3D Dissipation Mechanism in Fast Magnetic Reconnection

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Magnetic reconnection is a promising process which provides efficient energy release in solar flares and geomagnetospheric substorms. The process is also considered be important in fusion devices because it can disturb the plasma confinement due to the magnetic field. The efficient energy release of the magnetic field requires a locally intense electric resistivity. However, the generation mechanism of the resistivity has been poorly understood in collisionless reconnection. The difficulty in understanding the dissipation processes is attributed to the nonlinear and multi-scale nature of magnetic reconnection. The dissipation takes place in a microscopic region where the plasma kinetics is significant, while it can have an impact on large-scale processes in macroscopic region where the fluid approximation is valid. On the other hand, large-scale field line topology also affects the kinetic processes in the microscopic region. Therefore, in order to reveal the dissipation mechanism in magnetic reconnection, it is necessary to describe self-consistently both the kinetic process in microscopic region and the fluid dynamics in macroscopic region.

It has been demonstrated that 2D magnetic reconnection is supported by an effective resistivity termed the inertia resistivity which is caused due to the electrons accelerated in a finite time near the x-line. However, the *in-situ* observations in the geo-magnetosphere and laboratory experiments have indicated that the current layer is not so thin as expected in the 2D model, and have detected active electromagnetic (EM) waves, which implys the importance of the anomalous dissipation (e.g., [1]).

The present study has investigated the 3D dissipation mechanism in a fast magnetic reconnection by using the large-scale particle-in-cell (PIC) simulations. The PIC model in this study employs the adaptive mesh refinement (AMR) [2]. The ion-to-electron mass ratio is 100. The number of the particles used reaches 10^{11} totally, and the maximum spatial resolution is $4096 \times 512 \times 4096 = 10^{10}$ [3]. Figure 1 shows a 3D snapshot around the x-line during the fast reconnection. It is found that an EM mode is excited around the x-line and kinks the electron current layer. The linear analysis indicates that the mode is a new-type shear mode excited due to the velocity shear across the current layer rather than the classical drift mode driven by the ion-electron relative velocity. Furthermore, it is confirmed that the mode is unstable even for the realistic mass ratio.

Figure 2 shows the anomalous momentum transport of the electrons due to the EM turbulence. One can see that the anomalous transport due to the shear driven mode is dominant in the localized region around the x-line. Since the reconnection electric field is $E_y \approx 0.1$, the estimated contribution to the magnetic dissipation of the anomalous transport is about 50 % in the fast magnetic reconnection. In particular, it is found that the anomalous transport is enhanced in association with the plasmoid (flux rope) formations.

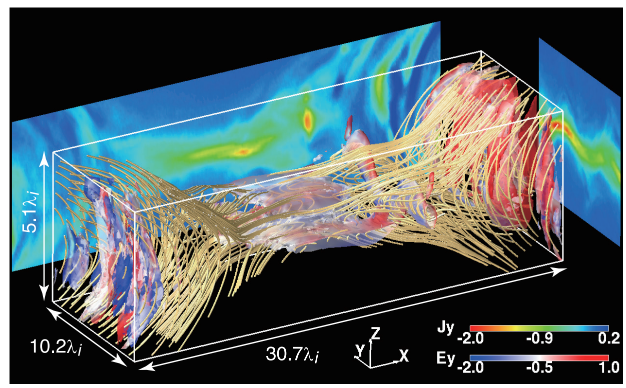

Figure 1: 3D snapshot around the x-line during the fast magnetic reconnection of an isosurface for $|J|/en_0V_A = 0.4$ colored by E_y with the magnetic field lines in yellow curves and 2D profiles of J_y.

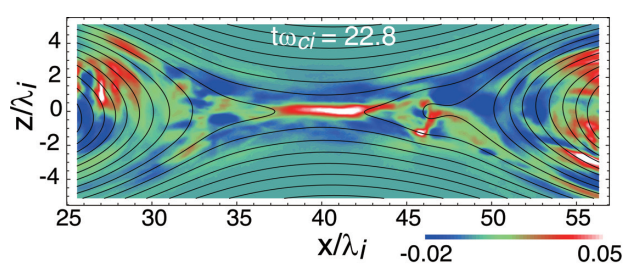

Figure 2: Anomalous momentum transport of the electrons due to the EM turbulence $\langle \delta(n_e\vec{V}_e) \times \delta\vec{B} \rangle / \langle n_e \rangle$, where $\langle \cdot \rangle$ indicates the average over y axis.

References

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[2] Fujimoto, K.: 2011, *J. Comput. Phys.*, **230**, 8508.
[3] Fujimoto, K., Sydora, R. D.: 2012, *Phys. Rev. Lett.*, **109**, 265004.