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Storm-Time Plasma Sheet Convection: Global Patterns and the Dynamics of Mesoscale Bursty Flows

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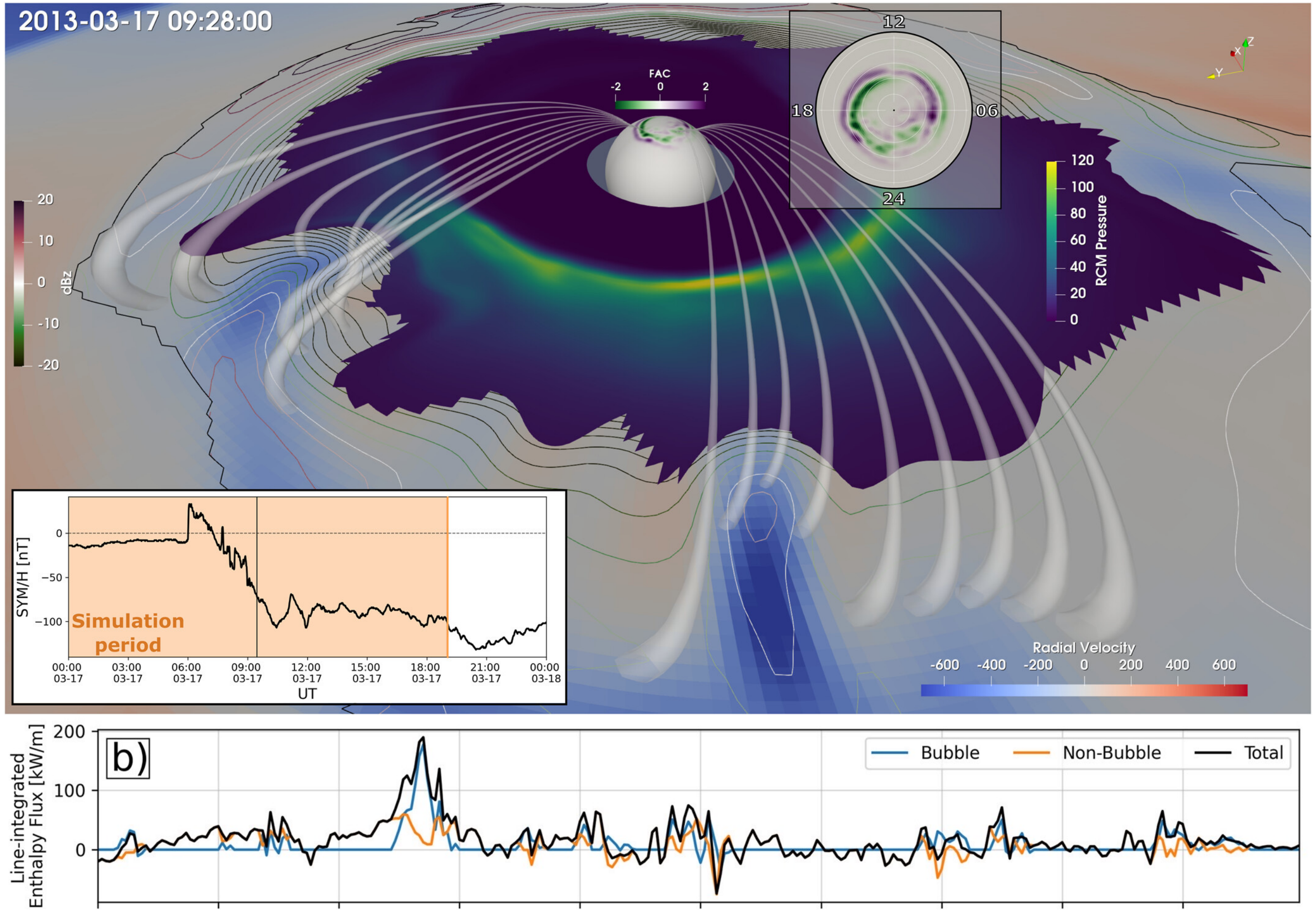
Outline

- Introduction
- Global Convection Patterns - Magnetic Flux **(*)**
- Bursty Interval Contribution (2 Ongoing – “soon” to be submitted works)
- Summary

(*) Raptis, S., Merkin, V., Ohtani, S., Gkioulidou, M., & Regoli, L. H. (2024). **Plasma sheet magnetic flux transport during geomagnetic storms**. Geophysical Research Letters, 51(18), e2024GL110839.

General Context & Motivation



50% of total energy flux transported into the inner magnetosphere by mesoscale structures

Sciola+ 2023

<u>One of CGS objectives:</u>

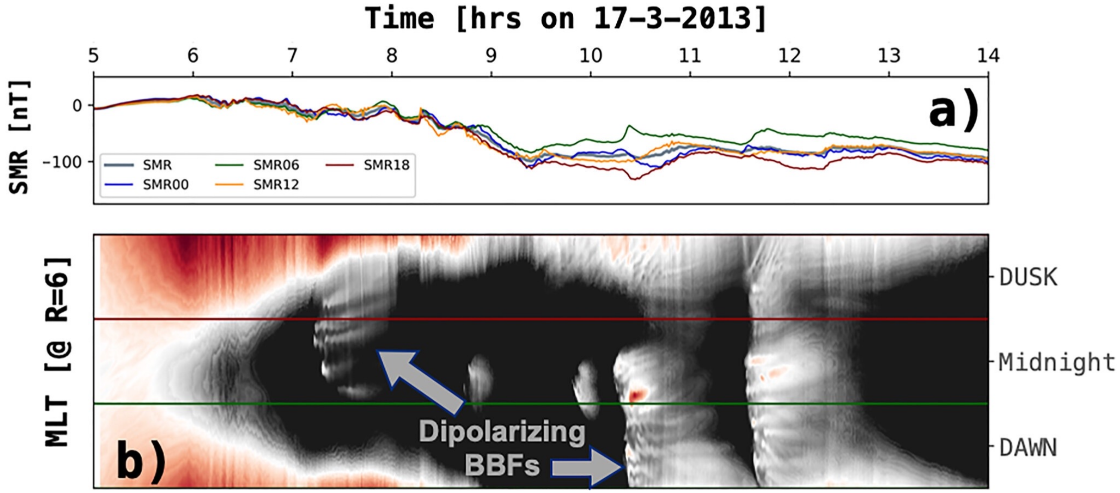
The role of **mesoscale plasma sheet** transport in the **ring current** build-up

- To tackle this **we need** to establish a **clear understanding** of the overall **plasmasheet transport during quiet and storm times**.

<u>This work:</u>

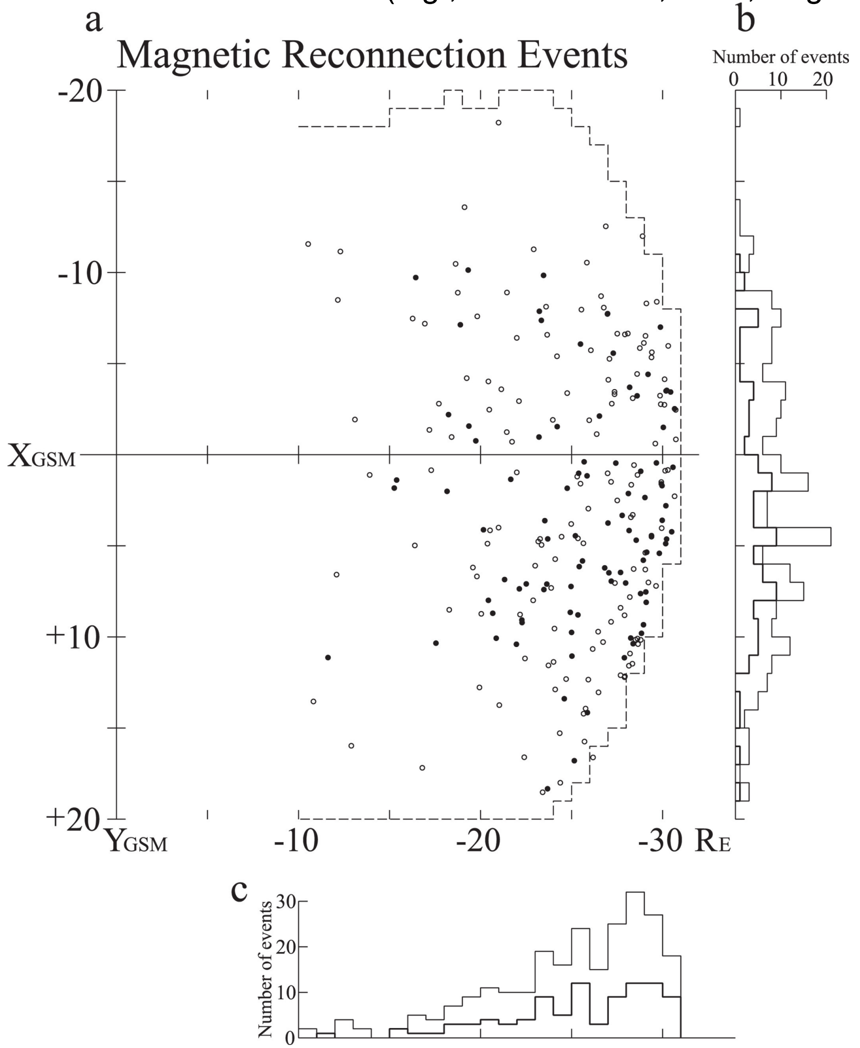
- Focus on **magnetic flux transport** during storms
- Building towards a holistic multi-spacecraft evaluation including mass and energy transport

Dawnside Current Wedge & Asymmetries in Magnetopause Reconnection



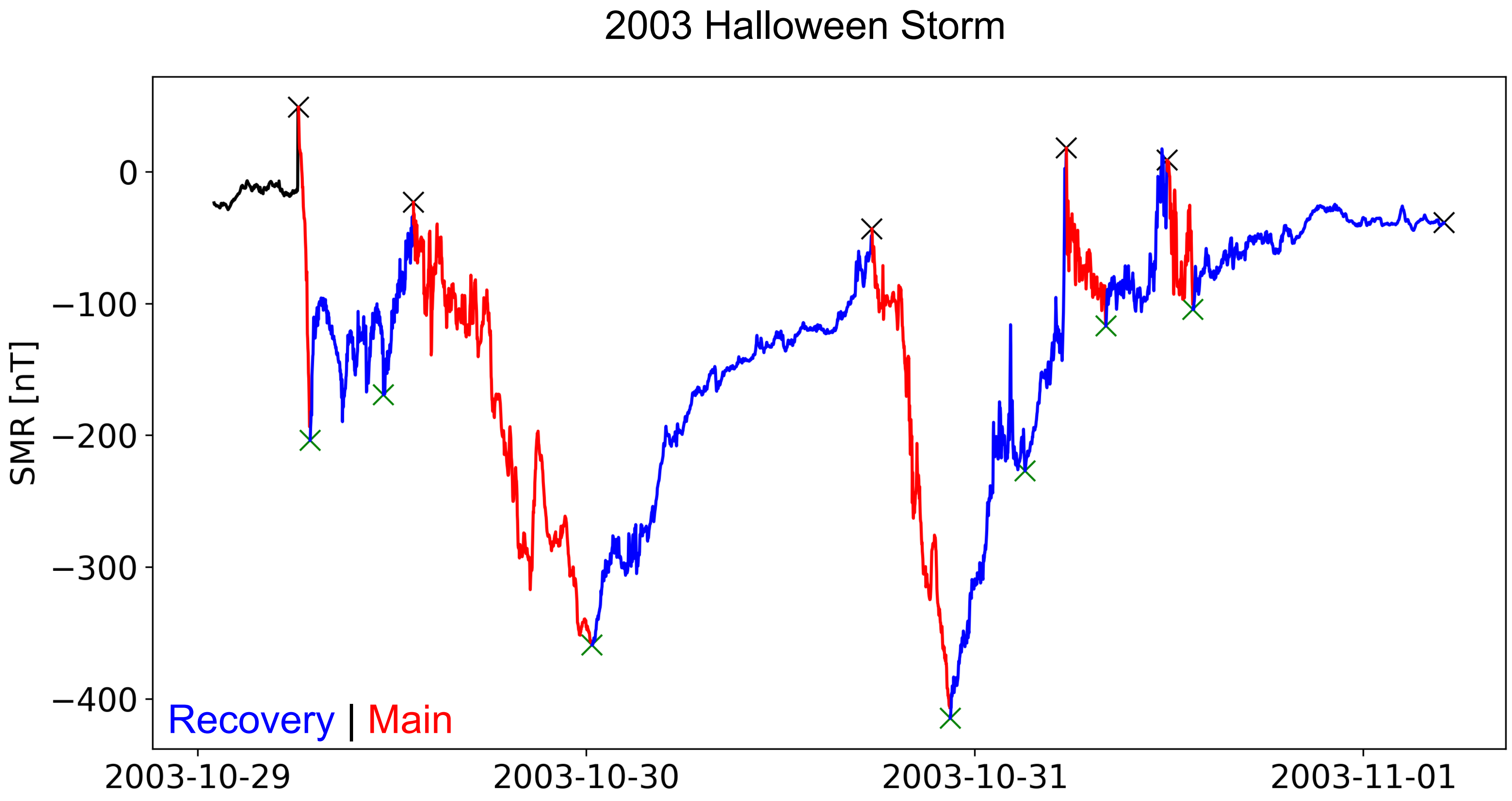
Ohtani+ 2021 Sorathia+ 2023

*Similar results with MMS (e.g., Hubbert et al., 2022; Rogers et al., 2023).



Nagai+ 2023

Storm phases classification



Verified with methodology of Ohtani 2021

https://zenodo.org/records/15127938

Plasmasheet Coverage per mission

Criteria to find CSP

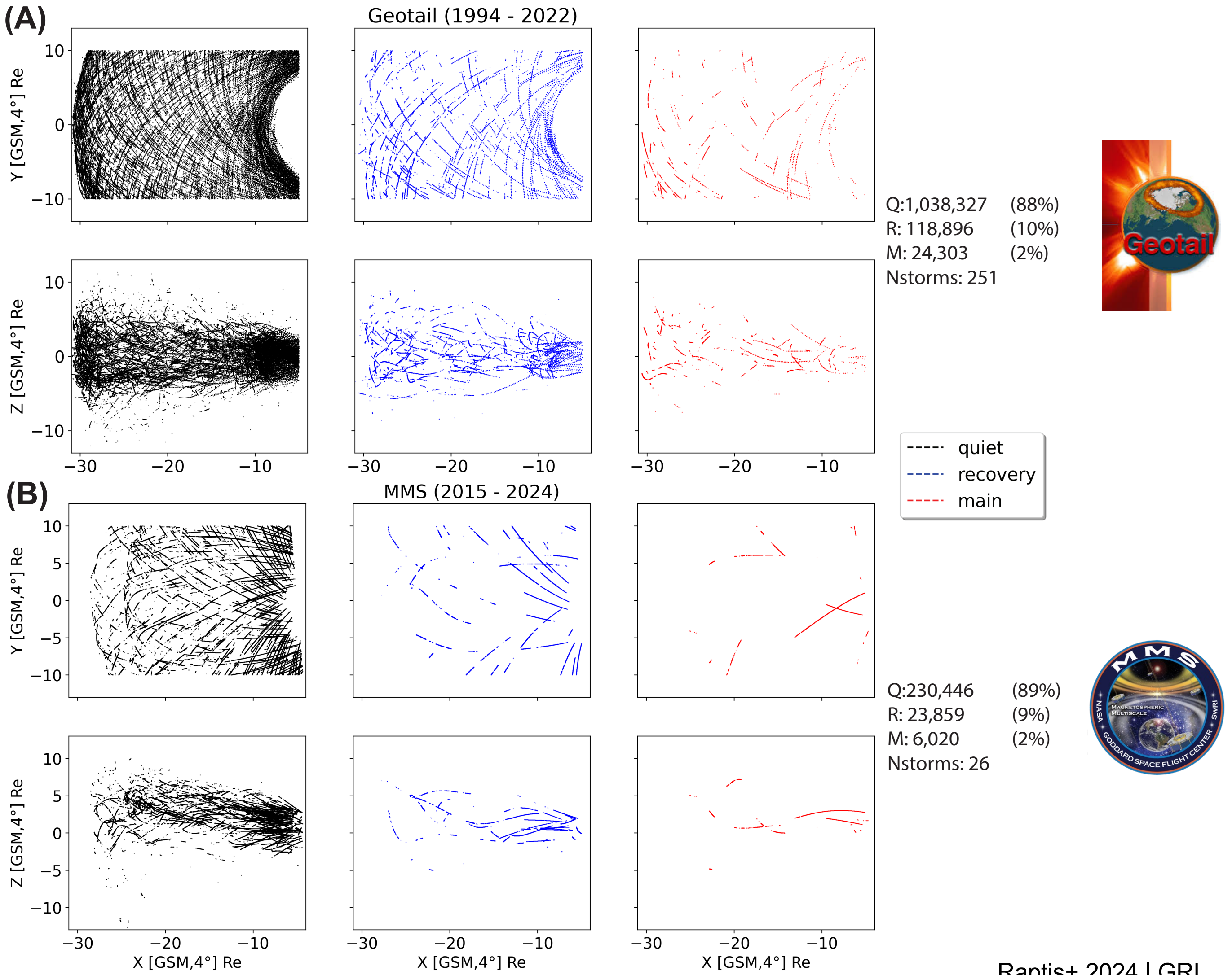
1. $|Y_{GSM,4°}| < 10$
2. $-5 < X_{GSM,4°} < -30$
3. $\beta = \frac{P_{the}}{P_{mag}} > 1$
4. $|Bz| > 2\sqrt{Bx^2 + By^2}$

See e.g., Ohtani+ 2008, Guild+ 2008, Roziers+ 2009, Vo+ 2023

Geotail > 1 million points ~250 storms
MMS ~ 250k points ~25 storms

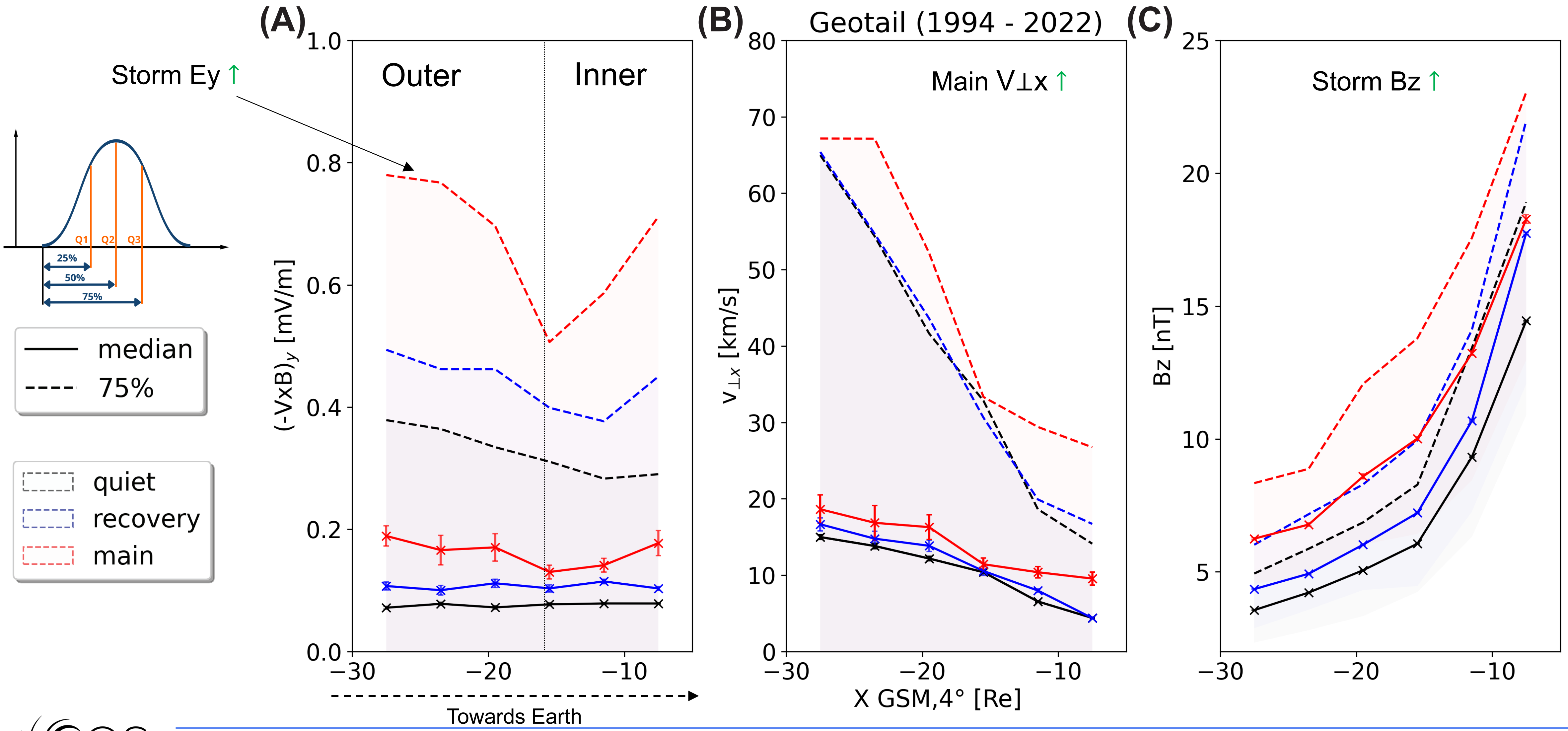
Findings:

1. **MMS** have limited observations during storm times (especially main phase)
2. Main phase contains data from about 6 storms for **MMS**
3. Slightly more dawnside data during main phase for **Geotail**

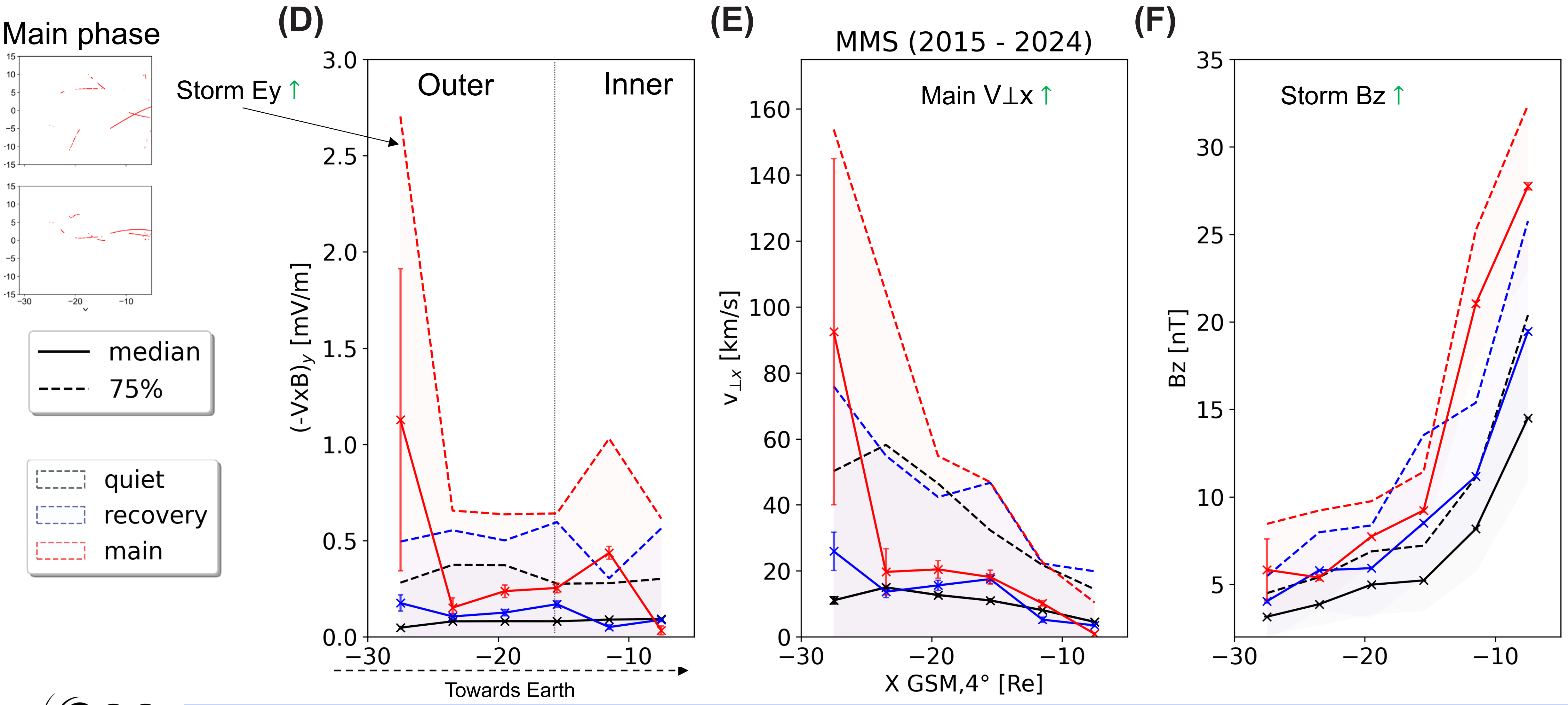


Raptis+ 2024 | GRL

Plasma Sheet Convection – Geotail

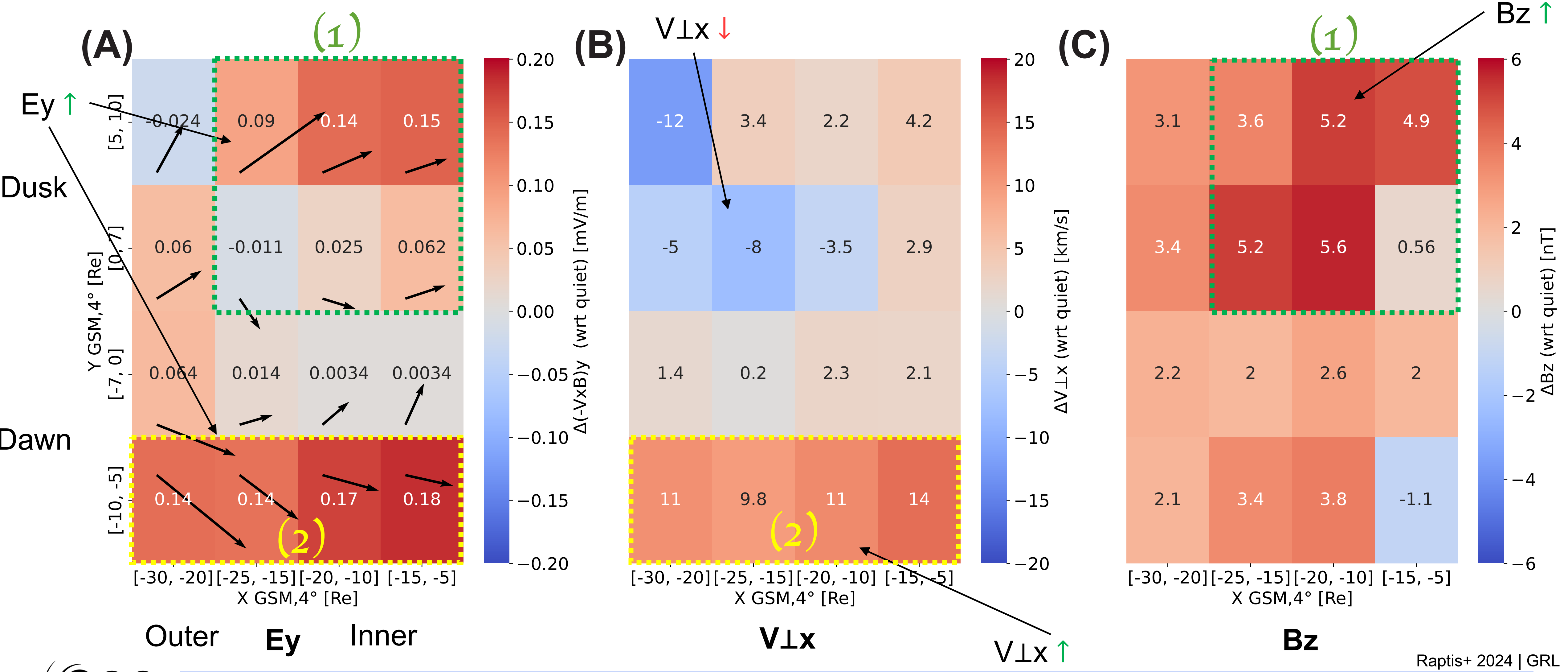


Plasma Sheet Convection – MMS



Storm - Main Phase Difference (Geotail | 1994 - 2022)

Dawn sector: storm-time magnetic flux transport linked to **faster plasma flows**
Dusk sector: storm-time magnetic flux transport linked to **stronger dipolar magnetic fields**



Raptis+ 2024 | GRL

What do we know so far?

<u>Plasma sheet storm time:</u>

1. **Elevated Ey** associated with **increased Bz**, and **limited enhancement of** V⊥x
2. **Dusk observations showing more dipolar magnetic field (Bz** ↑)
3. **Dawn** are associated to **relatively faster flow (V⊥x** ↑)

Let's move to Bursty Intervals

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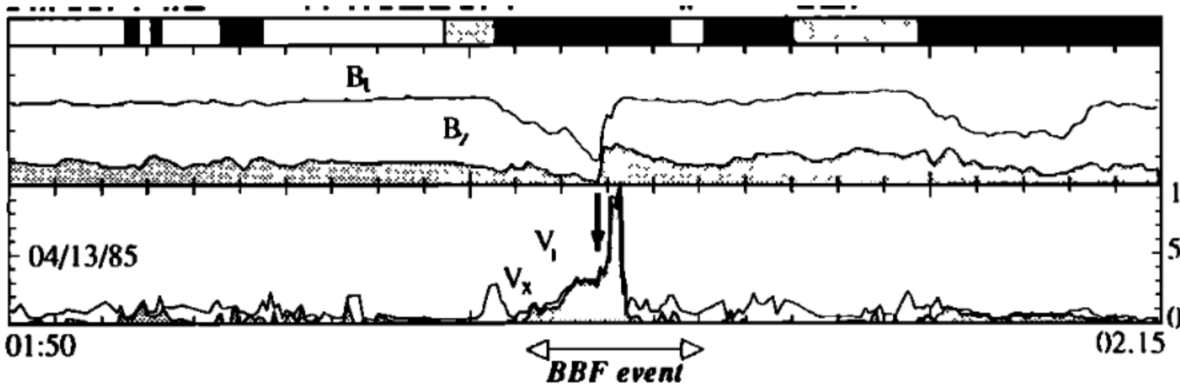
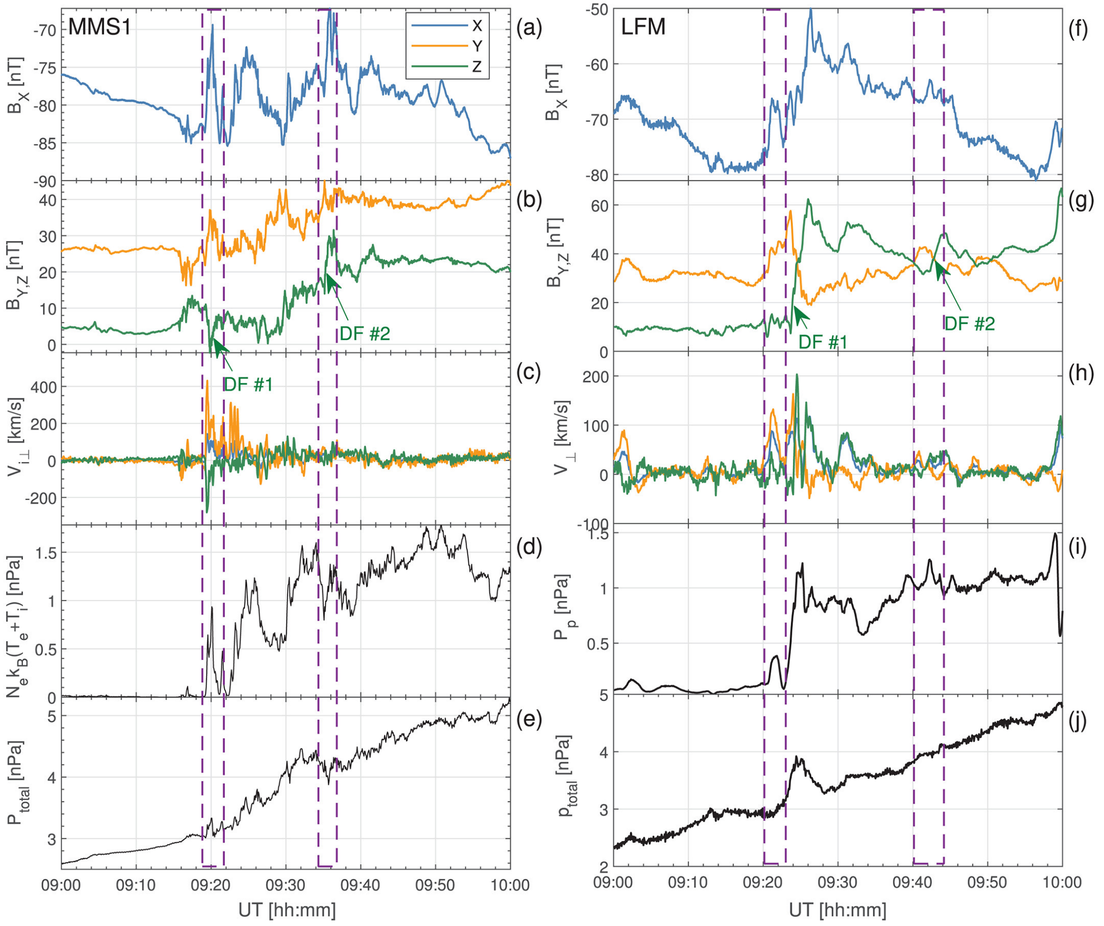
What is a bursty interval ? (BBFs, BEIs, etc.)



Scholer+ 1984, Baumjohan+ 1990, Angelopoulos+ 1991



Merkin+ 2019

<u>BBFs:</u>

- Fast ion flows (v >400 km/s),
- 10-100s in duration
- ~ 4 Re size
- Associated with a Dipolarization front (DF)

BEIs = Bursty Electric field Intervals.

Bursy Intervals – definition and issues

(1) What are the thresholds and in which quantity?
(2) Are these thresholds physical or ad hoc?
(3) Are there observational biases?
(4) What are instrumentation limitations?
(5) Do we combine nearby measurements?
++++

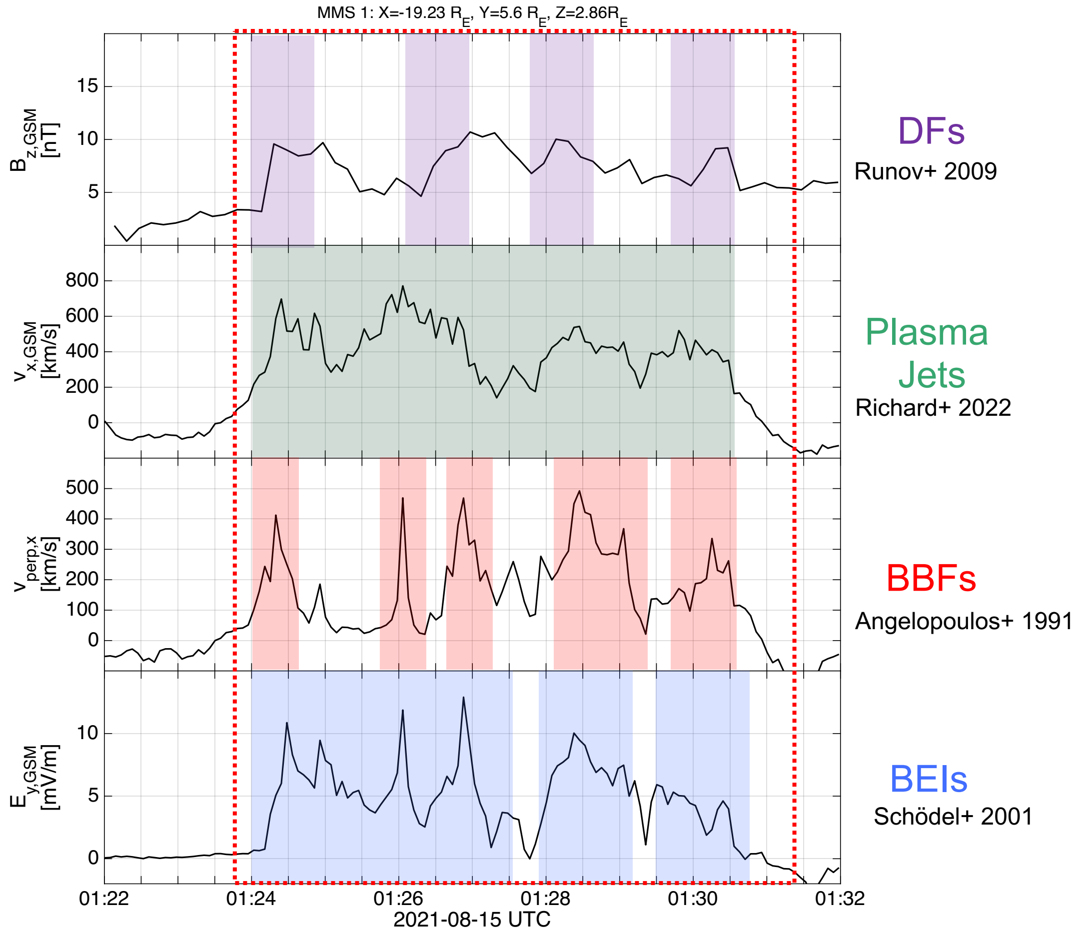
<u>Here, we used:</u>

- No combination of nearby intervals
- PS classified with 2 set of criteria*
- Geotail with total ion plasma instrument moments
- Ey ~ (-VxB)y

<u>BBFs | BEIs:</u>

1 point : $v_{\perp,x} > 250 \frac{km}{s}$ | $E_y > 2 \frac{mV}{m}$

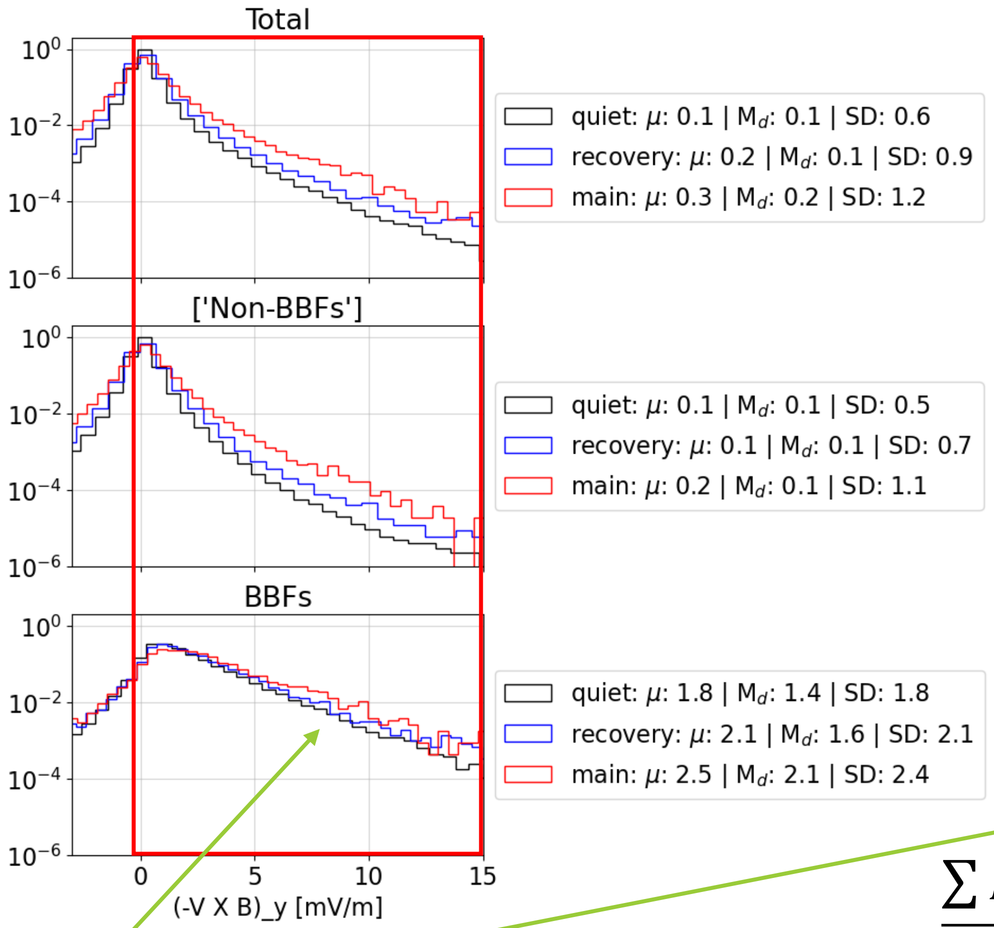
Interval: $v_{\perp,x} > 100 \frac{km}{s}$ | $E_y > 1 \frac{mV}{m}$



*Strict: |Y| <10 [Re] | β >1 | $|Bz| > 2\sqrt{Bx^2 + By^2}$ | n<3 [1/cc])
Flexible: |Y|< 15 [Re] | β > 0.5 | n <5 [1/cc])

Earthward Bursty Magnetic Flux Transport

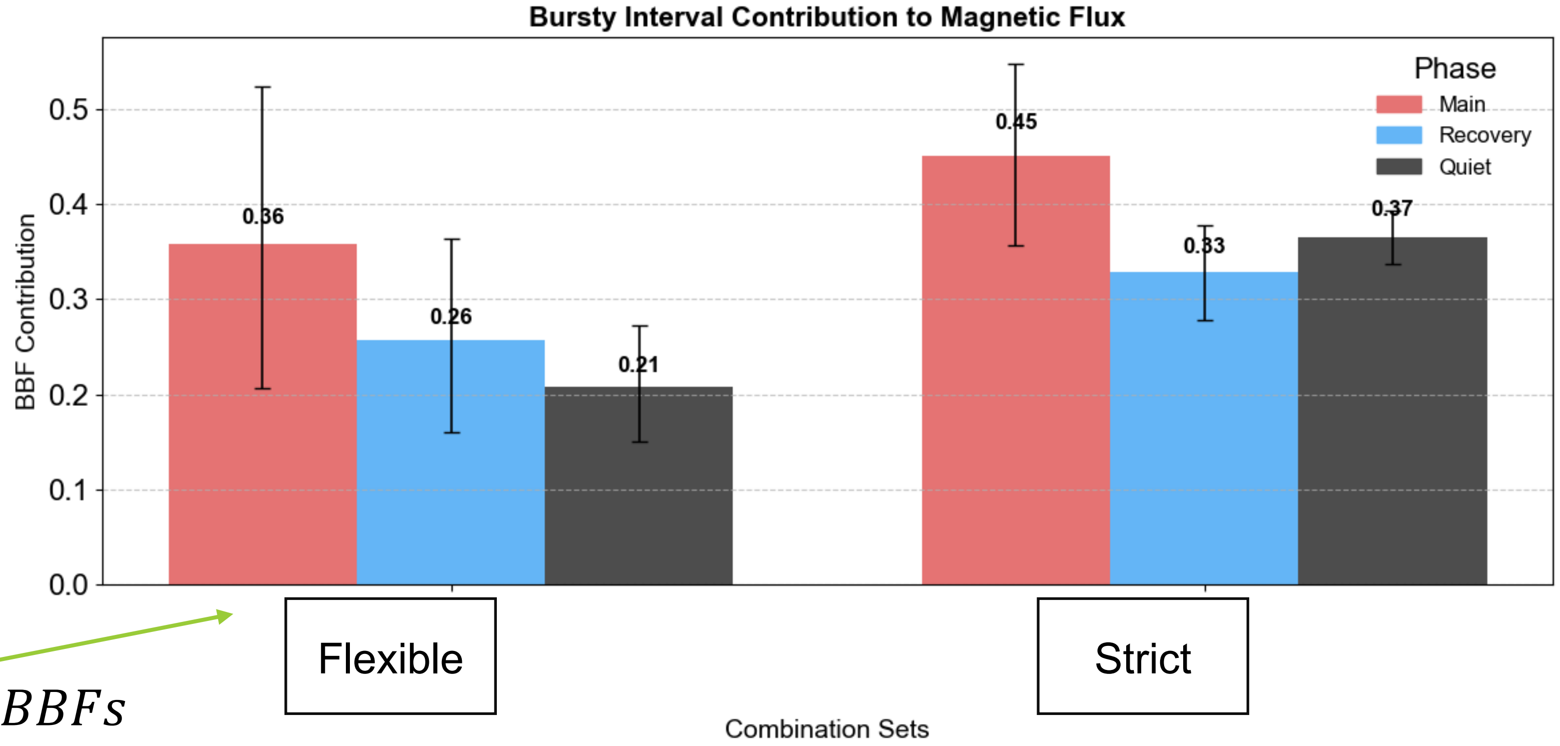
Histograms are normalized per phase



Similar profiles between phases*

Strict: |Y| <10 [Re] | β >1 | $|Bz| > 2\sqrt{Bx^2 + By^2}$ | n<3 [1/cc])

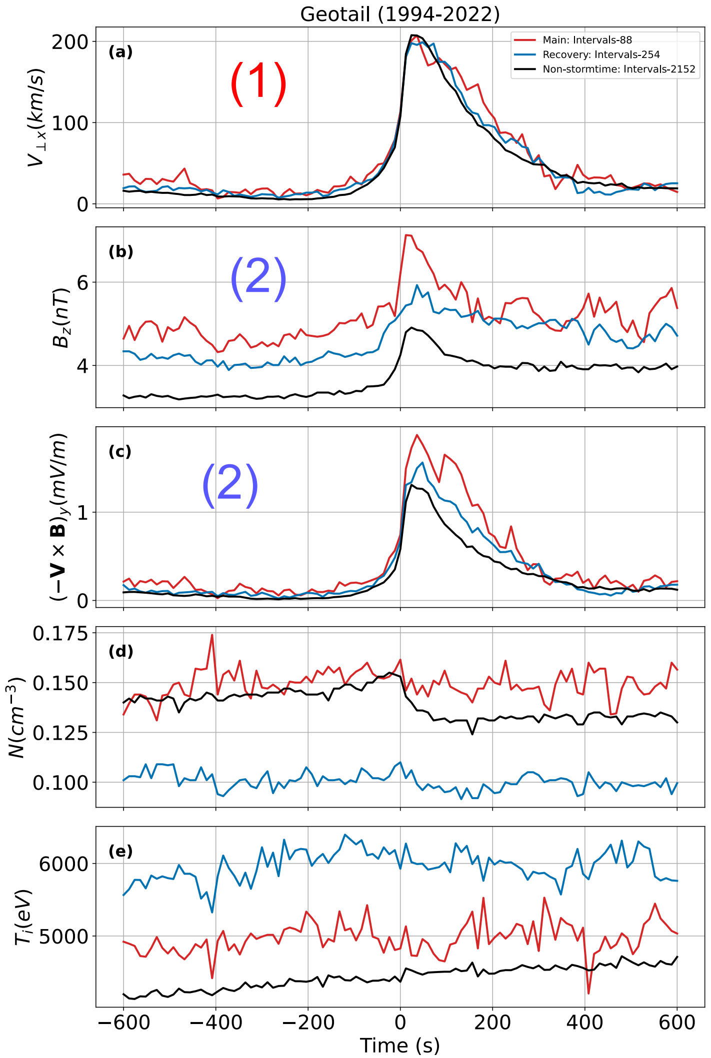
Flexible: |Y|< 15 [Re] | β > 0.5 | n <5 [1/cc])

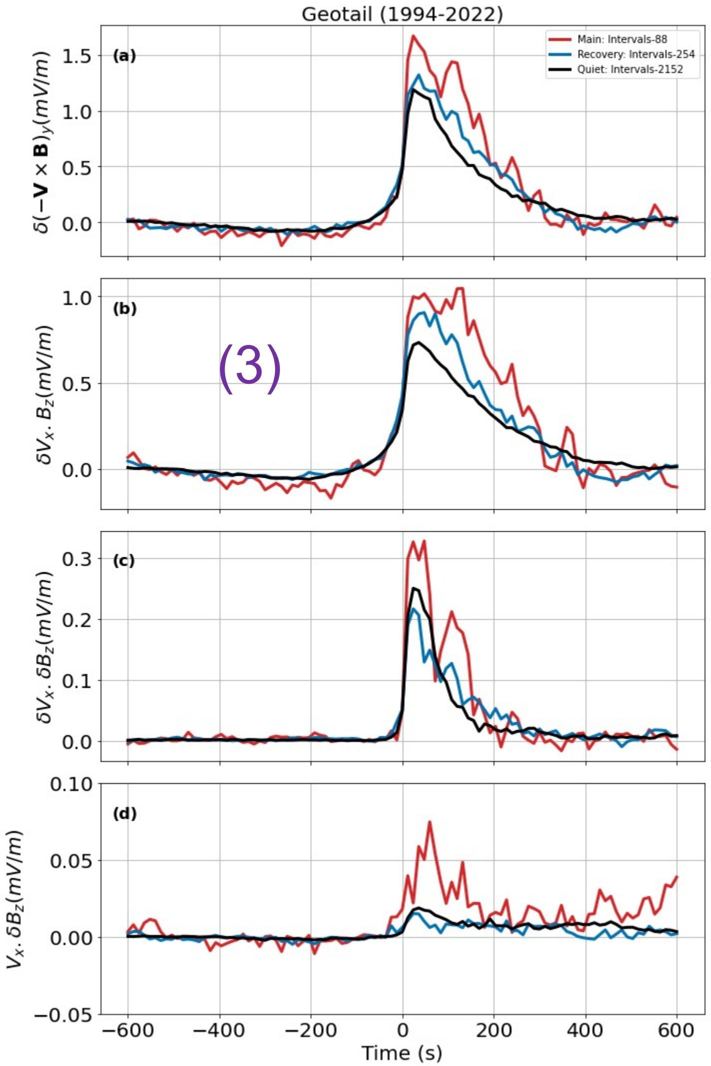


$$\frac{\sum BBFs}{\sum total}$$

Error bars: min/max of dataset variations

BBF Properties during Geomagnetic storms





Key Results:

1. Storm-time BBFs transport **more magnetic flux** than non-storm BBFs.
2. This is linked to a **stronger background Bz**, while BBF velocity stays about the same.
3. In both storm and non-storm cases, the **flux enhancement comes mainly from the elevated BBF velocity.**

Devanandan et al., 2025 (ongoing)

Summary and Next Steps

1. Stormtime Global Convection (**published**):
   1. **Plasma sheet Ey** is elevated due to **increased Bz**, with **limited enhancement of $V_{\perp x}$**
   2. **Bz enhancement** is more **prominent** at **Dusk**
   3. **$V_{\perp x}$** is more **elevated at Dawn**
2. Plasma sheet bursty Intervals (**Ongoing**):
   1. **BBFs can** contribute **~25%** of **earthward magnetic flux** during **quiet and ~40% during main phase.** This is linked to a **stronger background Bz**, while BBF velocity stays about the same.
   2. For storm and non-storm cases, **flux enhancement comes mainly from the elevated BBF velocity.**

Future plans:

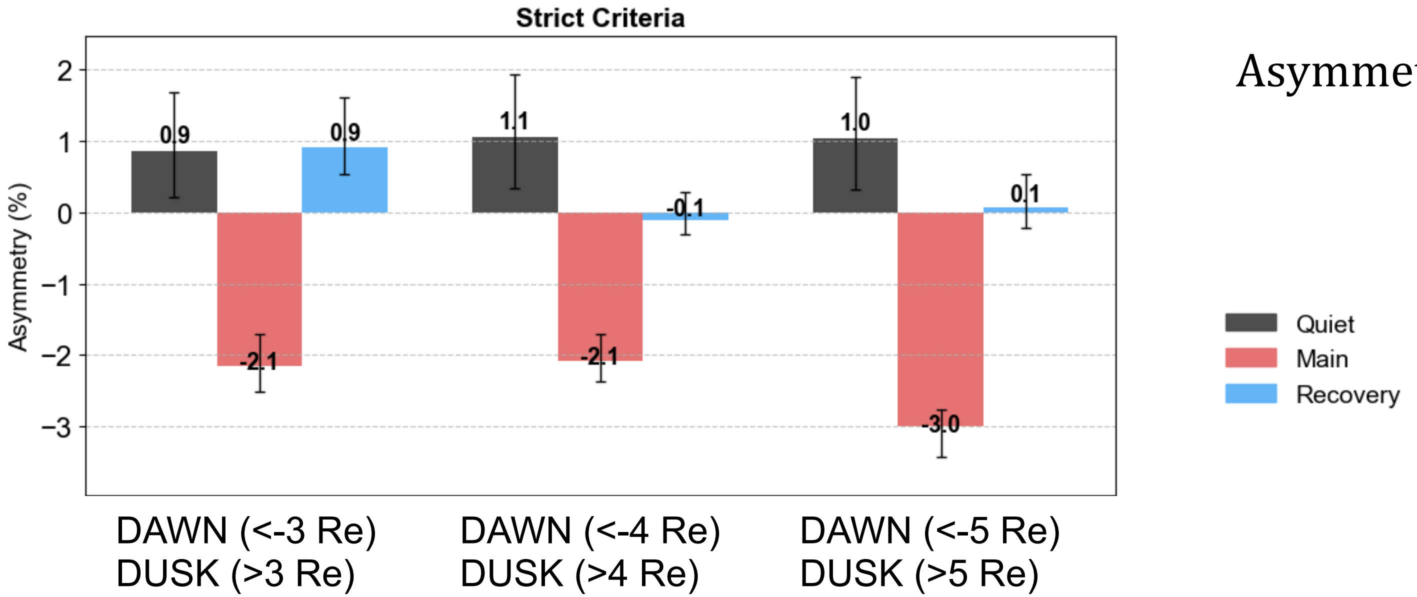
- Evaluate mass and energy flux transport
- Create similar datasets and evaluate THEMIS
- Evaluate MHD scales with MMS string-of-pearl campaign against MAGE simulations

Extra

Dawn – Dusk Asymmetry of BBFs/BEIs

Bursty Interval Occurrence: ~2-4% quiet times | ~4-8% main phase

$$\text{Occurence} = \frac{\text{BBF Points}}{\text{Total Points}}$$



$$\text{Asymmetry} = \frac{\text{Occurrence Dusk}}{\text{Occurrence Dawn}}$$

Same message: Across all combinations = Dawn preference during main phase and Dusk during quiet

Error bars = min/max based on definition of bursty interval

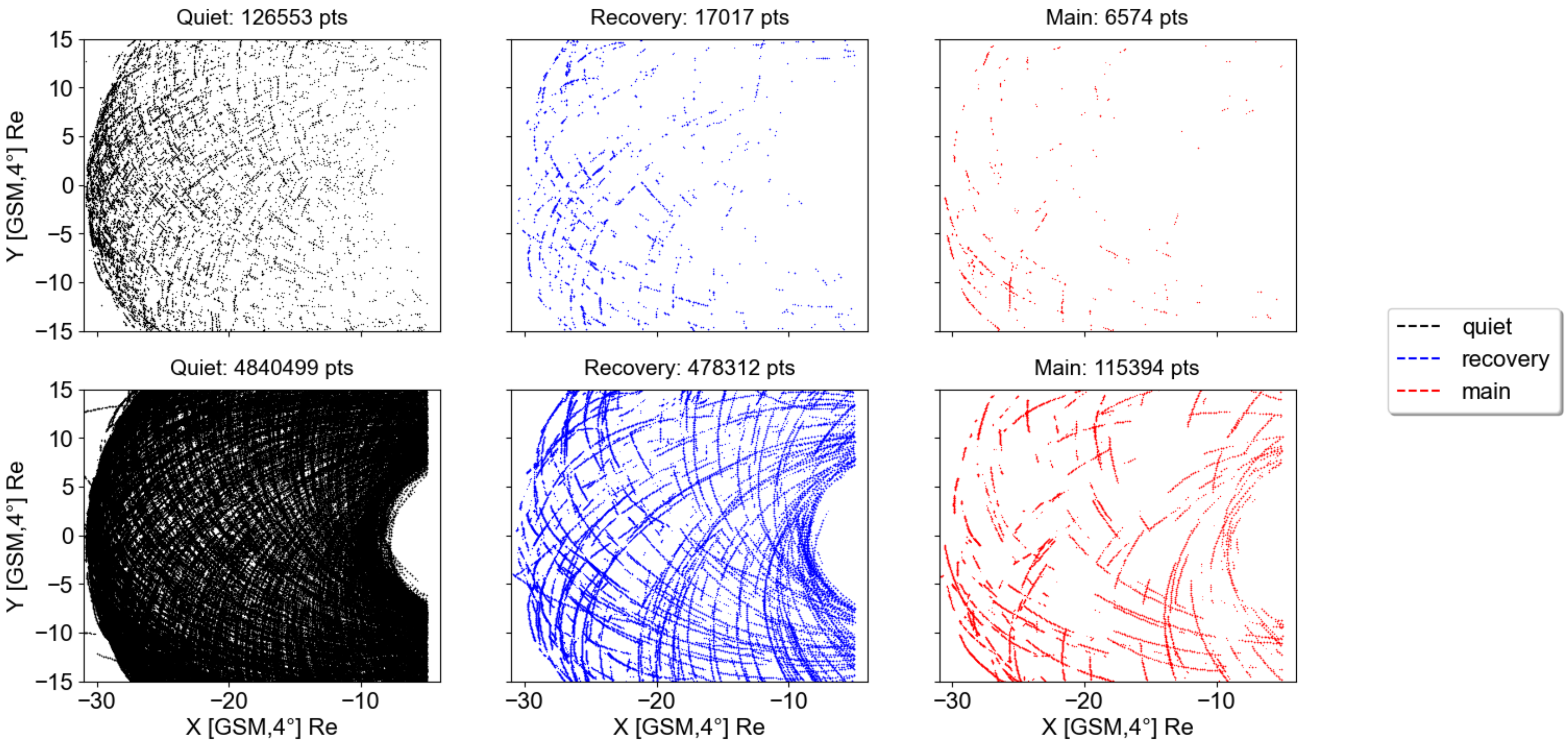
Different sets = Different definition of dawn/dusk

Consistent with Nagai+ 2023 and DCW

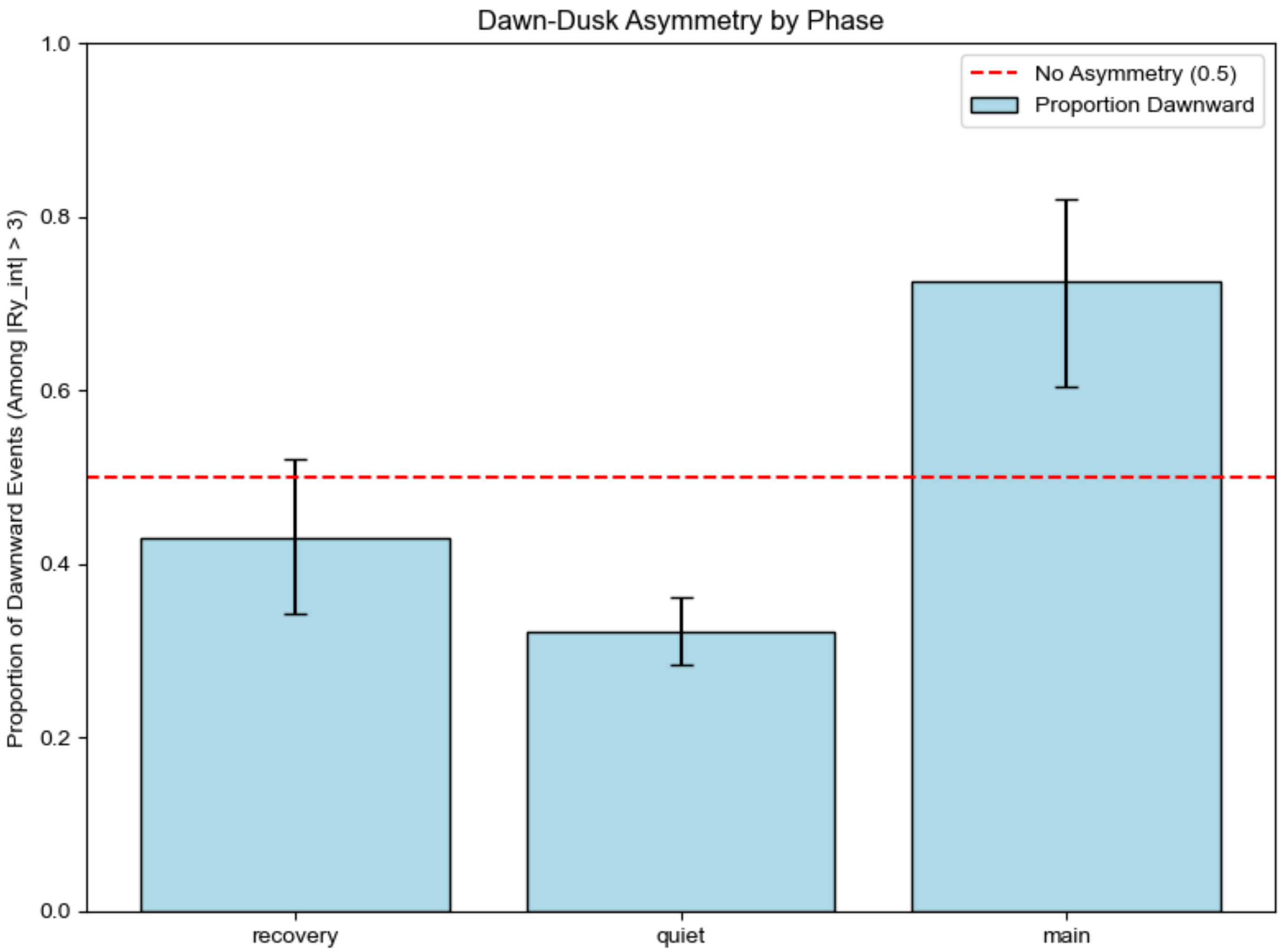
Statistics Caveat for bursty flows – Geotail (1994 – 2022)

BBFs

No BFFs

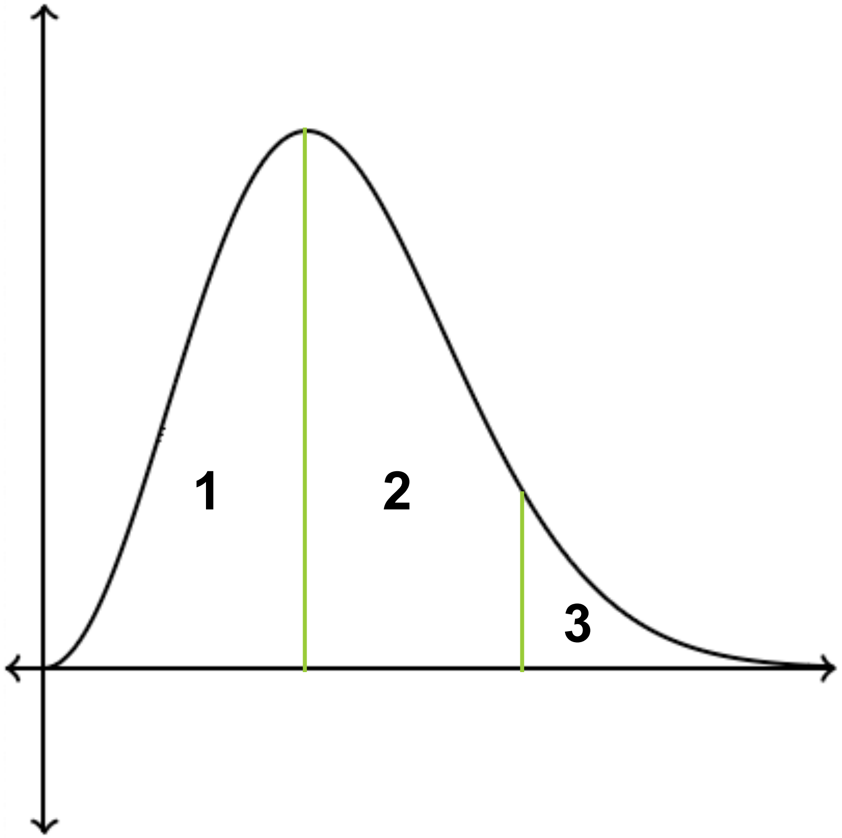


Magnetotail Reconnection Asymmetry



Nagai+2023 Geotail data

The problem of saying Mesoscale structure transfer everything



Definition of bursty mesoscale structures → tail

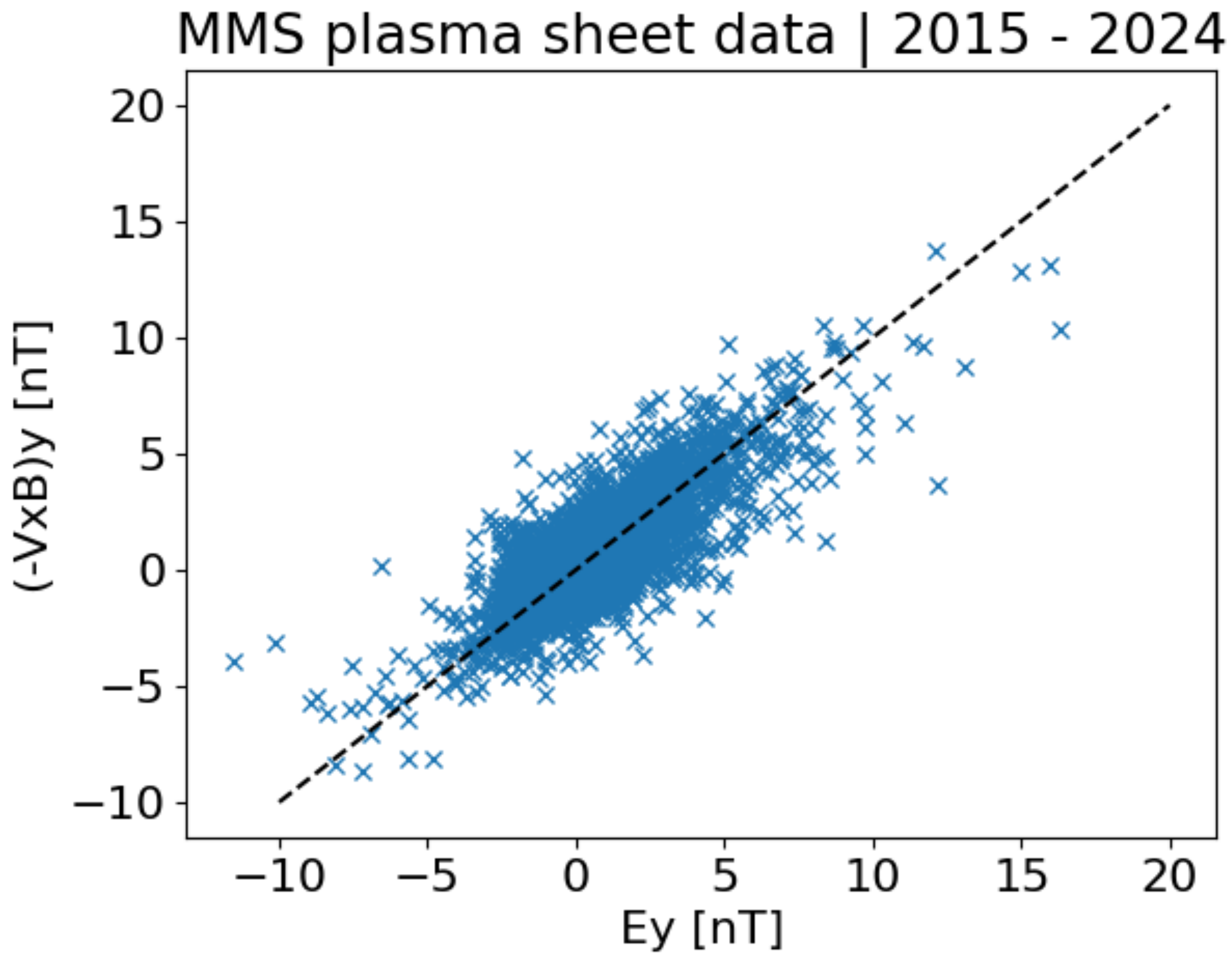
Case A: 1 ~ 2 → 3 is doing all the work
Case B: 1 ~ 3 → 2 is doing all the work

Both are equally valid in a statistical sense

Also, case A is mathematically speaking obvious.

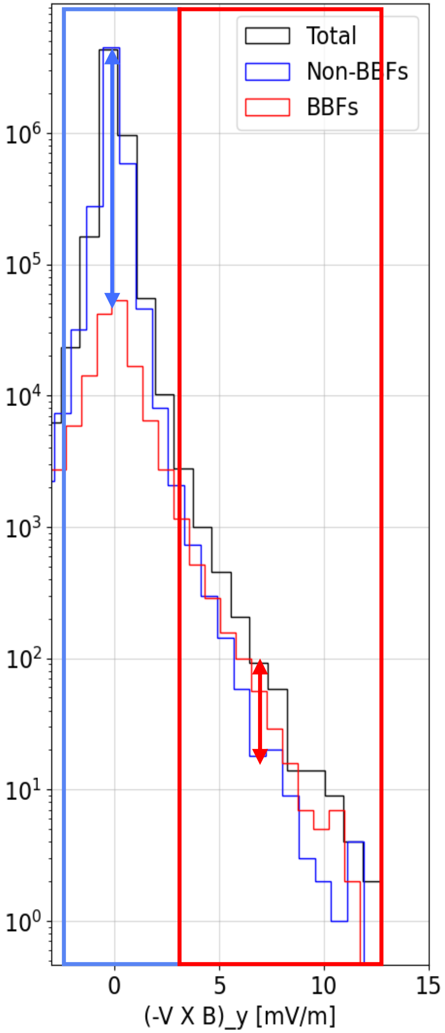
Can we use VxBy as a proxy of Ey?

Yes



No

Reminder: Bursty Intervals Dominate the Tail

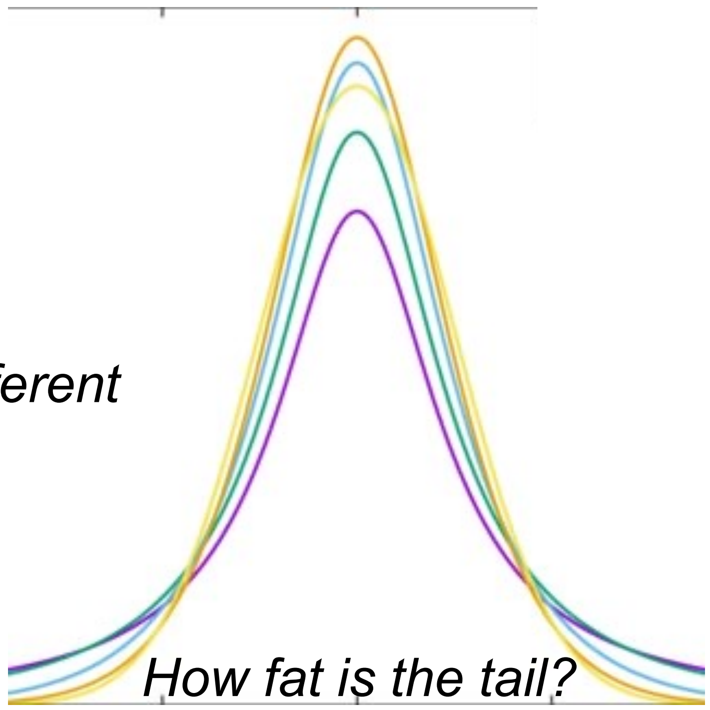


By definition:

Core is dominated by global convection (slow flow)
Tail is dominated by BBFs (fast flow)

The question is then mathematically speaking:

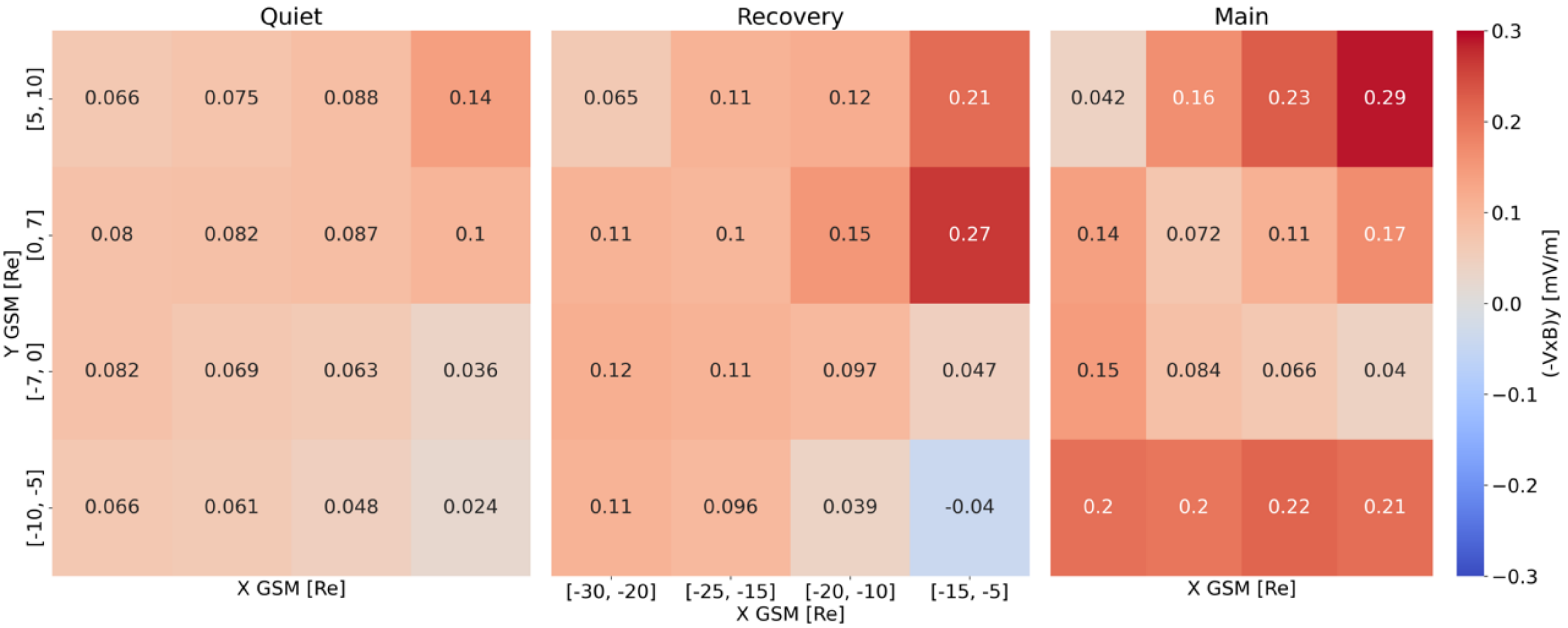
How strong the tail of a distribution is during different geomagnetic conditions?



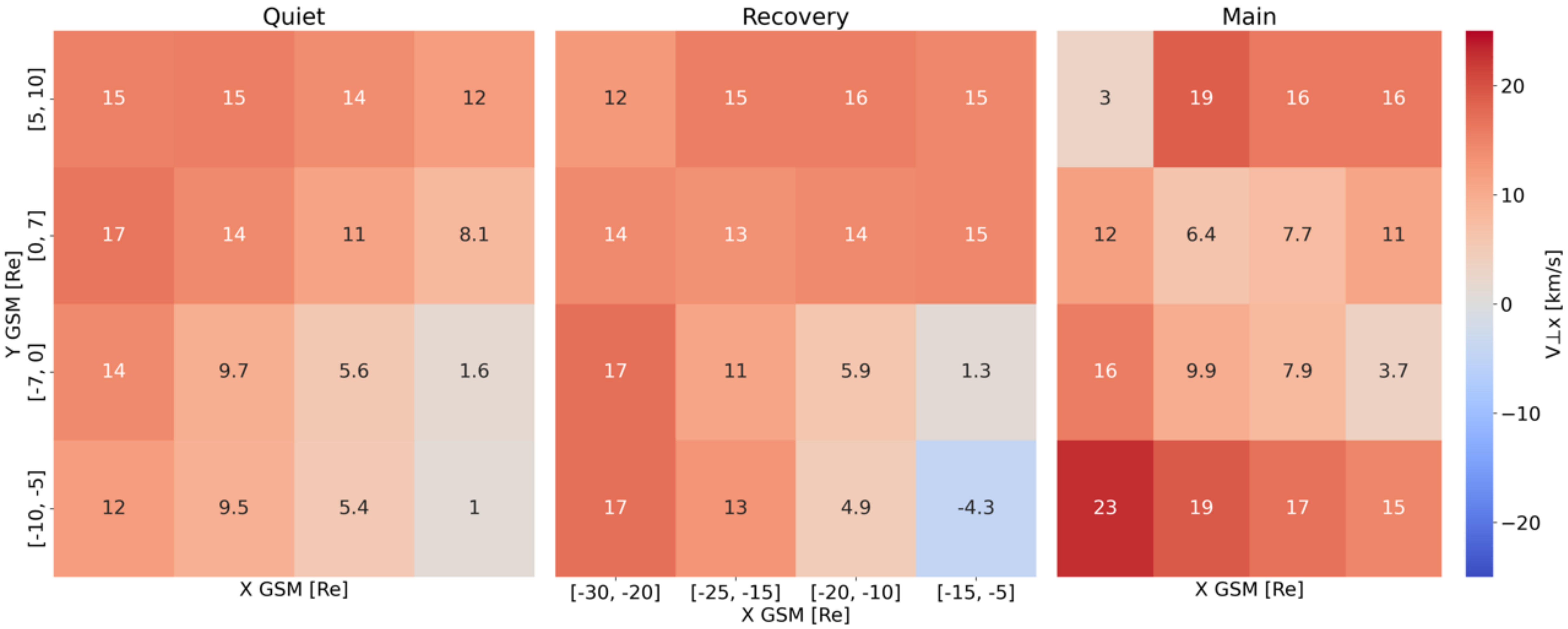
The problem is:

The tail is not well defined physically.
Future: Treat the problem purely mathematically

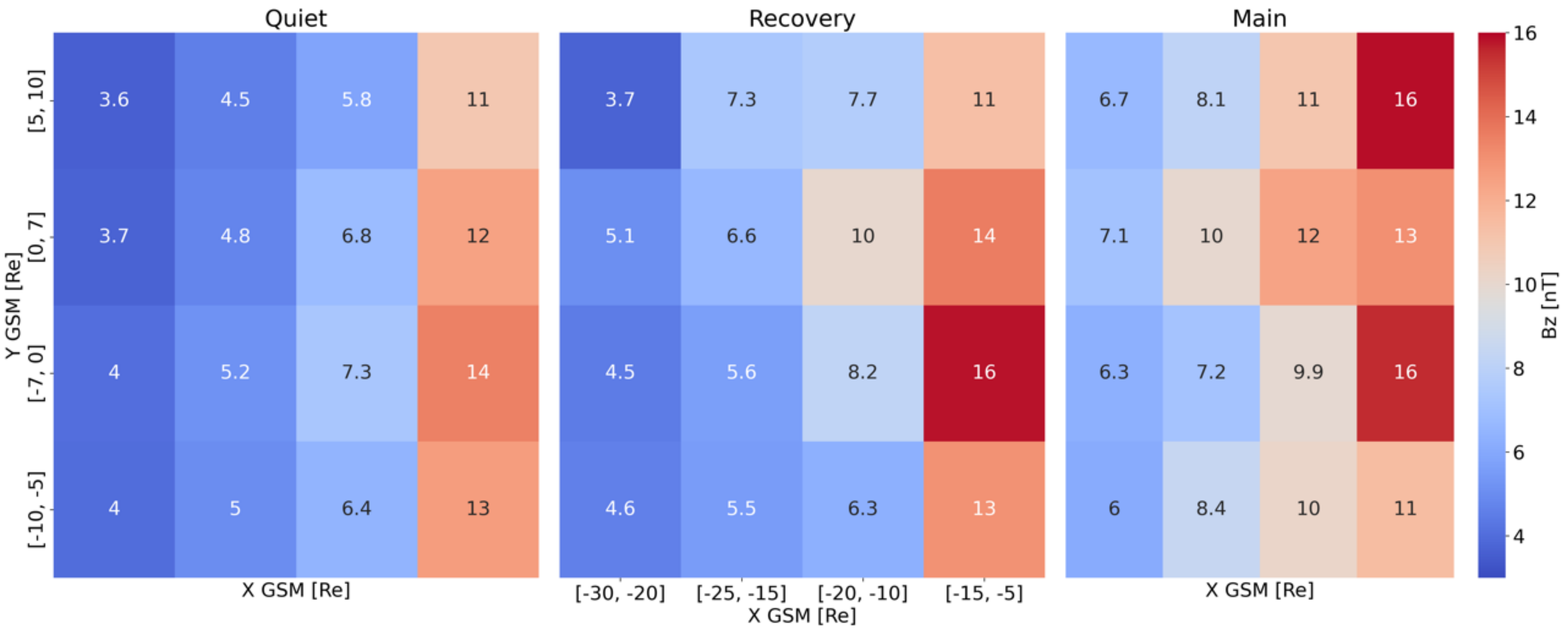
Spatial distribution - Ey



Spatial distribution - V⊥x



Spatial distribution - Bz



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