Analysis of Reconnection in the Magnetosphere on Kinetic Scales

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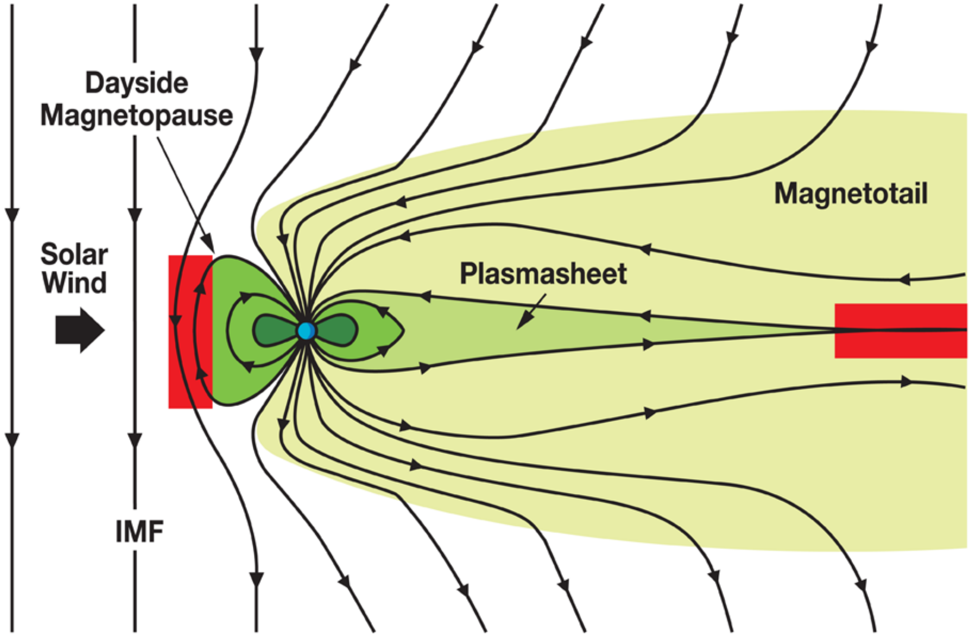
Abstract

We examine the role that ions and electrons play in reconnection using observations from the *Magnetospheric Multiscale* (*MMS*) mission on kinetic ion and smaller electron scales, which are much shorter than magnetohydrodynamic scales. This study reports observations with unprecedented high resolution that *MMS* provides for magnetic field (7.8 ms) and plasma (30 ms for electrons and 150 ms for ions). We compare probability distribution functions with wave activities during approaches to the dayside magnetopause to those at the nightside symmetric magnetotail region. We analyze three dimensional structures of the ion and electron diffusion regions and look for signatures of reconnection with various types of the magnetic field topologies. Besides usual magnetic field reversals, changes in the direction of the flow velocity, and ion and electron heating, *MMS* observed large fluctuations in the electron flow speeds when approaching the reconnection sites. The results obtained on kinetic scales may be useful for better understanding the physical mechanisms governing reconnection processes in various magnetized laboratory and space plasmas.

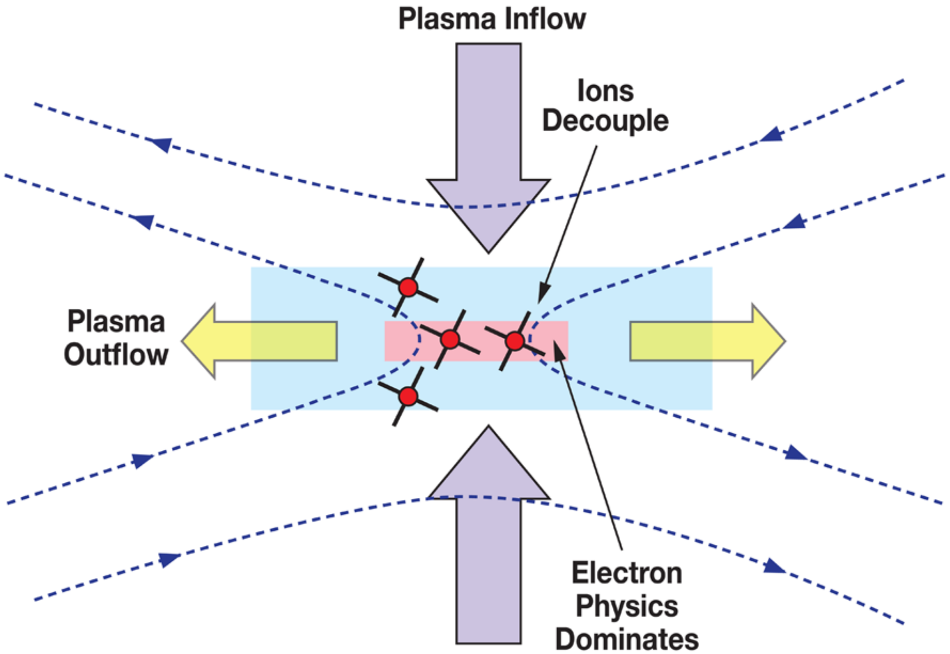
The Solar Wind and the Magnetosphere

The solar wind is a stream of charged particles (mainly ions and electrons) flowing from the Sun with the embedded interplanetary magnetic field (IMF). Interaction of this plasma of solar origin that fills-up the Solar System with the Earth dipole magnetic field results in the terrestrial magnetosphere including the magnetopause, plasmasheet, and magnetotail displayed in Fig. 1.



The structure of the Earth's magnetosphere is controlled by reconnection. As is known, reconnection occurs in two main regions of the magnetosphere: the dayside magnetopause and the nightside magnetotail, which are marked by red boxes in Fig. 1.

MMS and Reconnection



One of the the main objectives of the *Magnetospheric Multiscale* (*MMS*) mission is to determine the role of turbulence in reconnection processes and the roles of ions and electrons in these processes. Reconnection occurs mainly when the electrons cannot supply the current needed to support antiparallel magnetic fields. Inflowing plasma curries oppositely directed magnetic field lines into the ion (IDR, in blue) and electron (EDR, in pink) diffusion regions, as sketched in Fig. 2. The four *MMS* spacecraft (marked by red crosses) make the measurements needed to determine the processes that drive reconnection.

MMS data access

https://lasp.colorado.edu/mms/sdc/public/

https://spdf.gsfc.nasa.gov/

FGM
brst: 7.8 milliseconds
srvy: 0.0625 to 0.125 sec

FPI (ions and electrons)
brst: 30 milliseconds
fast: 4.5 seconds

We analyze the electric fields on sub-ion scales at the magnetopause and in the magnetotail near the X-line within highly variable plasmas to compare the characteristics of reconnection processes in both regions shown in Fig. 1, when going from the ion to electron kinetic scales, Fig. 2.

Methods

One-fluid MHD theory

The electric field $\mathbf{E}'_\mathrm{o} = \mathbf{E} + \mathbf{V} \times \mathbf{B} = \mathbf{R}$, seen in the rest frame by the plasma moving with the velocity $\mathbf{V}$, is described by the ideal case ($\mathbf{R} = 0$), see (e.g., Krall & Trivelpiece 1973).

Two-fluid theory

The sum of the contributions to the electric field, $\mathbf{E}_\mathrm{tot}$, consisting of various terms should be equal to the dissipation created by an anomalous resistivity η in the generalized Ohm's law (Rossi & Olbert 1970):

$$\mathbf{E}_\mathrm{tot} = \mathbf{E}'_\mathrm{o} + \mathbf{E}_\mathrm{H} + \mathbf{E}_\mathrm{a} + \mathbf{E}_\mathrm{p} = \eta \mathbf{j}, \qquad (1)$$

with $\mathbf{E}_\mathrm{H}$ (Hall), $\mathbf{E}_\mathrm{a}$ (inertial), and $\mathbf{E}_\mathrm{p}$ (pressure) terms.

The electric field $\mathbf{E}_\mathrm{p}$ becomes important in the region where ions decouple and electron physics dominates.

Hence, we propose that the ratio of the thermal pressure term to the sum of other terms including the ideal with Hall term $\mathbf{E}' \equiv \mathbf{E}'_\mathrm{o} + \mathbf{E}_\mathrm{H}$ and the electron (inertial) accelerating $\mathbf{E}_\mathrm{a}$ contributions, Equation (1),

$$r_\mathrm{e} \equiv |\mathbf{E}_\mathrm{p}| / |\mathbf{E}' + \mathbf{E}_\mathrm{a}|,$$

to be a useful **signature indicating approaches to the EDR**.

List of selected *MMS* spacecraft (s-c) interval samples

in the magnetopause (a) and the magnetotail (b–e)(hh.min.ss) with the current $\mathbf{j}$(μA/m2), the ideal $\mathbf{E}'_{\rm o}$ (mV/m) and the nonideal Hall, inertial, and pressure contributions, $\mathbf{E}_{\rm H}$, $\mathbf{E}_{\rm a}$, and $\mathbf{E}_{\rm p}$, respectively, together with the parameter $r_{\rm e}$ indicating approaches to the electron diffusion region (EDR)

Case	S-c	Time (y.m.d)	Begin	End	$\mathbf{j}$	$\mathbf{E}'_{\rm o}$	$\mathbf{E}_{\rm H}$	$\mathbf{E}_{\rm a}$	$\mathbf{E}_{\rm p}$	$r_{\rm e}$
(a)	2	2016.11.23	07.49:32	07.49:35	0.45	5–10	8	0.1–0.3	1–2.5	0.10
(b)	3	2017.07.11	22.34:01	22.34:05	0.064	3–8	12	1–2.5	2–3	0.08
(c)	2	2018.07.23	11.37:57	11.38:05	0.009	1–5	0.7	0.1–0.3	8–10	1.5
(d)	1–3	2018.07.24	17.46:33	17.46:41	0.037	1–1.5	0.25	0.15–0.25	100–200	90
(e)	1–3	2018.07.24	17.47:06	17.47:14	0.0056	$\lesssim$0.8	0.2	1–3	100–200	200

These newly observed electric fields when approaching the EDR (Macek et al. 2019a), cases (c–e), together with the first crossing of the EDR in the magnetotail by *MMS* on 11 July 2017 reported by Torbert et al. (2018) on the night side magnetosphere, case (b), were then compared with those at the magnetopause, (Webster et al. 2018), case (a). The estimated values for all these selected cases (a–e) are now displayed in Table 1.

Conclusions

- Following various observations of reconnection at the magnetopause and the first crossing of the EDR in the magnetotail by *MMS* on 11 July 2017 reported by Torbert et al. (2018) we have studied new *MMS* events on the nightside magnetosphere at the current sheet on 23 and 24 July 2018.

- In addition to ideal electric fields, our cases exhibit large electric field comparable in magnitude (1–10 mV/m) to those associated with the Hall current, which together with the rather moderate inertial accelerating fields (1–2 mV/m), are responsible for fast reconnection in the IDR.

- However, during the approaches to the EDR, as indicated by our newly devised reconnection parameter, the electric fields arising from the divergence of the full electron pressure tensor provide the main contribution (as large as 200 mV/m) to the generalized Ohm's law. We can hence expect that when ions decouple electron kinetic physics should provide the mechanisms responsible for reconnection processes.

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Collaboration

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