On the discrepancies of magnetosheath jet identification and statistical properties due to different temporal resolution and plasma moment derivation

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COSPAR 2022 – Athens, Greece
27/05/2022

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~~On the discrepancies of~~ magnetosheath jet ~~identification and statistical properties due to different temporal resolution and~~ plasma moment derivation & distribution functions with MMS

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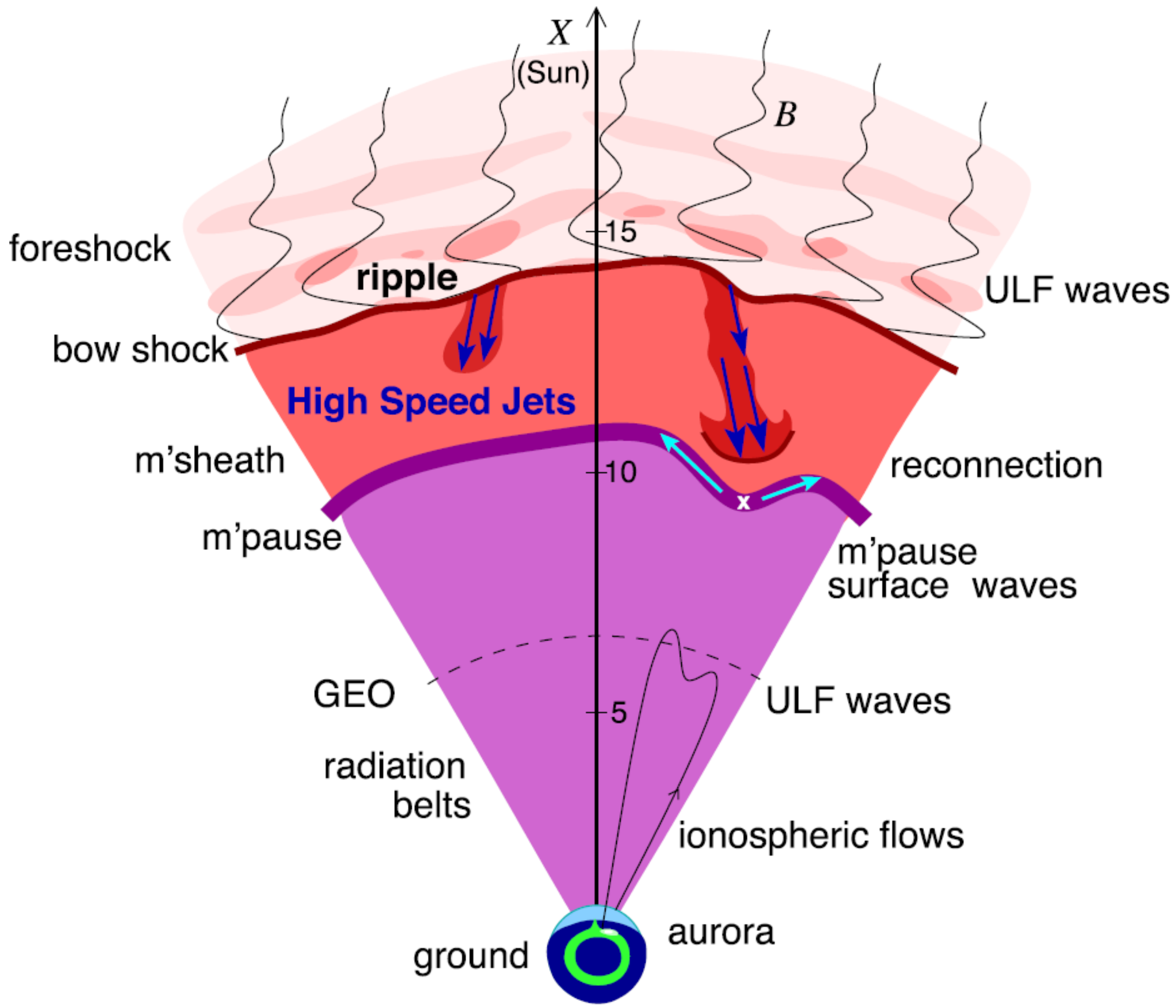
Introduction

Jets

Magnetosheath Jets – Definition



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

<u>Definition</u>

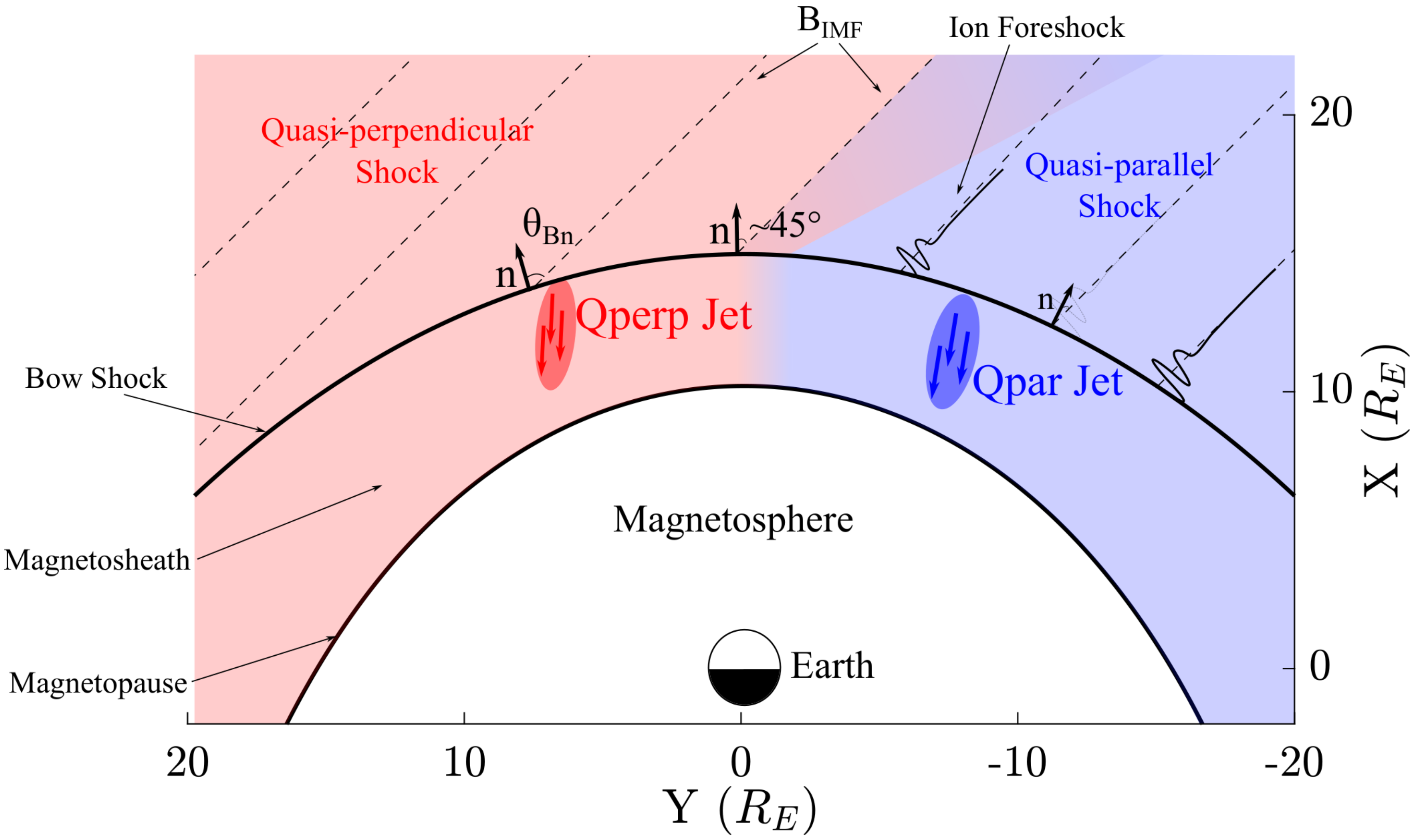
Magnetosheath jets are **transient localized enhancements** of **dynamic pressure** (density and/or velocity increase)

e.g., 200% dynamic pressure enhancement compared to background magnetosheath

<u>Related phenomena</u>

Radiation belts
Throat aurora
Magnetopause reconnection
Magnetopause penetration
Shock acceleration
Magnetopause surface eigenmodes
ULF waves

Shock, Magnetosheath & Jet classification



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

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

"Jets found ~9 times more often in the Qpar MSH"

Vuorinen et al. (2019)

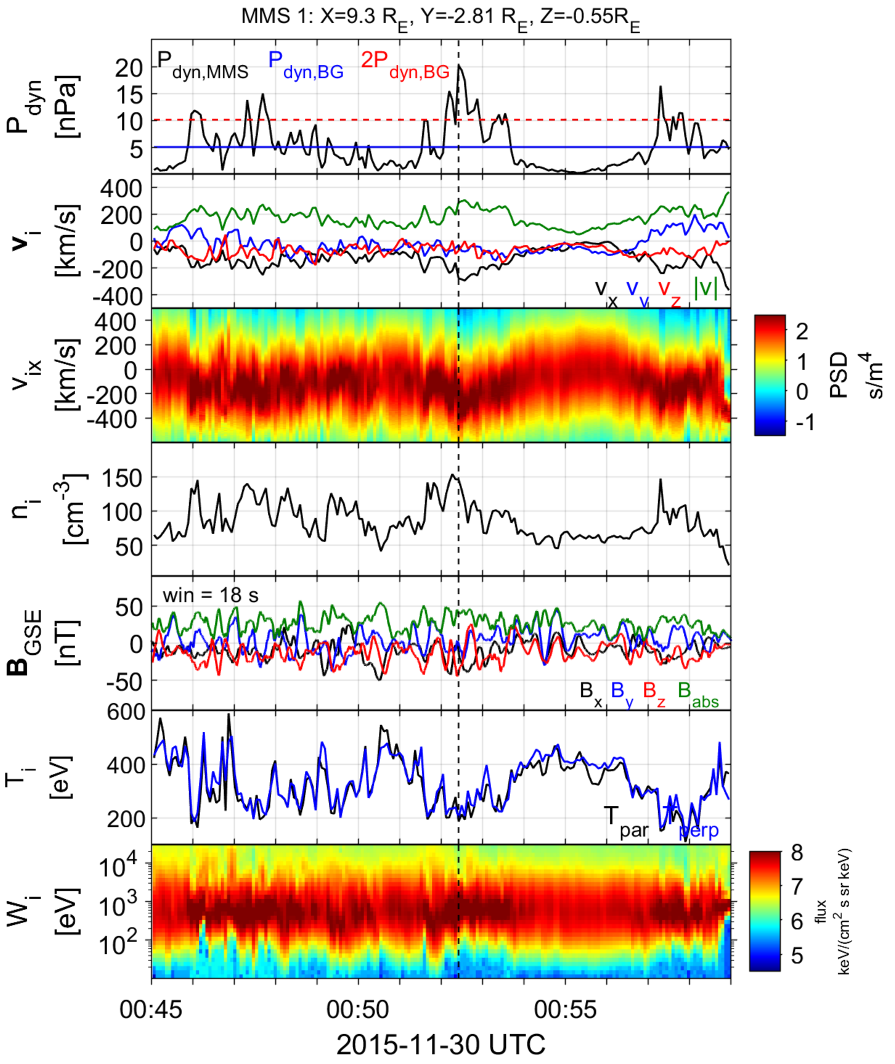
Raptis, Karlsson, et al. (2020) | JGR
Raptis, Aminalragia-Giamini et al. (2020) | Front. Astron. Space Sci
Karlsson, **Raptis** et al. (2021) | JGR
Kajdič, **Raptis** et al. (2021) | GRL

Summarized properties – Quasi Parallel

- Most common
- High dynamic pressure
- Primarily Earthward
- Associated with low temperature (ΔT)
- Associated with high |B| & ΔB
- High |B| variance
- Relevant to magnetospheric effects

Qpar Jet

Jets found in $Q_{\|}$ MSH



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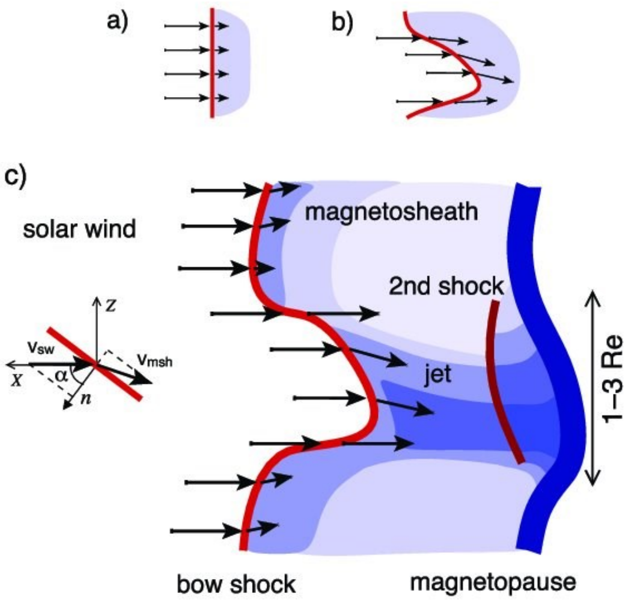
Raptis S., Karlsson T., et al. (2020) | JGR

How are these jets created (Qpar) ?

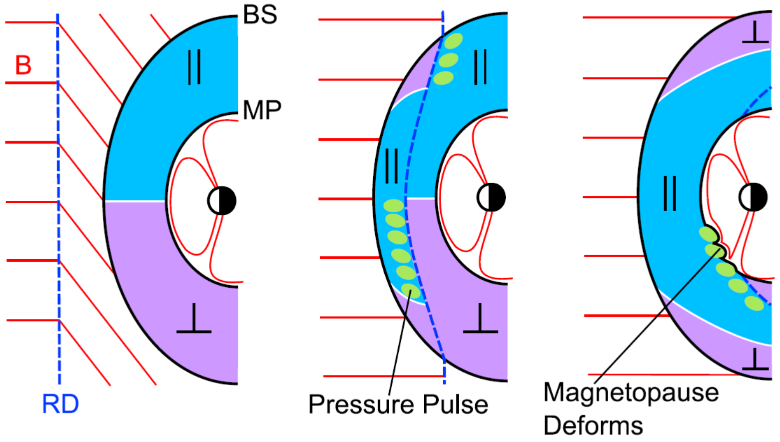
Shock ripples



SW → locally inclined part of the bow shock → less deceleration and heating

Hietala et al. (2009,2012)

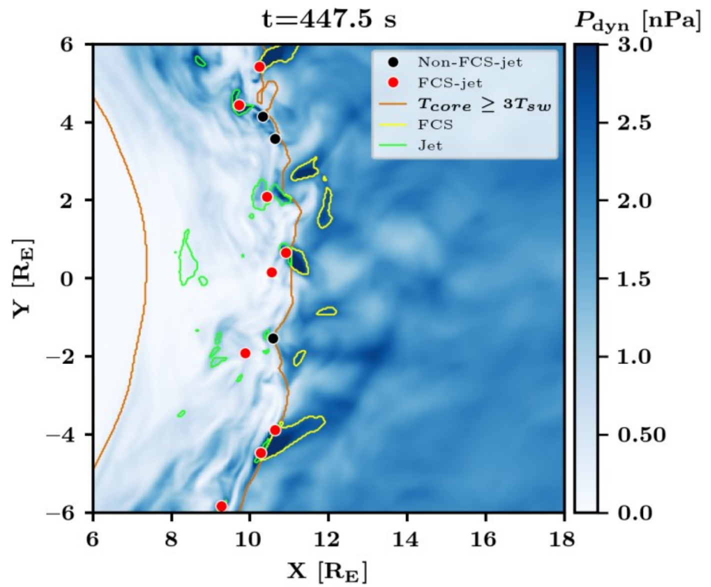
SW discontinuities



RD → Change in Foreshock position → Pressure pulses

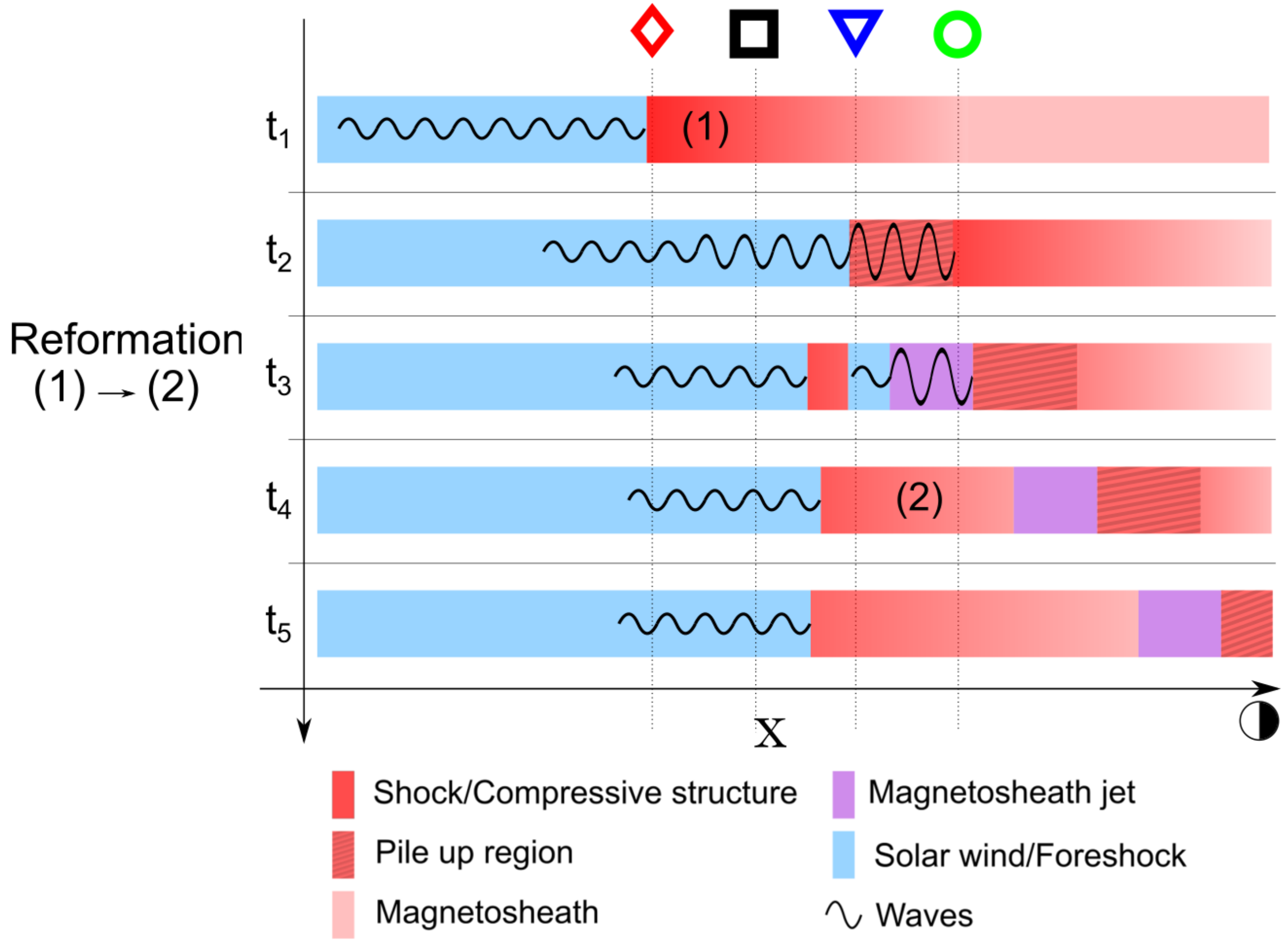
Archer et al. (2012)

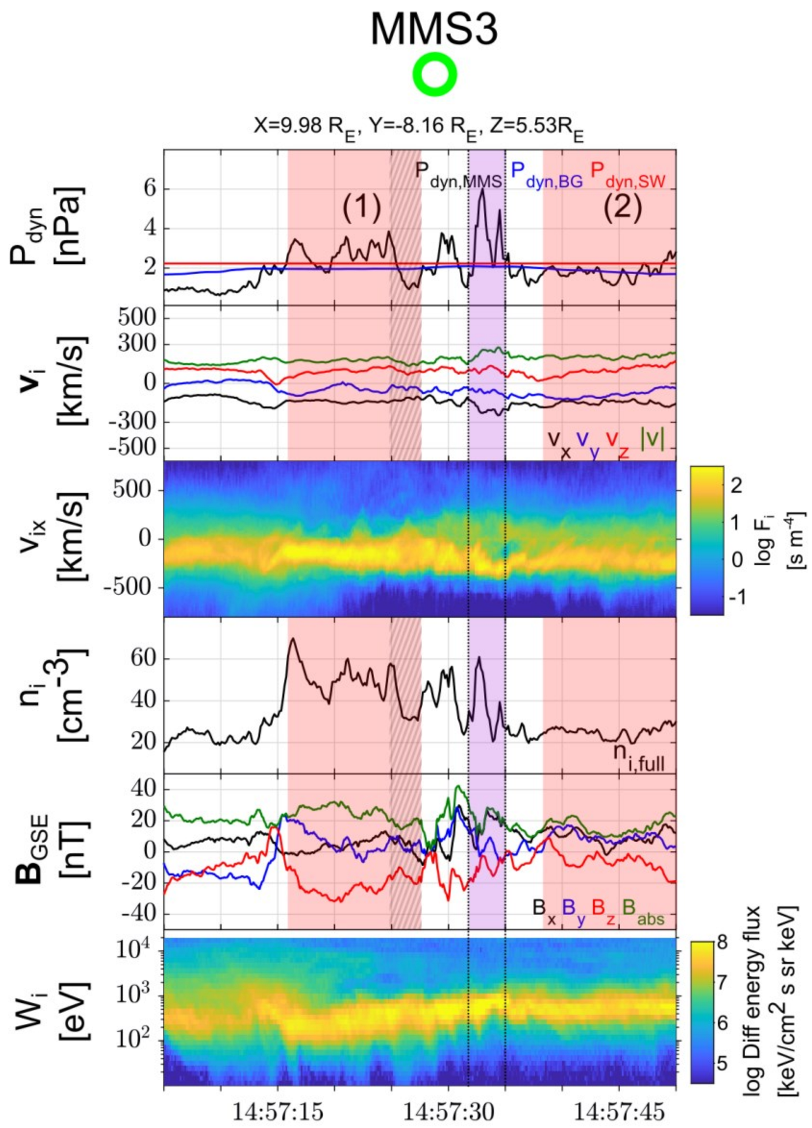
Foreshock Structures & Reformation



Karlsson et al.(2015), Suni et al. (2021), Raptis et al. (2022)

Shock Reformation & Magnetosheath Jets





Raptis, S., Karlsson, T., Vaivads, A. et al. Downstream high-speed plasma jet generation as a direct consequence of shock reformation. *Nature Communications* 13, 598 (2022). https://doi.org/10.1038/s41467-022-28110-4

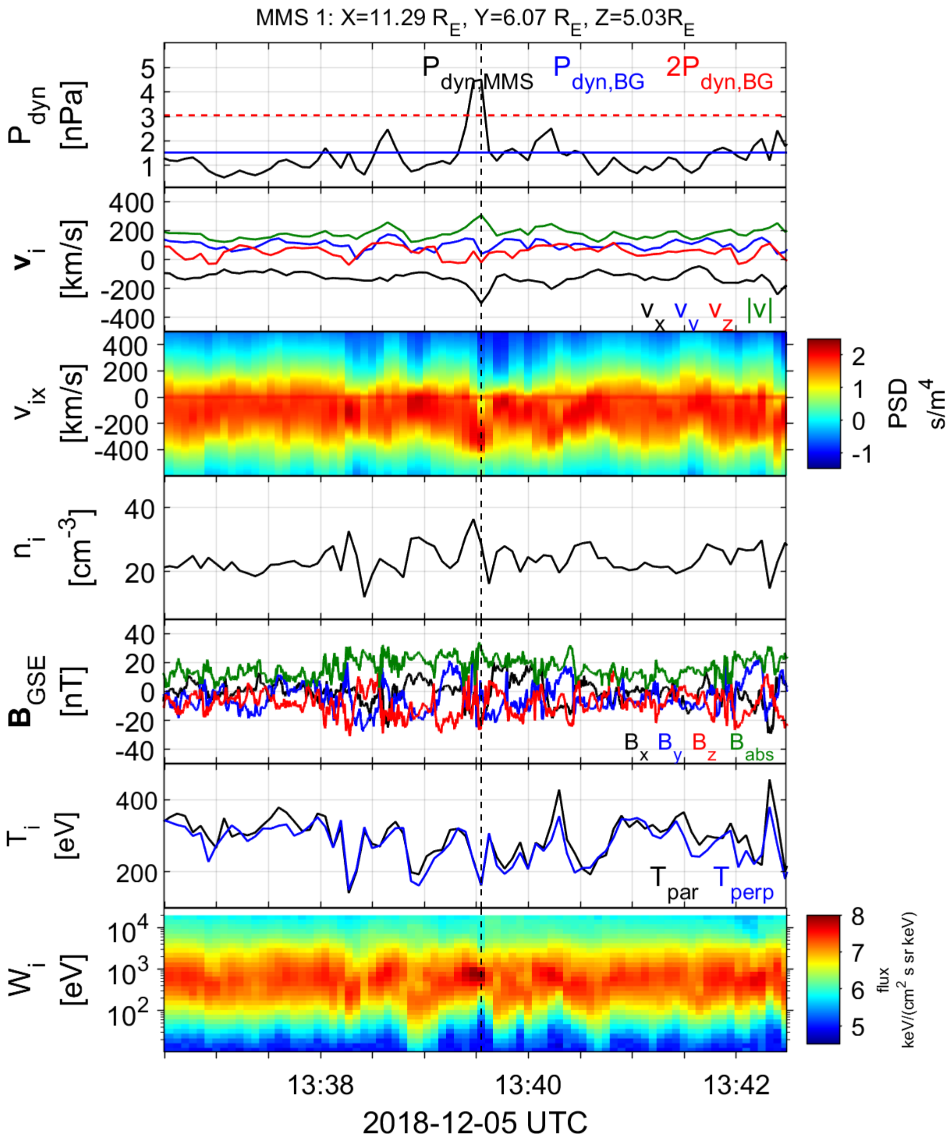
Results

Raptis, Karlsson, et al,. 2022 | (Under Review)

Qpar Magnetosheath jet – Fast data

<u>Qpar Magnetosheath:</u>

- High energy ions
- Low temperature anisotropy
- High **B** Variance



<u>Magnetosheath Jet</u>

$|V| \uparrow$

$V_x \uparrow$

$n \uparrow$

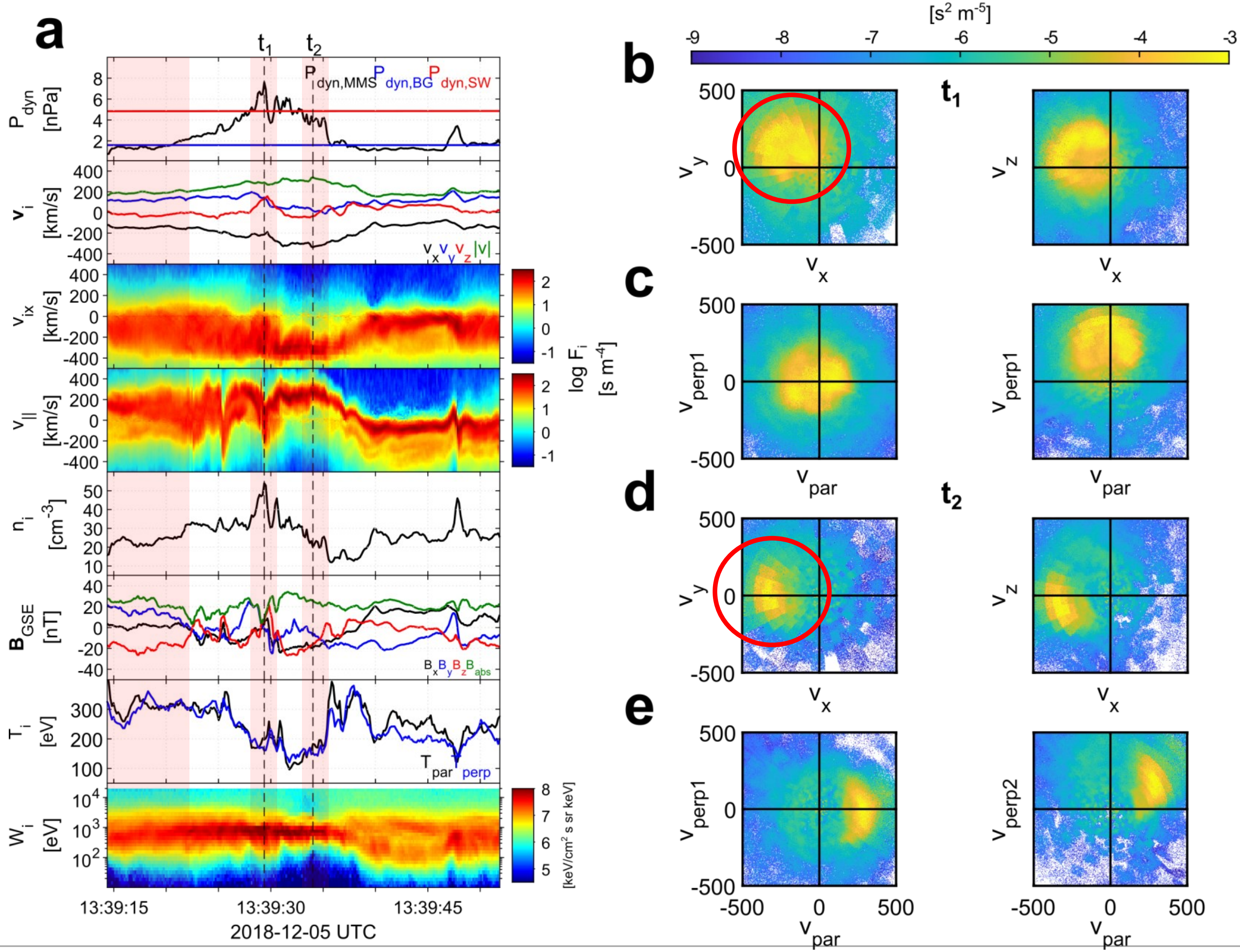
$P_{dyn} > 2\ P_{dyn,BG}$

Raptis S, et al,. 2022 | (Ongoing)

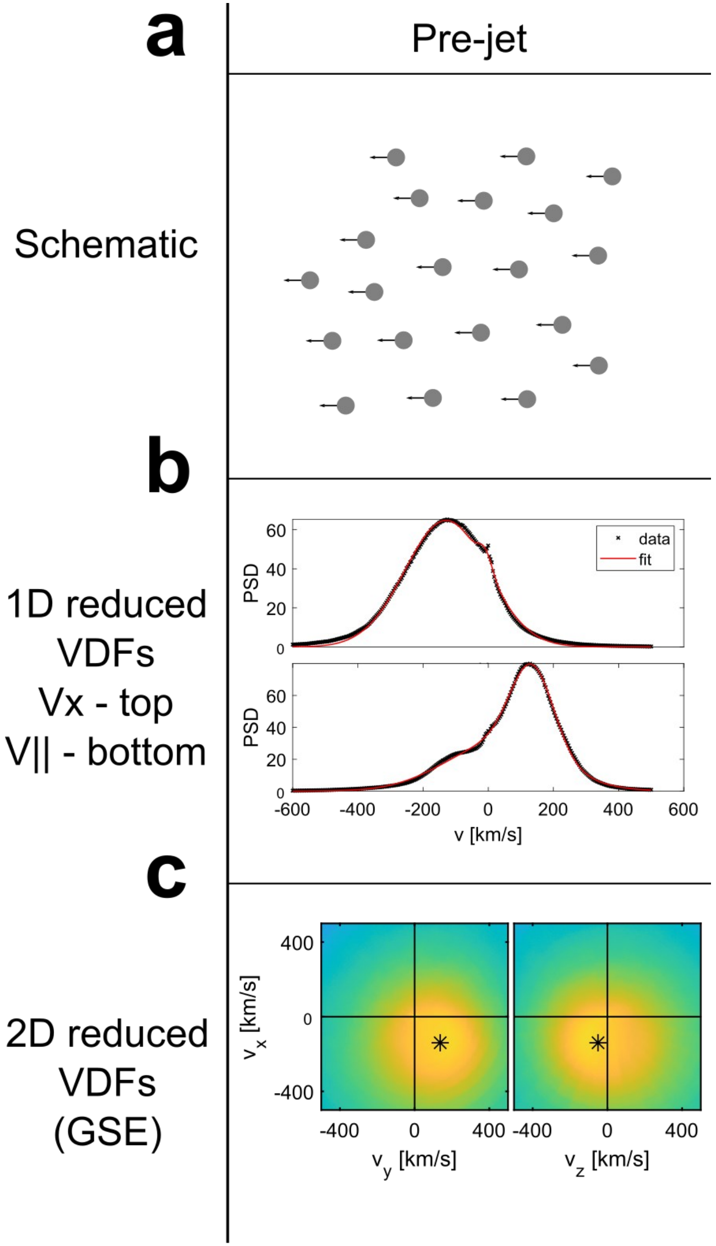
Qpar Magnetosheath jet – MMS Burst data

<u>Areas of Interest</u>

- Pre jet = Typical MSH
- $t_1 = P_{dyn}$ peak
- $t_2 = |\mathrm{V}|$ peak

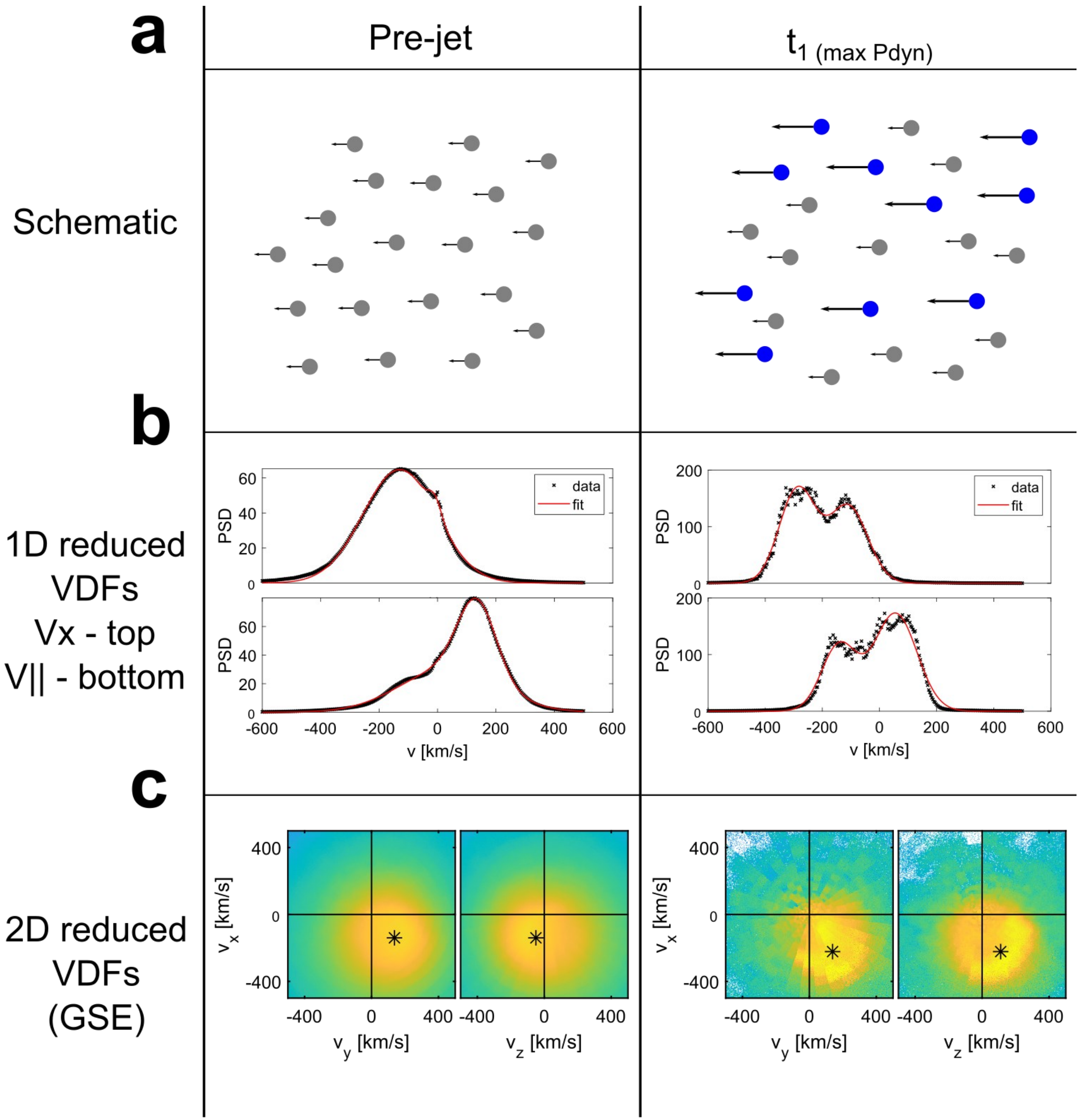


Jet evolution in Qpar Magnetosheath



Raptis S, et al,. 2022 | (Ongoing)

Jet evolution in Qpar Magnetosheath



Raptis S, et al,. 2022 | (Ongoing)

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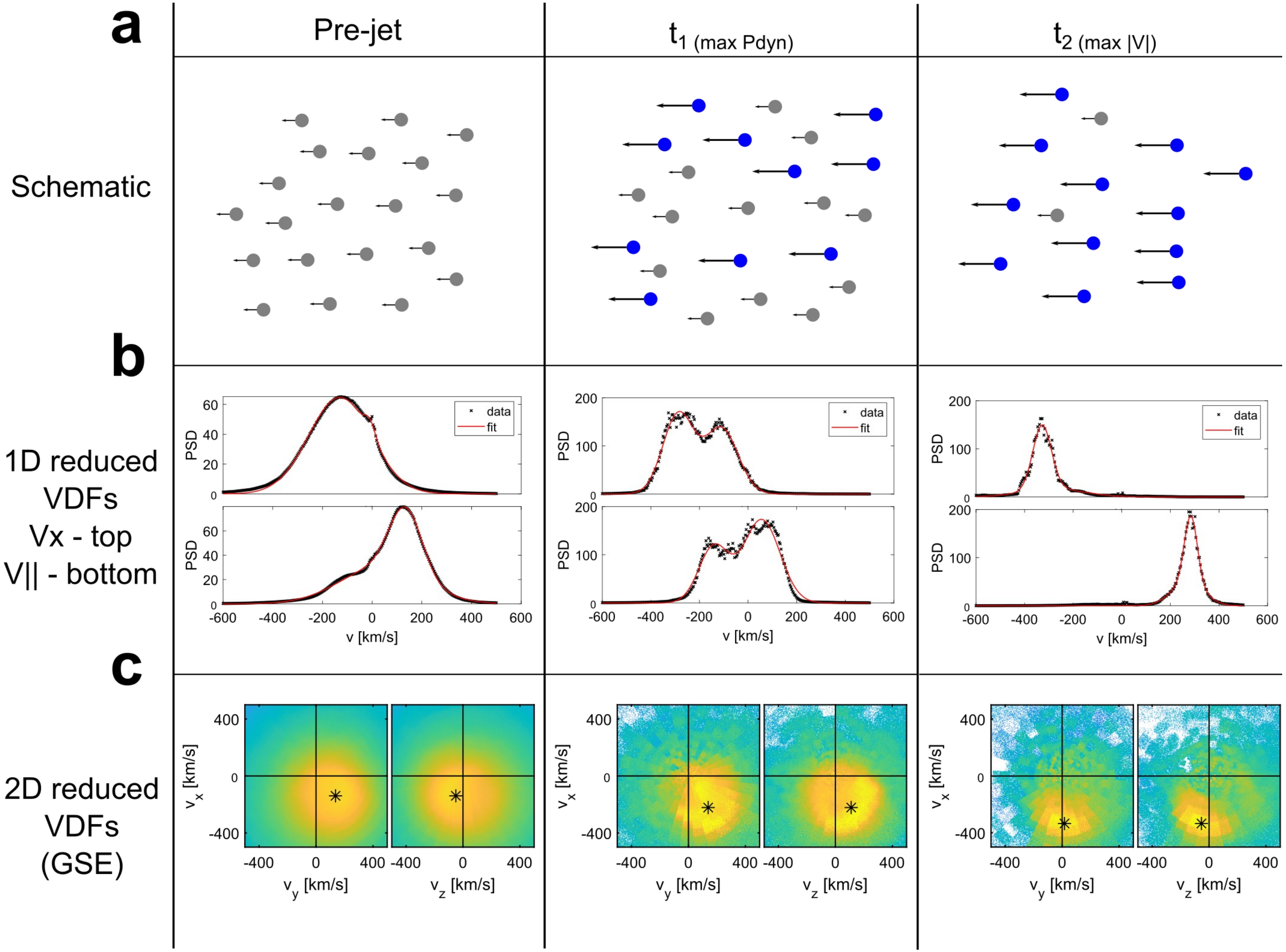
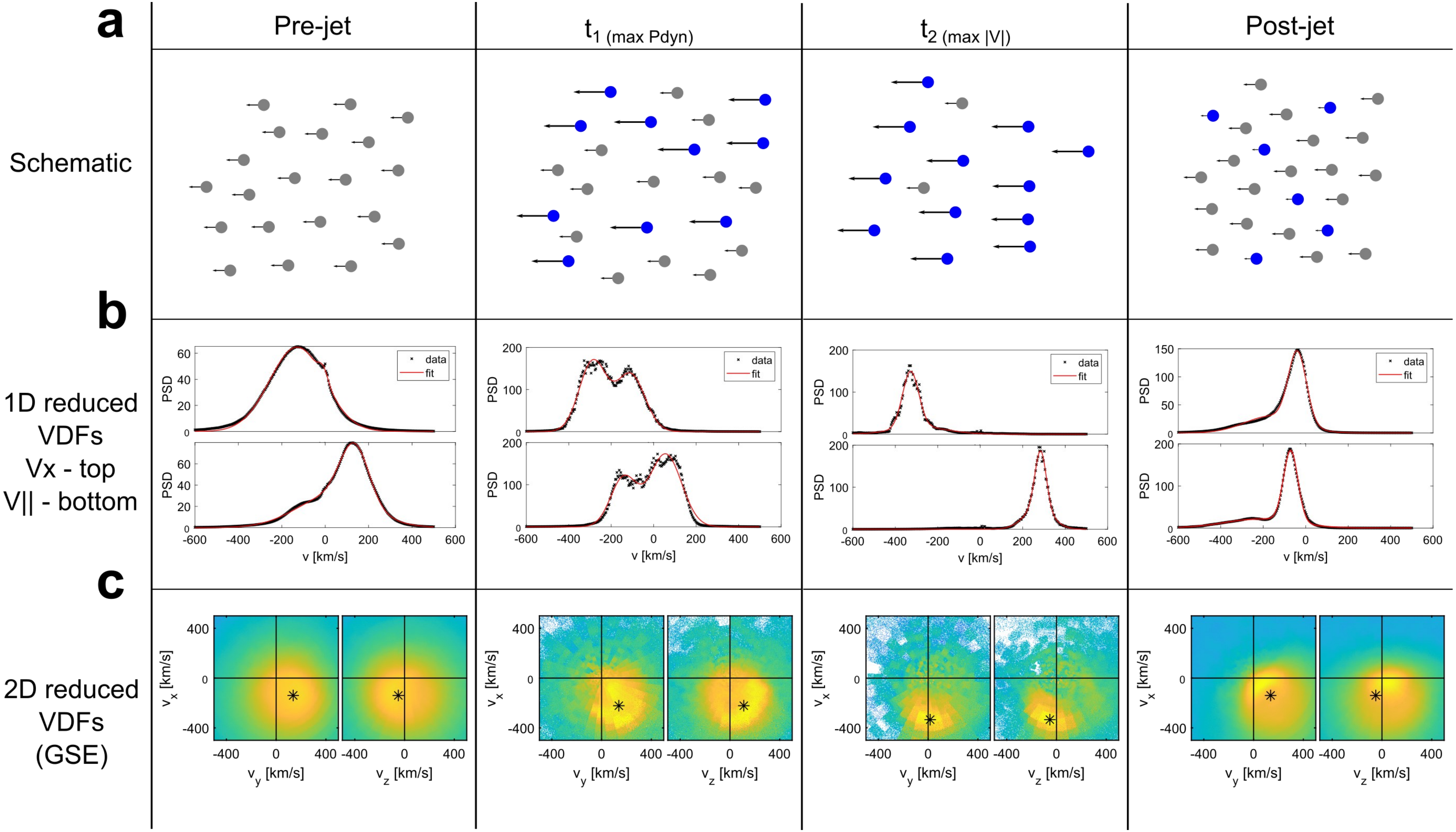


Raptis S, et al,. 2022 | (Ongoing)

Jet evolution in Qpar Magnetosheath

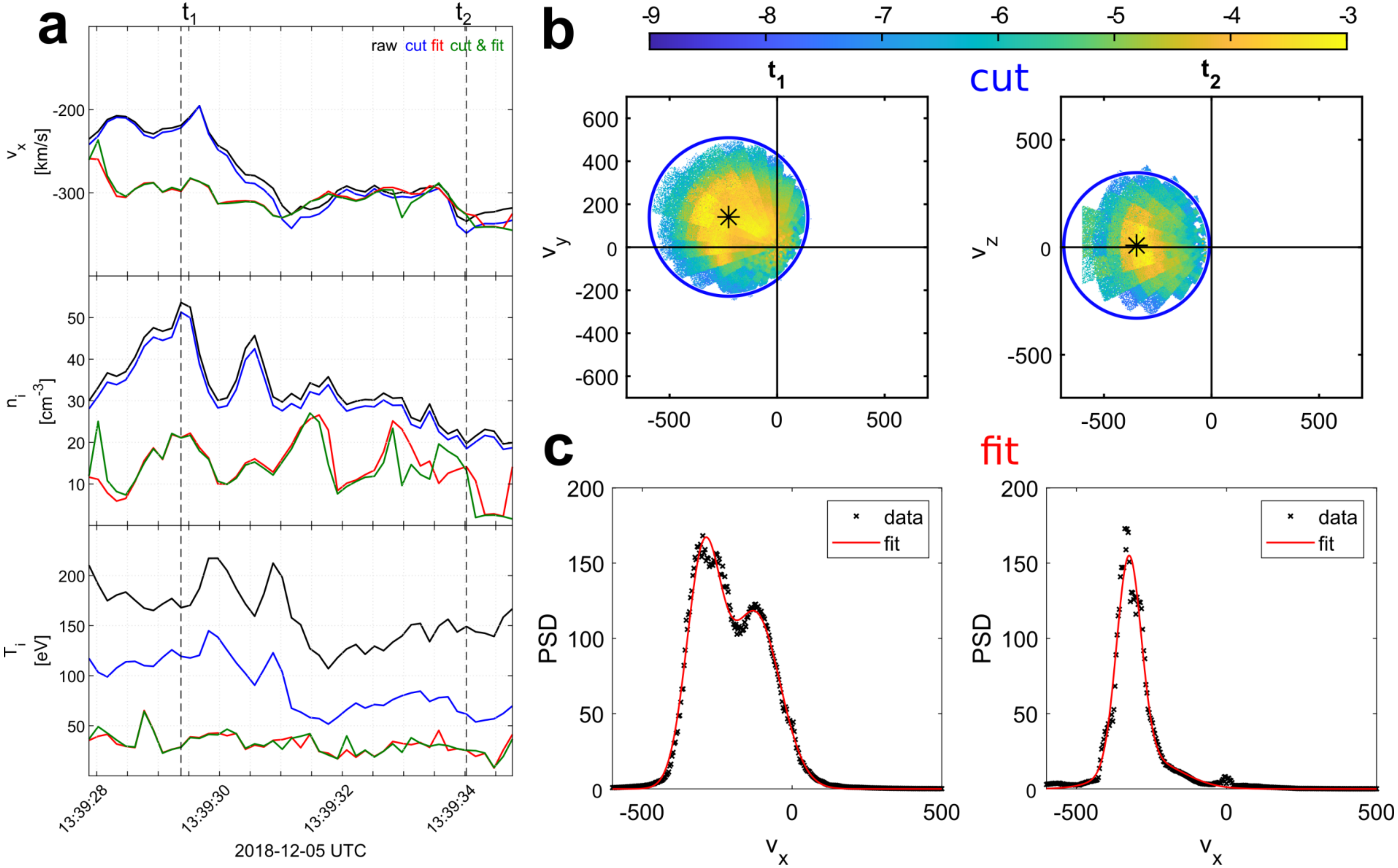


Raptis S, et al,. 2022 | (Ongoing)

Partial Moment Derivation

Methods:

- Cut : $1v_{th}$ sphere in 3D VDF around bulk velocity
- Fit : Fit 2 Maxwellians in 1D reduced VDFs to obtain



Raptis S, et al,. 2022 | (Ongoing)

Summary & Conclusion

Main points

- Jets are inherently kinetic structures with complicated VDFs throughout their life
- They interact with background plasma (magnetic structures), evolving as they propagate.
- Their plasma moments are not well captured by the full particle moments since at least for part of their lifetime.

Future work

- Evaluate previous statistics (done with low-resolution full particle moments).
- More events to see how properties change on different environments/stages
- Simulations : (TBD – Quite some interesting results already though)
- Investigation of wave generation

Thank you for listening and enjoy your time in Greece ☺

Extras

	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 electron 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 smaller scale 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

MMS – Jet Database

Fast/Survey

9/2015 - 9/2020

Subset	Number	Percentage (%)
Quasi-parallel	2458	26.7
Final cases	**901**	10.1
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Encapsulated	80	0.9
Final cases	**60**	0.7
Other	5335	58.0
Unclassified/Uncertain	3789	41.2
Border	1500	16.3
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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
Kajdic P., **Raptis S**., et al. (2021) | GRL

Raptis S., Karlsson T., et al. (2022) | Nat. Commun
Raptis S., Karlsson T., et al. (2022) | Under Review

Jets – references update (>2019)

Jets Downstream of Collisionless Shocks

Plaschke et al. (2018)

https://link.springer.com/article/10.1007/s11214-018-0516-3

Associated phenomena & effects

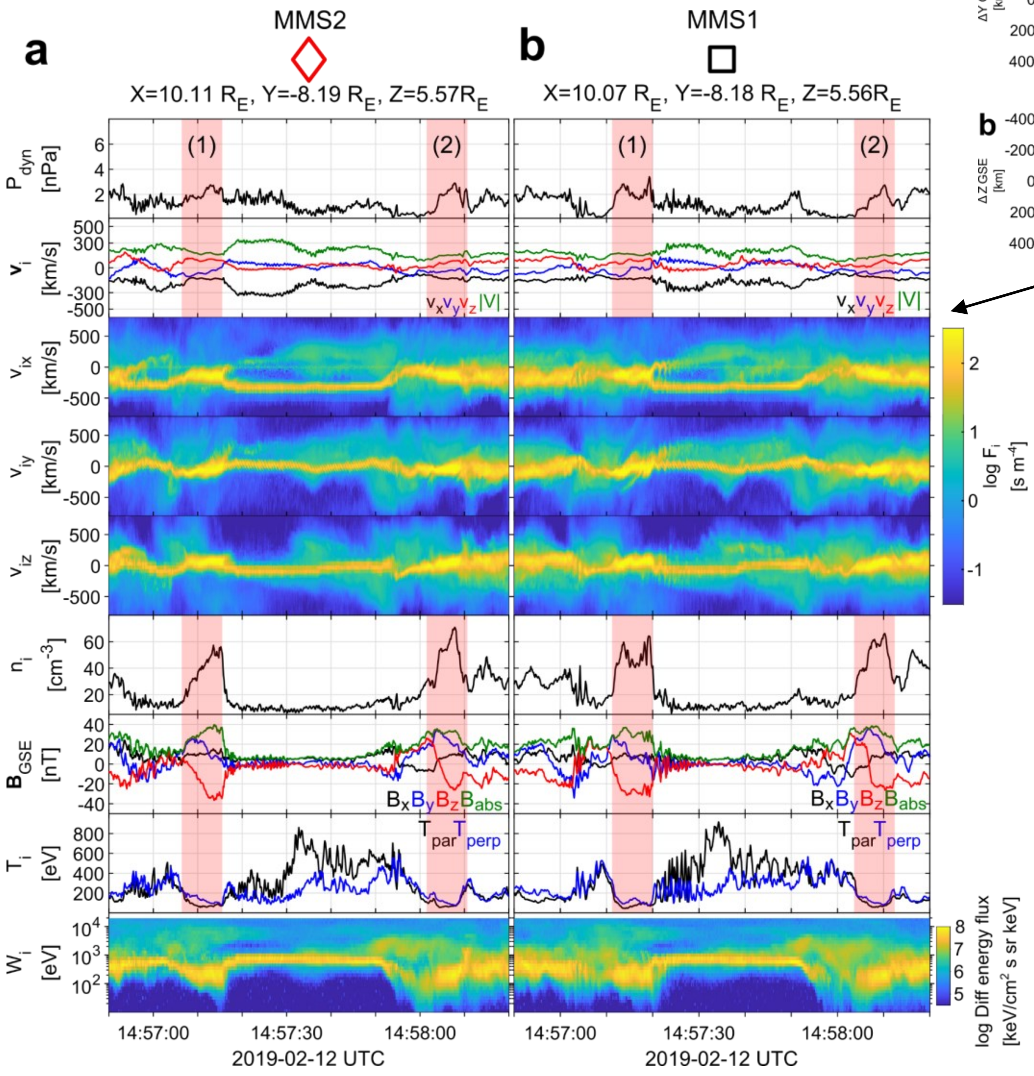
- **Excitation** of surface **eigenmodes** at magnetopause: Archer et al. (2019, 2021)
- **Mirror mode waves** and jets **:** Bianco-Cano et al. (2020)
- Bursty **magnetic reconnection** at the Earth's magnetopause : Ng et al. (2021)
- **Ground-based magnetometer** response : Norenius et al. (2021)
- Generation **of Pi2 pulsations** : Katsavrias et al. (2021)
- B in jets, **Bz variations near magnetopause** : Vuorinen et al. (2021)

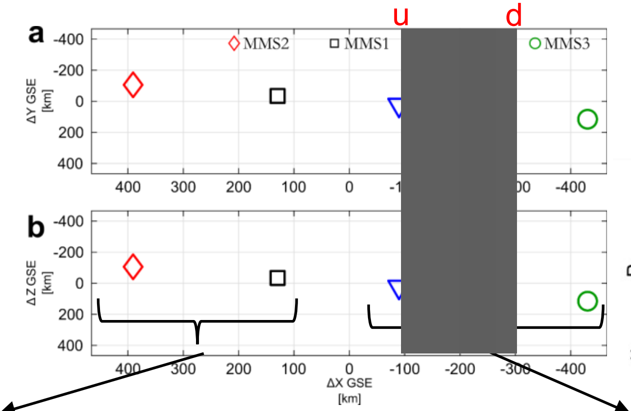
Modeling & formation

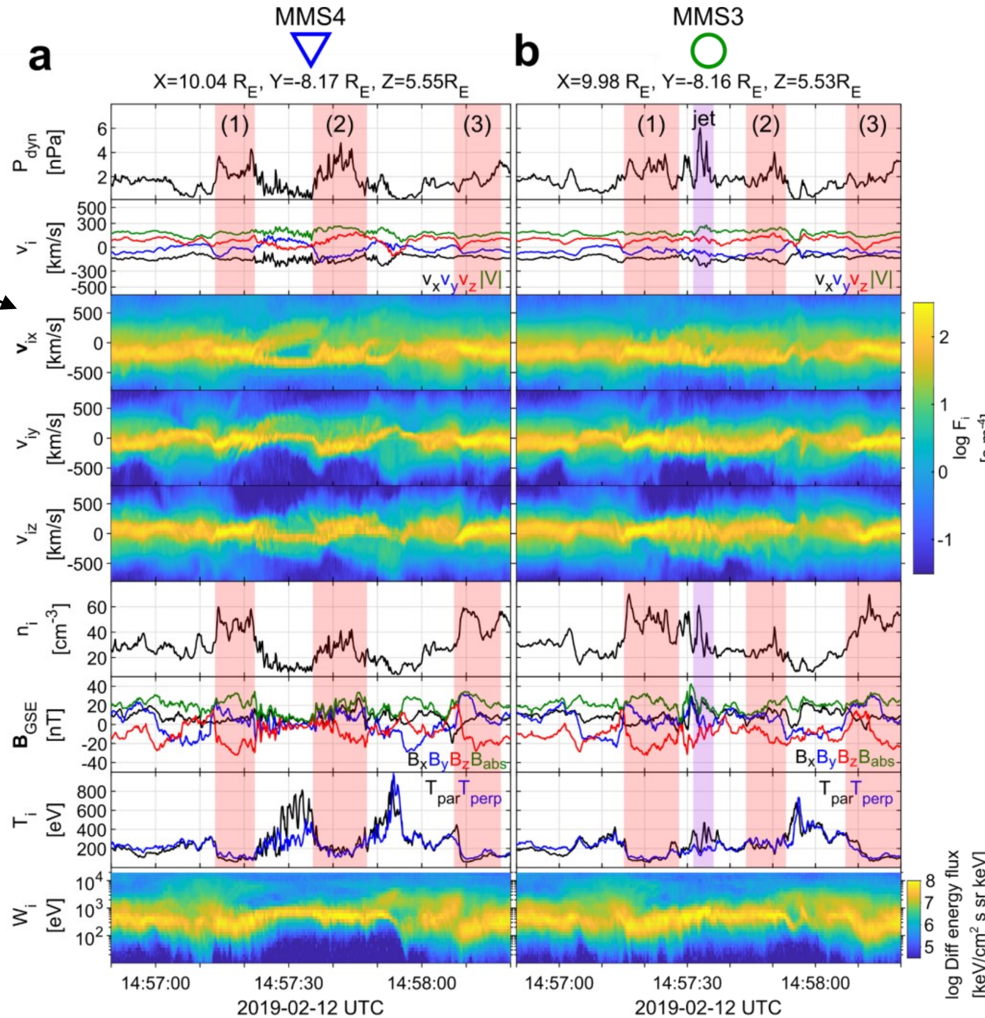
- **Velocity & magnetic field alignment** in jets **:** Plaschke et al. (2020)
- **Classification** of jets using MMS & Neural Networks : Raptis et al. (2020a,2020b)
- Comparison **MMS vs simulations** : Palmroth et al. (2021)
- **Solar wind effect** on jet formation : LaMoury et al. (2021)
- Magnetosheath Jets and **Plasmoids** - Hybrid Simulations : Preisser et al. (2020)
- **Formation** of jets in **Quasi-perpendicular magnetosheath** : Primoz et al. (2021)

And more : Liu et al. (2020a,2020b), Omelchenko et al (2021), Sibeck et al. (2021), Suni et al. (2021), Tinoco-Arenas et al. (2022) … etc. etc.

General Observations of MMS







<u>Solar Wind:</u>

$v_x \gg$

$v_{y,z} \sim 0$

$n_i \ll$

$\boldsymbol{B} \ll$

Beam like distribution

<u>Foreshock → Magnetosheath (compressed – thermalized plasma)</u>

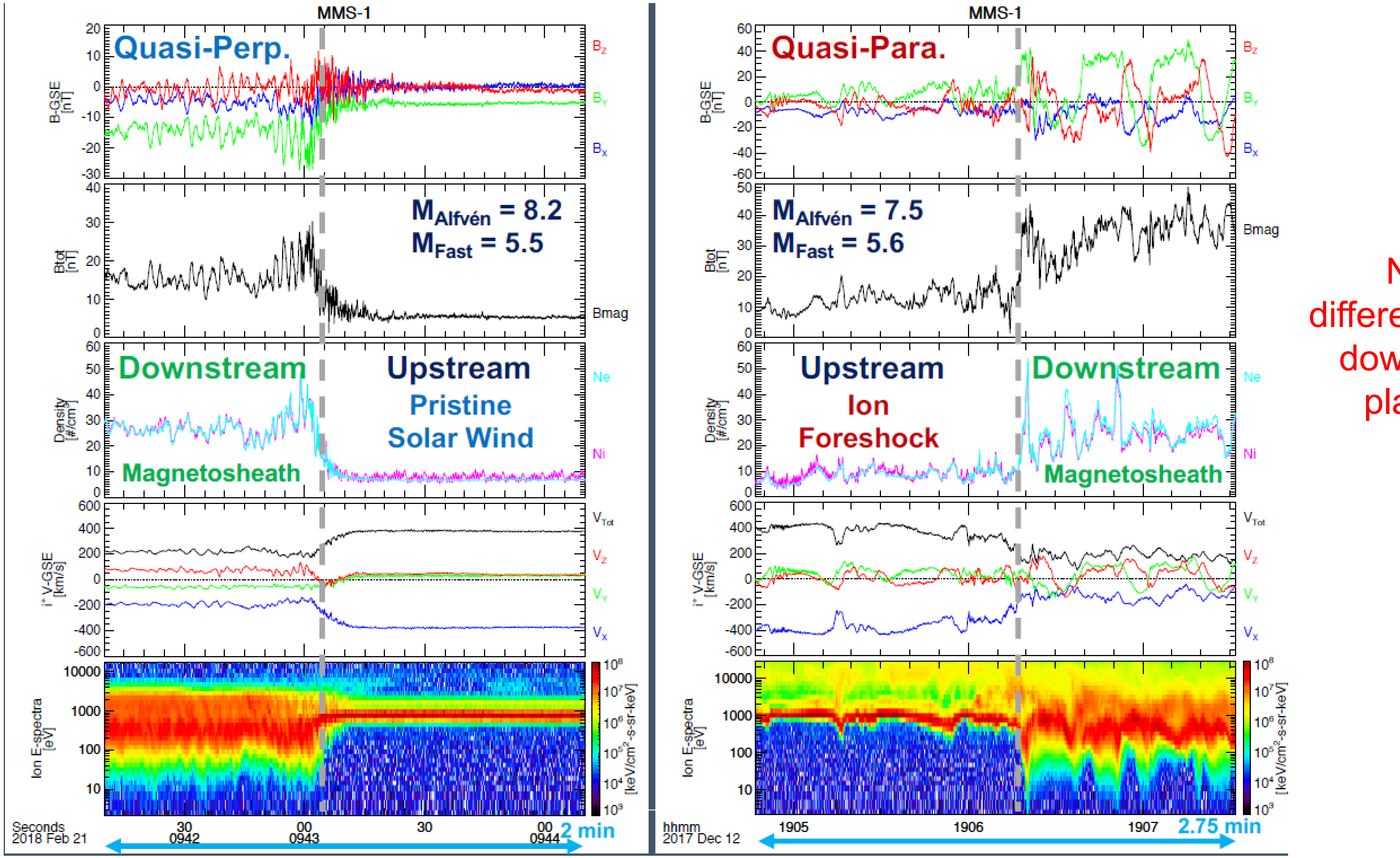
$v \ll v_{SW}$

$n_i \gg n_{SW}$

$\boldsymbol{B} \gg$

Thermalized distribution

Shock transitions with MMS



Notice difference in the downstream plasma ?

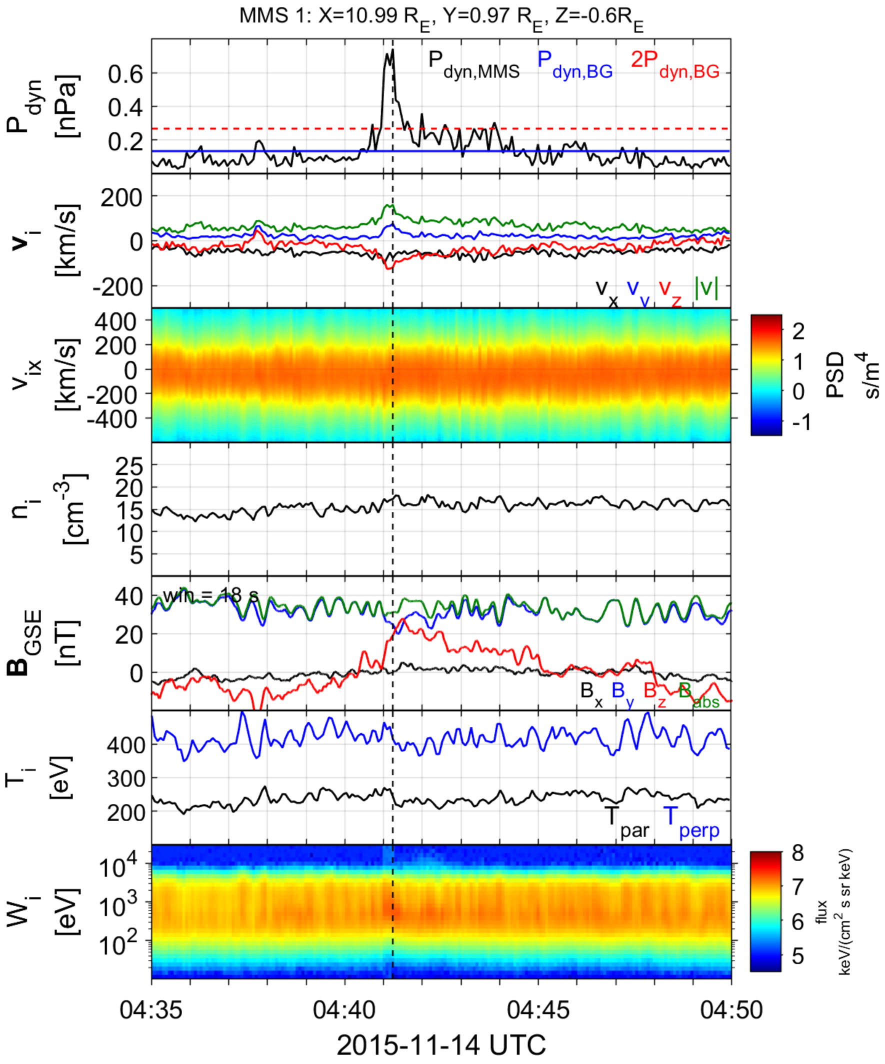
Figure taken from : Drew Turner's talk | SWSG2021

Summarized properties – Quasi Perpendicular

- Less common
- Less Energetic
- Mainly velocity driven
- Very small duration (~4 sec)
- Could be connected to MSH reconnection or FTEs
- Connection mirror mode waves

Qperp Jet

Jets found in $Q_\perp$MSH



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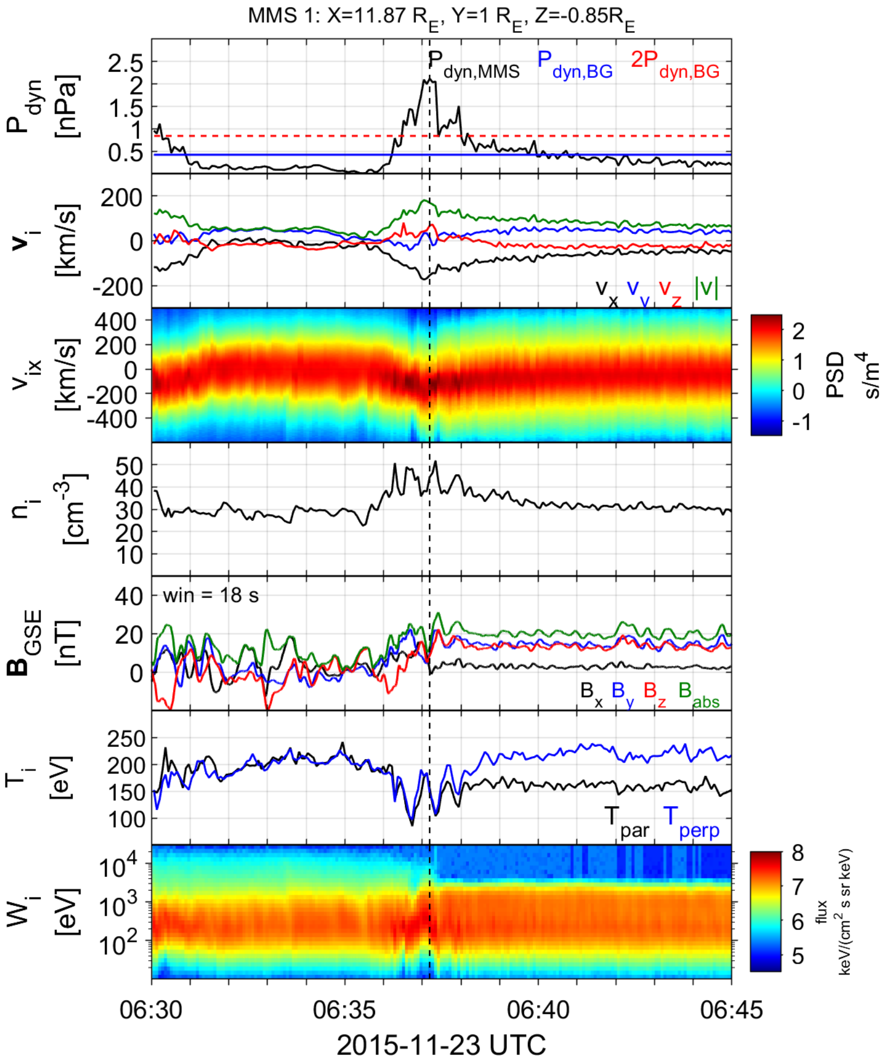
Raptis S., Karlsson T., et al. (2020) | JGR

Summarized properties – Boundary

- Hard to estimate their occurrence rate
- Quite energetic and long duration
- Similar properties to Qpar jets
- Could be geoeffective (GMAGs) [Norenius et al. 2021]
- Maybe associated to pressure pulses of SW [Archer et al. 2012]

Boundary Jet

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



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