Magnetic diffusion and ion nonlinear dynamics in magnetic reconnection

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Magnetic reconnection is a fundamental process in many plasma systems, ranging from laboratory and solar-terrestrial environments to extreme astrophysical settings. The reconnection process is controlled by magnetic dissipation physics in a small-scale region near the reconnection point (X-line), and therefore the structure of the reconnection site is of strong interest. According to the standard picture of collisionless reconnection, the X-line is surrounded by a compact electron diffusion region and by an outer ion diffusion region. While the electron region has been extensively studied, much less is known about the ion region.

In this work, we examine key aspects of the ion region in magnetic reconnection. First, we evaluate the “diffusion” of magnetic field lines, going back to the topology theorems. Unlike in the MHD, the idealness, the frozen-in, magnetic diffusion, and the energy dissiation can be all different in a kinetic plasma. We will apply these concepts to the reconnection site in two-dimensional particle-in-cell (PIC) simulations. Importantly, in the outer part of the ion region, even though the ion ideal condition is violated, the magnetic fields are frozen to plasma fluids. This raises a serious question to the widespread definition of the ion diffusion region, based on the ion nonidealness.

We further examine the ion velocity distribution function in the same region. The distribution function contains multiple populations such as global Speiser ions, local Speiser ions, and trapped ions. The particle motion of the local Speiser ions in an appropriately rotated frame explains the plasma nonidealness. The trapped ions are the first demonstration of the regular orbits in Chen and Palmadesso (1986), in self-consistent PIC simulations. They would be observational signatures in the ion current layer near reconnection sites.