JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Transient phenomena in foreshock, shock, and magnetosheath – Expectations from large separation campaign

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SR acknowledges the support by John Hopkins University Applied Physics Laboratory independent R&D fund

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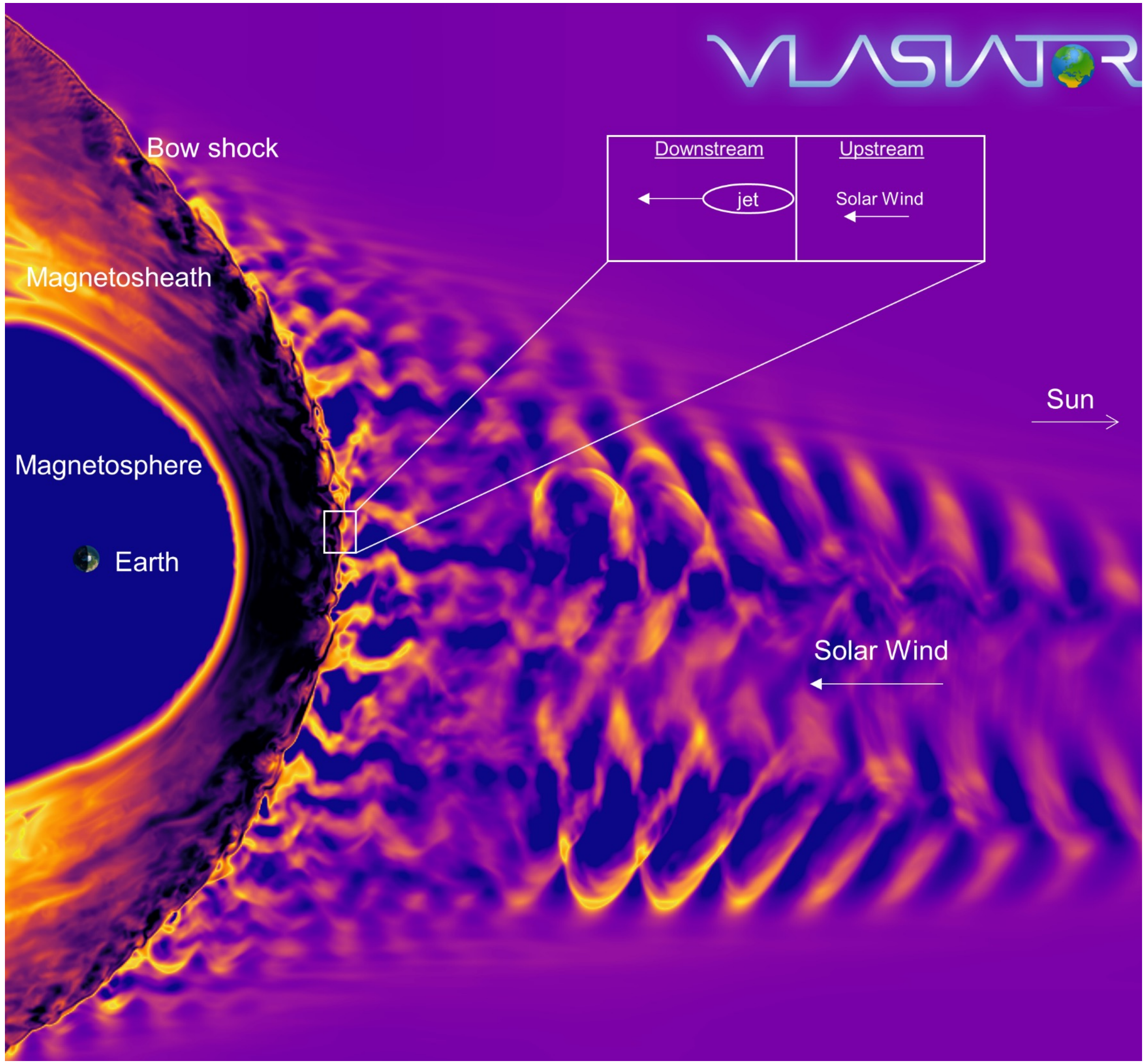
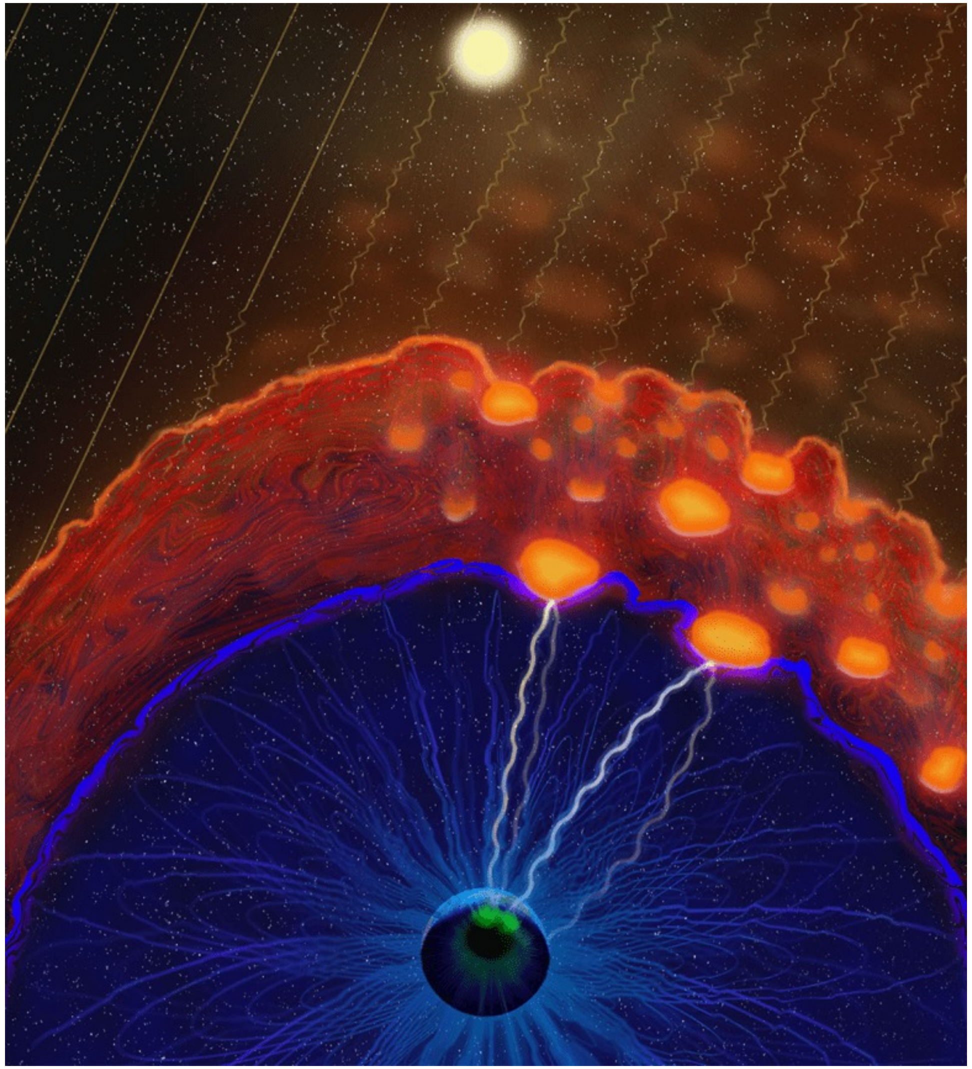
CGS | CENTER FOR GEOSPACE STORMS

Transient Phenomena in Foreshock & Magnetosheath

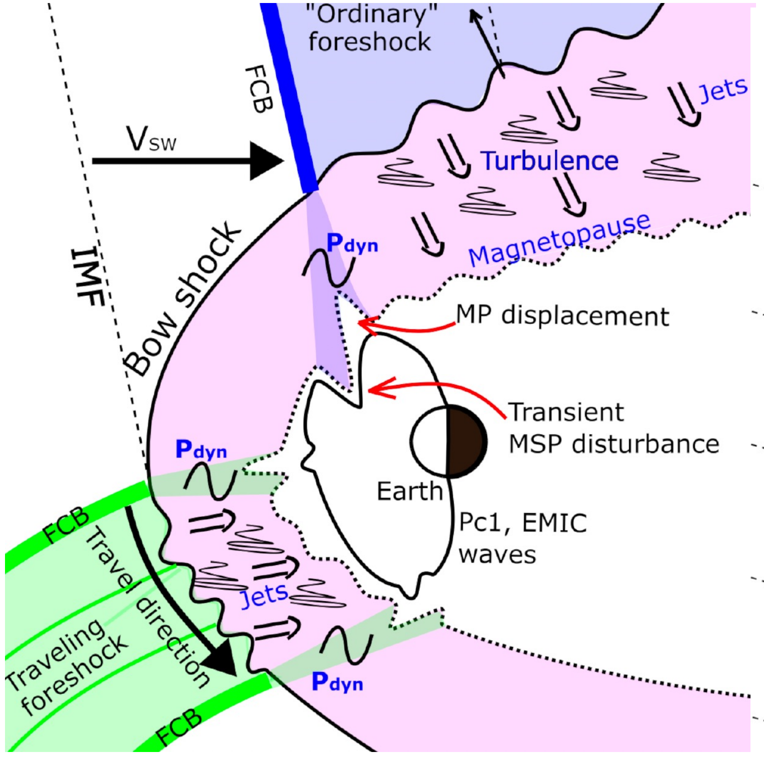




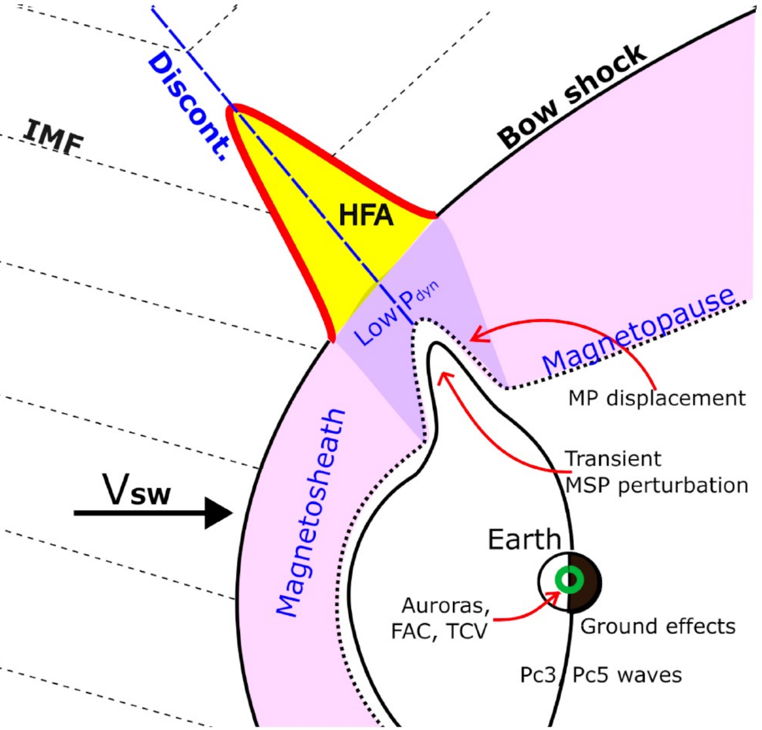
Courtesy of M. Palmroth, U Helsinki

Credits: Vuorinen et al. (2022) https://eos.org/features/space-raindrops-splashing-on-earths-magnetic-umbrella

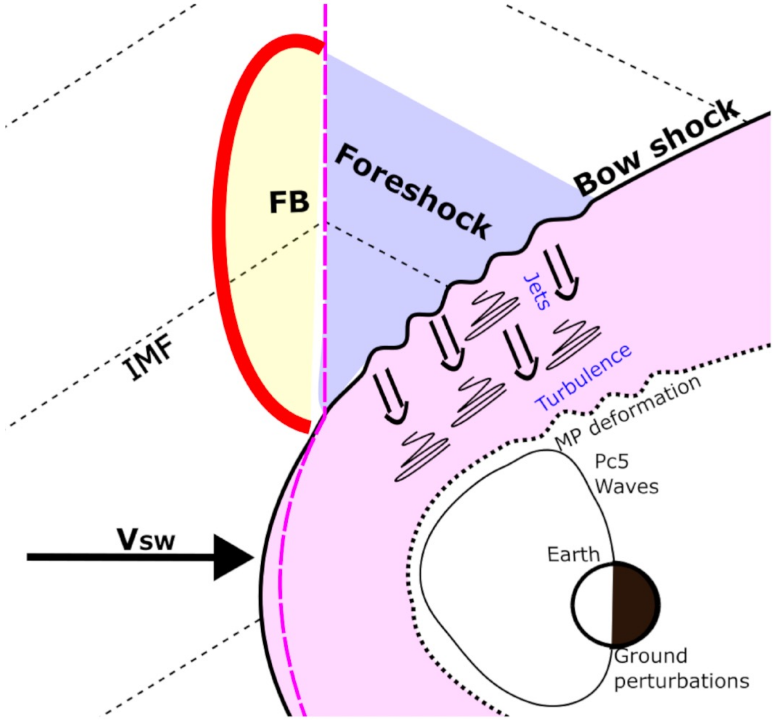
Foreshock Transients



Travelling Foreshocks and
Foreshock Compressive Boundaries



Hot Flow Anomalies

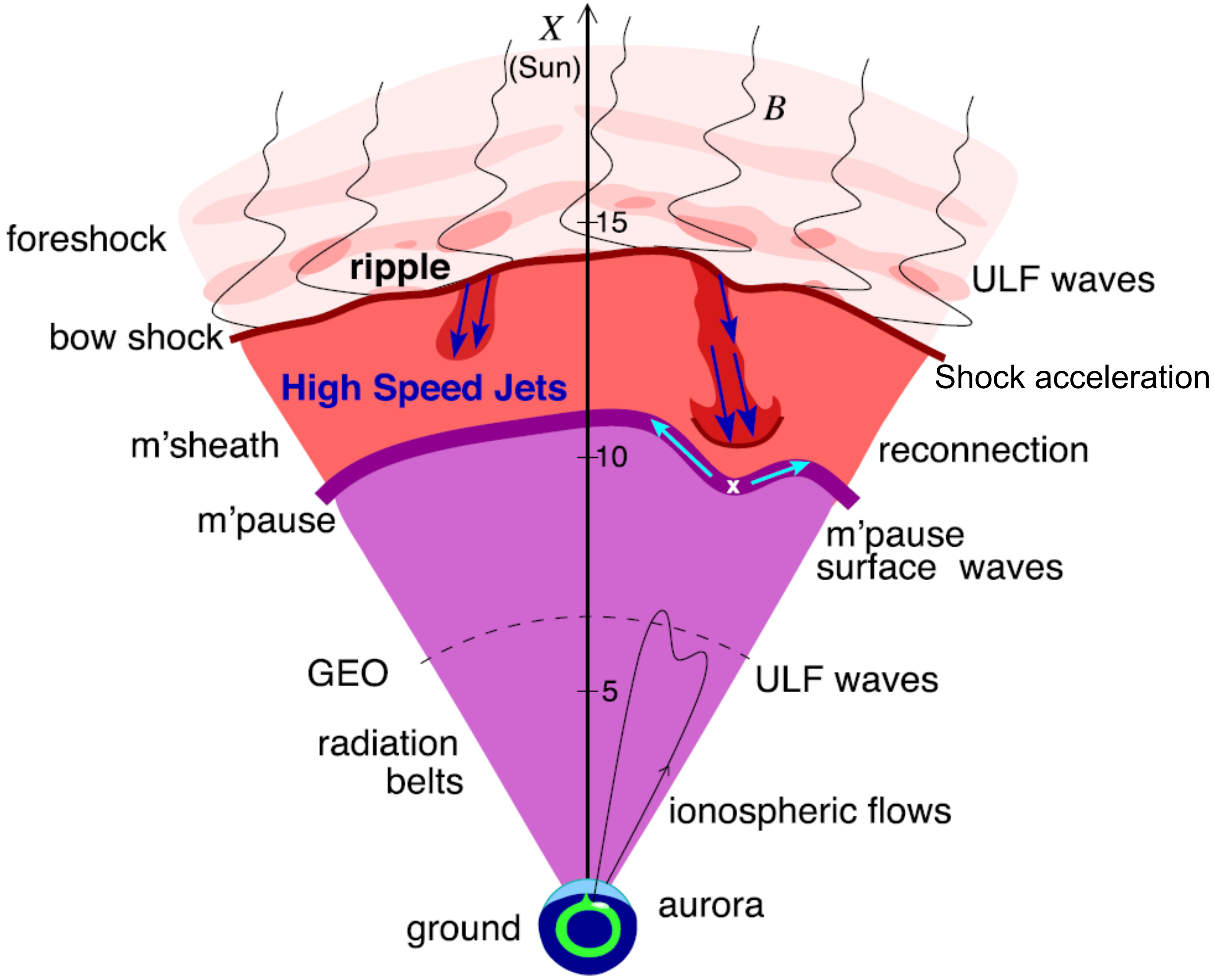


Foreshock Bubbles

Primož K. et al. (2023 ongoing)

Different type of TUMS (Transient Upstream Mesoscale Structures)

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)

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

Related phenomena

Radiation belts
Throat aurora
Magnetopause reconnection
Magnetopause penetration
Shock acceleration
Magnetopause surface eigenmodes
ULF waves
Substorms
Ground magnetometer detection

Jets – references update (>2019)

~110 citations

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)
- High-Speed Jets **Triggering Dayside Ground ULF**: Wang et al. (2022)
- **Waves** and **jets** using burst MMS data: Krämer et al. (2023)

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)
- **Occurrence** in relation to **CMEs and SIRs**: Koller et al. (2022)
- **Shock reformation** and the **formation of high-speed jets**: Raptis et al. (2022a)
- **Electron acceleration** and **bow waves in** jets: Vuorinen et al. (2022)
- **Kinetic structure** of jets **and partial plasma moments**: Raptis et al. (2022b)

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.

Jets – references update (>2019)

~110 citations

Jets Downstream of Collisionless Shocks

Plaschke et al. (2018)

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

→

Jets Downstream of Collisionless Shocks: The Last Five Years

Ongoing review (TBD)

Dayside transient community & expectations from MMS

1. ISSI Science International Team 555 "**Impact of Upstream Mesoscale Transients on the Near-Earth Environment**"
2. The **Graz Jet Workshop** (Group working on magnetosheath jets)
3. ISSI Science International Team 546 "**Magnetohydrodynamic Surface Waves at Earth's Magnetosphere (and Beyond)**"

1

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Katariina Nykyri (co-leader)	Embry-Riddle Aeronautical University, USA
Simone Di Matteo	Catholic University of America, USA
Tom Elsden	St Andrews University, UK
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Michael Hartinger	Space Science Institute, USA
Anatoly Leonovich	Institute of Solar-Terrestrial Physics, Irkutsk, Russia
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Zhonghua Yao	Chinese Academy of Sciences, Beijing, China
Kevin Blasl	Austrian Academy of Sciences, Graz, Austria
Rachel Rice	University of Maryland, USA
Frances Staples	University of California, Los Angeles, USA

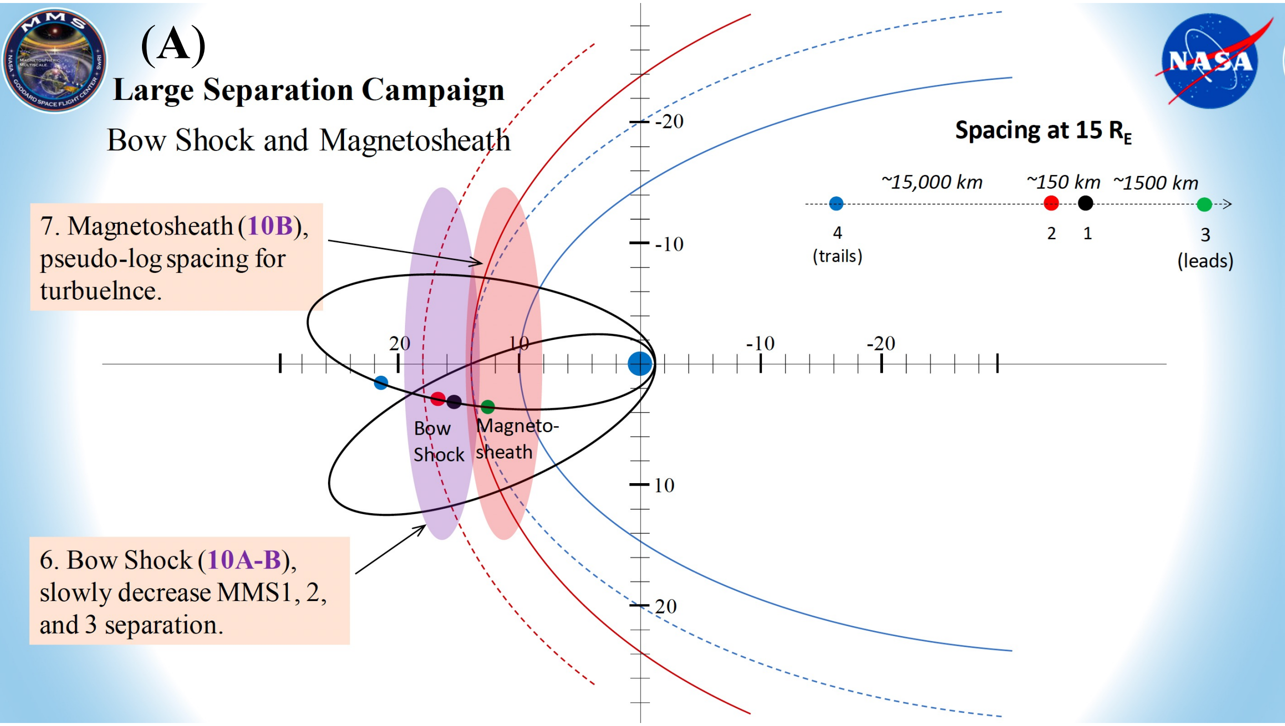
What we wished for?

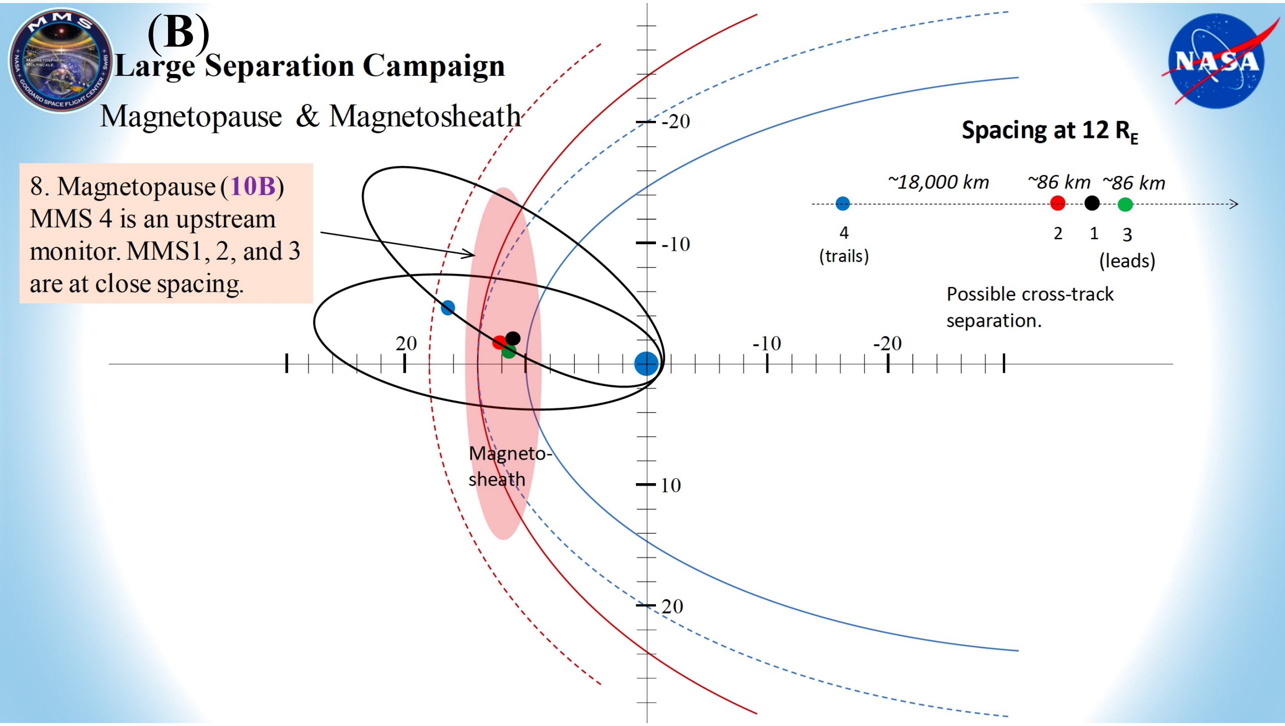
String-of-pearls campaigns with variable separation:

(a) 1000s kms to investigate the effect of dayside transients on the magnetosphere

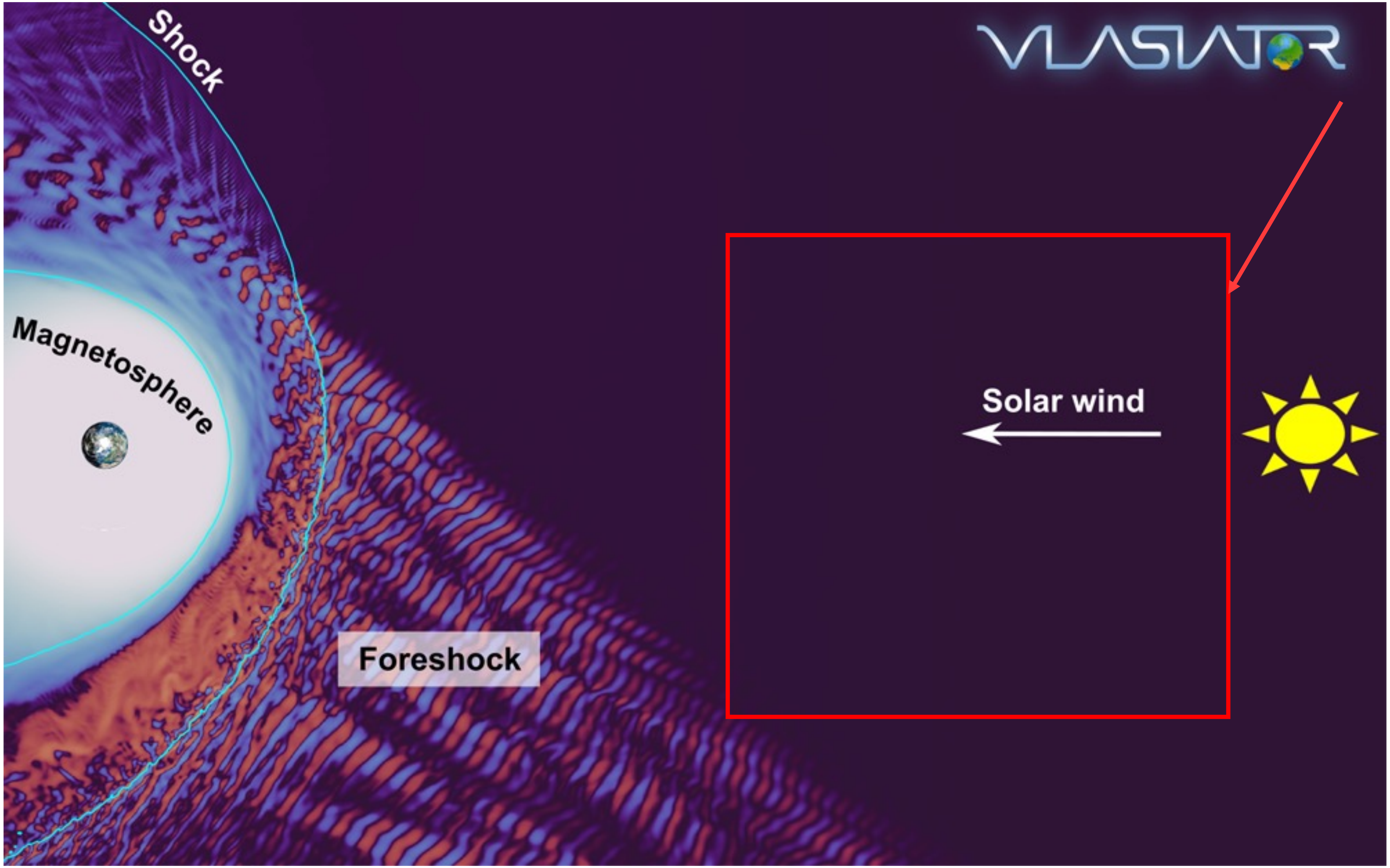
(b) 1-2 satellites upstream and 1-2 downstream to evaluate the transmission and potential effects for the shock

(c) Magnetopause response (1000s km separation) while upstream SW/foreshock (several Re)

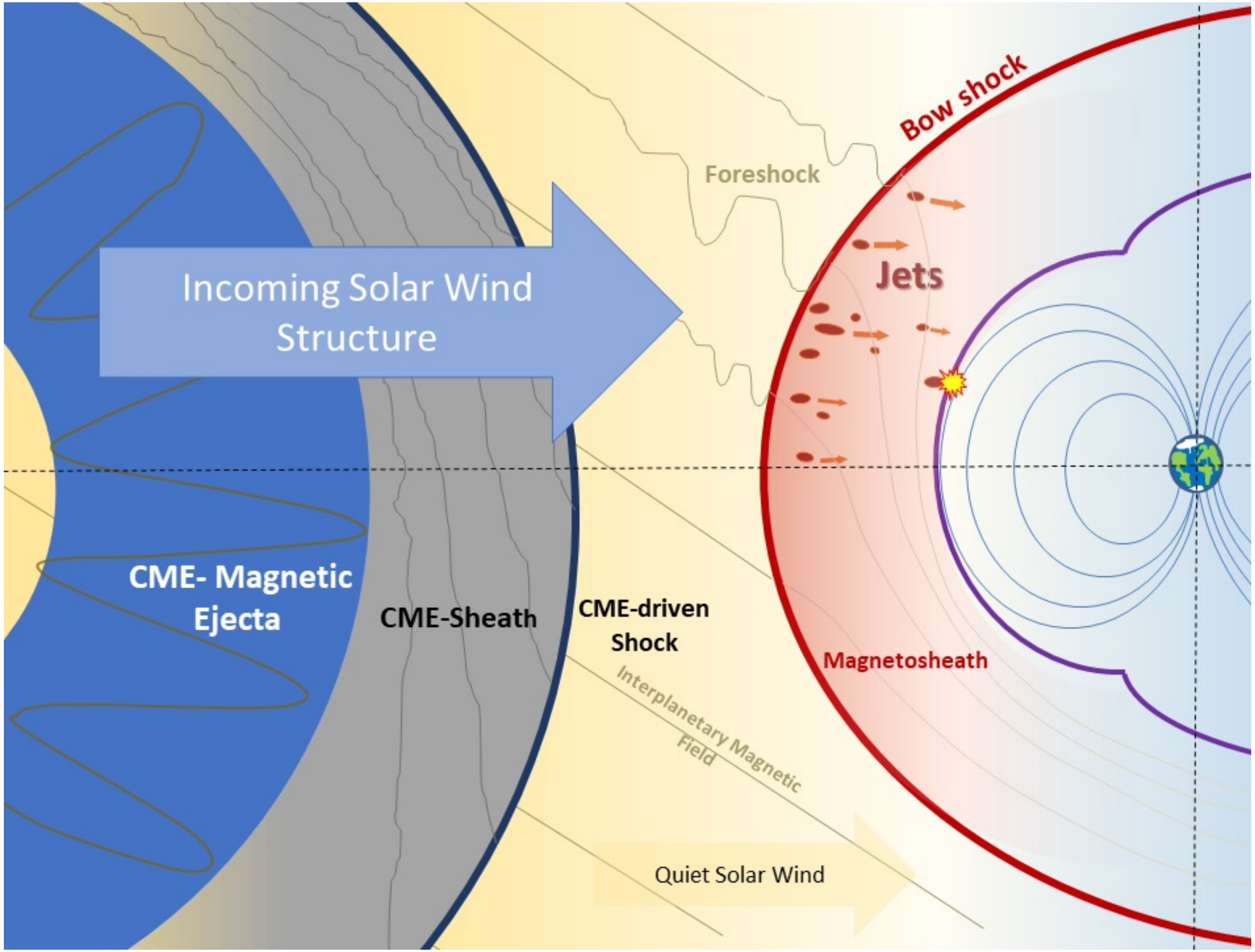




Why we need that ?
(i.e., test cases)



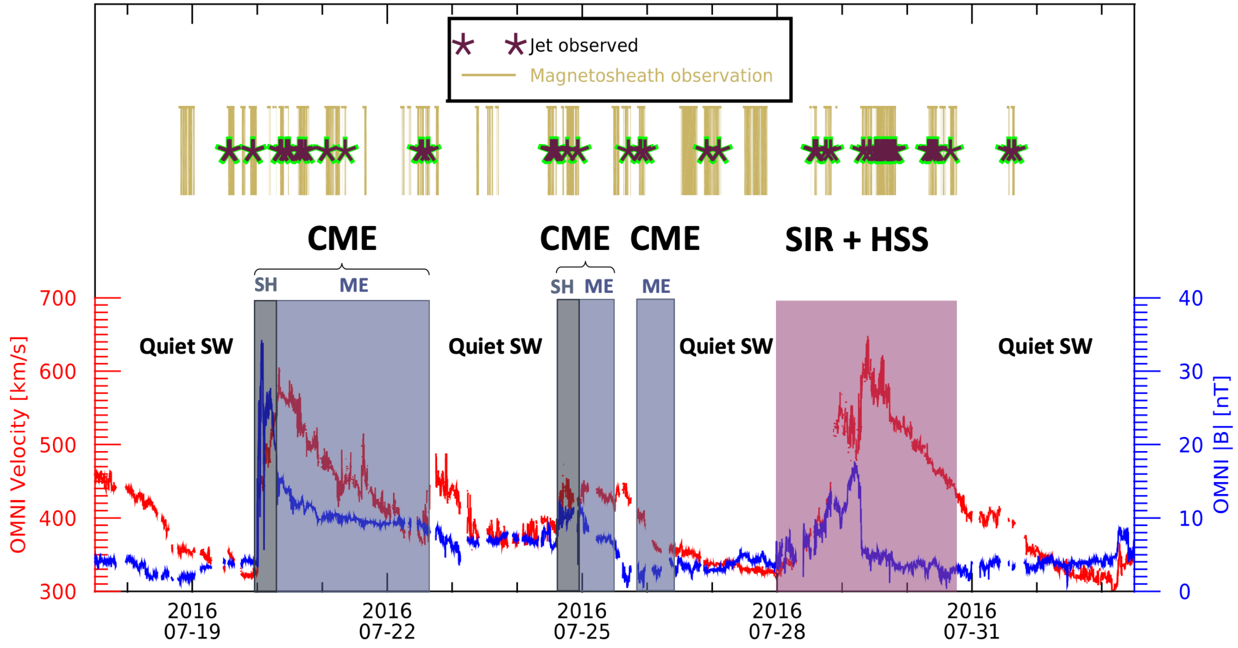
Credits: Lucille Turc / Vlasiator team



Credits: Florian Koller

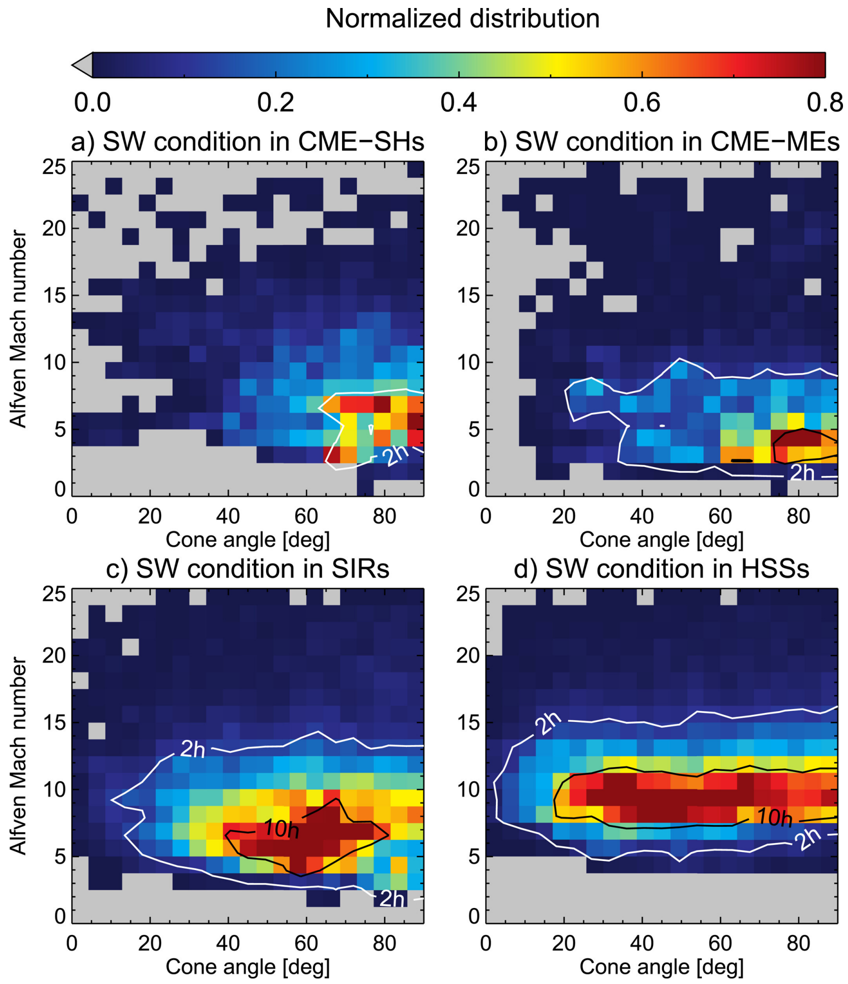
Jet formation – Solar Transients

Magnetic Ejecta ↓ #jets
SIR + HSS ↑ # jets



Koller F., et al. 2022 | JGR

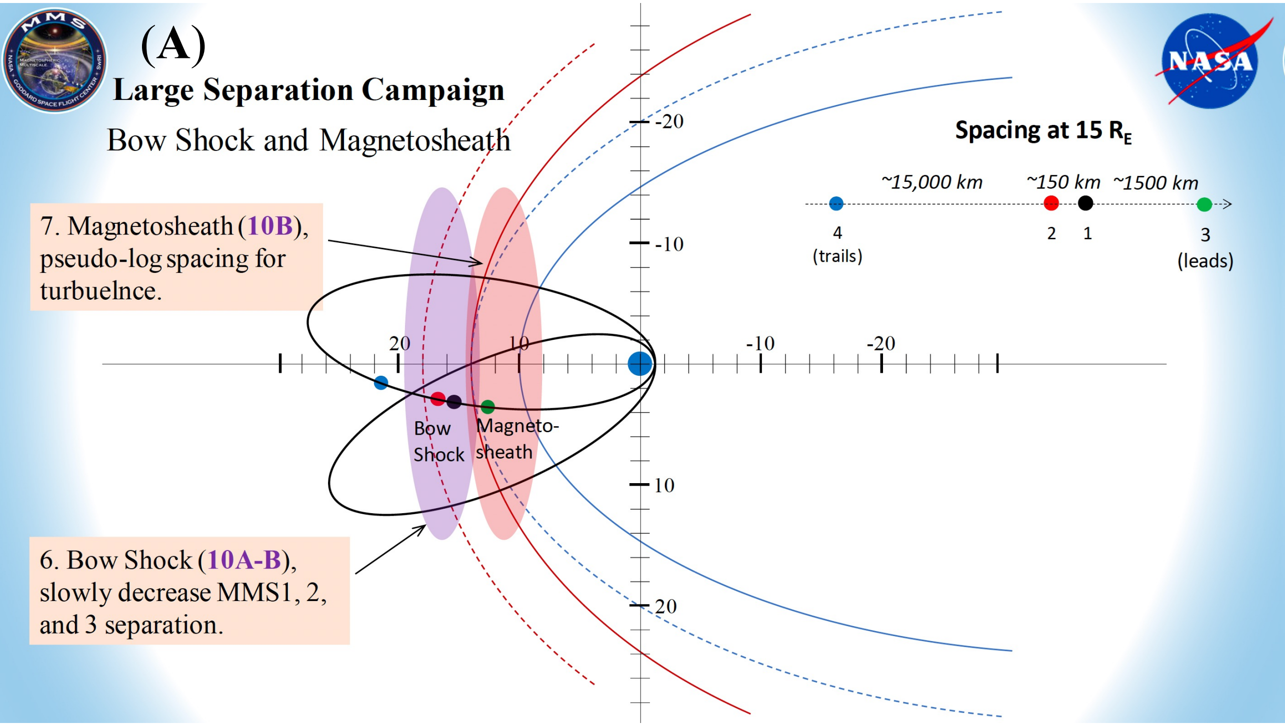
Variable or extreme parameters modify the occurrence and properties of transients in the foreshock / magnetosheath

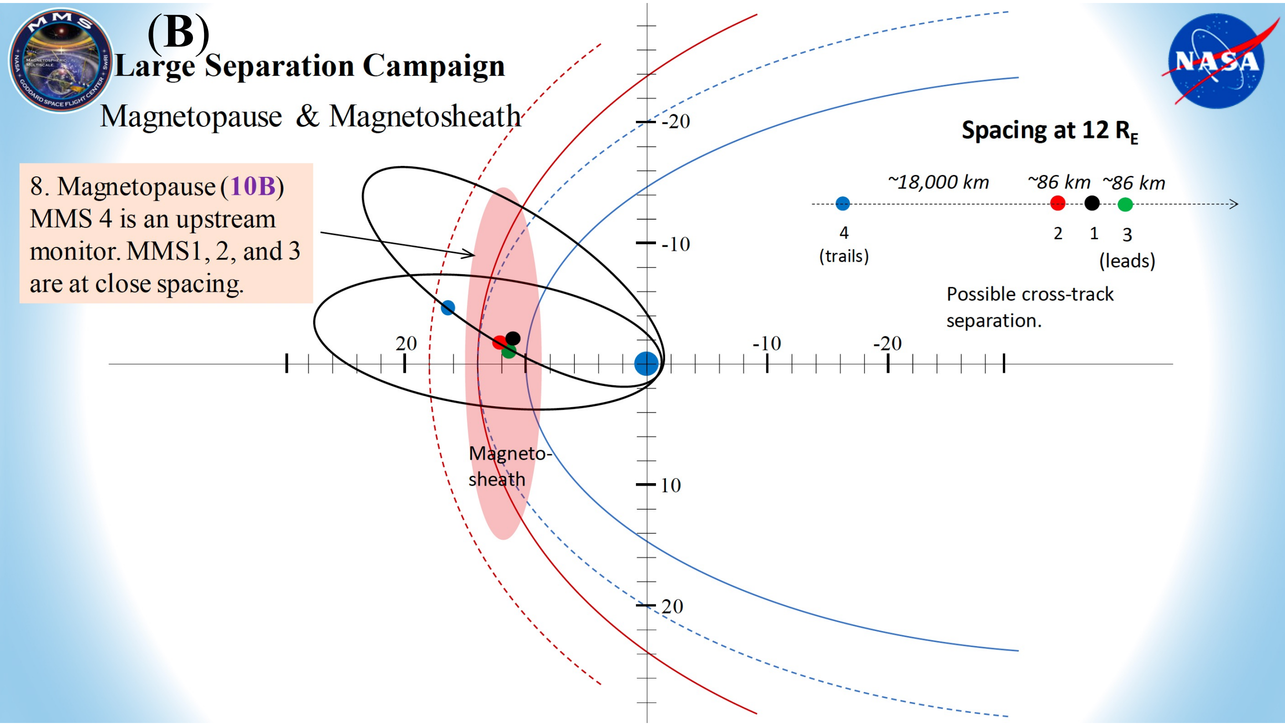


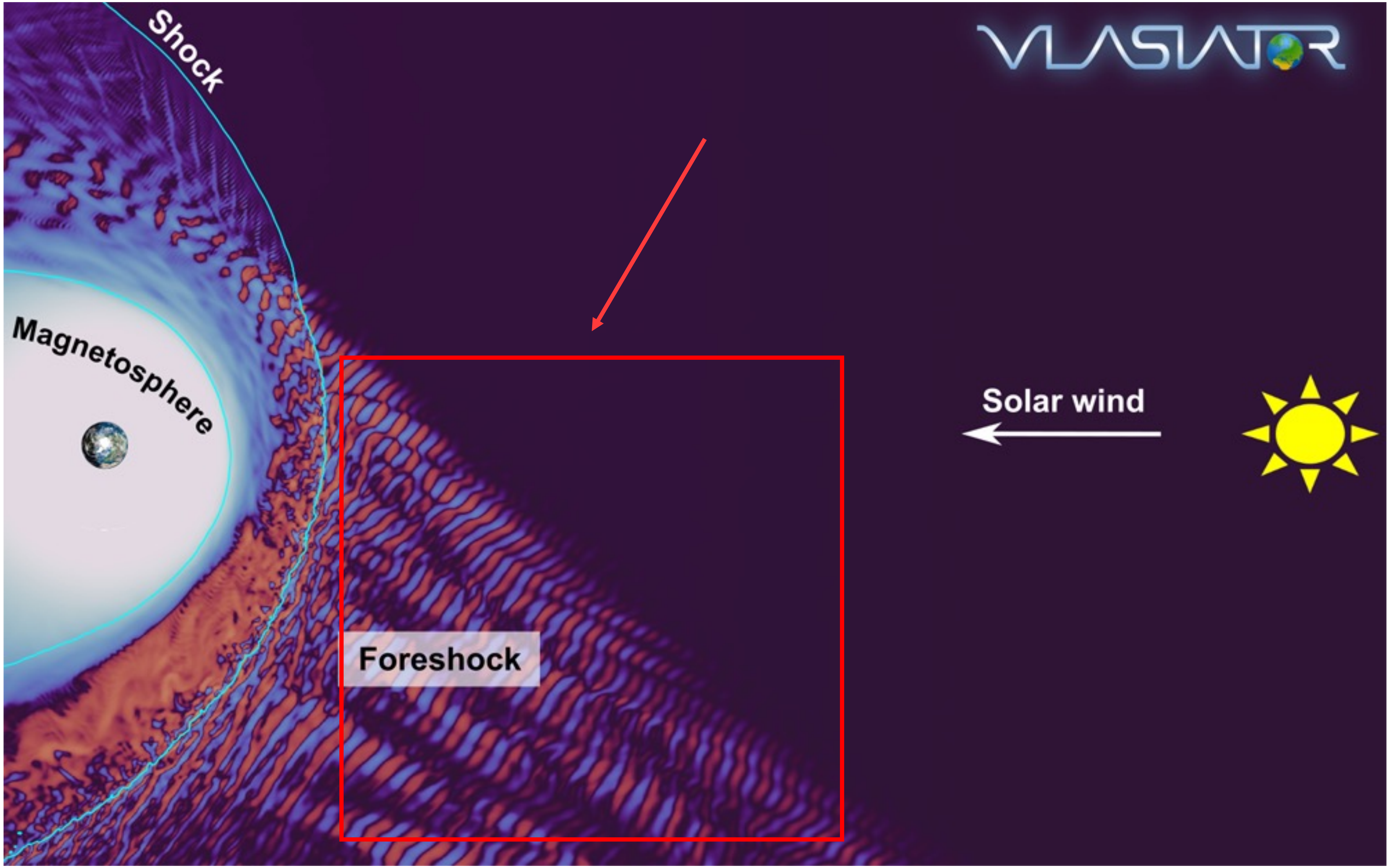
Koller F, et al,. 2023 | JGR

Open questions on Solar transients

1) How do close to shock conditions vary with the presence of SW transient phenomena (magnetic clouds, CMEs, high speed streamers etc.) ? (**A**)
2) How does the formation of foreshock and magnetosheath transient change when there are SW transients? (**A**)
3) What are the exact effects of the solar transients to the magnetopause (**B**)



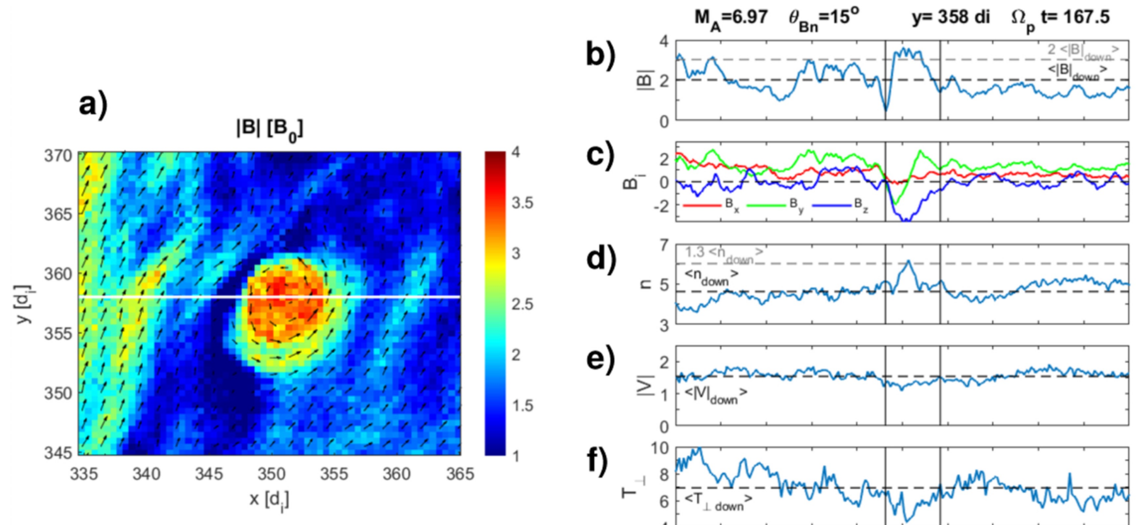




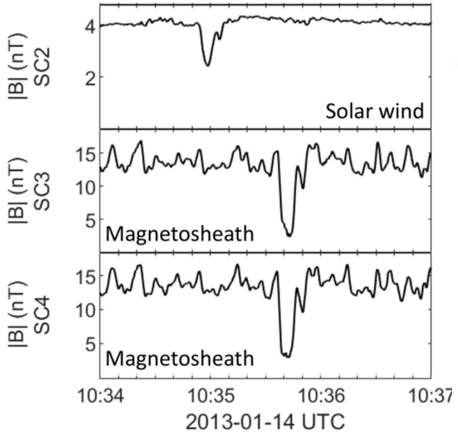
Credits: Lucille Turc / Vlasiator team

Transmission of Foreshock Transients

ULF waves are transmitted and so are the non-linear associated phenomena (Shocklets, SLAMS, etc.)

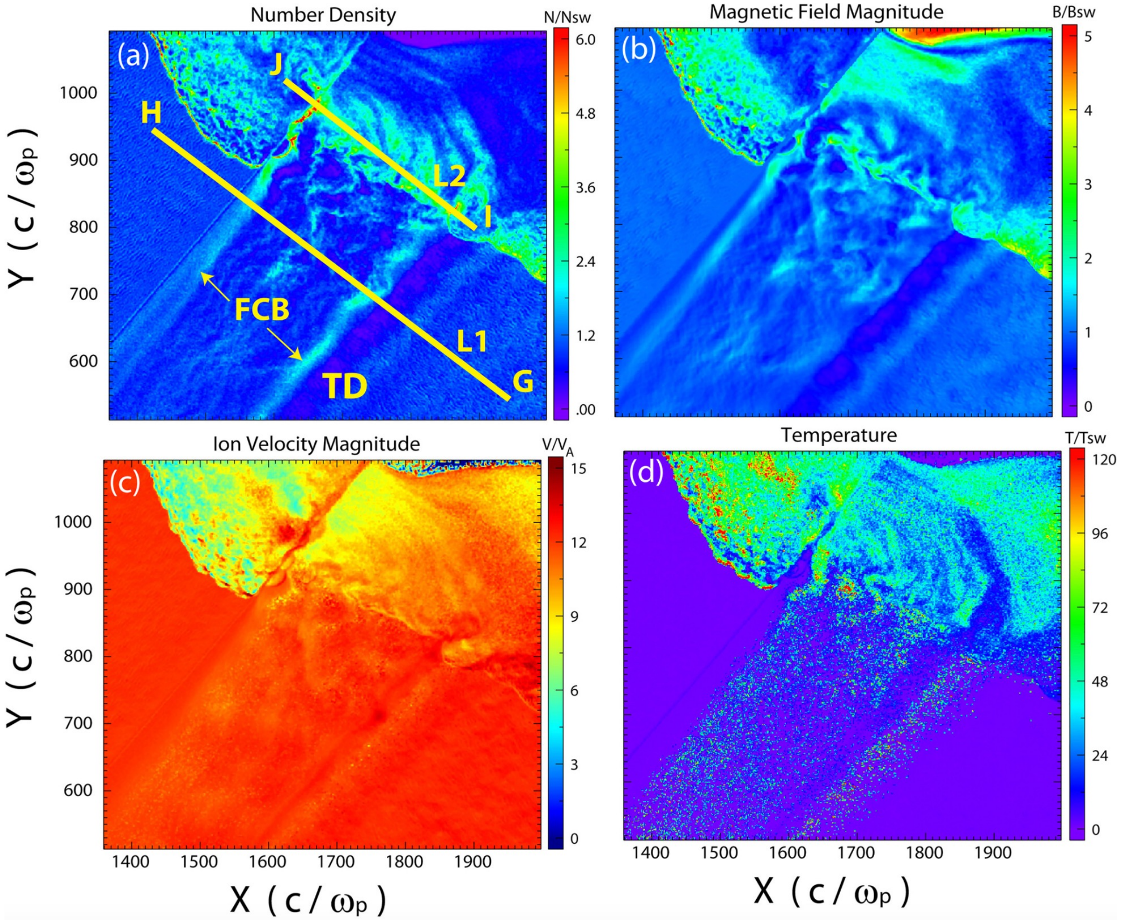


Preisser L., et al. 2020 | ApJL



Karlsson T., et al. 2022 | ANGEO

Transmission of FCB, FBs, HFAs, etc. has been shown in simulation and observations.



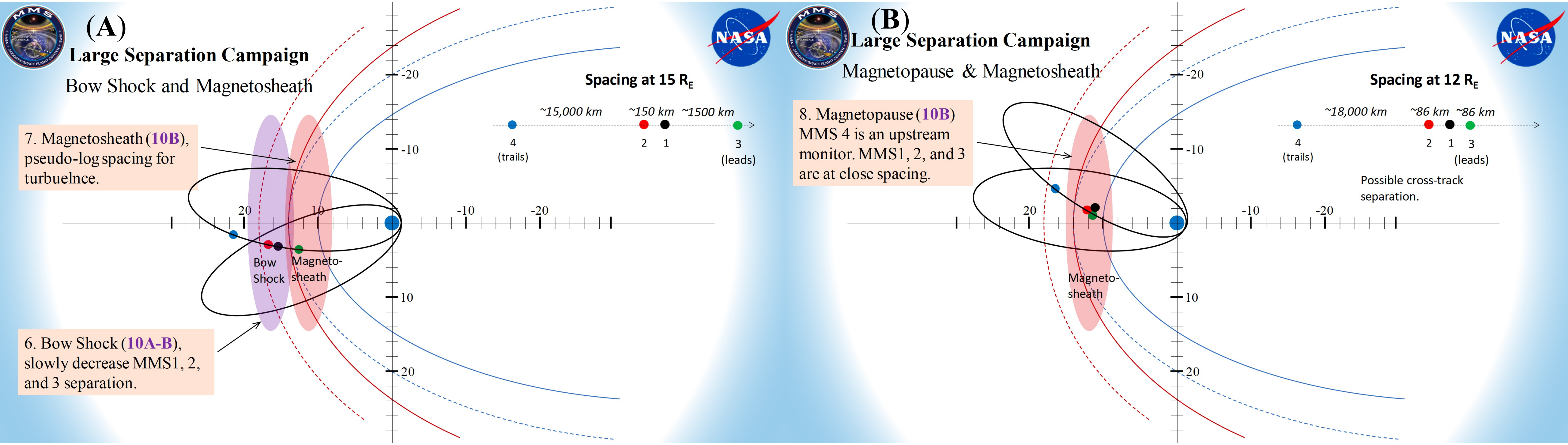
Sibeck D., et al. 2021 | JGR

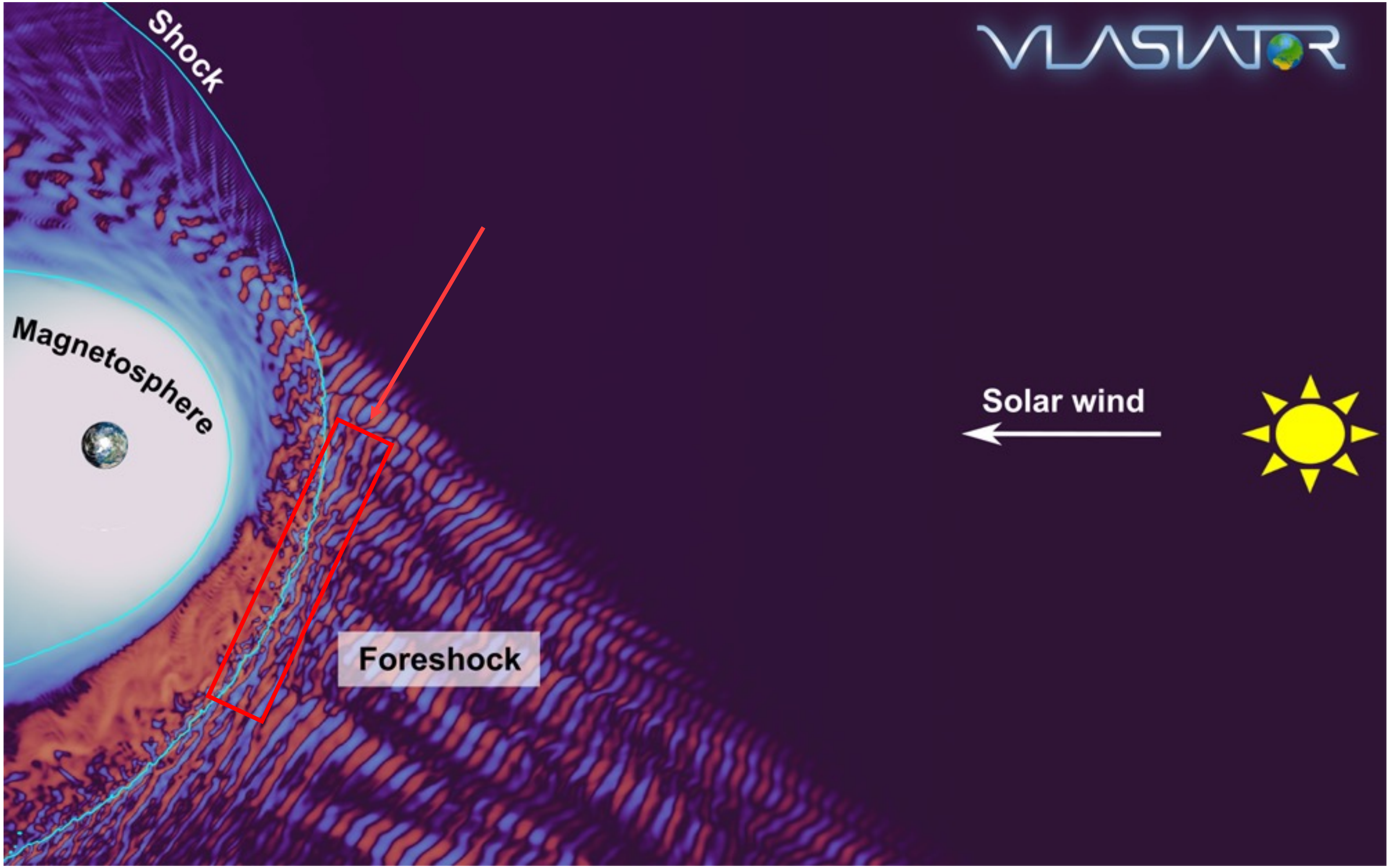
Turc L., et al. 2023 | Nat. Physics **Raptis S.**, et al. 2022a | Nat. Commun **Kajdic P.**, et al. 2022 | JGR **Wang C-P.**, et al. 2023 | Frontiers **Eastwood J.P.**, et al. 2008 | JGR **Zhou Y.**, et al. 2023 | GRL

Open questions on Foreshock transients

1. What are the observational signatures of ULF (and associated phenomena) transmission ? How are the properties changing ? (**A**)

2. What effects can be caused in the magnetosheath plasma and in the magnetopause through the interaction of these structures with the ambient plasma (**A, B**)

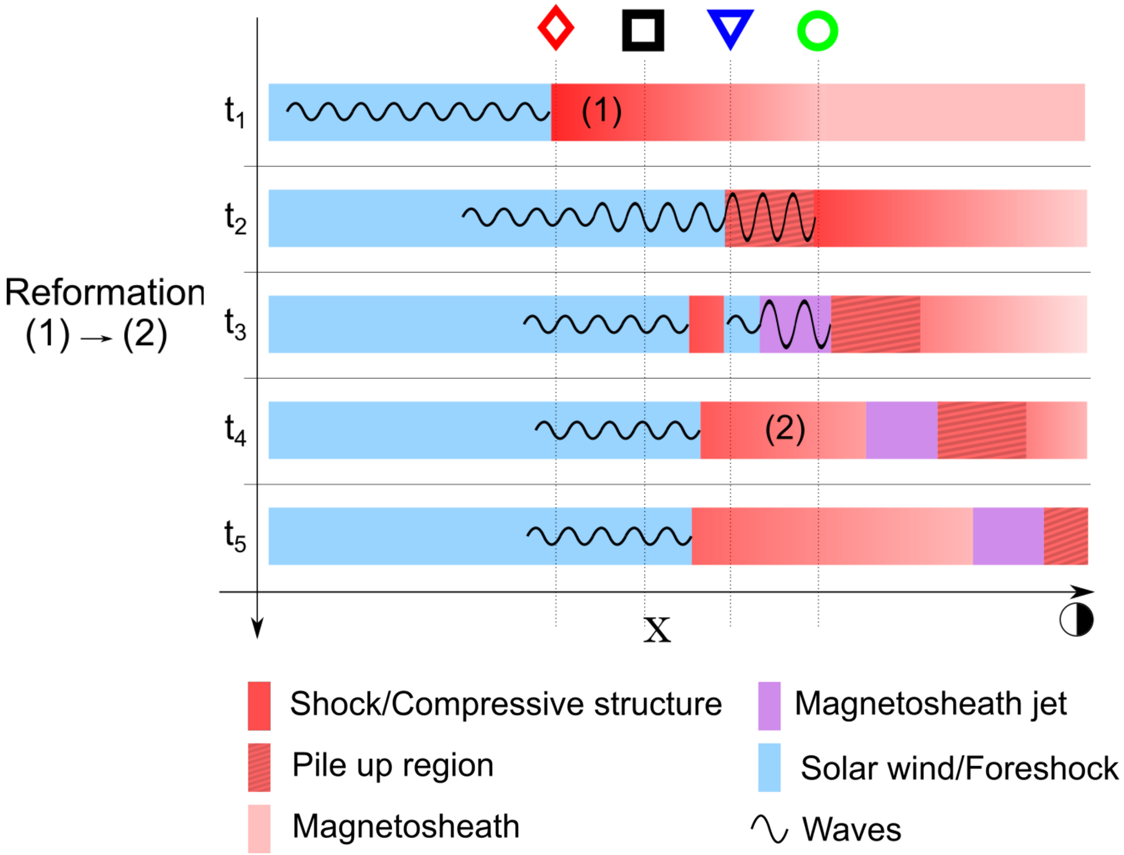




Credits: Lucille Turc / Vlasiator team

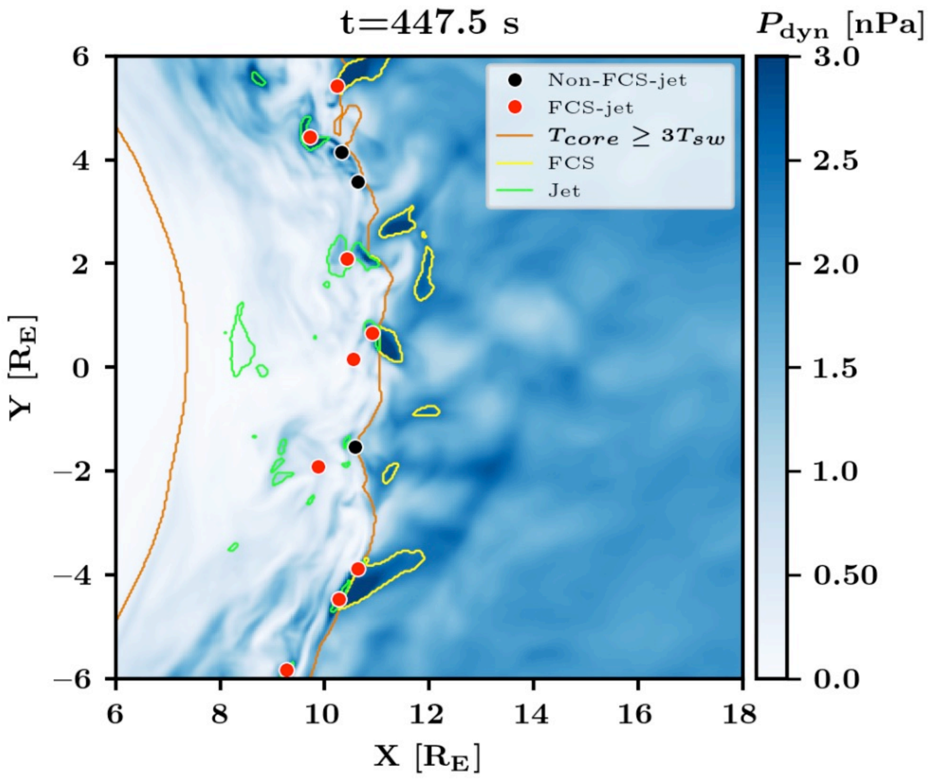
Jet formation

Jets forming from shock's fundamental non-stationarity



Turbulence Campaign 2019

75% of jets caused by Foreshock Compressive Structures



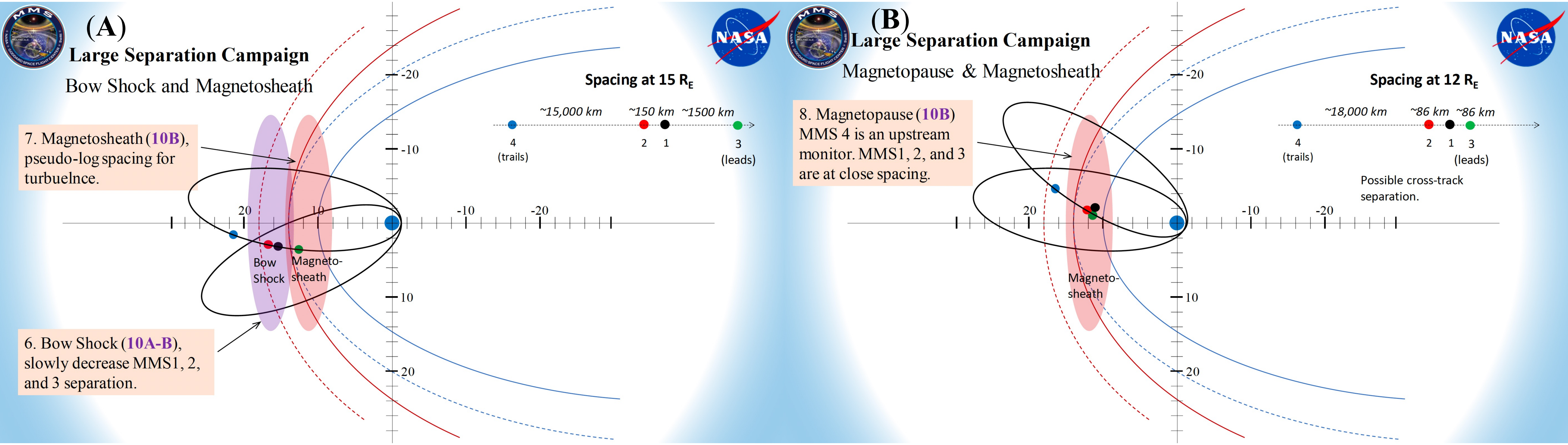
Raptis S., et al. 2022a | Nat. Commun.

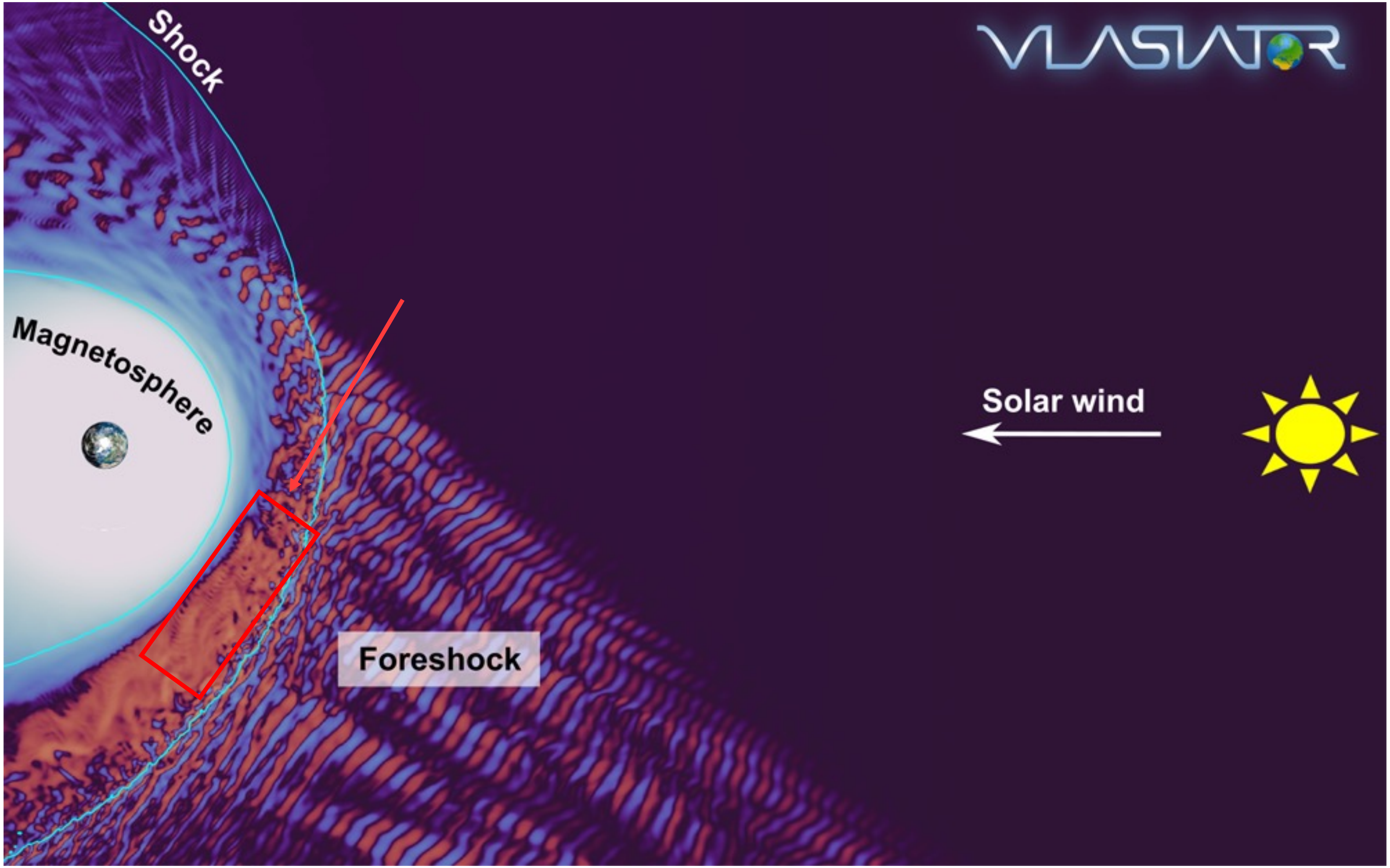
Suni J, et al,. 2021 | GRL

Open questions on formation

1) Is global shock reformation the answer to jets ? or maybe faster flows get dissipated and become part of the background population before reaching the MP ? **(A)**

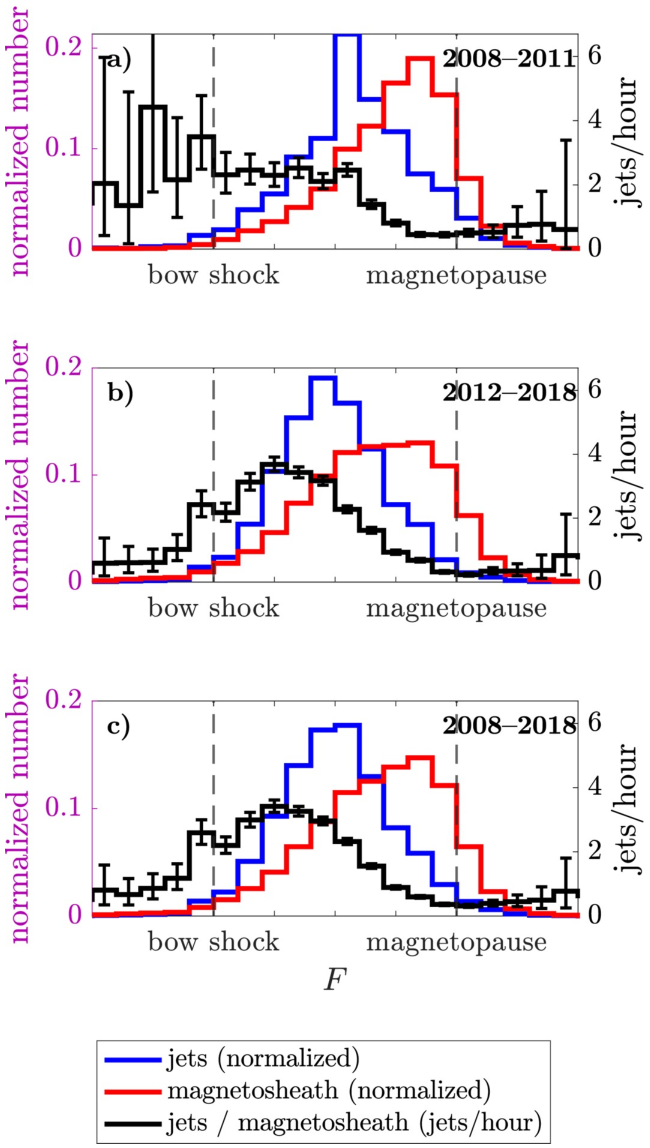
2) How are close to the shock upstream conditions affecting the formation of downstream jets ? **(A, B)**





Credits: Lucille Turc / Vlasiator team

Jet evolution



LaMoury A., et al. 2021 | JGR

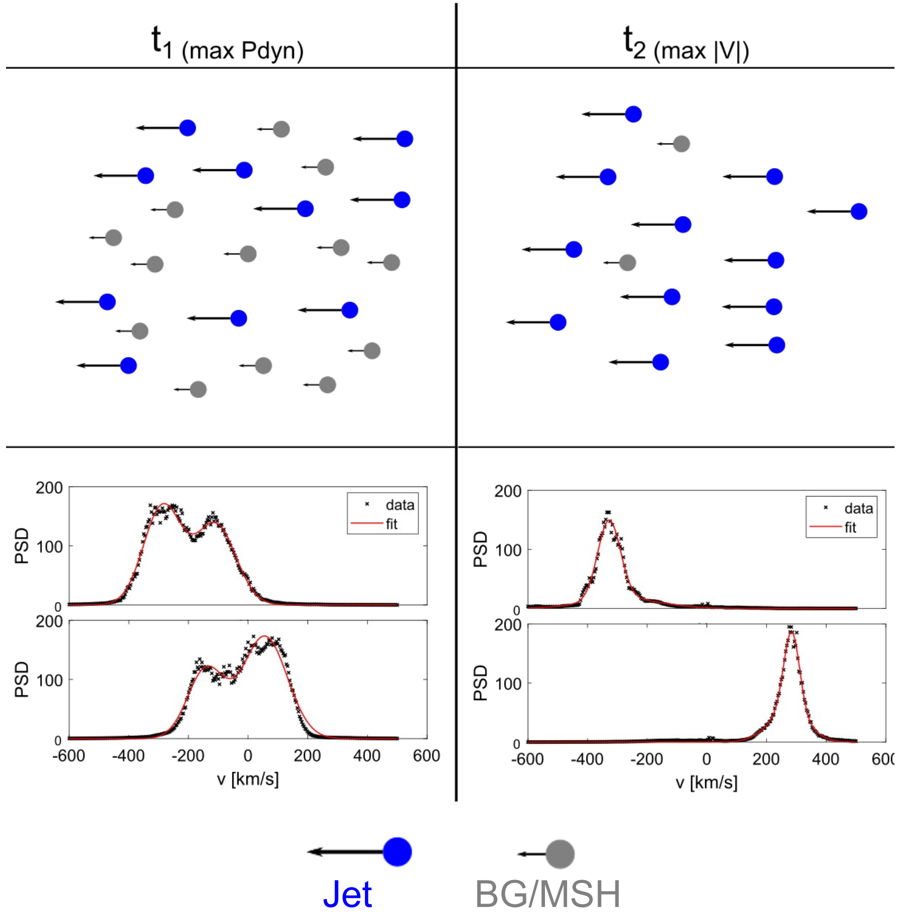
When can a jet reach the MP ?

- 8 times more likely for high solar wind speed
- 17 more likely for low cone angles

*Jets **thermalize** towards the magnetopause, the shape of the jets **flatten** and they are able to **maintain their flow velocity** and direction within the magnetosheath flow*

Palmroth M, et al,. 2021 | ANGEO

Jets exhibiting 2+ populations = partial moments needed = similar properties to upstream SW



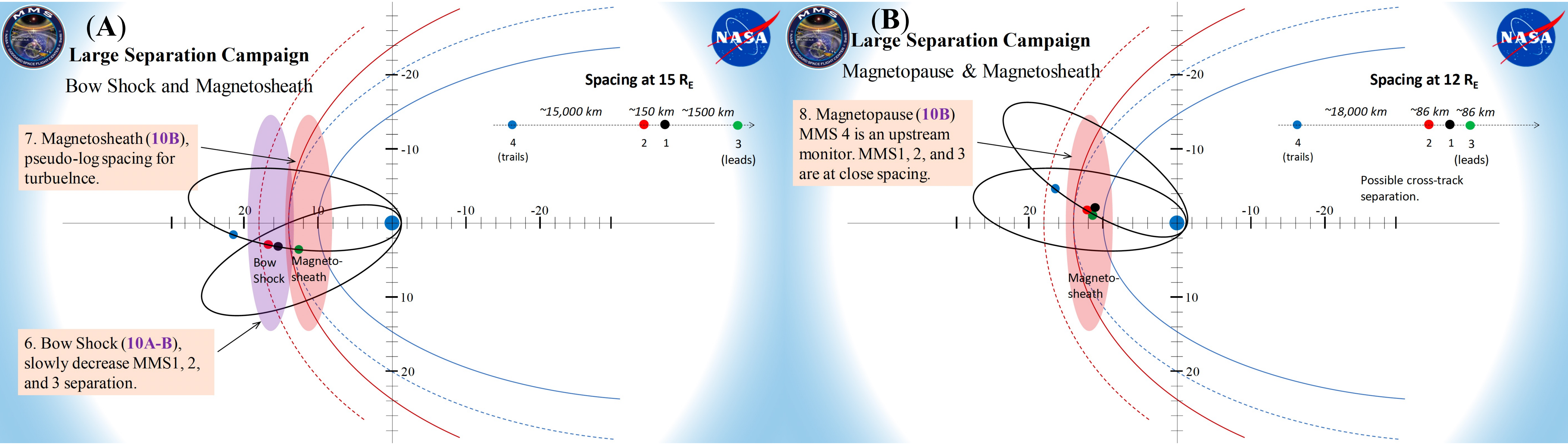
Raptis S, et al,. 2022b | GRL

Open questions on Evolution

1) Do jets continue to show a clear double population? Does this change over time or closer to the MP ? (**A**)

2) How are the properties and the shape vary over distance from the bow shock/magnetopause? (**A**)

3) How do jets contribute to the generation of wave activity, turbulence and particle energization? (**A**)



Discussion

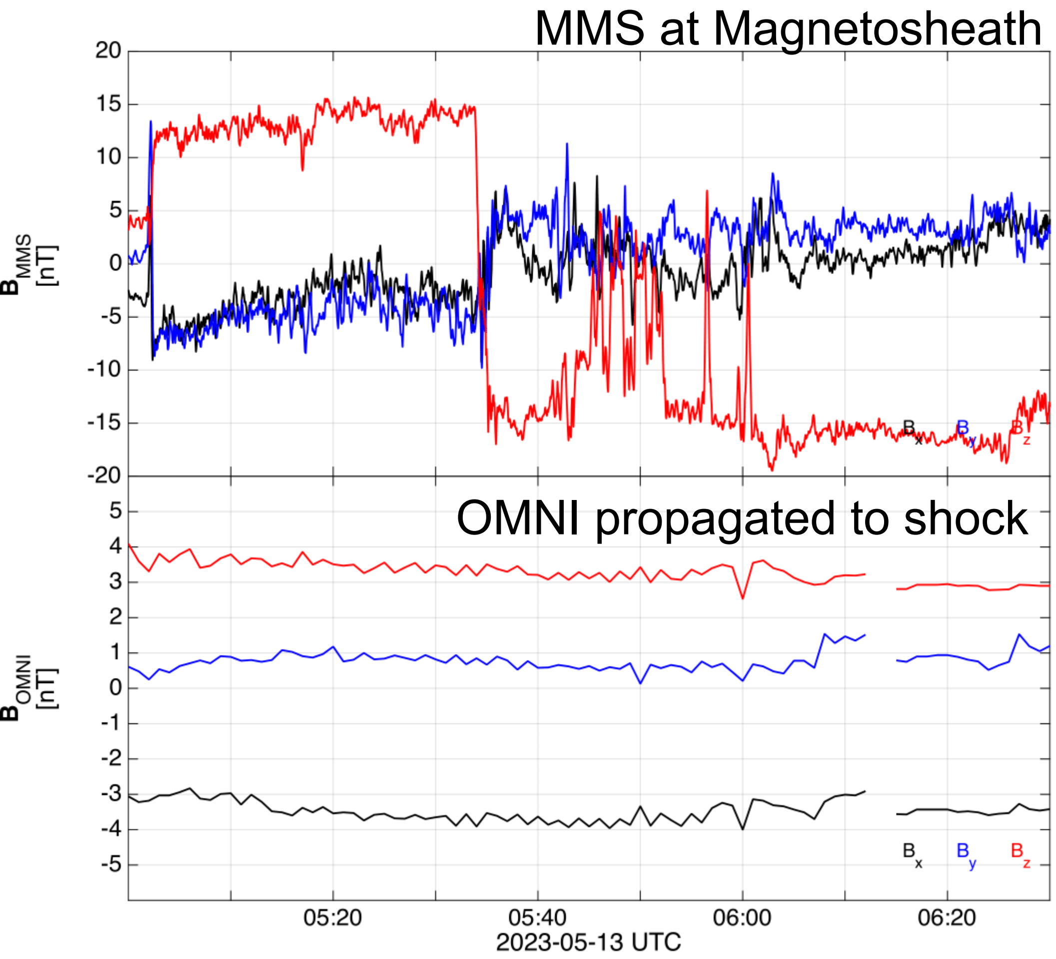
1. Foreshock & magnetosheath phenomena, in particular transient events = Interesting multi-scale physics, space weather effects, and overall unique environments to expand our understanding and test our codes.

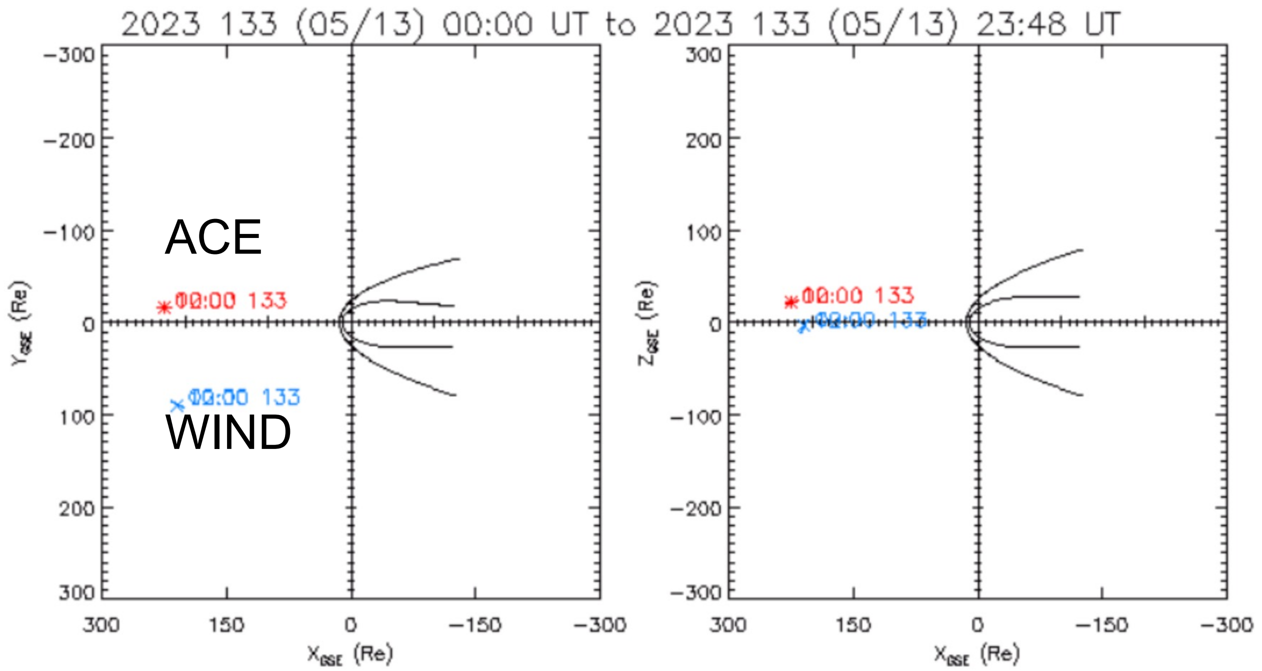
2. MMS future campaigns: Opportunity to investigate different scales in high time-resolution, revealing previously unknown relationships between phenomena.

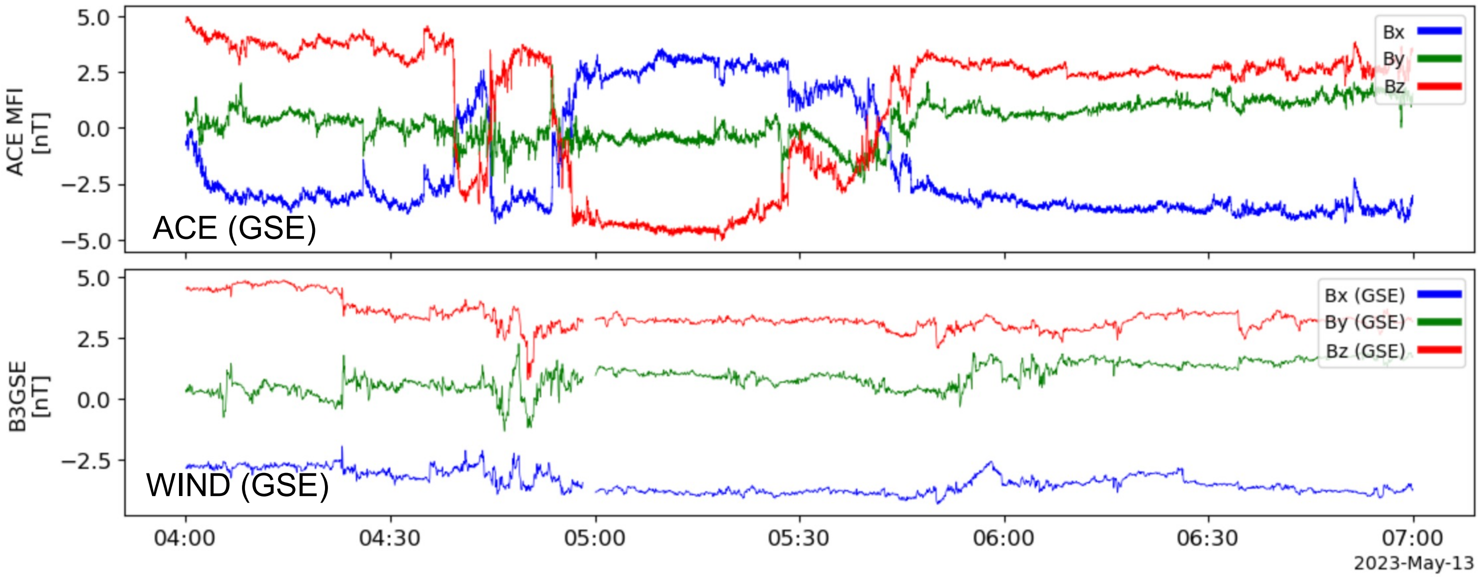
3. (Skipped): Effects on inner magnetosphere, excitation of ULF waves, etc.

4. (Skipped): Potential conjunctions with THEMIS/Cluster and other missions for investigating even larger scale evolution.

+1 bonus reason for the upstream monitor campaign







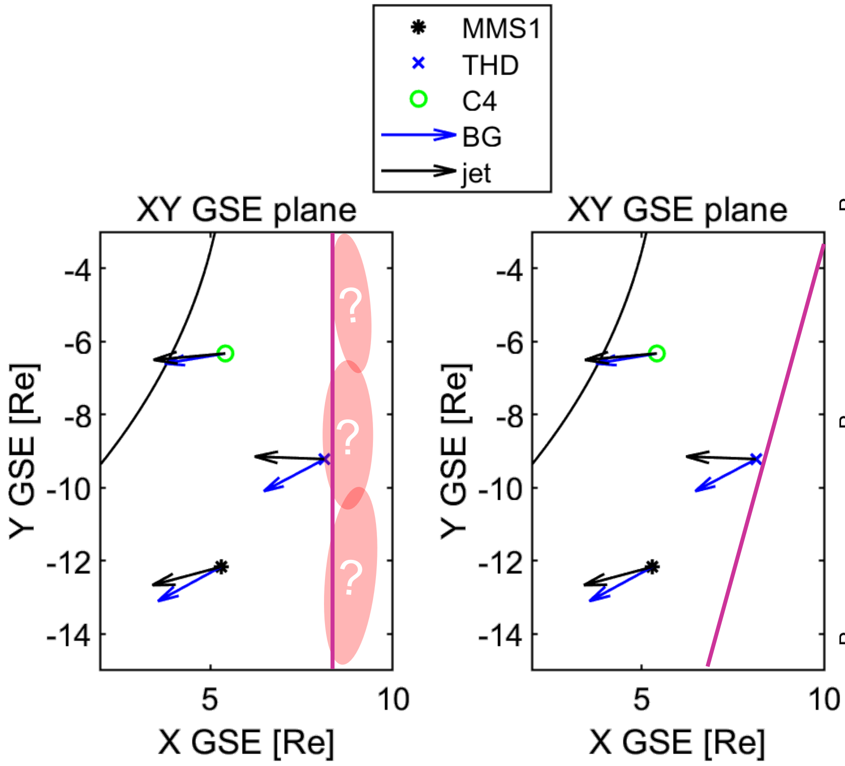
Key-point: Several minutes of Dt is typical, but cases like above are not rare either.

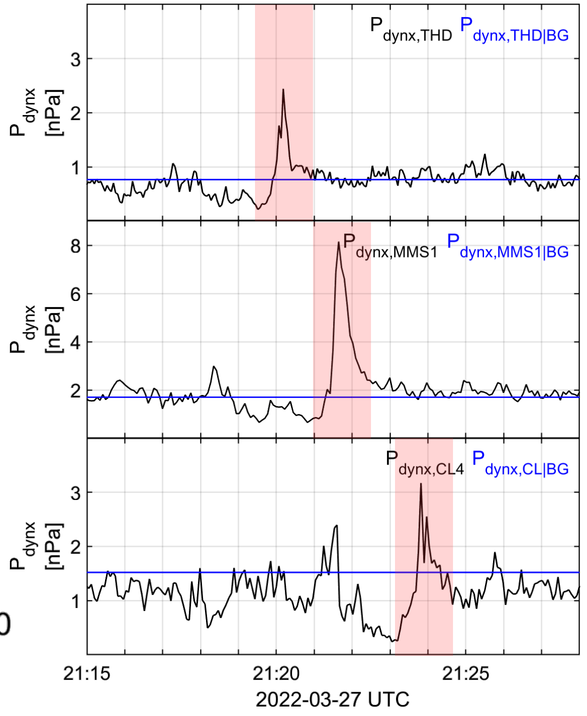
Be careful when using propagated values

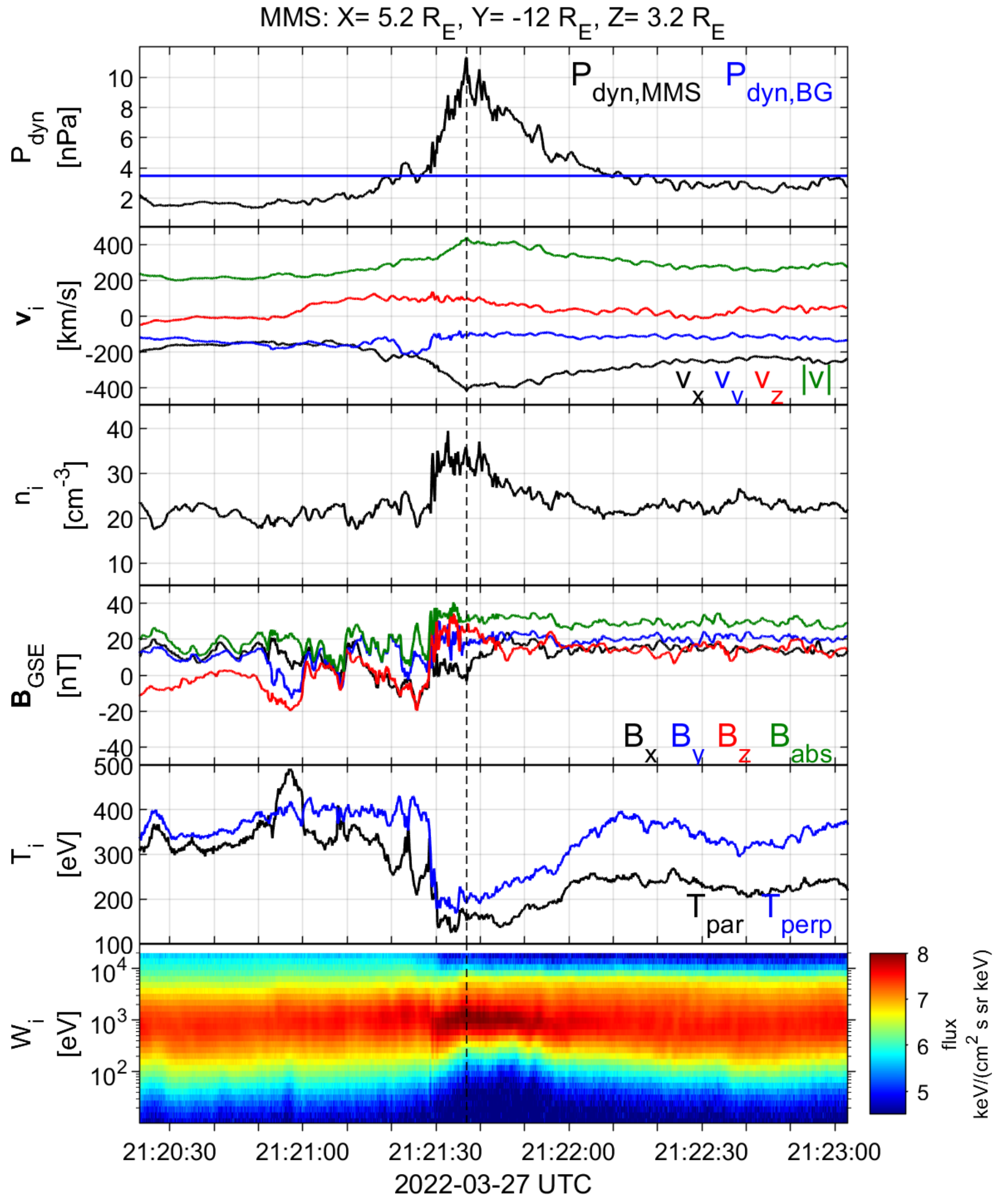
Extras

General

Example of a multi-SC Jet

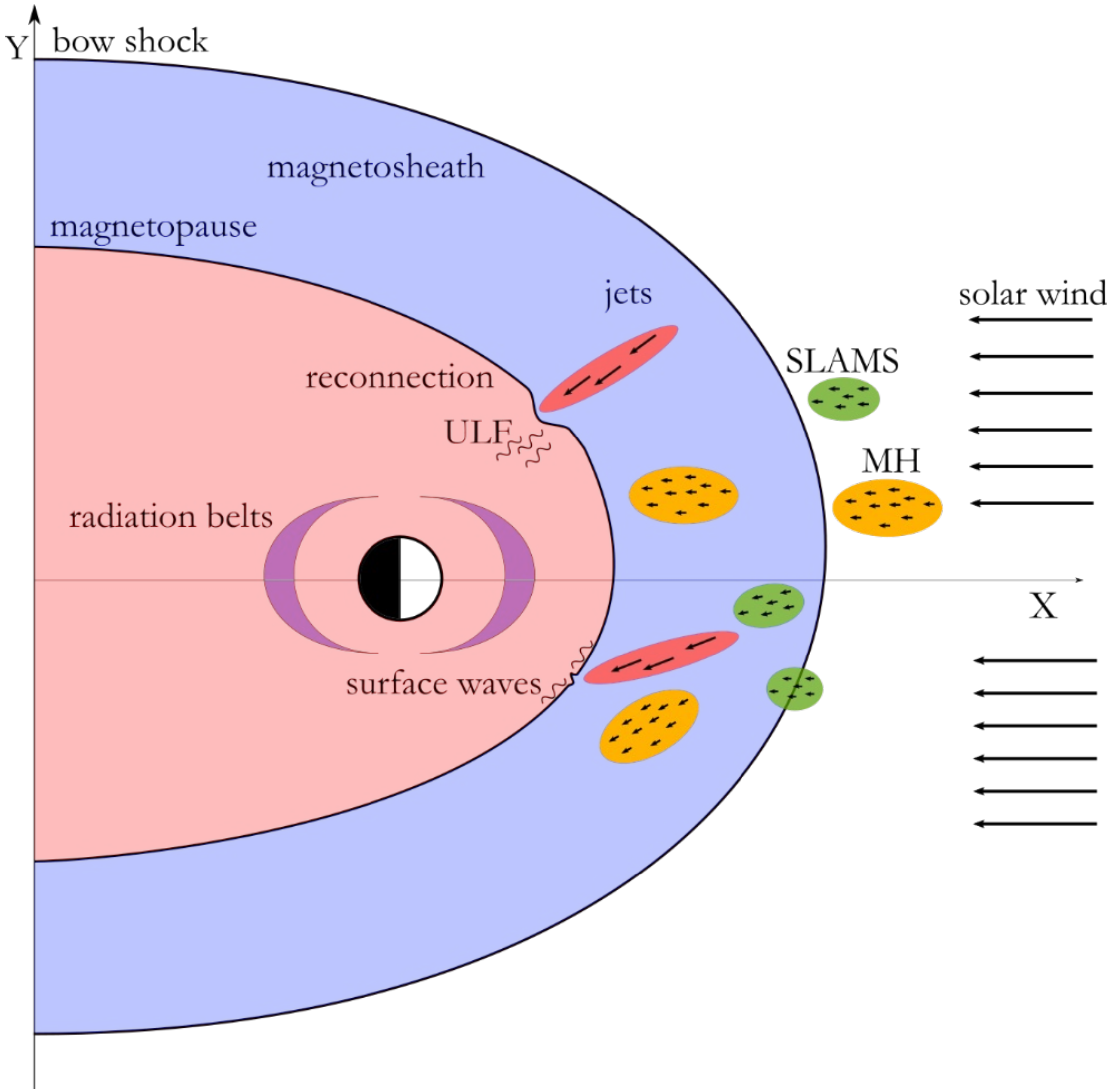


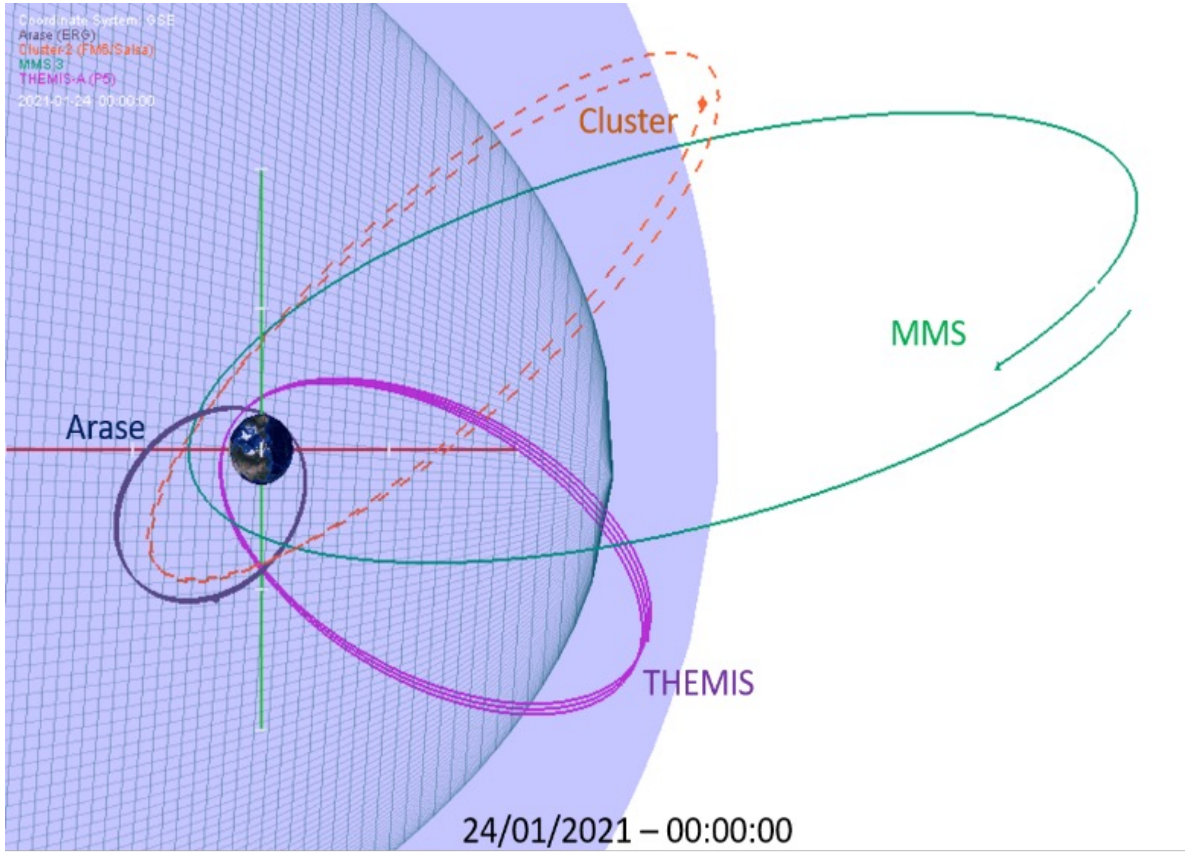




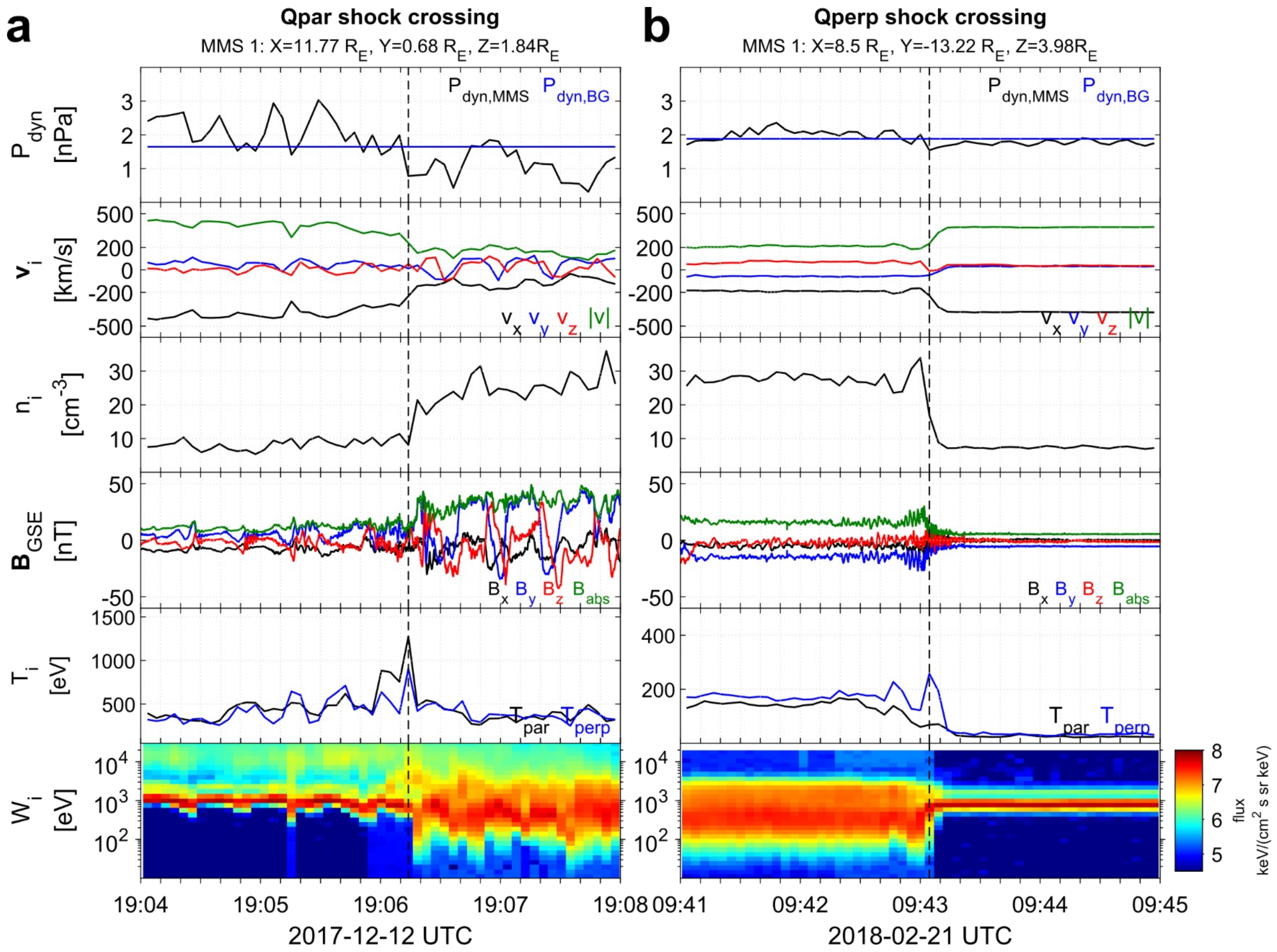
(Ongoing work – TBD)

A lot of data are not fully used (conjunctions)

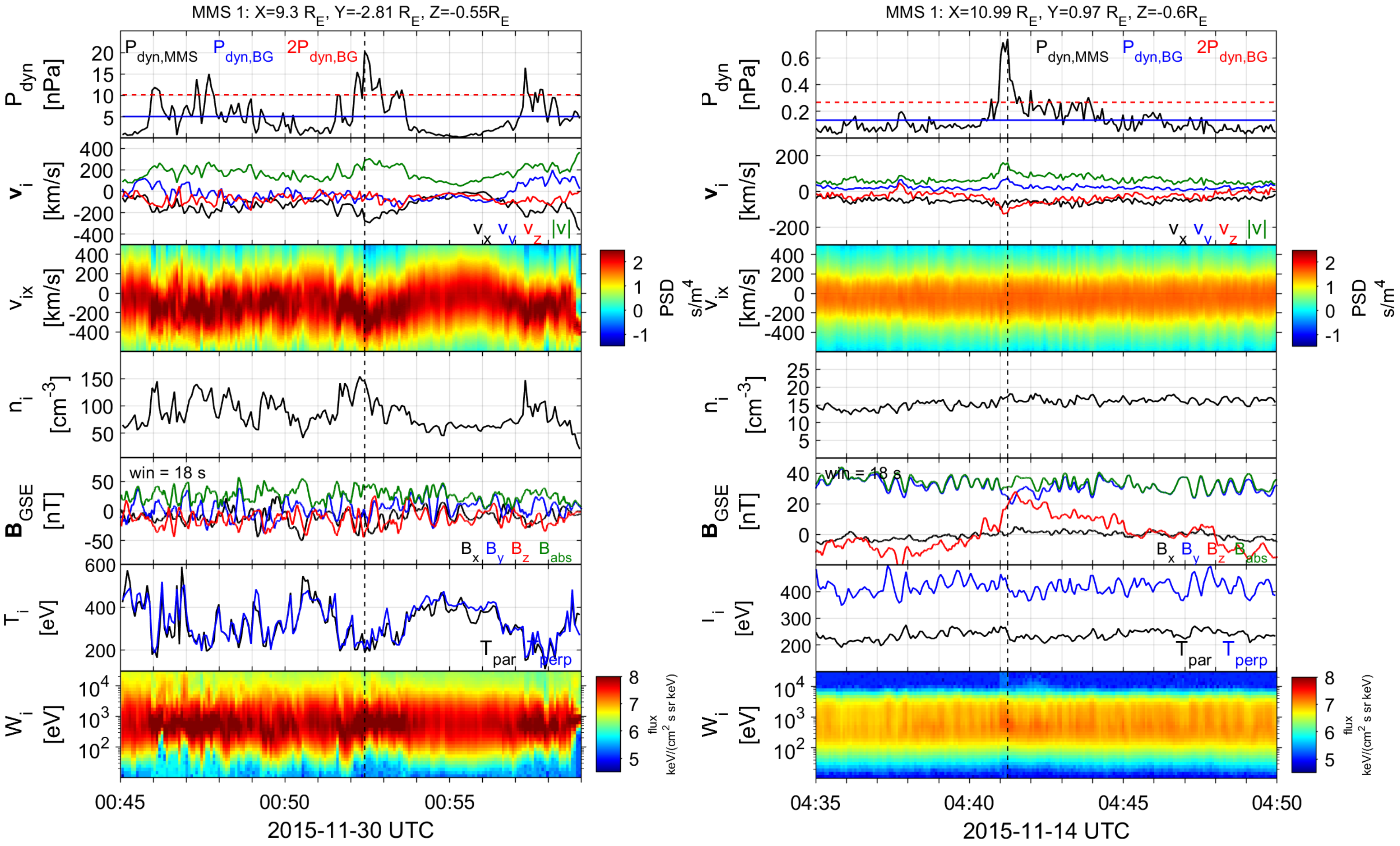




Qpar – Qperp crossings



Qpar – Qperp Jets



Why do we care? "big picture"

Dayside Transient Phenomena and Their Impact on the Magnetosphere and Ionosphere

Hui Zhang, Qiugang Zong, Hyunju Connor, Peter Delamere, Gábor Facskó, Desheng Han, Hiroshi Hasegawa, Esa Kallio, Árpád Kis, Guan Le, Bertrand Lembège, Yu Lin, Terry Liu, Kjellmar Oksavik, Nojan Omidi, Antonius Otto, Jie Ren, Quanqi Shi, David Sibeck & Shutao Yao

Space Science Reviews **218**, Article number: 40 (2022) | Cite this article

Transmission of foreshock waves through Earth's bow shock

L. Turc, O. W. Roberts, D. Verscharen, A. P. Dimmock, P. Kajdič, M. Palmroth, Y. Pfau-Kempf, A. Johlander, M. Dubart, E. K. J. Kilpua, J. Soucek, K. Takahashi, N. Takahashi, M. Battarbee & U. Ganse

Nature Physics (2022) | Cite this article

Downstream high-speed plasma jet generation as a direct consequence of shock reformation

Savvas Raptis, Tomas Karlsson, Andris Vaivads, Craig Pollock, Ferdinand Plaschke, Andreas Johlander, Henriette Trollvik & Per-Arne Lindqvist

Nature Communications **13**, Article number: 598 (2022) | Cite this article

Geophysical Research Letters

Research Letter | Free Access

Investigating the Role of Magnetosheath High-Speed Jets in Triggering Dayside Ground Magnetic Ultra-Low Frequency Waves

Boyi Wang, Yukitoshi Nishimura, Heli Hietala, Vassilis Angelopoulos

First published: 07 November 2022 | https://doi.org/10.1029/2022GL099768

Geophysical Research Letters

Research Letter | Open Access

Connection Between Foreshock Structures and the Generation of Magnetosheath Jets: Vlasiator Results

J. Suni, M. Palmroth, L. Turc, M. Battarbee, A. Johlander, V. Tarvus, M. Alho, M. Bussov, M. Dubart, U. Ganse, M. Grandin, K. Horaites, T. Manglayev, K. Papadakis, Y. Pfau-Kempf, H. Zhou

INTERNATIONAL SPACE SCIENCE INSTITUTE

Impact of Upstream Mesoscale Transients on the Near-Earth Environment

ISSI team lead by Primož Kajdič & Xóchitl Blanco-Cano

EGU General Assembly 2023

EDI

Foreshock and magnetosheath transient phenomena and their effects on planetary magnetospheres.

Co-organized by PS2

Convener: Savvas Raptis[ECS] | Co-conveners: Heli Hietala, Ferdinand Plaschke, Tomas Karlsson, Christian Mazelle

Abstract submission

Foreshocks Across The Heliosphere: System Specific Or Universal Physical Processes?

ISSI Team led by H. Hietala (UK) & F. Plaschke (AT)