The waves were recognized as lower hybrid waves, Langmuir waves, electrostatic solitary waves (ESWs), and whistler waves. In most cases, they were associated with cold electron beams and density cavity. However, because of the limited space-time resolutions of the observations, it has been difficult to identify the generation mechanisms of the waves and their roles in magnetic reconnection.

We have developed a new electromagnetic particle-in-cell model with adaptive mesh refinement (AMR-PIC model) in order to achieve efficient multi-scale kinetic simulations [2]. Recently we further applied an open boundary condition to the AMR-PIC model, which enabled us to pursue longer-time evolution of magnetic reconnection. Using the 2D AMR-PIC code, we have performed a large-scale simulation of anti-parallel magnetic reconnection with more realistic parameters of the geomagnetotail (e.g., the mass ratio m_i/m_e = 400 and the background density n_b/n_0 = 0.04) than most previous simulations.

As a result, the simulation has successfully reproduced the waves consistent with those observed frequently in the separatrix regions of magnetic reconnection in the geomagnetotail (see upper panel of Fig. 1). The key process generating the waves is intense parallel acceleration of the electrons due to an electrostatic potential jump formed in a localized region of the inflow side of the separatrices. The intense electron beams trigger the electron two-stream instability and the beam-driven whistler instability. The Buneman instability is also excited due to moderate electron beams arising upstream the potential jump. The electron two-stream instability generates the Langmuir waves, while the Buneman instability gives lower hybrid waves. Both modes evolve the ESWs in the nonlinear phases. The Langmuir waves trap the electrons in the parallel direction and forms a flat-top distribution with high-energy cutoff (lower left panel of Fig. 1), which is well consistent with the observations. On the other hand, the whistler waves scatter the electrons in the perpendicular direction, producing isotropic distribution with non-thermal high-energy tail [3] (lower right panel of Fig. 1).

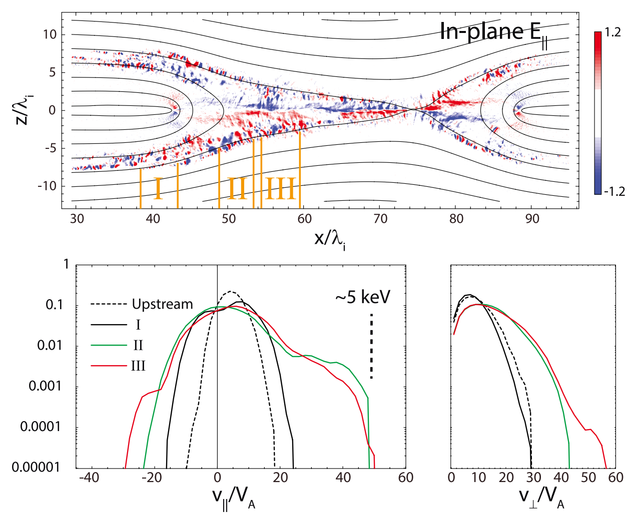

Figure 1: Wave activities seen in the parallel electric field around the reconnection region (upper panel) and the electron distribution functions (lower panels) in each wave active region.

References

[1] Viberg, H., et al.: 2013, *Geophys. Res. Lett.*, **40**, 1032.
[2] Fujimoto, K.: 2011, *J. Comput. Phys.*, **230**, 8508.
[3] Fujimoto, K.: 2014, *Geophys. Res. Lett.*, **41**, 2721.