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Magnetic Dissipation in Turbulent Current Layer to Drive Magnetic Reconnection

Keizo Fujimoto[1], Richard D. Sydora[2]
[1] School of Space and Environment, Beihang University
[2] Department of Physics, University of Alberta
e-mail: fujimoto@buaa.edu.cn

Magnetic reconnection is a natural energy converter of magnetic field energy into plasma kinetic energy. The magnetic dissipation is needed in the localized current layer to drive the reconnection process extending to a large scale beyond the kinetic scales. Intense electromagnetic waves are often observed in the current layer in space and laboratory observations. The waves near the x-line can potentially produce the dissipation through momentum exchange between the species and/or momentum transport across the flow shear layer. Recent 3D kinetic simulations have also demonstrated intense activities of electromagnetic waves in the thin current layer formed around the x-line. Nevertheless of these evidences in observations and simulations, the generation mechanisms of the waves and their roles in reconnection are currently poorly understood.

We have carried out a large-scale 3D PIC simulation with the magnetic field $B_x(z) = -B_0\tanh(z/\delta)$ and the number density $n(z) = n_0\mathrm{sech}^2(z/\delta)+n_b\tanh^2(z/\delta)$, where $\delta = 0.5\lambda_i$ (λ_i is the ion inertia length) and $n_b=0.044n_0$ are chosen. The simulation code employs the adaptive mesh refinement to achieve efficient computation of multiscale processes. The system size is $L_x\times L_y\times L_z = 82\lambda_i\times41\lambda_i\times82\lambda_i$, which is entirely covered by base-level (coarsest) cells with $\Delta_{LB} = 0.08\lambda_i$ and can be locally subdivided up to dynamic range level with $\Delta_{LD} = 0.02\lambda_i$. The resultant highest resolution is 4096×2048×4096 and the maximum number of particles is $\sim4\times10^{11}$. The physical parameters are m_i/m_e=100, c/V_A=27, and T_{0i}/T_{0e} =5, where V_A is the Alfven velocity based on B_0 and n_0.

The simulation is initiated with a small perturbation to B_x and B_z to trigger magnetic reconnection. The laminar current layer at early stage is subject to flow shear instabilities, and becomes significantly turbulent, in particular, after plasmoid ejections from the current layer (Fujimoto & Sydora, 2012) as shown in Fig. 1a. The simulation reveals that two kinds of the shear modes dominate at the x-line, which are identified as the current sheet shear instability (CSSI) (Fujimoto & Sydora, 2017) and the electron Kelvin-Helmholtz instability (eKHI) (Fujimoto, 2016). Both modes can give rise to the dissipation. Figure 1b shows the contribution of electromagnetic (EM) turbulence to the reconnection electric field (E_R). It is found that the contribution is mainly from δB_z (blue dotted curve) which corresponds to the eKH waves as is evident from Figs. 1c and 1d.

It is interesting to notice in Fig. 1e that the EM turbulence mainly works on the electrons alone, while the ions are not significantly affected. This means that the EM turbulence hardly drives the momentum exchange between the species, which fails to produce the electrical resistivity (Miyamoto, 1989). Instead, we found that the eKH waves cause the momentum transport across the flow shear layer, leading to the viscosity around the x-line. The present results suggest a fundamental modification of the previous MHD models using the resistivity to drive reconnection.

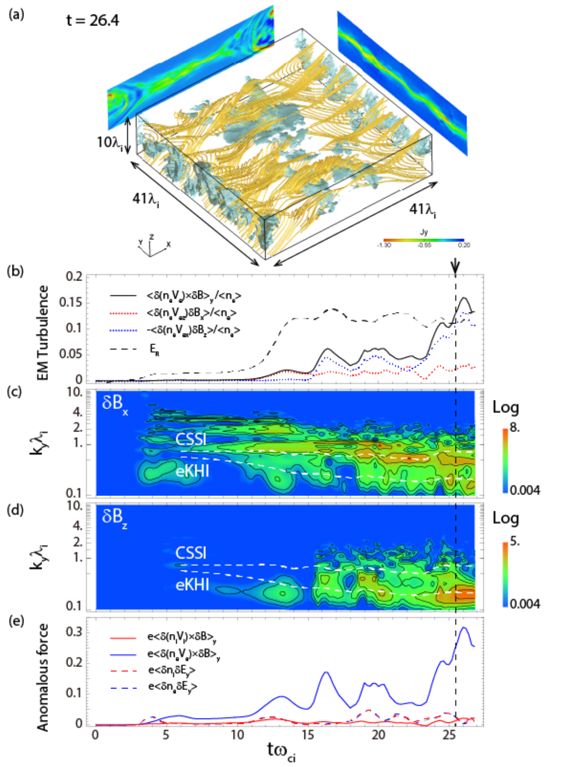

Figure 1: Simulation results showing (a) 3D view of the turbulent current layer at tωci=26.4 with iso-surface of the current density, magnetic field lines (yellow tubes), and 2D cuts of Jy, followed by time evolution at the x-line of (b) EM turbulence, (c) power spectrum of δBx, (d) power spectrum of δBz, and (e) anomalous forces on ions and electrons.

References

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