Shock Reformation Generating High-speed Magnetosheath Jets

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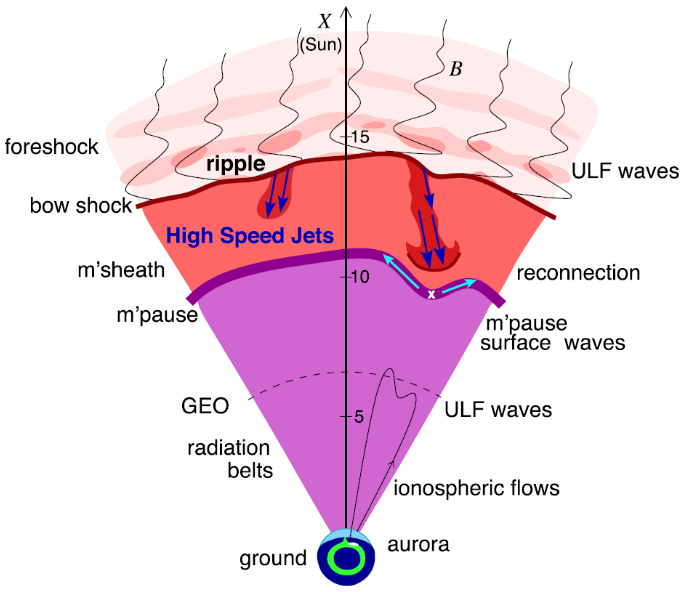
Raptis, S., Karlsson, T., Vaivads, A. et al. Downstream high-speed plasma jet generation as a direct consequence of shock reformation. Nature Communications 13, 598 (2022). https://doi.org/10.1038/s41467-022-28110-4

Title = Shock Reformation Generating High-speed Magnetosheath Jets

Shock & Jets

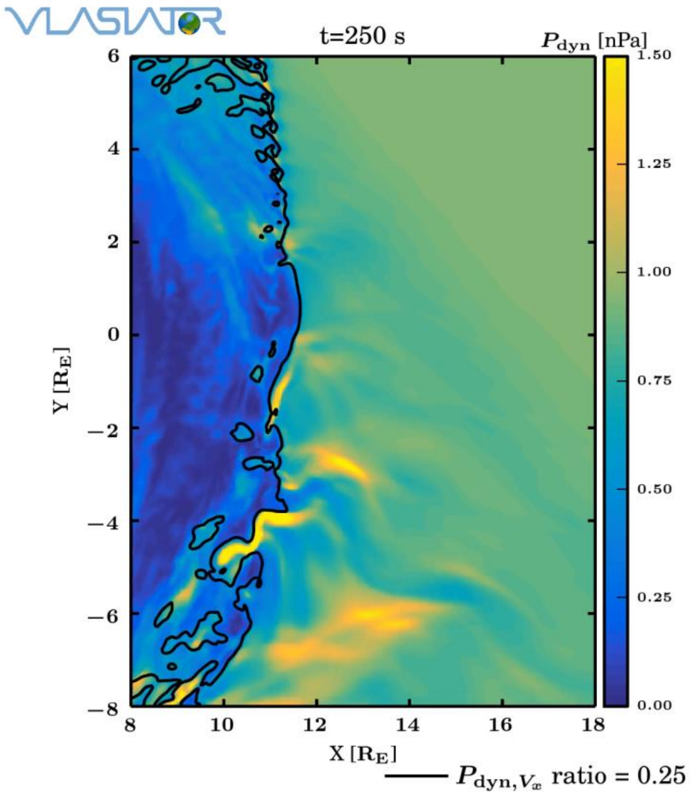


transient localized enhancements of **dynamic pressure** (density and/or velocity increase)

e.g. $P_{dyn} \geq 2\langle P_{dyn}\rangle_{MHS}$

Plaschke et al. (2018); sketch by H. Hietala

Generation

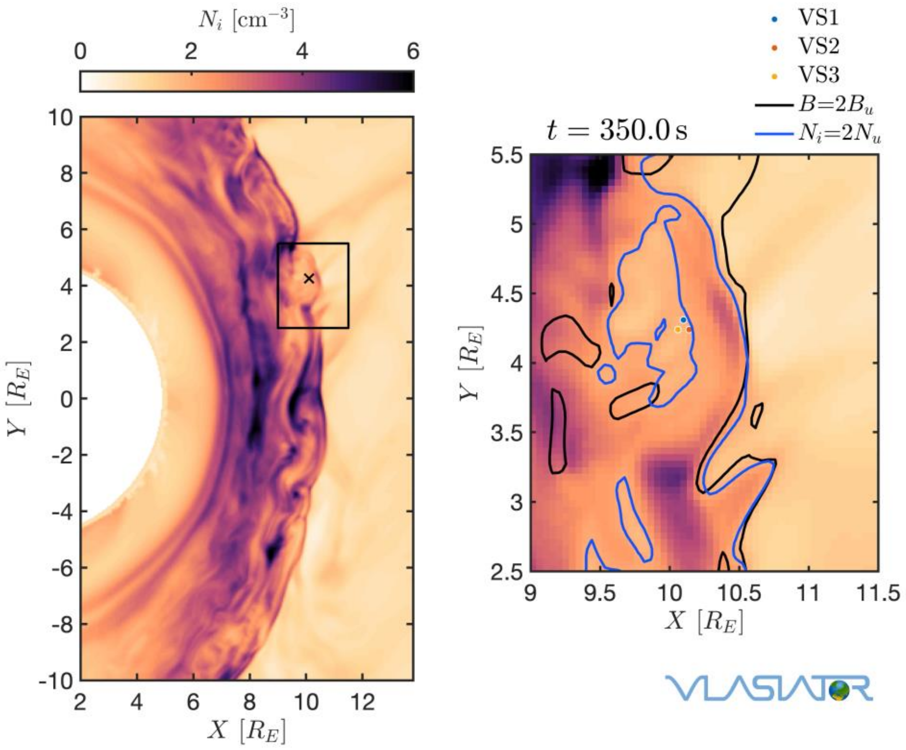


Hietala et al. (2009) Archer et al. (2012) Karlsson et al. (2015), Suni et al. (2021)

Ripples? SW discontinuities ? Foreshock?

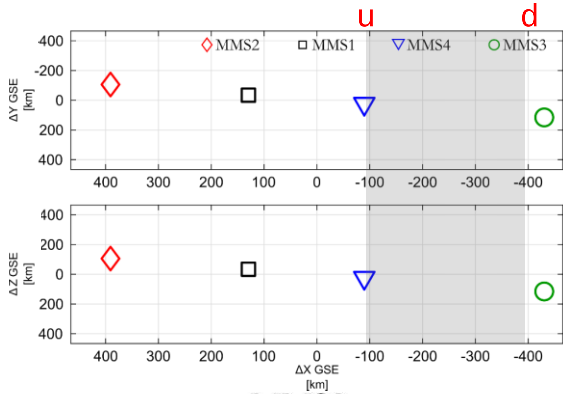
Palmroth et al. (2018, 2021)

Reformation

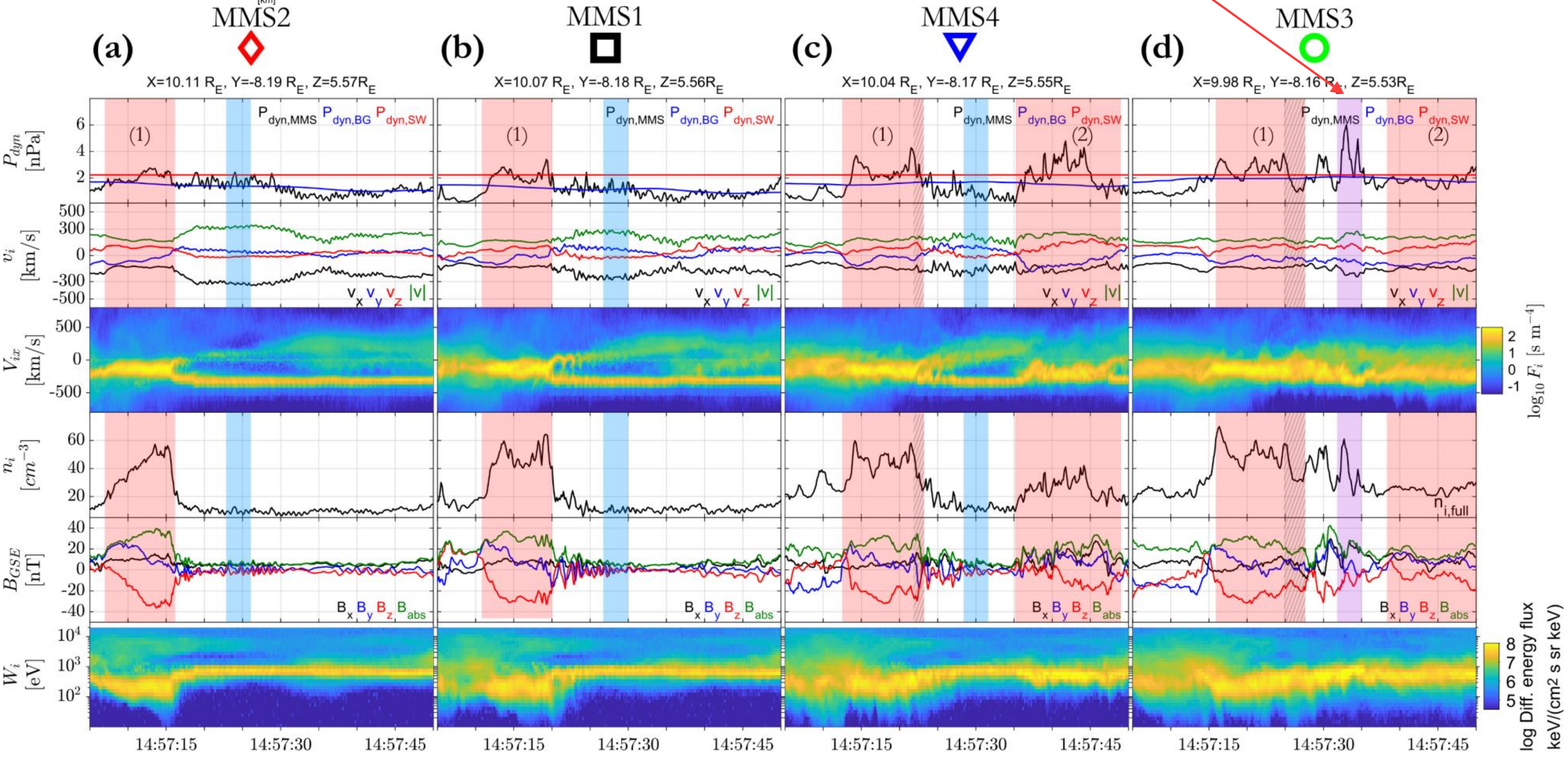


Burgess (1989): "the shock exhibits a cyclic behavior ….. cyclic shock reformation;"

Johlander et al. (2022)



Jet is formed from (1)'s upstream wave evolution (**density** increase) and reformation (1-2) (relative **velocity** increase)



Observations

Macroscale
(MMS2 &3)
(*Upstream to Downstream*)

1. $n_{SW} \ll n_{MSH}$
2. $|B|_{SW} \ll |B|_{MSH}$
3. Beam like distribution → Thermalized

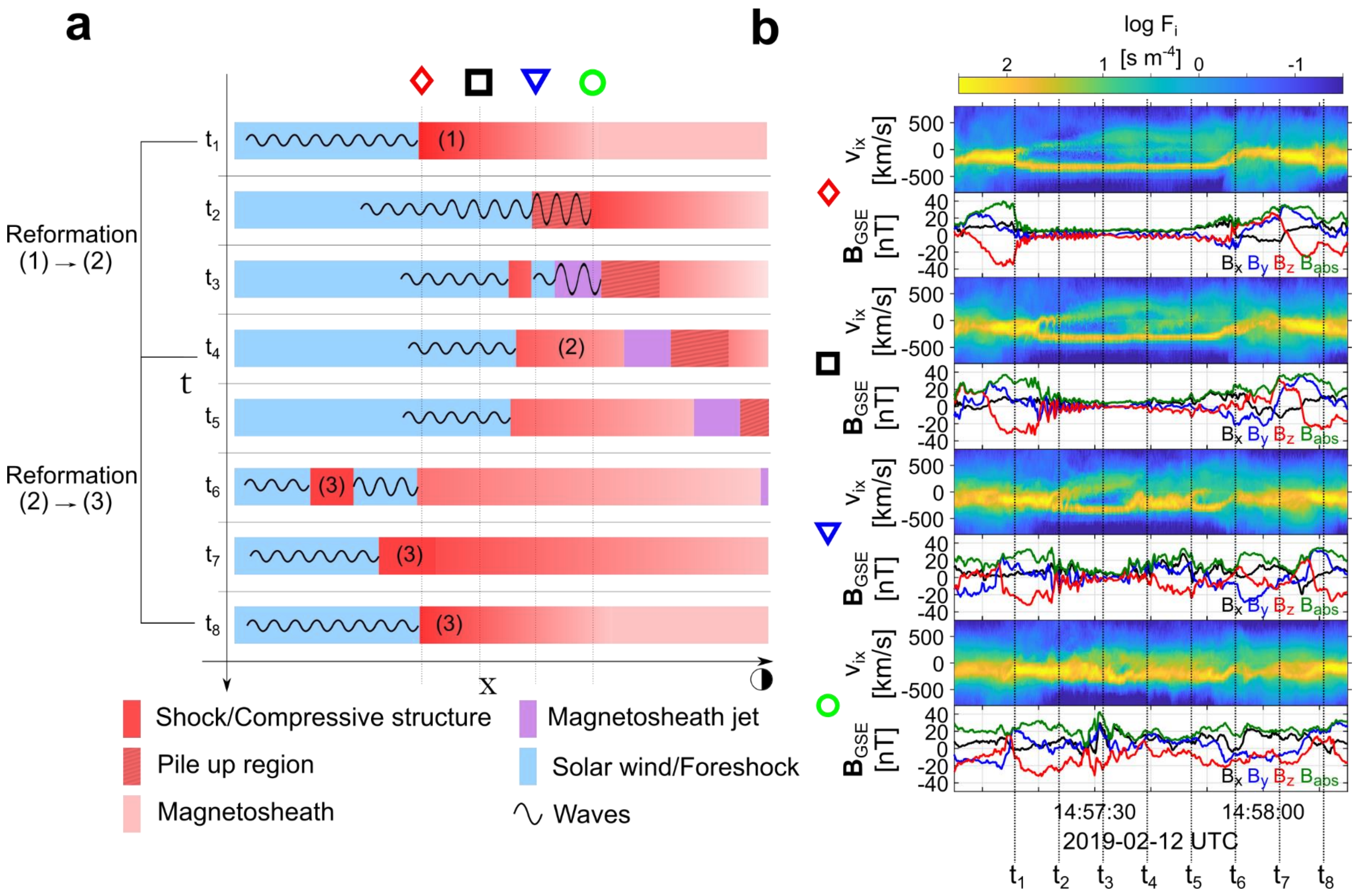
Mesoscale
(MMS 1 & 4)
(*Reformation*)

1. Evolution of (1) – Red Shaded area
2. Development of (2)
3. Spatially "enclosing" area between (1) – (2)

Microscale
(MMS 3)
(*SLAMS evolution & Jet*)

- Old shock front (1) → *Embedded plasmoid*
- Evolution of (1) upstream waves → Local *density increase*
- Reformation (1-2) → SW downstream of (2) → *Relative velocity increase*

Model of the shock evolution, reformation and the generation of a magnetosheath jet.



Article: https://www.nature.com/articles/s41467-022-28110-4
GitHub: https://github.com/SavvasRaptis/Jets-Reformation
Popular science version: https://astronomycommunity.nature.com/posts/how-the-solar-wind-slips-through-earth-s-bow-shock

Main points

- ***Shock fronts*** become "***embedded plasmoids***" (density enhanced downstream regions).
- ***Jets*** forming from the evolution of collisionless shock (**reformation & upstream waves**)

Implications & open questions

- Is this a general property of shocks (astrophysical, planetary, lab) ?
- If this mechanism is applicable to all jets, are they an extension of the foreshock evolution ?

Future work

- *Details on SLAMS/waves* – Exact properties & evolution study of FCs numbered 1-3
- *Simulation comparison* – Can we find cases like these in simulations ?
- *Statistics* – We need more events, currently found ~3 of similar signatures.
- *Modeling* – Can this process explain jets close to MP ? Or are just a subset of "small" jets ?

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
- ✗ Could be misleading close to boundary surfaces (Magnetopause, Bow shock etc.)

Burst MMS data

Pros

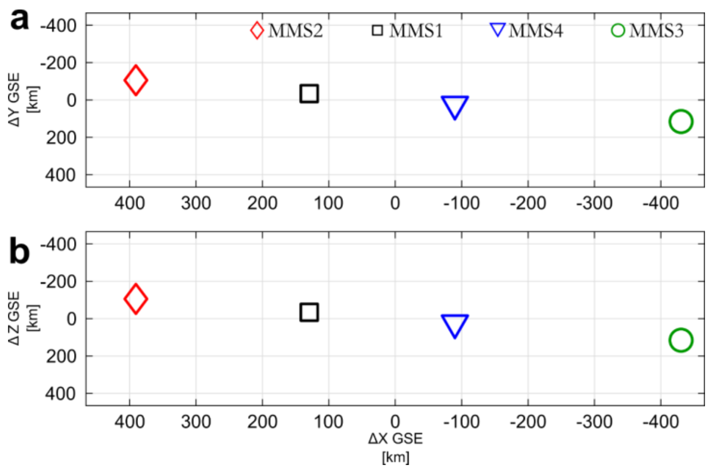
- ✓ Very high resolution
- ✓ Able to resolve structures close to boundary surfaces (e.g. mix of plasma close to magnetopause, bow shock, foreshock etc.)

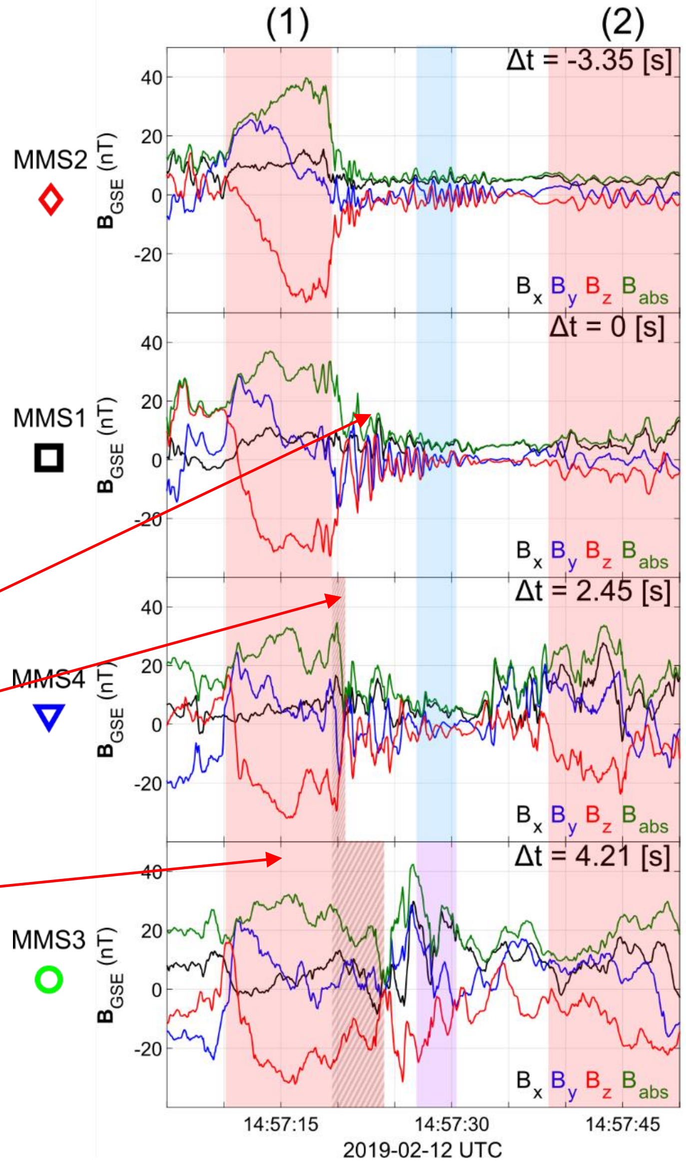
Cons

- ✗ 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

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)

MMS – Jet Database

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

Jets with full burst data →

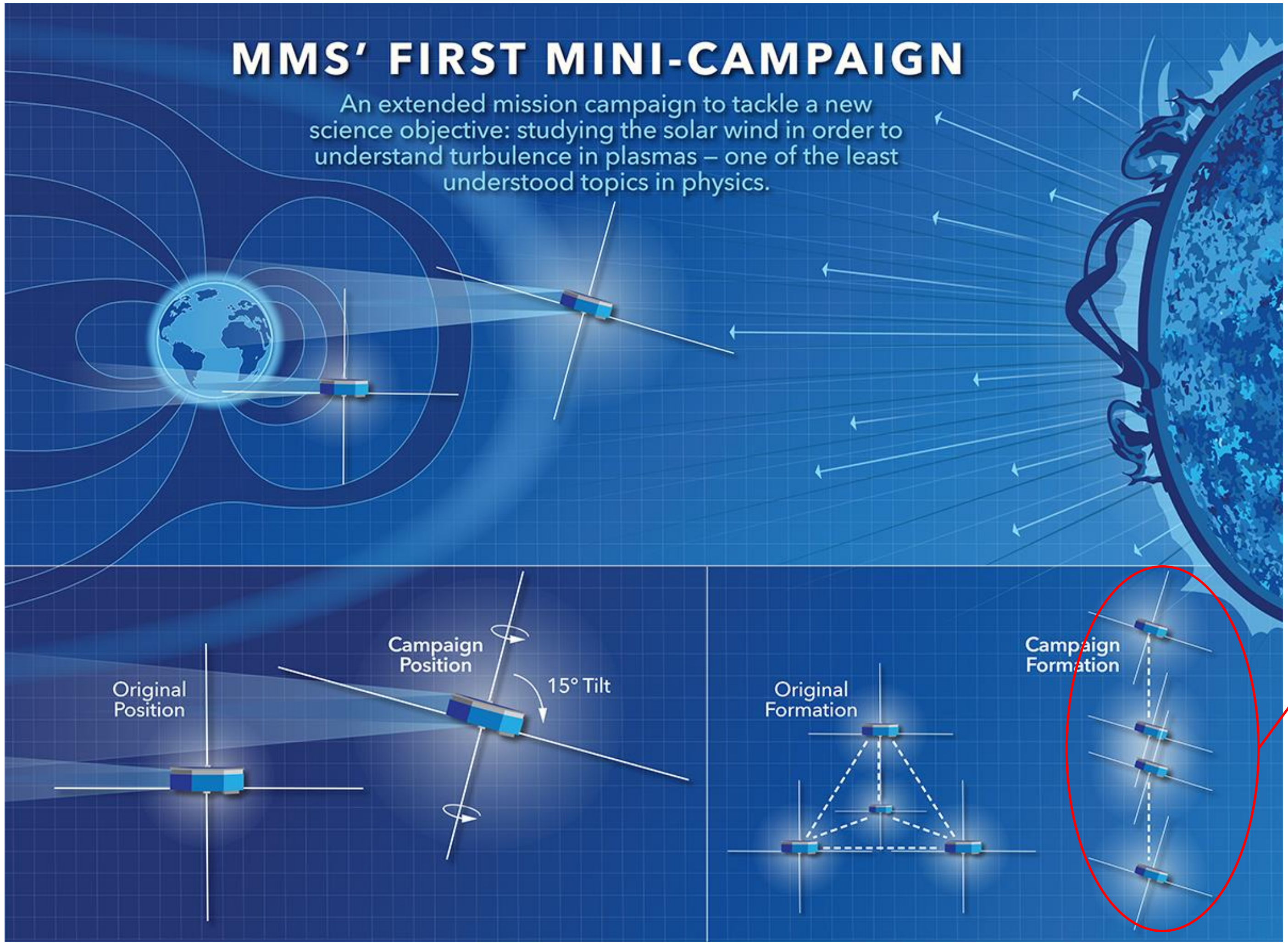
Burst

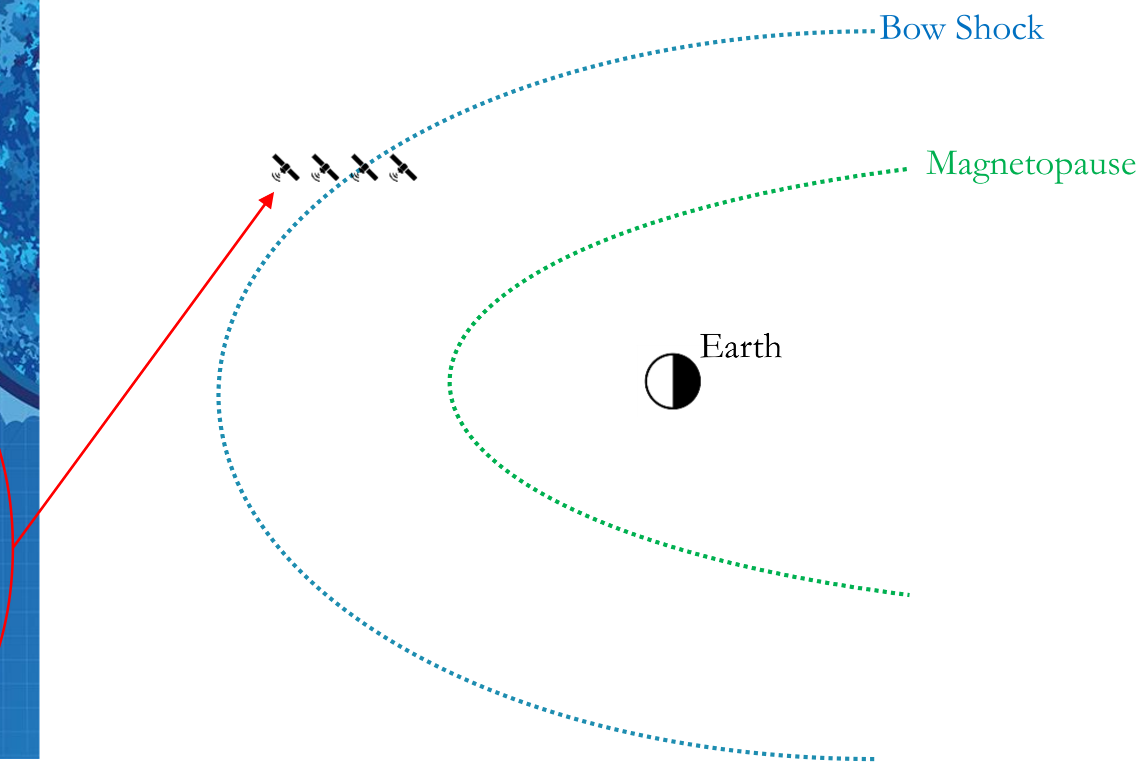
Qpar	423
Qperp	34
Boundary	35
Encapsulated	31
Close to BS / MP	495
Others	428

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

MMS spacecraft + String of Pearl Configuration



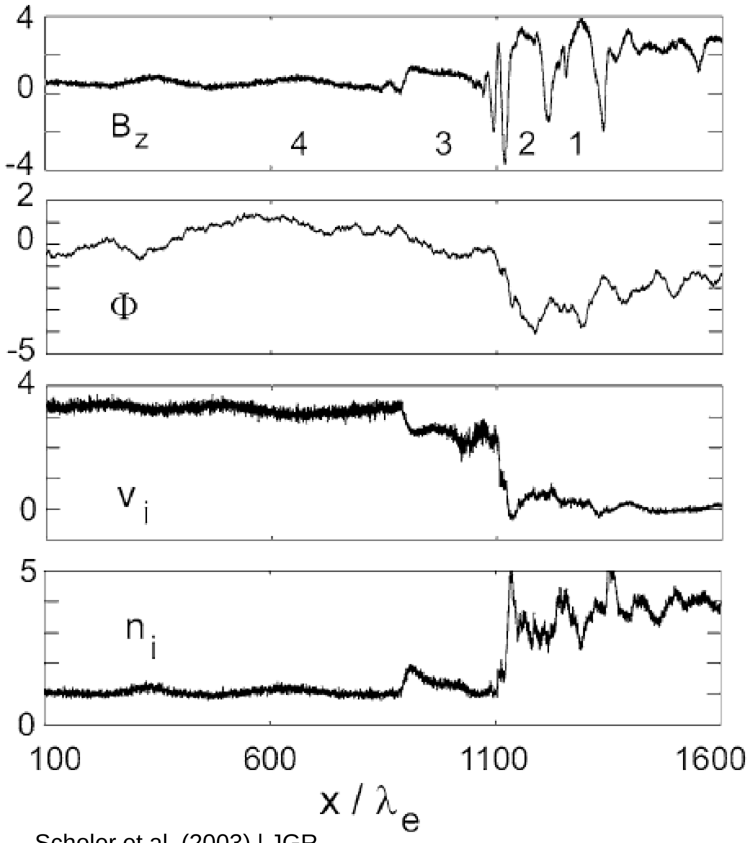


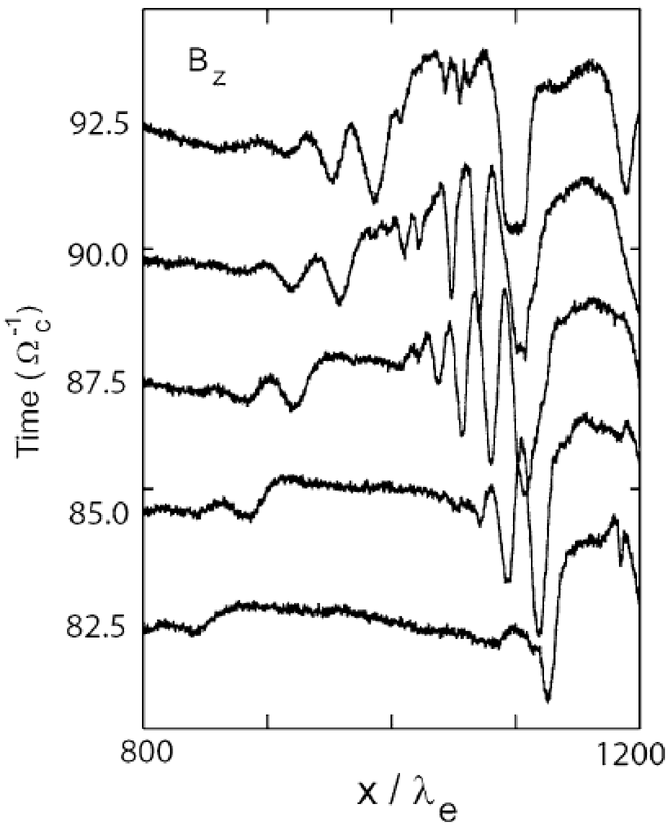
Credits: NASA's Goddard Space Flight Center/Mary Pat Hrybyk-Keith

Shock Reformation – Simulations

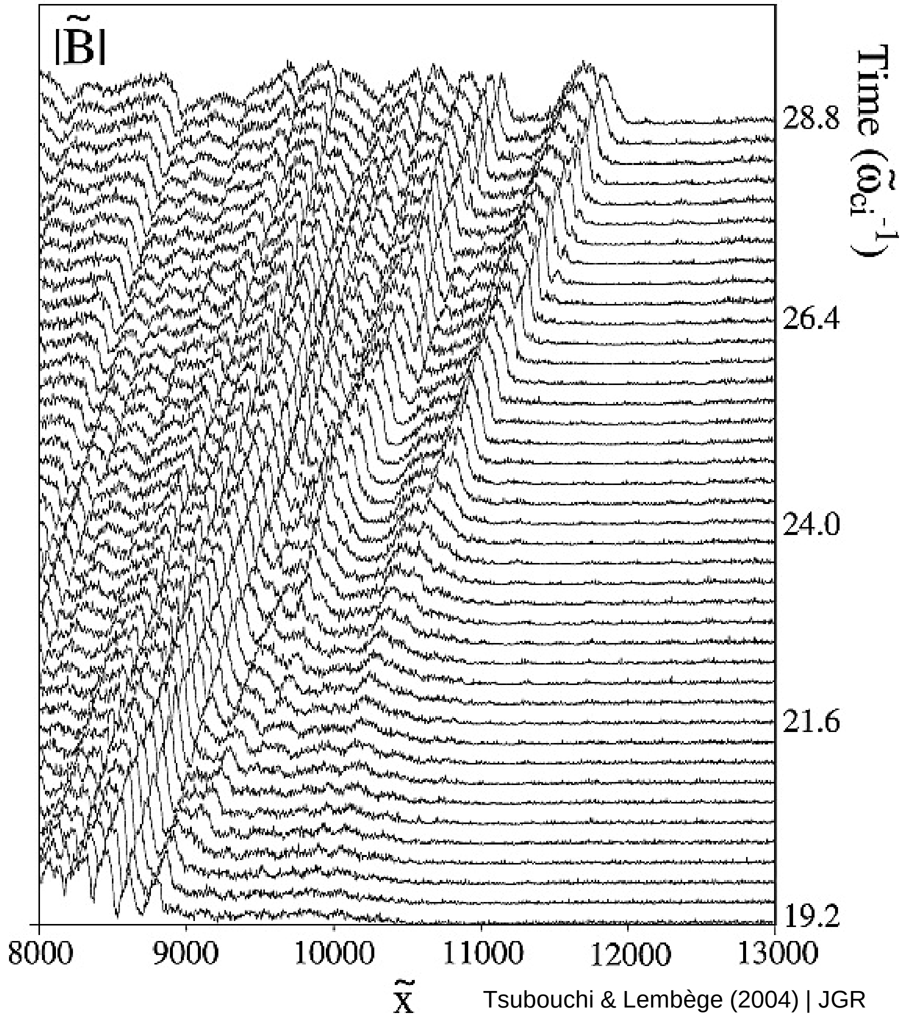
1D-PIC simulation (30°), $M_A = 4.7$
mi/me = 100 and ωpe/Ωce = $\sqrt{10}$.

mi/me = 50 and ωpe/Ωce = 4.





Scholer et al. (2003) | JGR



Tsubouchi & Lembège (2004) | JGR

More nice sources for review : Burgess & Scholer (2015), Willson (2016)

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.