A New Measure of the Dissipation Region in Collisionless Magnetic Reconnection

無衝突磁気リコネクションの磁気拡散領域の新定義

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We propose a new measure to identify a small-scale dissipation region in collisionless magnetic reconnection. Formulating the energy transfer in the electron's rest frame, we introduce an electron-frame dissipation measure. The measure is an invariant scalar and extensively tested by particle-in-cell simulations: the innermost region surrounding the reconnection site is accurately located in various cases. We further discuss implications for nonideal MHD dissipation and reconnection structures.

1. Background

Collisionless magnetic reconnection is an important process in many plasma systems, ranging from solar-terrestrial environments to extreme astrophysical settings. It is known that the reconnection process is critically controlled by the compact dissipation region (**DR**) near the X-point and therefore the structure of the DR has been of great interest. Typically, the innermost DR has been identified by the out-of-plane electron nonidealness, $E + v_e \times B \neq 0$. However, it is not clear whether this is applicable to general cases. In fact, recent numerical simulations exhibited puzzling results and reconnection scientists were at a loss how to find the DR [1-6].

2. A new measure of the DR

In this work, we present our solution to these important problems. Considering the energy transfer from the electromagnetic field to plasmas in the electron's fluid frame, we introduce the electron-frame dissipation measure D_e [7]:

$$D_e = \vec{j}' \cdot \vec{E}' = \gamma_e \left[\vec{j} \cdot \left(\vec{E} + \vec{v}_e \times \vec{B} \right) - \rho_c \vec{v}_e \cdot \vec{E} \right] \quad (1)$$

This measure is a Lorentz-invariant, i.e. frame-independent scalar quantity. We test our measure by two-dimensional particle-in-cell simulations, and show that the measure accurately identifies the innermost region surrounding the reconnection site (see Figure). From the MHD viewpoint, it is related to the nonideal energy conversion.

We further extend our theory to structures of reconnection sites: the central dissipation region, which is controlled by electron physics, an anti-dissipative electron jet, and an electron shock are identified. Our measure provides a new perspective on understanding the inner structures in collisionless magnetic reconnection.

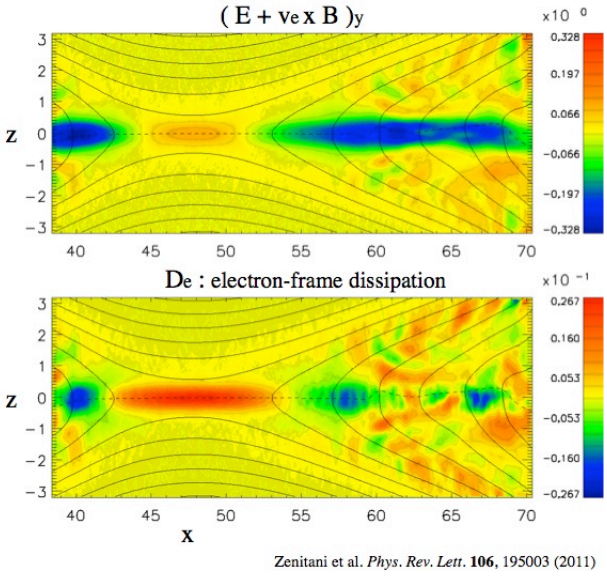

Fig.1. 2D particle-in-cell simulation from Ref. [7]
Top: A conventional measure $[E + v_e \times B]_y$
Bottom: Our new dissipation measure D_e (Eq. 1)

References

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