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Stacked Electron Diffusion Regions and Electron Kelvin-Helmholtz Vortices within the Ion Diffusion Region of Collisionless Magnetic Reconnection

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The structure of the electron diffusion region (EDR) is essential for determining how fast the magnetic energy converts to plasma energy during magnetic reconnection. Conventional knowledge of the diffusion region assumes that the EDR is a single layer embedded within the ion diffusion region (IDR). Recent 3-D kinetic simulations show that kinetic-scale instabilities significantly affect the electron dynamics, which alters the structure of the diffusion region, setting it apart from the conventional description. The lower-hybrid drift instability developed along the X-line substantially disturbs the X-line and leads to a turbulent diffusion region.[1,2] The electron shear instability can drive the filamentation of reconnecting current sheets, providing anomalous viscosity for reconnection.[3] Liu et al.[4] demonstrate that multiple EDRs may be stacked within a broader ion-scale diffusion region due to the oblique tearing modes at different electron resonance layers. In situ observations are urgently required to resolve fine structures of the diffusion region.

This work reports the first observation of two EDRs that stack in parallel within an IDR by the Magnetospheric Multiscale (MMS) mission. The oblique tearing modes can result in these stacked EDRs. Intense electron flow shear in the vicinity of two EDRs induced electron Kelvin-Helmholtz vortices, which subsequently generated kinetic-scale magnetic peak and holes, which may effectively trap electrons. Our analyses show that both the oblique tearing instability and electron Kelvin-Helmholtz instability are important in three-dimensional reconnection since they can control the electron dynamics and structure of the diffusion region through cross-scale coupling as illustrated in Figure 1.

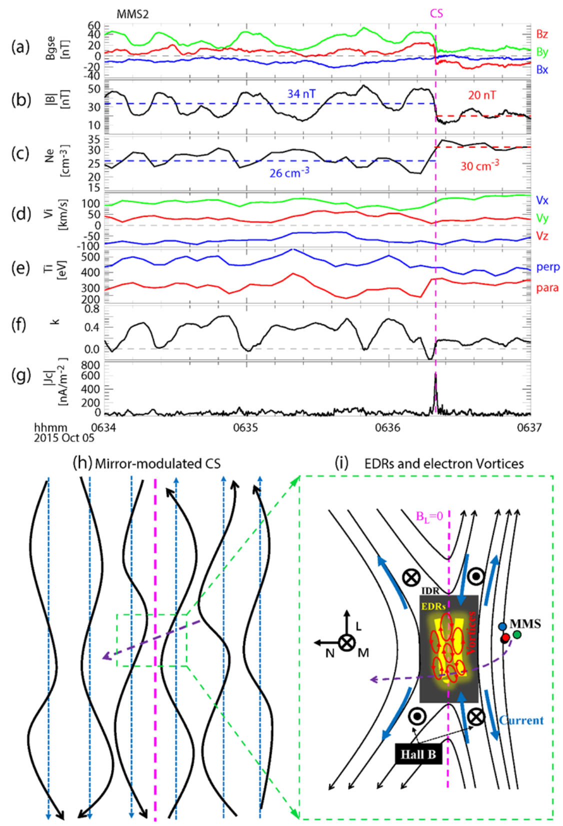

Figure 1. MMS observations between 06:34:00 and 06:37:00 UT. (a) Three components of the magnetic field; (b) total magnetic field; (c) electron density; (d) ion bulk velocities; (e) ion temperatures; (f) the parameter $k = \frac{T_{i\perp}}{T_{i\parallel}} - \left(1+\frac{1}{\beta_{\perp}}\right)$, which is critical to the ion-mirror instability; (g) current density estimated by the curlometer method, $J_c = \nabla \times B$. (h) a sketch of the mirror-modulated reconnecting current sheet: the blue dashed lines are the unperturbed magnetic field; the magenta dashed line indicates the center of the current sheet and the black solid lines represent the mirror-modulated magnetic field. (i) a sketch of two EDRs and electron flow vortices (red rings) within the IDR.

References

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