Fast Plasma Flows Downstream of the Bow Shock Using MMS: Correlations and Generation Mechanisms

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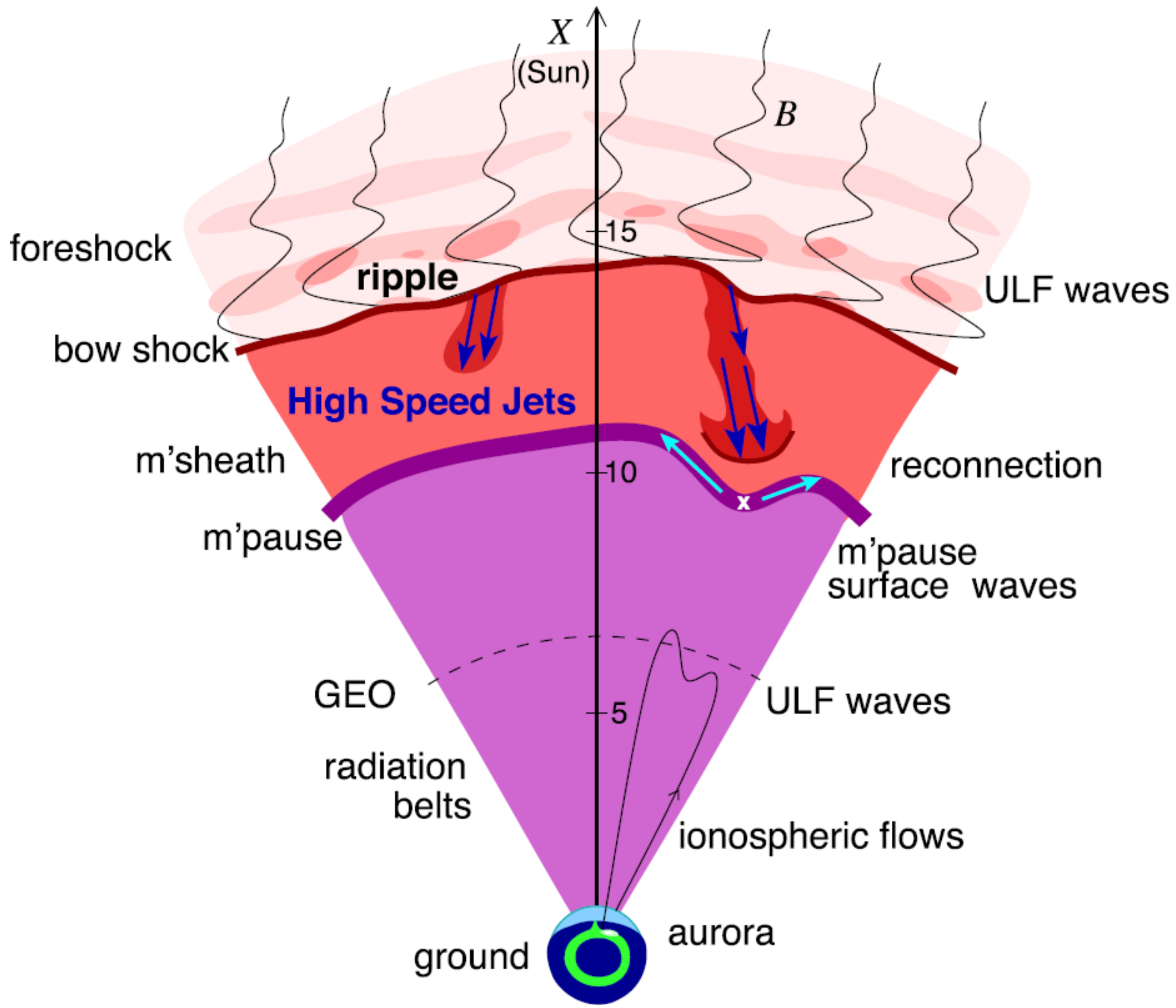
Introduction

Magnetosheath Jets



Plaschke F. et al. (2018); sketch by H. Hietala | Space Sci. Rev

<u>Definition</u>

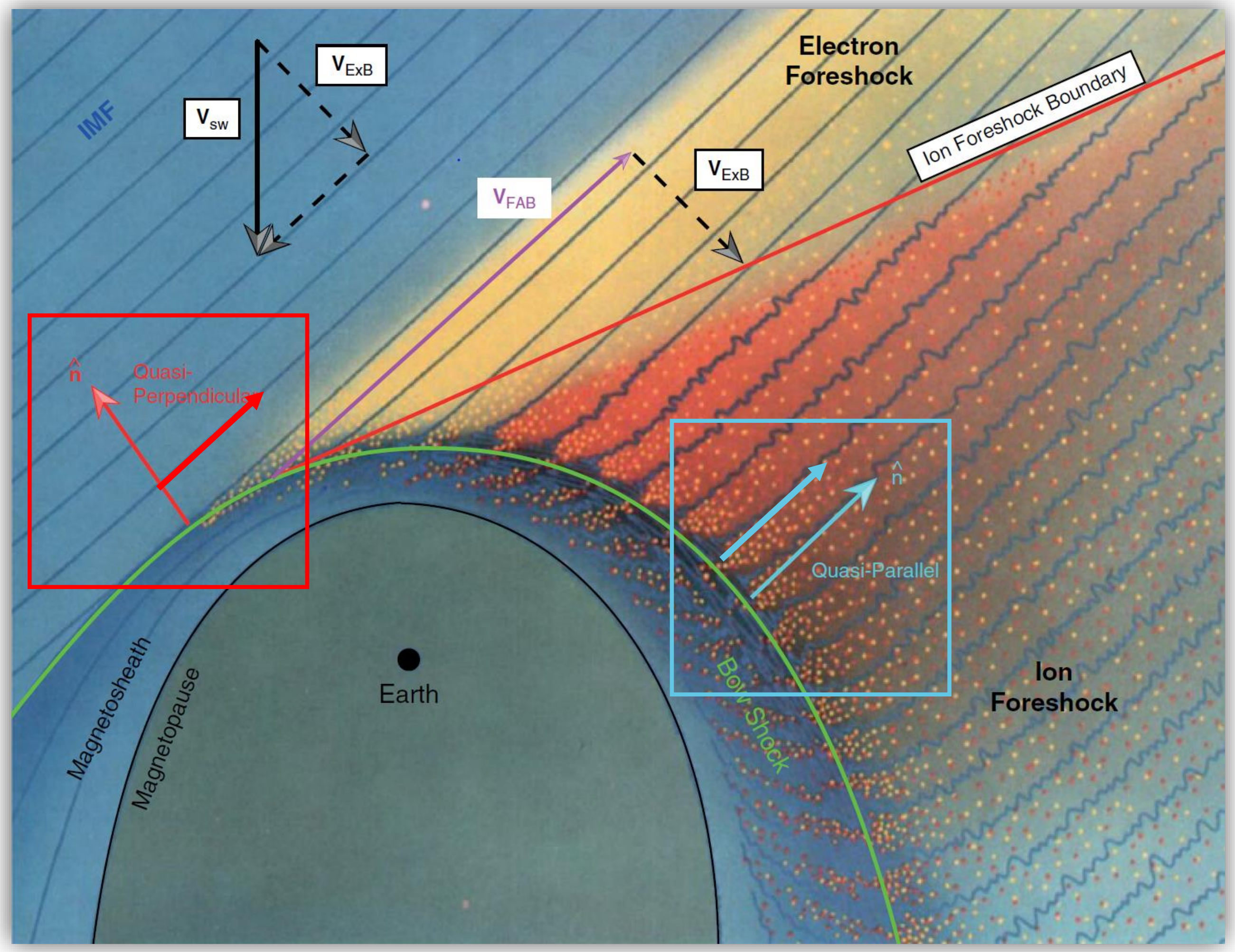
Magnetosheath jets are transient localized enhancements of dynamic pressure (density and/or velocity increase)

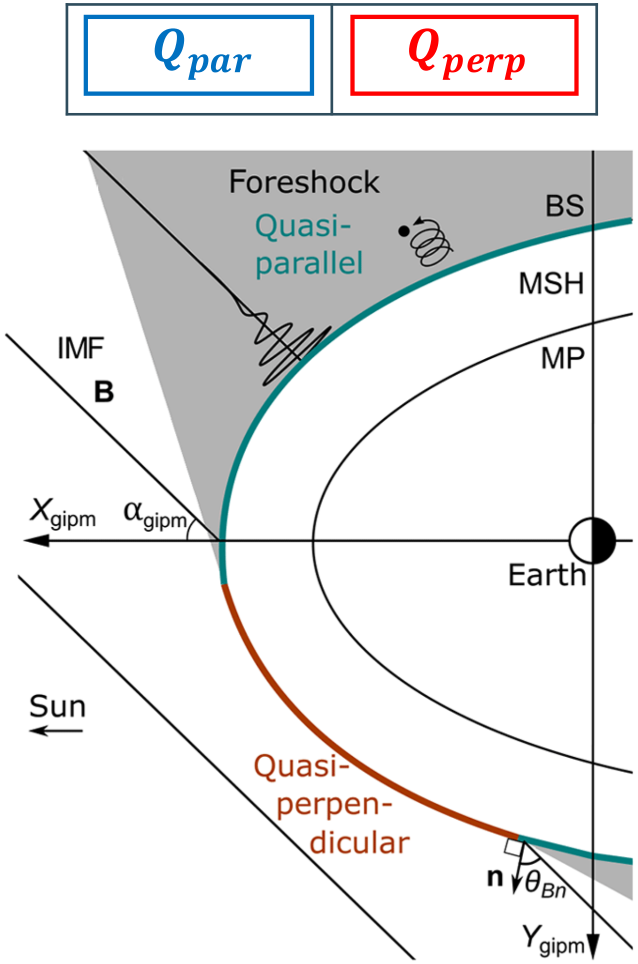
e.g. 100% dynamic pressure enhancement compared to background magnetosheath

<u>Related phenomena</u>

ULF wave excitation
Radiation belts
Aurora
Magnetopause reconnection
Magetopause penetration
Shock acceleration
Magnetopause surface eigenmodes

Motivation – Shock configuration and Jets





"Θ_{Bn} is the angle between the IMF and the shock's normal vector"

Qpar = $\Theta_{Bn} \lesssim 45^\circ$
Qperp = $\Theta_{Bn} \gtrsim 45^\circ$

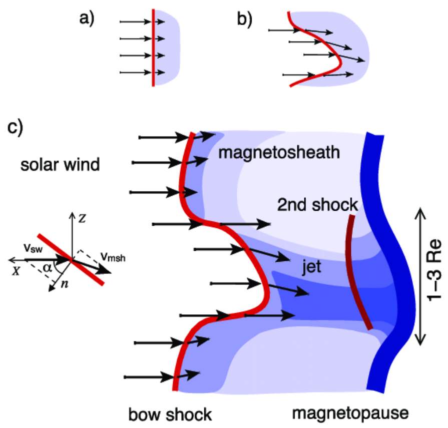
"Jets are found ~9 times more often behind the Qpar bow shock"

L. B. Wilson (2016) | Geophysical Monograph Series

Vuorinen, et al. (2019) | Annales

Some Possible Generation Mechanisms

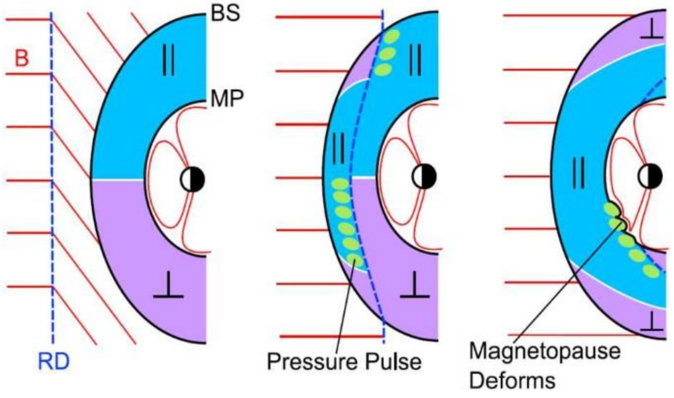
Bow Shock Ripples



Solar wind slipping through the local inclination of the shock ripples

Qpar : Hietala et al., (2009,2012) | Qperp : Johlander et al. (2016)

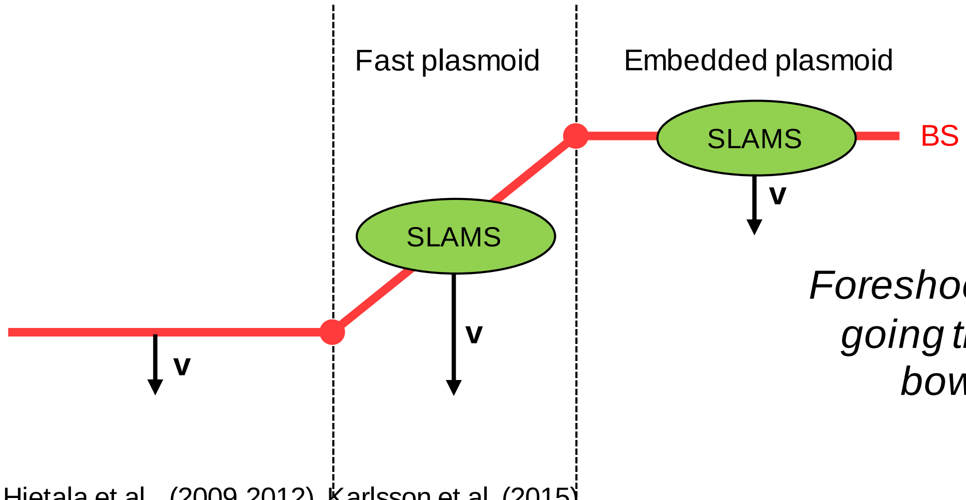
Pressure Pulses



Association to Solar wind rotational discontinuities and pressure pulses

Archer et al. (2012)

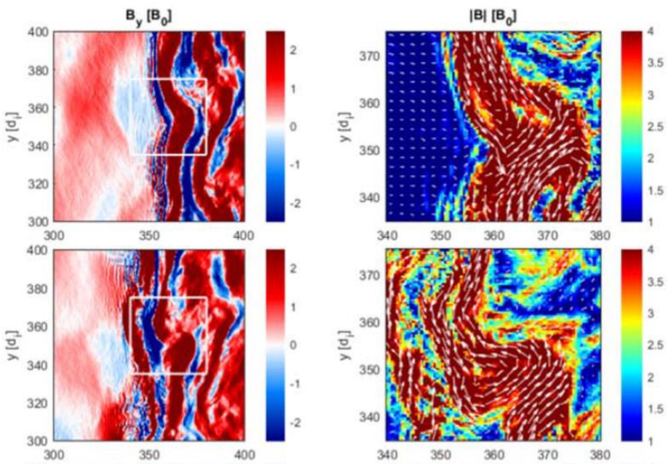
Foreshock structures (e.g. SLAMS)



Foreshock structures going through the bow shock

Hietala et al., (2009,2012), Karlsson et al. (2015)

Reconnection

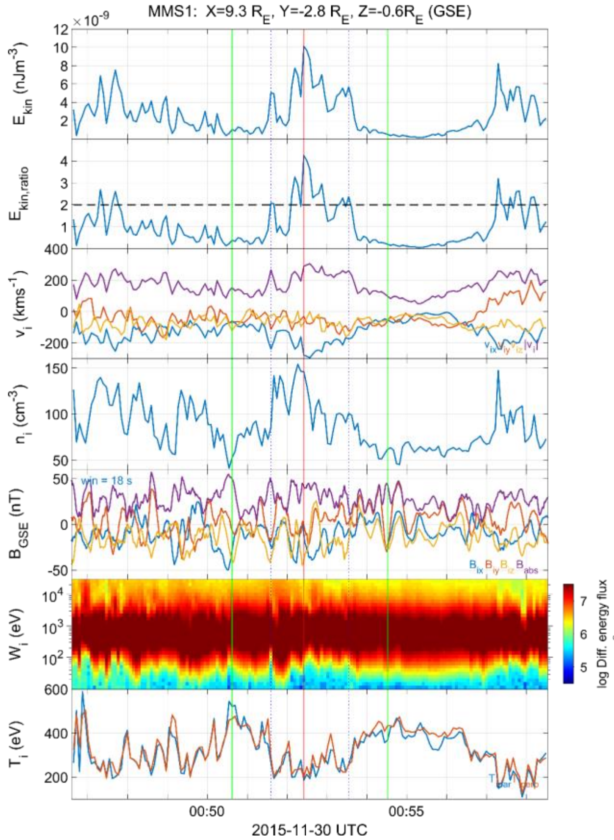


Reconnection at the bow shock

Preisser, Luis, et al. (2020) | ApJL

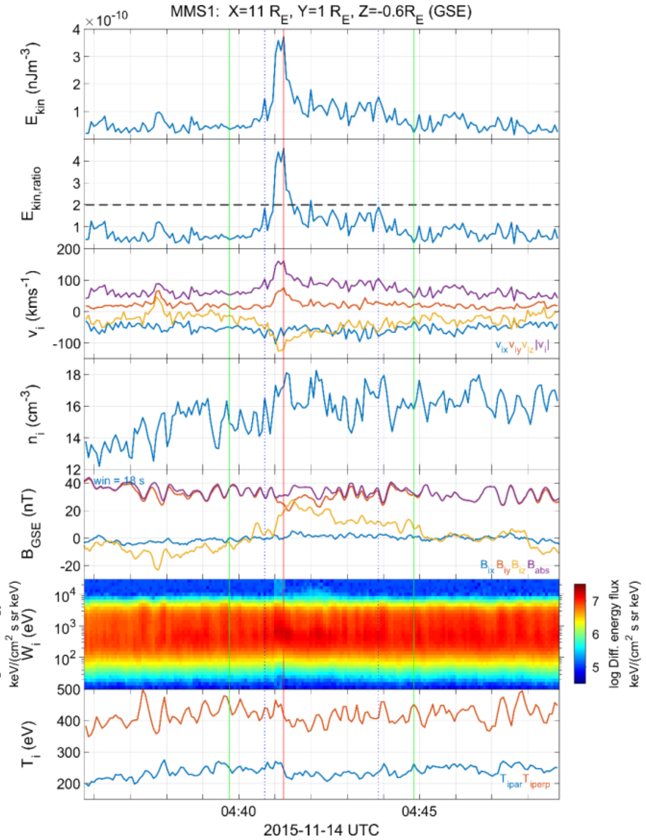
Database generation & jet classes

Different Classes



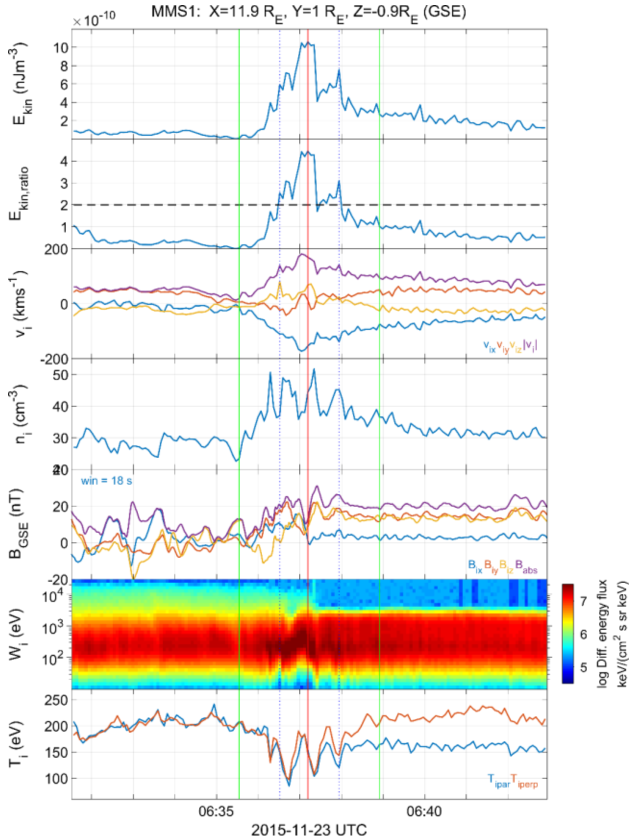
Qpar Jet

Jets found in $Q_{\parallel}$ MSH



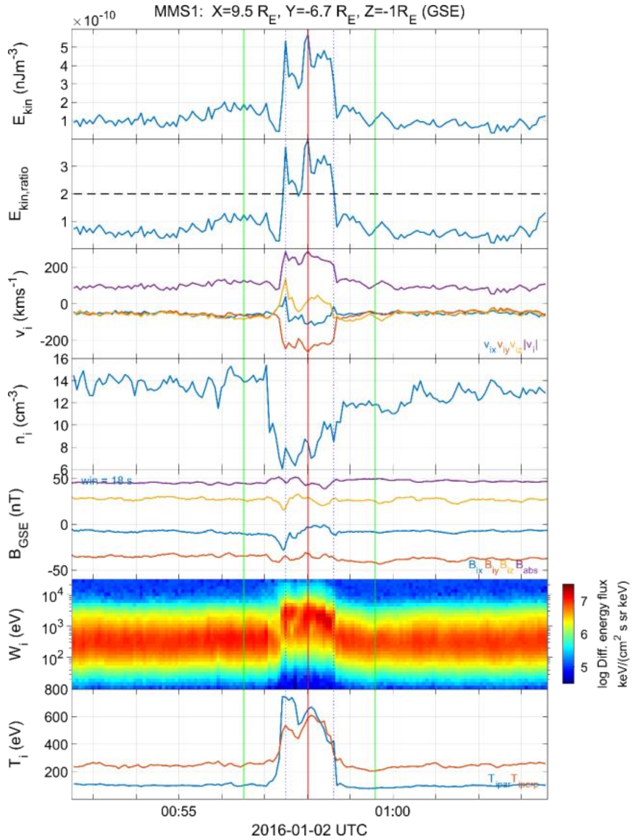
Qperp Jet

Jets found in $Q_{\perp}$ MSH



Boundary Jet

Jets found in the boundary between $Q_{\parallel}$ and $Q_{\perp}$ MSH



Encapsulated Jet

Jets corresponding to “$Q_{\parallel}$-like” MSH plasma enclosed in $Q_{\perp}$ MSH

Raptis S., Karlsson T., et al. (2020) | JGR
Raptis S., Aminalragia-Giamini S., et al. (2020) | Frontiers
Kajdic P., **Raptis S.**, et al. (2021) | GRL (under review)

Fast/Survey MMS data	**Burst** MMS data

	Resolution (samples/s)	Resolution (samples/s)
FGM (magnetic field):	0.0625	0.0078
FPI (plasma moments ions):	4.5	0.15
EDP(electric field):	0.0313	0.00012218

Fast/Survey MMS data

Pros

- ✓ Always available
- ✓ Decent resolution
- ✓ Can be good for statistics due to availability

Cons

- ✗ Not suitable for small scale studies especially these related to ion moments
- ✗ Could be misleading close to boundary surfaces (Magnetopause, Bow shock etc.) due to very similar observational signatures

Burst MMS data

Pros

- ✓ Very high resolution
- ✓ Able to resolve structures close to boundary surfaces (e.g. mix of plasma close to magnetopause, bow shock, foreshock etc.)

Cons

- ✗ Not available all the time, mostly available close to vital mission objectives (magnetopause, diffusion regions, shock transitions etc.)
- ✗ Hard to do proper large scale statistics due to biases generated from specific availability and manual choice of intervals

More information: Baker, et al. (2016) | Space Sci Rev 19

Jets database of MMS

Fast/Survey

9/2015 - 9/2020

Subset	Number	Percentage (%)
Quasi-parallel	2458	26.7
Final cases	**901**	10.1
Quasi-perpendicular	542	5.9
Final cases	**214**	2.3
Boundary	781	8.5
Final cases	**191**	2.1
Encapsulated	80	0.9
Final cases	**60**	0.7
Other	5335	58.0
Unclassified/Uncertain	3789	41.2
Border	1500	16.3
Data Gap	46	0.5

Useful to study early properties & generation

Burst

Jets with full burst data

Qpar	423
Qperp	34
Boundary	35
Encapsulated	31
Close to BS / MP	495
Others	428

Raptis S., Karlsson T., et al. (2020) | JGR
Raptis S., Aminalragia-Giamini S., et al. (2020) | Frontiers
Palmroth M., **Raptis S.**, et al. (2021) | Annales
Raptis, Karlsson, et al. | Ongoing

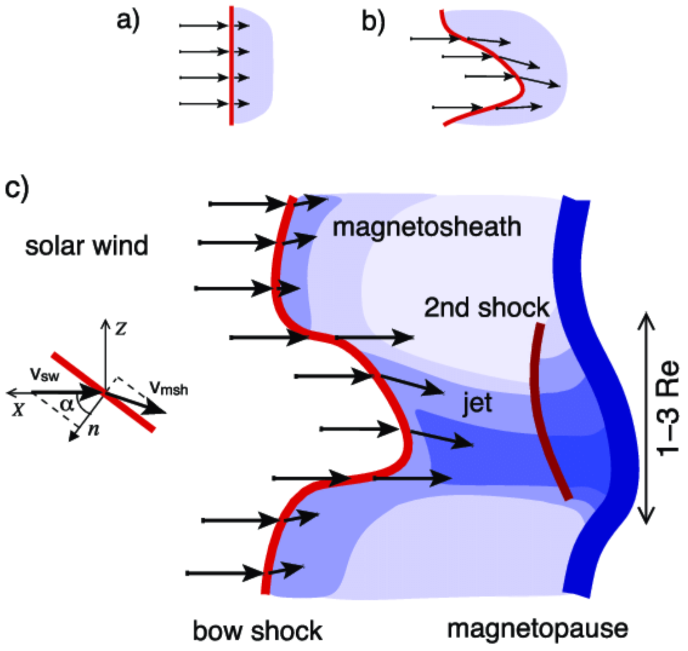
Statistical Results

Close to the Bow shock statistics (fast data) - Ripples

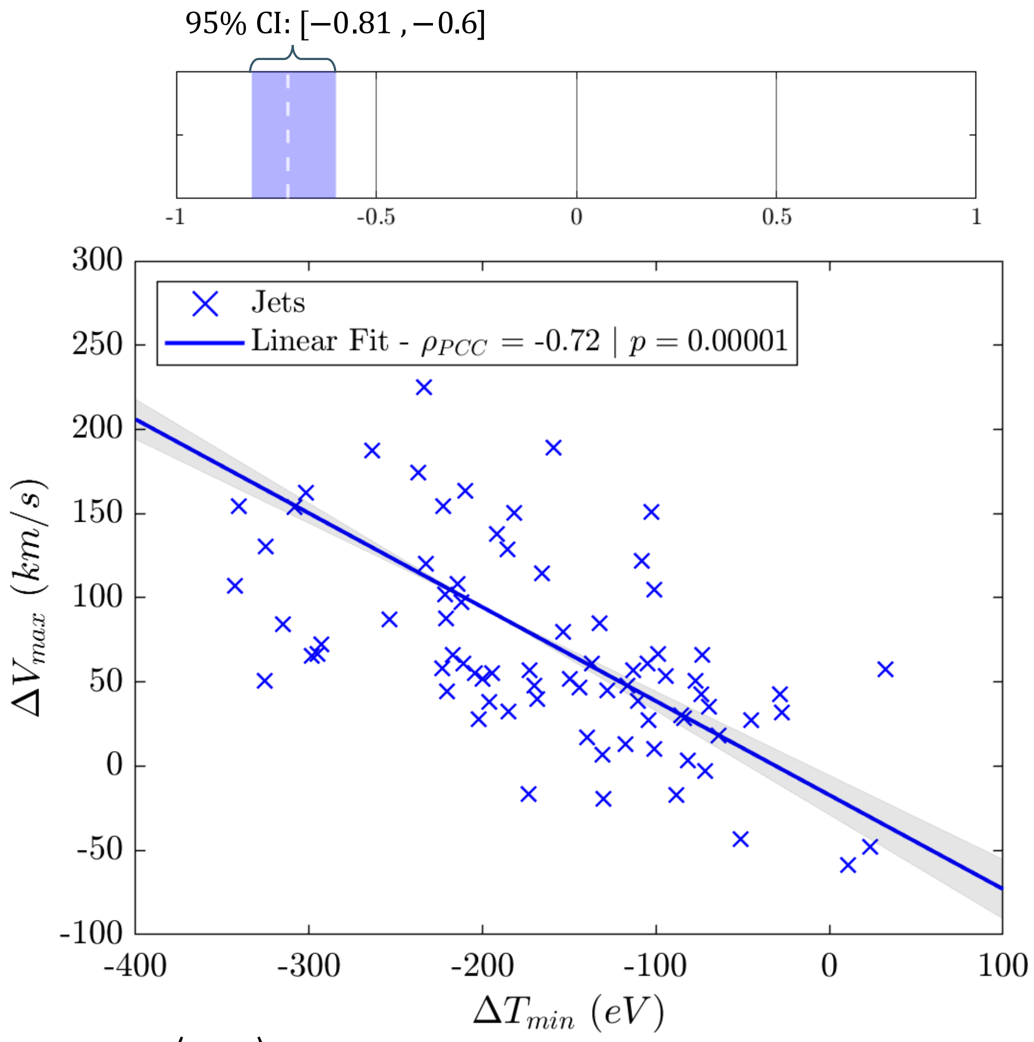
Theory / Expectation

$n = 90$

Statistics



Interaction of the solar wind with locally curved bow shock results in a less deaccelerated (ΔV) and less heated (ΔT) flow.



Qpar : Hietala et al., (2009,2012) | Qperp : Johlander et al. (2016)

$\Delta X = X_{jet} - \langle X_{BG} \rangle_{5min}$

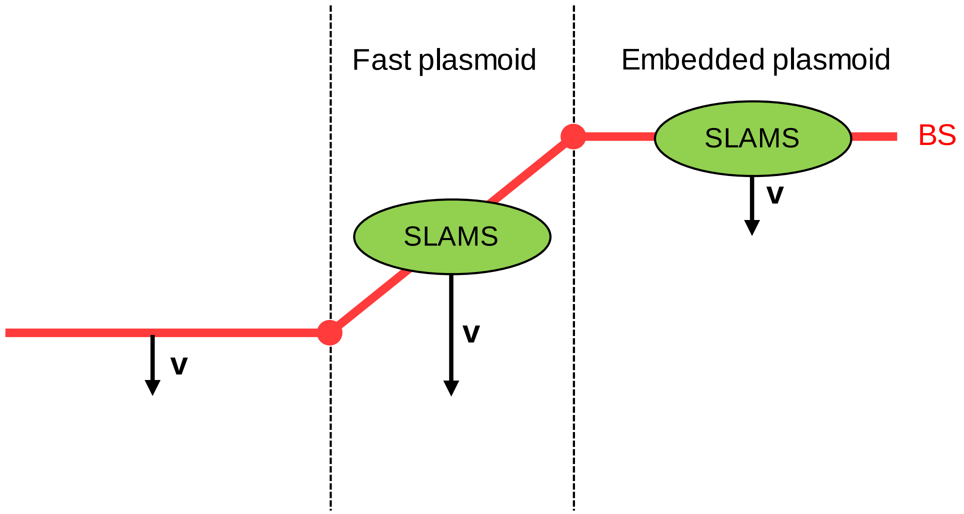
Raptis, Karlsson, et al. | Ongoing

Close to the Bow shock statistics (fast data) - SLAMS

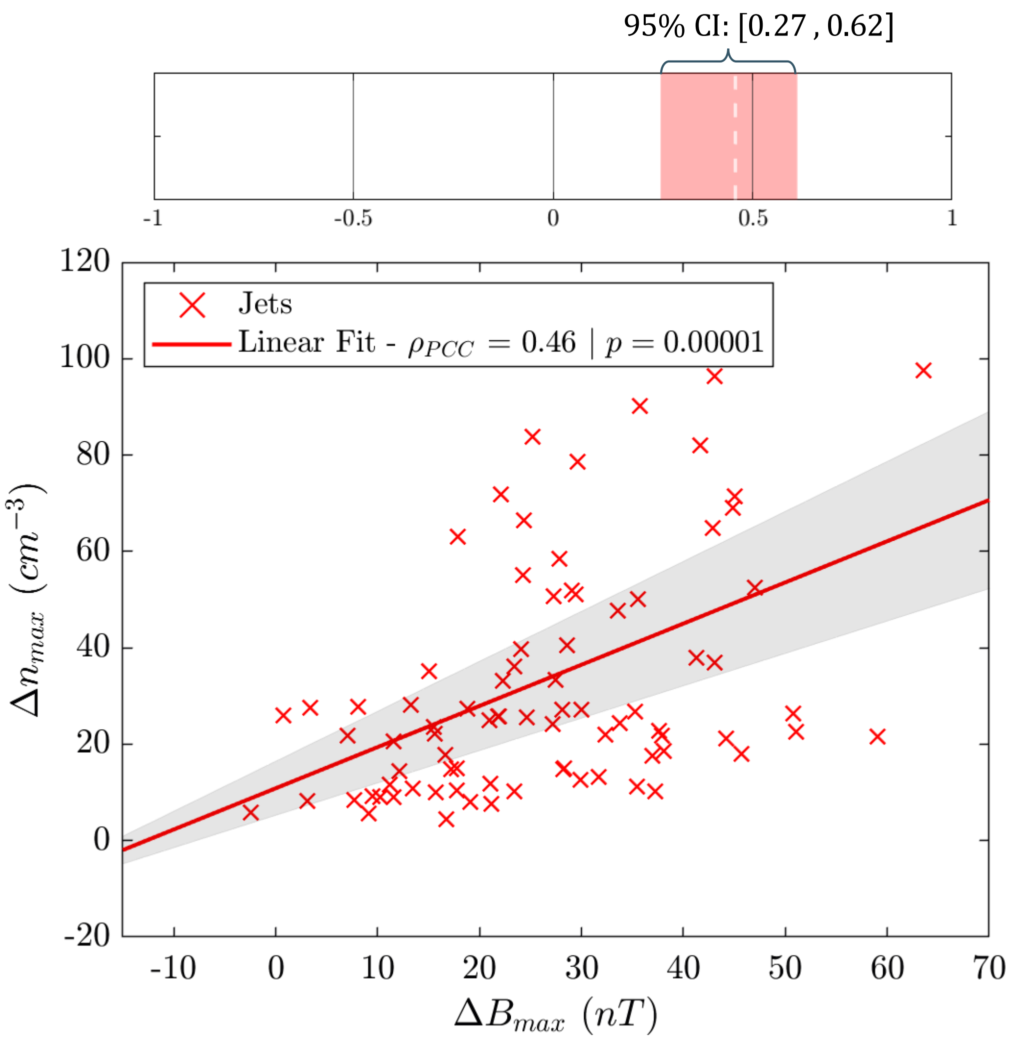
Theory / Expectation

$n = 90$

Statistics



Non linear evolution of steepened waves (ΔB) associated with density enhancement (Δn). Observed typically upstream of the Quasi-parallel bow shock



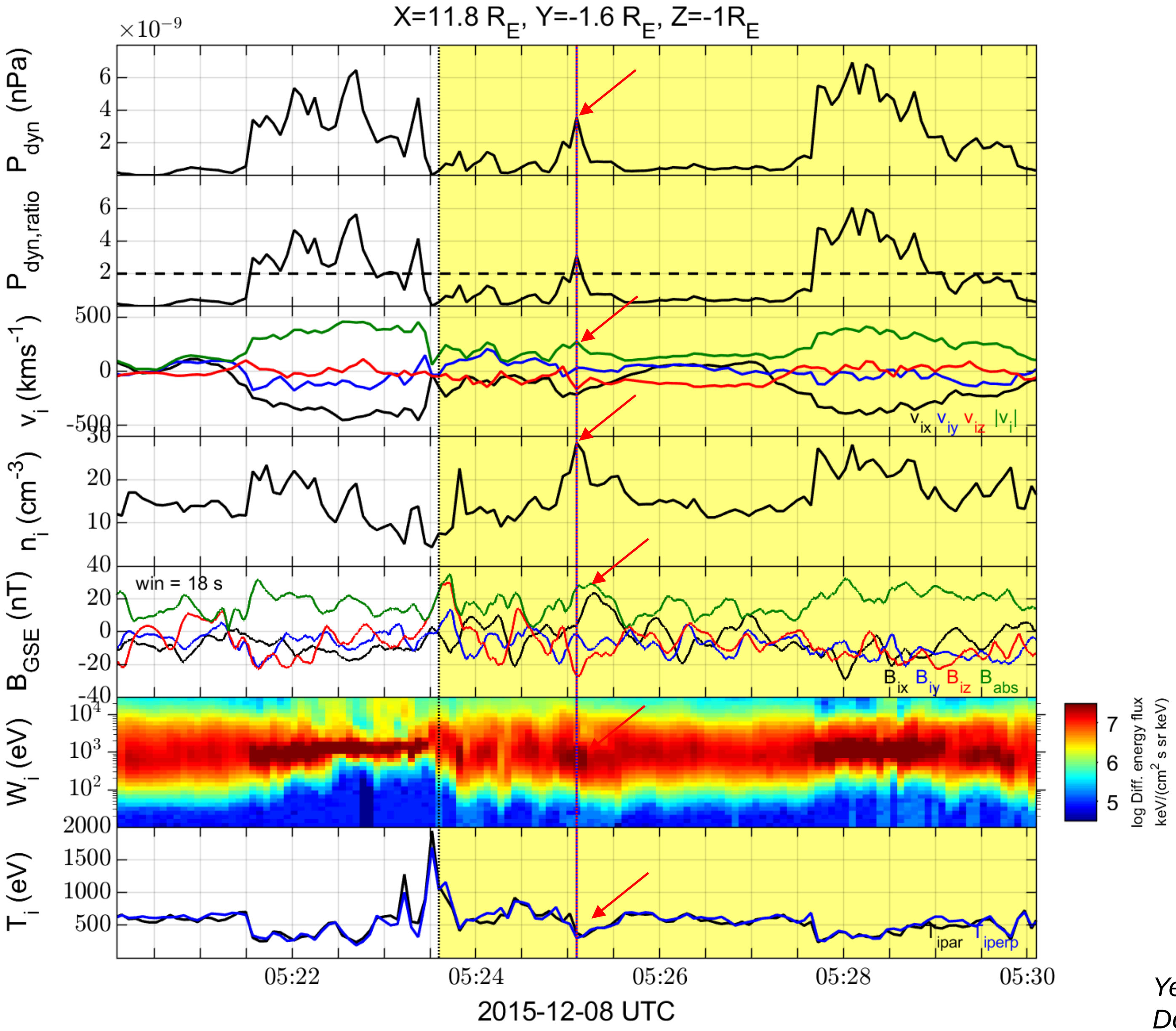
$\Delta X = X_{jet} - \langle X_{BG} \rangle_{5min}$

Hietala et al., (2009,2012), Karlsson et al. (2015)

Raptis, Karlsson, et al. | Ongoing

Case Studies / Examples

Example 1 (fast data): close to the bow shock jet

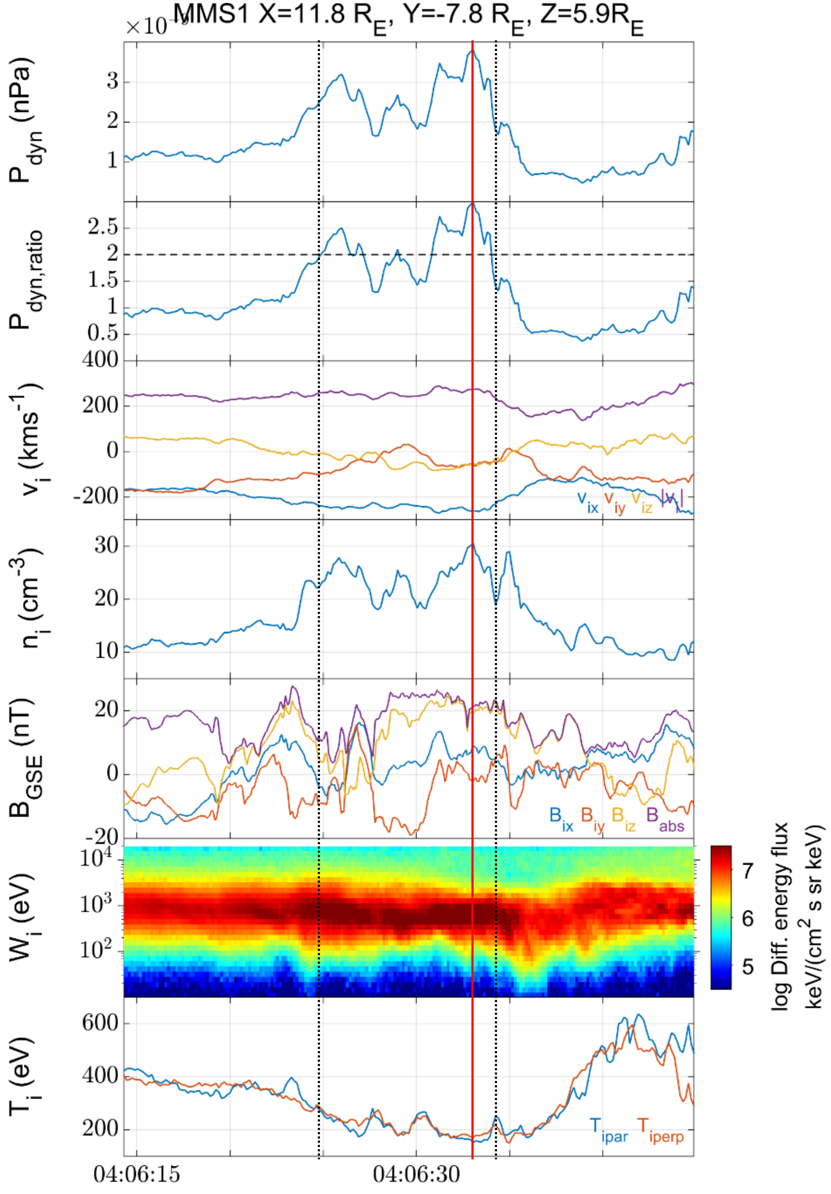


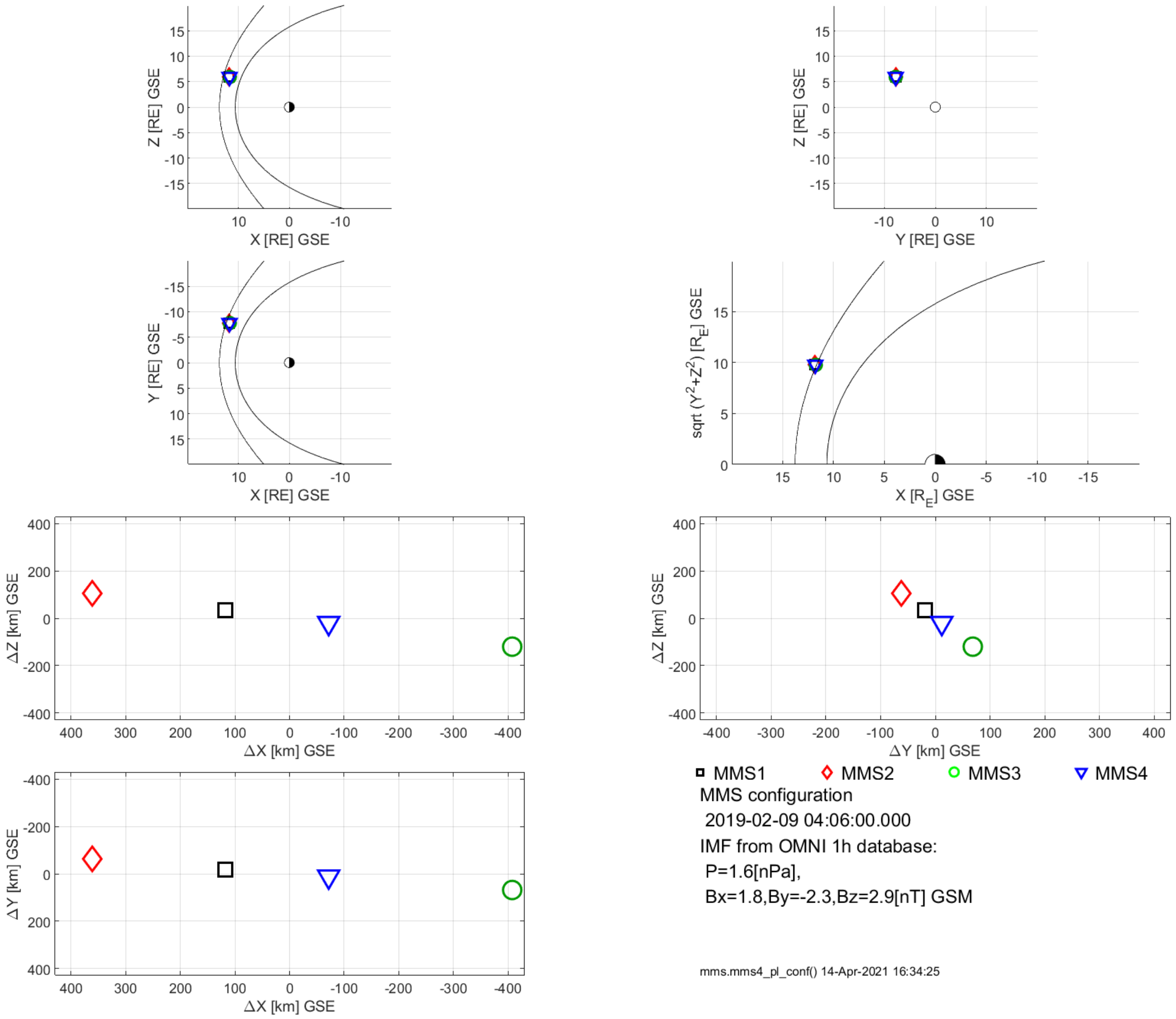
Basic Properties

- Dynamic pressure enhancement
-
- Velocity enhancement (Δ|v|>0)
- Magnetic field enhancement (Δ|B|>0)
- Density enhancement (Δn>0)
- Colder population shown in ion energy spectrum
- Less heated plasma (ΔT <0)
- Close proximity to BS (Δt < 5min)

Yellow area = estimated magnetosheath background
Dotted black line = estimated bow shock crossing

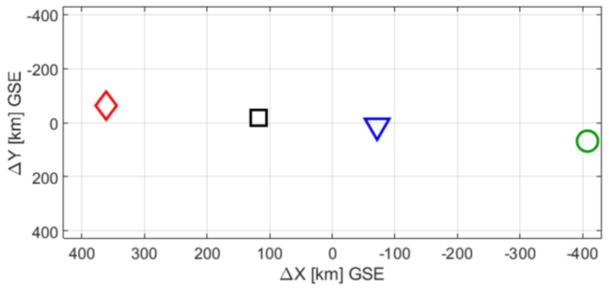
Example 2 (burst data): Close to the Bow shock jet

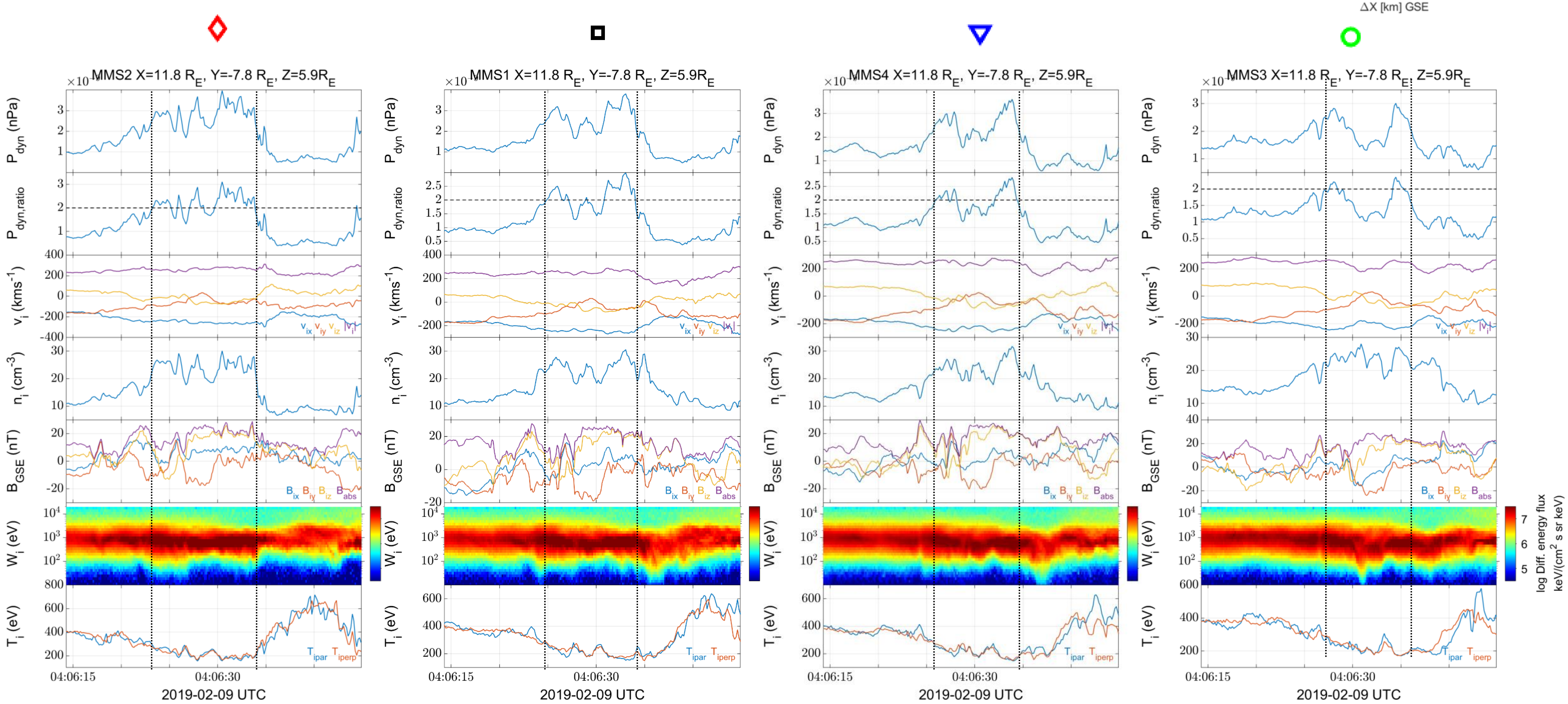




Raptis, Karlsson, et al. | Ongoing

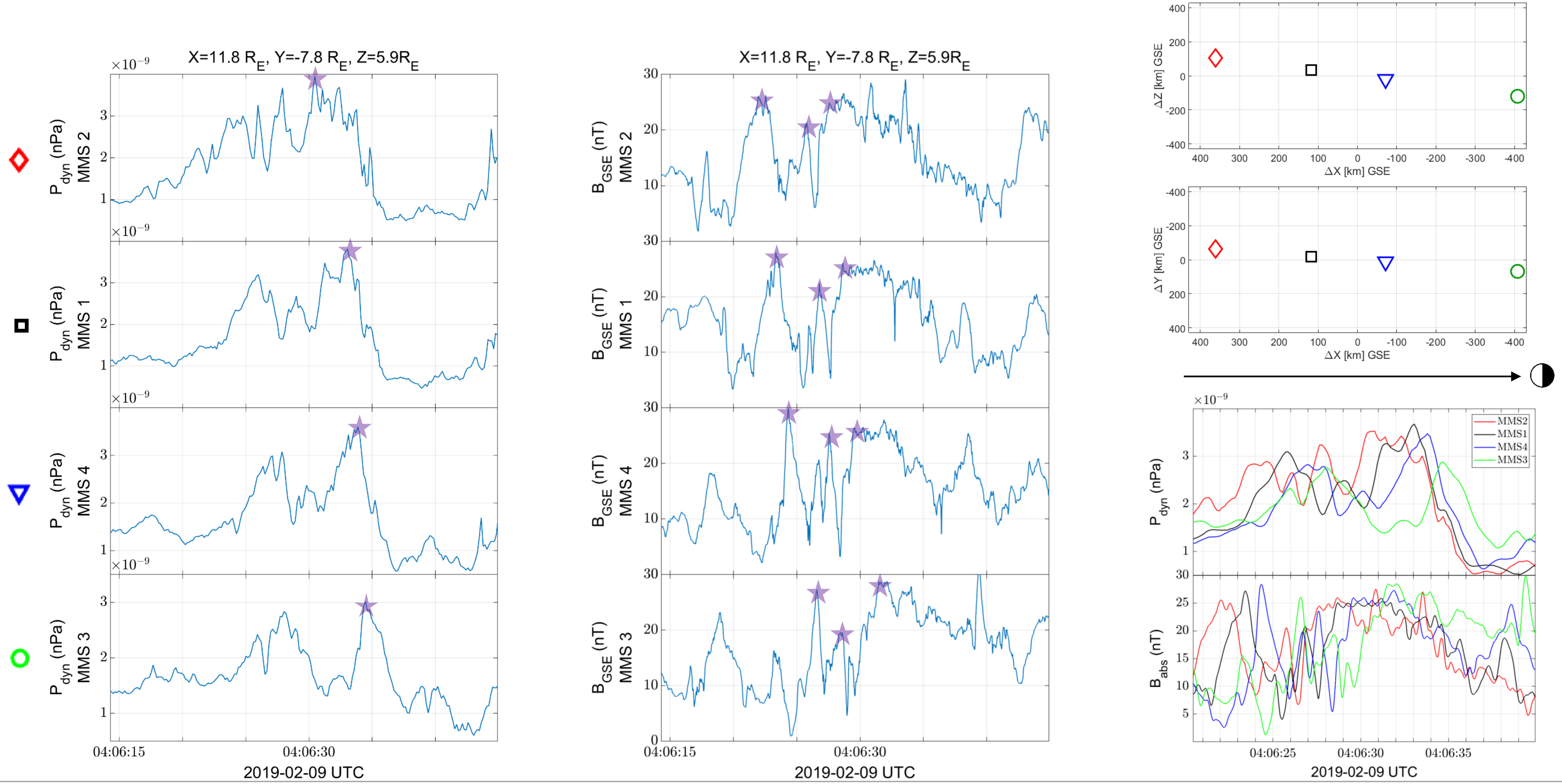
Multi point measurements (MMS 1 – 4)





Raptis, Karlsson, et al. | Ongoing

The structure is moving towards the Earth



Summary & Conclusion

Main points

- The statistics seem to support *SLAMS penetration* and *bow shock ripple* mechanism
- **However,** fast (*maybe even burst sometimes) data can be misleading close to the bow shock. One can confuse jets with foreshock, bow shock oscillation etc.
- The case studies show similar results to statistics but also showed some false positive events that require more work.

Future work

- Review each case with burst data to determine if structures are convective (jets) or nested (shock oscillation / foreshock excursions etc.)
- Quantify relationship between observed parameters and compute the likelihood of each generation mechanism.

This work has been supported by Hellenic Astronomical Society (https://helas.gr)