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Special Section:
First results from NASA's Magnetospheric Multiscale (MMS) Mission

Key Points:
- Electron-scale measurements of magnetic reconnection at the Earth's magnetopause with a moderate magnetic guide field were made by MMS
- Confirmed simulation results of a mixture of low- and high-energy electrons at magnetic null and nongyrotropic electrons at stagnation point
- Bifurcated out-of-plane current system was observed with peaks near the in-plane magnetic null and the flow stagnation point

Supporting Information:
- Supporting Information S1
- Figure S1
- Figure S2
- Figure S3
- Figure S4
- Movie S1
- Movie S2
- Movie S3
- Movie S4

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Magnetic reconnection at the dayside magnetopause: Advances with MMS

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Abstract Magnetic reconnection is known to be an important process for coupling solar wind mass and momentum into the Earth's magnetosphere. Reconnection is initiated in an electron-scale dissipation/diffusion region around an X line, but its consequences are large scale. While past experimental efforts have advanced our understanding of ion-scale physics and the consequences of magnetic reconnection, much higher spatial and temporal resolutions are needed to understand the electron-scale processes that cause reconnection. The Magnetospheric Multiscale (MMS) mission was implemented to probe the electron scale of reconnection. This article reports on results from the first scan of the dayside magnetopause with MMS. Specifically, we introduce a new event involving the radial traversal of guide-field reconnection to illustrate features of reconnection physics on the electron scale.

1. Introduction

The essentially continuous existence of magnetic reconnection along the magnetopause has allowed numerous measurements to be made at the MHD and ion scales, at which the predicted ion jets within reconnection exhaust regions are readily observed [e.g., *Paschmann et al.*, 1979; *Sonnerup et al.*, 1981; *Gosling et al.*, 1986]. Multispacecraft measurements of these ion jets have shown that the reconnection X lines from which they emanate can be greatly extended across the magnetopause [e.g., *Phan et al.*, 2000; *Hasegawa et al.*, 2016], providing a relatively high probability of their being detected by single spacecraft or spacecraft constellations. Because the magnetospheric magnetic field is generally stronger than the magnetosheath field, and the magnetospheric plasma densities are much lower, reconnection at the magnetopause is typically highly asymmetric. In addition, there can be significant guide fields, which are perpendicular to the reconnecting fields. These features tend to set magnetopause reconnection apart from its magnetotail counterpart. An advantage in the study of magnetopause reconnection is that a spacecraft moving relatively slowly near its apogee can sample numerous magnetopause crossings as the position of the boundary moves in response to the variable solar wind conditions. A strategy implemented by the Magnetospheric Multiscale (MMS) mission [*Burch et al.*, 2016a] is to capture and transmit all magnetopause crossings in burst mode so that no dissipation regions at the magnetopause encountered by the spacecraft would be missed [*Fuselier et al.*, 2016; *Phan et al.*, 2016a]. As described in the next section, because of the high data volume and relatively low data transmission rate, only a few percent of the data can be acquired at the highest data rate, which is burst mode. Beginning on 1 September 2015 MMS performed a 6 month scan of the dayside magnetopause with a geocentric apogee of 12 Earth radii. The total number of magnetopause crossings captured in burst mode exceeded 3000, allowing the investigation of reconnection under many different boundary conditions.

Previous missions such as ISEE, Active Magnetospheric Particle Tracer Explorers, Wind, Polar, Geotail, Equator-S, Cluster, and Time History of Events and Macroscale Interactions during Substorms have made plasma measurements primarily on MHD and ion scales, which enabled the investigations of the large-scale structures and dynamics of reconnection. The main objective of MMS is to extend measurements of reconnection to the electron scale in order to address kinetic processes that cause reconnection and the dissipation of magnetic energy. This extension requires particle measurements to be made much faster than ever before with 3-D electron distribution functions acquired every 0.03 s and 3-D ion distributions acquired in 0.15 s, as compared to time resolutions in the few second range for the previous missions, which relied on spacecraft rotation to sample the full 3-D sky [*Pollock et al.*, 2016]. These required time resolutions were arrived at by the simple consideration of an electron dissipation/diffusion region (EDR) with a width of a few electron skin depths (d_e~2 km), a typical magnetopause radial velocity of 40 km/s [*Berchem and Russell*, 1982], and a