§23. Electron Flow Circulation in Collisionless Driven Reconnection

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Microscopic pictures of steady collisionless driven reconnection are disclosed by using an electromagnetic particle simulation code for an open system (``PASMO") [1,2,3,4,5,6]. The simulation starts from the Harris equilibrium. Temporal evolutions of reconnection electric field, electron number density per cell at the mid-point, and total number of particles are plotted in Fig. 1, where the total number of particles is about 560 000 000, and the simulation domain is implemented on a (256 × 129 × 128) point grid, the ratio of ion to electron temperature is $T_i/T_e = 1$. After an initial transit phase ($\omega_{ce}t > 600$), the system relaxes to a steady state in which the inflow rate of magnetic flux ($E_0 = -0.04$) from the upstream boundary is balanced with the reconnection rate at the center ($E_{z,mid}$). A kinetic regime appears in the central current sheet, in which frozen-in condition is broken due to kinetic processes. The kinetic regime is separated into two dissipation regions with different spatial scales, i.e., ion dissipation region (IDR) and electron dissipation region (EDR) [1,4,5].

Figure 2 demonstrates the spatial profiles of electron number flux (top) and out-of-plane magnetic field B_z (bottom) in the steady state ($\omega_{ce}t = 842$). The electron outflow with high velocity comparable to electron Alfven velocity is generated from EDR as a result of collisionless reconnection [1,4,6]. When the electron outflow reaches the downstream boundary, strong electron inflow should be supplied into the system to keep the charge neutrality, because the ion outflow velocity is usually much smaller than the electron one in the kinetic regime and so the ions cannot compensate for the loss of electron charge at the downstream boundary. In this way, electron return current is formed along magnetic separatrix from the downstream boundary to the electron dissipation region. It is worthy to note that this physical process can be described only under the open boundary model. Furthermore, this result is in contrast with that of classical Sweet-Parker model in which uniform plasma inflow from the upstream boundary is assumed to be balanced with the plasma mass outflow from the dissipation region. The difference between the ion and electron motions in the reconnection plane leads to the generation of out-of-plane magnetic field B_z with quadrupole structure, as seen in the bottom panel of Fig. 2.

It is also found from this simulation that large electric resistivity is generated through kinetic processes [1-6]. Normalized effective resistivity, which is defined by ion inflow speed divided by Alfven speed at the inflow edge of IDR, is estimated to be 0.15 in the steady state.

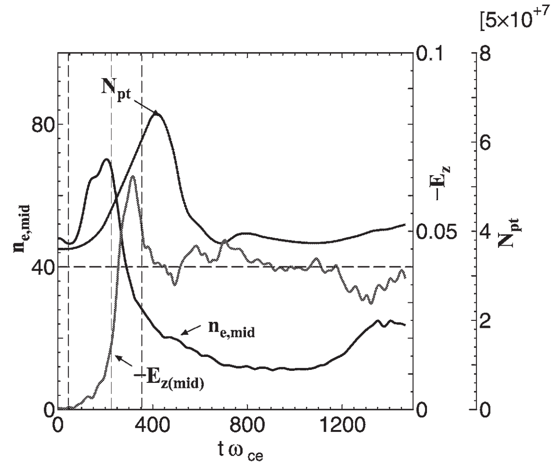

Fig. 1. Temporal evolutions of reconnection electric field (red), electron number density per cell at the mid-point (black), and total number of particles (blue).

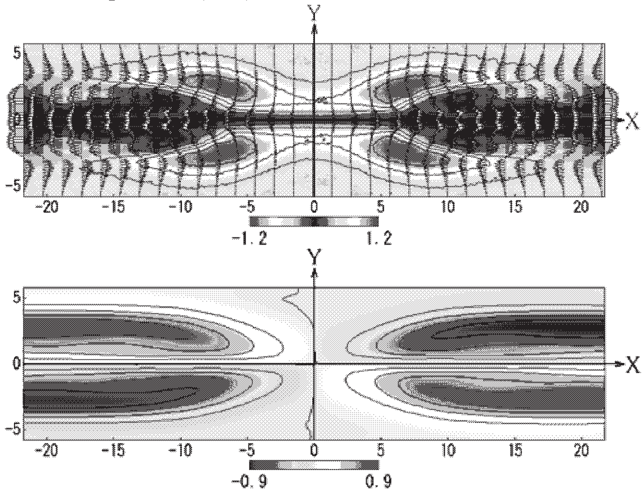

Fig. 2. Spatial profiles of electron number flux (top) and out-of plane magnetic field Bz (bottom) in the (x,y) plane at $\omega_{ce}t = 842$, where color coded contours in the top panel stand for the number flux along the inflow (y) direction. In top panel, the red color represents the region in which the high inflow flux towards the center (y=0) exists.

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