The inner structure of collisionless magnetic reconnection

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Magnetic reconnection is a driving engine of solar flares, stellar flares, and quite probably bursty events in high-energy astrophysical sites. The reconnection process is driven by a small-scale "dissipation region" surrounding the reconnection point (X-point), at which a plasma ideal condition breaks down. Recently, kinetic particle-in-cell (PIC) simulations have revealed that the electron ideal condition is violated in many locations in collisionless reconnection: i.e., the nonidealness cannot locate the dissipation region. To overcome this problem, we have proposed an electron-frame dissipation measure as a new marker of the dissipation region [1],

$$D_e = \gamma_e \big[\vec{j} \cdot (\vec{E} + \vec{v}_e \times \vec{B}) - \rho_c (\vec{v}_e \cdot \vec{E}) \big], \qquad (1)$$

where $\gamma_e = [1 - (v_e/c)^2]^{-1/2}$ is the Lorentz factor for the electron velocity and ρ_c is the charge density. This stands for the nonideal energy conversion in the MHD framework as well as the energy transfer in the moving frame of electron's bulk flow.

The measure gives us a new perspective to understand the structure of magnetic reconnection. Figure 1 shows magnetic field lines and key physical quantities in a 2-$\frac{1}{2}$ dimensional PIC simulation with antiparallel symmetric fields [2]. Kinetic reconnection exhibits a highly-modulated field-line structure due to Hall effects. One can recognize a well-known quadruple pattern of the out-of-plane magnetic field B_y in the rear panel. In such a complicated geometry, the previous measure (the electron frozen-in) falsely detects an elongated nondissipative region. In contrast, our new measure D_e successfully distinguishes a compact and narrow dissipation region around the X-point (the central red region in the front panel). Series of PIC simulations suggest that the size of the dissipation region is controlled by electron physics. The dissipation region is typically $\sim \mathcal{O}(1) d_e^{loc}$ thick and $\sim \mathcal{O}(10) d_e^{loc}$ long, where d_e^{loc} is a local electron inertial length. More work is necessary for better prediction. We have also discussed structures surrounding the dissipation region, such as a narrow fast electron jet and a shock-like jet front. Our understanding is summarized in a unified picture in Ref. [2].

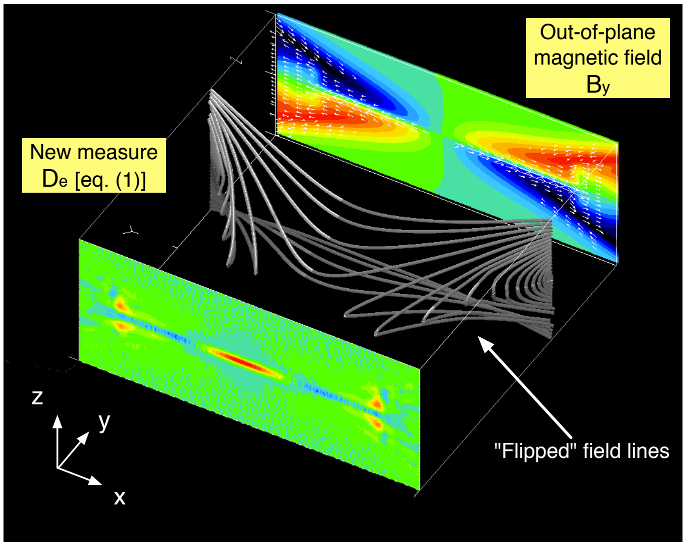

Figure 1: Magnetic field lines, the dissipation measure D_e (Eq. 1), and the out-of-plane magnetic field B_y from run 1A in Ref. [2].

It is important to verify the new theory in the real world. Efforts are in progress to probe the dissipation region by laboratory experiments or by satellite observations in the terrestrial magnetosphere. Hopefully NASA's upcoming magnetospheric multiscale (MMS) mission [3] will observe reconnection sites at electron-scale spatial and temporal resolutions after 2014. We hope that MMS will find an unambiguous evidence for the dissipation region.

References

[1] Zenitani, S. *et al.*: 2011, *PRL*, **106**, 195003.

[2] Zenitani, S. *et al.*: 2011, *Phys. Plasmas*, **18**, 122108.

[3] http://mms.gsfc.nasa.gov/.