Magnetosheath Jets using MMS

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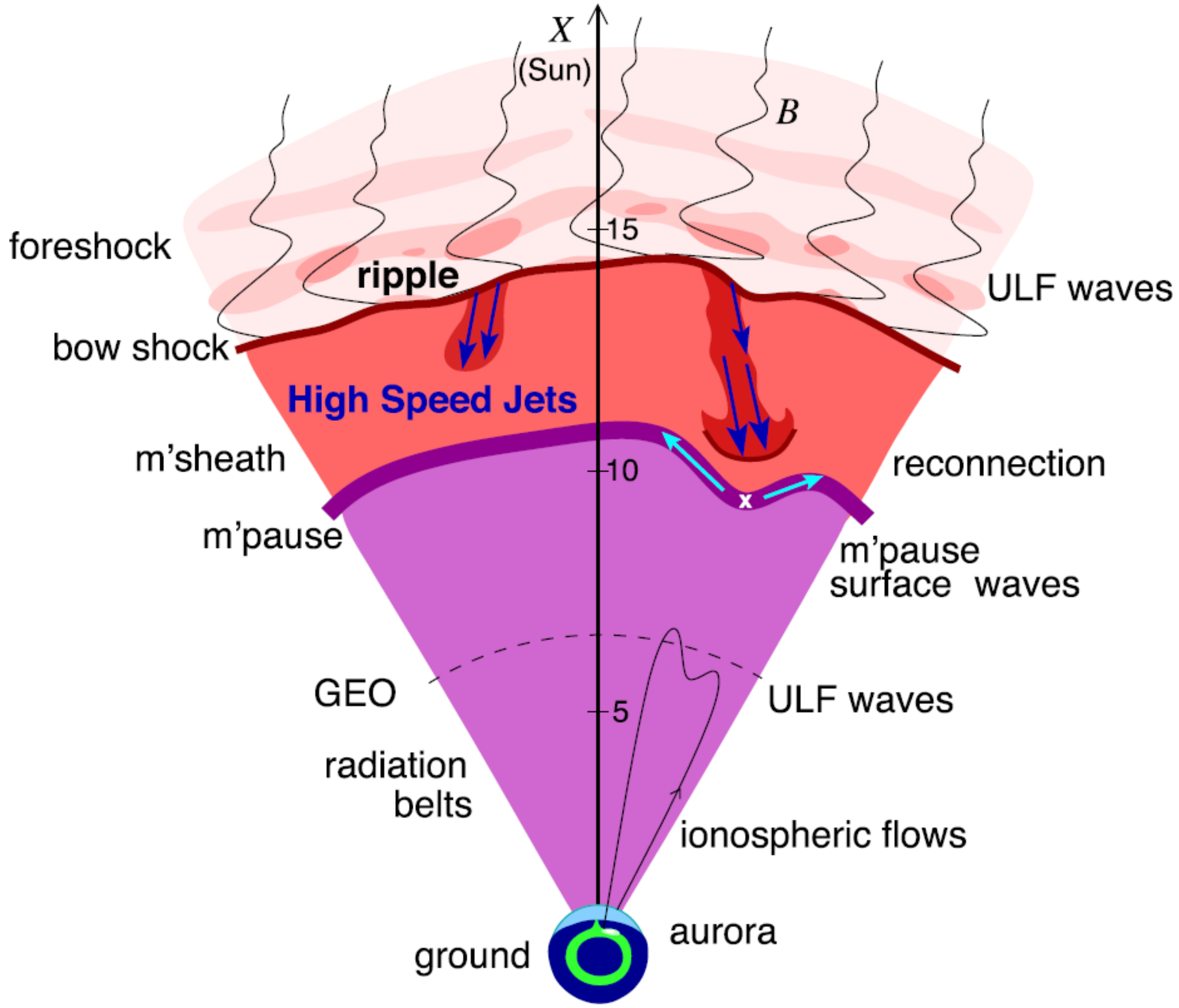
Magnetosheath Jets



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

Definition

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

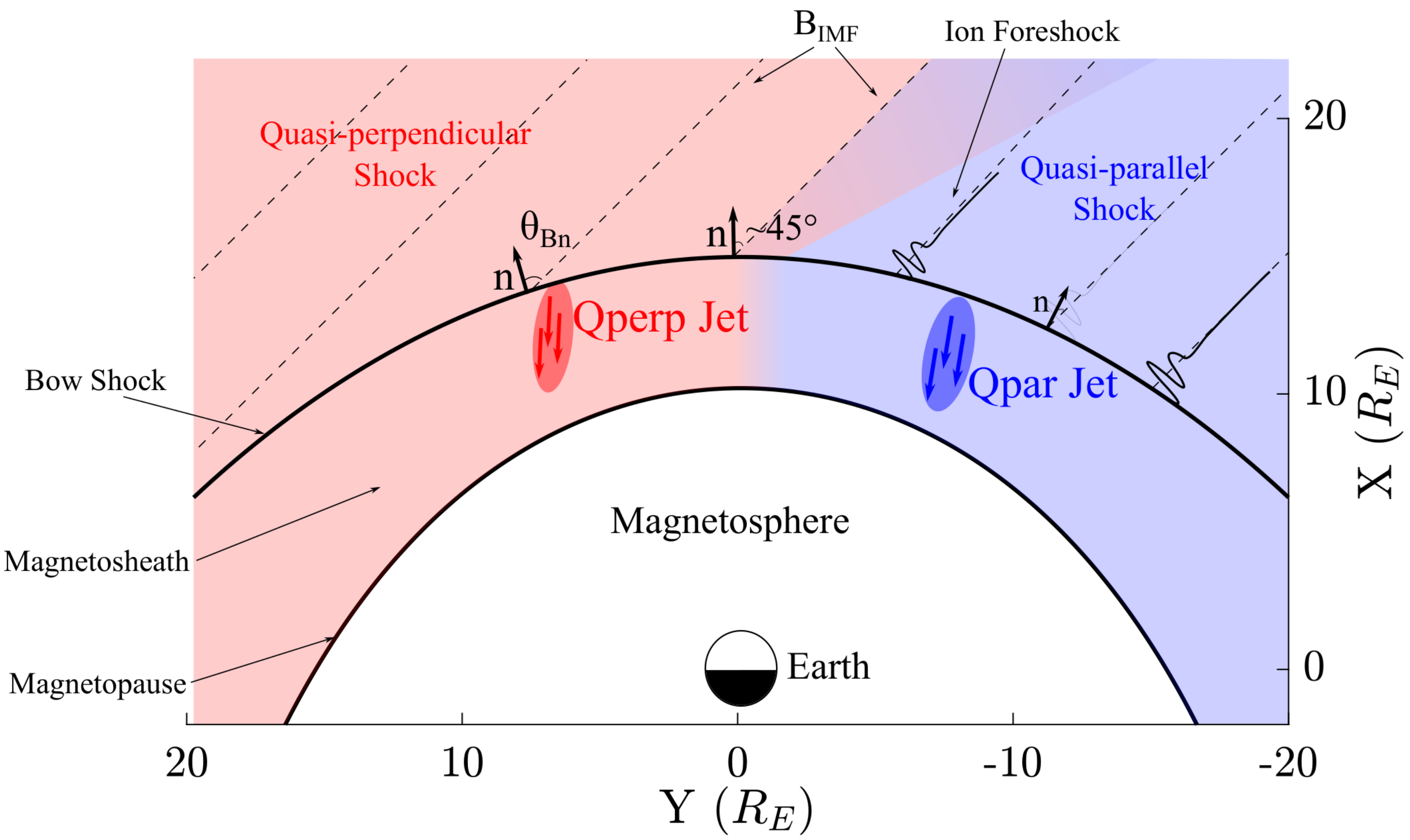
Related phenomena

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

Jets

Classes & Properties | Formation & Evolution

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)

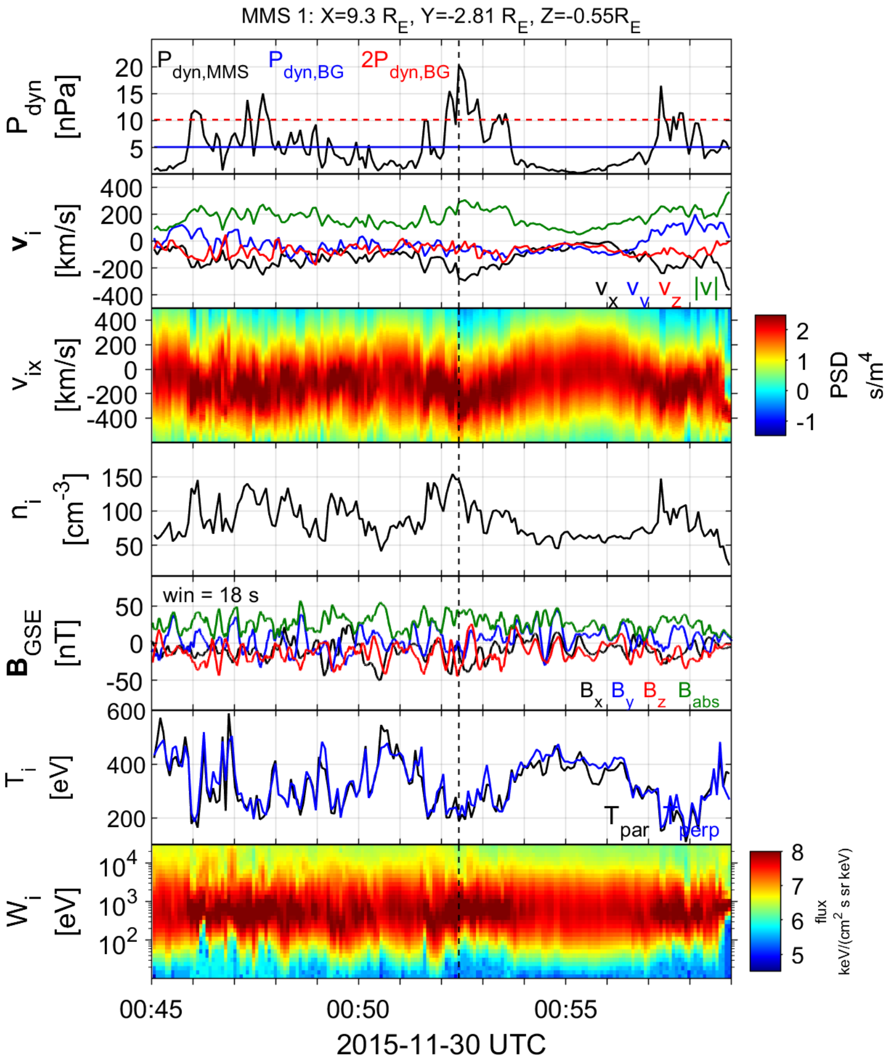
Raptis, Karlsson, et al. (2020) | JGR
Raptis, Aminalragia-Giamini et al. (2020) | Front. Astron. Space Sci
Karlsson, **Raptis** et al. (2021) | JGR
Kajdič, **Raptis** et al. (2021) | GRL

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 $Q_{\parallel}$ MSH



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

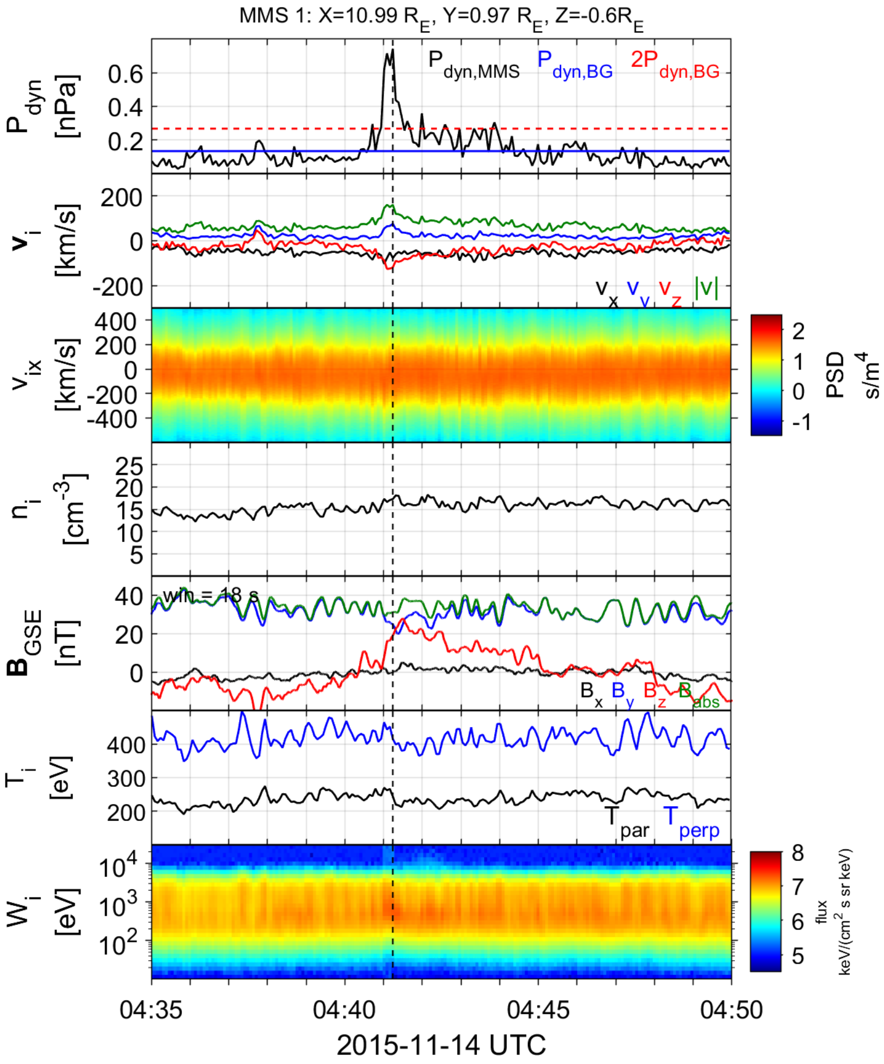
Raptis S., Karlsson T., et al. (2020) | JGR

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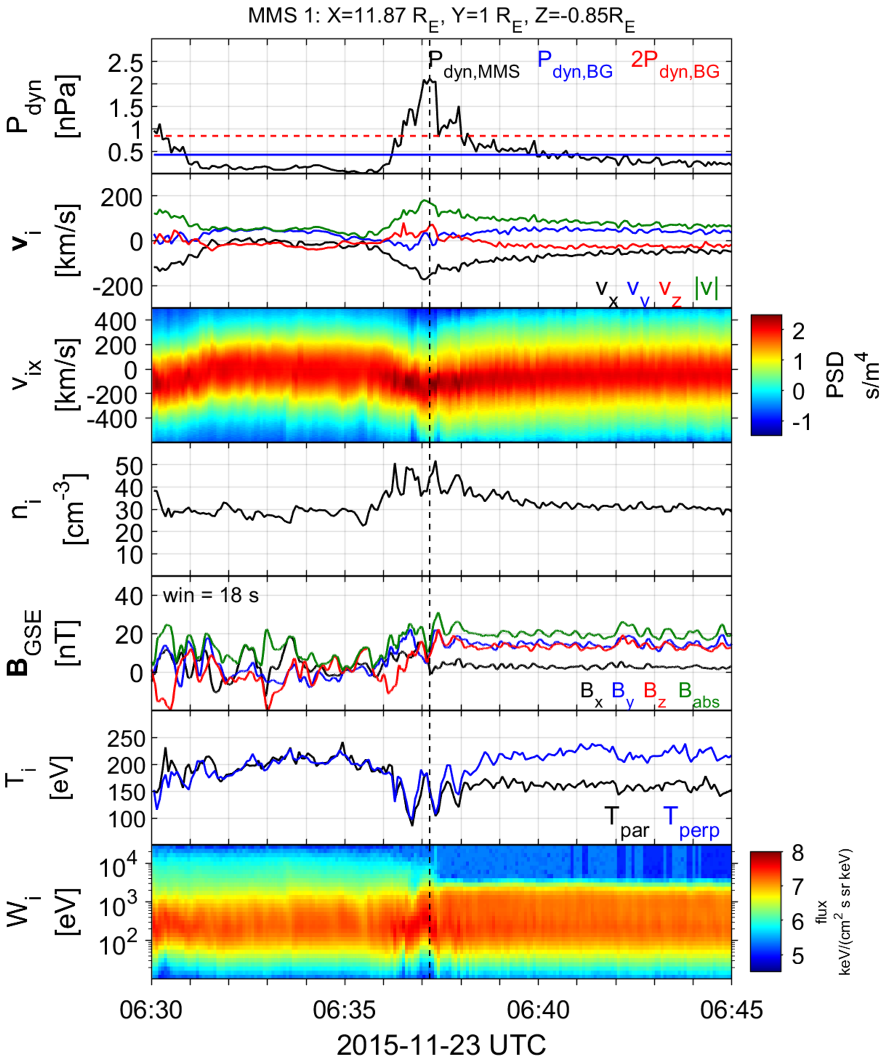
Raptis S., Karlsson T., et al. (2020) | JGR

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]



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Boundary Jet

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

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

MMS – Jet Database

Fast/Survey (low res)

9/2015 - 9/2020

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Burst (high res)

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

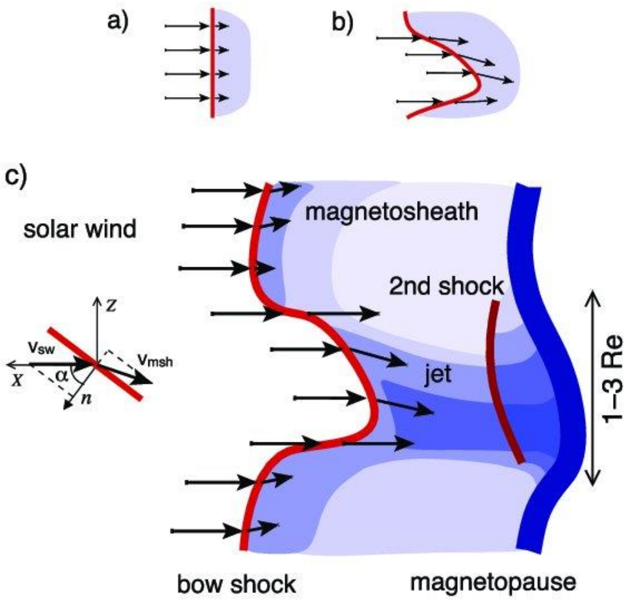
Raptis S., Karlsson T., et al. (2022) | Nat. Commun
Raptis S., Karlsson T,, et al. (2022) | Ongoing

Jets

Classes & Properties | Formation & Evolution

How are these jets created (Qpar/Boundary) ?

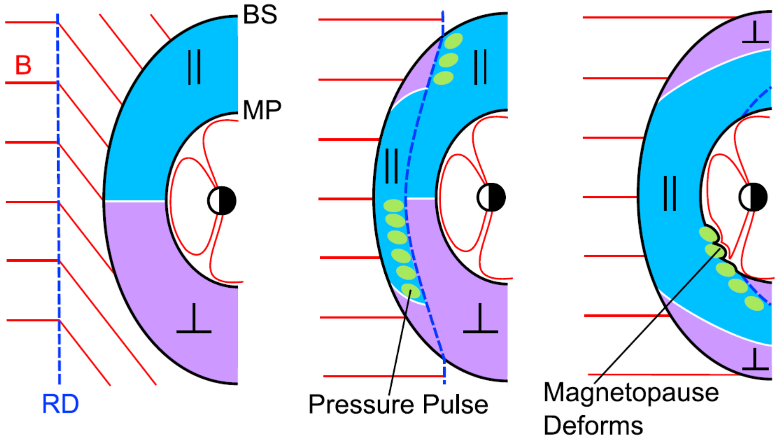
Shock ripples



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

Hietala et al. (2009,2012)

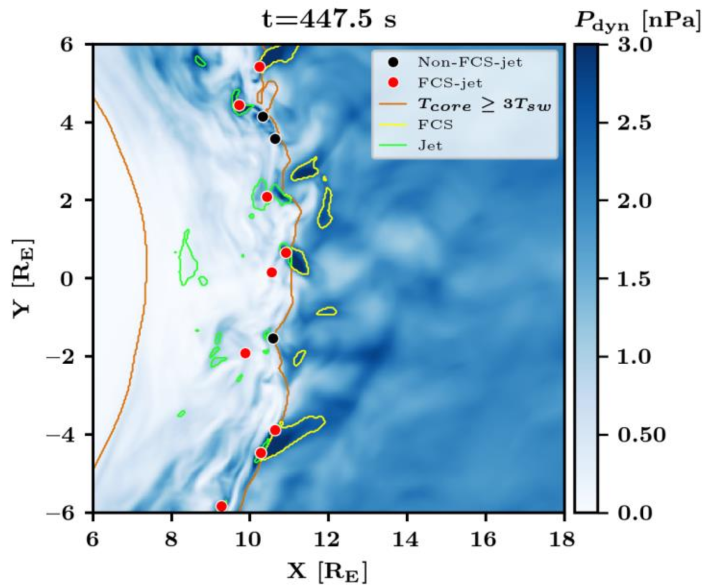
SW discontinuities



RD → Change in Foreshock position → Pressure pulses

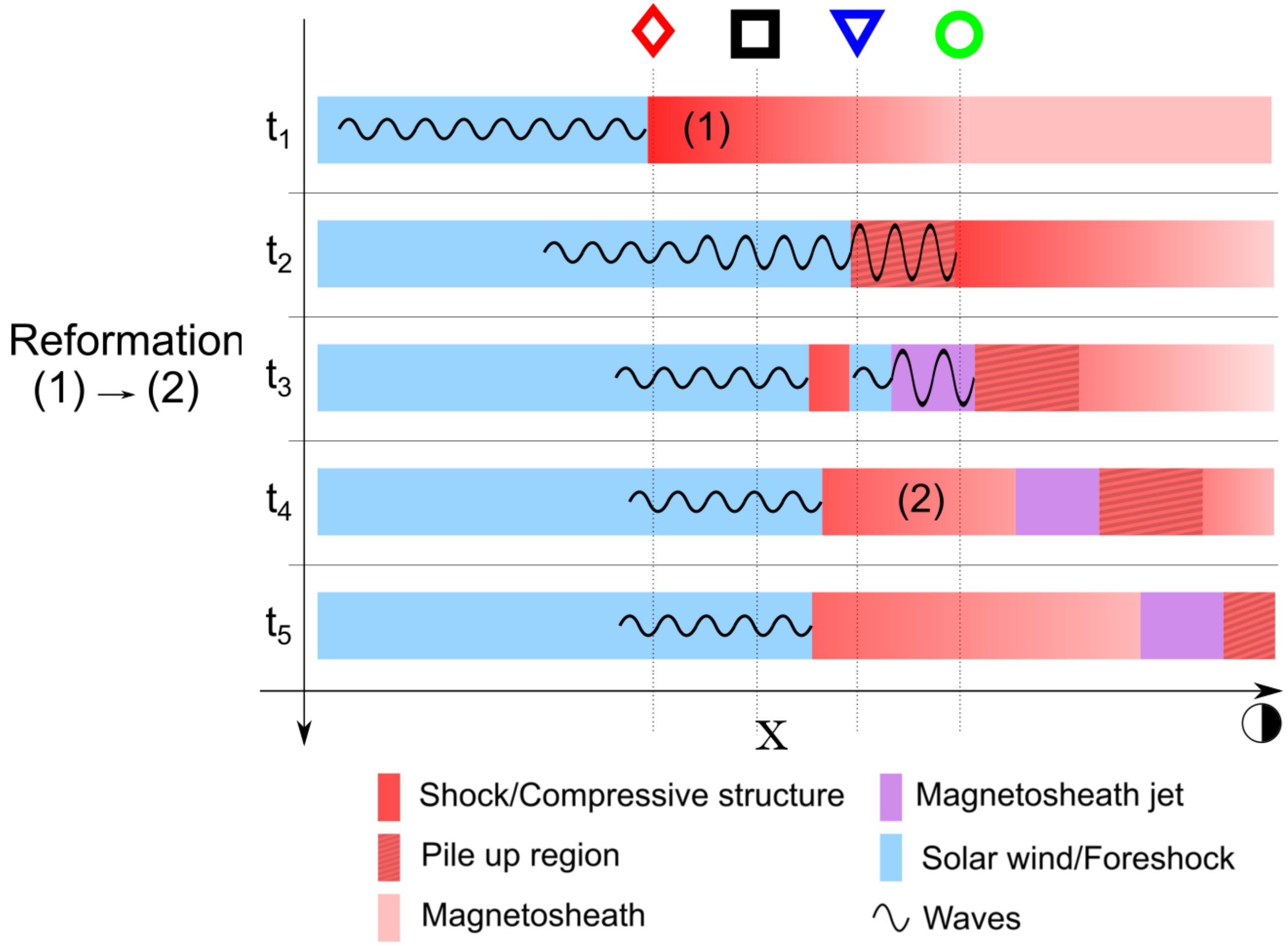
Archer et al. (2012)

Foreshock Structures & Reformation



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

Shock Reformation & Magnetosheath Jets



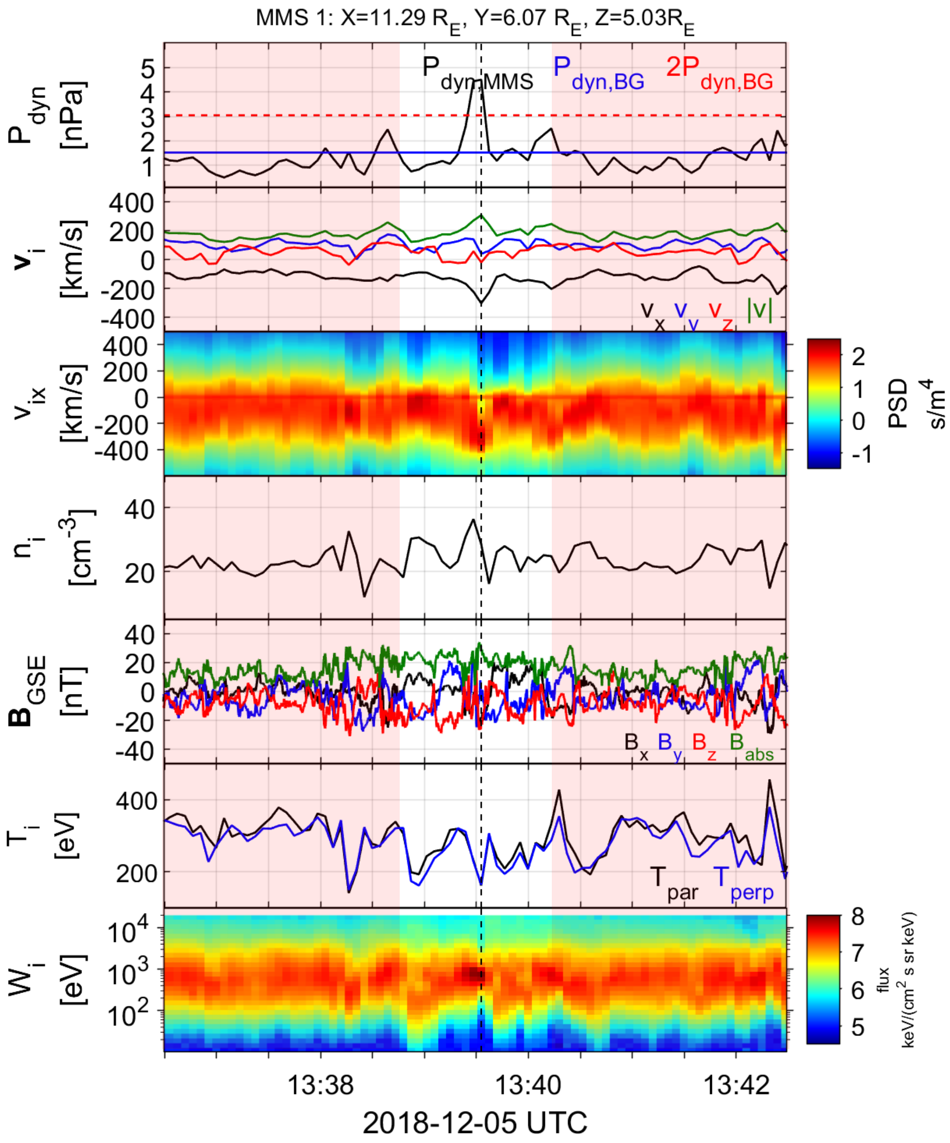
Raptis, S., Karlsson, T., Vaivads, A. et al. Downstream high-speed plasma jet generation as a direct consequence of shock reformation. Nature Communications 13, 598 (2022). https://doi.org/10.1038/s41467-022-28110-4

Recent Results

MMS | Schematic

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

Qpar Magnetosheath jet – Fast data



Qpar Magnetosheath:

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

Magnetosheath Jet

$|V| \uparrow$

$V_x \uparrow$

$n \uparrow$

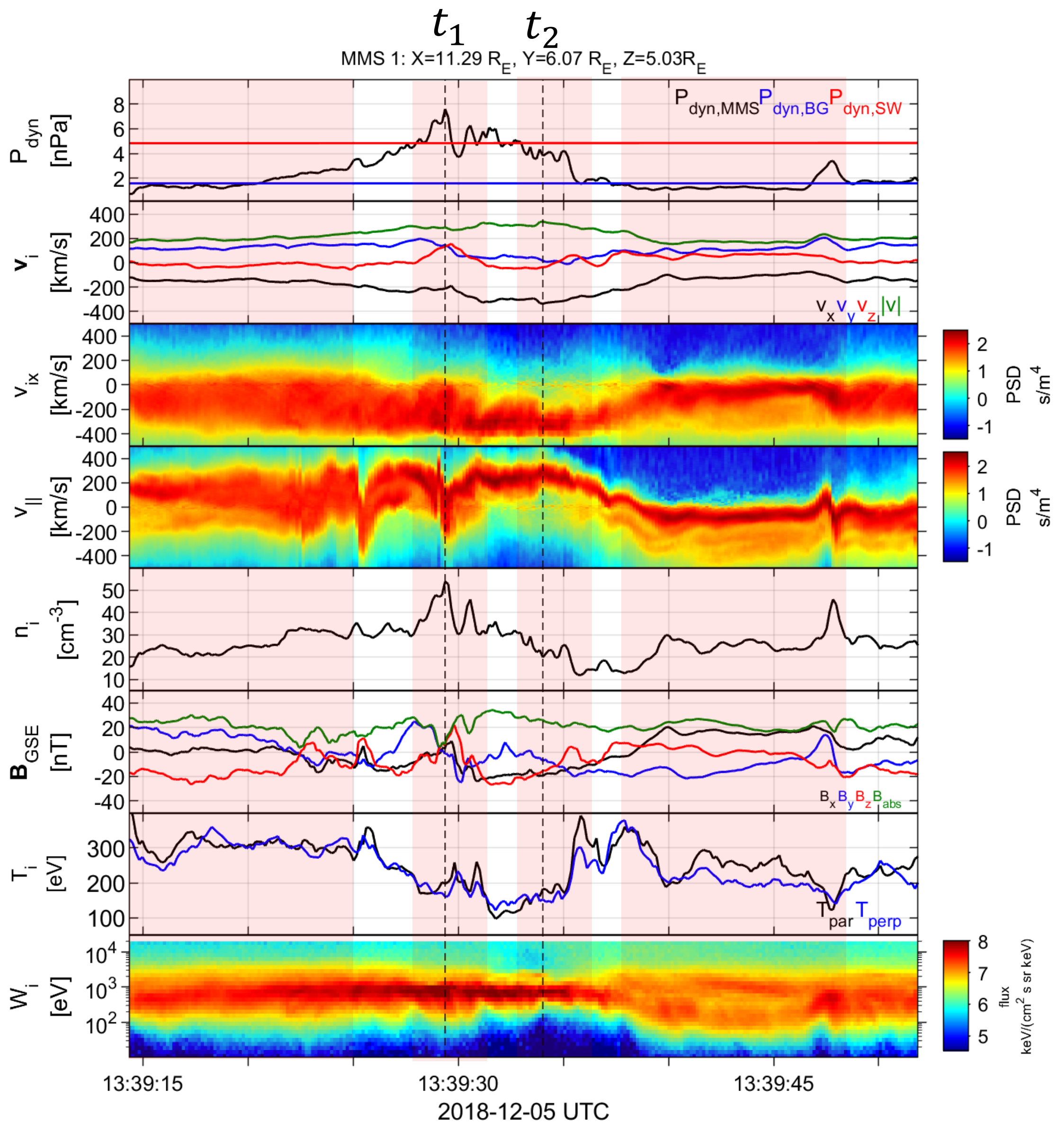
$$P_{dyn} > 2\,P_{dyn,BG}$$

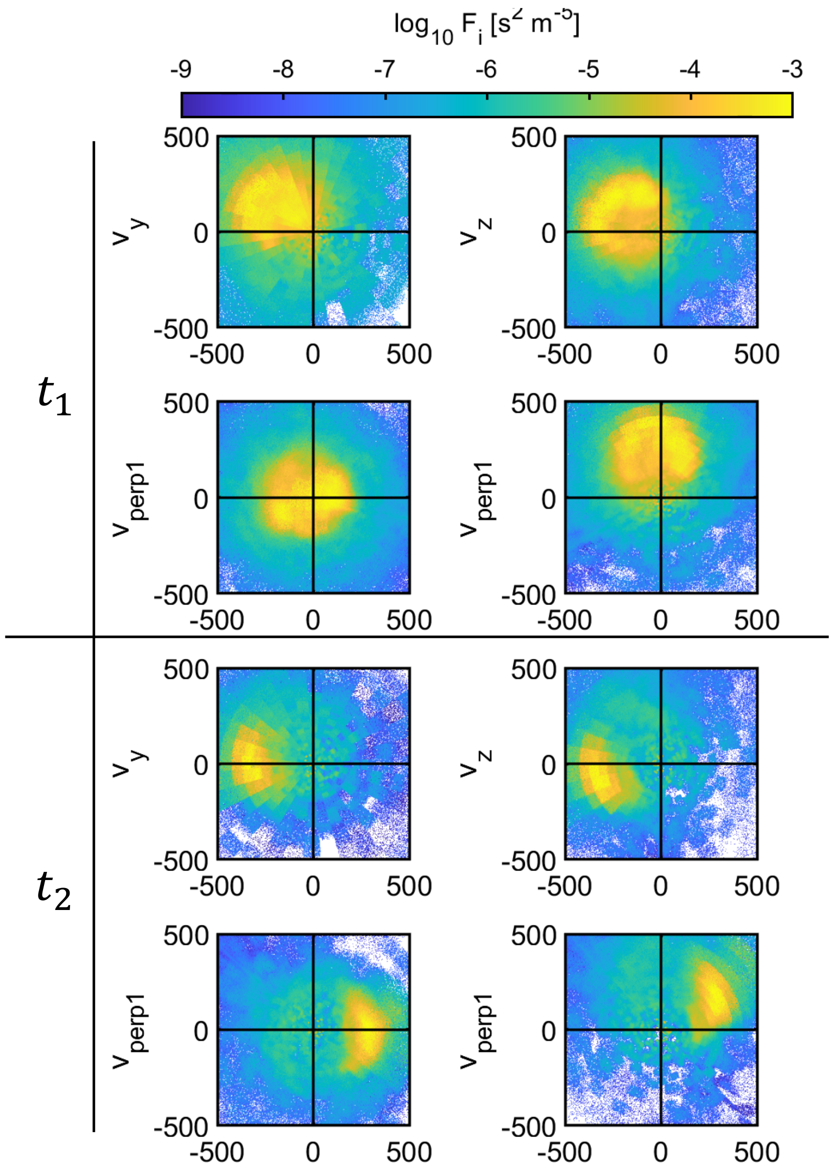
Raptis, Karlsson, et al,. 2022 | (Ongoing)

Qpar Magnetosheath jet – Burst data

Areas of Interest

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





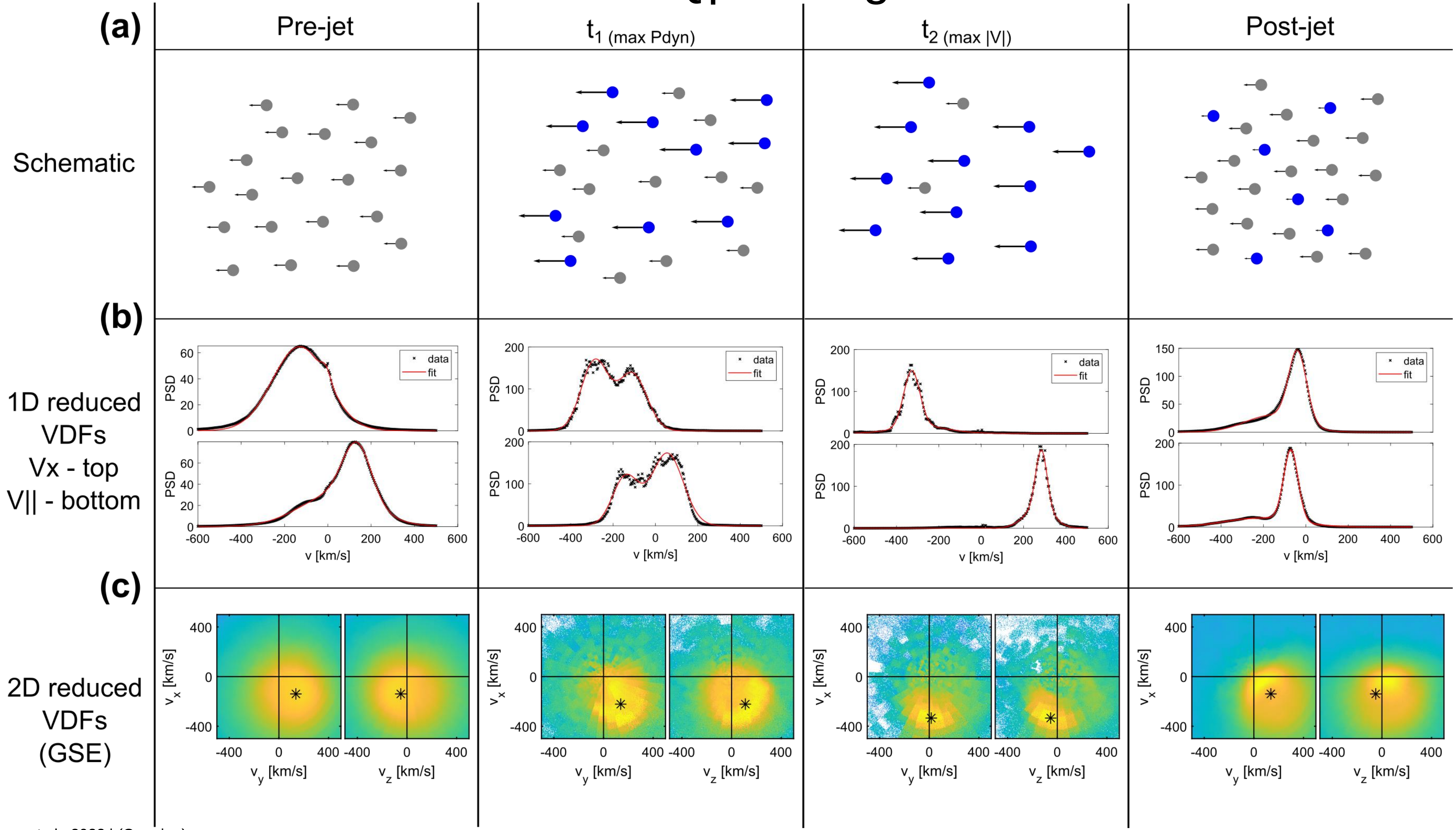
Raptis, Karlsson, et al,. 2022 | (Ongoing)

Recent Results

MMS | Schematic

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

Jet evolution in Qpar Magnetosheath



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

Summary & Conclusion

Main points

(A)

Jets = “Umbrella” term = Many different phenomena can cause downstream density and/or velocity enhancement = many classes and generation mechanisms.

(B)

We recently showed two, relevant to Qpar shock dynamics:

Shock reformation → Embedded plasmoids (SLAMS / old shock fronts : n↑) & “trapped” SW within evolving upstream waves (n↑,V↑)

(C)

Jets in Qpar MSh = different VDFs throughout their life

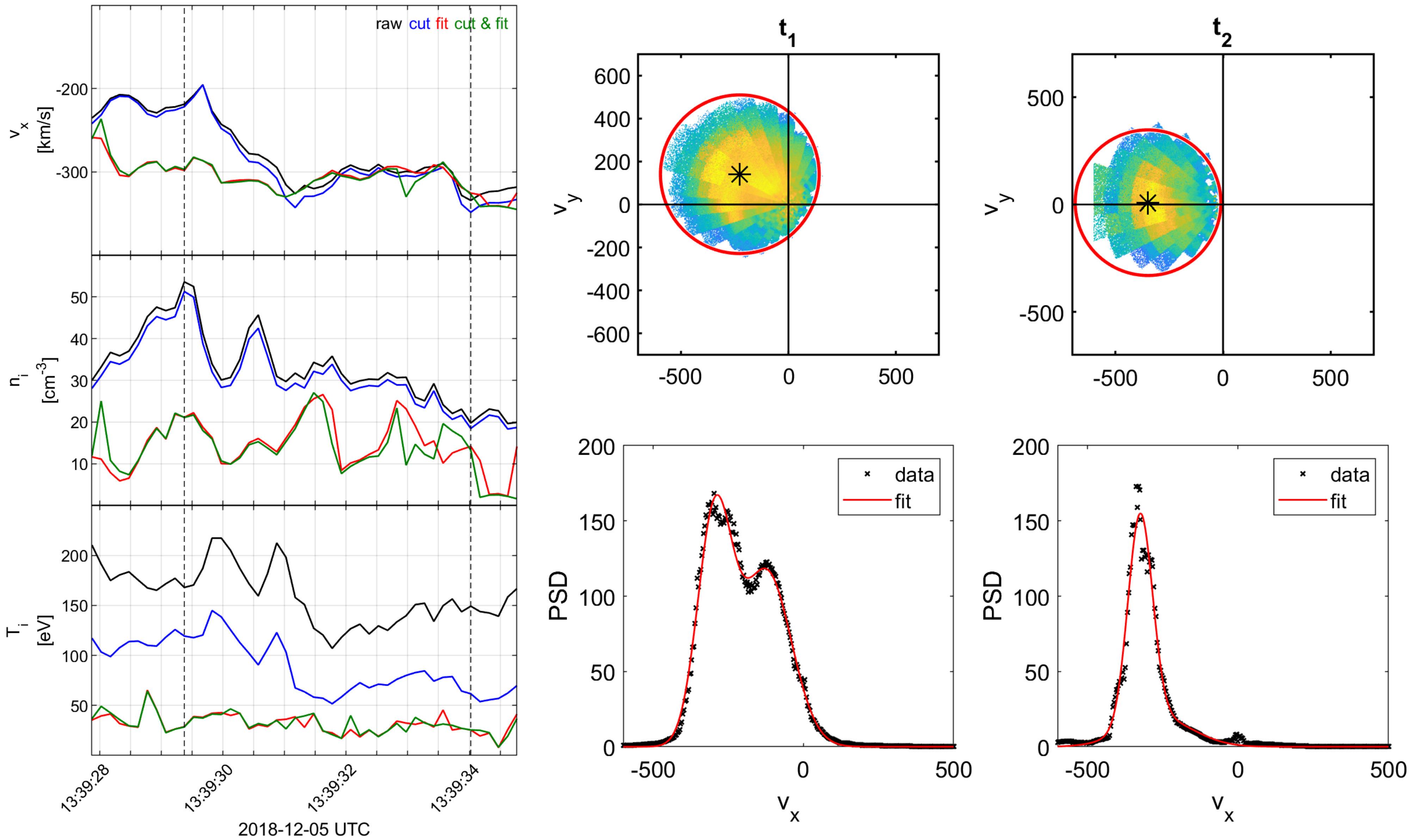
- “wrong” properties due to more than 1 plasma population co-existing (t_1)
- Interaction with MSH magnetic field changing velocity direction
- VDFs connected to wave generation
- Consequences on statistics/properties (size, propagation time, ability to generate bow waves, etc.)

Future work

- Statistics : Need more events (I have quite a few but process is hard to automate it and manual labor is painful)
- Simulations : (TBD – Quite some interesting results already though ☺)
- Investigation of wave generation (Eva: Jets & Ida : MSh)

Extras

Partial moments



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

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.

Fast/Survey MMS data

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

Pros

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

Cons

- ✗ Not suitable for small scale studies
- ✗ Could be misleading close to boundary surfaces (Magnetopause, Bow shock etc.)

Burst MMS data

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

Pros

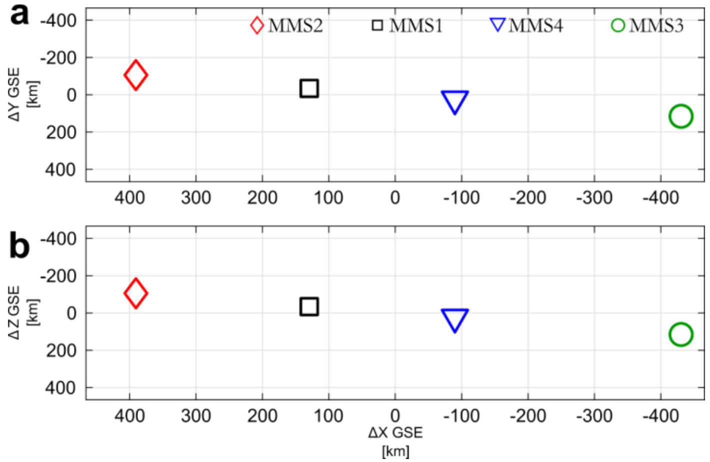
- ✓ Very high resolution
- ✓ Able to resolve structures close to boundary surfaces (e.g. mix of plasma close to magnetopause, bow shock, foreshock etc.)

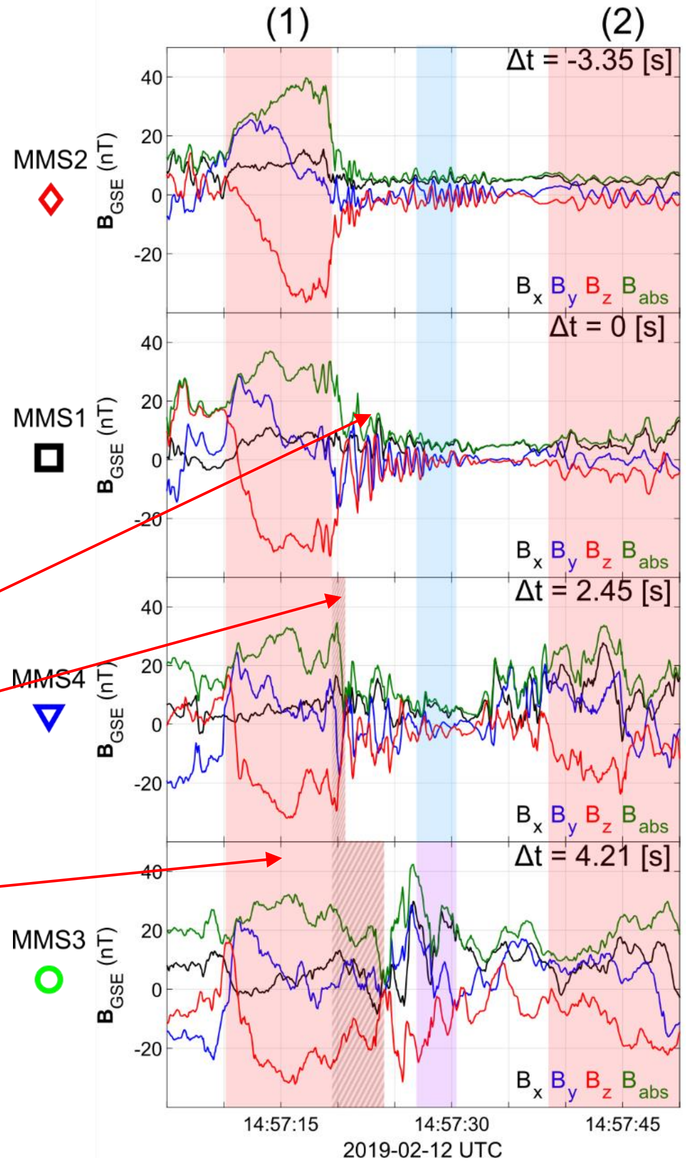
Cons

- ✗ 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

SLAMS & wave activity co-moving picture





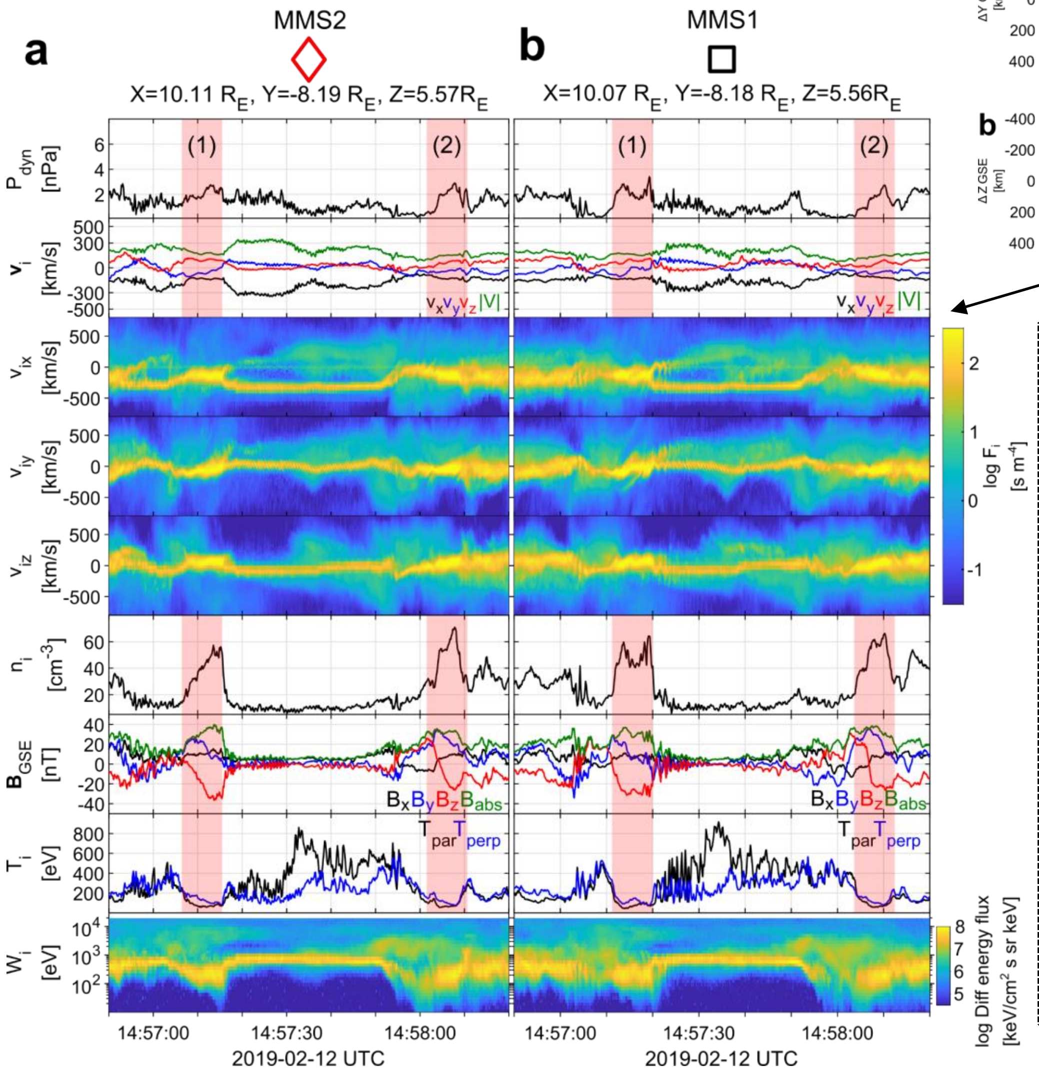
Evolution of SLAMS

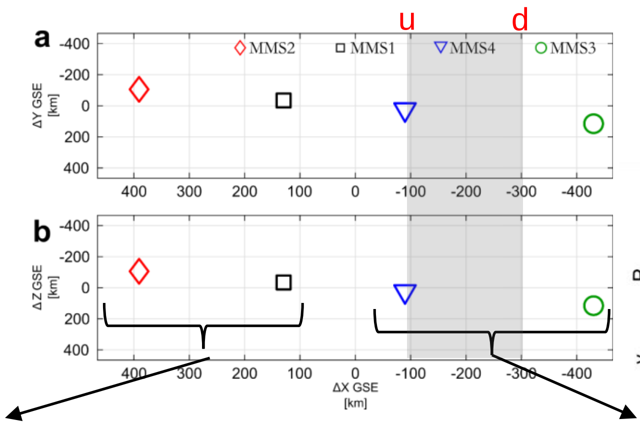
- Interaction with upstream whistler
- New peak /evolution*
- Formation of embedded plasmoid (*downstream density enhancement*)**

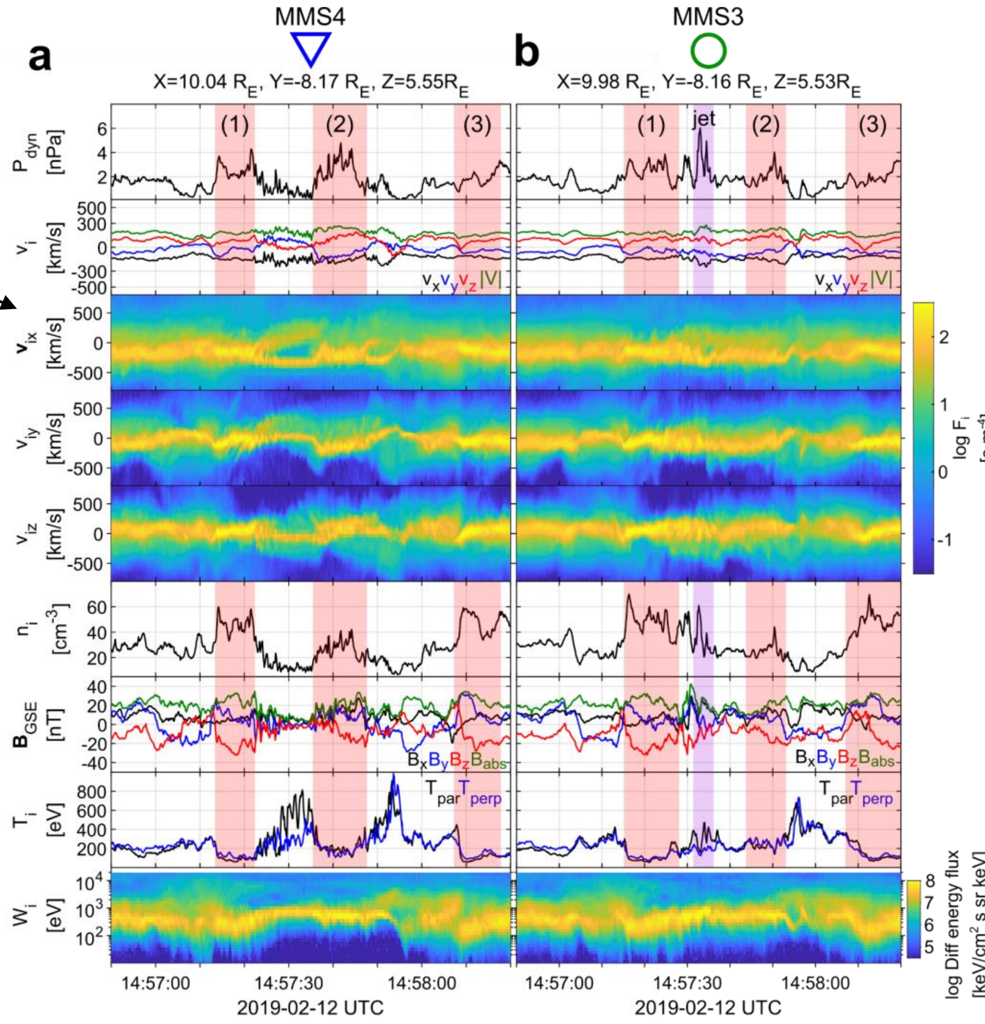
* See similar examples by Turner et al. (2021), Chen et al. (2021)

** See similar example by Liu et al. (2021)

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>

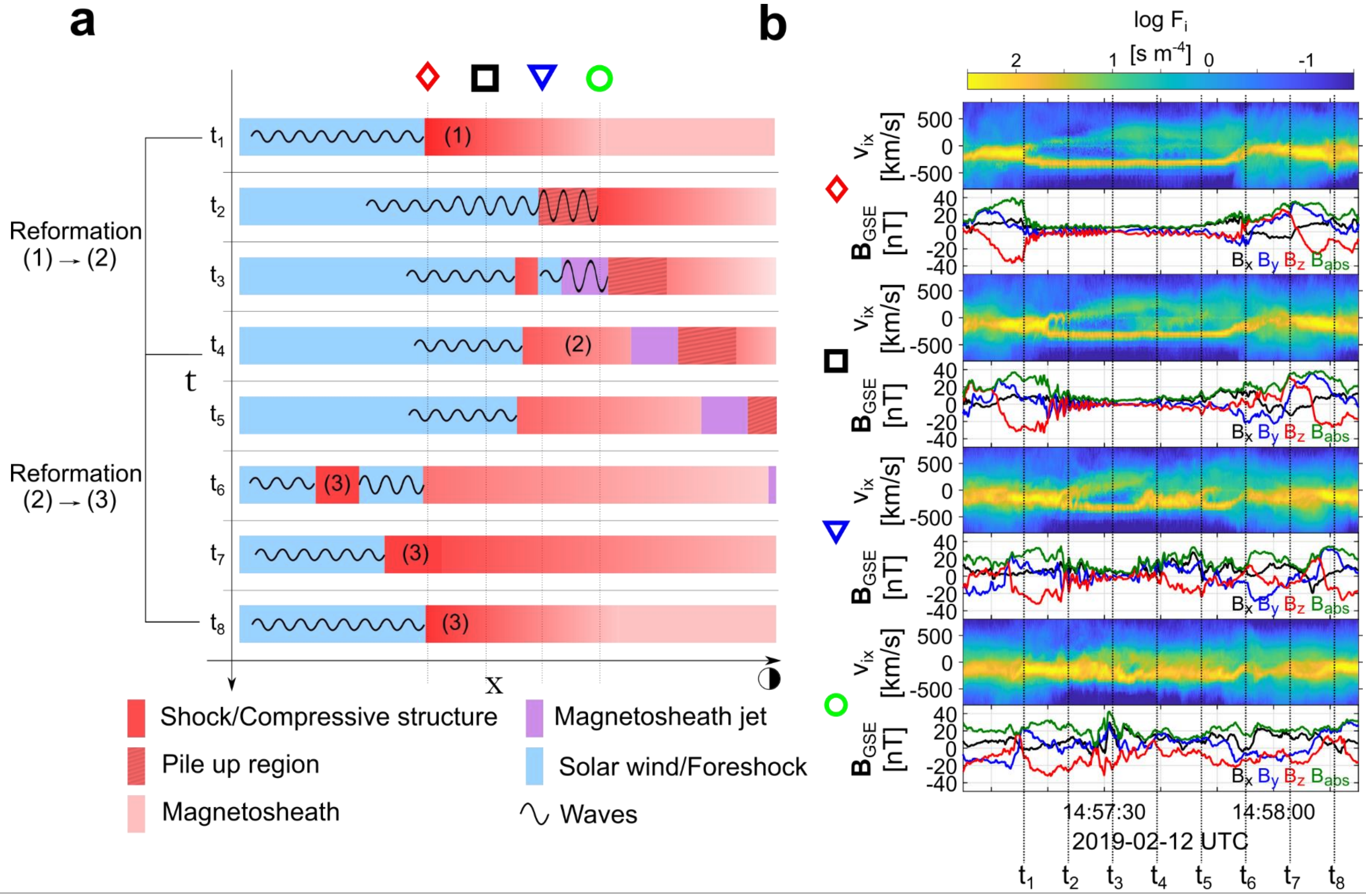
$v \ll v_{SW}$

$n_i \gg n_{SW}$

$\boldsymbol{B} \gg$

Thermalized distribution

Formation mechanism



Why in-situ classification with MMS?

Not simultaneously upstream & downstream measurements = Huge errors when using our only SW monitor

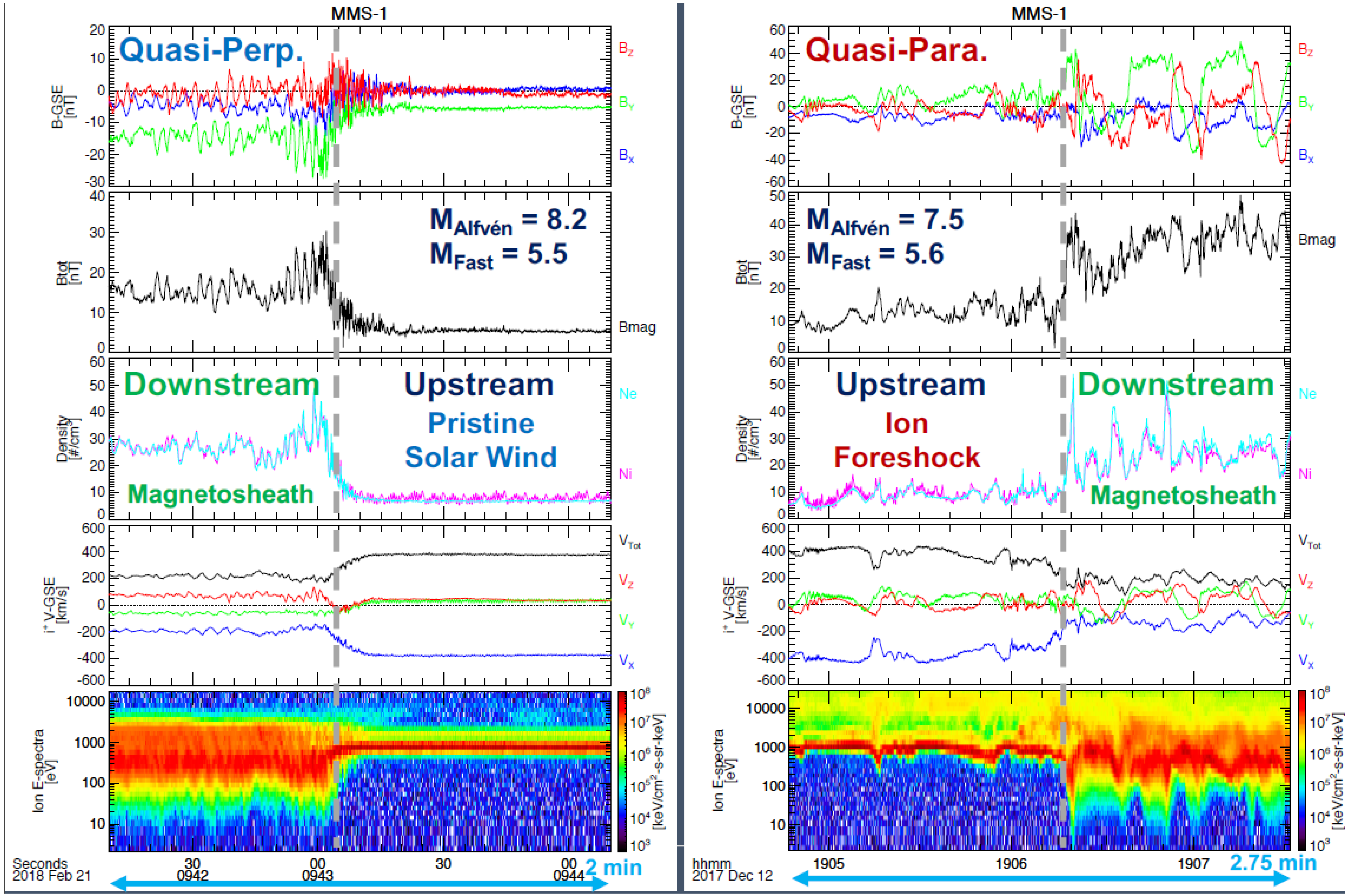
TABLE 4 | Accuracy of each method used per class.

Class	NN - age (%)	NN - leave-1-out (%)	θ_{cone} (%)	Coplanarity (%)	Bow shock model (%)
Qpar	98	97	61	81	74
Qperp	88	88	94	79	86
Mean	93	93	77.5	80	80

*The neural network accuracy is taken as the average performance of the 100 random iterations as shown in **Figures 5, 6**.*

Raptis, Aminalragia-Giamini et al. (2020) | Front. Astron. Space Sci

Shock transitions with MMS



Notice difference in the downstream plasma ?

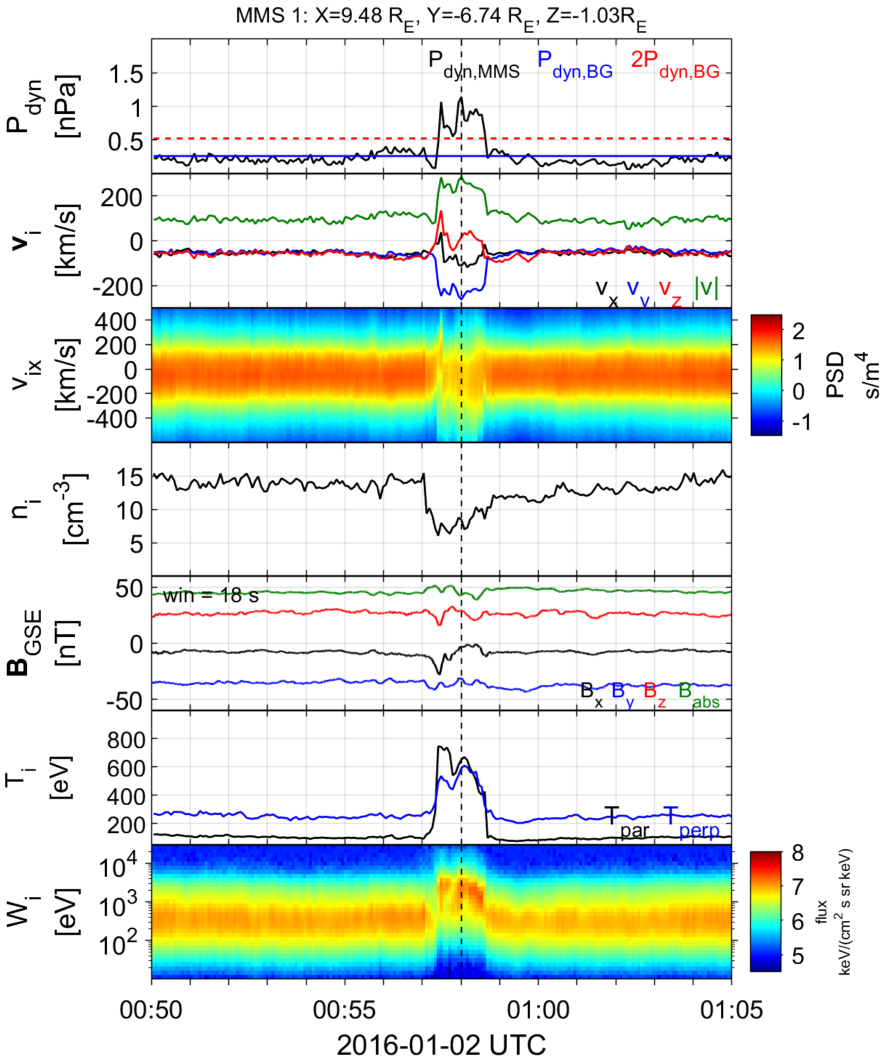
Figure taken from : Drew Turner's talk | SWSG2021

Summarized properties – Encapsulated

- Possibly of magnetospheric origin (Vortices, KH)
- Maybe connected to flank Qpar shock (High By,Bz IMF)
- Foreshock transient & reconnection association [Kajdič et al 2021]
- Mainly velocity driven
- Typically density reduction

Encapsulated Jet

Jets of $Q_{\parallel}$-like MSH plasma enclosed in $Q_{\perp}$ MSH



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