Electron particle dynamics in collisionless magnetic reconnection

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In order to study the inner workings of magnetic reconnection, NASA has recently launched Magnetospheric Multiscale (MMS) spacecraft. MMS observes electron-physics signatures such as velocity distribution functions (VDFs) at ultrahigh resolution in space. Since VDFs and other signatures are outcomes of electron kinetic motion, it is important to understand the electron orbits in the reconnection system. In this work, we study electron orbits and dynamics near the X-line, by using two-dimensional particle-in-cell (PIC) simulations.

First, we study electron dynamics in magnetotail-type symmetric reconnection. By analyzing millions of electron orbits, we discovered many new orbits in the electron-physics layer near the X-line, as indicated in Figure 1. The new orbits include (1) Figure-eight-shaped regular orbits inside the electron jet, (2) noncrossing Speiser orbits that do not cross the midplane, (3) noncrossing regular orbits on the jet flanks, and (4) nonadiabatic orbits in the downstream of the jet termination region. Among them, the noncrossing orbits are mediated by the polarization electric field (Hall electric field E_z) near the midplane. Properties of these orbits are organized by an electrostatic extension of the particle-orbit theory (Buchner & Zelenyi 1989 JGR). Surprisingly, the new noncrossing electrons appear to be the majority in the system. This raises a serious question to our present understanding of physics of collisionless magnetic reconnection, which only assumes crossing populations. We will also discuss spatial distribution of energetic electrons and observational signatures of noncrossing electrons.

Second, we study electron dynamics in magnetopause-type asymmetric reconnection. In this case the polarization electric field enhances the meandering motions of sheath-origin electrons. They are evident in a crescent-shaped VDF, as highlighted in recent studies (Hesse+ 2014 GRL, Burch+ 2016 Science). The chaotic electron orbits are found in conjunction with the violation of the electron idealness in the sheath-side vicinity of the X-line and inside the outflow exhaust.

Finally, we will organize our understanding of electron physics in collisionless magnetic reconnection, based on these investigations.

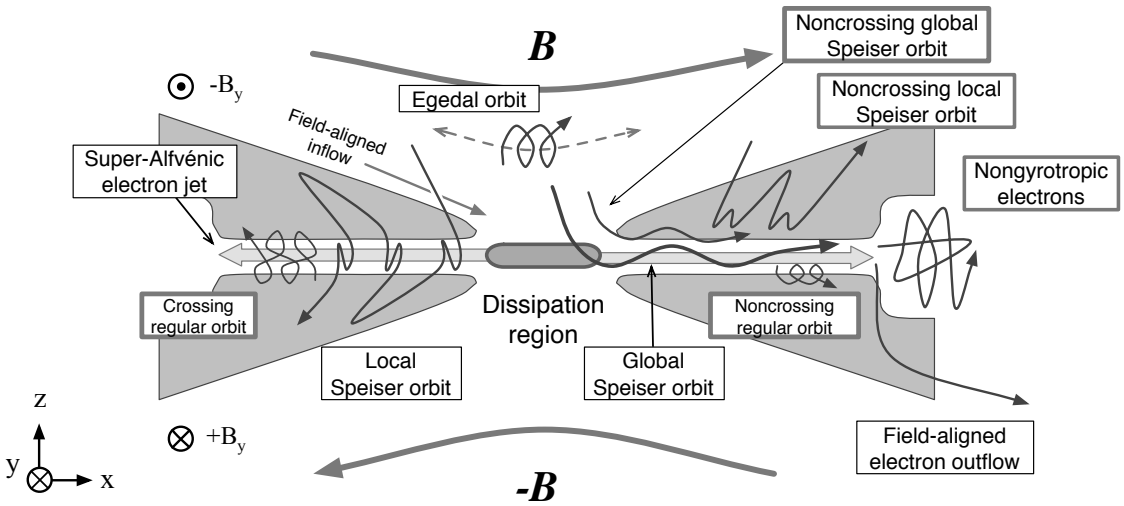

Figure 1: Summary of electron orbits in symmetric magnetic reconnection (Ref. [1]).
The new orbits are indicated by the double frames.

References:

[1] Zenitani & Nagai, *Phys. Plasmas* **23**, 102102 (2016)
[2] Zenitani, Hasegawa, & Nagai, submitted to JGR Space Physics (2017)