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The Relationship Between Electron-Only Magnetic Reconnection and Turbulence in Earth's Magnetosheath

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Overview

Objective

We perform a survey of turbulence-driven reconnection in Earth's magnetosheath using the Magnetospheric Multiscale (MMS) mission to examine the role of electron-only reconnection in turbulent plasmas

Outline

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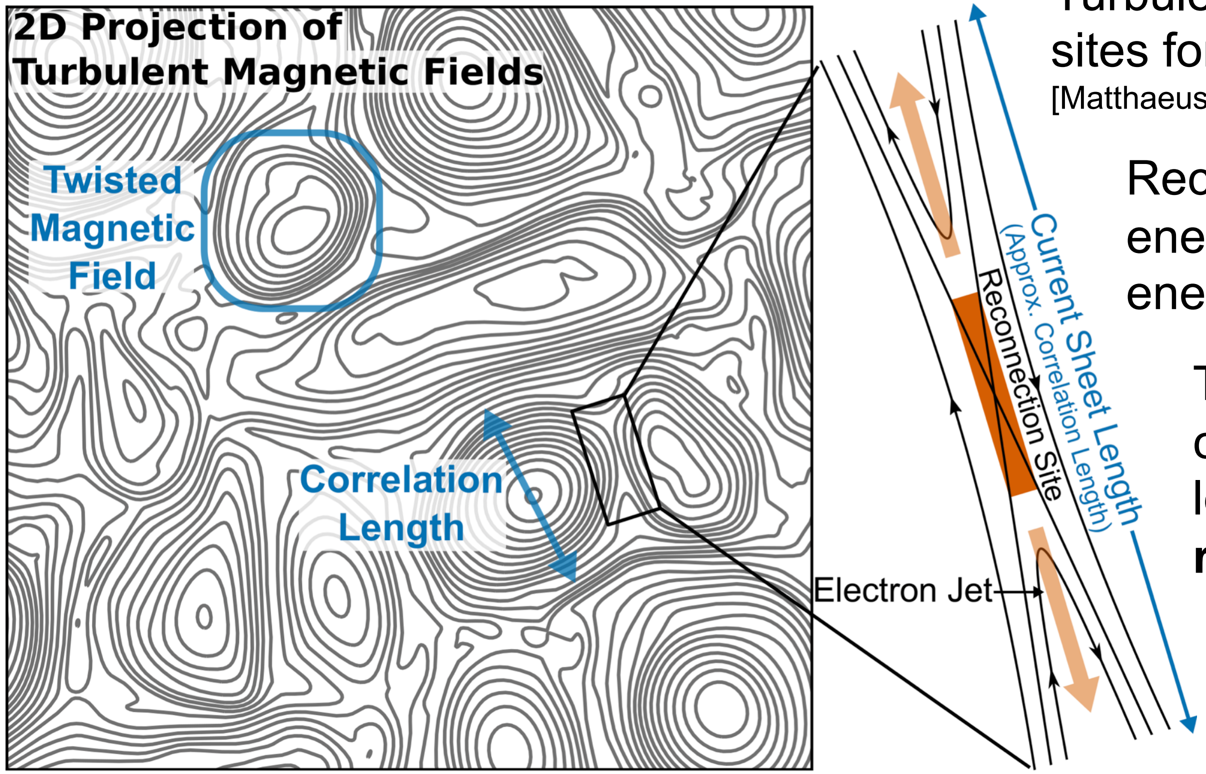
Part I: Reconnection in Turbulent Plasmas

Fig. 1



Adapted from Phan+ (2018) *Nature*

Turbulence generates thin current sheets that are potential sites for magnetic reconnection
[Matthaeus & Lamkin 1986; Carbone+ 1990; Servidio+ 2009; Franci+ 2017]

Reconnection can both convert magnetic energy to flow energy, contributing to nonlinear dynamics, and facilitate energy dissipation

Turbulent dynamics can limit the length of reconnecting current sheets, suppressing ion jet formation if the length is $\lesssim 40d_i$ and leading to **electron-only reconnection** (Fig. 1) [Phan+ 2018; Sharma Pyakurel+ 2019]

Current sheet length is limited by the size of twisted magnetic structures formed by the turbulence, which is quantified by the magnetic correlation length

Examples of turbulence-driven reconnection have been reported observationally in the magnetosheath both with and without ion jets
[Retinò+ 2007; Sundkvist+ 2007; Yordanova+ 2016; Vörös+ 2017; Phan+ 2018]

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Part II: Survey of Turbulence-Driven Reconnection

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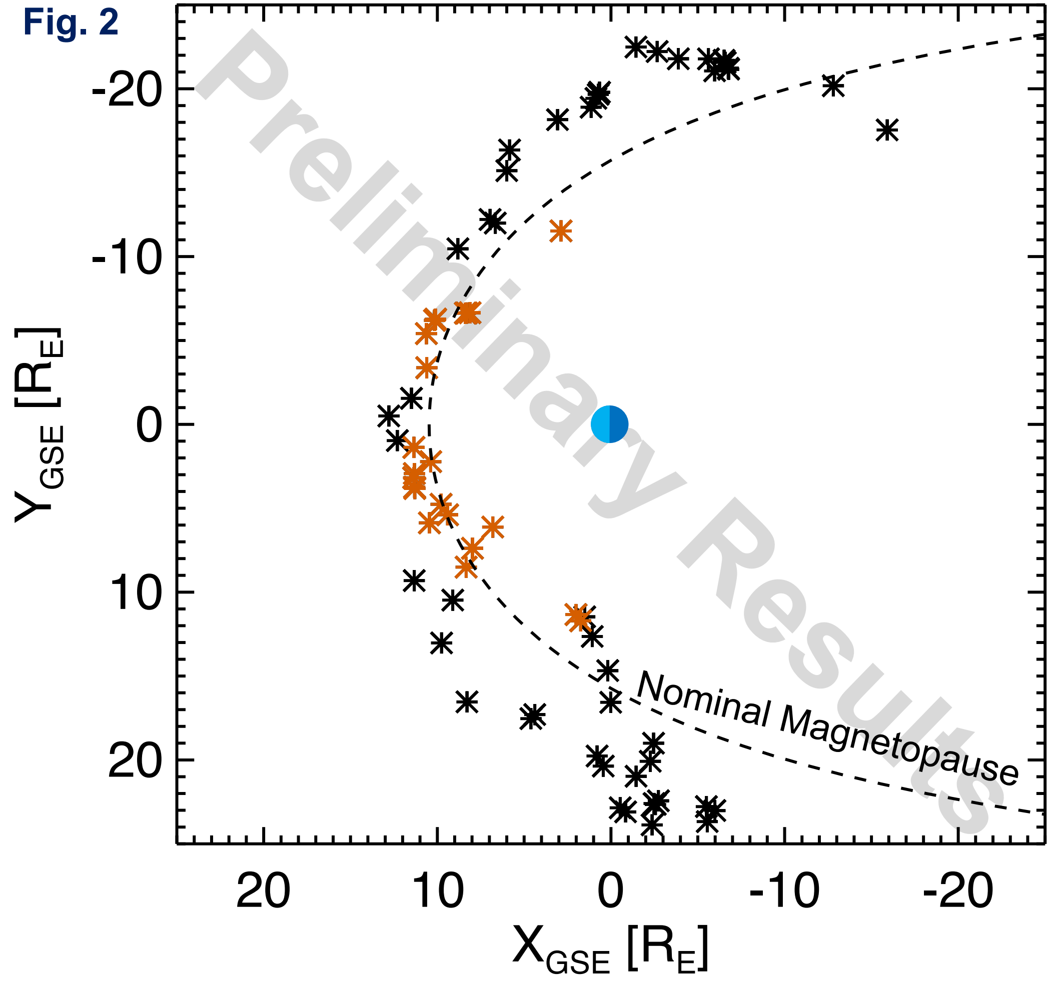
Magnetosheath Turbulence Intervals

Fig. 2



71 intervals of high-resolution turbulence data from MMS are identified in the magnetosheath (Fig. 2)

23 intervals have been examined in detail for evidence of turbulence-driven magnetic reconnection so far

Interval Selection Criteria

3+ minutes in length → many correlation lengths

Intervals with large-scale inhomogeneities were avoided

Validity of Taylor hypothesis ($\Delta x = V_0 \Delta t$) was verified using multi-spacecraft measurements

[Chen & Boldyrev 2017; Chasapis+ 2017; Chhiber+ 2018; Stawarz+ 2019]

→ allows conversion of timescales to length scales for turbulence analysis

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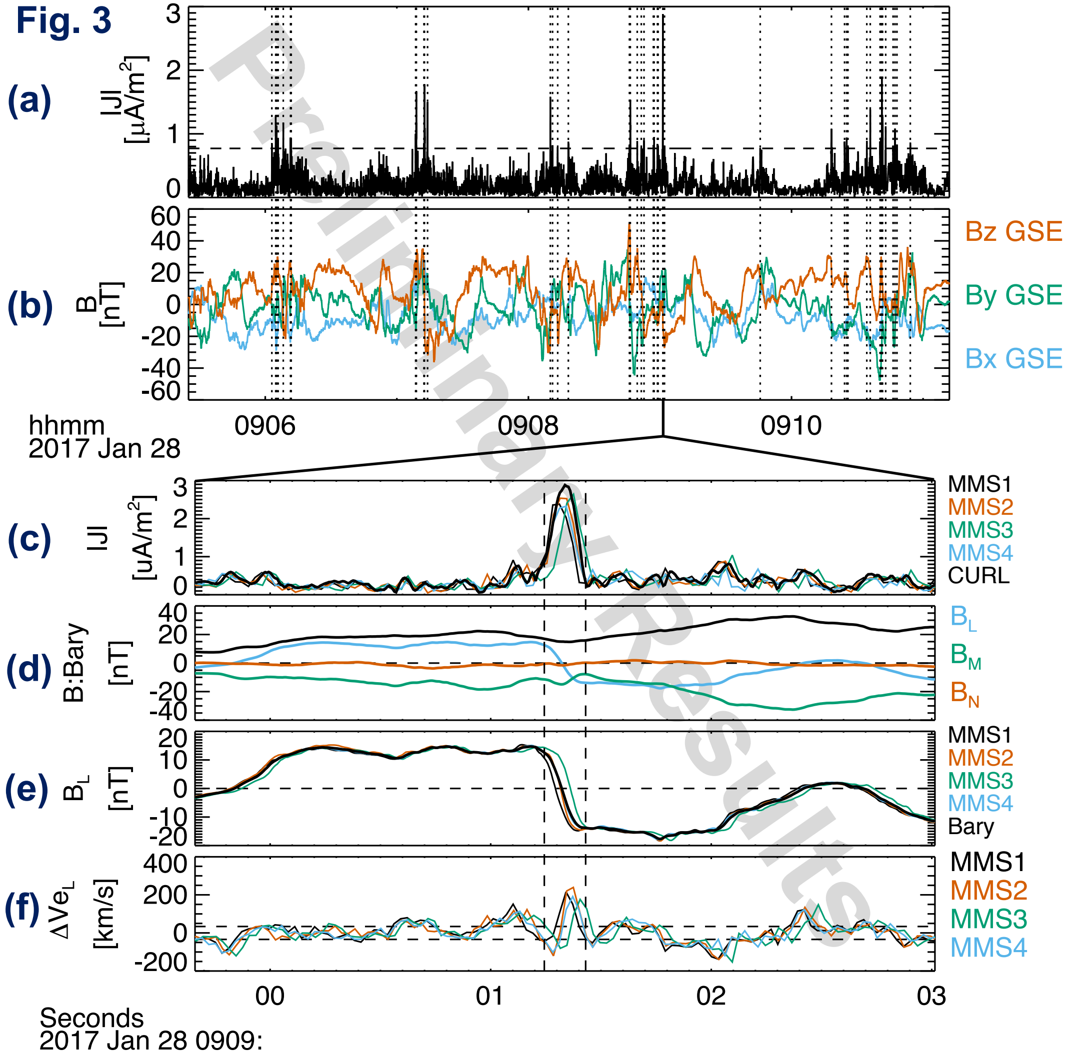
Identifying Reconnection Sites

Fig. 3



Potential reconnection events identified using partially automated algorithm – performed on 23 out of 71 intervals so far (see Fig. 2)

Current Structure Identification

All local maxima in $|J|$ with $J_{peak} > 3J_{rms}$ identified (Fig. 3a)

Adjacent $|J|$ peaks considered unique structures if minimum between them $< J_{peak}/2$

Reconnection Event Identification

Each structure rotated into local Hybrid-MVA coordinates (Fig. 3d)

$\hat{N} = \hat{b}_1 \times \hat{b}_2$, (current sheet normal) $\hat{M} = \hat{x}_{max} \times \hat{N}$, (guide field direction) $\hat{L} = \hat{N} \times \hat{M}$ (outflow direction)

Determined if B_L changes sign within current structure (Fig. 3e)

Determined if $|\Delta v_{e,L}| > 0.7 V_{A,L}$ near B_L reversal (Fig. 3f)

Potential reconnection events are then manually verified

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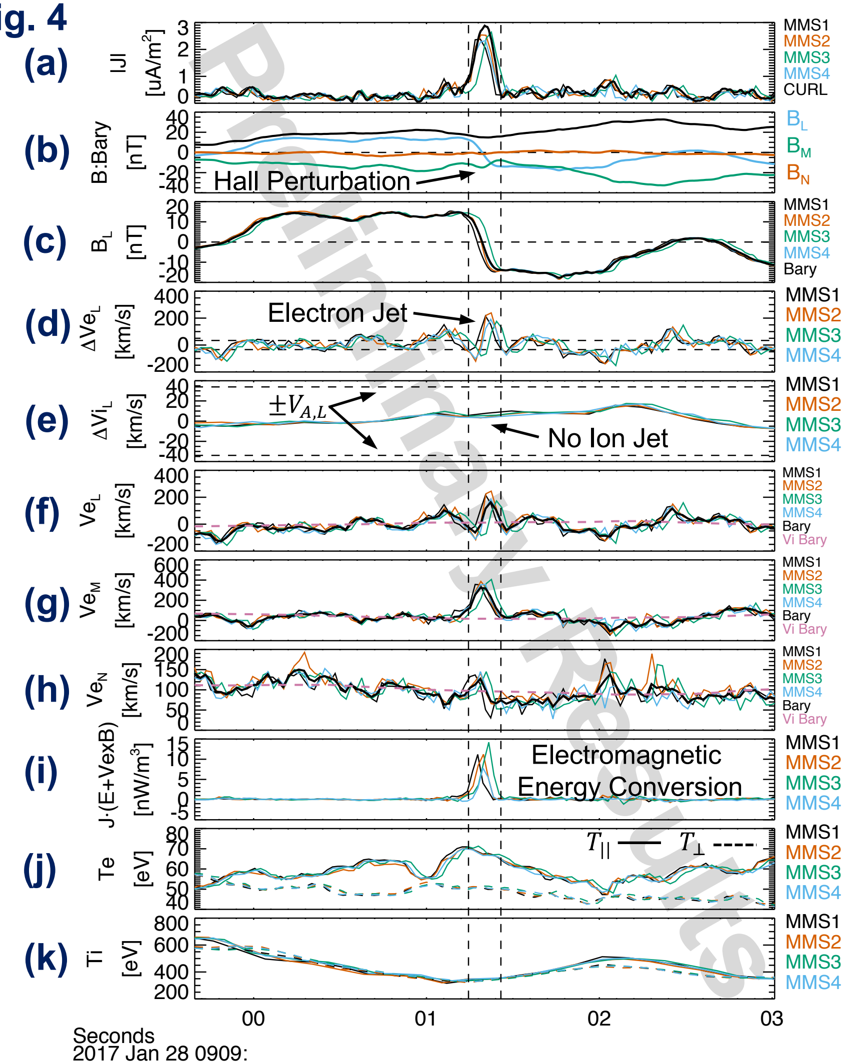
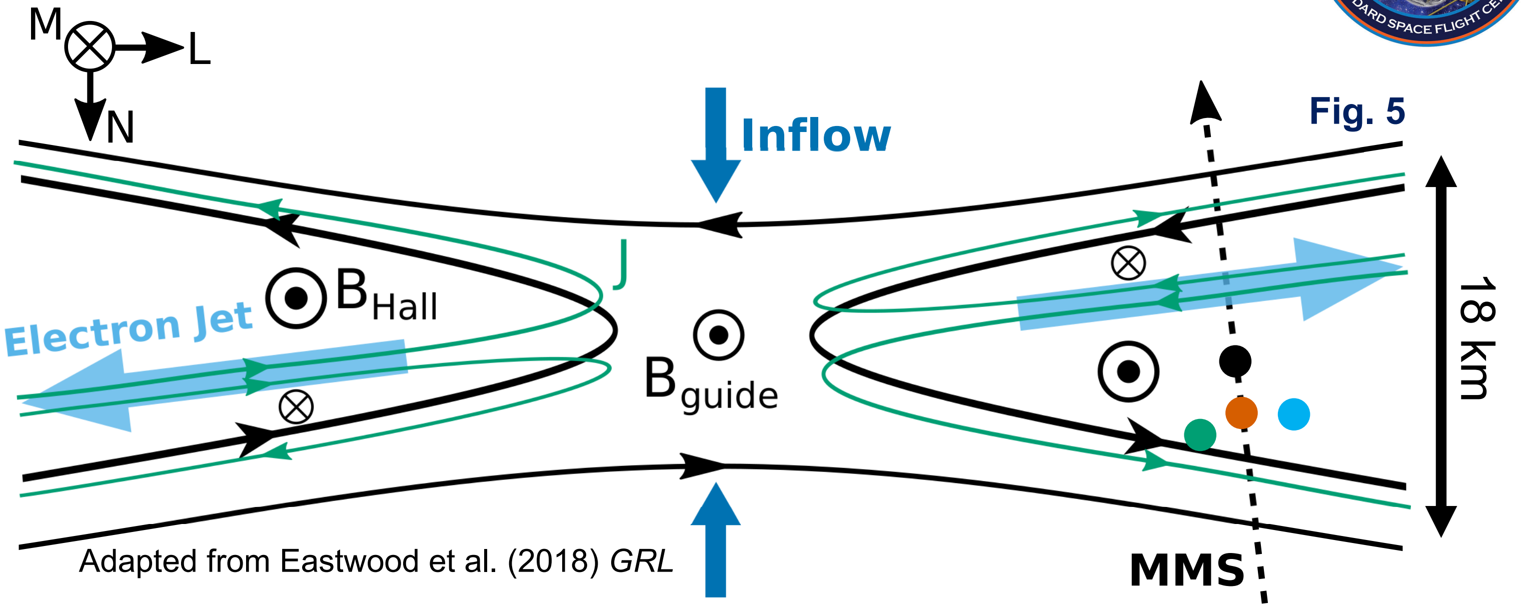
Example Reconnection Event

Fig. 4





Adapted from Eastwood et al. (2018) *GRL*

Key features consistent with magnetic reconnection

Fig. 4b – Negative to positive Hall field perturbation in B_M

Fig. 4d – Electron jet deflected to $-B_L$ side due to $J \times B_{guide}$ force

Fig. 4e – No ion jet → either ion diffusion region encounter or electron-only reconnection

Fig. 4i – Intense energy conversion from fields to particles

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Part III: Reconnection Statistics

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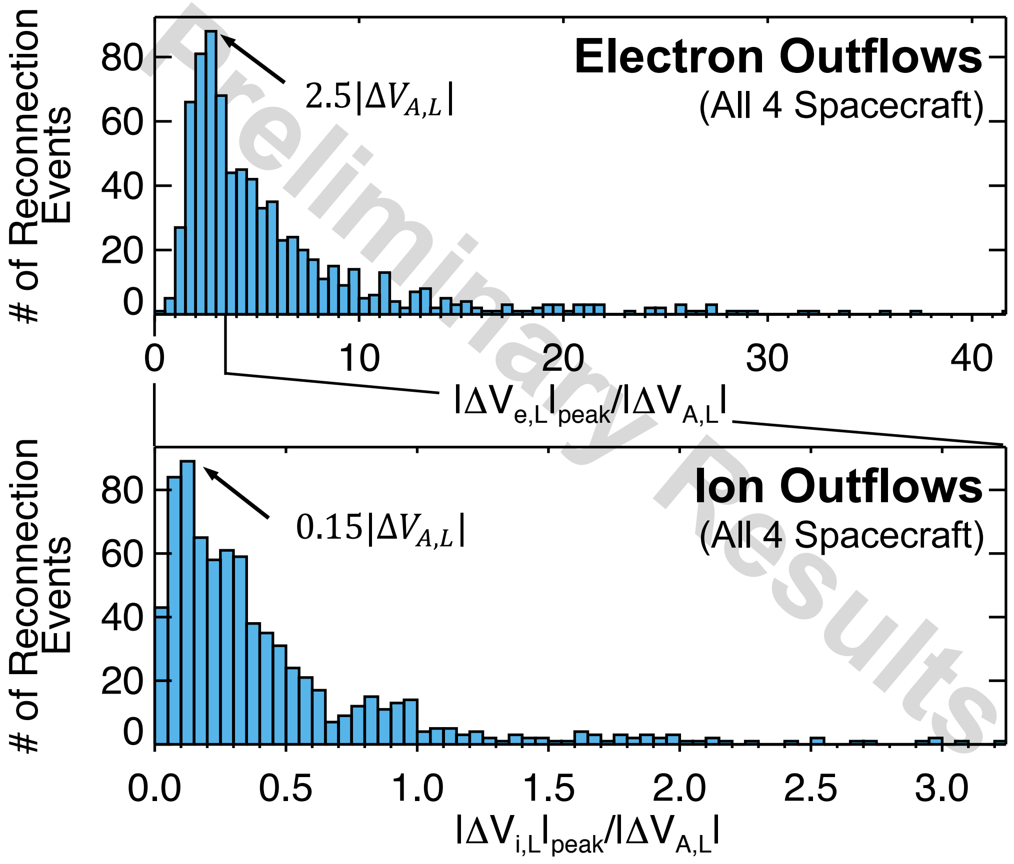
Reconnection Outflows

Fig. 6



Survey Results

207 potential reconnection events identified across 23 intervals

Every interval examined so far contains reconnection events

Overall 20% of intense current sheets have evidence of reconnection

Ion and Electron Outflows

Outflow speeds estimated as the peak deviation of V_L relative to a $10d_i$ running average within the current structures

Most events have super-Alfvénic electron outflows (Fig. 6a) and sub-Alfvénic ion outflows (Fig. 6b), consistent with electron-only reconnection

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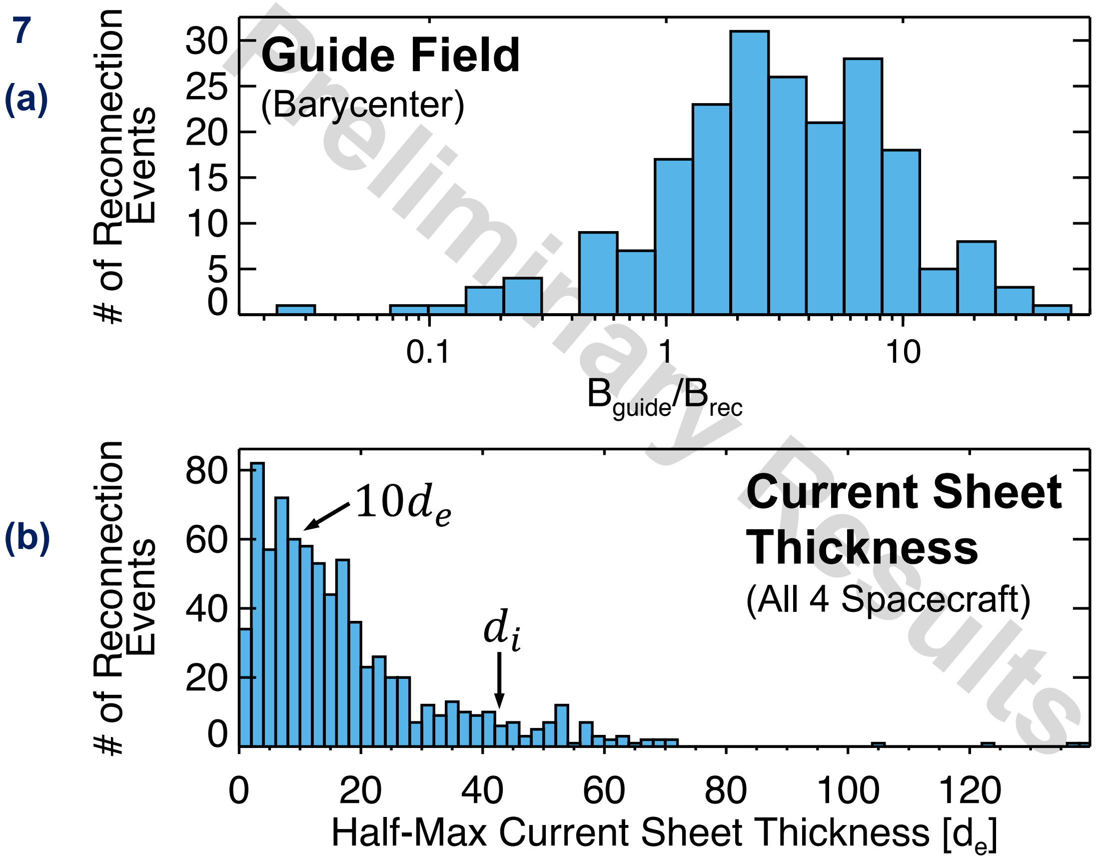
Reconnecting Current Sheet Properties

Fig. 7



Guide Fields

B_{guide} estimated as barycenter $|B_M|$ at time of B_L zero crossing and B_{rec} estimated as barycenter $|\Delta B_L|/2$ at two edges of current sheet

Most events have significant guide fields (Fig. 7a), similar to Phan+ [2018] results

Reconnecting Current Sheet Thickness

Half-max current width used to quantify thickness of reconnection sites encountered by each spacecraft

Linear interpolation used to estimate times of half-max crossing if between particle measurements

Temporal width converted to spatial thickness using average V_{iN} over $10d_i$ surrounding the current structure

Most reconnecting current sheet thicknesses are sub-proton scale with peak between a few and $10d_e$ (Fig. 7b)

Part IV: Turbulence Properties

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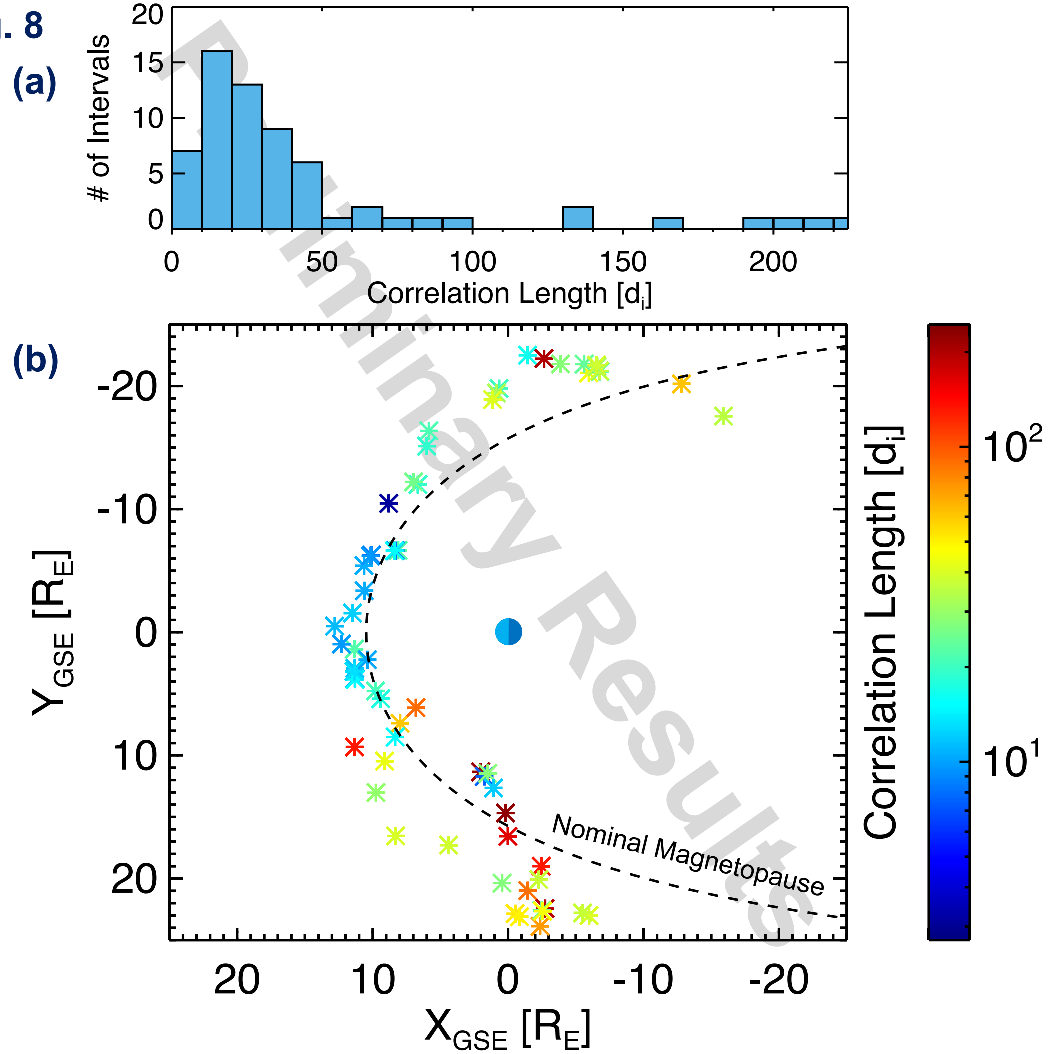
Magnetic Correlation Length

Fig. 8



Magnetic correlation length characterises typical size of magnetic structures – sets typical length of current structures (see Fig. 1)

Fig. 8a**:** Majority of intervals have correlation length $\lesssim 40 d_i$ consistent with expected regime for electron-only reconnection

Fig. 8b**:** Correlation lengths tend to be shorter near sub-solar point and longer on the flanks in the magnetosheath

Autocorrelation Function: $R(\ell) \equiv \frac{\langle \delta b(x+\ell)\cdot\delta b(x)\rangle}{\langle |\delta b|^2 \rangle}$

Correlation Length: $\lambda_c = \int_0^\infty R(\ell) d\ell$

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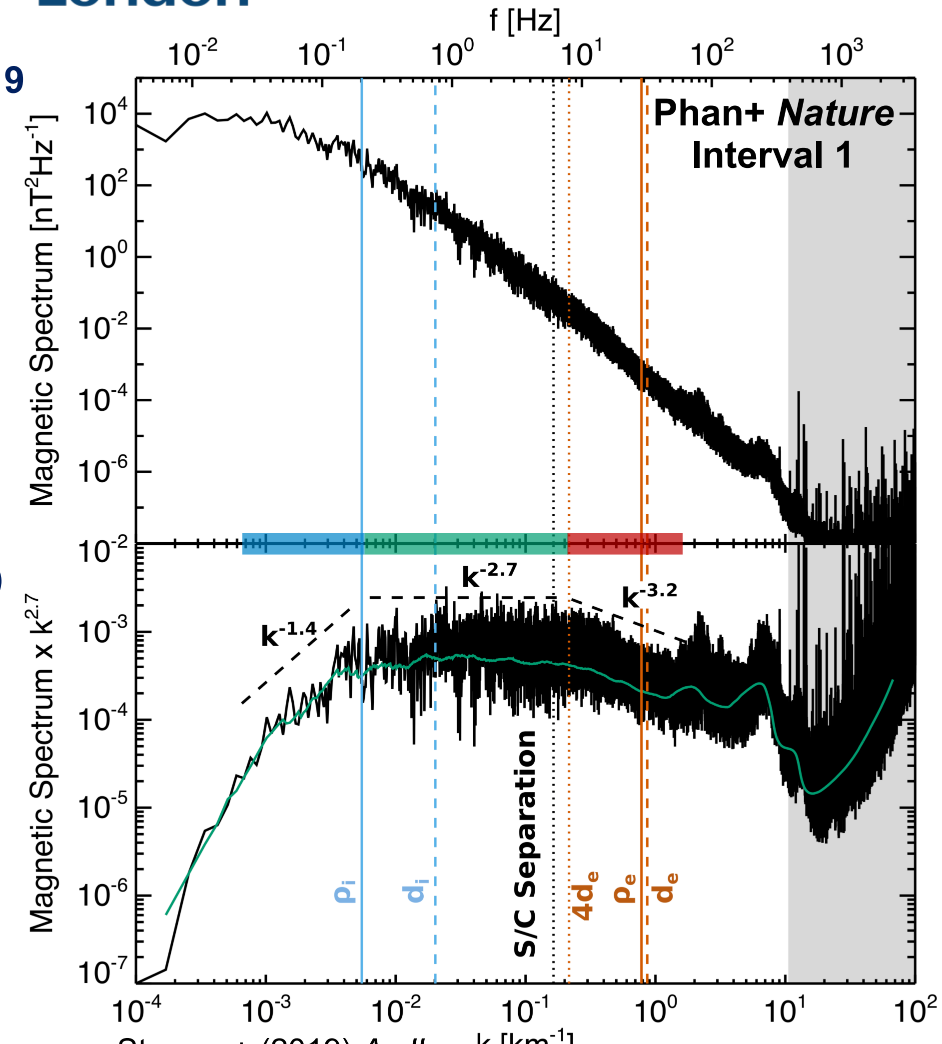
Magnetic Energy Spectrum

Fig. 9



Stawarz+ (2019) *ApJL*

Slope of the energy spectrum with k is dictated by timescale for nonlinear energy transfer

Larger than ρ_i: $E_M(k) \sim k^{-1.4}$

→ Shallower than expected from MHD

→ May suggest turbulence is still developing near sub-solar point [Huang+ 2017]

Sub-ion scales: $E_M(k) \sim k^{-2.7}$

→ Consistent with previous observations of sub-ion scale turbulence [Alexandrova+ 2012; Chen & Boldyrev 2017; Huang+ 2017]

Scale of reconnecting current sheet thickness: $E_M(k) \sim k^{-3.2}$

17/71 (~25%) of intervals have second spectral break between ion and electron scales

→ May be consistent with reconnecting current sheet thickness [Stawarz+ 2019]

→ Recent theoretical work predicts similar behaviour due to impact of electron-only reconnection on nonlinear dynamics and structure formation [Mallet+ 2019]

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Conclusions

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Survey of high-resolution Magnetospheric Multiscale data reveals that small-scale magnetic reconnection events are a common feature of magnetosheath turbulence

- → Every turbulent interval analysed so far has magnetic reconnection events
- → ~20% of intense current structures show evidence of magnetic reconnection

Many of the reconnection events identified so far have super-Alfvénic electron jets and sub-Alfvénic ion jets, consistent with electron-only magnetic reconnection

Weak ion jets may be associated with the relatively short correlation length of the turbulence in the magnetosheath

- → Ion signatures may become more prevalent on magnetosheath flanks, but further identification of reconnection events within the flank intervals is needed to verify this

Electron-only reconnection may have an impact on the small-scale magnetic energy spectrum, which is supported by recent theoretical work

- → Further research is needed to determine why this apparent signature is only present in a subset of the intervals

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