Magnetosheath Jets Close to the Bow Shock: Generation Mechanisms Using MMS

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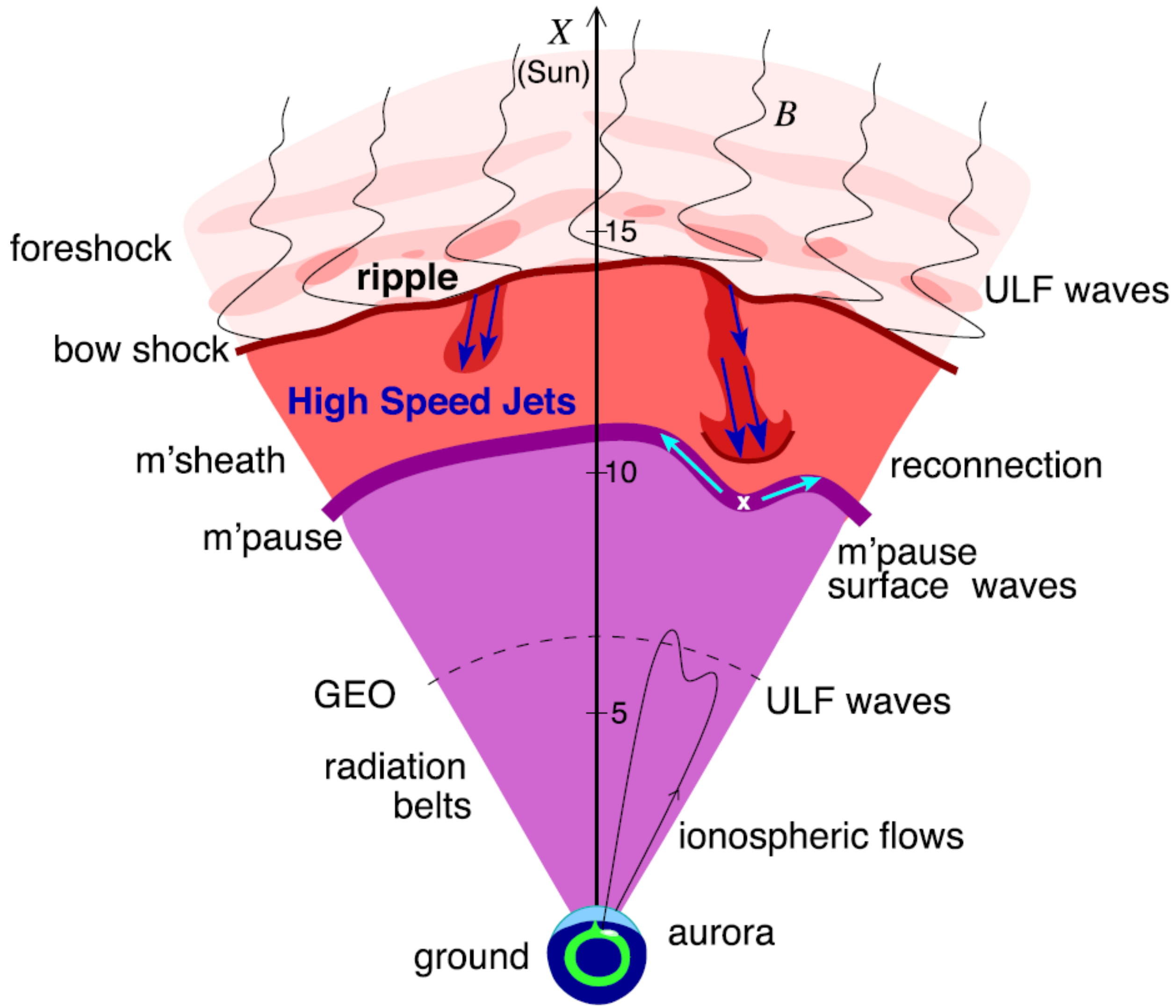
Introduction

Magnetosheath Jets



Definition

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

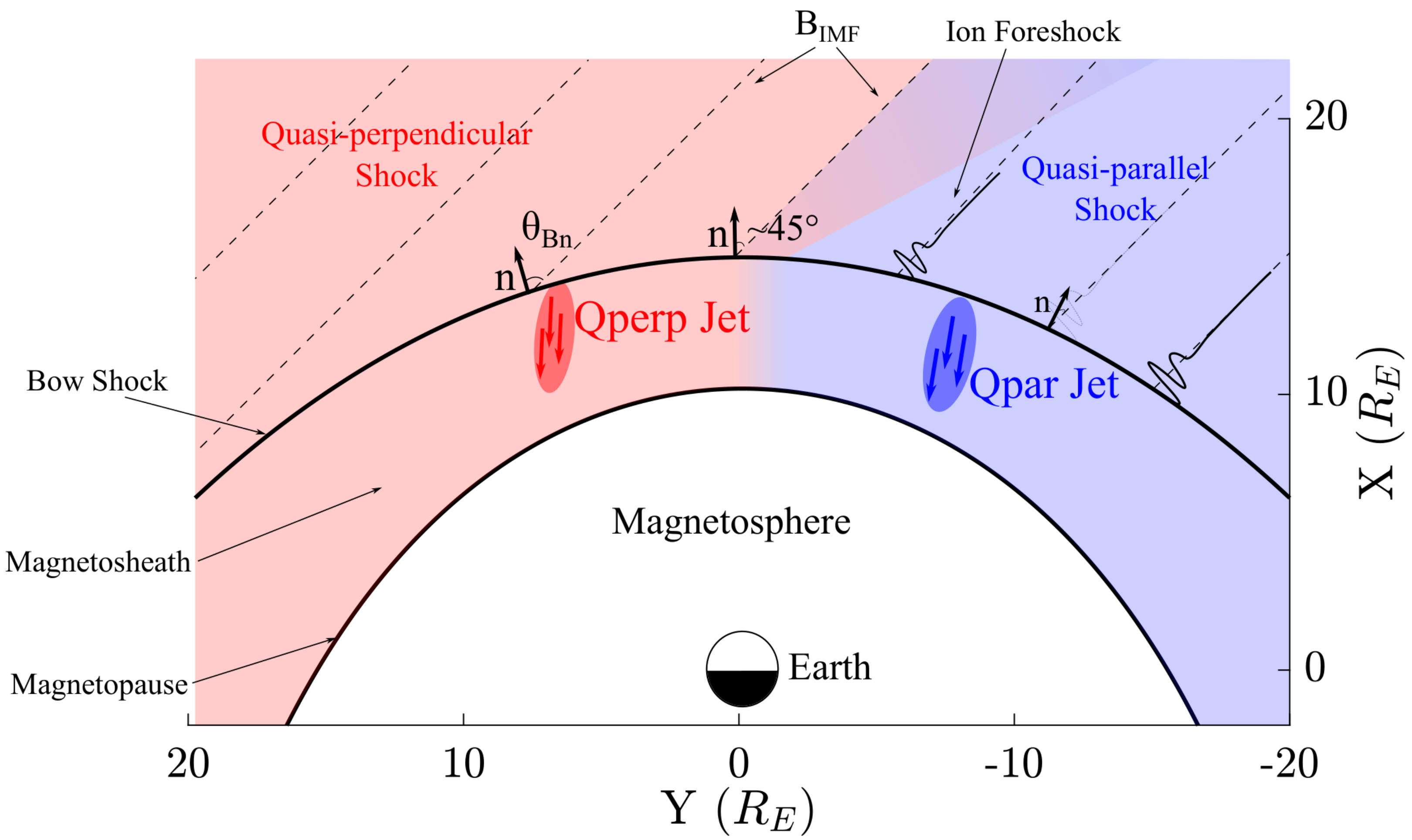
e.g. 200% dynamic pressure enhancement compared to background magnetosheath

Related phenomena

Radiation belts
Aurora
Magnetopause reconnection
Magnetopause penetration
Shock acceleration
Magnetopause surface eigenmodes
ULF waves (see Christos' talk few minutes ago)

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

Shock, Magnetosheath & Jet classification



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

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

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

Raptis, Karlsson, et al. (2020) | JGR
Raptis, Aminalragia-Giamini et al. (2020) | Front. Astron. Space Sci
Palmroth M., **Raptis S.**, et al. (2021) | ANGEO
Kajdič, **Raptis** et al. (2021) | GRL
Karlsson, **Raptis**, et al. (2021) | JGR - Under Review
Raptis, et al. (2021b) | Ongoing

Latest Results (to be submitted)

Downstream Super-magnetosonic Plasma Jet Generation as a Direct Consequence of Shock Reformation

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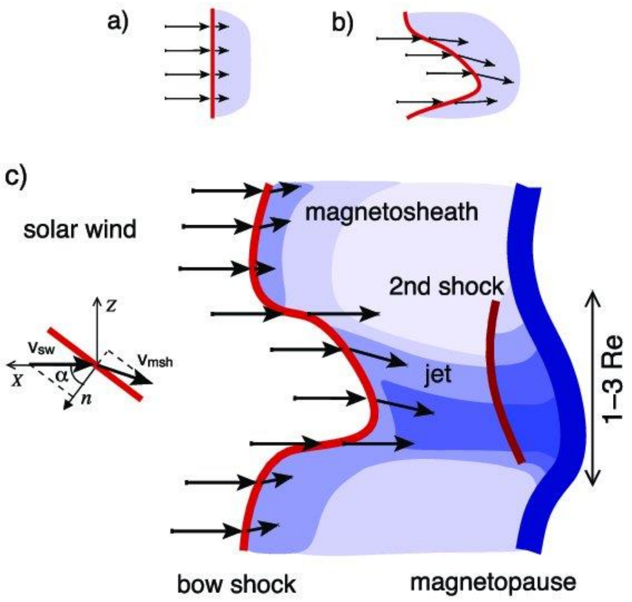
Raptis, Karlsson et al. (2021a) | Ongoing

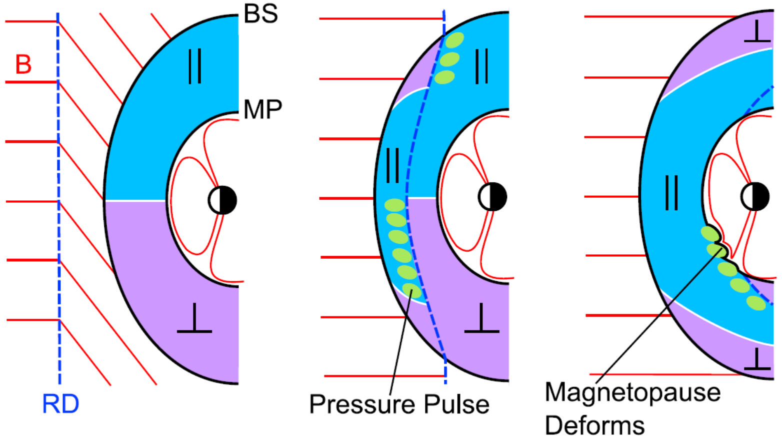
How are these jets created ?

Shock ripples



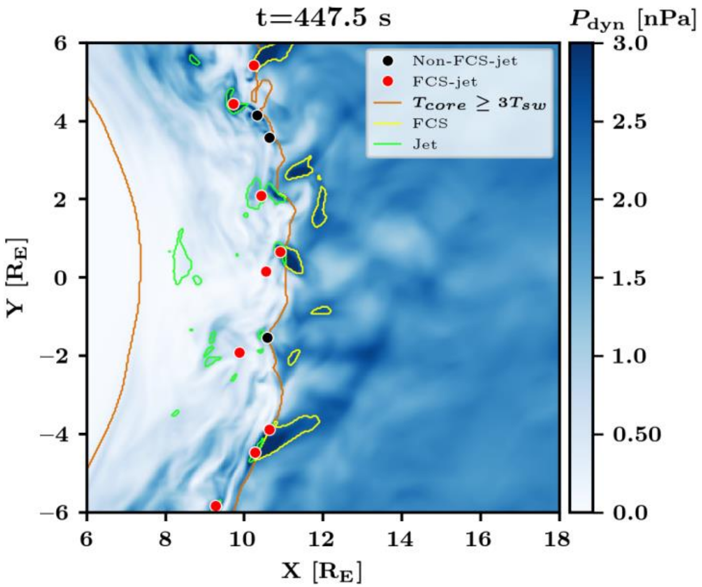
Hietala et al. (2009,2012)

SW discontinuities



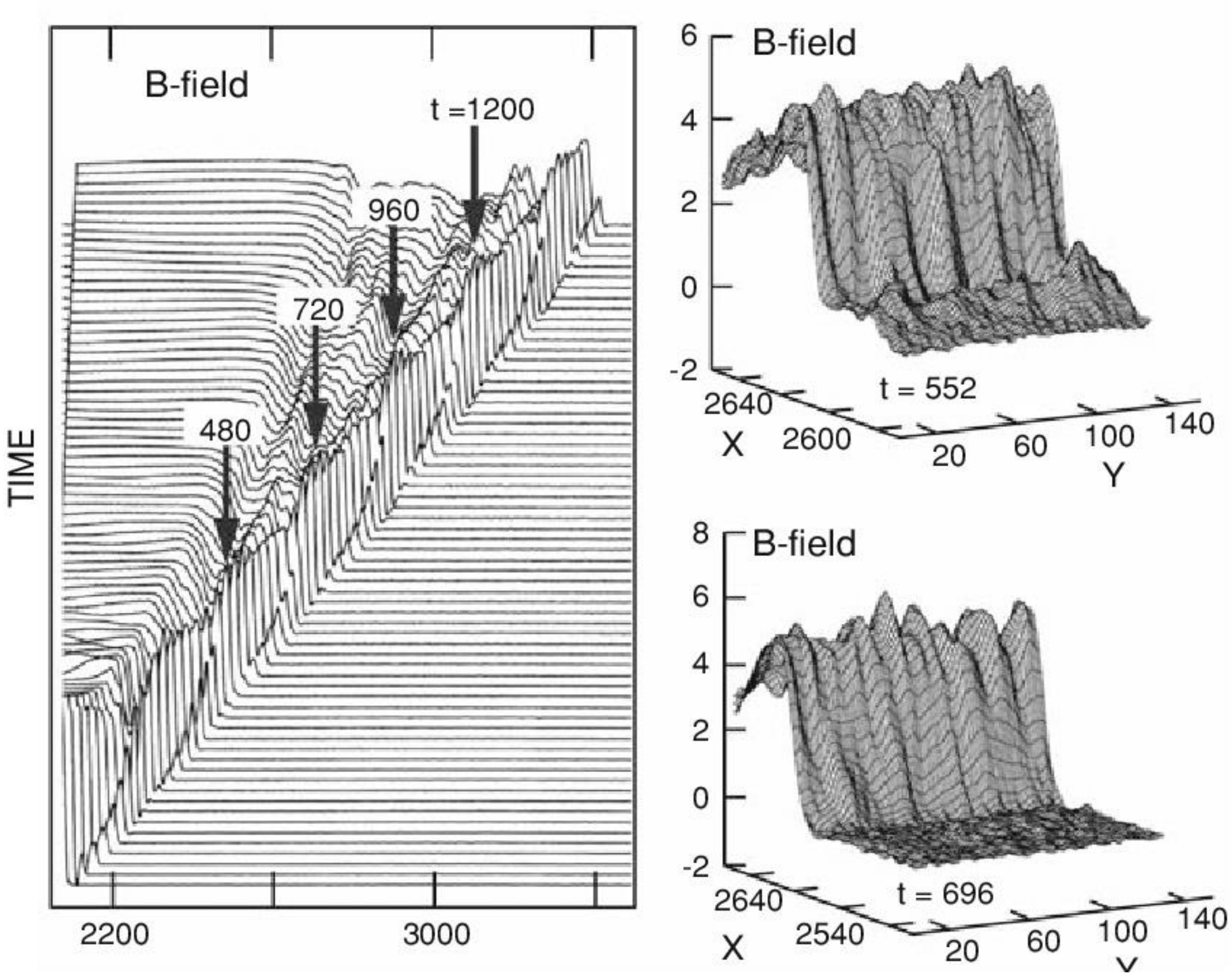
Archer et al. (2012)

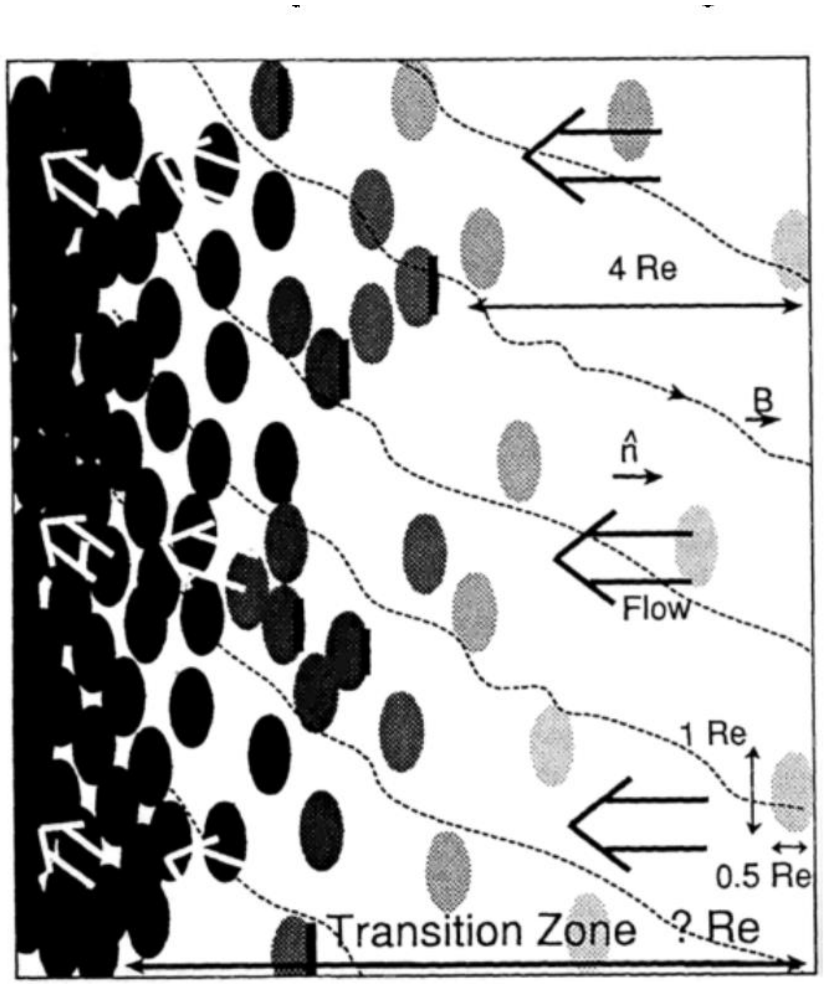
Foreshock Structures



Suni et al. (2021)

Shock Reformation idea

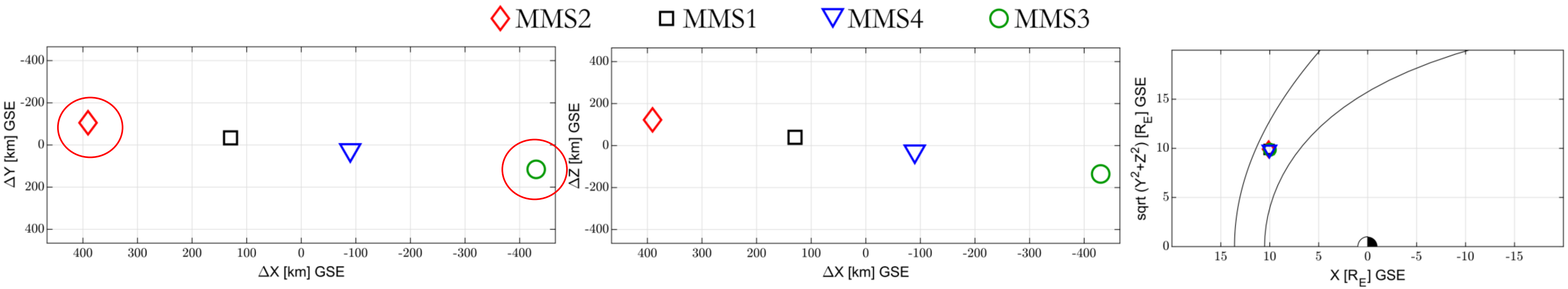




Lembège and Savoini 2002

Schwartz, 1990

Results



Dyn. Pres

Ion velocity

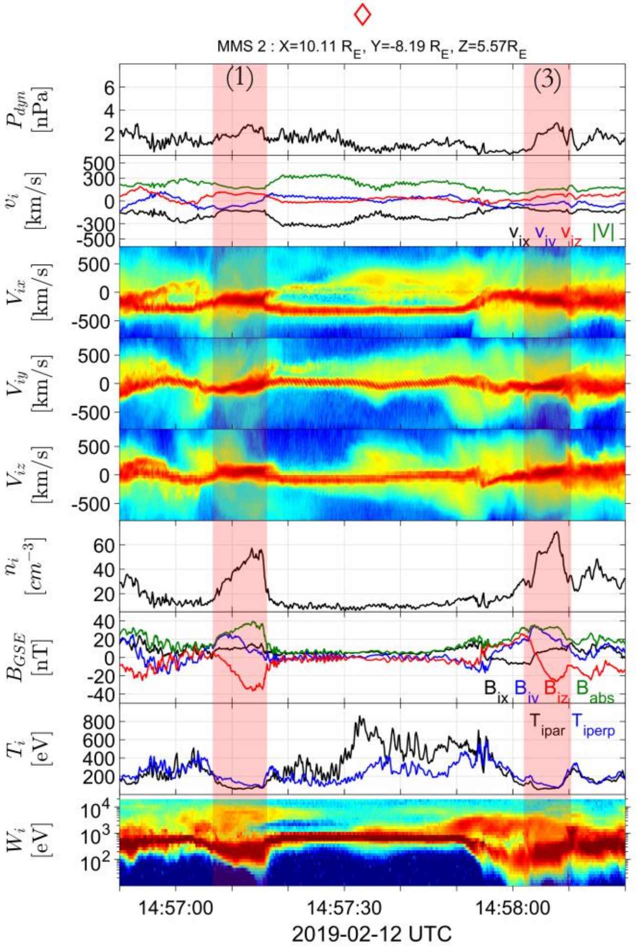
Reduced VDFs

Ion Density

Magnetic Field

Ion Temperature

Energy Spectrum



<u>Solar Wind:</u>

$v_x \gg, v_{y,z} \sim 0$

$n_i \ll$

$\boldsymbol{B} \ll$

Beam like distribution

<u>Magnetosheath</u>

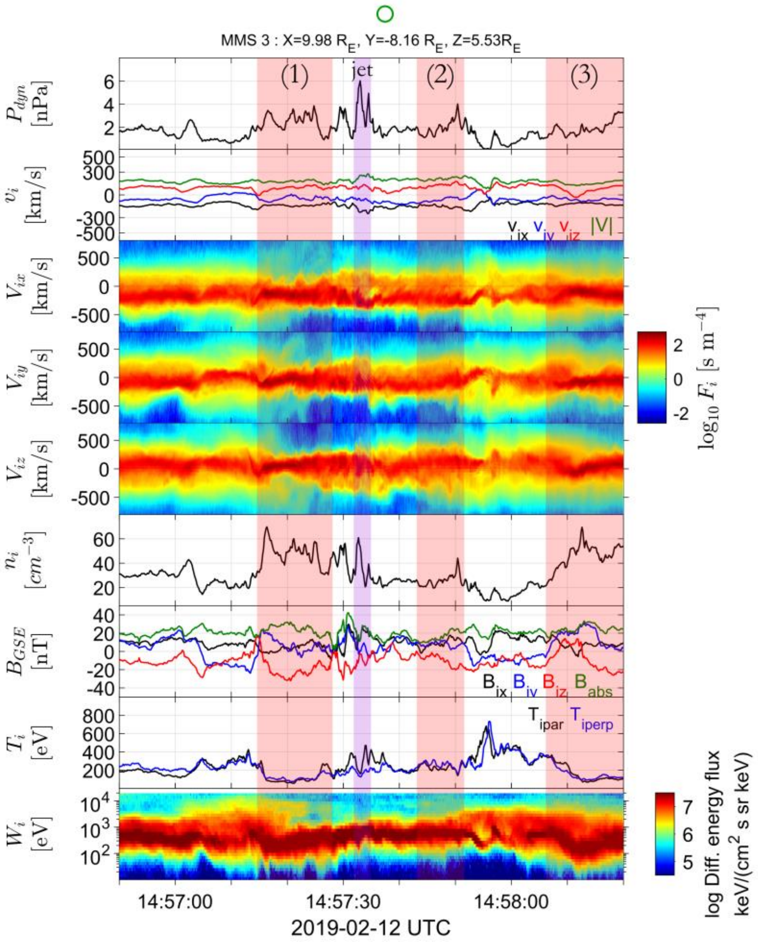
<u>(compressed – thermalized plasma)</u>

$v \ll v_{SW}$

$n_i \gg n_{SW}$

$\boldsymbol{B} \gg$

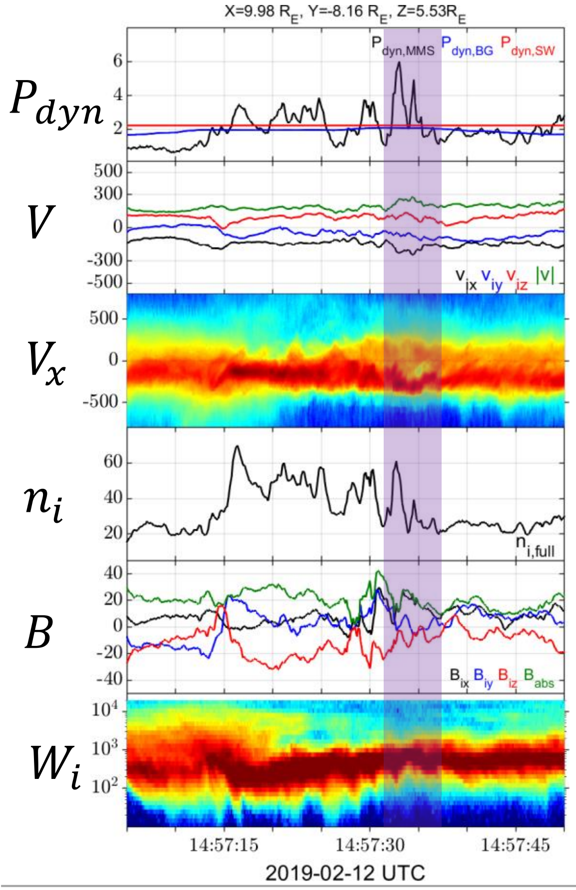
Thermalized distribution

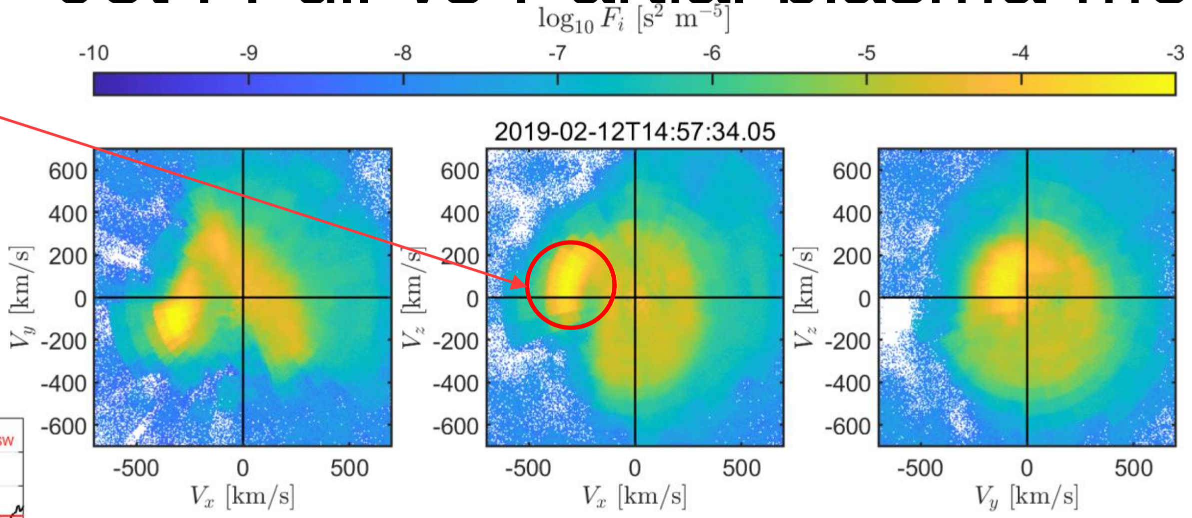


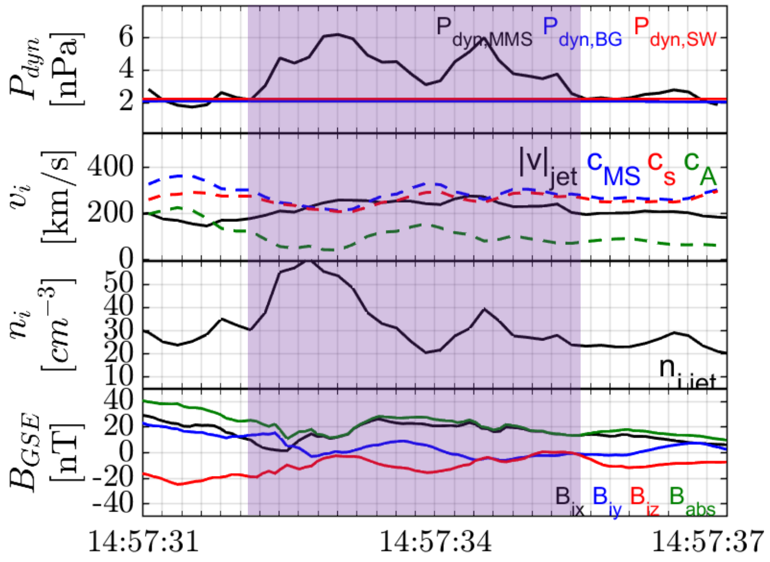
Raptis, et al. (2021a) | Ongoing

Jet : Full vs Partial plasma moments

Actual jet



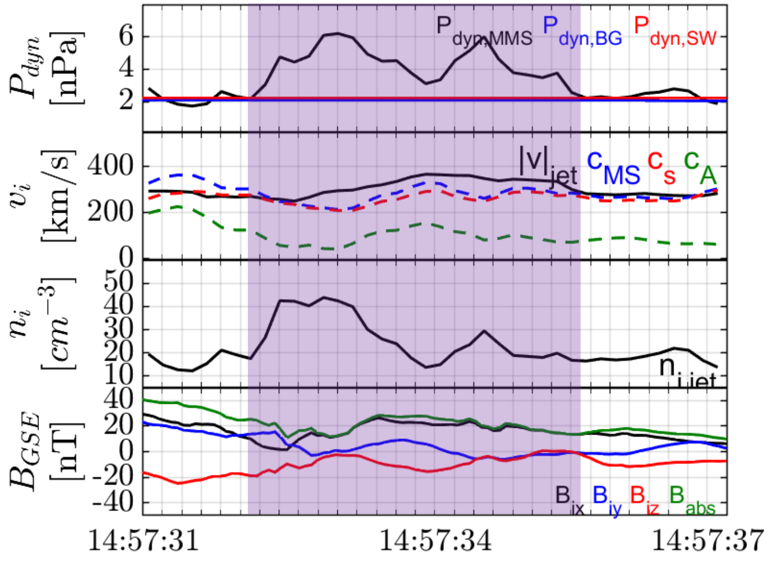




Full moments

$n \gg$

$V < c_{MS}$

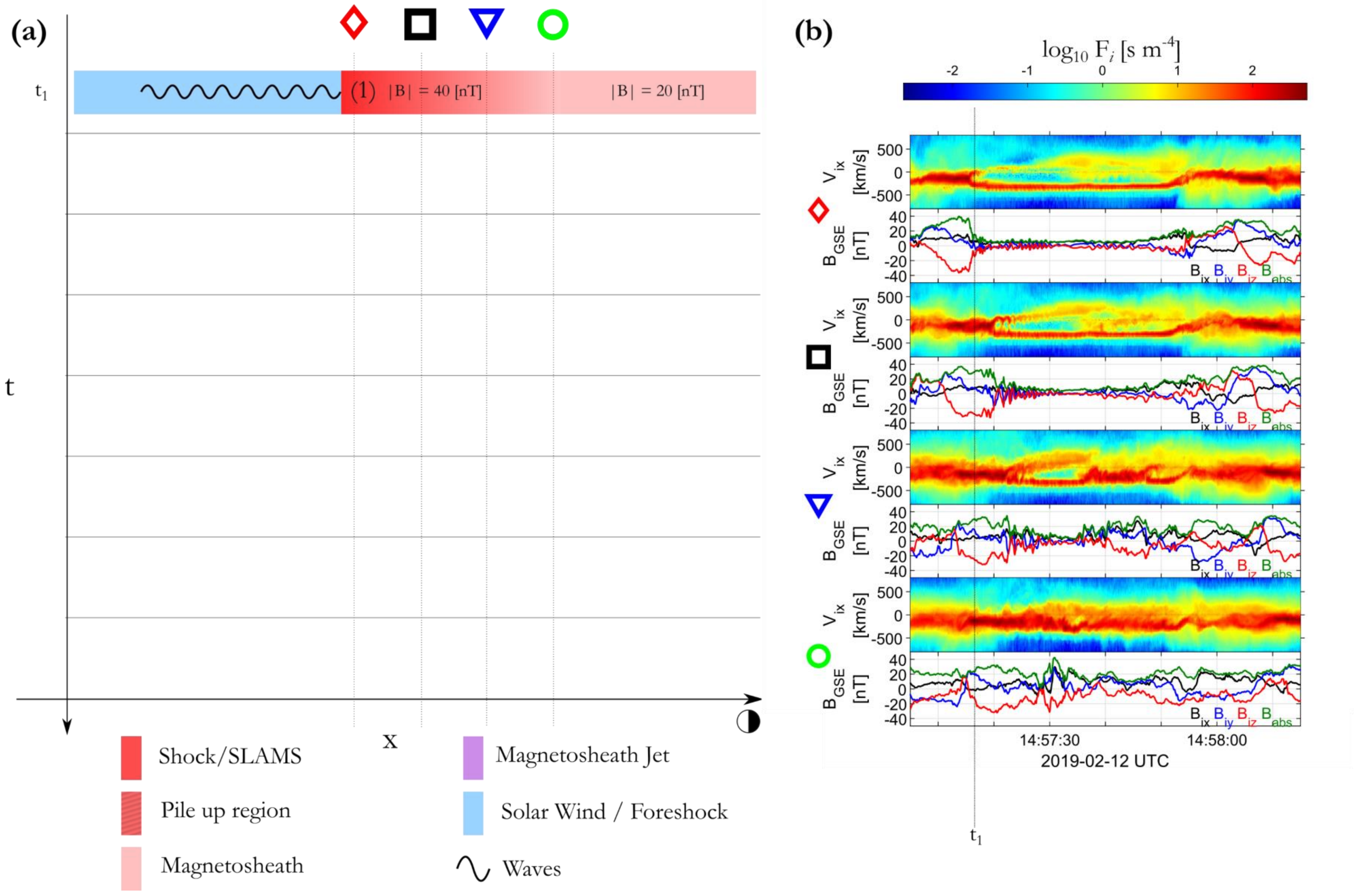


Partial moments

$n_{jet} < n_{full}$,

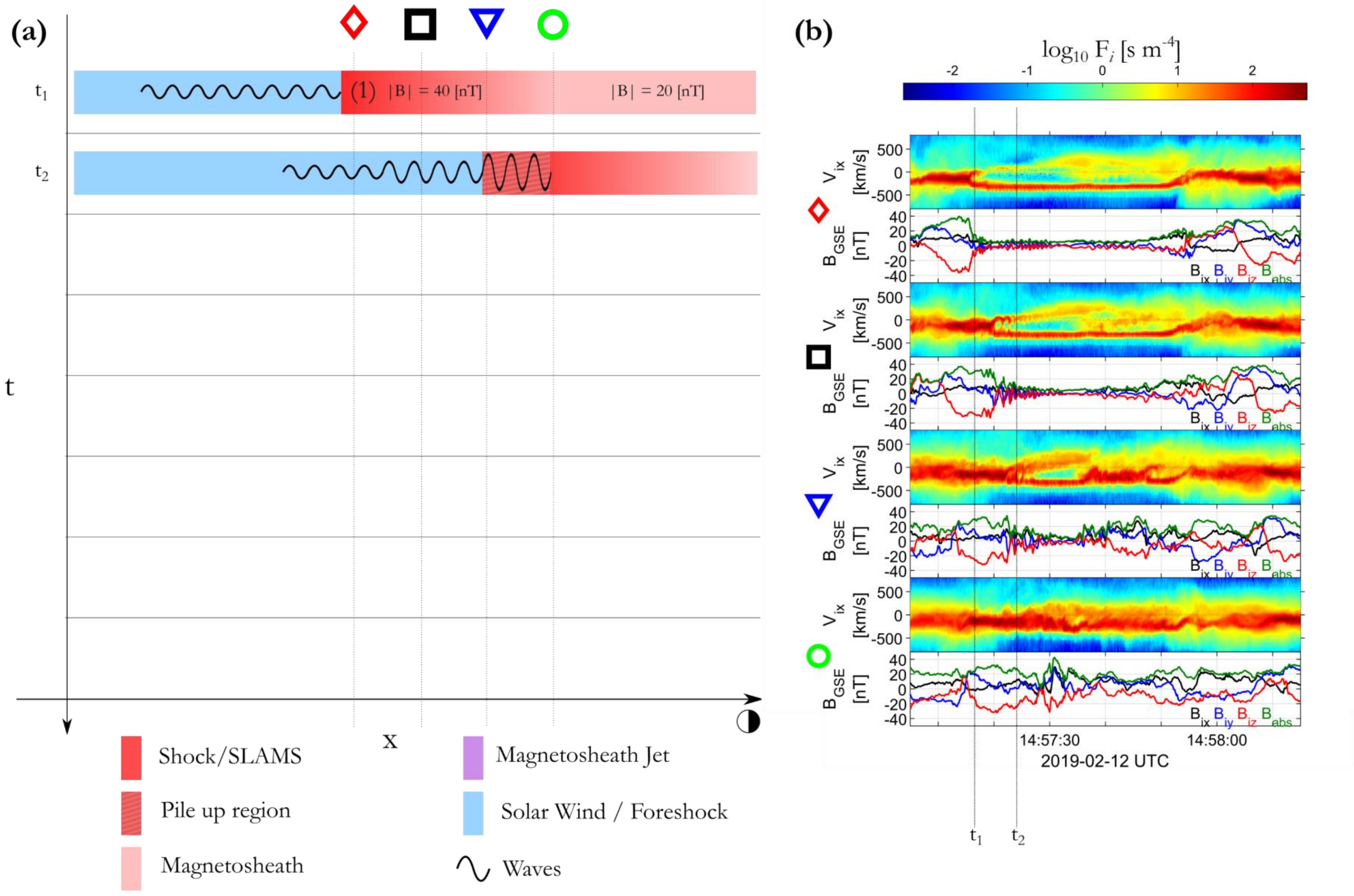
$V > c_{MS}$

Whole mechanism & physical picture



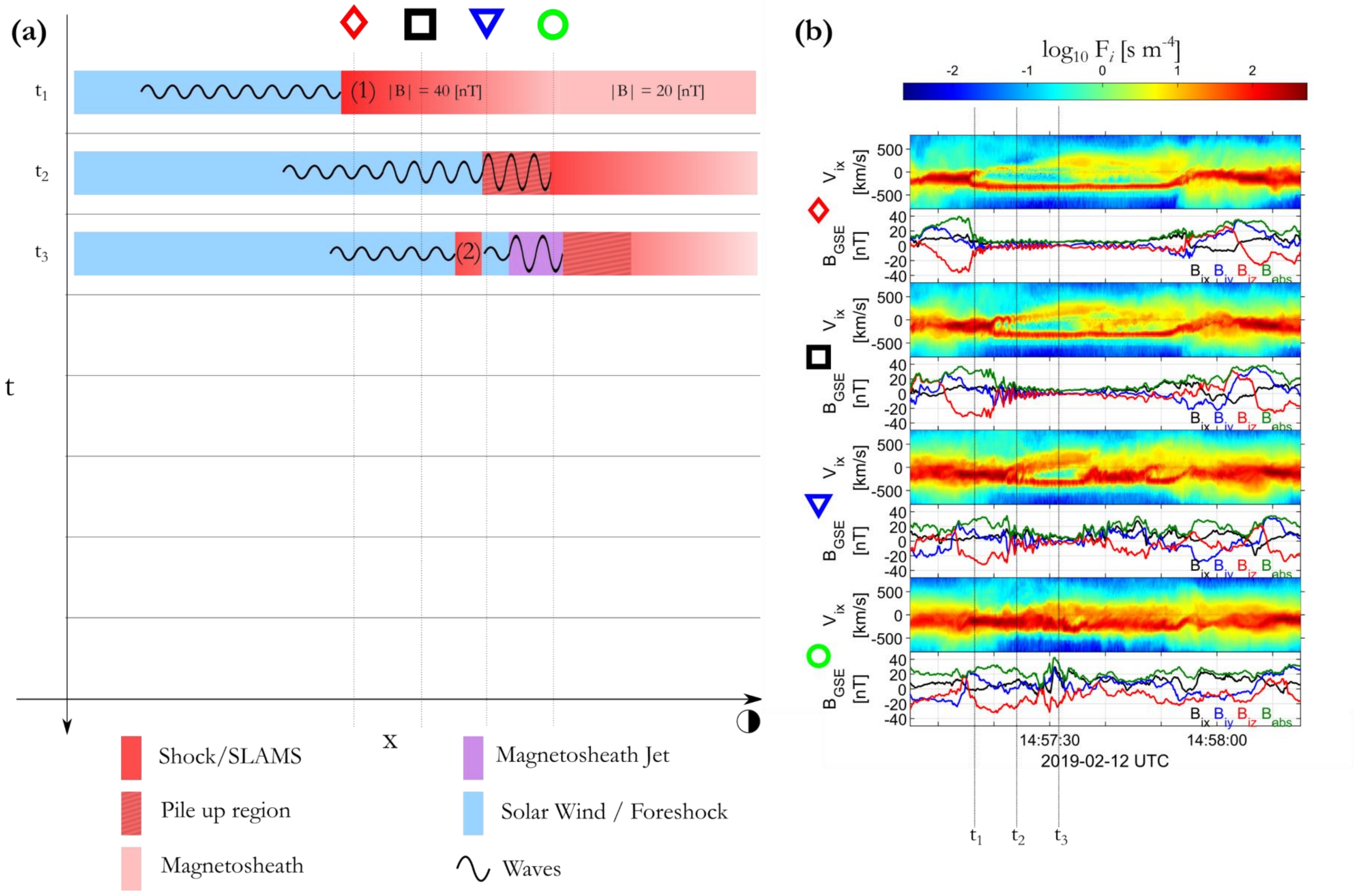
Raptis, Karlsson et al. (2021a) | Ongoing

Whole mechanism & physical picture



Raptis, Karlsson et al. (2021a) | Ongoing

Whole mechanism & physical picture



Raptis, Karlsson et al. (2021a) | Ongoing

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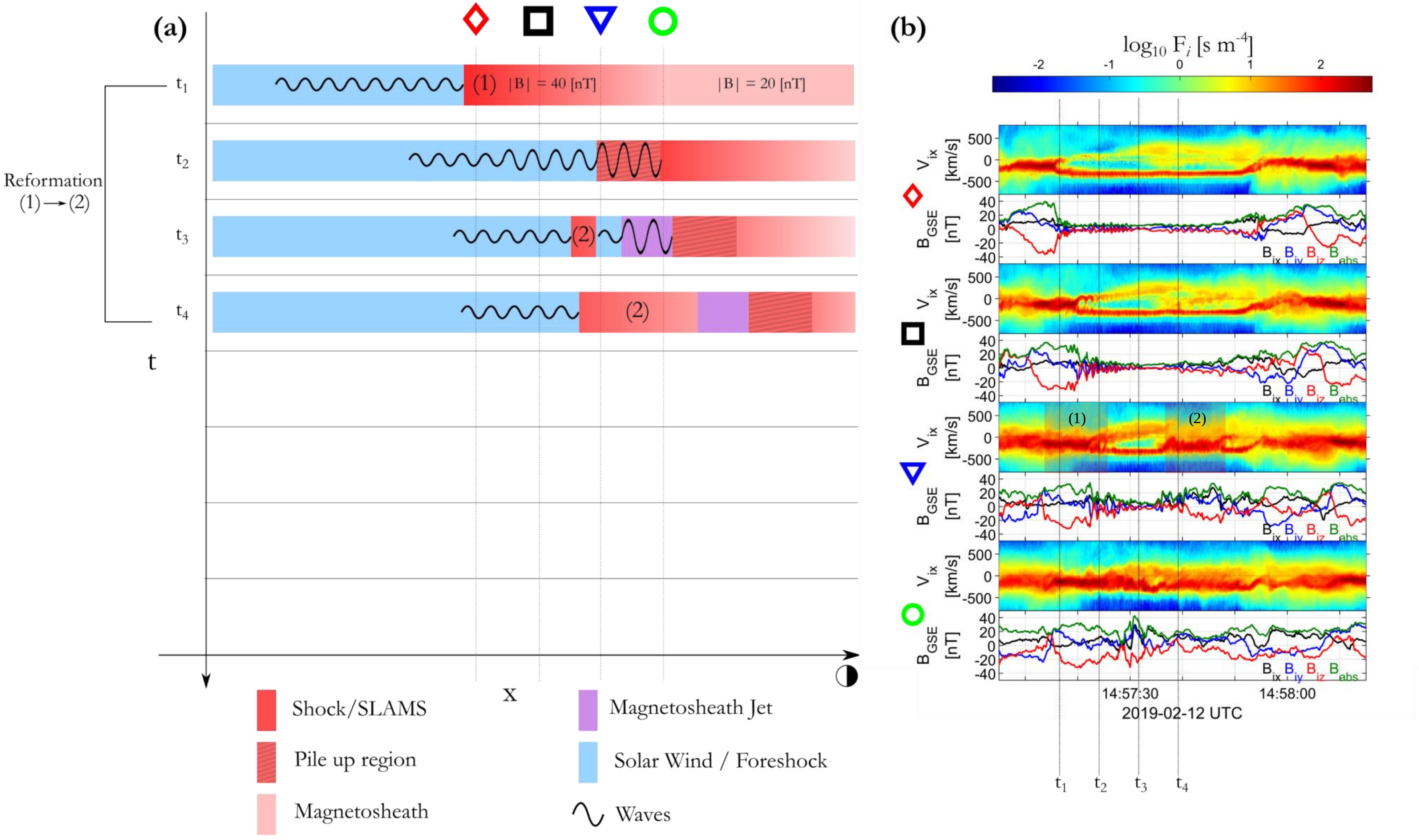

Raptis, Karlsson et al. (2021a) | Ongoing

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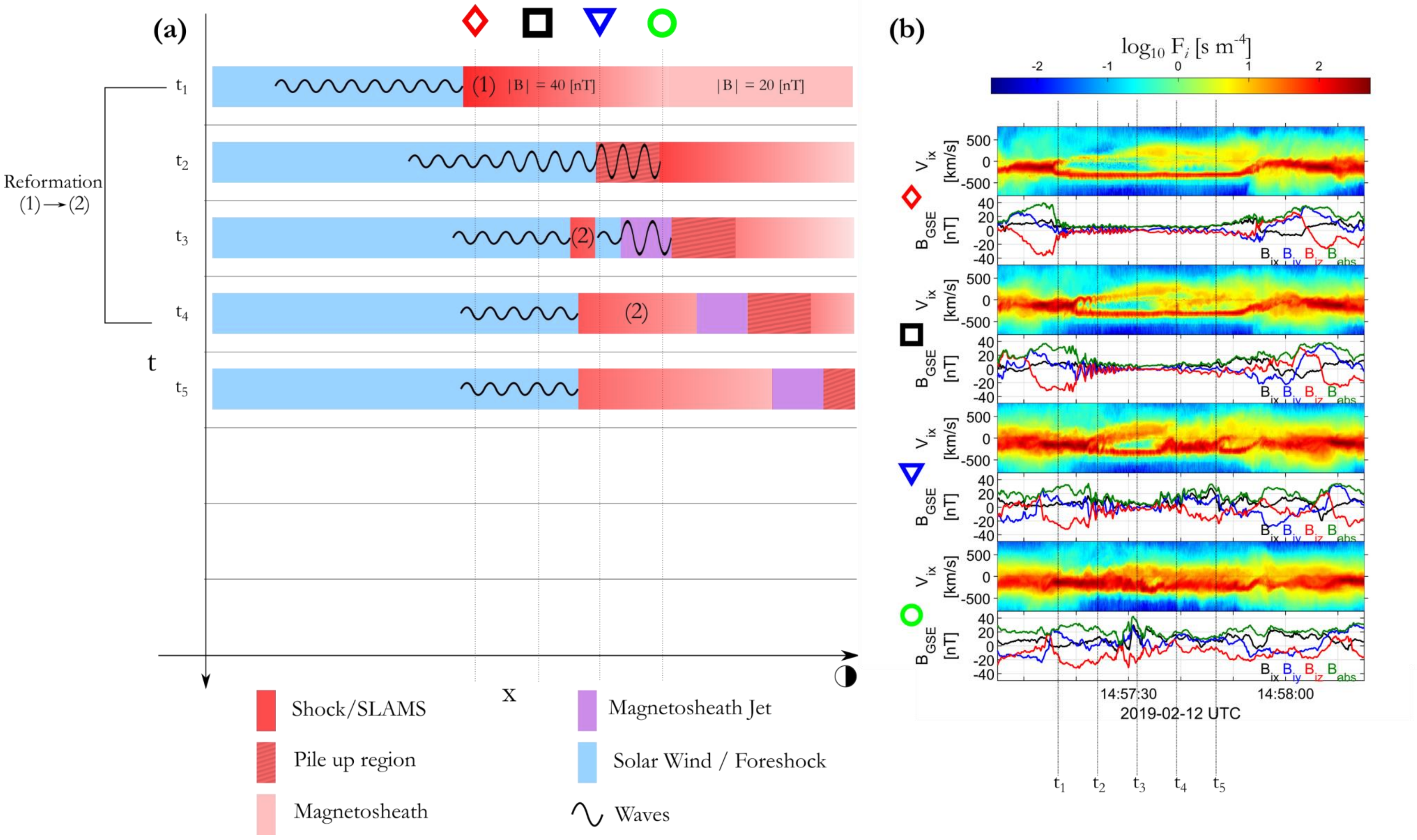

Raptis, Karlsson et al. (2021a) | Ongoing

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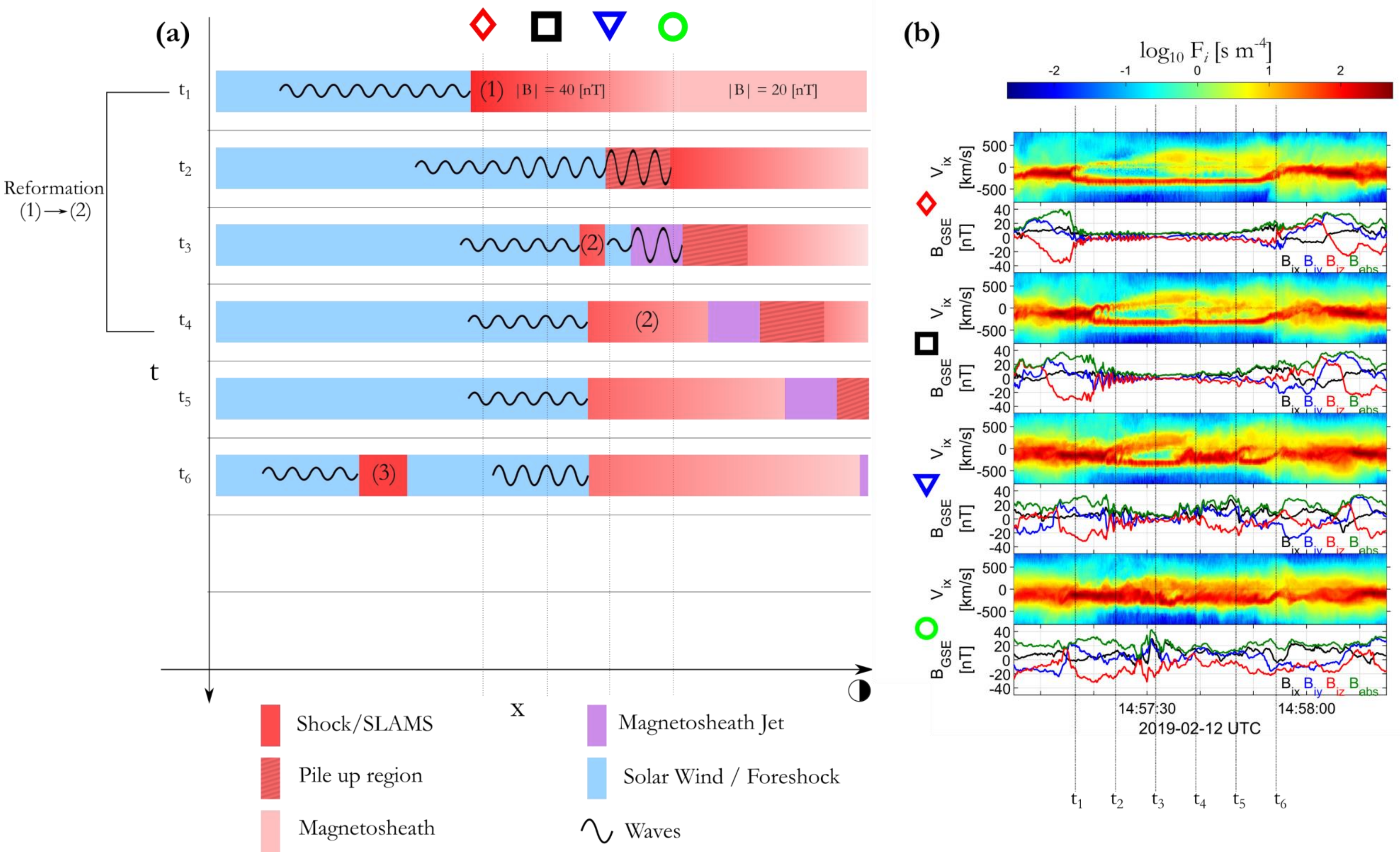
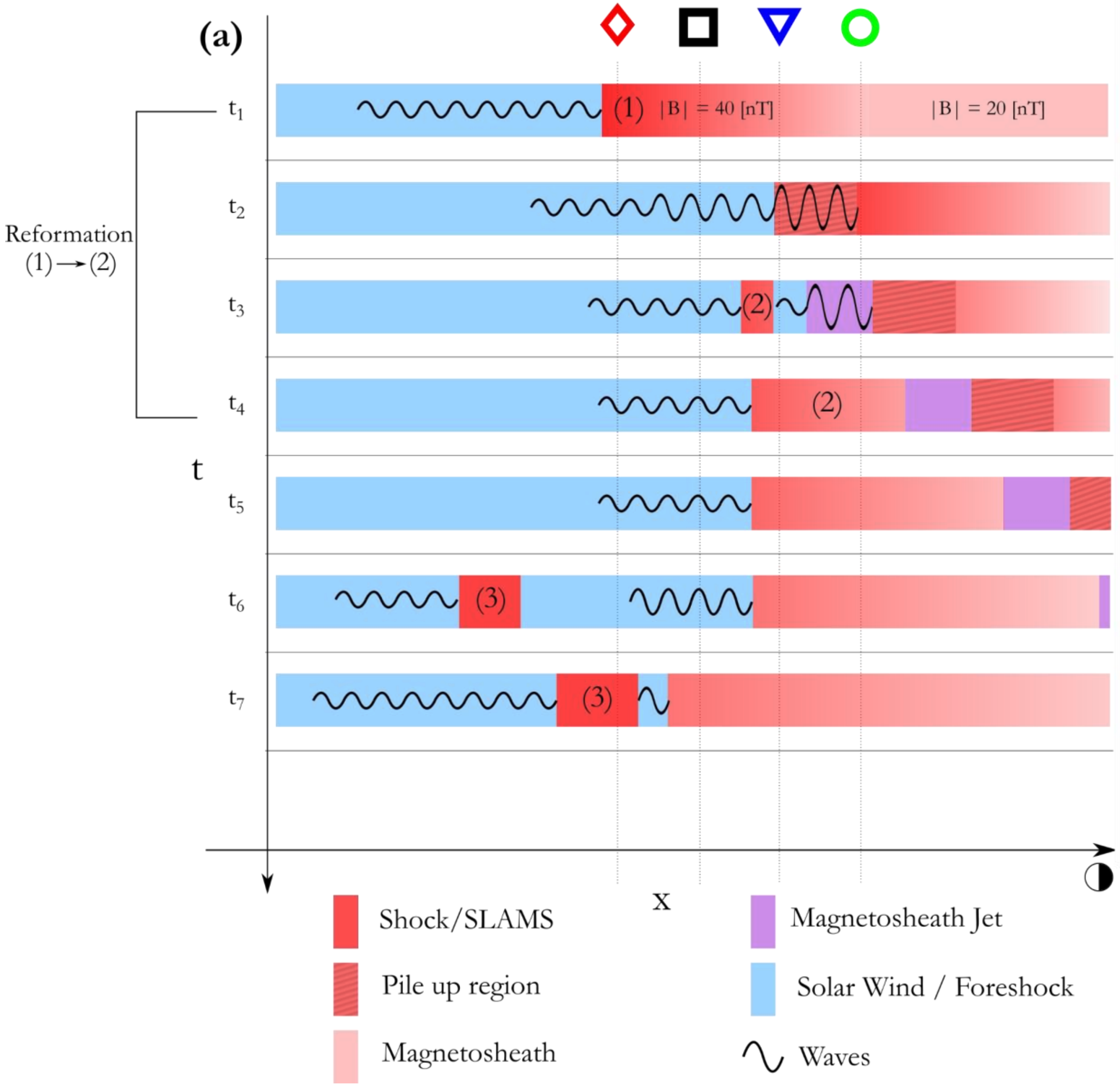
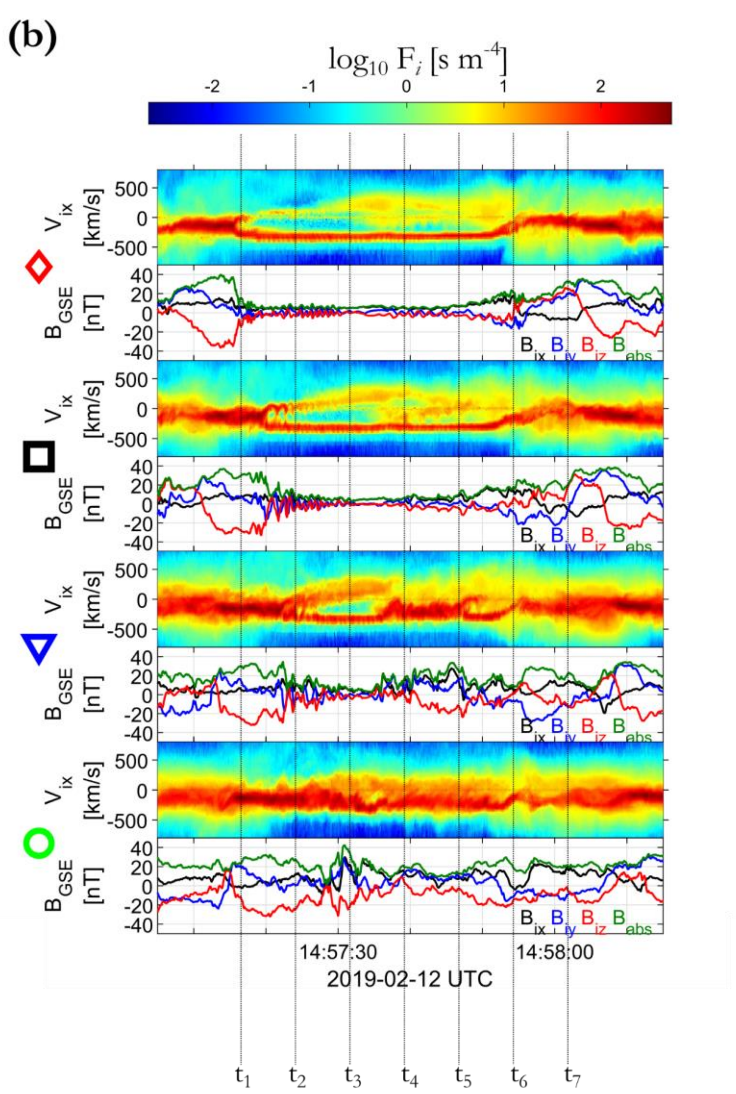


Raptis, Karlsson et al. (2021a) | Ongoing

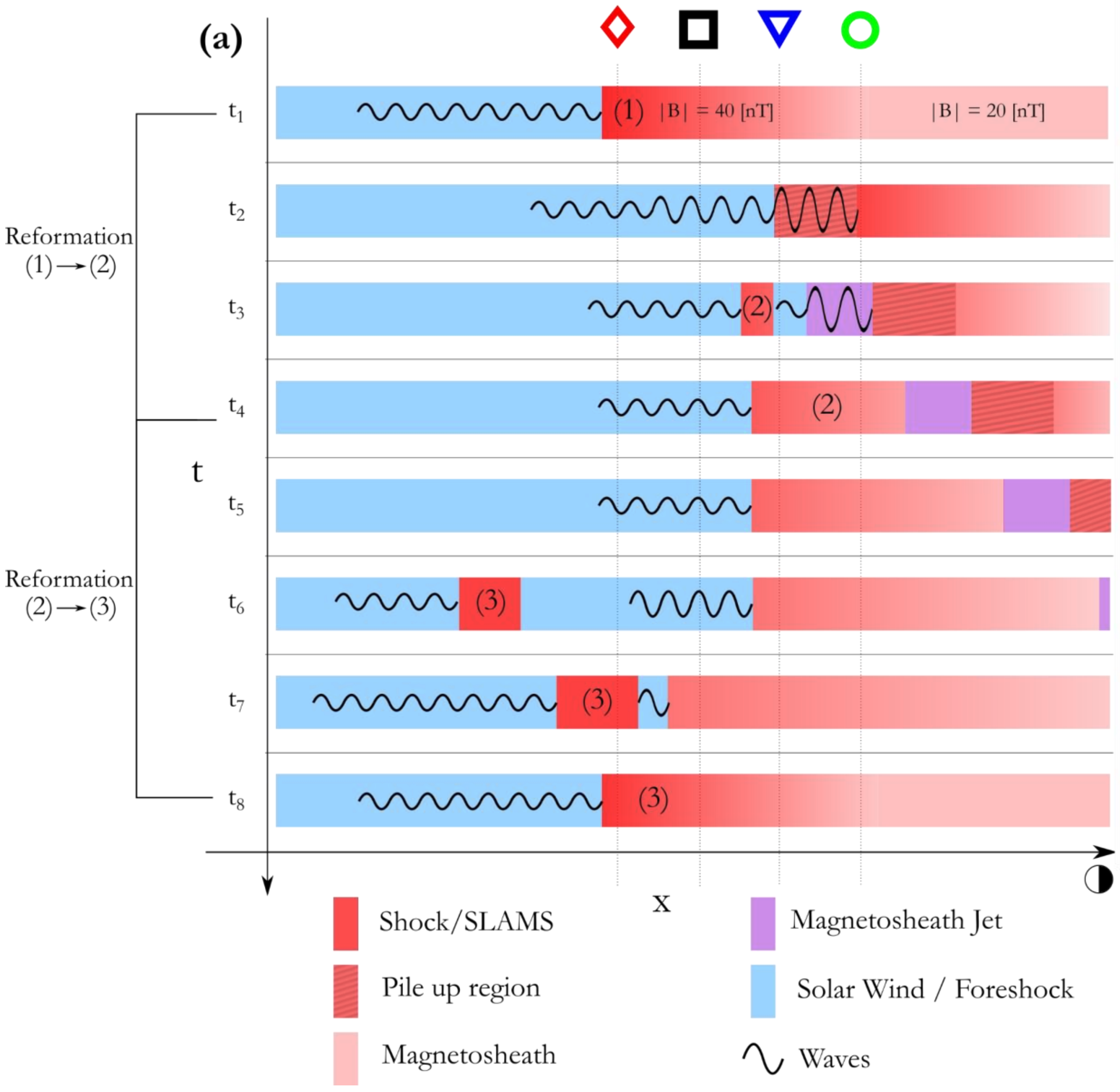
Whole mechanism & physical picture

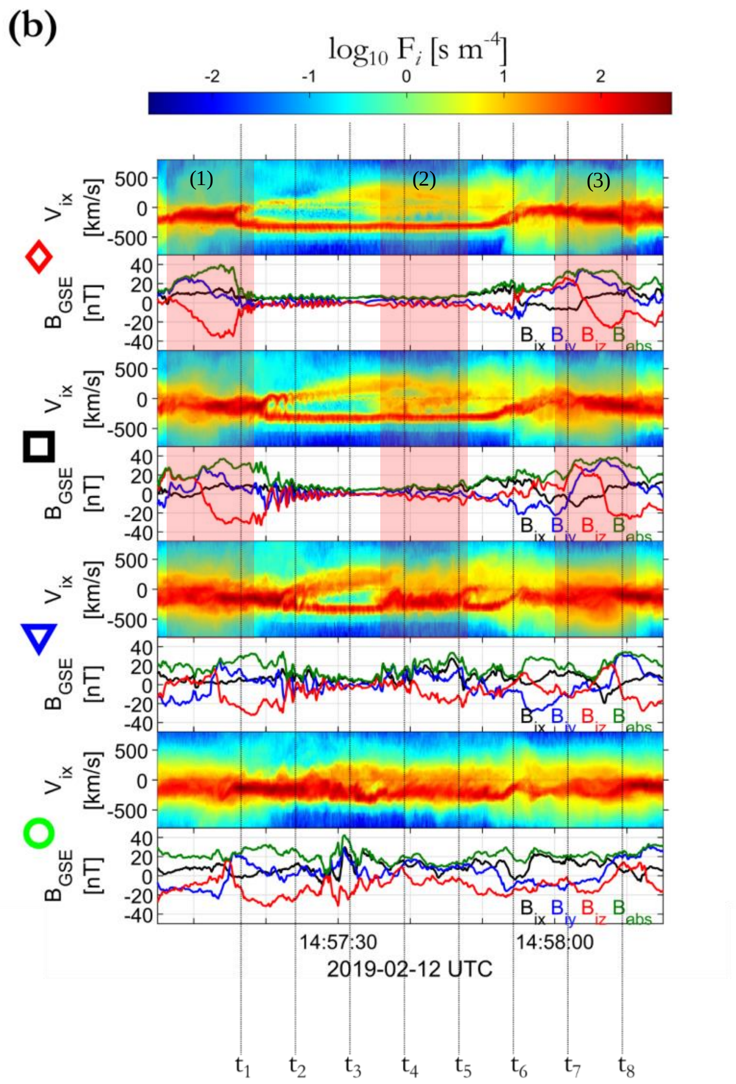




Raptis, Karlsson et al. (2021a) | Ongoing

Whole mechanism & physical picture





Raptis, Karlsson et al. (2021a) | Ongoing

Summary & Conclusion

Main points

- *In-situ* observations of shock fronts (SLAMS) becoming "embedded plasmoids" (density enhanced downstream regions).
- **First** *in-situ* observations of jets generated by the dynamical evolution of collisionless shock (Reformation)

Implications

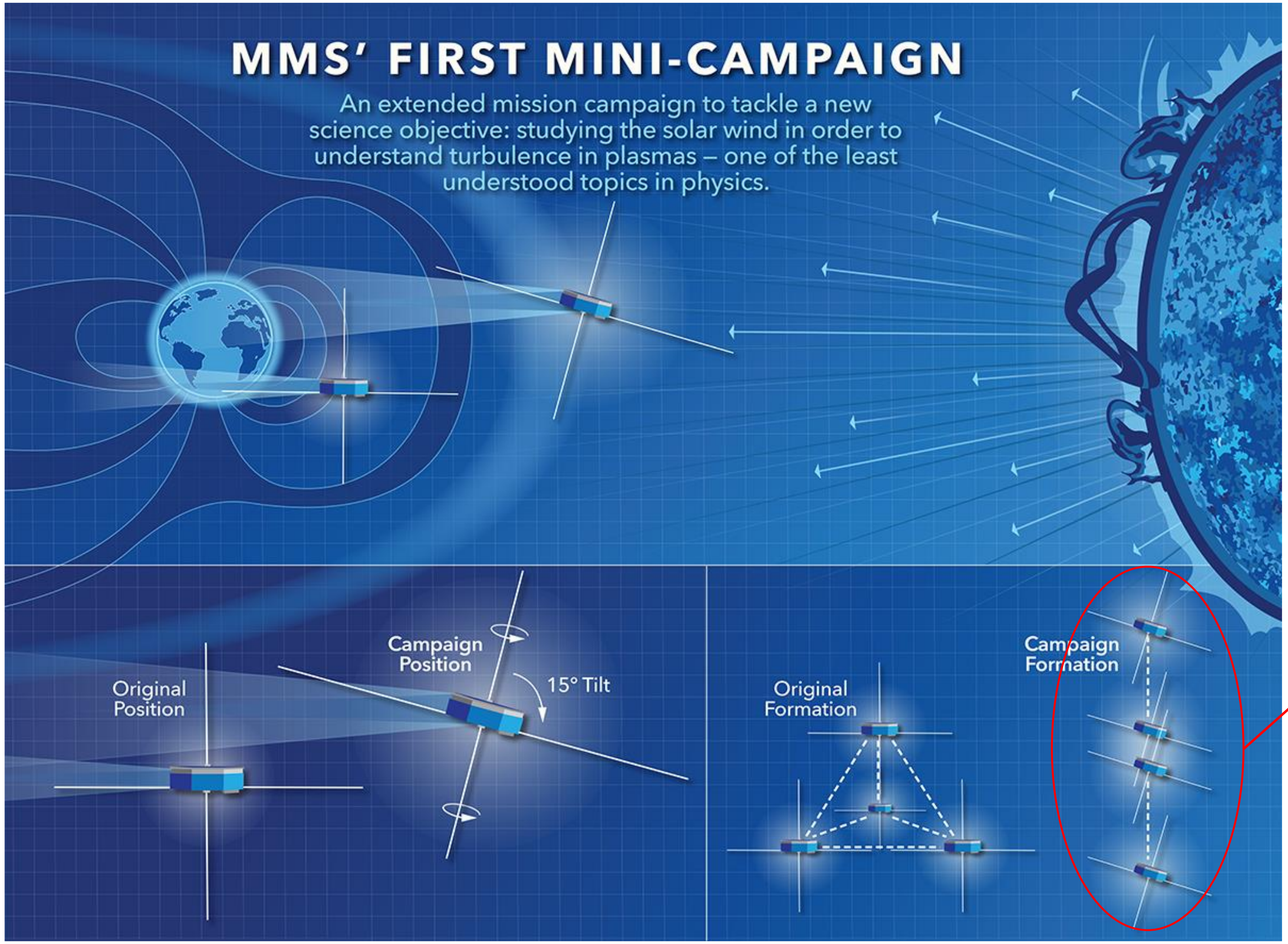
- Direct observations of jets generated as consequence of the dynamical evolution of shocks. Possibly a fundamental process of collisionless shocks that can be found everywhere in planetary, astrophysical and laboratory shocks.

Future work

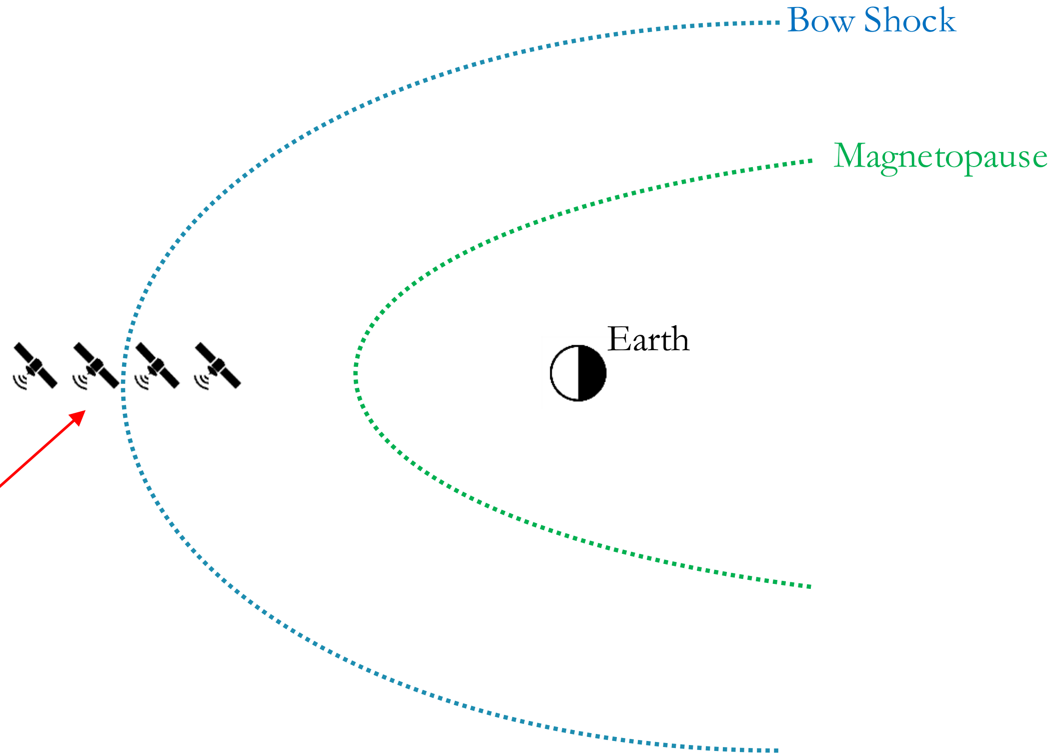
- Simulation comparison (ongoing, already very supportive results from various groups)
- Statistical confirmation (need more events, currently 3 of very similar signatures)
- Further physical modeling (Can this process explain jets close to MP ? How exactly are the dynamic evolution of this particular population change in time while they propagate ?)

Extras

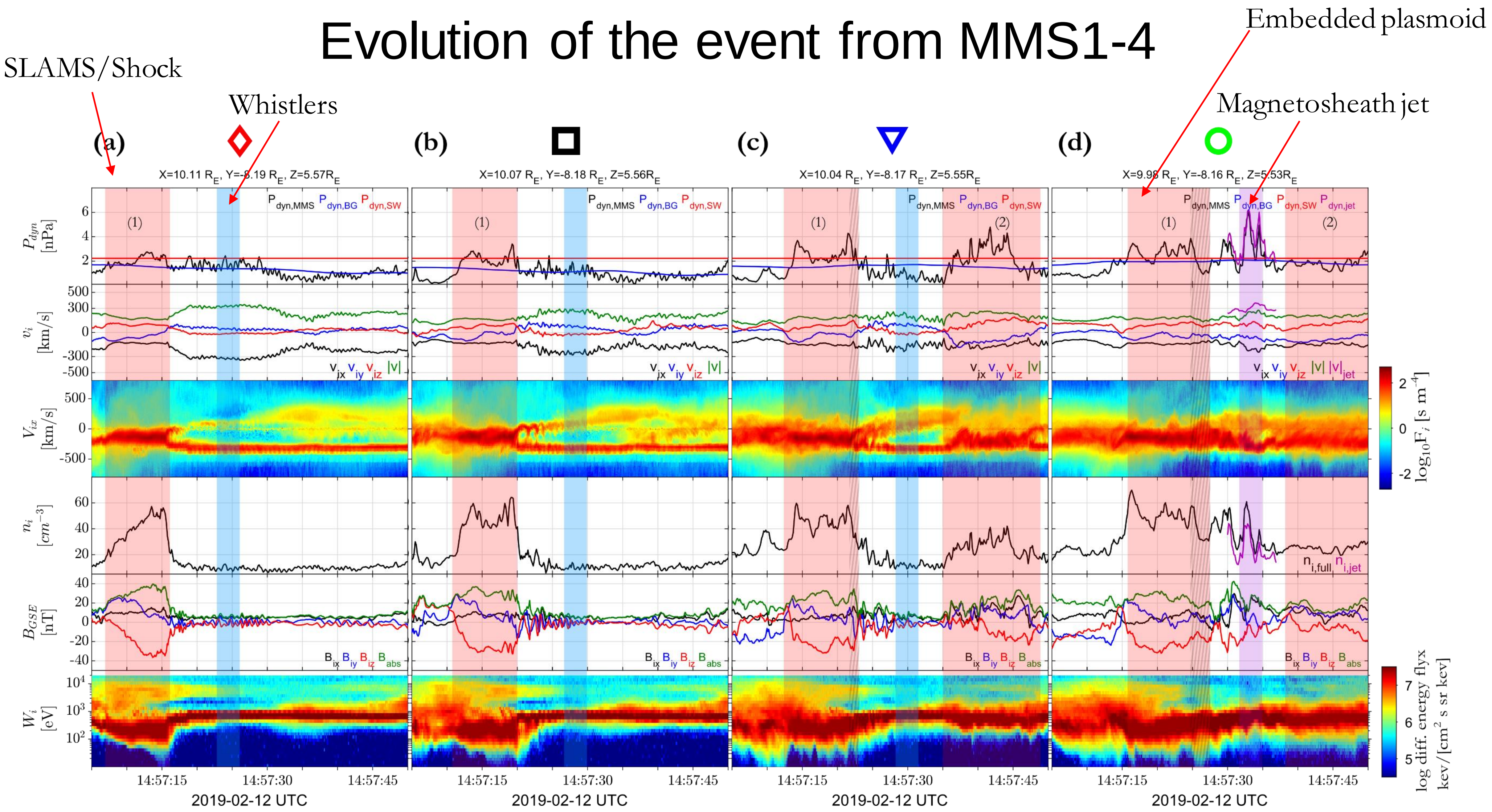
MMS spacecraft + String of Pearl Configuration



Very useful for people studying the collisionless shock evolution



Evolution of the event from MMS1-4

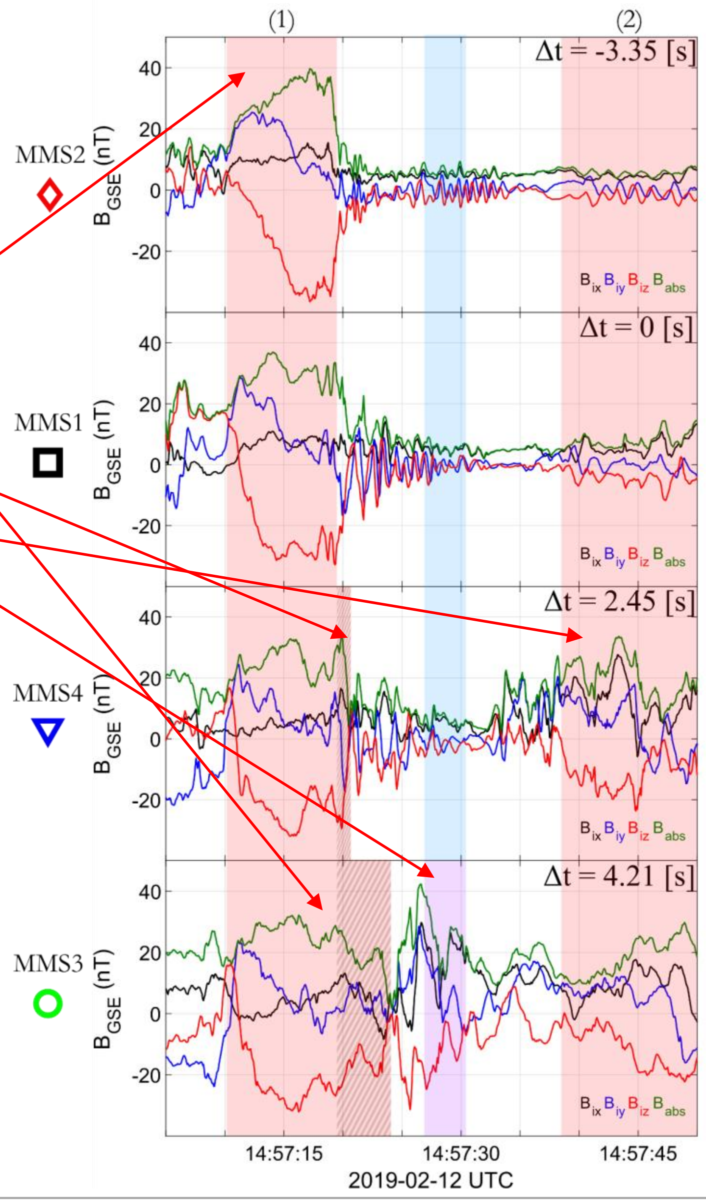


Evolution of local shock front

<u>4 Key points:</u>

Viewed from a co-moving reference point of "1"

1. Evolution of local shock front **"1"**
2. Generation of new shock ramp
3. Location of **jet** observations
4. New shocked plasma (MSH) **"2"**



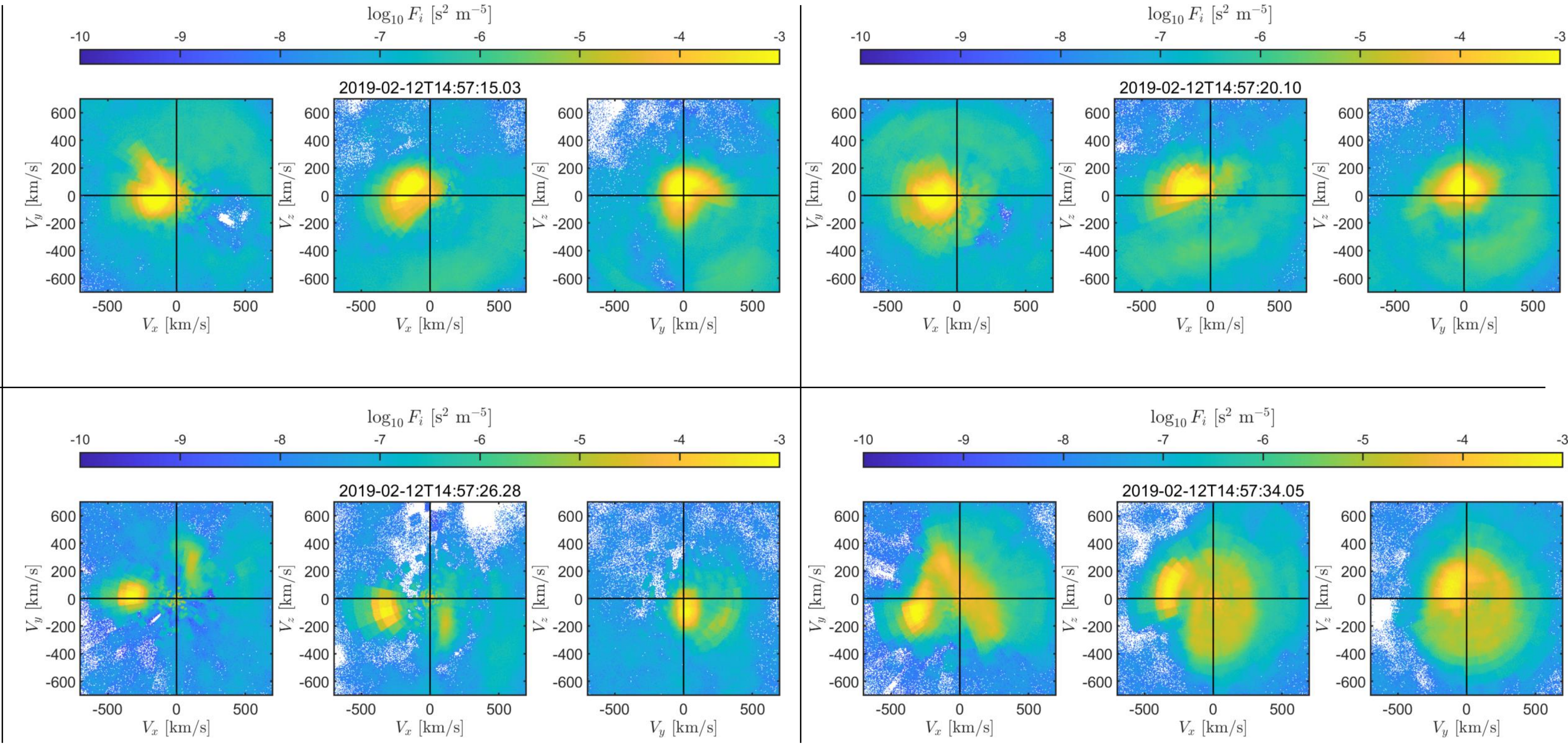
2D reduced VDFs

MMS 2 - Upstream

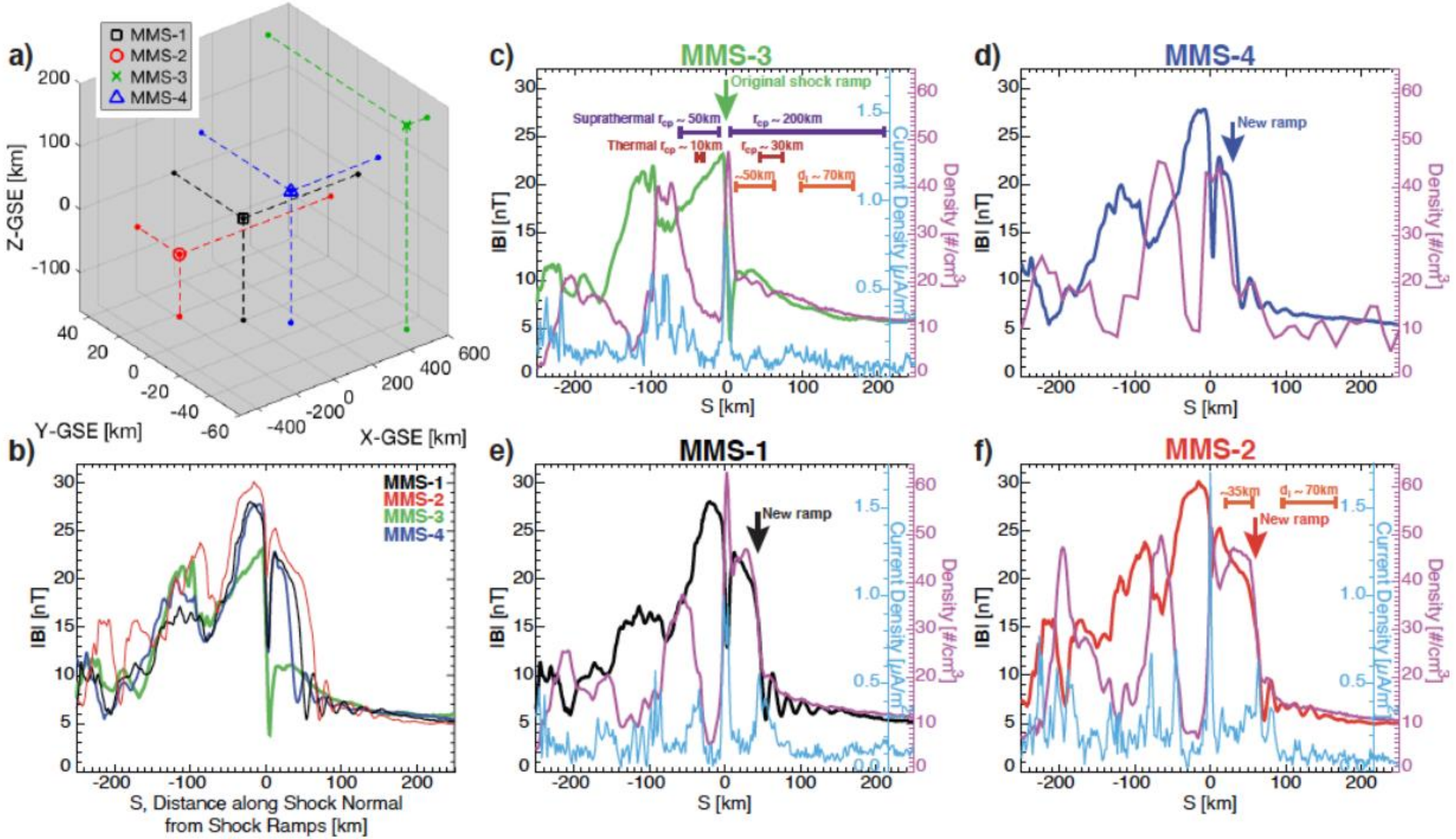
MMS 3 - Downstream

Region 1 – Shock

Upstream waves – Jet



Turner et al. 2021 (local reformation/evolution)



Jets Database

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
Kajdic P., **Raptis S.**, et al. (2021) | GRL

Raptis, Karlsson, et al. | Submitted
Raptis, Karlsson, et al. | Ongoing

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

Resolution (samples/s)	Fast/Survey	Burst
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