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Three-dimensional Patchy Magnetic reconnection in Magnetosphere

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Magnetic reconnection releases large amounts of magnetic energy in astrophysical, space and laboratory plasmas. Hall reconnection model can explain the fast release of magnetic energy and most of its predictions have been demonstrated by in situ satellite observations[1-4]. However, this model is two-dimensional while the three-dimensional effect to reconnection is poorly known. It has been shown by numerical simulation that three-dimensional evolution, because of the freedom in the out-of-plane direction, is distinct from the two-dimension laminar reconnection in that reconnection occurs in multiple sites that are not necessarily in the primary neutral current sheet. It is characterized by the formation and interaction of multiple magnetic flux ropes[5], or chaotic magnetic field lines in the outflow region[6]. Although small-scale magnetic flux ropes and their interactions have been observed[7], one important missing piece of this scenario is whether reconnection occurs at the separatrix region, or say, the region away from the neutral current sheet. Here we present the first evidence for localized secondary reconnection at the separatrix surface of a magnetic flux rope (Fig. 1). This secondary reconnection occurs between the axial magnetic field of the magnetic flux rope, which points out-of-plane of the magnetopause reconnection, and the magnetospheric field (Fig. 2). This three-dimensional patchy reconnection in the exhaust facilitates the cross-scale energy conversion from the macro-scale down to electron-scale and leads to a turbulent evolution of reconnection.

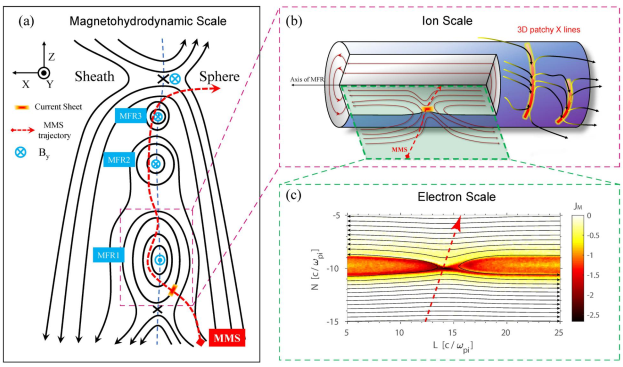

Fig. 1. (a) 2-D sketch of MMS trajectory in GSM coordinates through the three MFRs in the reconnection exhaust, which was produced by a magnetopause reconnection northward of the spacecraft; (b) 3-D diagram of the current sheet and X-lines at the separatrix surface of the MFR, and (c) a zoomed-in view of the X-line from the 2-D PIC simulation at t = 25 Ω_{ci}^{-1}. The red dashed lines represent the spacecraft trajectory in N-L plane. The color codings show the out-of-plane current density and the black curves represent the magnetic field lines.

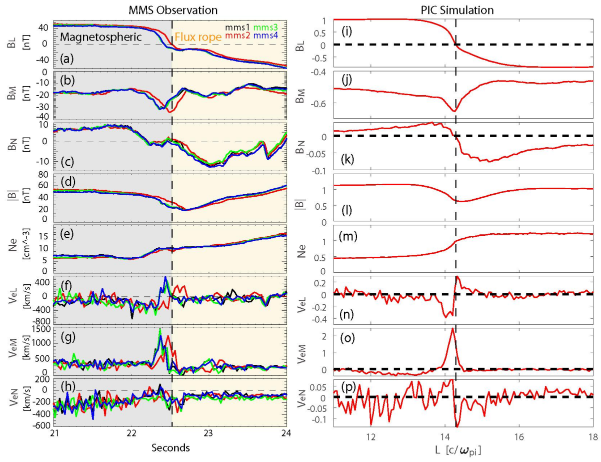

Fig. 2. The left column presents the four MMS observatio in LMN coordinates: (a)-(c) three components of magnetic field; (d) total magnetic field; (e) electron number density and (f)-(h) three components of the electron bulk velocity. The right column shows the two-dimensional PIC simulation results at t=25 Ω_{ci}^{-1} along the red arrow in Fig. 2c: (i)-(k) three components of the magnetic field; (l) total magnetic field; (m) electron density; and (n)-(p) three components of the electron bulk velocity. The gray shaded area marks the magnetospheric side of the current sheet, while the yellow shaded area marks the region within the flux rope. The vertical dashed lines mark the center of current sheet, B_L=0.

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