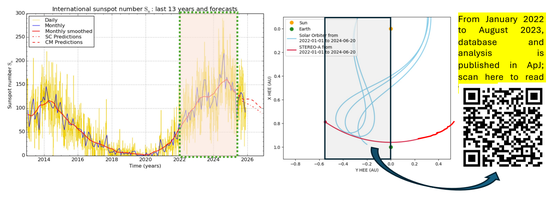
Variation in CME Structures and Shock-Sheath Characteristics Across ±35° from the Sun–Earth Line: Insights from STEREO-A and L1

Sahanaj Aktar Banu[1], Noé Lugaz[1], Bin Zhuang[1], Nada AlHaddad[1], Charles J. Farrugia[1], and Antoinette Galvin[1]

[1]University of New Hampshire, NH

email: Sahanaj.banu@unh.edu

1. Introduction



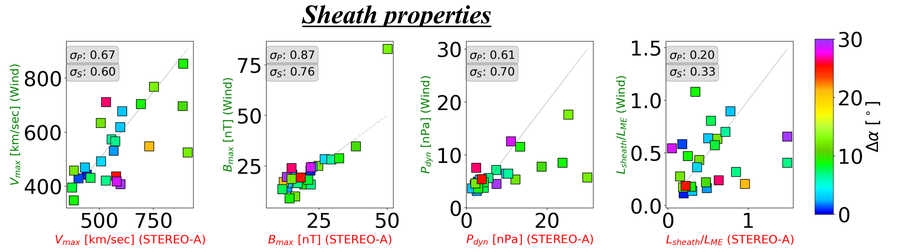
Between January 2022 and May 2025, STEREO-A moved from 35° east of Earth to west.

Objectives:

1. Analyze ***longitudinal size and various properties of CMEs*** using multipoint observations from STEREO-A and L1 spacecraft.
2. Perform detailed assessments of ***CME-driven shock and ejecta morphology*** and their propagation characteristics.

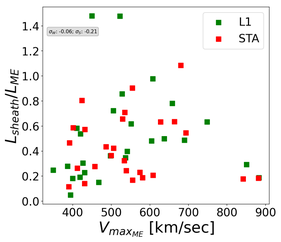
4. Average properties of Sheath and Magnetic Ejecta (ME)

Sheath properties



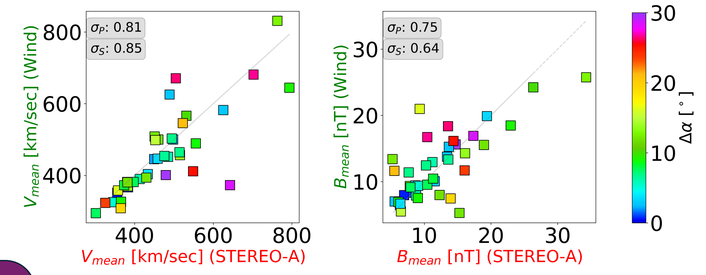
* The colorbar stands for the angular separation between two measurements.

- 25 of 39 simultaneous events show sheath signatures at both spacecraft.
- Peak magnetic field is highly consistent, while peak speed and dynamic pressure show moderate correlation; the sheath-to-ejecta length ratio is poorly correlated because each spacecraft crosses different parts of the CME.
- Mean magnetic field and mean dynamic pressure are strongly consistent, whereas sheath length and average sheath speed are only moderately correlated, with substantial variation even for separations <10°.



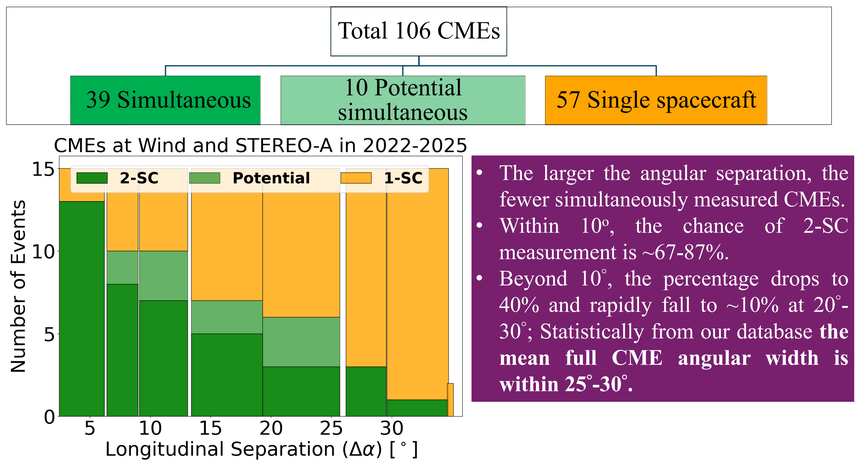
- While a faster ME speed (as seen at STEREO-A) is generally expected to correspond to a smaller sheath-to-ME length ratio, L1 measurements doesn't align.

Magnetic ejecta properties



- Average speed and mean magnetic field strength are consistent from L1 and STEREO-A.
- However, the expansion signatures such as expansion speed, Distortion parameter (DiP), and front-to-back ratio of magnetic field are low to moderately correlated at two points, highest for front-to-back ratio.

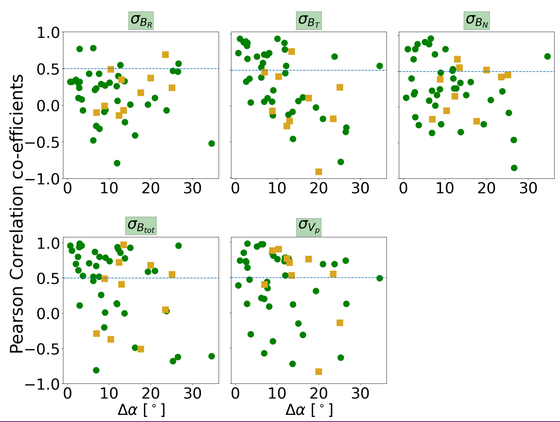
2. Database



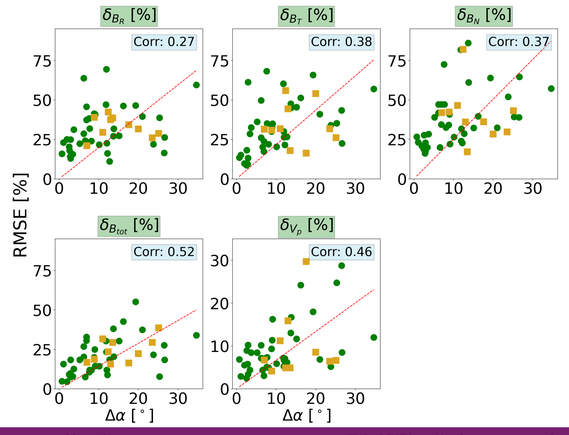
- The larger the angular separation, the fewer simultaneously measured CMEs.
- Within 10°, the chance of 2-SC measurement is ~67-87%.
- Beyond 10°, the percentage drops to 40% and rapidly fall to ~10% at 20°-30°; Statistically from our database **the mean full CME angular width is within 25°-30°.**

5. Analyzing Time-evolution

Pearson correlation & normalized RMSE of magnetic field and velocity



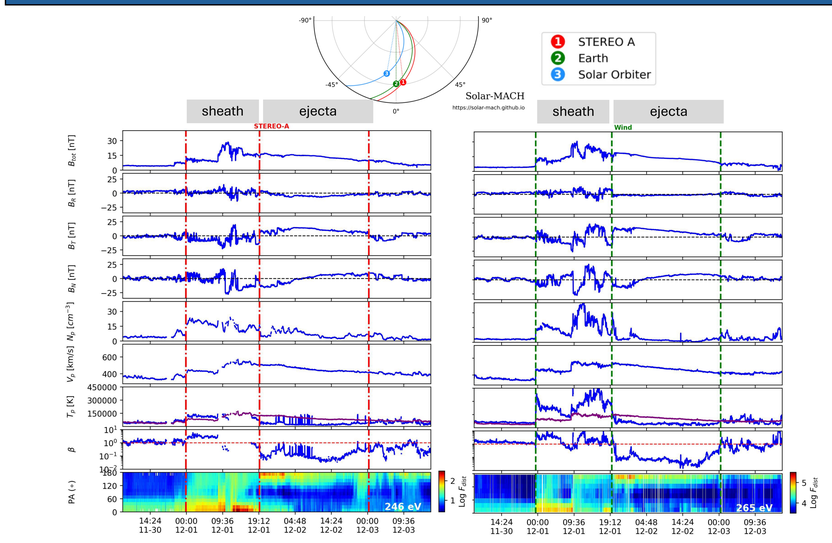
- Pearson correlation coefficient (σ) between L1 and STEREO-A measurements decreases with increasing angular separation (Δα) with very large variability.
- Correlation for B_{tot} and V_p are highest; low or uncorrelated events could be due to local compression.
- Field components are not well correlated (<0.5) even within 10° maybe due to small values.



- The normalized root mean square error (RMSE), δ, between the L1 and STEREO-A measurements increases monotonically as the angular separation separation, Δα .
- Potential events follow similar trend like 2-SC events.
- As beyond ~5°, RMSE tends to be larger, more datapoints lie above the trend line at larger separation.

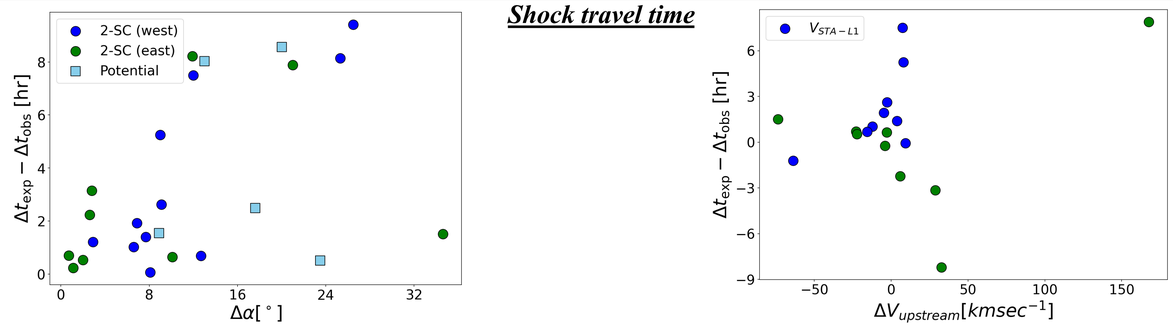
RMSE is more consistent than correlation for angular separation range in our study!

3. CME event on 2023-12-01



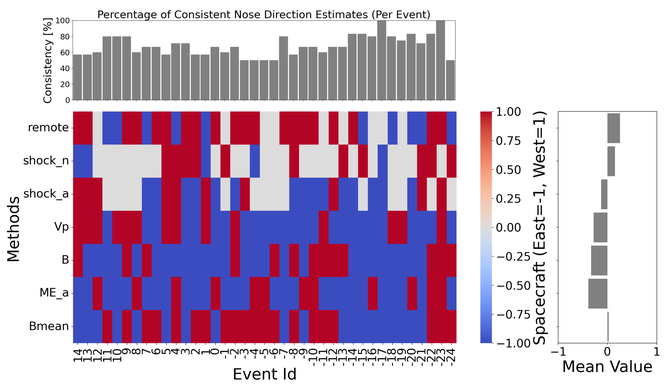
6. Shocks

Shock travel time



• Among the 49 events (2-SC + Potential), 30 show a shock or shock-like disturbance at both spacecraft.
•The results indicate that shocks propagate largely radially outward, meaning STEREO-A can forecast shock arrival at Earth.
•Together, the figures suggest that shock behavior depends more on local conditions—such as upstream solar wind speed—than on angular separation.

CME nose estimate using various methods



- Using 49 two-spacecraft CMEs, we estimated whether the CME nose lay to the east or west.
- We applied seven methods, spanning remote-sensing and in-situ approaches, including shock arrival and normal direction; ejecta arrival, proton speed, and mean/max magnetic field.
- A westward bias is observed in remote-sensing estimates while *in situ* methods predominantly indicate eastward directions.
- The consistency histogram indicate all seven methods agree for only two events.

7. Conclusions

- Built a catalog of 106 CMEs combinedly by Wind and STEREO-A within 2022 to May 2025. Only 49 CMEs (~46%) measured by 2-SC while their angular separation ranges between 35° each side from the Sun-Earth line.
- From 0° and 35° separation, percentage of detecting same CME simultaneously by 2-SC reduced 85% to below 10%.

Average CME full angular width near 1 au is likely to be 25° to 30°, smaller than previously thought.

- Average properties of sheath and ME such as, speed, magnetic field are found to be consistent, regardless of separation between measurements.
- However, close inspection by using RMSE, correlation coefficients suggests that locally, properties vary significantly within such a smaller longitudinal width of CMEs.

MEs are globally coherent structure within the scale of 10° to 20°, however, field components do vary significantly in smaller scale.

- Globally, shocks are consistent with a circular cross-section.

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