Magnetic Diffusion and Ion Nonlinear Dynamics in Magnetic Reconnection

ZENITANI, Seiji (NAOJ)
SHINOHARA, Iku (JAXA/ISAS)
NAGAI, Tsugunobu (Tokyo Institute of Technology)
WADA, Tomohide (NAOJ)
UMEDA, Takayuki (Nagoya University)

Collisionless magnetic reconnection is an important process of energy release in space and astrophysical plasmas. It is challenging to understand the physics of collisionless reconnection, because we have to deal with the fully kinetic motion of all particle species. In this work, we study the ion kinetic motion in the reconnection outflow region by means of 2D particle-in-cell (PIC) simulations [1].

Collisionless reconnection exhibits a 3D structure of magnetic field lines, as they are dragged out-of-page (Fig. 1). This stems from the decoupling of the motion of electrons and ions. Such complex magnetic topology makes it difficult to understand the particle dynamics. Figure 2 shows an ion velocity distribution function (VDF), taken in the "Hall physics region" in Figure 1. As can be seen, it is very different from an isotropic one of gyrating ions.

We analyze this VDF in analogy with the nonlinear particle dynamics in curved magnetic topology [2]. We translate the VDF to a Poincaré map (the bottom-left panel in Fig. 2) in the curved field. The Poincaré map tells us that the ions undergo chaotic motions instead of full gyrations, and it brings deep insight to particle motions. We extensively discuss the components of the VDF and the relevant ion motions in Ref. [1]. For example, we find that some ions are confined in a narrow path, the so-called "regular orbit." This is evident in the small hump in the VDF and the closed circles in the Poincaré map, as indicated by the arrows in Figure 2.

It is noteworthy that the ion ideal condition is violated in the Hall-physics region, $\vec{E} + \vec{v}_i \times \vec{B} \neq 0$, because the ions no longer gyrate. Traditionally, the plasma nonidealness has been considered as a signature of the reconnection diffusion-region. However, we argue that this Hall-physics region is outside the diffusion region, because the diffusion region should the place where the system relaxes into the plasma frozen-in state of $\nabla \times (\vec{E} + \vec{v} \times \vec{B}) = 0$ [3]. The physics and the structure of the reconnection site should be reconsidered, taking these updates into account.

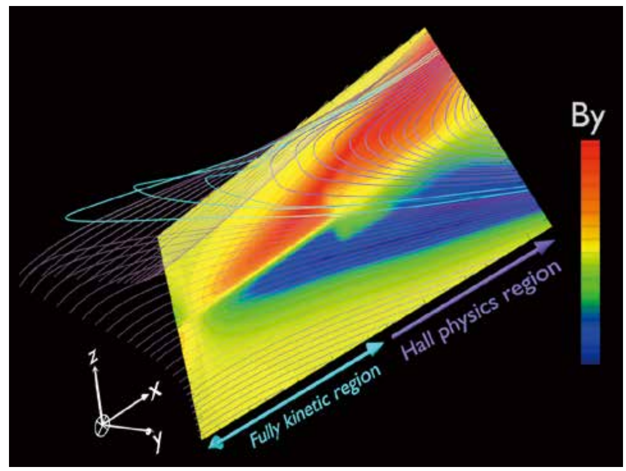

Figure 1: The magnetic field lines in our 2D PIC simulation. The rear panel (color contour) indicates the out-of-plane component, B_y (Reprinted from Ref. [1]).

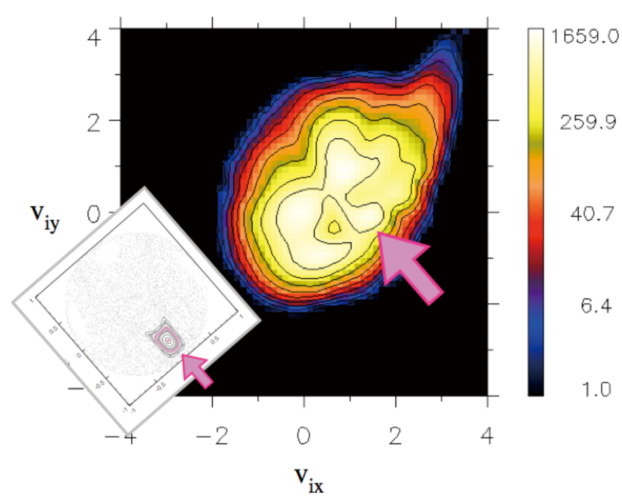

Figure 2: (Main) Ion velocity distribution function in the Hall-physics region. (Bottom-left) Poincaré map for a relevant parameter.

References

[1] Zenitani, S., et al.: 2013, *Phys. Plasmas*, **20**, 092120.
[2] Chen, P., Palmadesso, P. J.: 1986, *J. Geophys. Res.*, **91**, 1499.
[3] Zenitani, S., Umeda, T.: 2014, *Phys. Plasmas*, **21**, 034503.