Imperial College London

The Relationship Between Collisionless Plasma Turbulence & Electron-Only Reconnection

Magnetospheric Multiscale Observations from Earth's Magnetosheath

Julia E. Stawarz,[1] J. P. Eastwood,[1] T.-D. Phan,[2] I. L. Gingell,[3] P. Sharma Pyakurel,[2] and M. A. Shay[4]

[1]Imperial College London, [2]University of California Berkeley, [3]University of Southampton, [4]University of Delaware

Key Points

- Recent observations have revealed a novel type of magnetic reconnection, known as *electron-only reconnection*, is present in Earth's turbulent magnetosheath [Phan+ (2018) *Nature*; *Stawarz+ (2019) ApJL*]
- Electron-only reconnection is thought to occur when the length of current sheets is too short for ions to fully couple to the newly reconnected field lines before they relax **(Fig. 1)**
- We systematically examine reconnection events in 60 intervals of magnetosheath turbulence using observations from NASA's *Magnetospheric Multiscale* (MMS) spacecraft
- Properties of the reconnection events are found to depend on correlation length of the turbulence

Figure 1

Adapted from Phan+ (2018) *Nature*

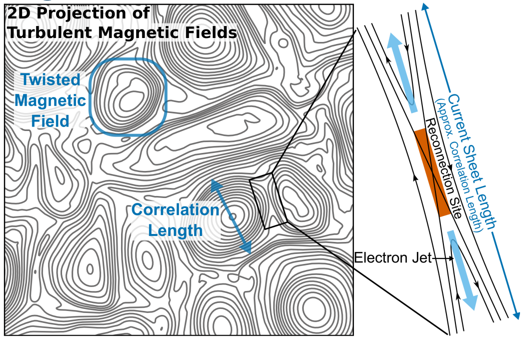
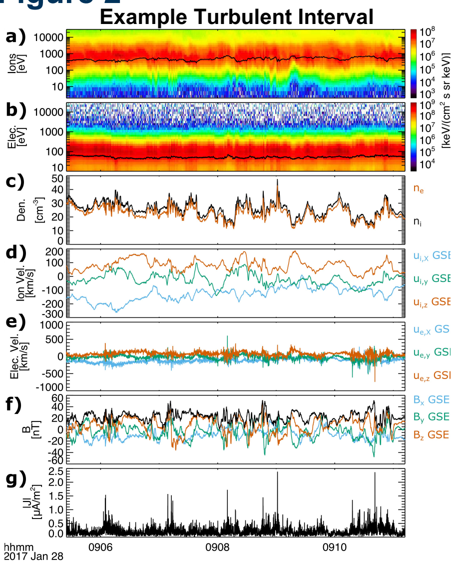


Figure 2



The region of shocked solar wind plasma downstream of Earth's bow shock is filled with complex turbulent fluctuations that generate many thin current sheets, which can be sites for magnetic reconnection **(Fig. 1)**

Whether ions couple into the reconnection dynamics could influence both the nonlinear turbulent dynamics and how dissipated energy is partitioned between particle species

→ Important to determine under what conditions electron-only reconnection occurs

---

We identify 60 magnetosheath turbulence intervals spread across the dayside magnetosheath for which high-resolution MMS *burst* data is available **(Fig. 2 & Fig. 3)**

Intervals are selected such that they are:

→ Roughly homogeneous on large-scales

→ Contain many turbulent correlation lengths

→ Taylor hypothesis is valid allowing the conversion of timescales to length scales (i.e., $\Delta x = -U_0 \Delta t$)

Science and Technology Facilities Council

THE ROYAL SOCIETY

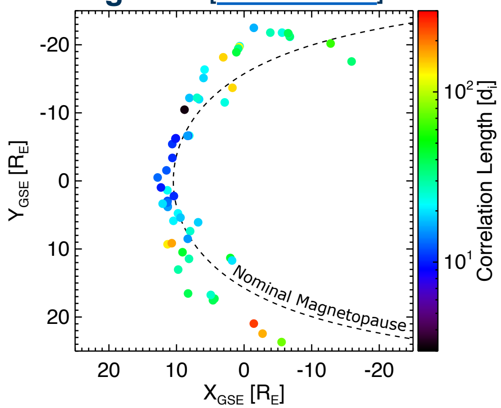
j.stawarz@imperial.ac.uk

@JEStawarz

Imperial College London

Analysing Magnetosheath Turbulence with MMS

Figure 3 [return to slide 1]



Magnetic Correlation Lengths

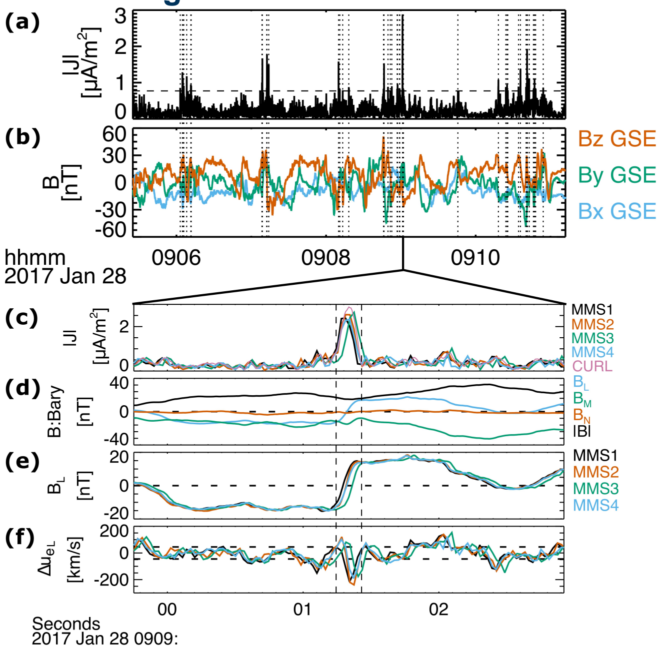
In a turbulent environment, typical length of current sheets expected to be set by size of turbulent magnetic field structures, which is characterised by the magnetic correlation length (λ_C)

$$R(\Delta \boldsymbol{x}) = \frac{\langle \delta \boldsymbol{b}(\boldsymbol{x}+\Delta \boldsymbol{x}) \cdot \delta \boldsymbol{b}(\boldsymbol{x}) \rangle}{\langle |\delta \boldsymbol{b}(\boldsymbol{x})|^2 \rangle}, \qquad \lambda_C = \int_0^\infty R(\Delta x) d\Delta x$$

In the analysed intervals, λ_C systematically varies from shorter values near the sub-solar point to longer values in the flanks of the magnetosheath **(Fig. 3)**

Idealised simulations show reconnection transitions from traditional ion-coupled reconnection to electron-only reconnection between ~ 10 to 40 ion inertial lengths [Pyakurel+ (2019) Phys. Plasmas], consistent with range of values observed in magnetosheath

Figure 4



Reconnection Events

MMS provides a unique dataset of high-resolution, multi-spacecraft measurements allowing us to systematically identify small-scale reconnection events and examining their properties

Reconnection Identification Method

- Local maxima in $|\boldsymbol{J}| > 3J_{rms}$ are identified **(Fig. 4a)**
- Adjacent maxima considered unique structures if minimum between them $< J_{peak}/2$
- Each structure is rotated into a local current sheet coordinate system **(Fig. 4d)**
  - $\widehat{\boldsymbol{N}} = \widehat{\boldsymbol{b}}_1 \times \widehat{\boldsymbol{b}}_2$, (current sheet normal)
  - $\widehat{\boldsymbol{M}} = \widehat{\boldsymbol{x}}_{max} \times \widehat{\boldsymbol{N}}$, (guide field direction)
  - $\widehat{\boldsymbol{L}} = \widehat{\boldsymbol{M}} \times \widehat{\boldsymbol{N}}$ (outflow direction)
- Check for reversals in B_L **(Fig. 4e)** and perturbations in $|\Delta \boldsymbol{u}_{e,L}| > 0.7 V_{A,L}$ **(Fig. 4f)**
- Manually verify each reconnection event

Overall, $\sim 10\%$ of the intense current sheets show clear evidence of reconnection

Science and Technology Facilities Council

THE ROYAL SOCIETY

j.stawarz@imperial.ac.uk

@JEStawarz

Imperial College London

Example Reconnection Events

Several additional features are observed for many events that are consistent with expectations from quasi-2D reconnection:

- → Bipolar variations in the out-of-plane (B_M) magnetic field component consistent with the Hall effect **(Fig. 5b & Fig. 6b)**
- → Deflection of electron jet toward one side of the current sheet due to $\boldsymbol{J}\times\boldsymbol{B}_{guide}$ force **(Fig. 5d)**
- → Strong electromagnetic energy conversion from fields into the particles in the reconnecting current sheet **(Fig. 5h & Fig. 6h)**
- → In some events, heating is be observed in conjunction with electromagnetic energy conversion **(Fig. 6i)**

Presence of ion jets in the events can be examined using the Walén relation

- → Look for change in correlation between $\Delta B_L/\sqrt{\mu_0 m_i n}$ and Δu_{iL} centred on the B_L reversal **(Fig. 6k-n)**
- → Majority of events do not show clear evidence of ion jets **(e.g., Fig. 5)**
- → Subset of 18 events have either fully or partially coupled ion jets **(e.g., Fig. 6)**

For an individual event, the lack of ion jets could be due to either electron-only reconnection or encountering the event near the x-line

Figure 5

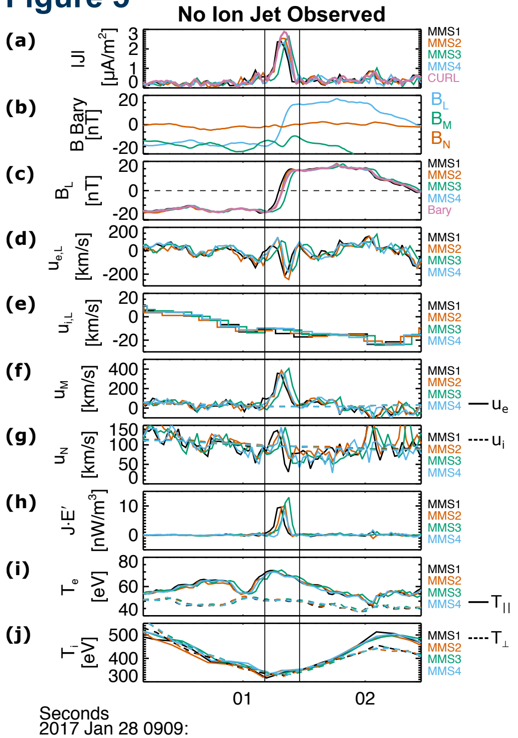
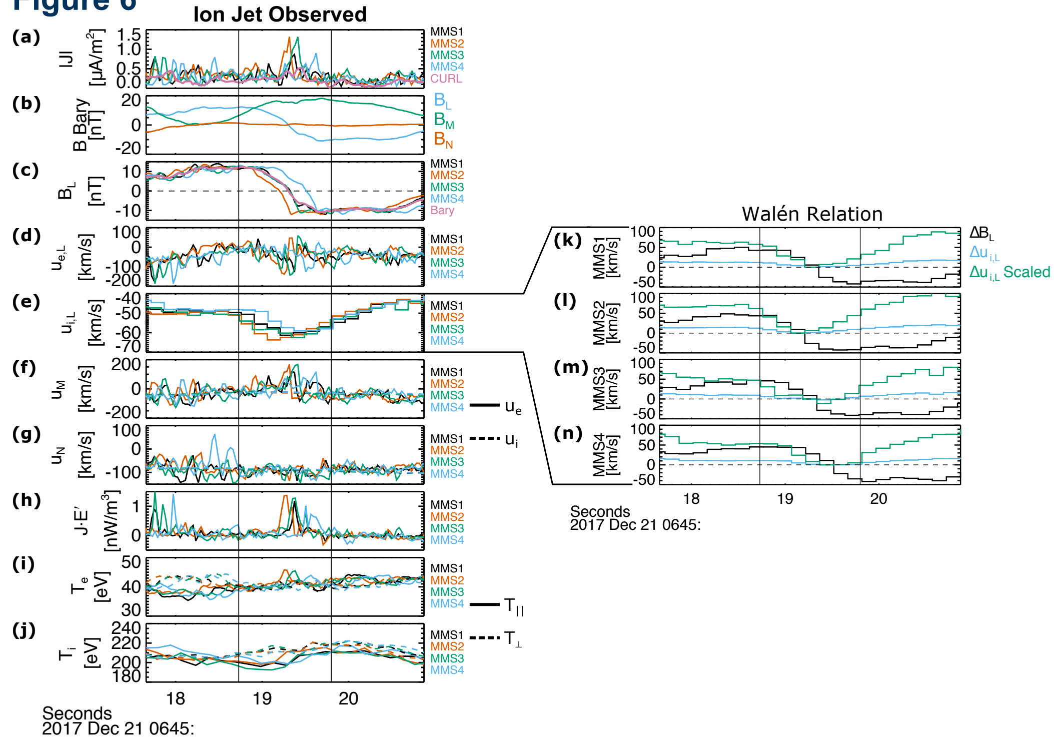


Figure 6



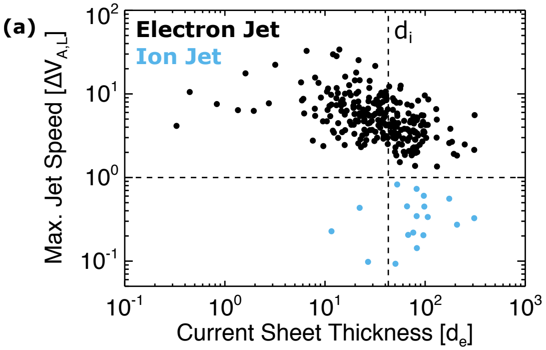
Science and Technology Facilities Council
THE ROYAL SOCIETY

j.stawarz@imperial.ac.uk
@JEStawarz

Imperial College London

Relationship Between Reconnection Properties & Magnetic Correlation Length

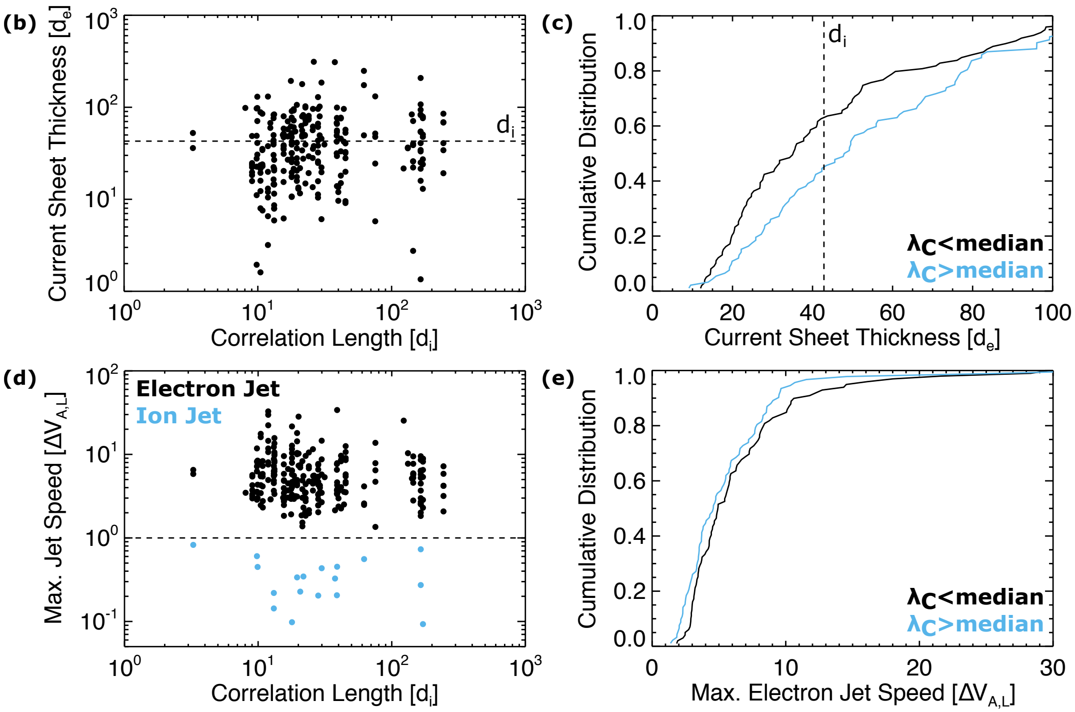
Figure 7



Unlike standard ion-coupled reconnection, electron-only reconnection is expected to occur at thin sub-ion scale current sheets and only produce fast super-Alfvénic electron jets [Phan+ (2018) *Nature*; Pyakurel+ (2019) *Phys. Plasmas*]

For each event, peak ion and electron jet speeds across the four MMS spacecraft and current sheet thickness observed at the spacecraft with the largest peak current are quantified

Fastest electron jets are observed at thin sub-ion scale current sheets, while ion jets are only observed at ion-scale current sheets **(Fig. 7a)**



Current sheet thicknesses are centred on ion inertial length for large λ_C and shift toward sub-ion scale current sheets at smaller λ_C **(Fig. 7b)**

→ Cumulative distributions show clear shift to thinner current sheets at short λ_C even when potential bias due to finite time resolution of observations is considered **(Fig. 7c)**

Tendency for faster electron jets in intervals with the shortest λ_C also apparent **(Fig. 7d)**

→ Difference in cumulative distributions is not as clear as for current sheet thickness but there may be a slight difference in large velocity tail **(Fig. 7e)**

No clear trend in ion jet speeds is apparent, but more events would be needed to identify one if it were present **(Fig. 7d)**

Results are consistent with electron-only reconnection being more prevalent for turbulence with shorter magnetic correlation lengths

j.stawarz@imperial.ac.uk

@JEStawarz