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Observation of non-gyrotropic electron distribution across the electron diffusion region in the magnetotail reconnection

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Magnetic reconnection is a fundamental plasma process, by which magnetic energy can be effectively converted into plasma kinetic and thermal energy in space, astrophysical and laboratory plasmas. In collisionless environments, magnetic reconnection includes multi-scale process in the current sheet. A particular interesting area is the electron diffusion region (EDR), surrounding the X-line, where the electron frozen-in condition was broken, resulting in the reconfiguration of the magnetic field topology. Numerous simulations predicted that the EDR corresponded to the electron current layer formed by the electron flows along the X-line. Direct measurements of the EDR were few before the launch of the Magnetospheric Multiscale (MMS) mission.

Based on accurate measurements of electron velocity distribution function from MMS, the crescent-shaped electron distribution was first reported in the plane perpendicular to the magnetic field in close proximity to an EDR at the magnetopause[1], which was predicted as one distinct EDR feature in asymmetric reconnection simulations. The following study of tens of EDR events at the magnetopause further confirmed this kind of electron distribution. A few mechanisms were proposed to interpret such distribution, such as meandering (cusp-like) electron orbits[2] and a drift-kinetic model[3]. Most recently, the crescent-shaped electron distribution was detected in the EDR of a symmetric reconnection in the magnetotail as well[4], as predicted by numerical simulations[5]. Moreover, multiple discrete striation of the crescent-shaped and the triangle-shaped in the electron distribution functions were measured and attributed to multiple meandering bounces in the diffusion region.

Using measurements by the Magnetospheric Multiscale (MMS) spacecraft in the magnetotail, we studied electron distribution functions across an electron diffusion region. The dependence of the non-gyrotropic distribution on the energy and vertical distance from the EDR mid-plane was revealed for the first time. The non-gyrotropic distribution was observed everywhere except for an extremely narrow layer right at the EDR mid-plane. The energy of the non-gyrotropic distribution increased with growth of the vertical distance from the mid-plane. For the electrons within certain energy range, they exhibited the non-gyrotropic distribution at the distance further away from the mid-plane than that expected from the meandering motion. The correlation between the crescent-shaped distribution with multiple stripes and the large Hall electric field was established. It appears that the measured non-gyrotropic distribution and the crescent-shaped distribution were caused by the meandering motion and the Hall electric field together.

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