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Magnetic island formation in reconnecting electron-scale current sheet: Magnetospheric Multiscale observations in Earth's magnetotail

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Magnetic reconnection in Earth's magnetotail is fast, with an inflow plasma speed of ~0.1 times the inflow Alfvén speed, and has large-scale impacts, for example, on explosive release of magnetic energy during magnetospheric substorms. Magnetotail reconnection occurs under such simple boundary conditions that on the two sides of the current sheet the magnetic fields are approximately oppositely-directed with a comparable intensity, and plasmas are laminar with similar densities and temperatures. Such nearly anti-parallel and symmetric reconnection is ideal for studying intrinsic properties of reconnection in collisionless plasmas.

In the standard model of reconnection, an electron-scale diffusion region (EDR) where both ions and electrons violate the 'frozen-in condition' and a magnetic-to-electron energy conversion occurs is localized with an X-type magnetic-field geometry (Fig. 1a). It is generally accepted that in such EDRs most of the energy of anti-parallel magnetic fields injected by the inflow is partitioned to the bulk-flow energy of electrons ejected into the regions downstream of the EDR, by magnetic tension (Lorentz force) of reconnected field-lines. Numerical simulations[1] suggest that the EDR may be elongated to a planar geometry (Fig. 1b) and such a spatially extended EDR can be a site ideal for the generation and growth of small-scale magnetic islands (Fig. 1c,d). However, evidence for islands forming in the EDR itself has so far been lacking. Moreover, it is unknown exactly how the energy conversion occurs in observed EDRs. This is not only because unambiguous identification of EDR structures in space requires high-spatiotemporal-resolution plasma measurements, but also because there has been no data-analysis method to distinguish whether the magnetic field injected into the EDR is reconnected or annihilated.

Here we present in-depth analysis of the fortuitous multi-spacecraft observations during a weak substorm of a magnetotail EDR, providing direct evidence for a magnetic island forming in an elongated electron-scale current sheet (ECS). Fast four-point measurements of electromagnetic fields and plasmas by the Magnetospheric Multiscale (MMS) mission,[2] combined with novel data-analysis techniques,[3,4] demonstrate that fast magnetic-to-particle energy conversion in the detected ECS was dominated by magnetic-field annihilation, rather than reconnection. The experimental discovery of magnetic-field annihilation in a reconnecting ECS provides the first direct confirmation that magnetic energy can be irreversibly dissipated through collisionless reconnection[5]. Our finding reveals a new form of magnetic-to-particle energy conversion in the reconnection process that can occur when the EDR has evolved from the X-type to planar geometry (Fig. 1b,c).

References

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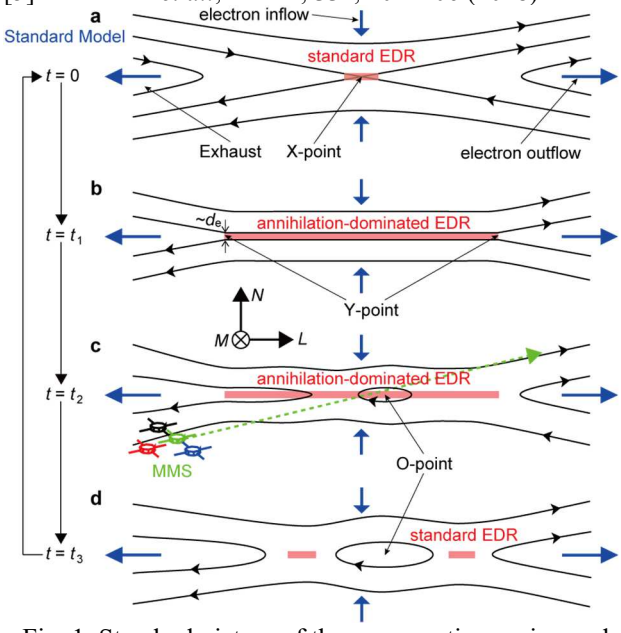

Fig. 1. Standard picture of the reconnection region and possible sequence of time evolution of the electron-scale current sheet observed by the MMS spacecraft.