On The Coherence & Substructure of CMEs

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Drew L. Turner, Manuel Cuesta, Hameedullah Farooki, Tim Horbury + many others

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Main Idea & Synergy

Use all 6-spacecraft around the Sun-Earth L1 point to compare and contrast the structure and spatiotemporal evolution of solar wind, and its transient processes.

Current plan:

- Two companion papers one lead by Drew L. Turner and one by Savvas Raptis
  - **First paper (Drew L. Turner)** tackles general solar wind and SIRs spatiotemporal evolution in terms of coherency and substructure
  - **Second paper (Savvas Raptis)** focuses on 2-3 CMEs and their different regions (i.e., shock, sheath, magnetic cloud etc.)
    - 11-13 Nov 2025 | 19 Jan 2026 | 4-9 Feb 2026
- Support efforts by **Manuel Cuesta & Hameedullah Farooki**

Reasoning:

(a) Multiple science articles on a vital topic in heliophysics and space weather

(b) Consistent methodological framework, also applicable to all future related analysis efforts

(c) Initiate L1 constellation science with IMAP leading on data curation, availability, and science

(d) Support other members of science team on ongoing efforts to facilitate collaboration

First Thoughts

”Our” community’s usual approaches:

- Cross-correlation, maybe some non-linear methods (mutual information) or some coherency metric (e.g., cross-wavelet)

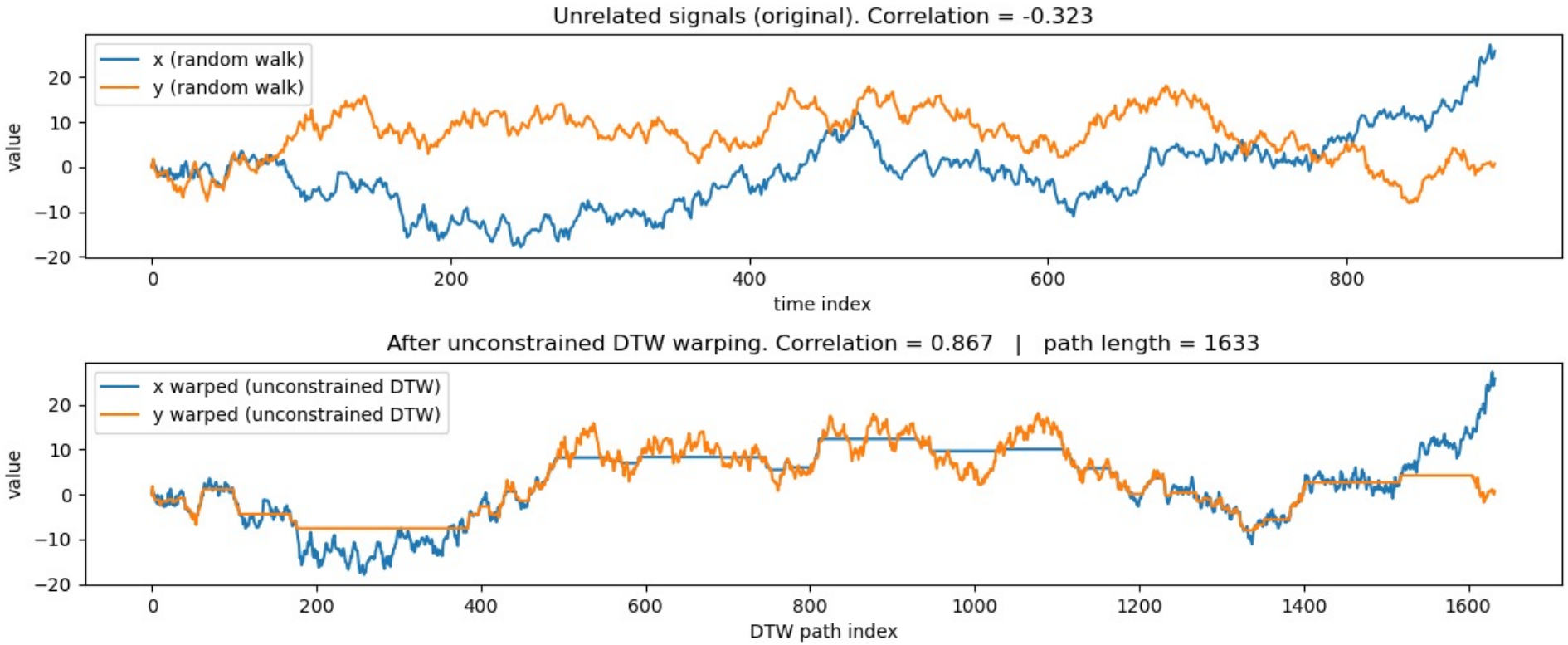
Other communities who deal with timeseries:

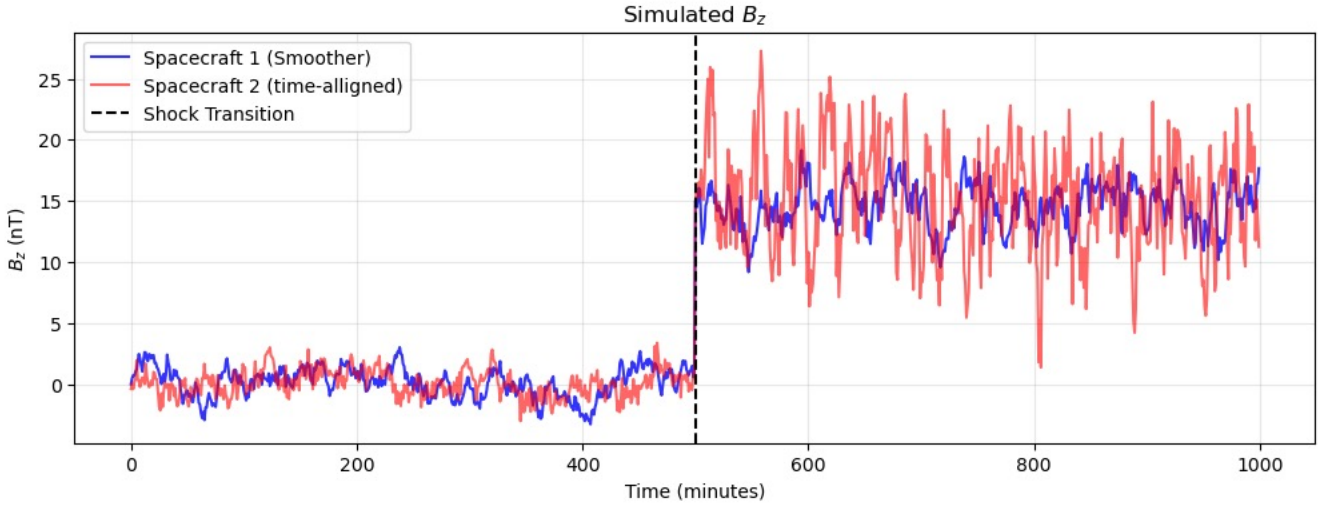
Dynamic Time Warping (DTW), Predictability metrics (coefficient of determination, prediction efficiently etc.), Longest Common Subsequence (LCS), Fréchet Distance etc.

Still investigating what we can use, but let’s keep it simple for now (mostly correlations)

*See: https://www.sktime.net/en/stable , http://tslearn.readthedocs.io, https://www.statsmodels.org/stable/ etc.

Toy data and DTW



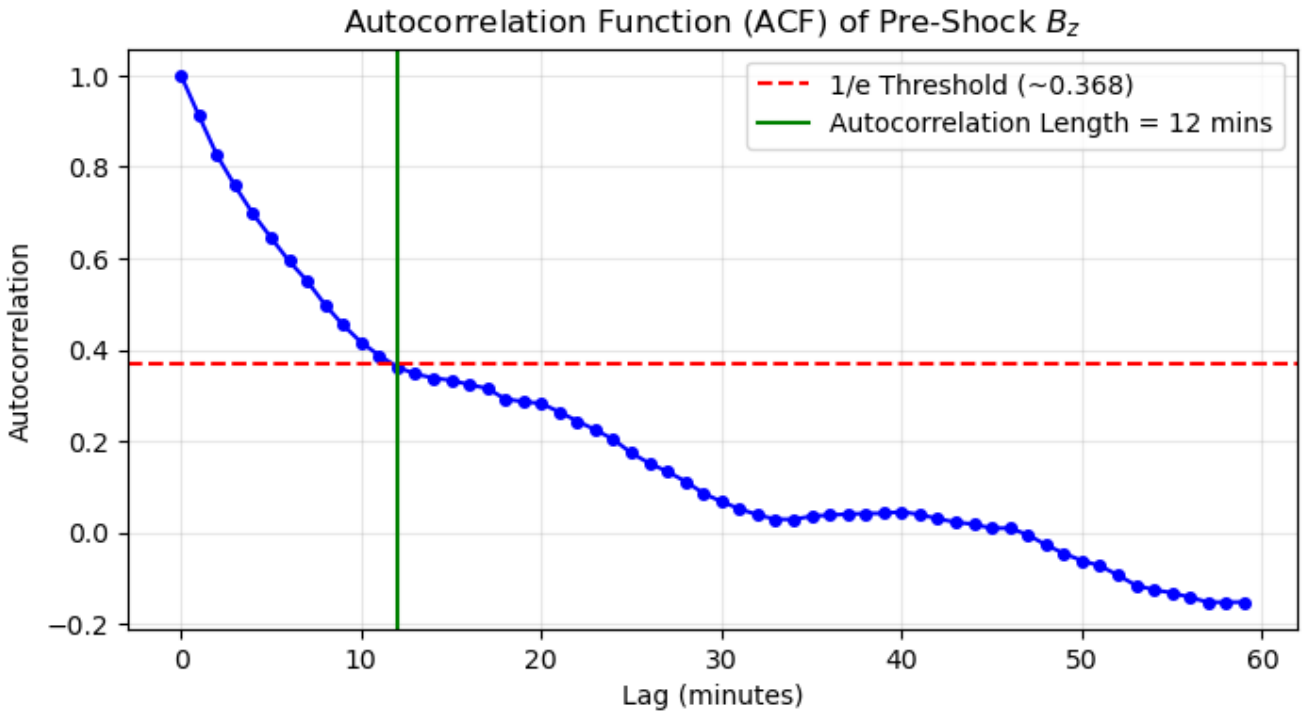


Demonstration of 2 challenges Using Toy Data

Challenge 1 – Solar Wind "Memory" (Autocorrelation)

Metrics like **correlation assume independent data points**.

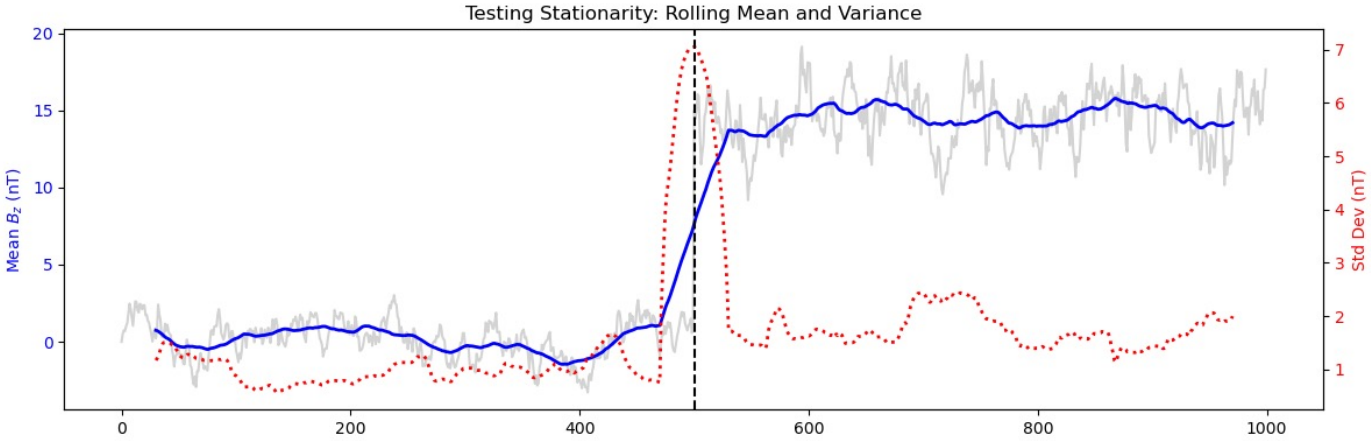
Solution: Calculate the 1/e drop-off (e-folding time) to find when the plasma "*forgets*" its previous state.



Rule of thumb: to be safe go ~2-3 times that, so 25-40mins in this toy example. **So how far can we go?**

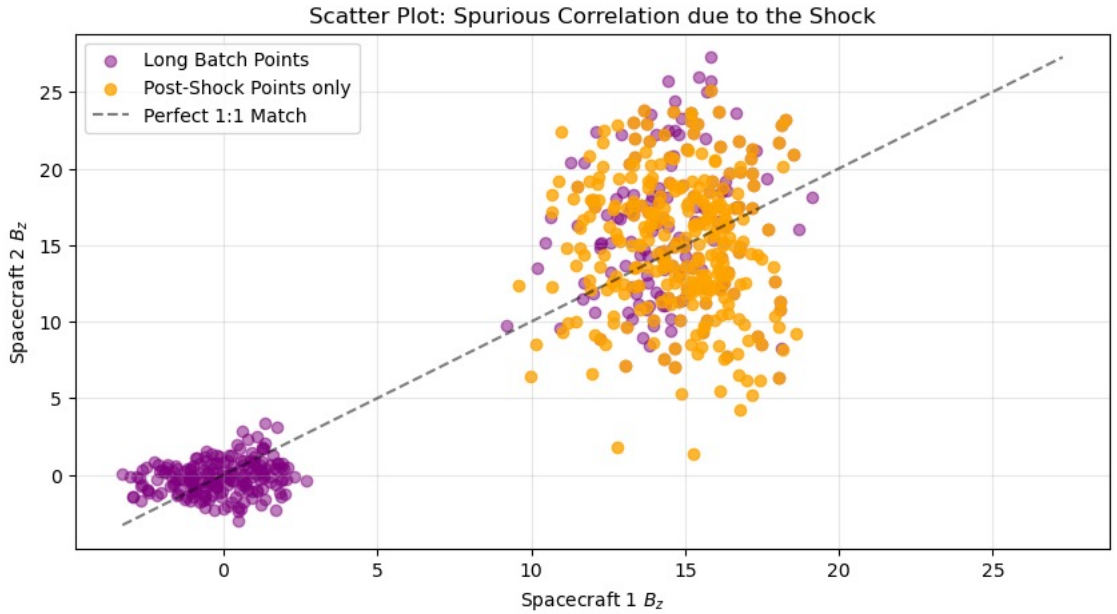
Challenge 2 – The "Long interval" illusion (Non-Stationarity)

Mixing two distinct regimes breaks "stationarity." *Macro-scale* variations wash out *micro-scale* differences in such metrics



<u>Solution</u>:

Reasonable **batches** & **distinct** plasma **environments**



Pre-Shock Only: r = 0.267

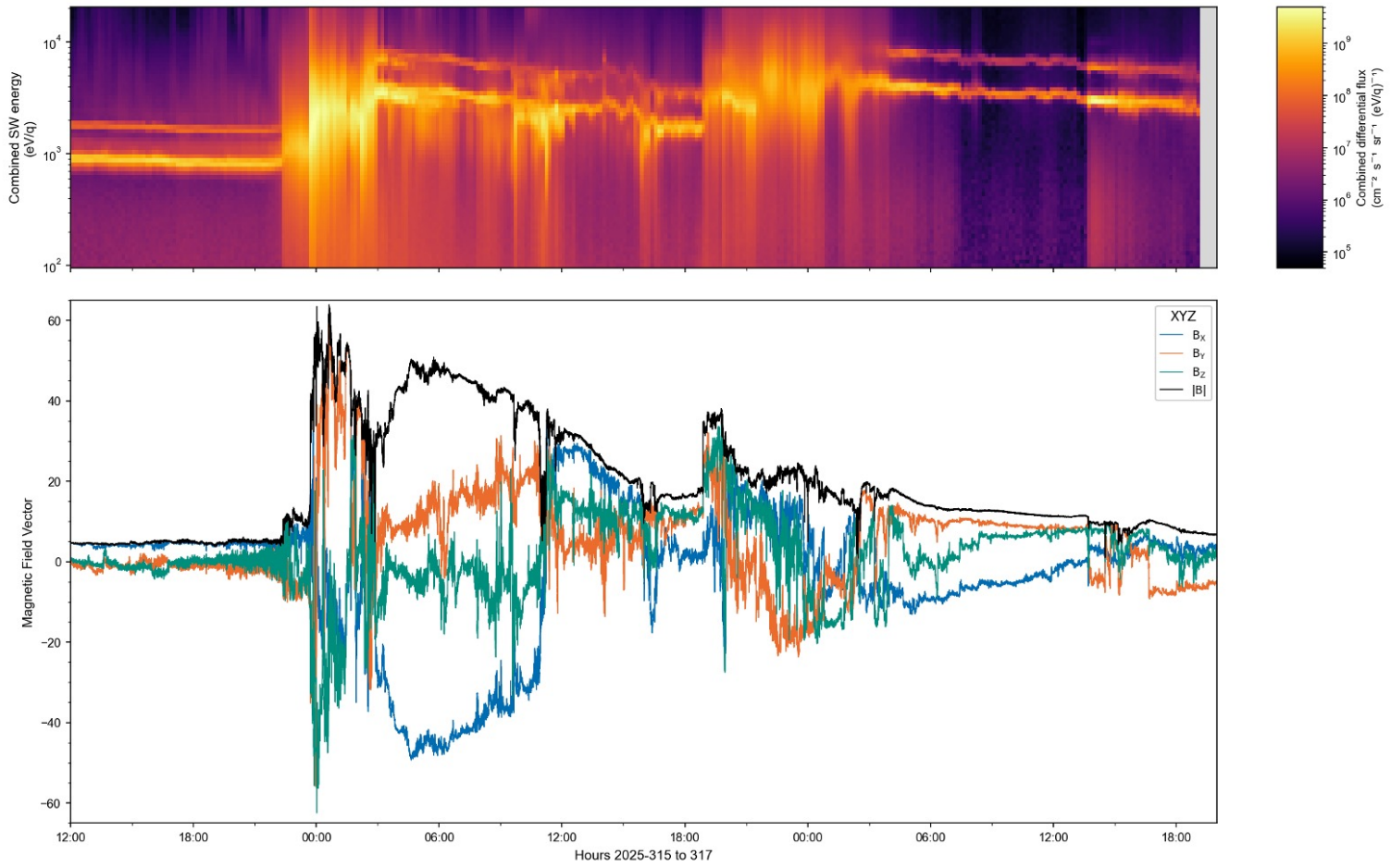
Post-Shock Only: r = -0.076

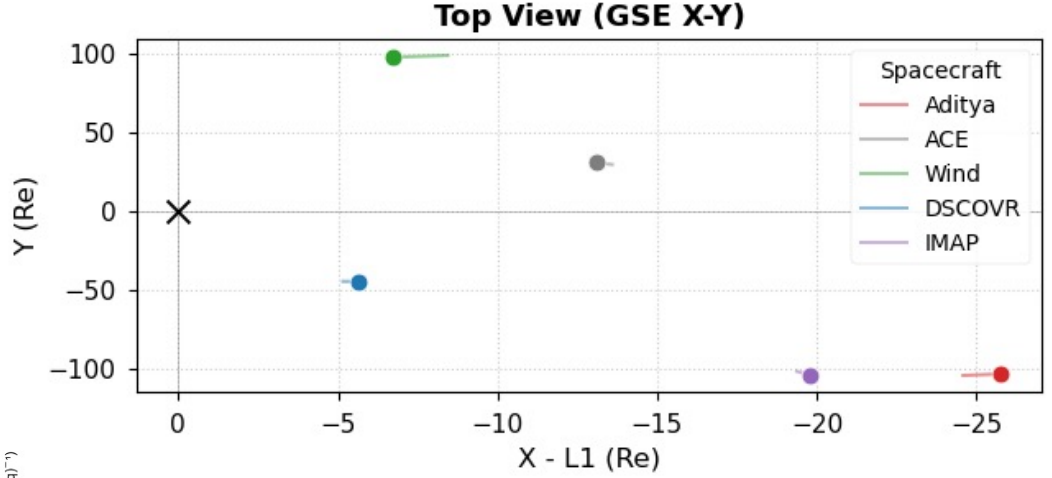
Spanning the Shock: r = 0.914

<u>Community Reminder</u>: if we mix different environments are result can be statistically dubious

PRELIMINARY IMAP DATA
PLEASE DON'T SHARE

Real Data
Nov 11-13 2025 CME





Great example because:

- ❖- 2 CMEs interacting with each other
- ❖Geoeffective event
- ❖Over 200 Re transverse separation between missions

PRELIMINARY IMAP DATA
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November 11-13 Coronal Mass Ejection (CME)

Figure has the following postprocess steps:

- Dead-time Calibration of Aditya
- Resampling to common resolution (12 sec)
- Automatic Shock Finding. Based on |B|
- Automatic time alignment between all probes wrt IMAP

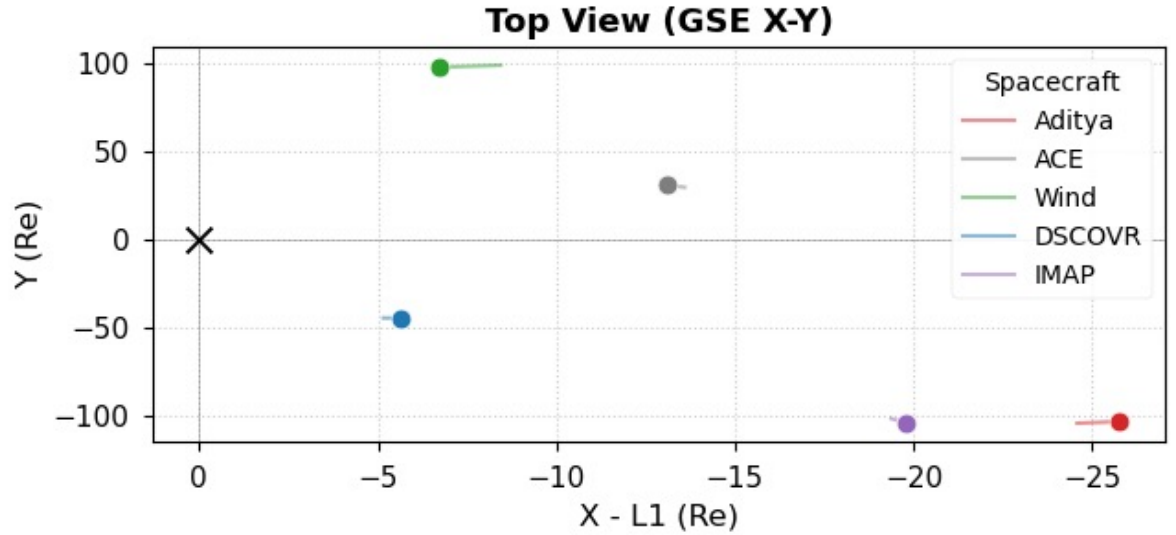
i.e., **the CDF product we have available already**!

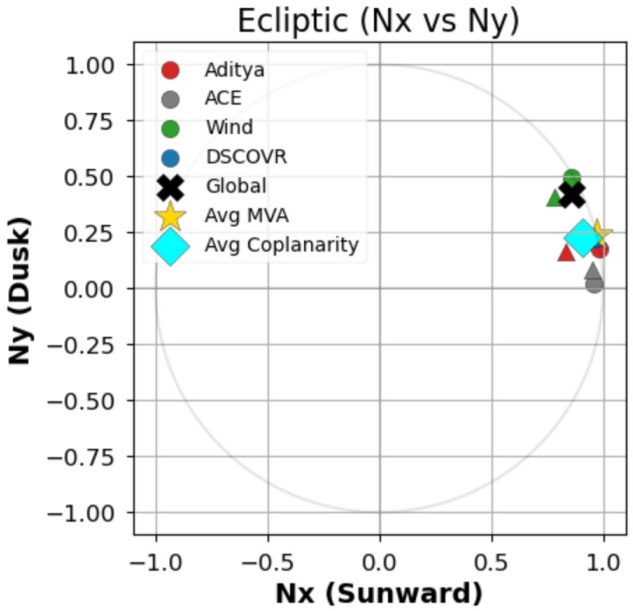
CME IP Shock Geometry Calculation

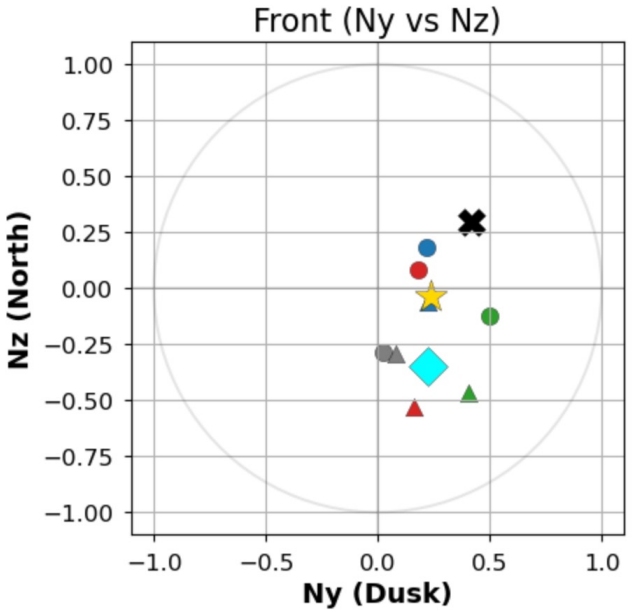
Automated methodology for Shock geometry using

1) Magnetic Coplanarity
2) MVA
3) Timing

Interestingly, there is great agreement between all methods!







*Working with Manuel Cuesta to verify these

The 2 Challenges With Real Data

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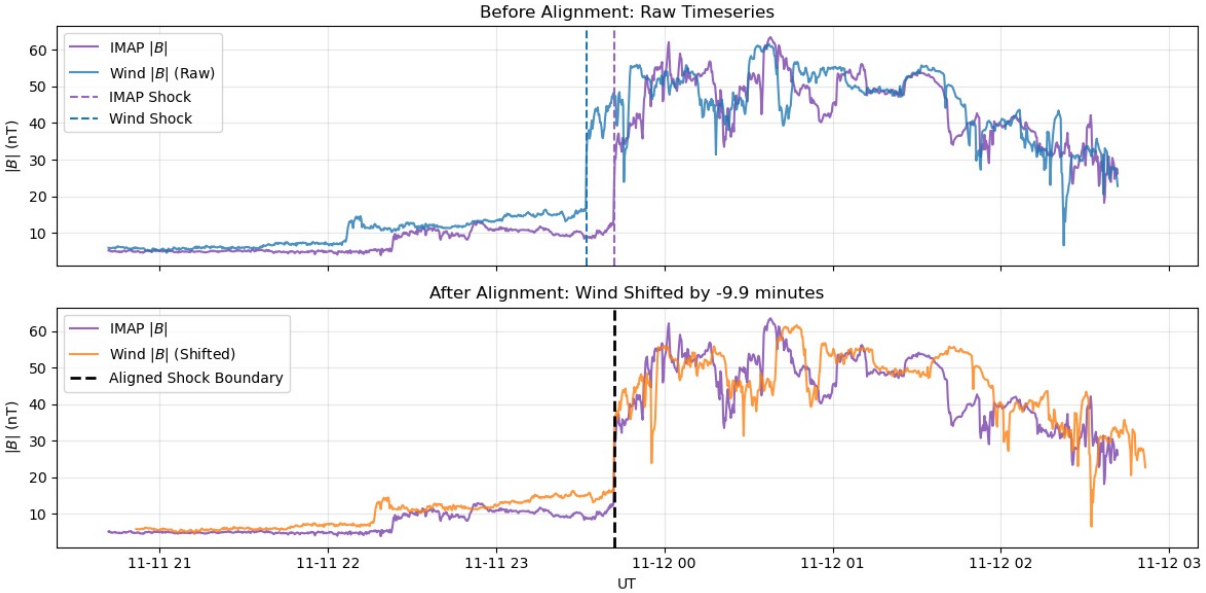
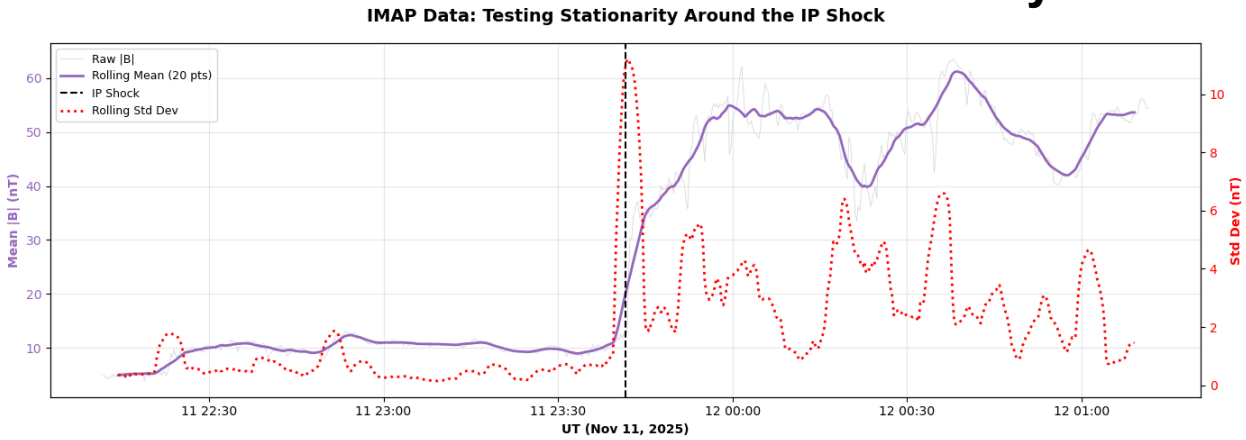
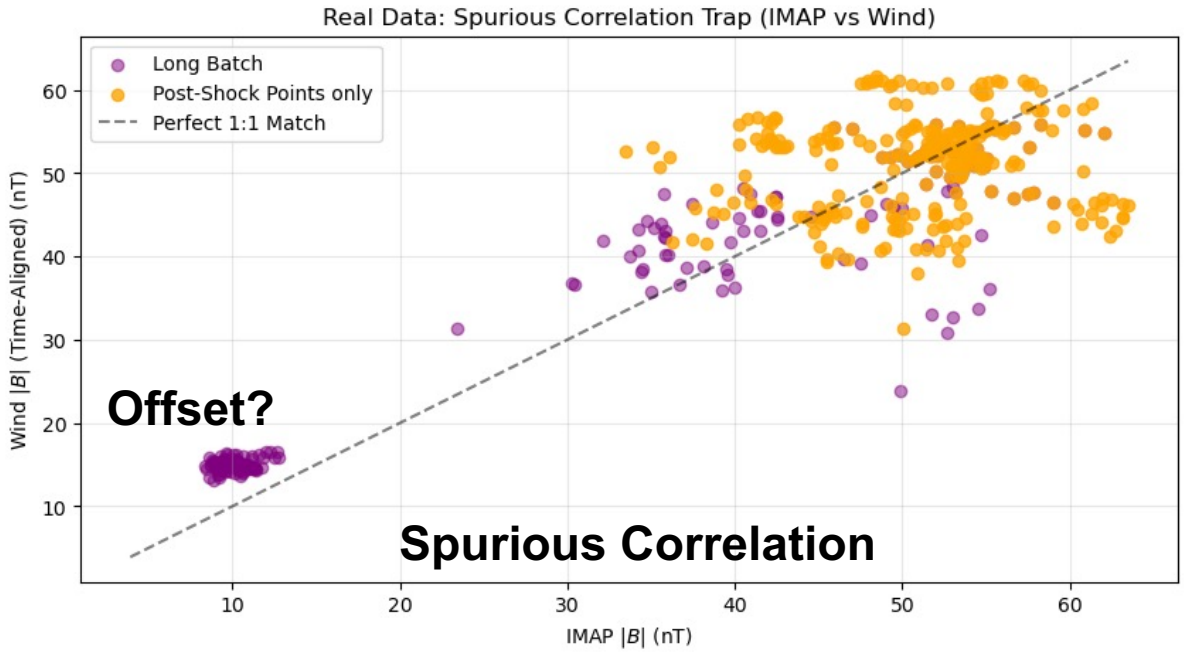
The Same Challenges on Real Data

STEP 1: Time alignment



STEP 2: Confirm non-stationarity





ACF e-fold: ~10min (~12 with toy data)

Pre-Shock Only: r = -0.200

Post-Shock Only: r = +0.103

Spanning the Shock: r = 0.963

Results

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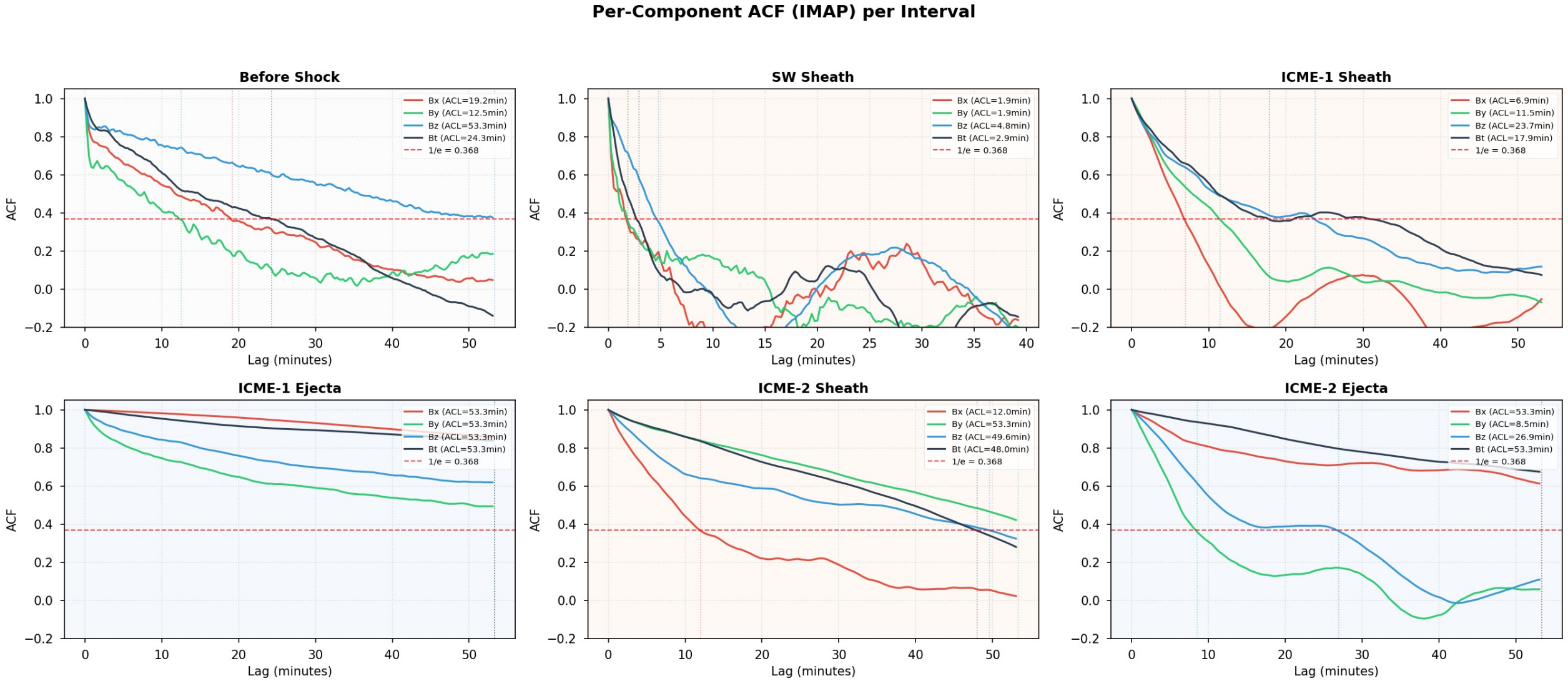
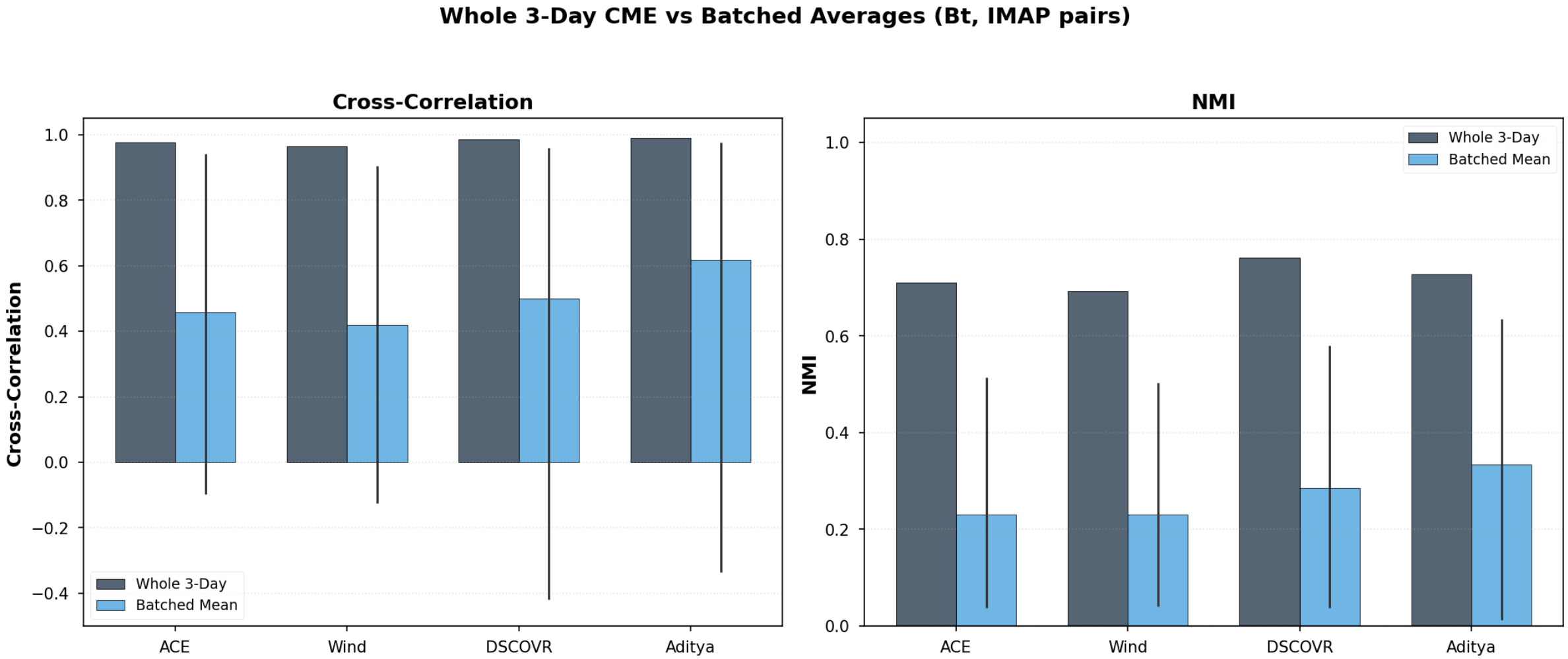
Autocorrelation results per region



Key Takeaway: ACF can be different per component and for each environment

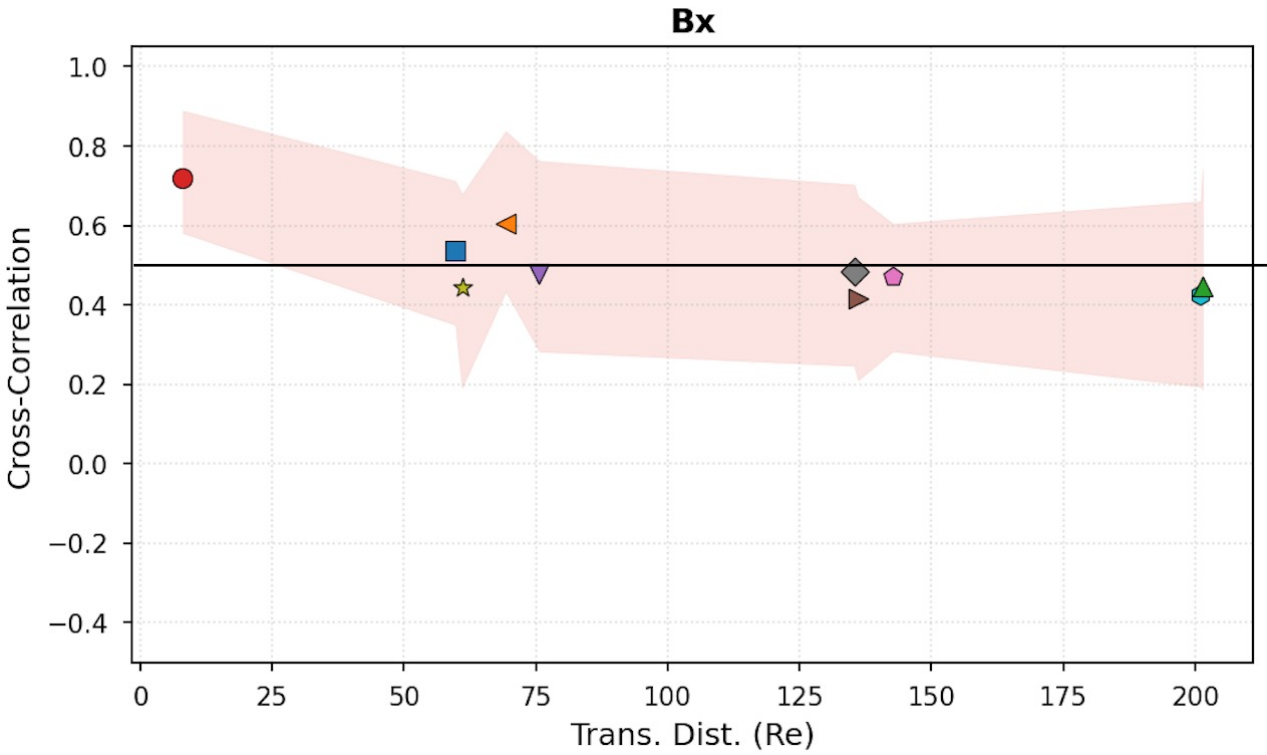
Visual reminder: |B| metrics batched vs 3 days



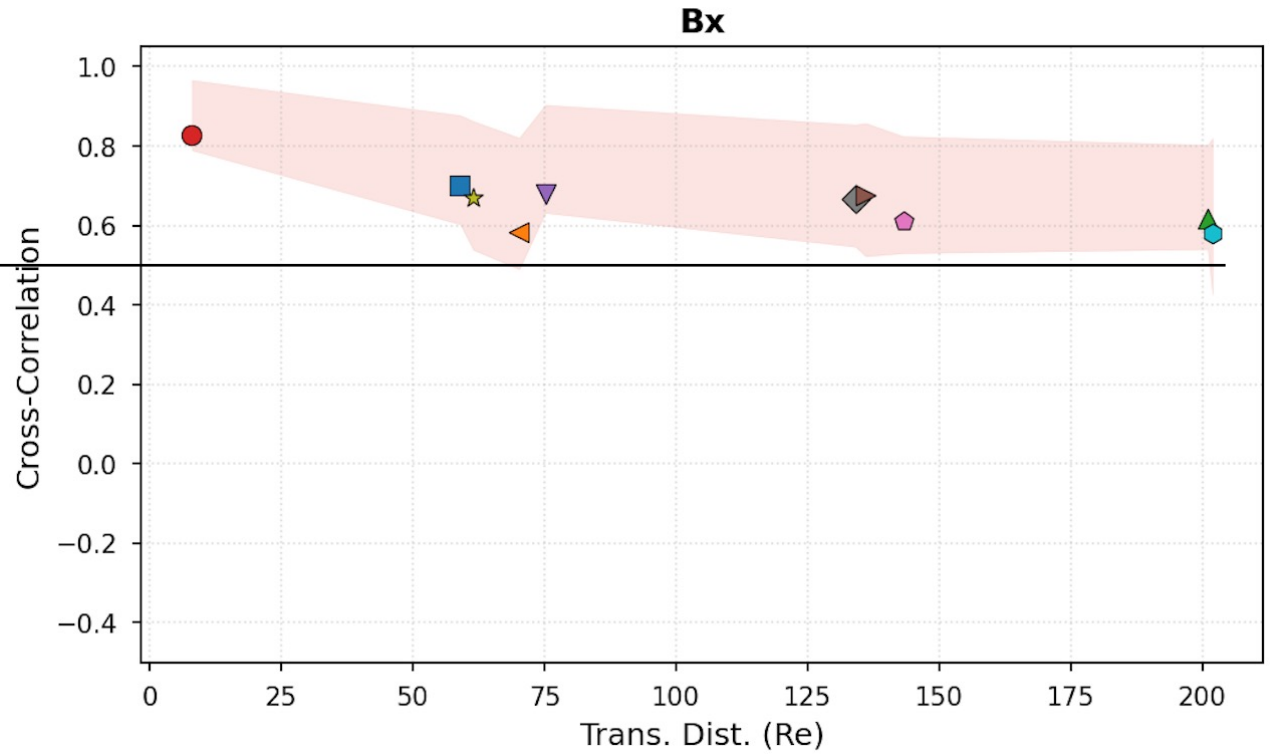
Key Takeaway: batched mean + range reveals variation previously hidden

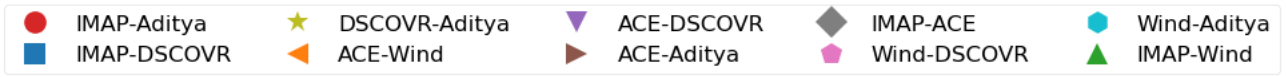
Bx correlation evolution over distance

CME #1Sheath



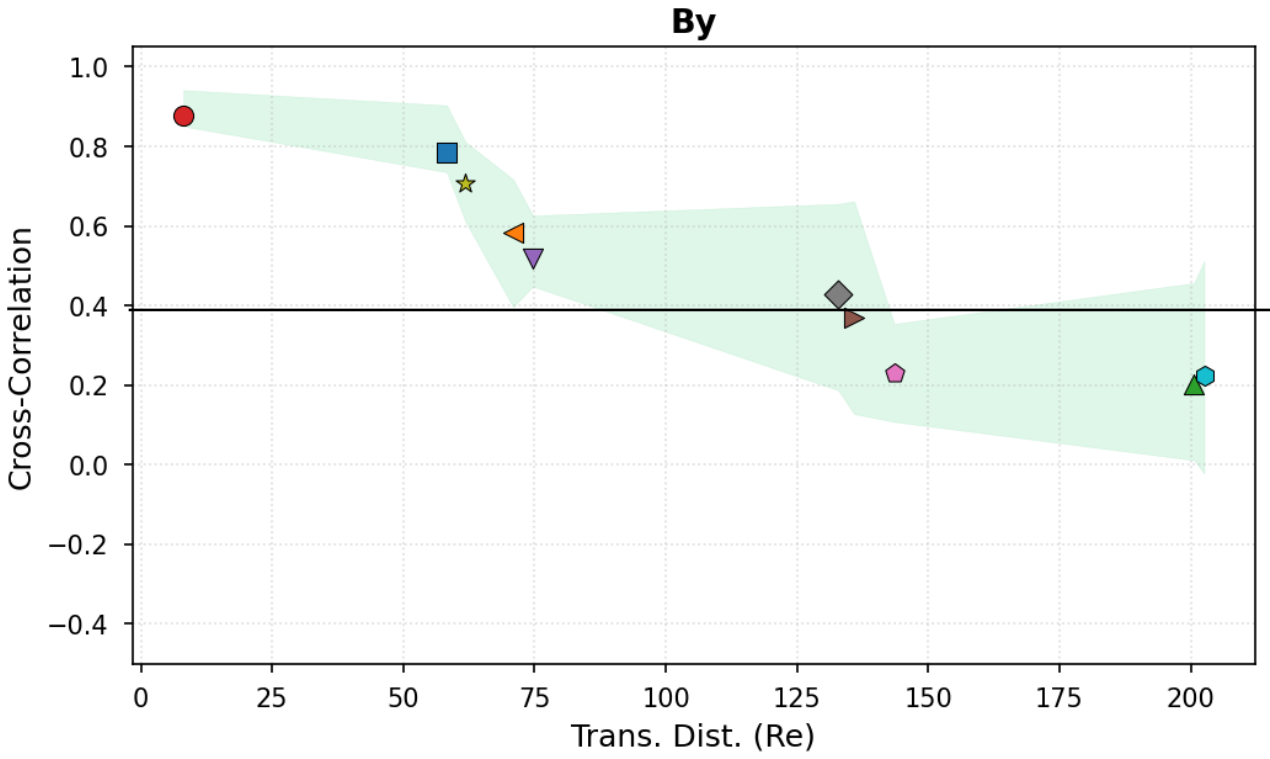
CME #1Ejecta



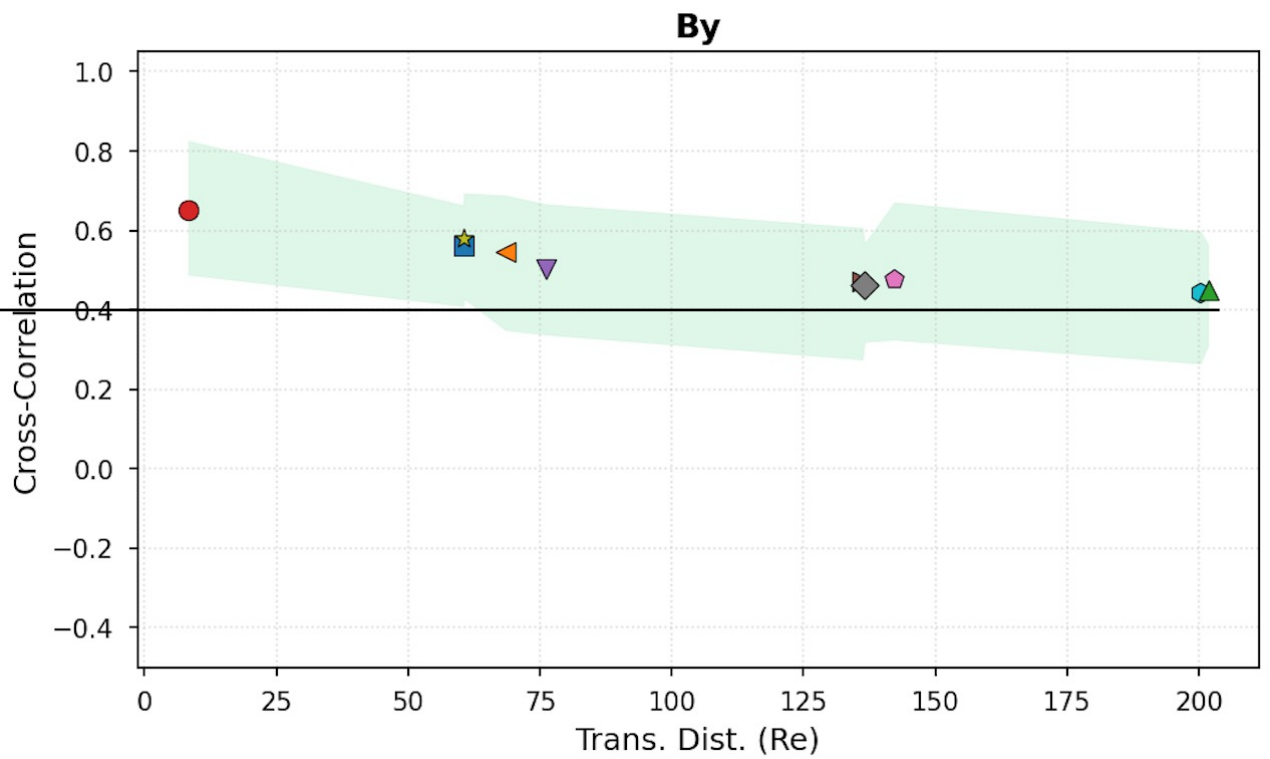


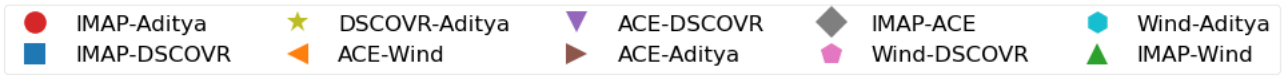
By correlation evolution over distance

CME #1Sheath



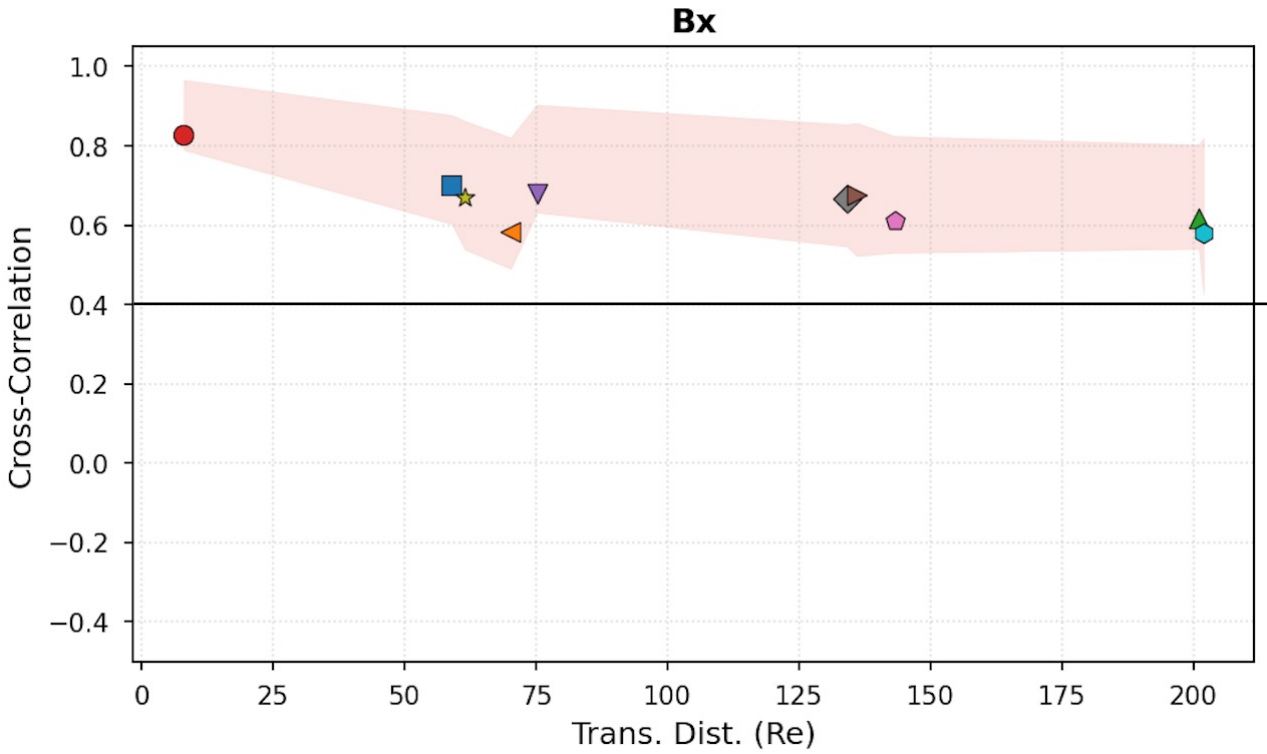
CME #1Ejecta



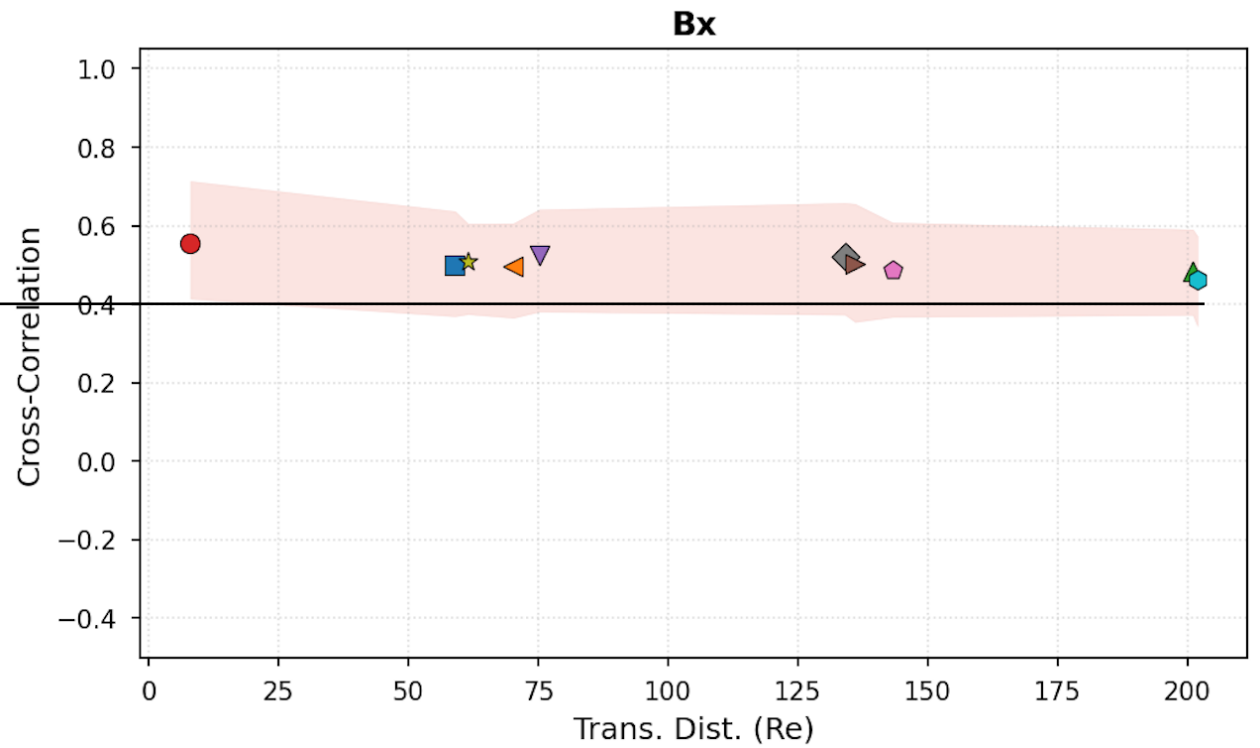


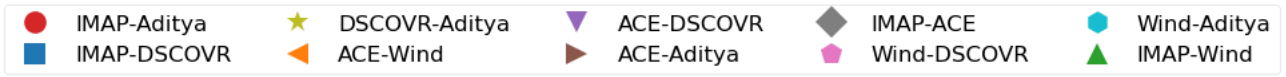
CME Ejecta Full versus Detrend

CME #1Ejecta - Full



CME #1Ejecta - Detrend





Some Next Steps

Methodological

Use normal of shock (orientation) to calculate the scales and propagation of each CME environment.

Evaluate the effect of resampling

Evaluate Aditya's Bx component calibration problem

Include the other 2 CMEs in the analysis to see if differences are consistent.

Science:

Revise up on literature Wing+ Borovsky+, Lugaz+ ,Owens+ and looking for suggestions by the team (if you know things mail them please)

IMAP Related Advertisements

SHINE Workshop Session (2026):

Shock Waves and Energetic Particles Across the Heliosphere: Evolution of Structure and Processes from the Sun to the Outer Heliosphere

June 29- July 2 | Madison, WI

Organizers: Parisa Mostafavi, Christina Cohen, Savvas Raptis

GEM Focus Group (2025 – 2029):

Multiscale Dayside Transients and their Effect on Earth's Magnetosphere (MDT)

July 12-17 | Portland, ME.

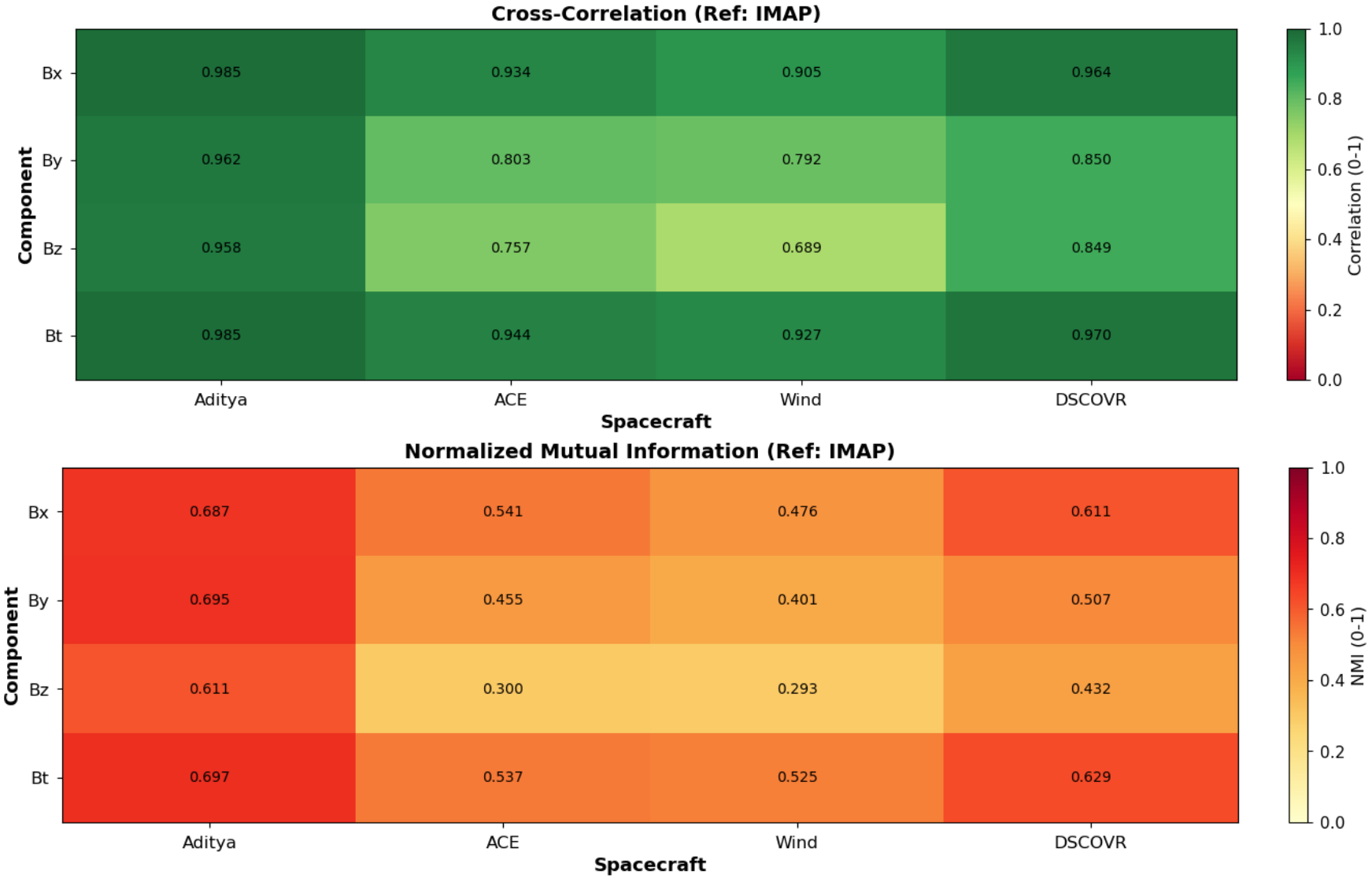
Leads: Savvas Raptis, Ivan Vansko, Imogen Gingell, Terry Z. Liu, Ying Zou, Yuxi Chen, Gonzalo Cucho Padin

Appendix

Cross Correlation & Mutual information wrt IMAP

First Impressions:

- Cross correlation is naturally high
- Aditya & IMAP are almost at the same location.
- Metrics can drop significantly in large distances (e.g., IMAP to Wind)

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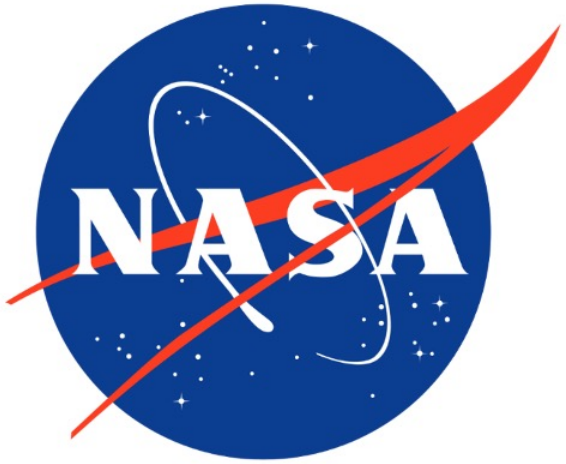
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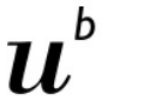


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