GEM Focus Group: **Multiscale Dayside Transients (MDT)** and their Effect on Earth's Magnetosphere

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Runyi Liu[4], David Tonoian[2]

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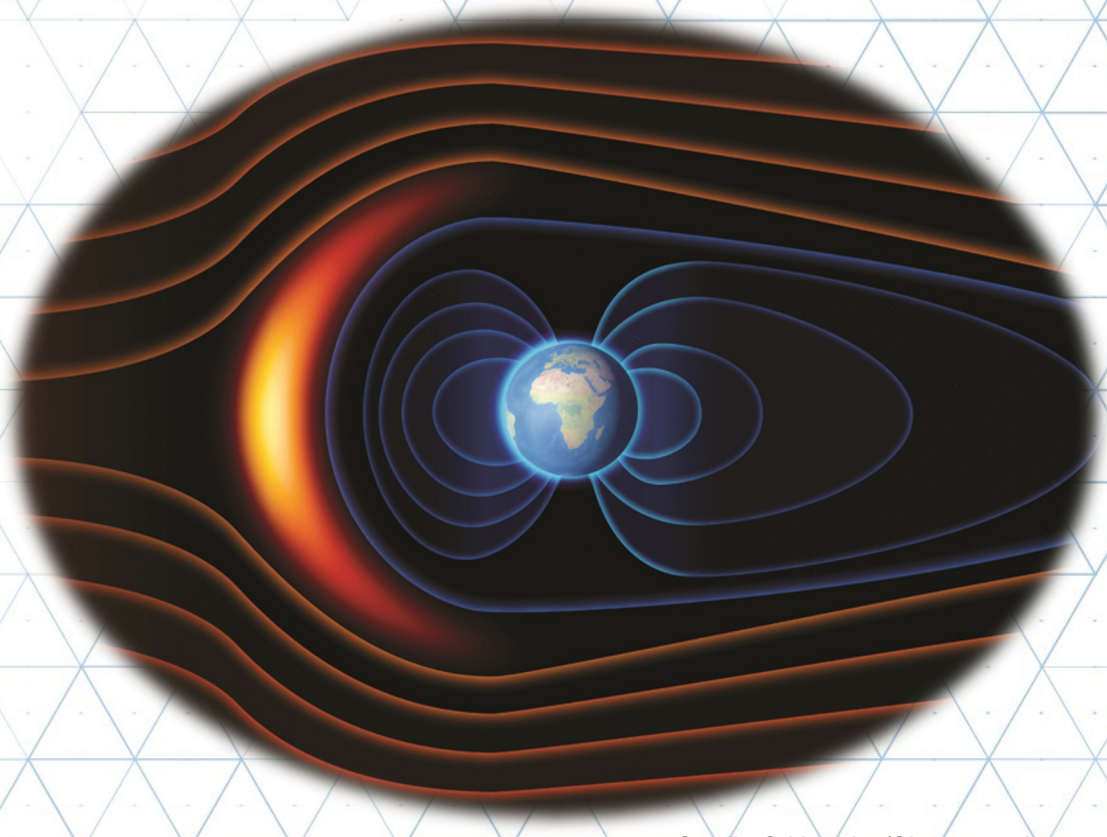
[2] University of Texas at Dallas
[3] University of Southampton
[4] University of California, Los Angeles

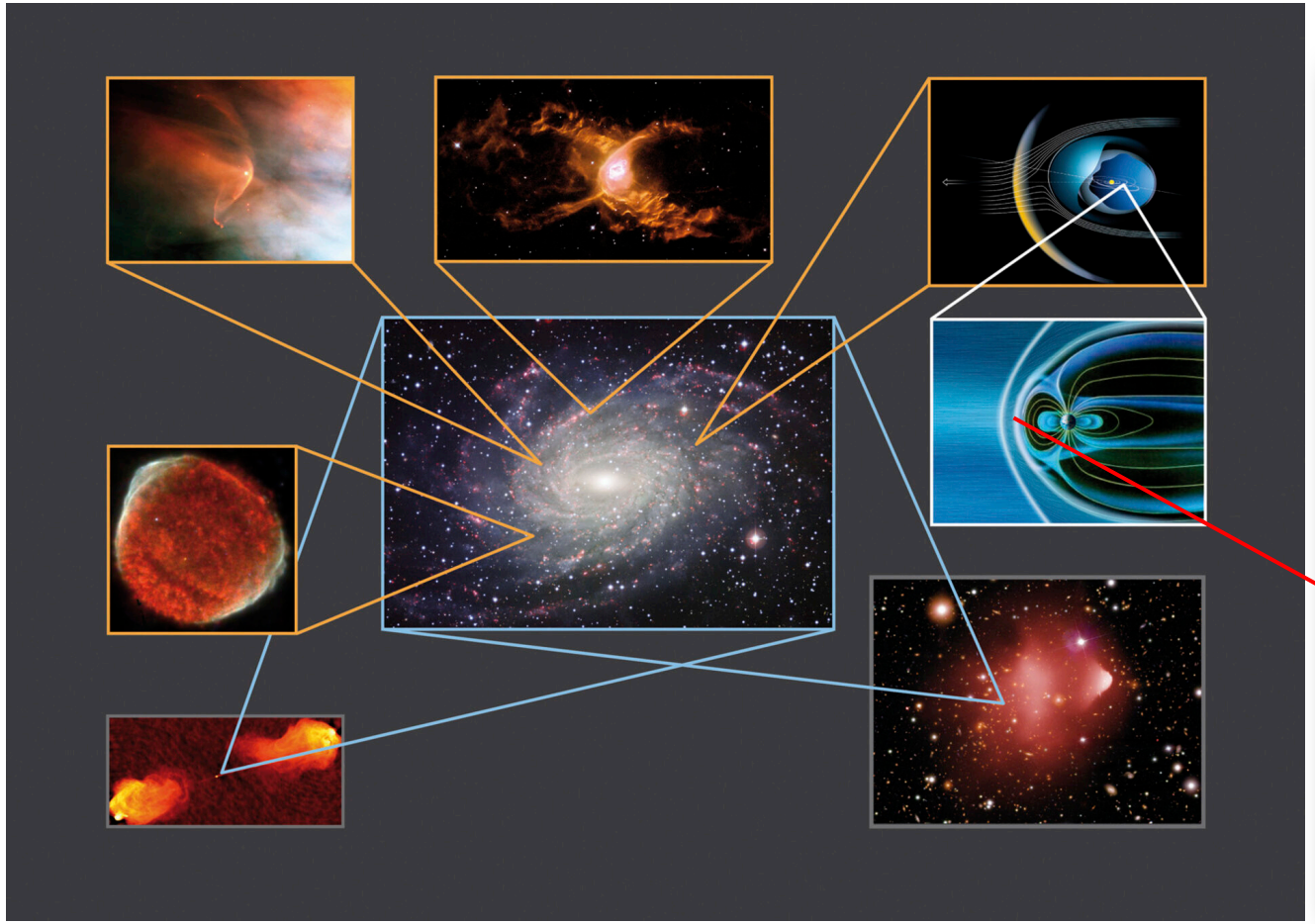


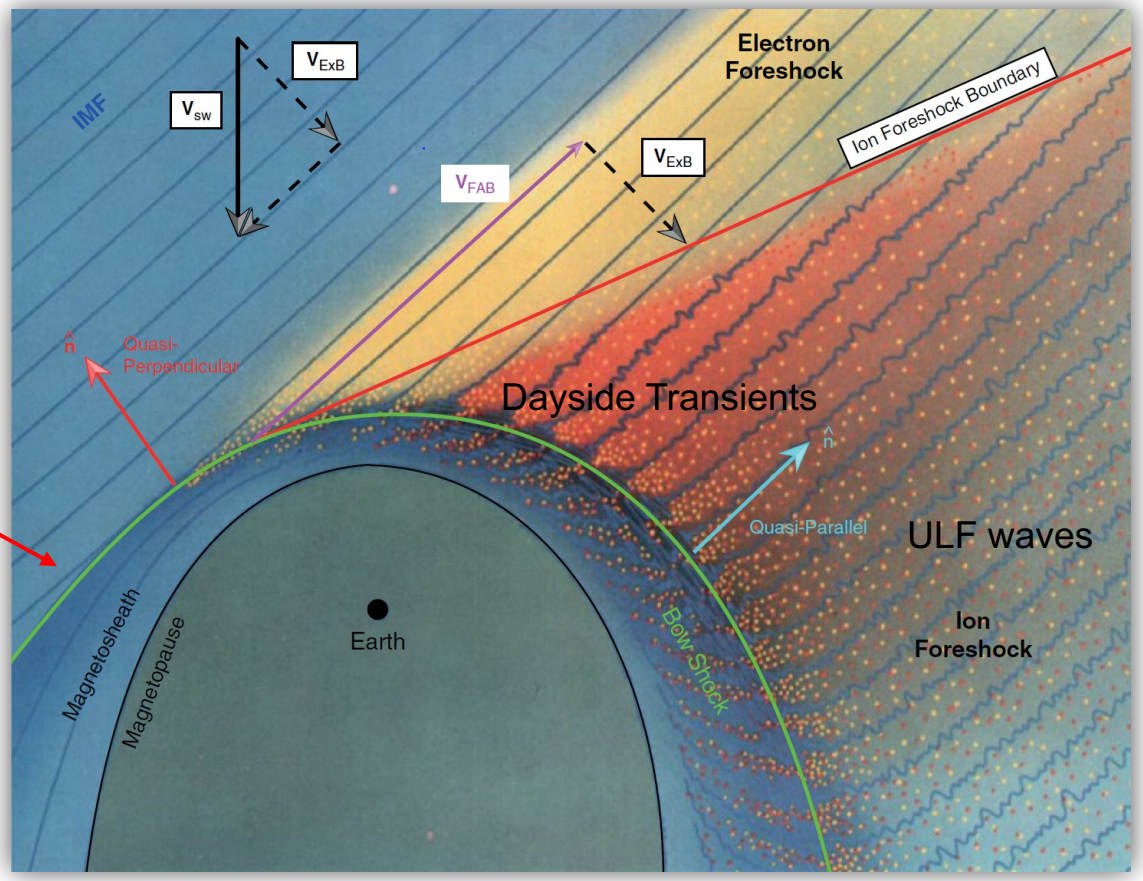
Credit: © Naeblys/Shutterstock

Primary: Solar Wind - Magnetosphere Interaction (SWMI)

1. Shocks and foreshocks in 3 mins
2. Dayside Transient Processes
3. Effects on the Magnetosphere-Ionosphere system
4. Team & Goals
5. Our first GEM sessions & Next Steps

Earth's magnetosphere & shock environment



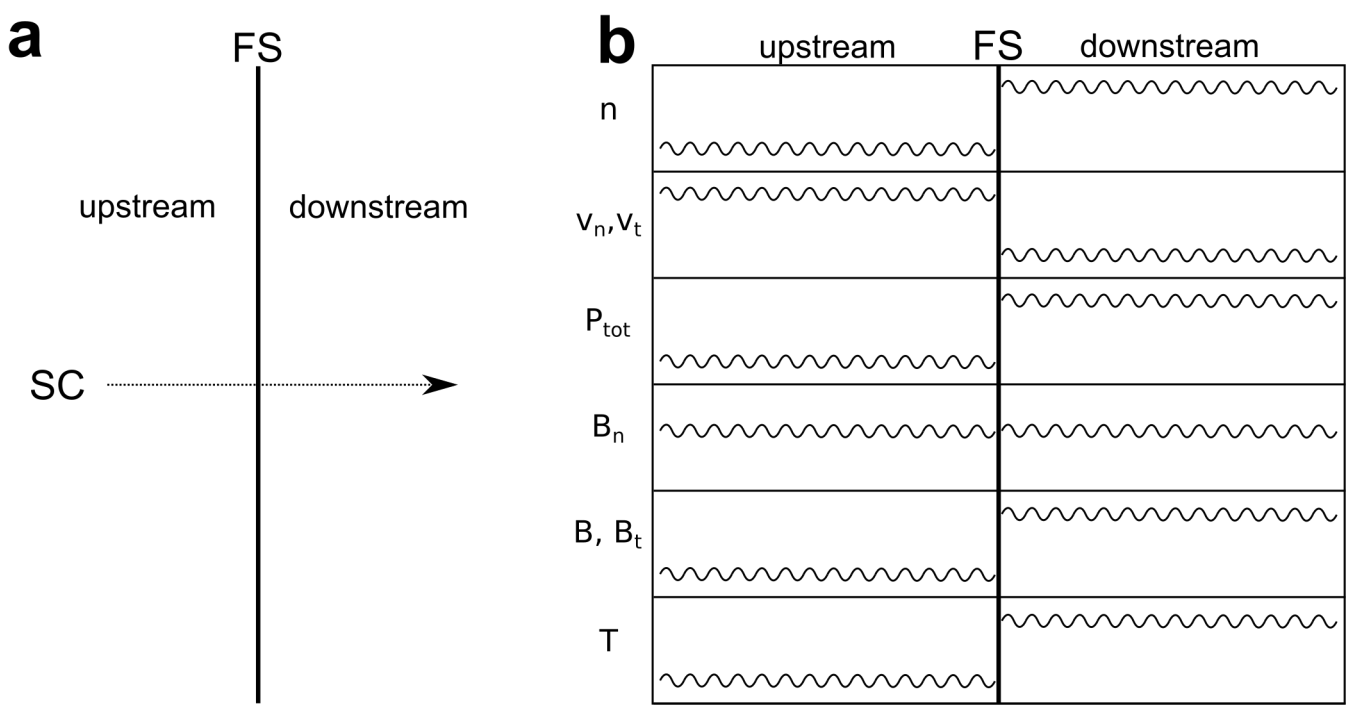


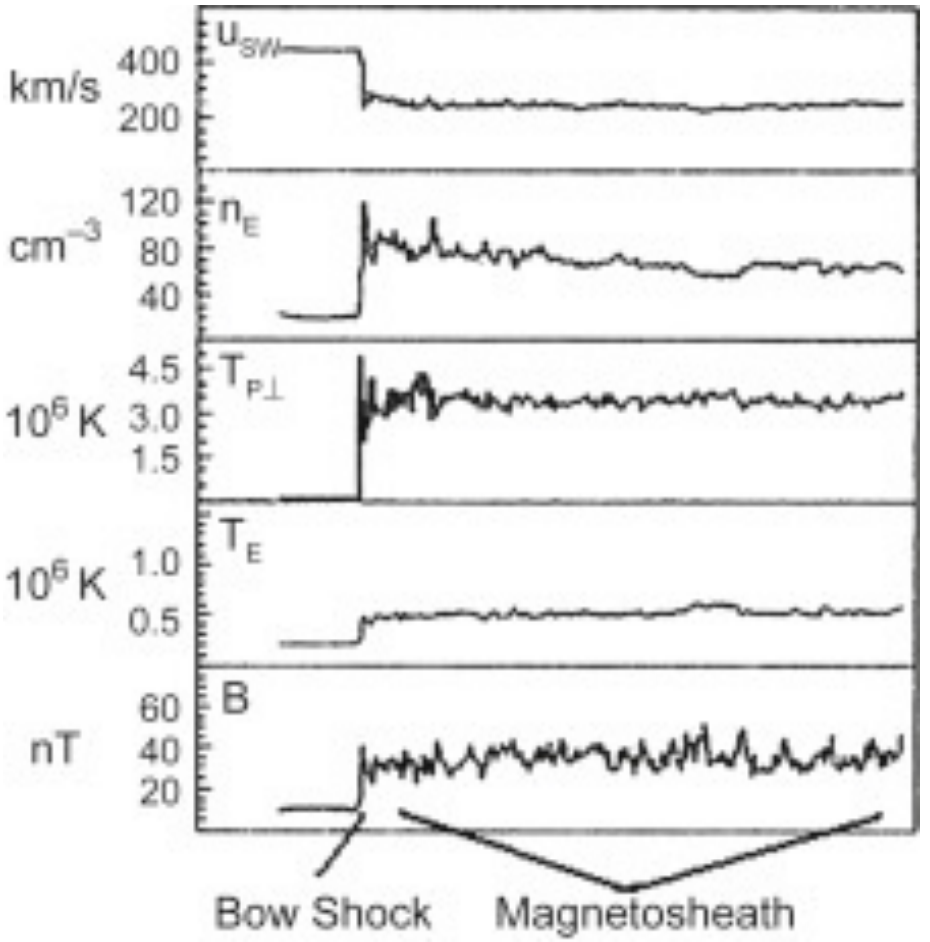
<u>Shock waves:</u>
Formed when structure moves with speed above local wave speed (e.g., sound, magnetosonic)

Heating, accelerating particles and converting energies
+ forming transient phenomena upstream and downstream

L. B. Wilson (2016)

Fast shock transition (Theory & initial data)





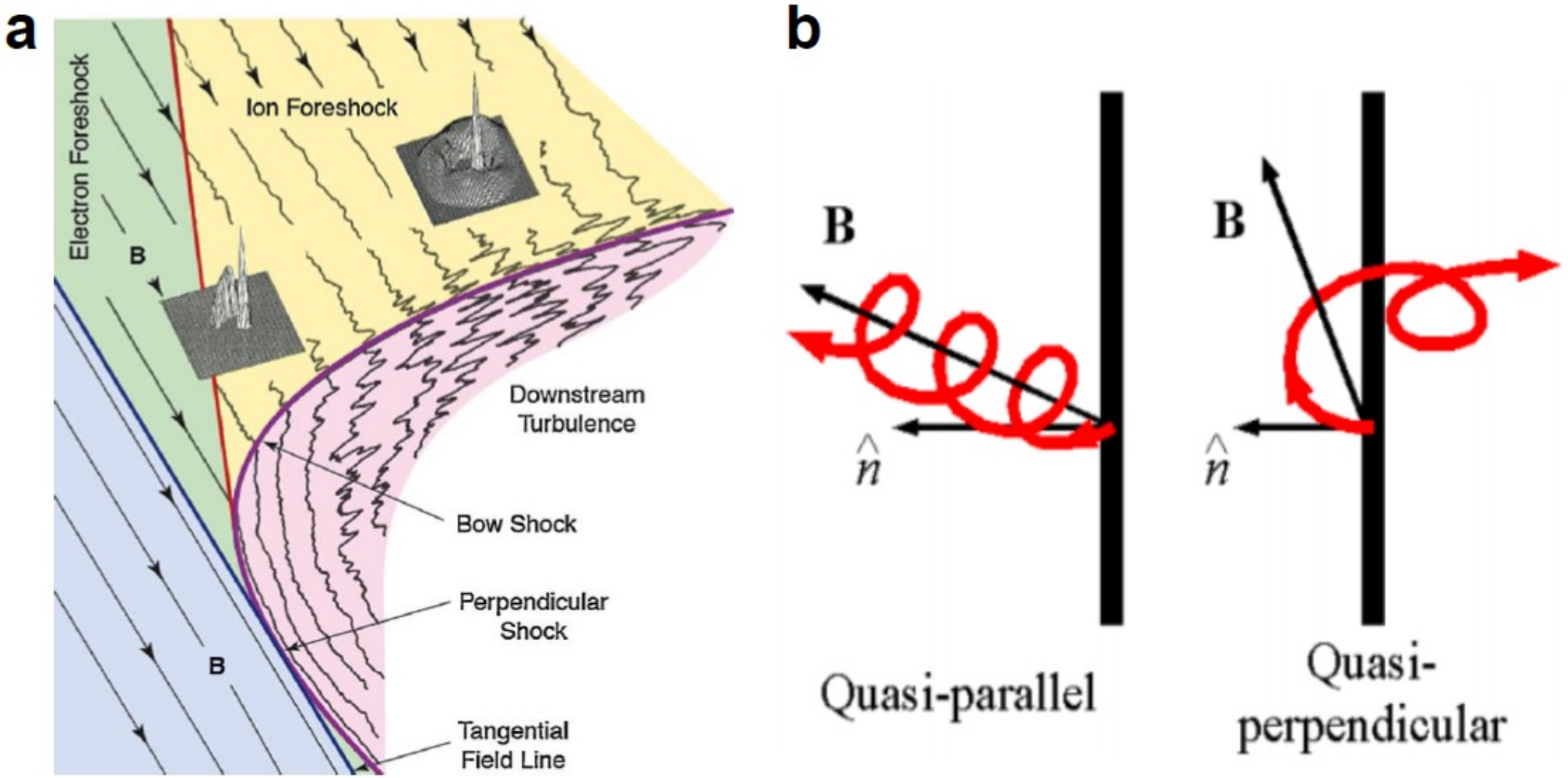
Rankine Hugoniot relations / Jump Conditions

Thermalization, Compression, Breaking

1D Isotropic and adiabatic one fluid plasma shock transitions

1964. Initial results of IMP-1 magnetic field experiment.

The Supercritical Bow Shock & foreshock

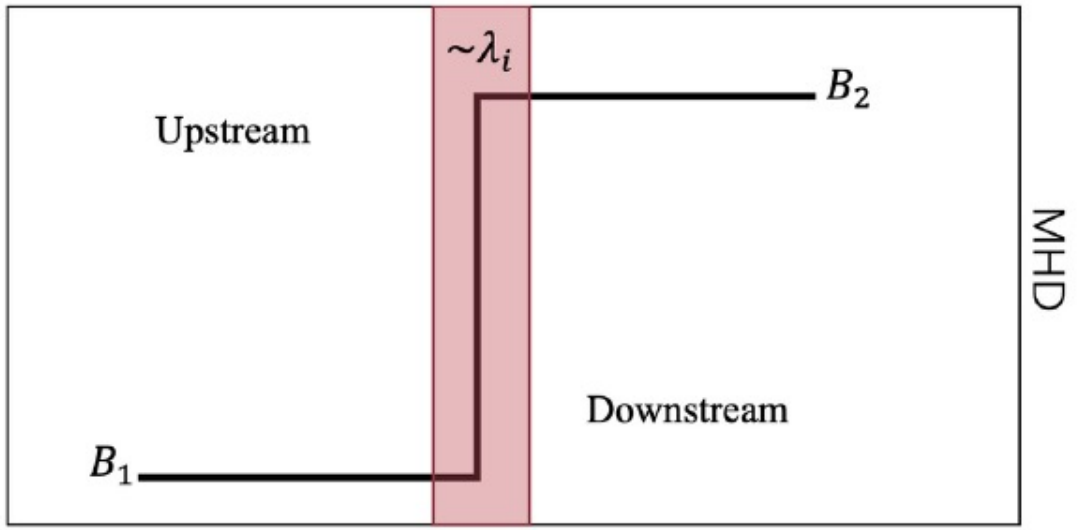


Reproduced from [Balogh and Treumann, 2013].

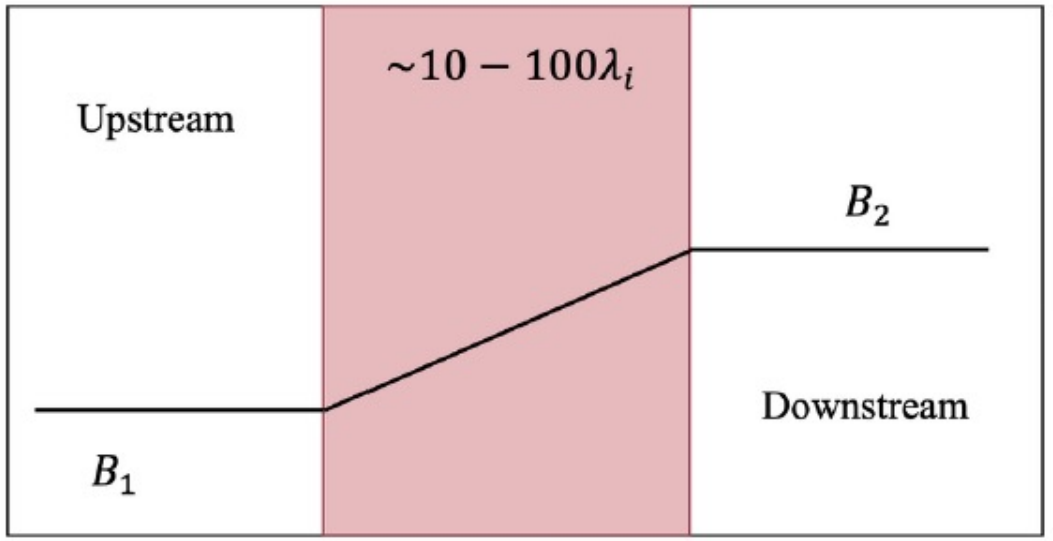
Assuming Specular Reflection

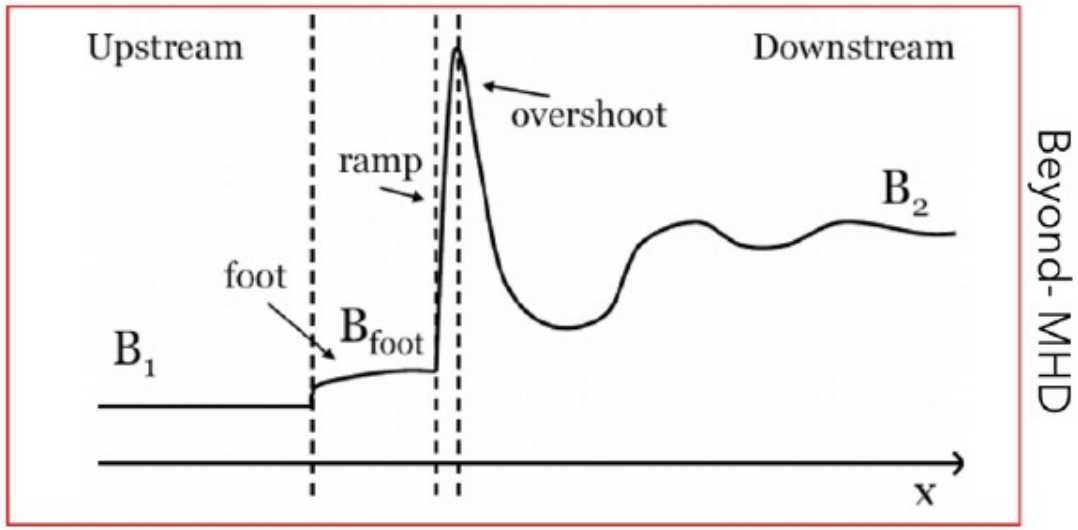
Quasi-parallel and Quasi-perpendicular shocks

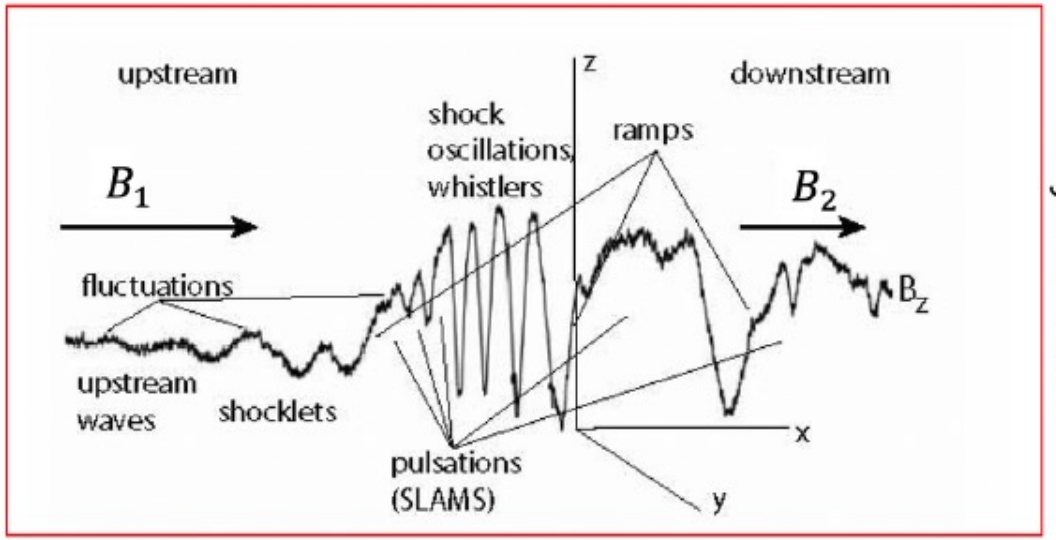
Qperp transition



Qpar transition







1. Dayside Transient Processes
2. Effects on the Magnetosphere-Ionosphere system
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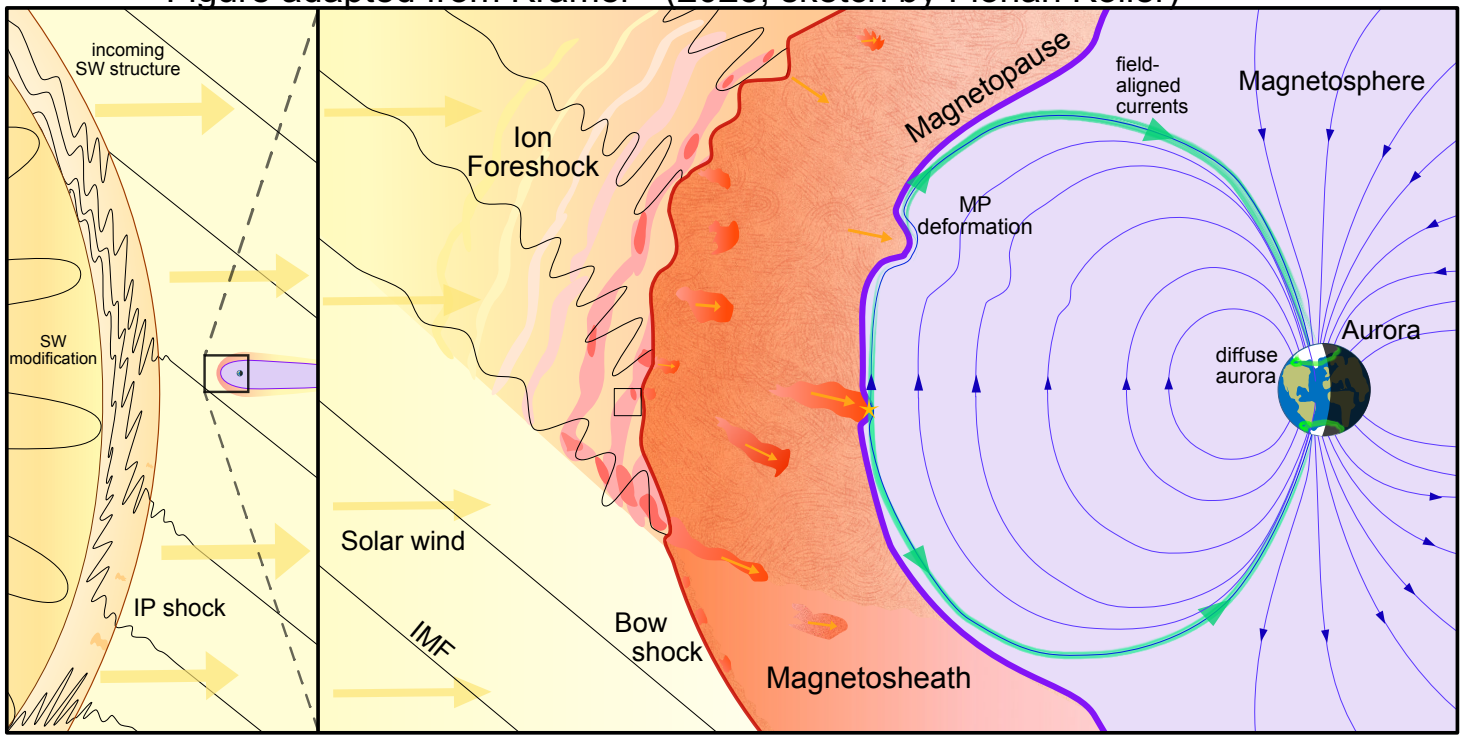
Multiscale Dayside Transients (MDT) and their Effect on Earth's Magnetosphere

What is a “Dayside” Transient?

Figure adapted from Krämer+ (2025; sketch by Florian Koller)



Our proposed Focus Group (FG) will investigate the multiscale nature of dayside transients, their variability in response to solar transients, and their overall effects on the magnetosphere-ionosphere system.

Transient phenomena are events that disrupt the steady-state plasma conditions, occurring temporarily and introducing dynamic changes to the physical system

- Global (Solar):
  - Coronal Mass Ejection (CME)
  - High-Speed Stream (HSS)
  - Pressure Pulse / IP Shocks
- Fluid scale:
  - Flux Transfer Event (FTE)
  - Magnetopause (bursty) Reconnection
- Mesoscale:
  - Hot Flow Anomalies (HFAs)
  - Foreshock Bubbles (FBs)
  - Magnetosheath jets
- Kinetic:
  - ULF waves
  - Shocklets
  - SLAMS

NOTE: Transients can be intrinsic (e.g., ULF waves) or driven (e.g., HFAs)

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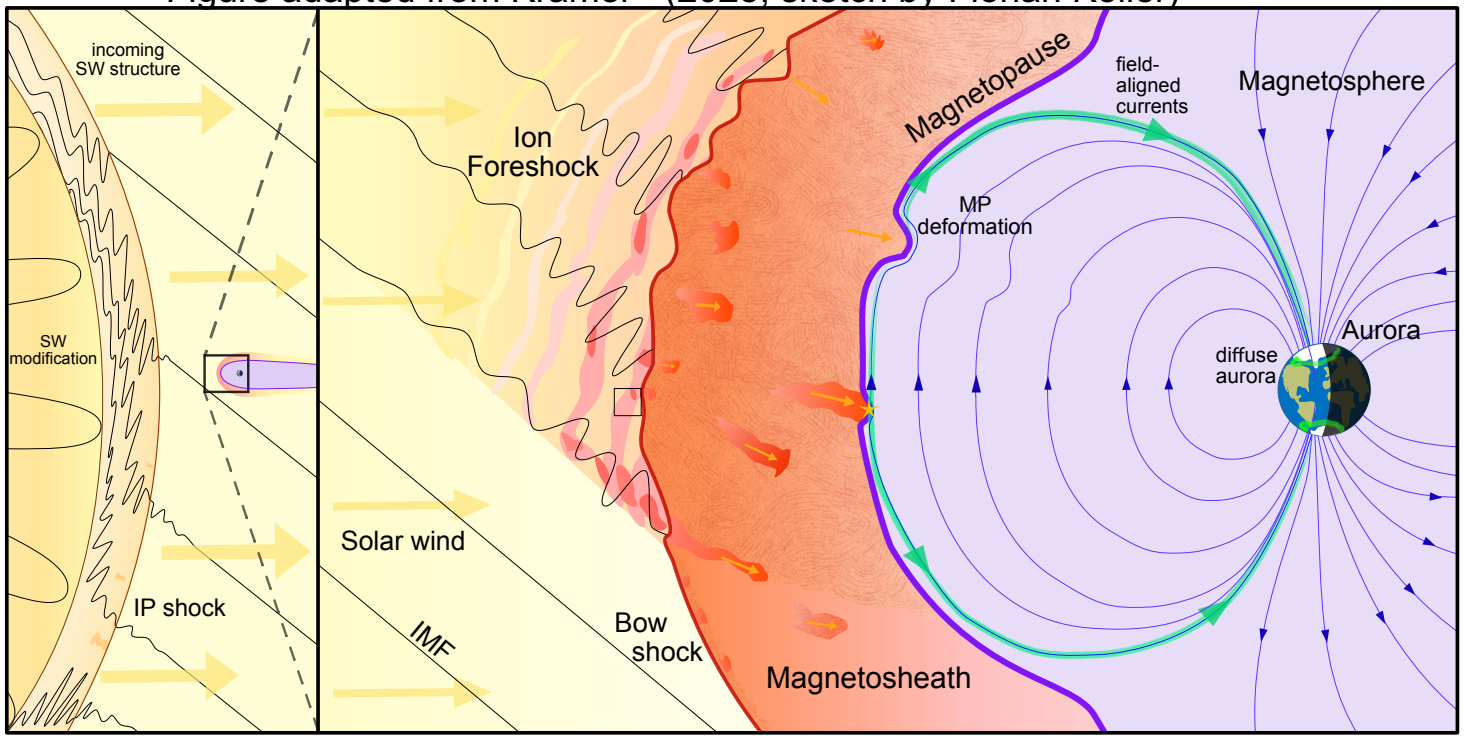

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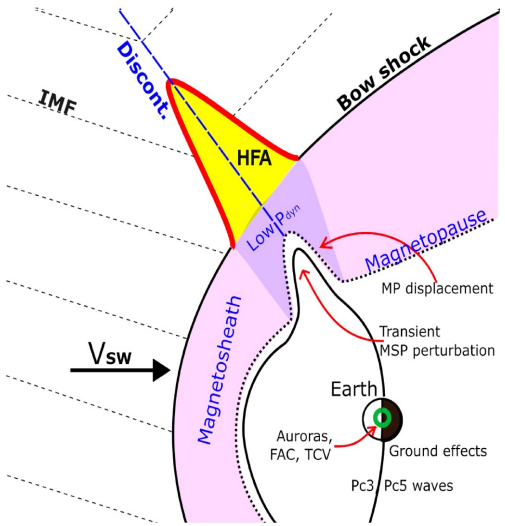
The anatomy of an HFA

How many: ~several per day!
How big: ~up to 10s of Re



Hot Flow Anomalies (HFA)

Kajdič+ (2024)

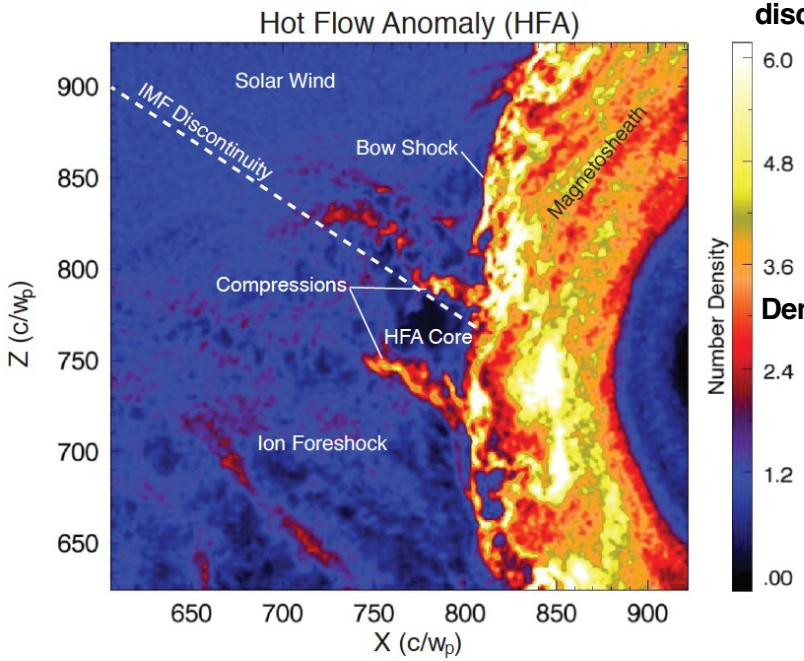


Figure by Nick Omidi

Crater-like B-field and IMF discontinuity

Density compressions and cavity

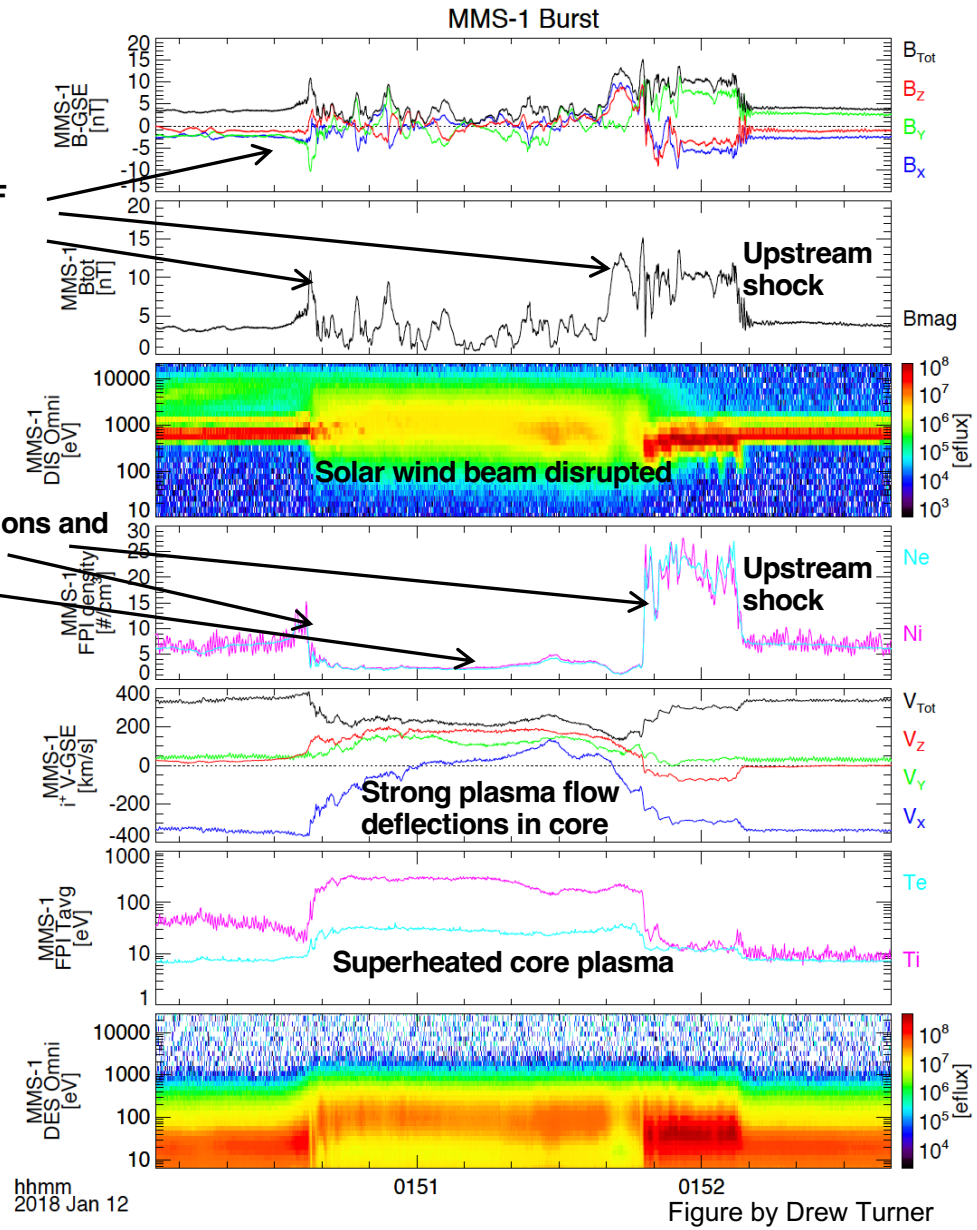


Figure by Drew Turner

Discontinuity intersects the bow shock and the convection electric field (–V X B) points towards the sheet on at least one side.

Universality of shock-generated transients

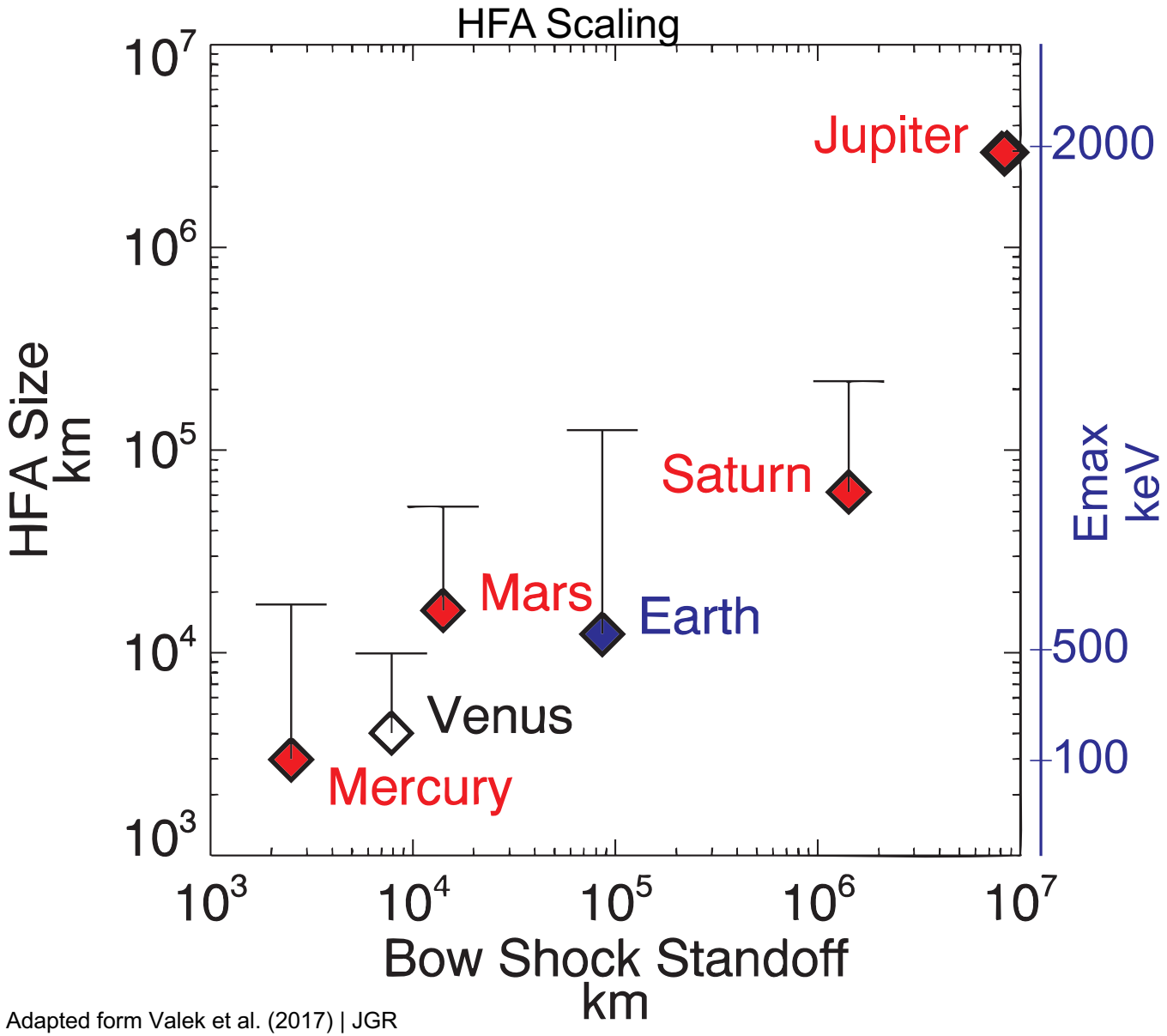
	coronal shocks	interplanetary shocks	Mercury	Venus	Earth	Mars	Jupiter	Saturn
ULFs	?	yes	yes	yes	yes	yes	yes	yes
shocklets	?	rare	yes?	yes	yes	yes	yes	yes
SLAMS	?	no?	yes	yes	yes	yes	yes	yes
SHFAs	?	?	?	yes	yes	yes	?	?
HFAs	?	?	maybe?	yes	yes	yes	yes	yes
FBs	?	?	?	?	yes	?	?	?
jets	?	yes	maybe?	?	yes	~~yes?~~	~~yes?~~	?

Hietala et al. ISSI 2019

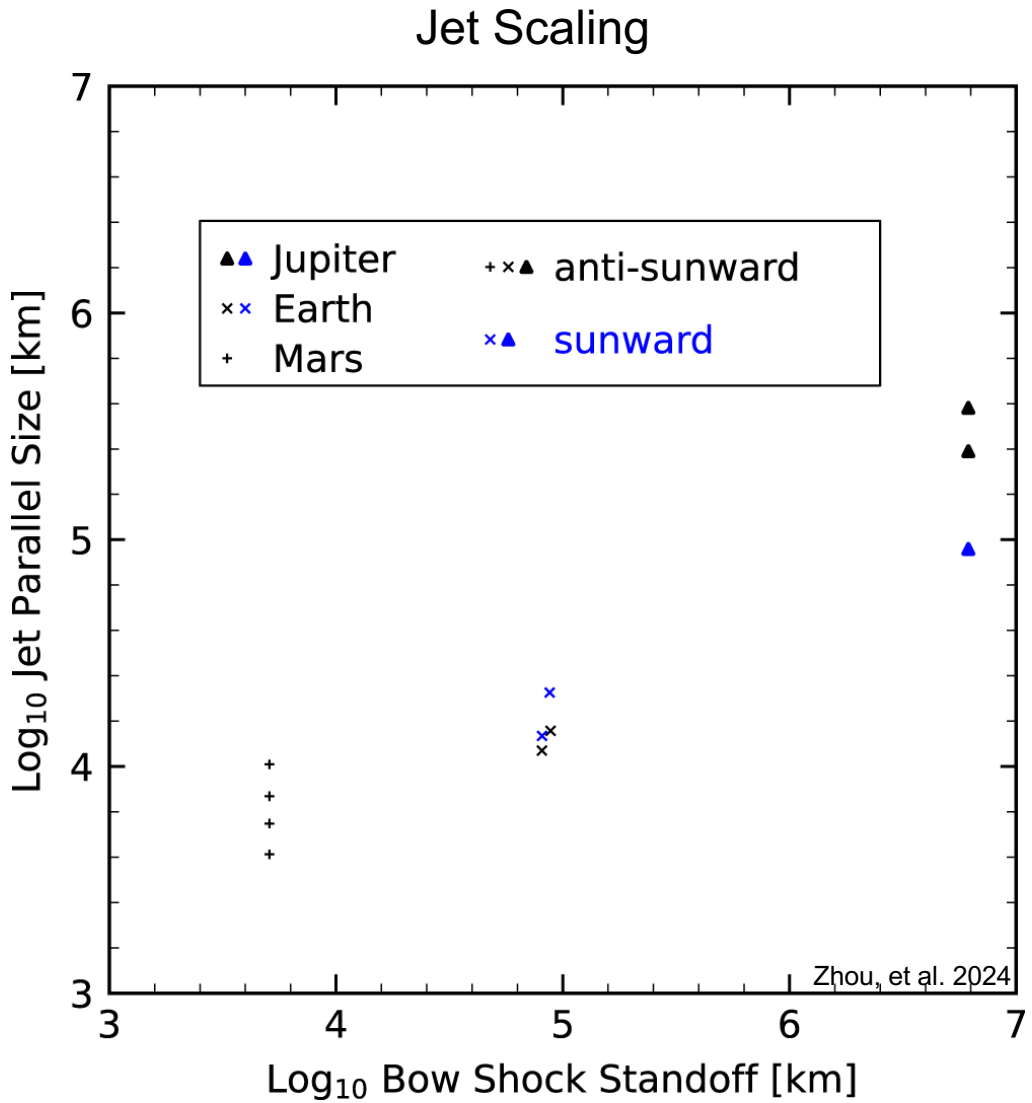
Yes!* Yes!*

*Gunell+ 2023, Zhou+ 2024, Mohammed-Amin+ 2025 (Poster of Abigail Tadlock #2)

Transients Scaling Across Systems



Adapted form Valek et al. (2017) | JGR



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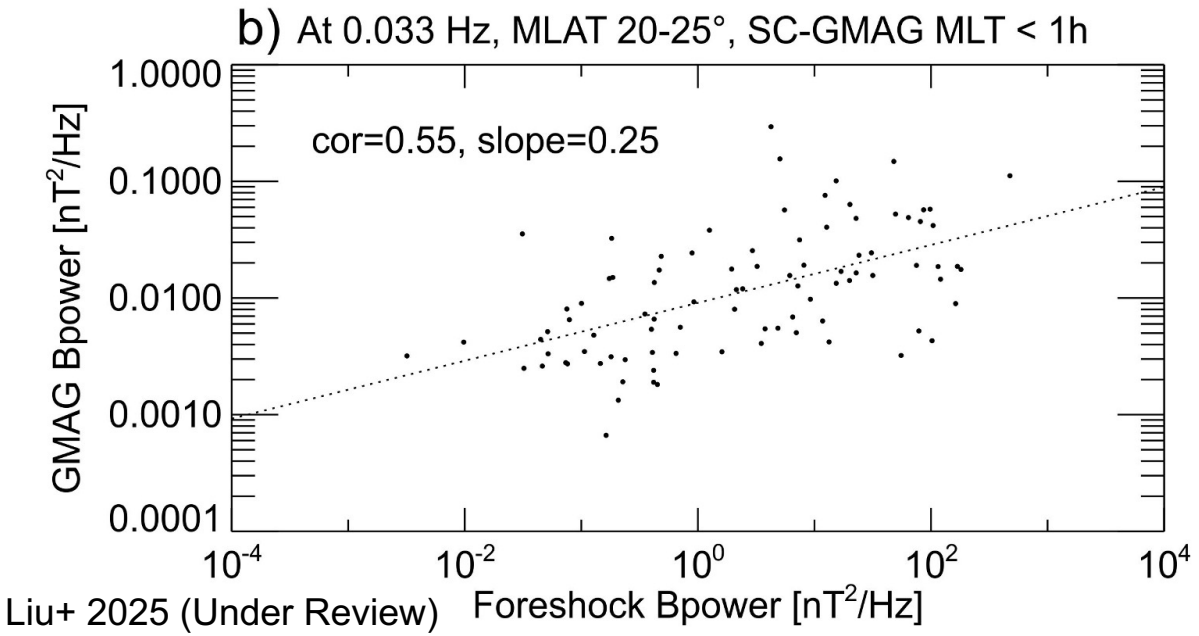
Transient and Wave transmission

Pi2 Pulsations transmitted associated to jets/foreshock transients (Katsavrias+ 2021)

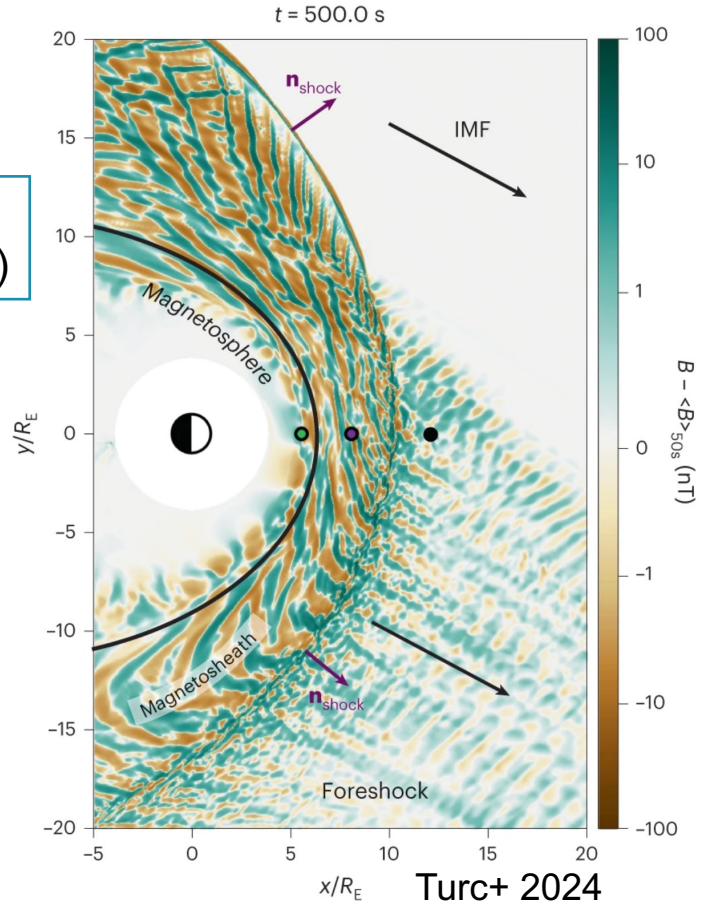
Evidence of Pc3 waves generated by a large HFA (Zhao+ 2017)



Liu+ 2025 (Under Review)

GMAG correlation with foreshock waves

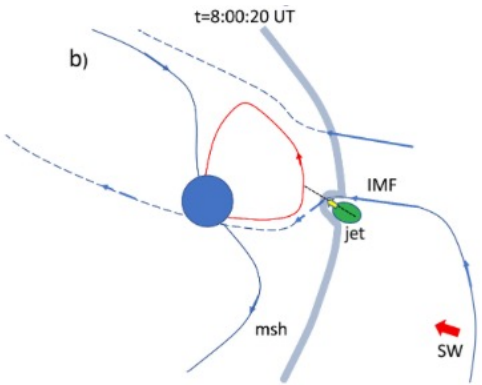
Foreshock transients driving Pc5 waves (Hartinger+ 2013)

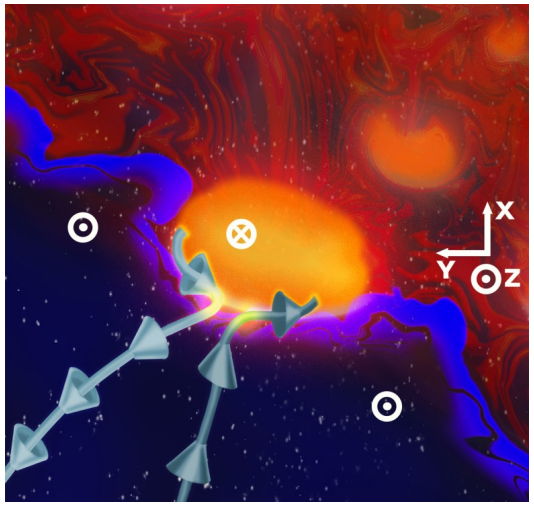


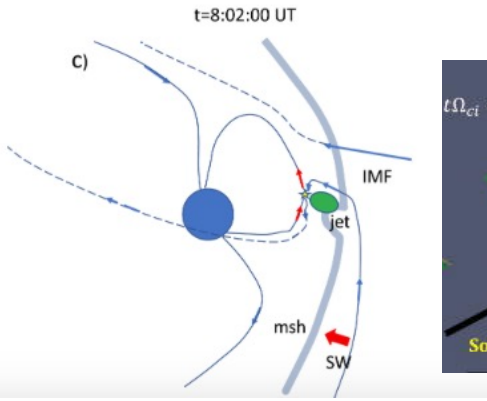
Turc+ 2024

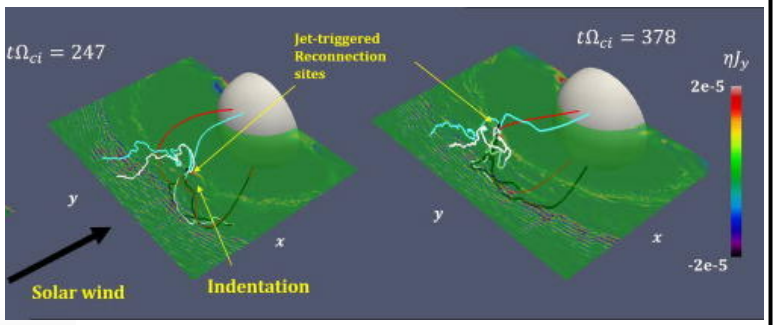
How are the ULF waves transmitted from the magnetosheath to magnetosphere?

Magnetopause Reconnection and Displacement









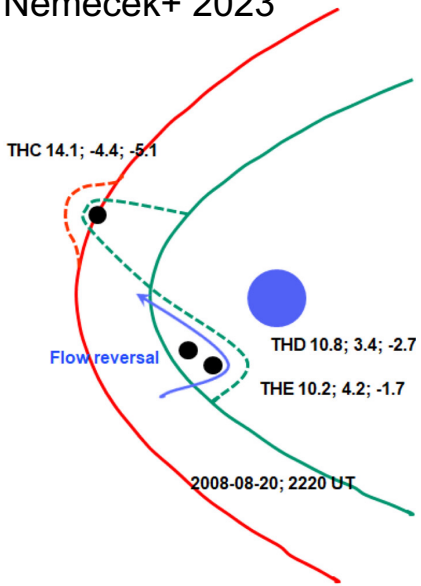
Ng+2021

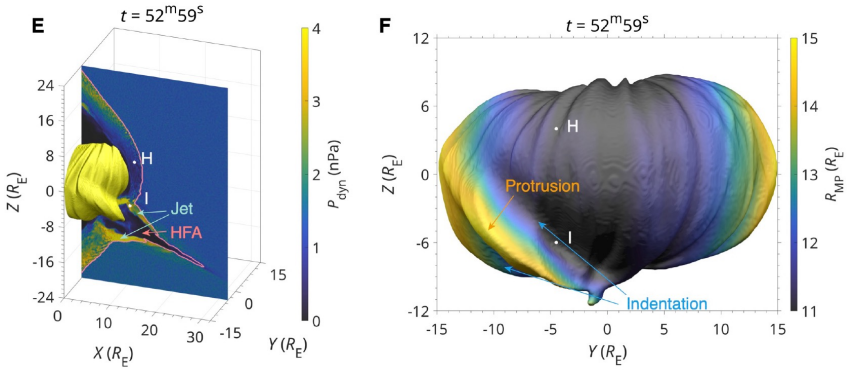
Transient localized processes drive and adapt MP bursty reconnection

Hietala+ 2018, Escoubet+ 2020, Vuorinen+ 2021

”Jets can have bursts of southward Bz”
Open question: Is this sufficient?

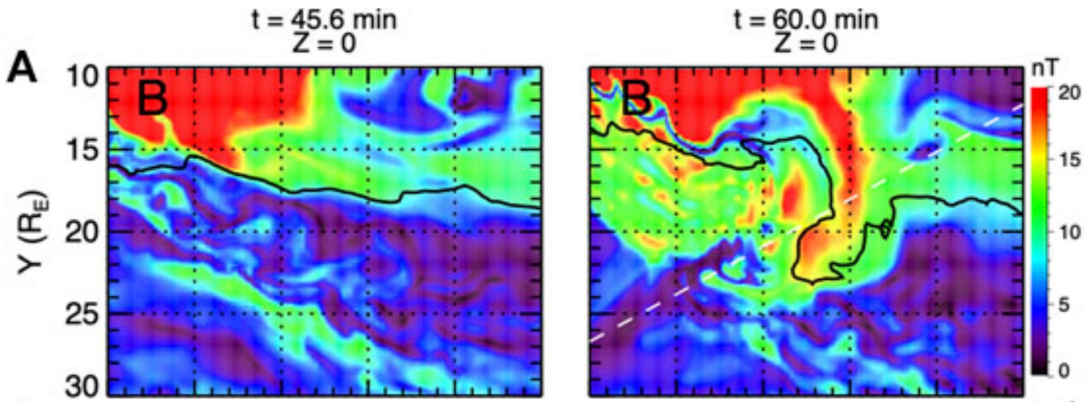
Němeček+ 2023





Zhou+ 2025 (under review)

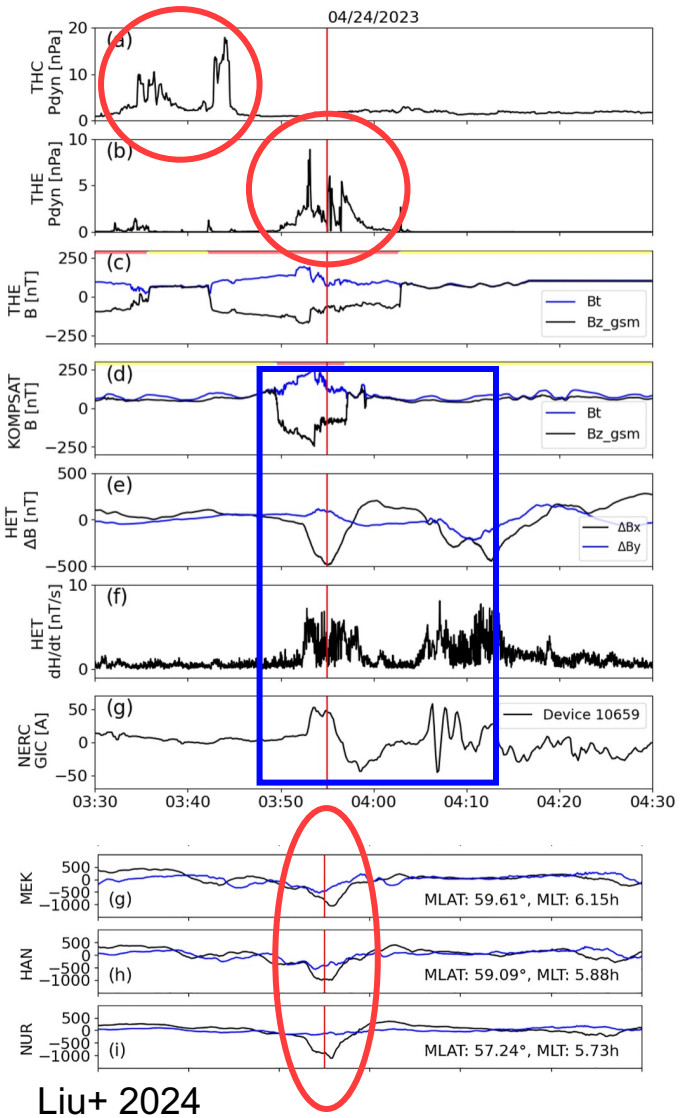
Jets ~ 4Re localized
HFAs ~6Re over the whole MSH
Open question: How “important” is this for preconditioning the magnetosphere?



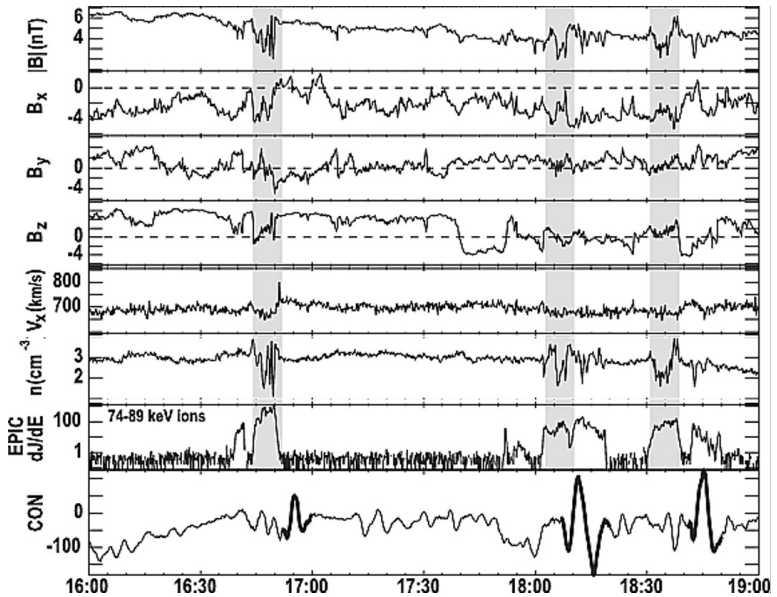
Wang+ 2021

Yang+2023, Guo+ 2023

Inner magnetosphere and Ionosphere effects



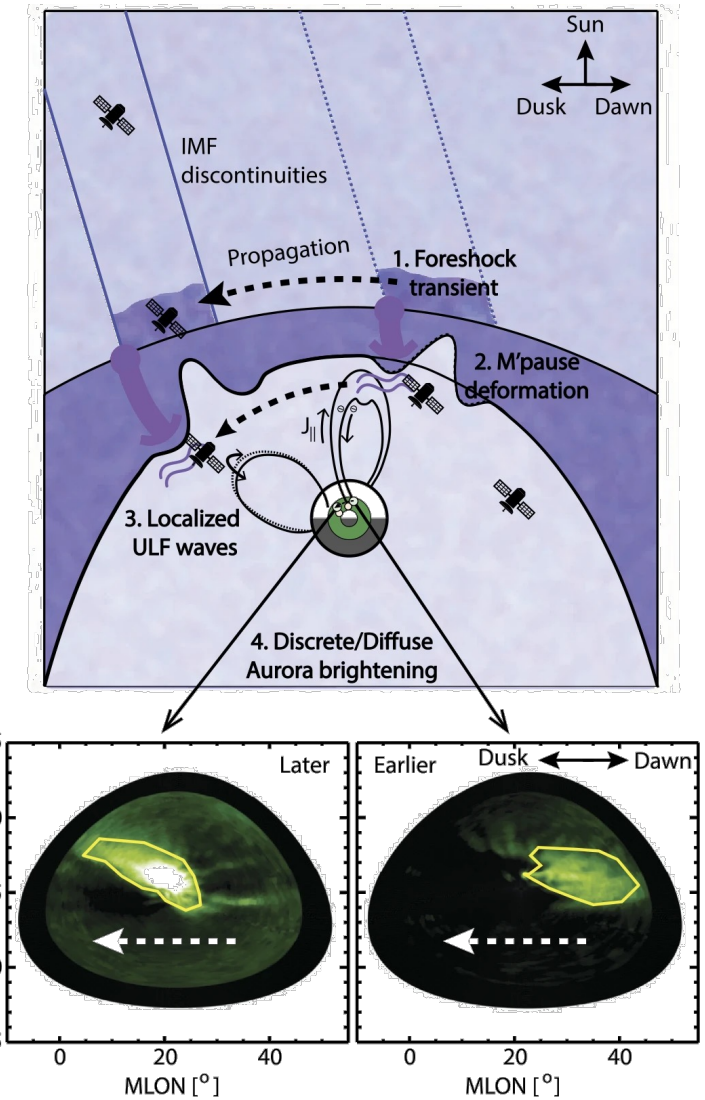
Liu+ 2024



Murr+ 2003

Which shock-generated transients cause ground perturbations?

How do shock-generated transients drive localized aurora brightening?



Shen+2018, Wang+ 2018

Team & Goals

Multiscale Dayside Transients (MDT) FG

Savvas Raptis
(Johns Hopkins University APL)
- Collisionless shocks
- Transient processes

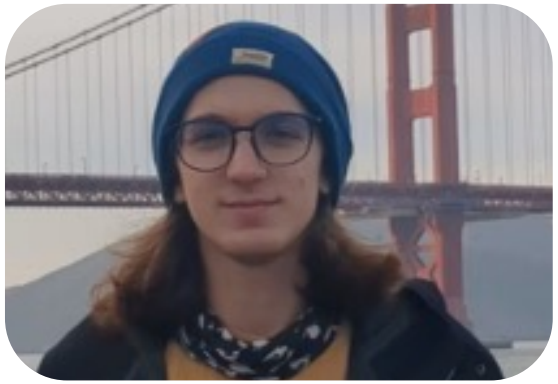
Ivan Vasko
(University of Texas at Dallas)
- Plasma waves
- Wave-particle interactions

Imogen Gingell
(University of Southampton)
- Hybrid & PIC simulations
- Shock, turbulence, reconnection

Terry Liu
(University of California)
- Particle acceleration
- Foreshock processes

Ying Zou
(Johns Hopkins University APL)
- Solar wind – Magnetosphere coupling
- Magnetosphere- ionosphere coupling

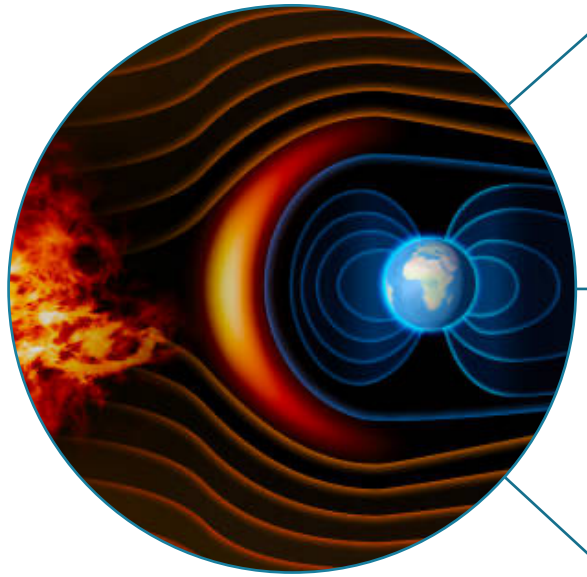
Runyi Liu
(University of California)
- ULF Waves
- Foreshock



David Tonoian
(University of Texas at Dallas)
- Wave-particle interactions
- Particle scattering

Relevance to Existing GEM Focus Groups

Multiscale Dayside Transients



COMP

- How do dayside transients manifest in other planets?

RX

- How do transient phenomena modulate dayside reconnection?
- How does reconnection processes modulate dayside transient processes?

GIC

- How are large scale solar transients change at Earth?
- How do mesoscale transients drive currents?

RG: Machine Learning

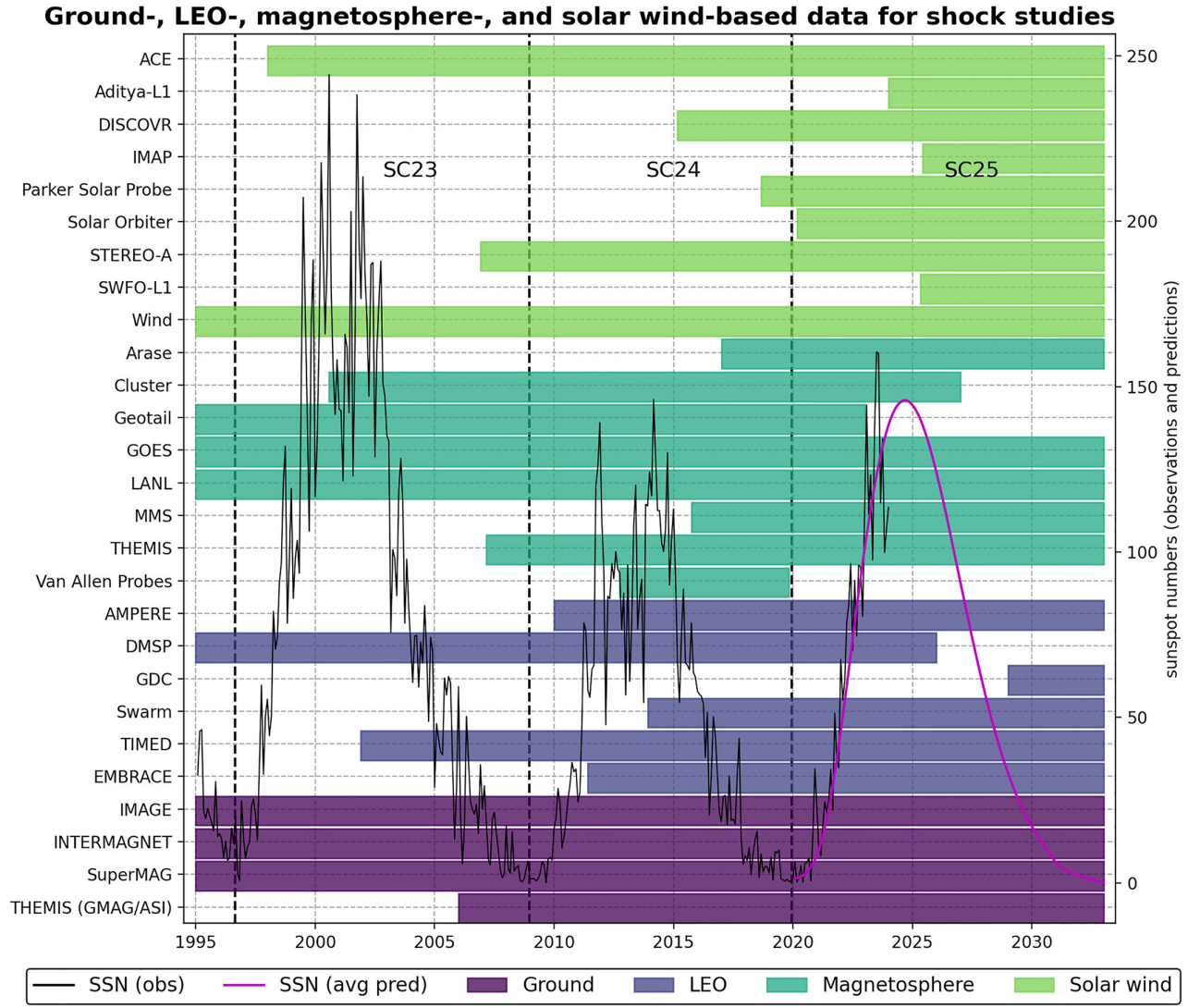
How do we these incorporate dayside processes to ML models?

Recent history of Transients' efforts (From Mike Hartinger)

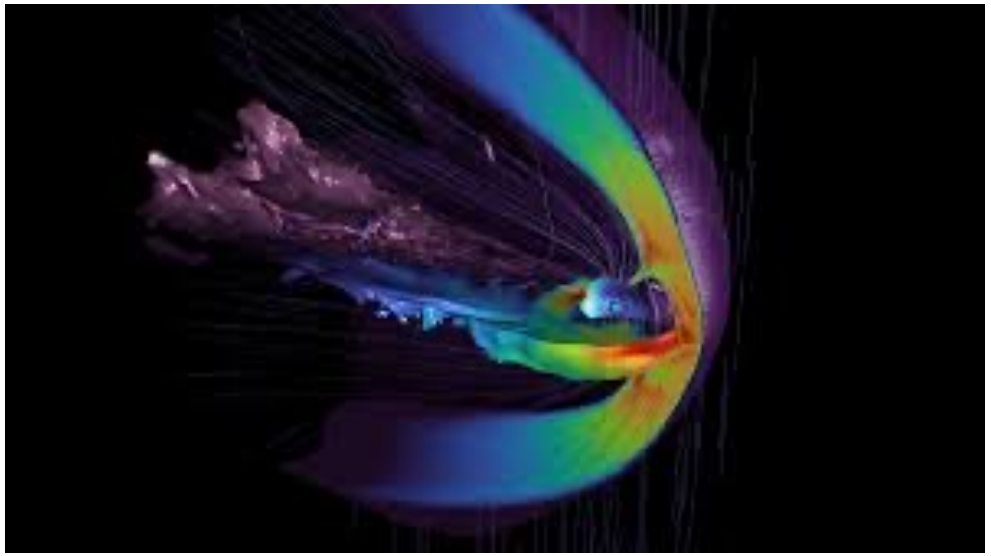
- GEM FG 2019-2024, "Particle Heating and Thermalization in Collisionless Shocks in the MMS Era"
- GEM FG 2016-2021, "Dayside Kinetic Processes in Global Solar Wind-Magnetosphere Interaction"
- GEM FG 2012-2016, "Transient Phenomena at the Magnetopause and Bow Shock and Their Ground Signatures"

- ISSI team, "Global study of the transmission of foreshock ULF waves into the magnetosheathand the magnetosphere"
- ISSI team, "Foreshocks Across The Heliosphere: System Specific Or Universal Physical Processes?"
- ISSI team, "Future directions for understanding surface waves throughout Earth's magnetosphere and beyond"
- ISSI team, "Jets Downstream of CollisionlessShocks"
- ISSI team, "Impact of Upstream Mesoscale Transients on the Near-Earth Environment"

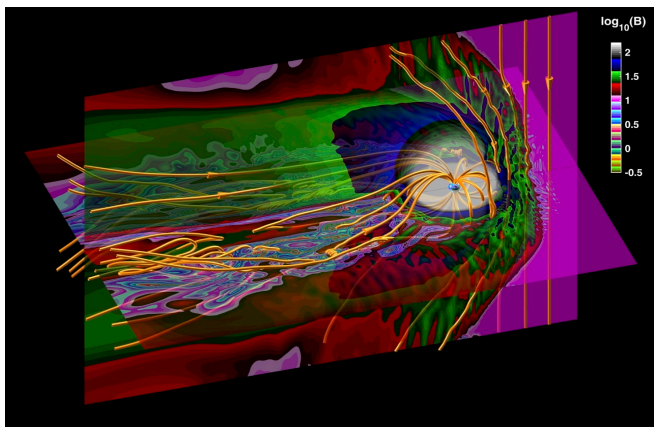
Why then do it again ?



Oliveira et al., 2024



Vlasiator



ANGIE3D

Goals and Deliverables

- Year 1: Invite experts and identify knowledge gaps
- Year 2: A GEM challenge on TBD topic
- Year 3: Update and continuation of GEM challenge
- Year 4: GEM challenge completion along with:
  - Session Summary
  - Review paper
  - Future goals (i.e., what was not addressed)
  - Database of in-situ events for cross-scale studies via multi-mission observations

Expected Activities

- **Collaborative Sessions:** Host joint meetings with existing Focus Groups to foster cross-disciplinary discussions.
- **Expert Reviews:** Invite specialists to provide state-of-the-art insights and compile critical unanswered questions.
- **Early Career Focus:** Prioritize talks from graduate students and young researchers to encourage active participation and form an EC driven session.
- **Hands-on Workshops:** Offer practical sessions on dayside processes, emphasizing multi-spacecraft techniques and observation-simulation comparisons across kinetic to fluid scales (e.g., magnetosheath current sheets to FTEs).

Please provide feedback and what you want to see in the future

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Our First Year Highlights

Our first GEM (Monday – Tuesday)

Session 3: MDT-RX - General Contributions - 06/25/2025 (Tuesday, 10:00 - 12:00)

1	10:00 - 10:10	Katy Goodrich	TRACERS Intro/Update
2	10:10 - 10:20	Naoki Bessho	Electron acceleration in reconnection and non-reconnecting current s Online
3	10:20 - 10:30	Jonathan Ng	3D electron and ion-scale reconnection at the quasi-parallel shock
4	10:30 - 10:40	Amy Rewoldt	Deriving dayside reconnection potential from MHD simulations
5	10:40 - 10:50	Daniel da Silva	Dayside Reconnection Rates from Cusp Ion-Energy Dispersion
6	10:50 - 11:00	Rachel Rice	Statistical study of MMS boundary layers (TBD)
7	11:00 - 11:10	Matti Ala-Lahti	Determining the Magnetospheric Response to Solar Wind Magnetic Field Fluctuations
8	11:10 - 11:20	Neha Srivastava	Response of the magnetospheric boundaries to the dynamic pressure variations in the Solar Wind : Global MHD Simulation using OpenGGCM
9	11:20 - 11:30	Brian Walsh	Variability and energy flow in the magnetosphere
10	11:30 - 11:40	Bob Strangeway	The TRACERS Mission: A Magnetic Fields Measurement Perspective
10	11:40 - 12:00	Open Discussion & Future Common Goals	

MDT: Multiscale Dayside Transients and their Effect on Earth's Magnetosphere		
24	Kun Zhang	Properties of solar wind discontinuities across Earth's bow shock: ARTEMIS observations
25	Peter Damiano	Dispersive Alfven wave driven electron energization in the cusp
26	Runyi Liu	Ion Acoustic Waves in Earth Foreshock Transients: Case Study on Wave Excitation and Electron Heating
27	Taylor Whitney Aegerter	Spatial Extent of EMIC Waves in Earth's Magnetosphere during Geomagnetic Storms
28	Youra Shin	Magnetospheric and Ionospheric Responses to Small-scale Magnetic Flux Ropes (SMFRs) in the Solar Wind

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23	Chen Shi	Investigating properties of the bow shock reflected ions using 2D local hybrid simulations
24	Hongyang Zhou	Kinetic Processes in the Dayside Magnetosphere: Insights from 2D PIC Simulations with FLEKS
25	Neha Srivastava	Response of the magnetospheric boundaries to the dynamic pressure variations in the Solar Wind : Global MHD Simulation using OpenGGCM
26	Nilay Ghalsasi	MMS Multi-Spacecraft Observations and Analysis of Electrostatic Waves in a Hot Flow Anomaly
27	Xiaolei Li	Signatures of Interplanetary Small Magnetic Flux Ropes Crossing Earth's Bow Shock and Magnetosheath from Global Hybrid Modeling

Session 1: Scene Setting and Discussion - 06/23/2025 (Monday, 13:30 - 15:30)

Order	Time	Speaker	Title/Topic	Notes
	Introduction (2-3 mins)			
1	13:30 - 14:00	Mike Hartinger	Dayside Transients: Recent Advances and Open Questions from an Observational Perspective	
2	14:00 - 14:30	Yu Lin	Global modeling of the dayside transients	
3	14:30 - 15:30	**Panel & Open Discussion**		

Session 2: General Contributions - 06/24/2025 (Monday, 16:00 - 18:00)

1	16:00 - 16:10	Mohamad Barani	Remote Gyrosensing of the Earth's Bow Shock	
2	16:10 - 16:20	Yufei Hao	Simulations of HSJs behind quasi-parllel shocks	Online
3	16:20 - 16:30	Mengmeng Wang	Multipoint Observations of Non-stationarity of an Isolated Short Large	Online
4	16:30 - 16:40	Xi Lu	Ion Acoustic Waves within Hot Flow Anomaly	
5	16:40 - 16:50	Yuda Zhi	Auroral and ionospheric responses to foreshock transients/HSJs	Online
6	16:50 - 17:00	Yuxi Chen	Geoeffectiveness of shock transients	
7	17:00 - 17:10	Hadi Madanian	Characteristics of the bow shock boundary at large geocentric distanc	Online
8	17:10 - 17:20	Connor O' Brien	PRIME-SH: Data-Driven Probabilistic Model of Earth's Magnetosheath	Online
9	17:20 - 17:30	Drew Turner	New opportunities for studying collisionless shocks with MMS	
10	17:30 - 17:40	Kevin Pham	Upstream conditions of Ganon storm and effects (TBD)	
11	17:40 - 17:50	Jesper Gjerloev	By Flip during Ganon storm (TBD)	
12	17:50 - 18:00	Katy Goodrich	Evidence of the Electron Cyclotron Drift Instability in an Oblique Shock Crossing	
13	18:00 - 18:02	Nilay Ghalasi	MMS Multi-Spacecraft Observation of Electrostatic waves	

2 standalone session, 1 joint with RX,
23 contributed talks, 2 invited scene setting talks, 10 posters

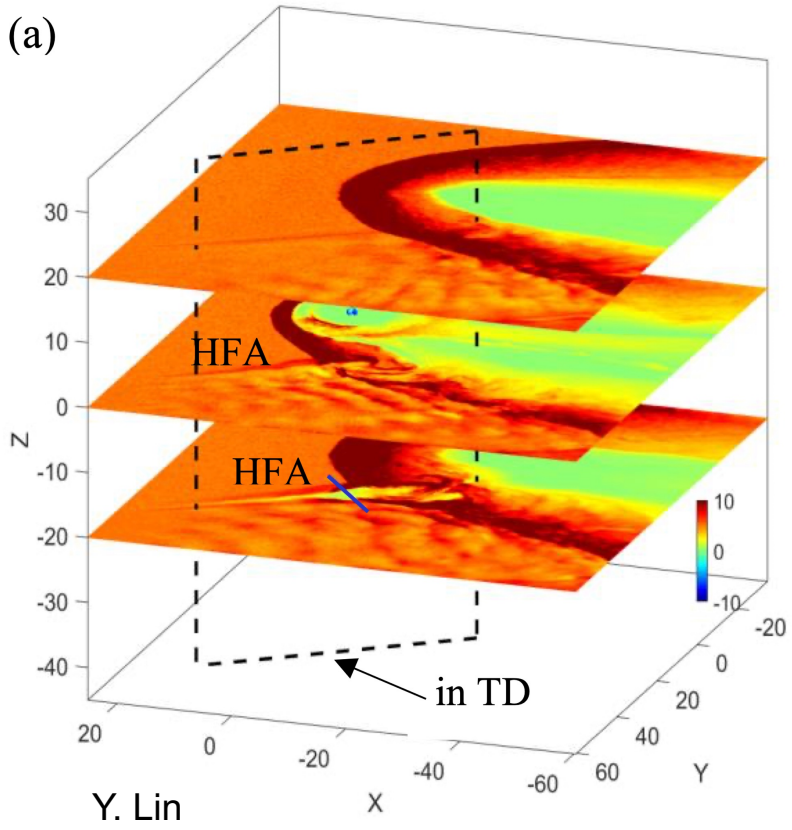
Special thanks to Mike Hartinger and Yu Lin!

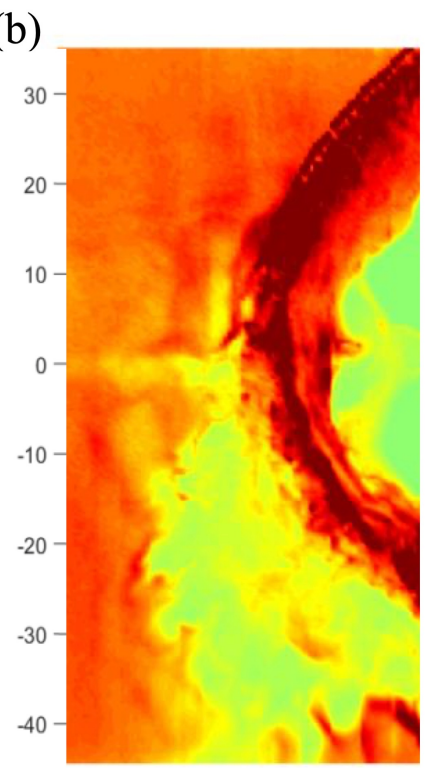
Let’s see some highlight from this week!

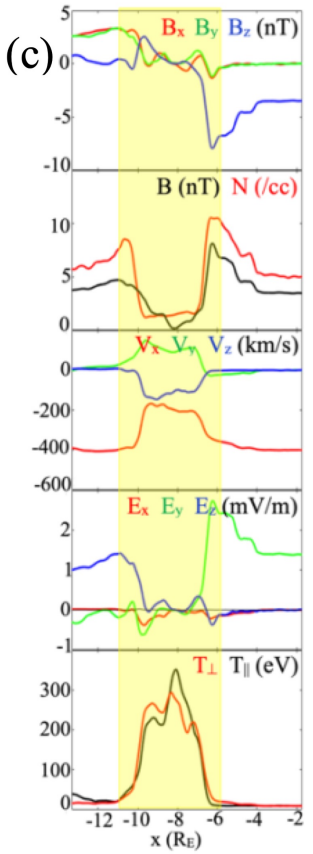
Highlights Monday 13:30 – 15:30

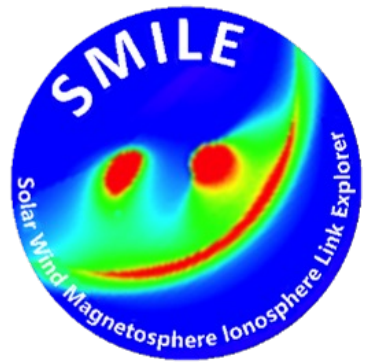
Counteract reporting bias by studying transients associated with large magnetopause displacements that produce no ionospheric/ground response –we can learn the most from these!

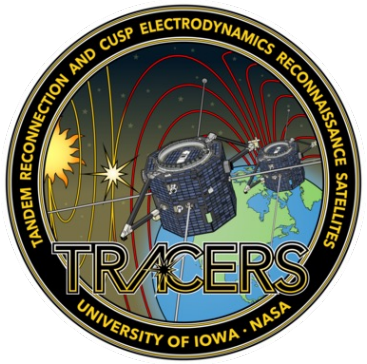
M. Hartinger



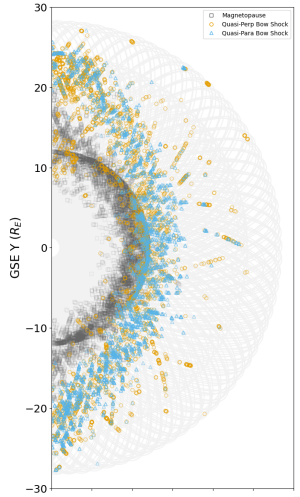






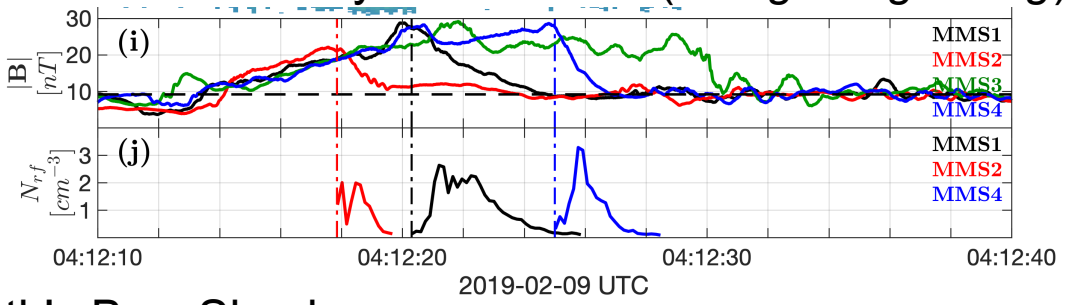


Highlights Monday 16:00 – 18:00 | Shock Physics



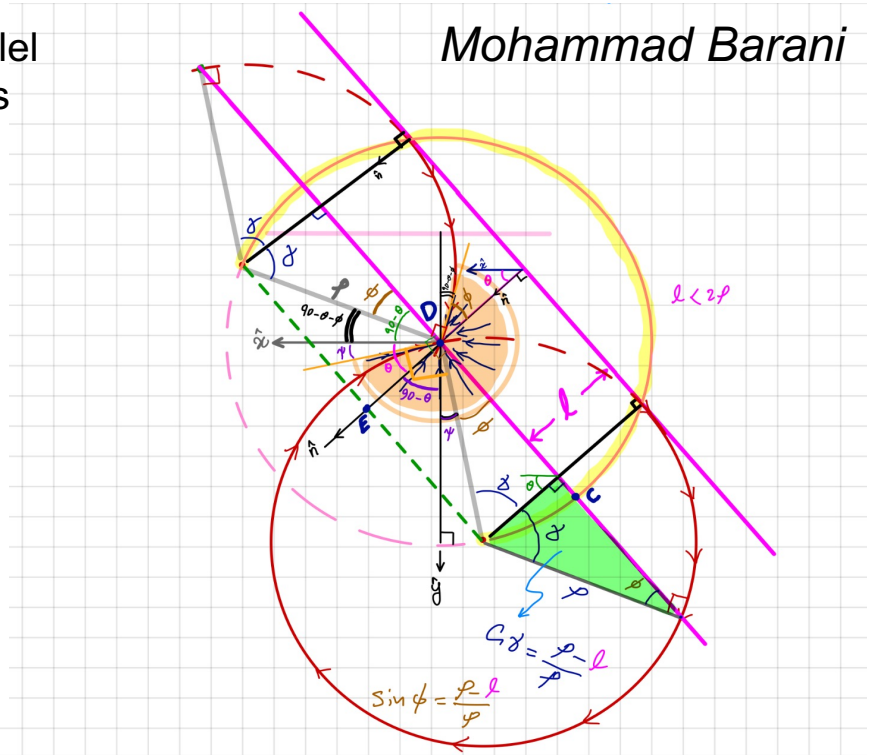
Toy-Edens+ [JGR 2024] :
Full list of dayside environments, magnetopause, bow shock list
(Drew Turner)

Non-stationarity of a SLAMS (*Mengmeng Wang*)

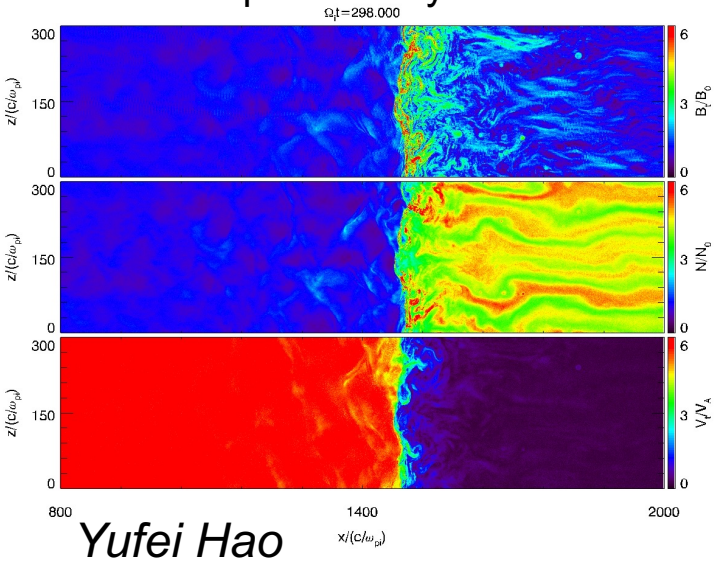


Remote Gyrosensing of the Earth's Bow Shock

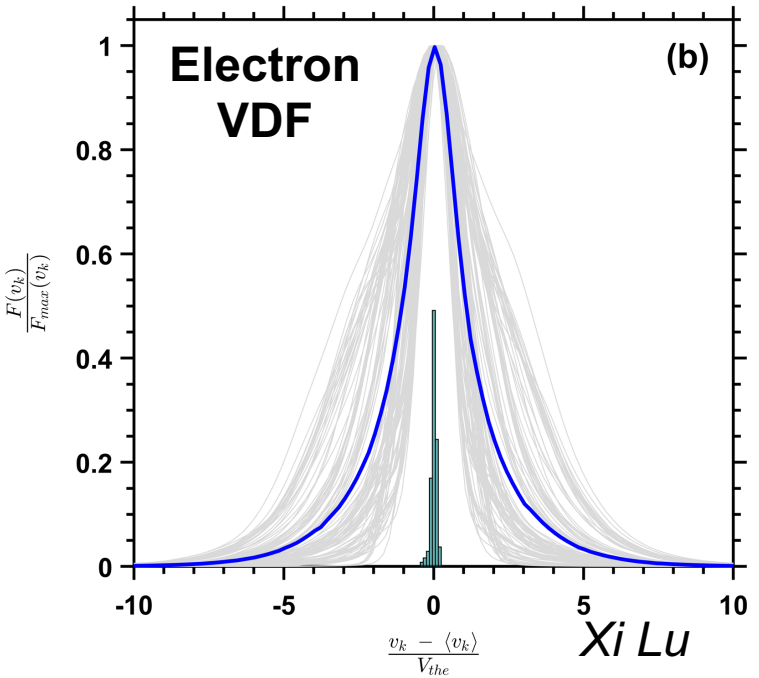
Mohammad Barani



Simulations of HSJs behind quasi-parallel shocks: Test particles/hybrid simulations

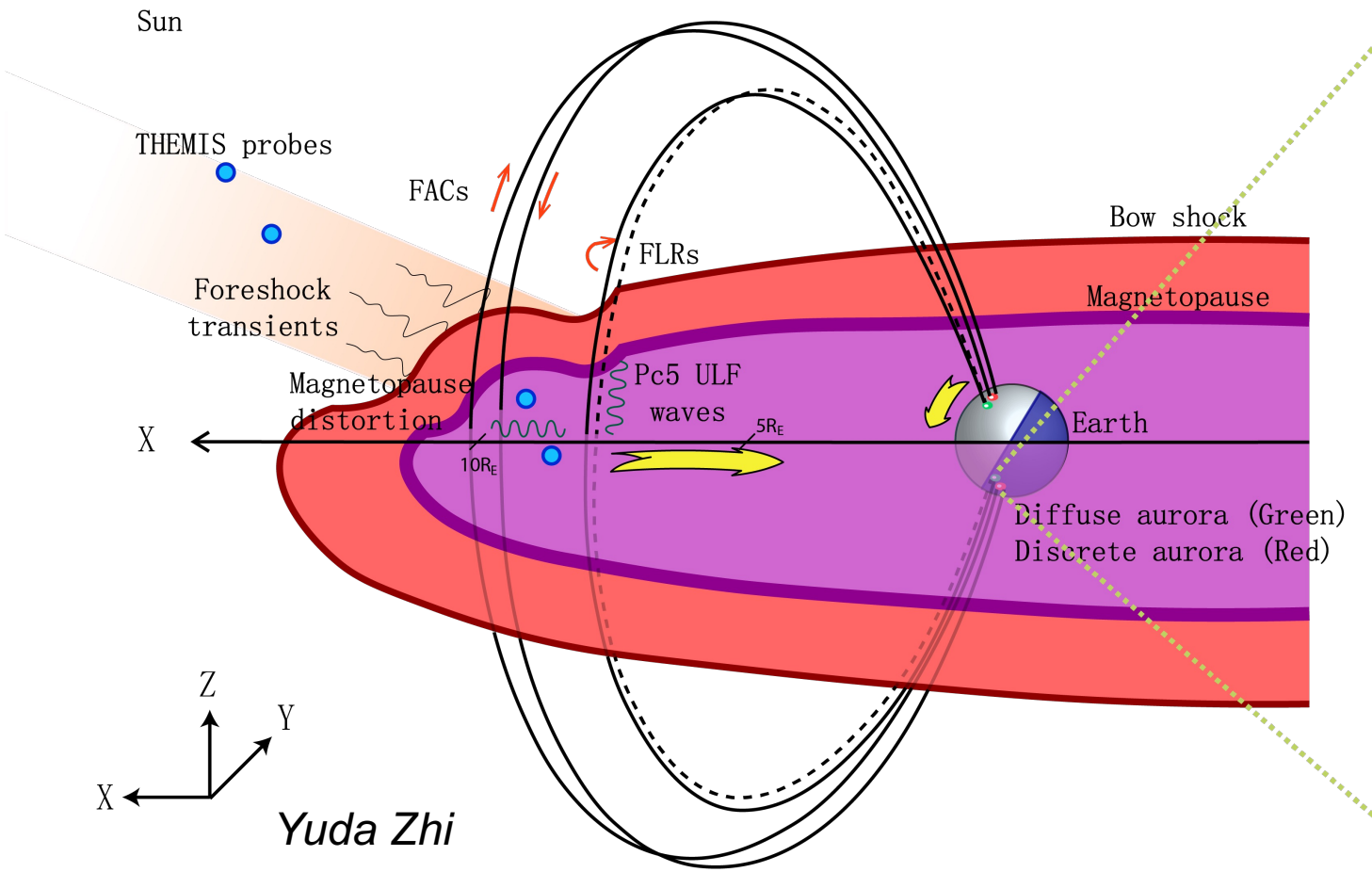


Yufei Hao

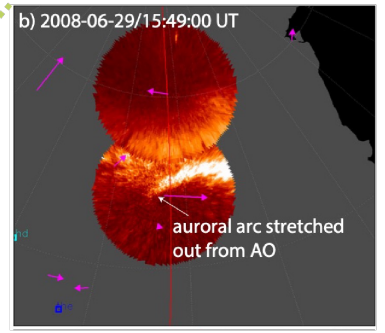


Xi Lu

Highlights Monday 16:00 – 18:00
Magnetosphere/Ionosphere Effects

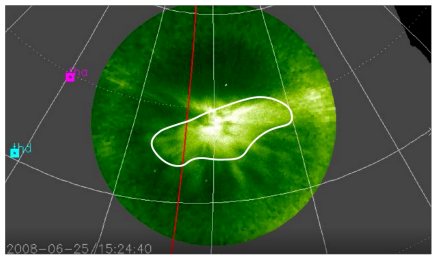


a) Discrete auroral responses



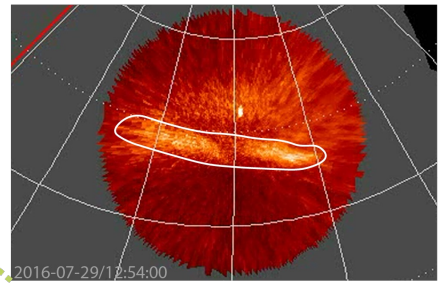
FACs/TCVs
Wang et al., (2025)

b) Diffuse auroral responses



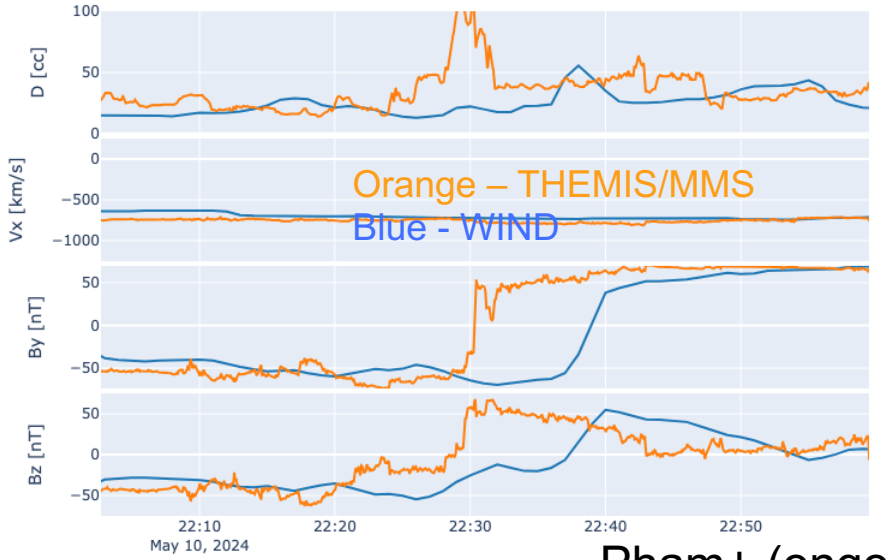
Compressional ULF waves
Wang et al., (2018a, 2018b); Xu et al., 2024 (about to submit)

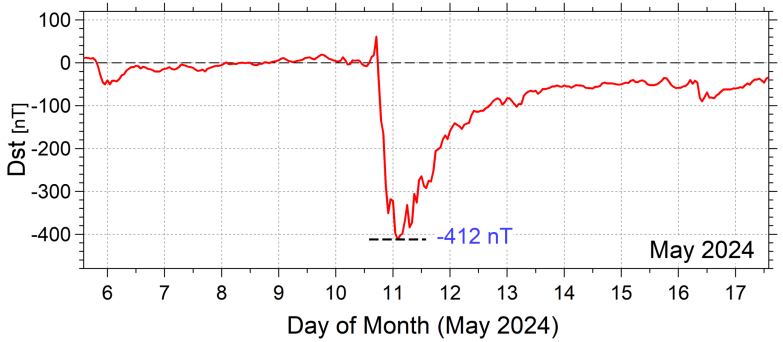
c) Periodic poleward-moving arcs



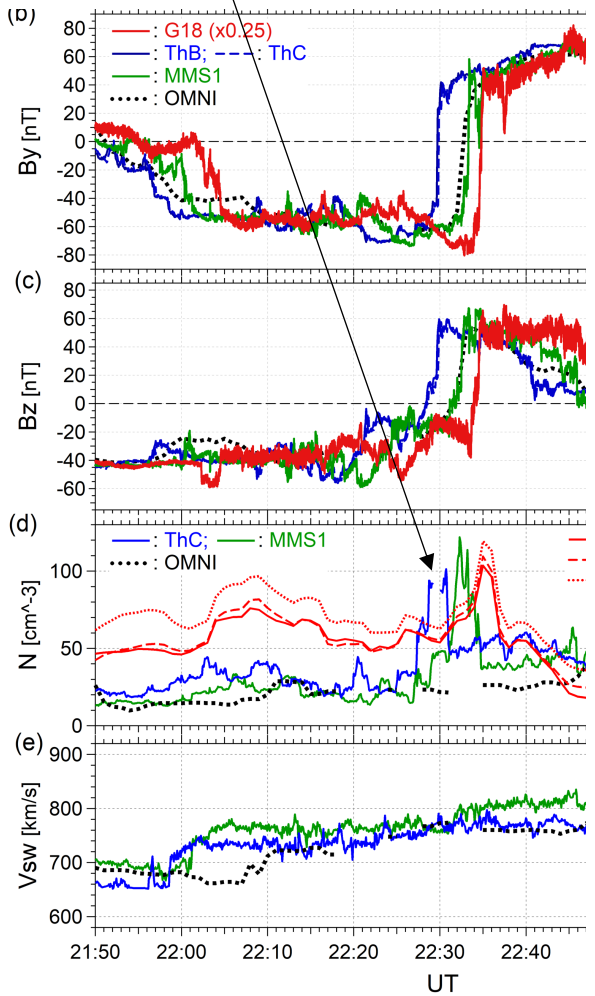
FLRs
Wang et al., (2019, 2020)

Monday (16:00 – 18:00) Gannon Storm Success Stories



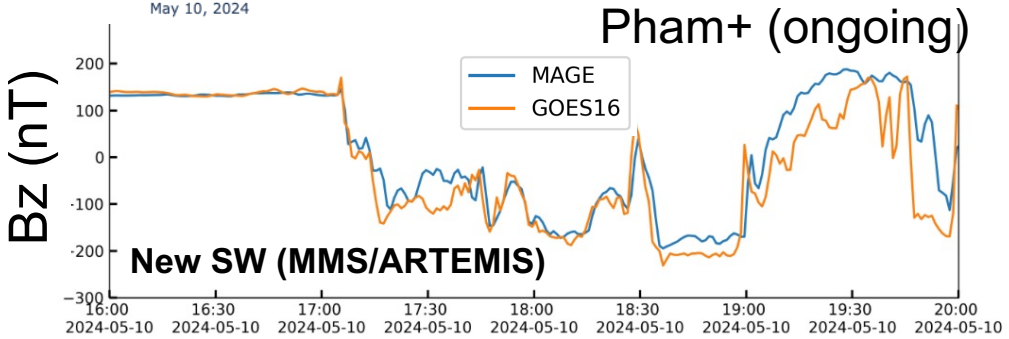


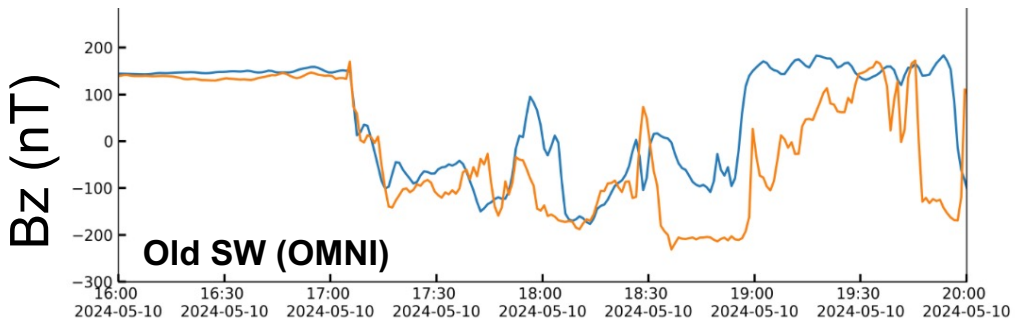
This density enhancement may play a crucial role



Ohtani+ (2025)

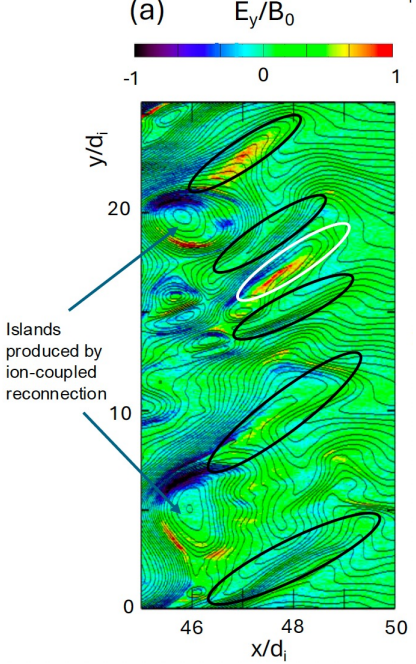
Pham+ (ongoing)



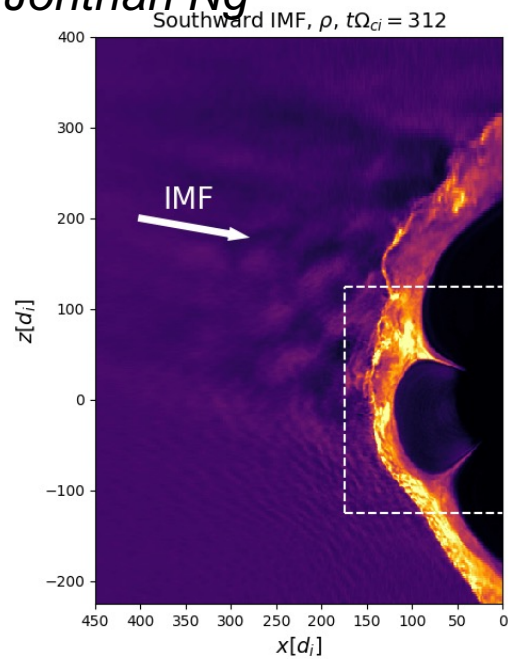


- Introduced local upstream (~10 min) transient variability from local in-situ observations
- Data–model agreement increased drastically
- Physical interpretation of ground data changed significantly

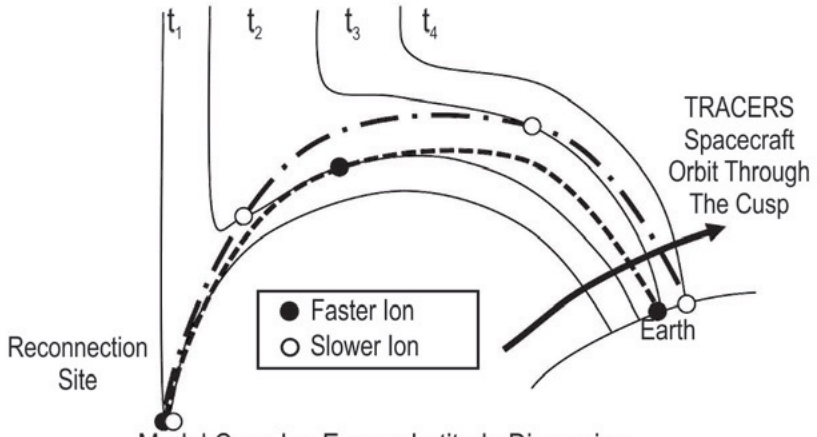
Highlights Tuesday 10:00 – 12:00

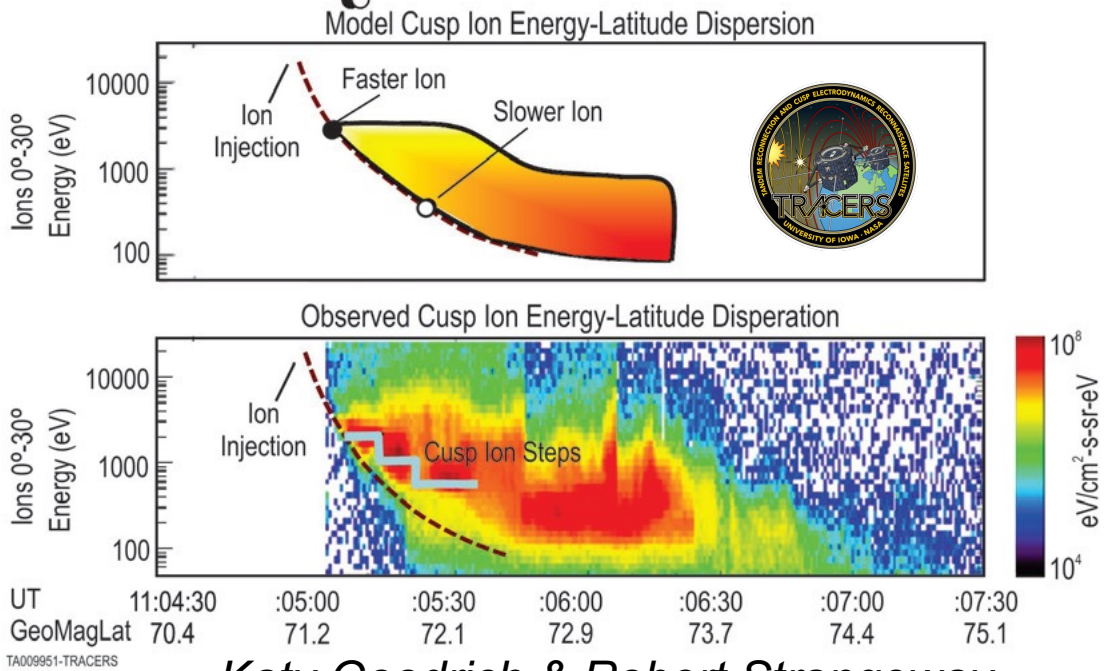


Jonthan Ng

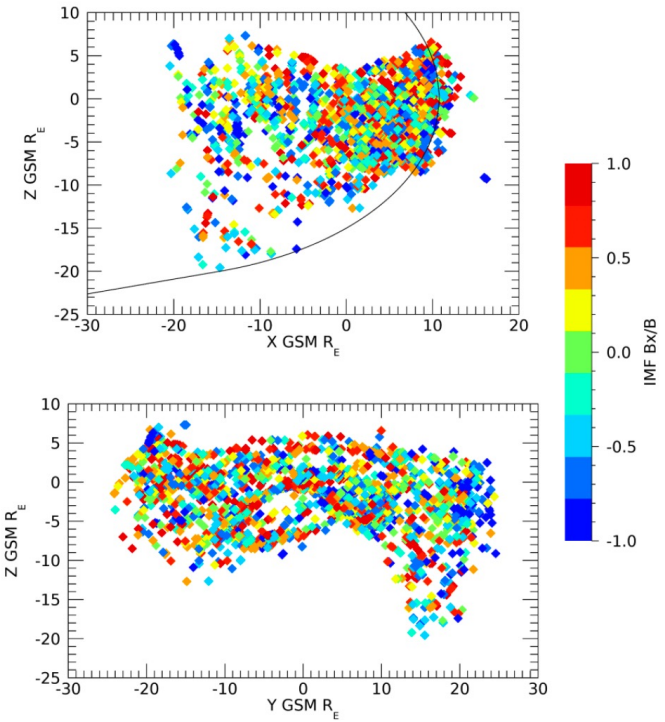


Naoki Bessho





Katy Goodrich & Robert Strangeway



Rachel Rice

Some quotes I read/heard for our FG

"What role do transients play in space weather?"
-M. Hartinger, (Monday) 2025 GEM

"What role do transients play in the development of storms?"
-B. Walsh, (Tuesday) 2025 GEM

"What's your focus group again?"
- Same Anonymous APL colleague, (Sunday) 2025 GEM

"Should we try to gather all lists of transient events to provide targets for modelers? To have examples that have both a space weather impact but also for these that don't?"
-Me, (Monday) 2025 GEM

Reply: "Asynchronous head nodding across the room"

"..aah ye ye.. you have a focus group?"
- Anonymous APL colleague, ~1 week before GEM

"….Daaaaaysiiiide what? …"
- Visibly confused Anonymous, (Tuesday) 2025 GEM

"Oh, nice, I didn't know people work on this?"
- Anonymous, (Tuesday) 2025 GEM

"I am so happy about this focus group! It's very relevant to my research!"
- Several people, 2025 GEM

"This focus group has perfect timing with my PhD topic!"
- Anonymous, 2025 GEM

Upcoming Actions

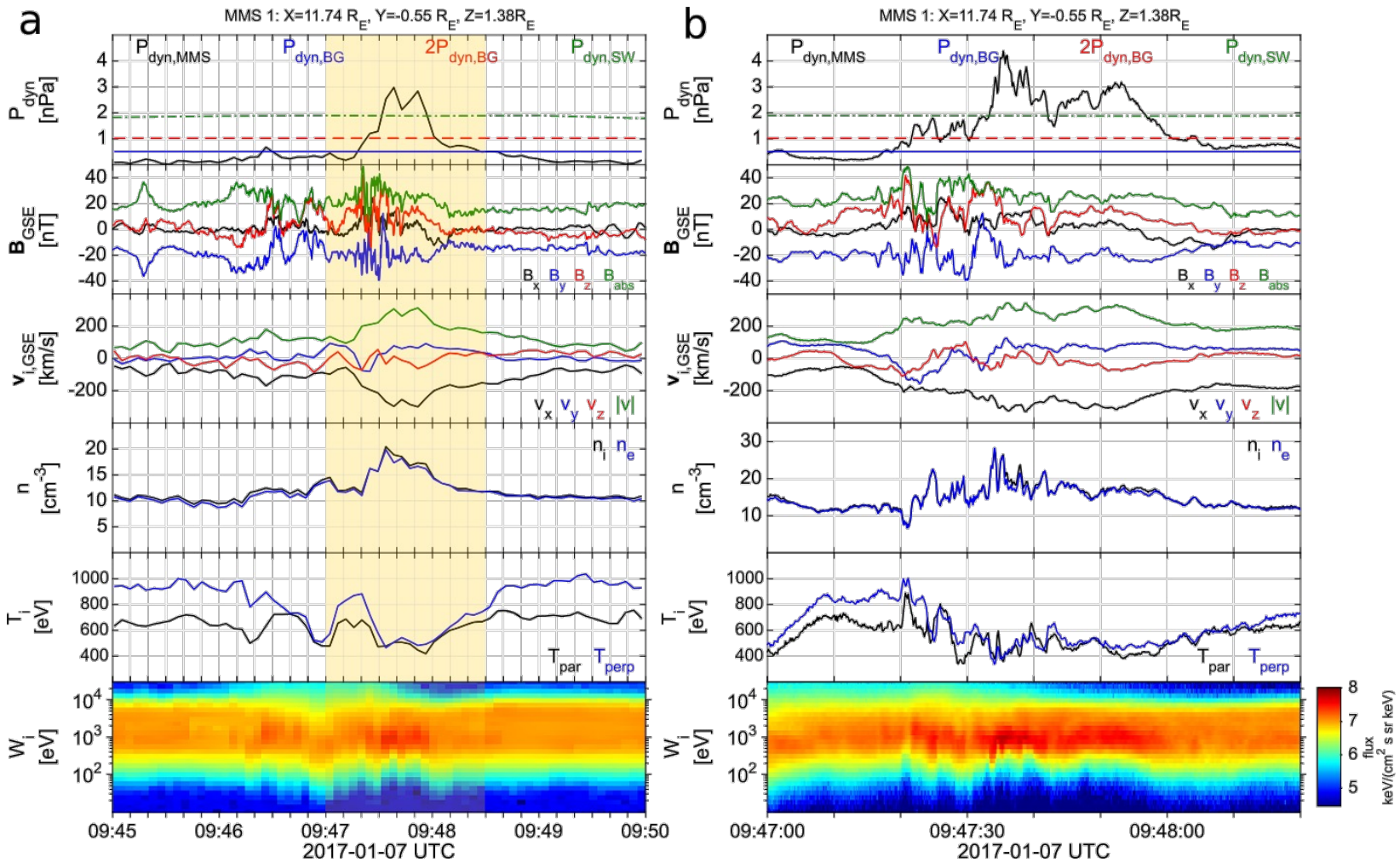
- Wiki Page: https://gem.epss.ucla.edu/mediawiki/index.php/FG:_Multiscale_Dayside_Transients_and_their_Effect_on_Earth%27s_Magnetosphere

Join our Google Group to (at some point…) get updates and information for our telecons and meetings: https://groups.google.com/g/helio-day-research (We will discuss our online activities during GEM/CEDAR 2025 workshop)

Extra Backup Slides

Example of a Transient Event (High-speed jet)

Example of High-Speed jet (MMS Data)



Krämer+ (2025)

MMS helped bridging fluid to ion/electron scales

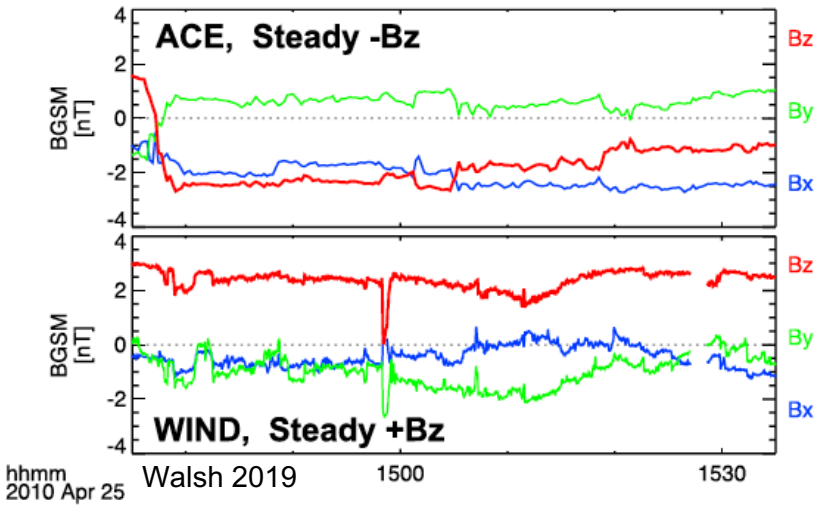
Clarified transient processes:

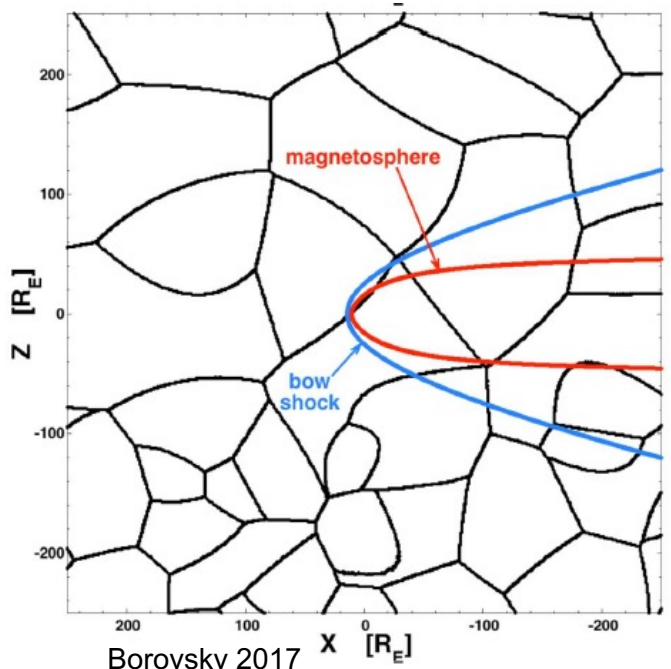
- Formation
- Particle acceleration
- Propagation
- Distribution-function evolution

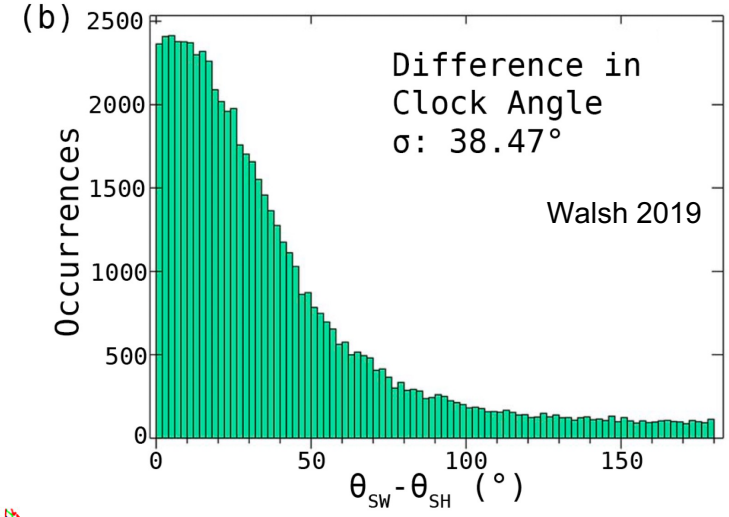
Remaining challenge: co-existing phenomena (HFAs, jets, SLAMS) are interconnected and need deeper investigation

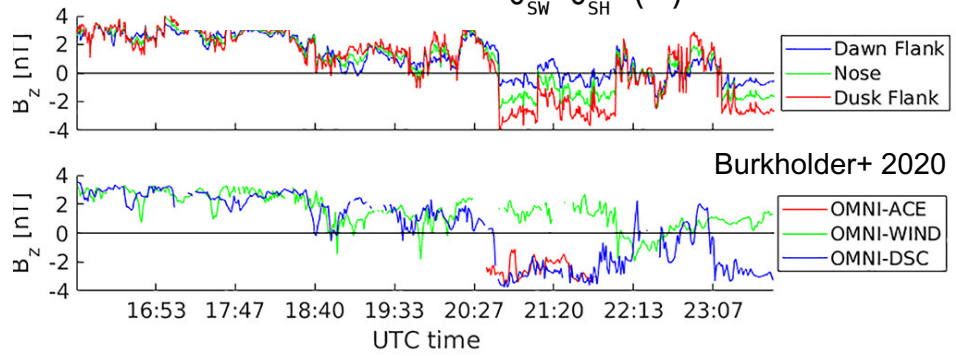
We need more than 4-point measurements and in various scales

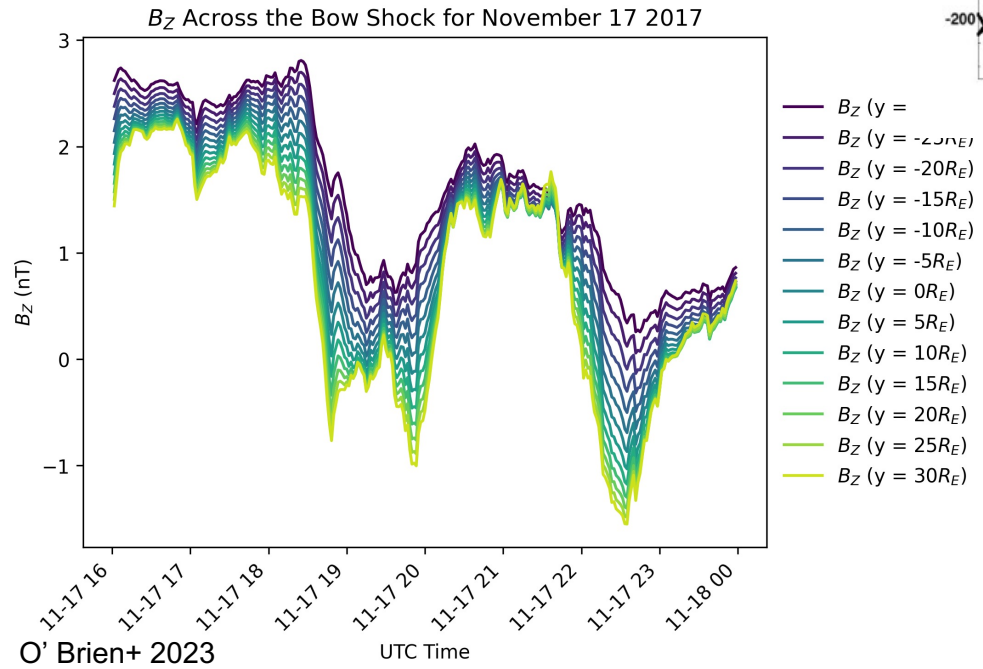
Spatial and Temporal Solar Wind Variability

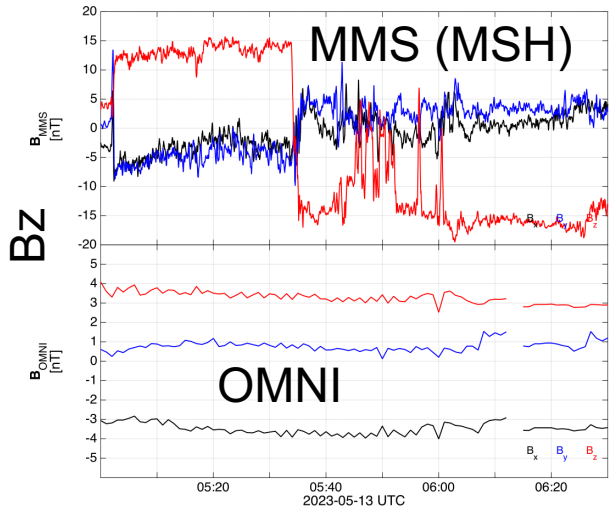


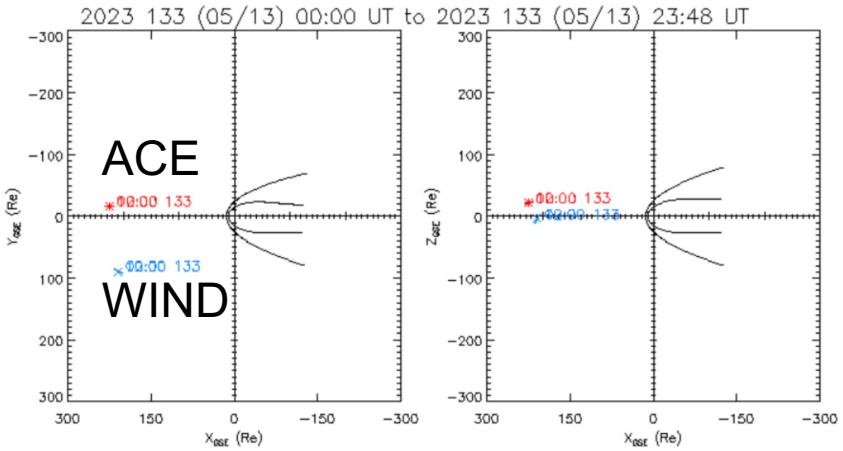




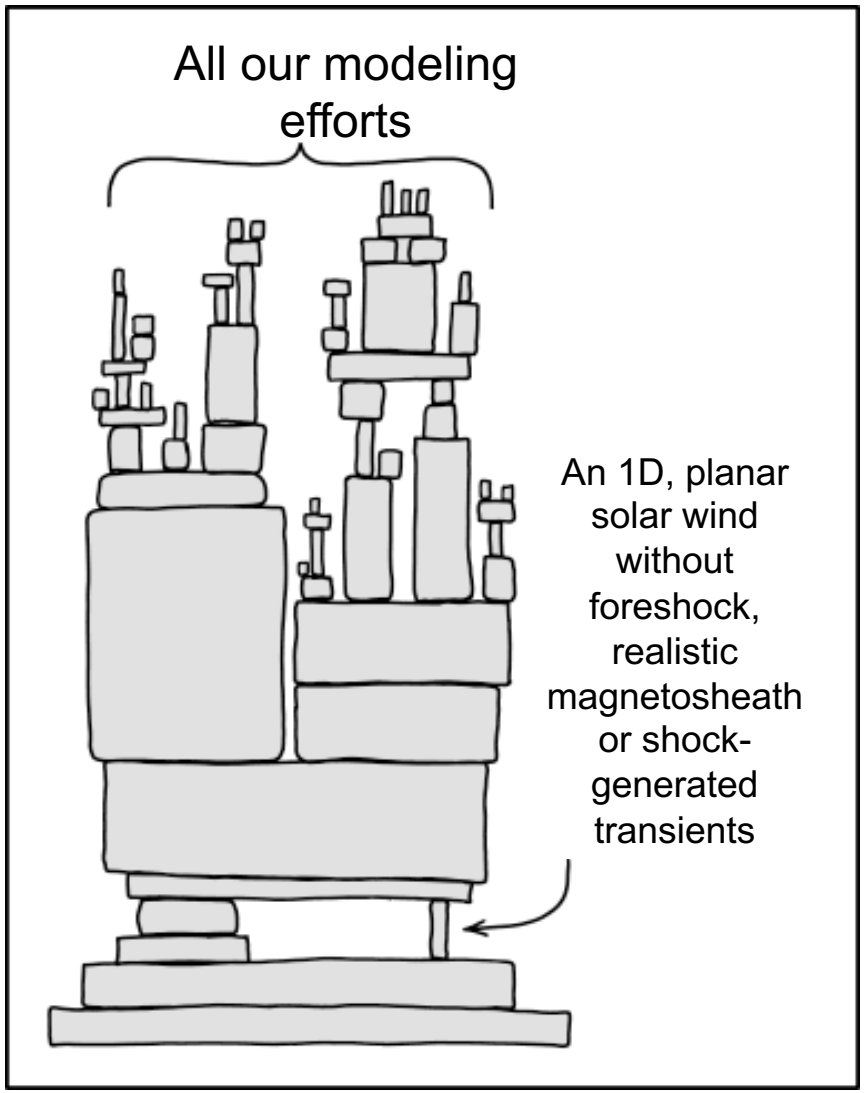








What are we dealing with?



Two challenges:

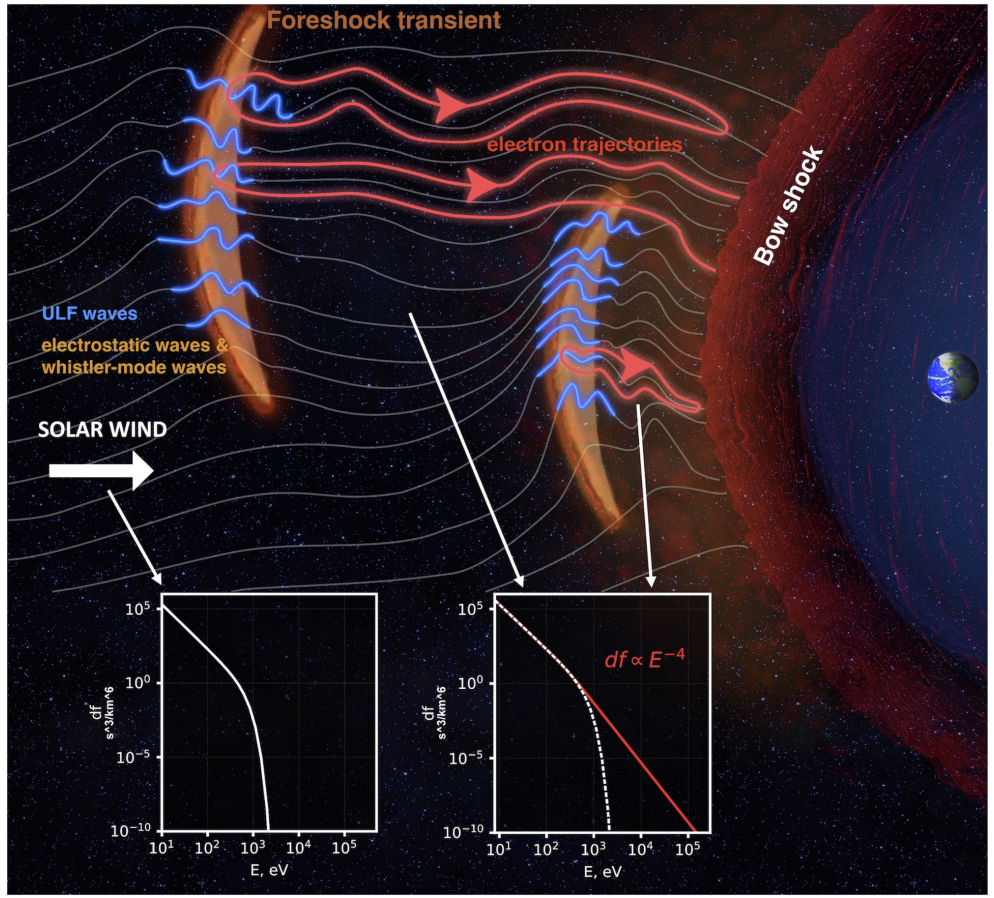
Solar wind information limitations:

- Reality has complex 3D structure and spatial variability.
- It is easier to rely on simple 1D picture that is available than do the extra effort.

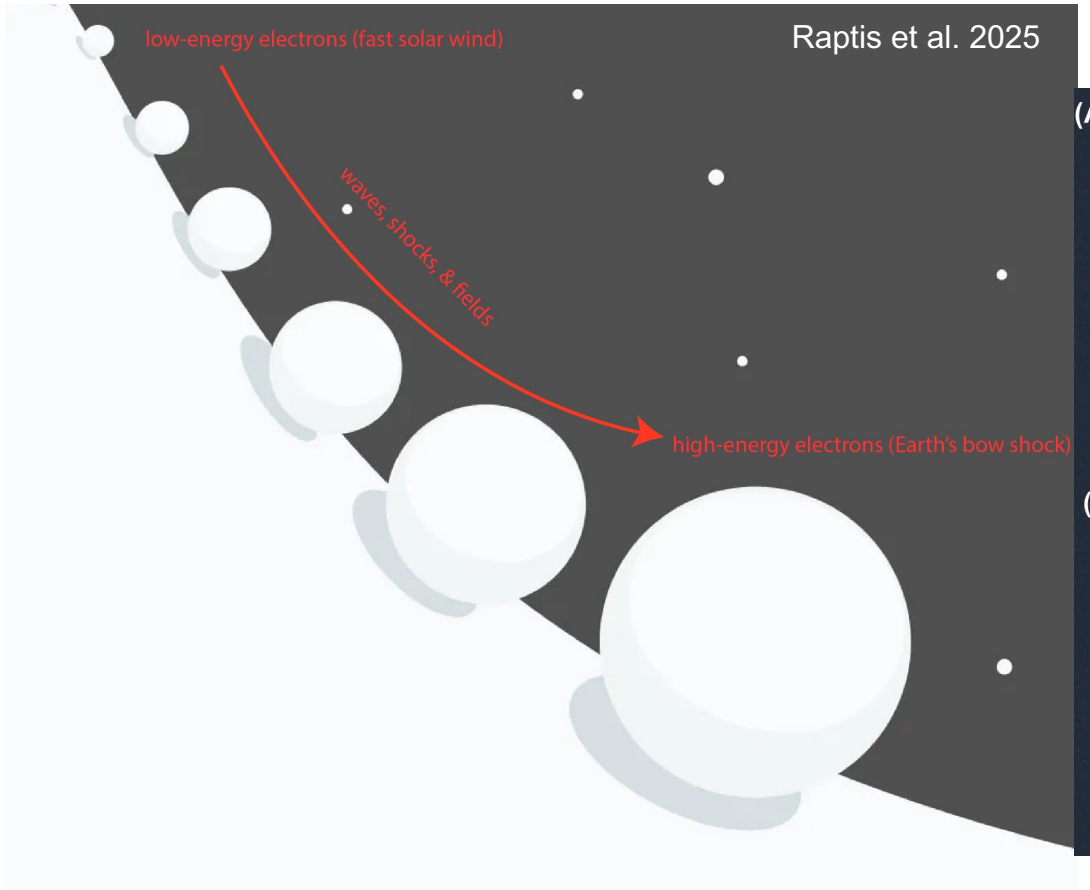
Neglected foreshock and magnetosheath transients:

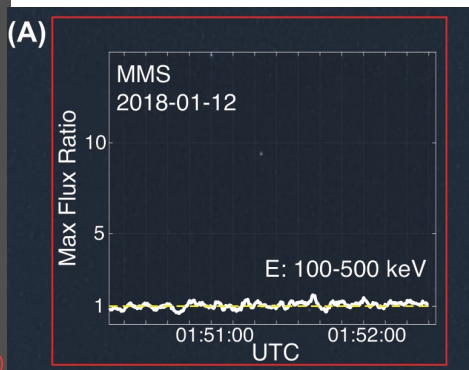
- These transients can affect magnetopause reconnection, and more.
- They are often omitted because they are difficult to include.

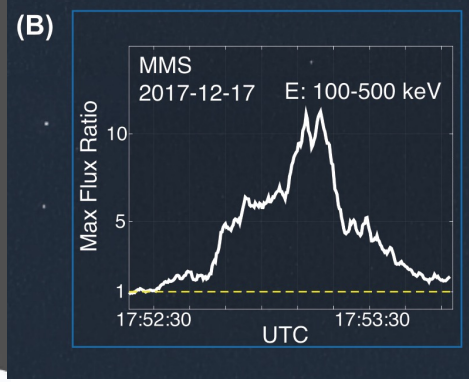
Example on the multiscale aspect: Particle Acceleration



Shi+ 2025







<u>Cross-scale framework from large to kinetic scales:</u>

- Solar wind seeding and universal maximum energy limits
- Excitation of waves and turbulence
- Acceleration mechanisms operating at multiple scales (shock, diffusion, fermi etc.)
- wave-particle interactions driving scattering and energy transfer

Adopting a cross-scale perspective is key to fully interpreting observations

More relevant articles: Turner et al. 2018; Liu et al. 2019; Shi et al. 2023; Tonoian et al. 2023; Kamaletdinov et al. 2024; Li et al. 2025; Oka et al. 2025