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Investigating the Longitudinal Asymmetry in ESP Detection: L1 vs. STEREO-A during the November 12, 2023 CME Event

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1. Background and Event

Energetic storm particle (ESP) enhancements and solar energetic particle (SEP) events depend strongly on an observer's heliolongitude relative to CME–driven shocks. However, it is not clear how small longitudinal separations control the presence or absence of local ESP signatures.

The CME that erupted on 2023-11-09 and drove the shock observed on 2023-11-12 provides a clean test case. A WSA–ENLIL+Cone run (via CCMC/DONKI) gives:

- CME apex longitude: about 10°,
- latitude: about 14°,
- speed: about 780 km s^{-1},
- half-angle: 45°.

At the time of the in-situ shock detections:

- WIND (near Earth) was at about 0° HEEQ longitude,
- STEREO-A was at about 6° HEEQ longitude.

In a CME-centered frame:

- WIND is about 10° west of the CME apex,
- STEREO-A is only about 4° west of the apex,

placing STEREO-A magnetically closer to the shock nose.

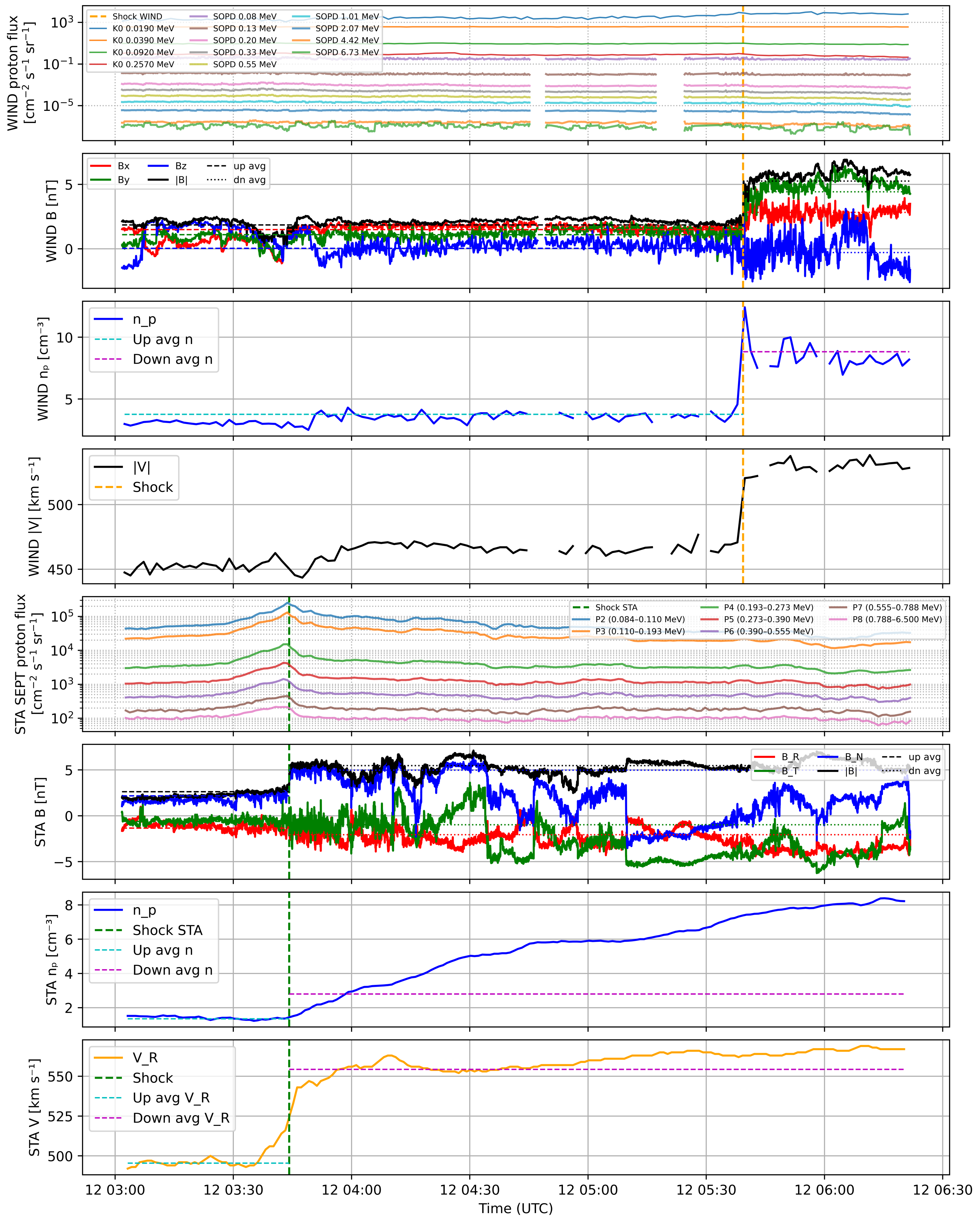

Figure 1. Multi-parameter overview of the 2023-11-12 shock at WIND (panels 1–4) and STEREO-A (panels 5–8). Panels 1 and 5 show proton intensities from WIND/3DP and STEREO-A/SEPT, respectively. Panels 2 and 6 show magnetic field magnitude and components, panels 3 and 7 the proton density, and panels 4 and 8 the solar wind velocity components. Vertical dashed lines mark the shock arrival times. Time axes are shifted to a common reference to ease comparison.

2. Objectives

- Quantify how small longitudinal separations affect SEP/ESP detection.
- Compare WIND and STEREO-A observations of the same CME-driven shock.
- Identify the physical reasons why STEREO-A shows a weak ESP enhancement, whereas WIND does not.
- Assess whether longitudinal proximity alone can be used to predict SEP impact.

3. Data and Methods

Spacecraft and instruments

WIND

- Energetic particles: 3DP (SOPA + K0).
- Magnetic field: MFI.
- Plasma: SWE.

STEREO-A

- Energetic particles: SEPT (omnidirectional).
- Magnetic field: IMPACT/MAG.
- Plasma: PLASTIC.

Analysis approach

- Identify shock times from magnetic field and plasma jumps.
- Compute upstream and downstream averages over 20-minute windows.
- Derive the shock normal using mixed coplanarity.
- Fit proton energy spectra with single power laws

$$J(E) \propto E^{-\gamma}$$

  using:
  - ten-minute sliding windows stepped by 2 minutes for time evolution of γ,
  - fixed 20-minute upstream/downstream windows for reference spectra.
- Estimate basic magnetic connectivity using Parker-spiral geometry and HEEQ positions from SSCWeb, combined with CME apex longitude from WSA–ENLIL.

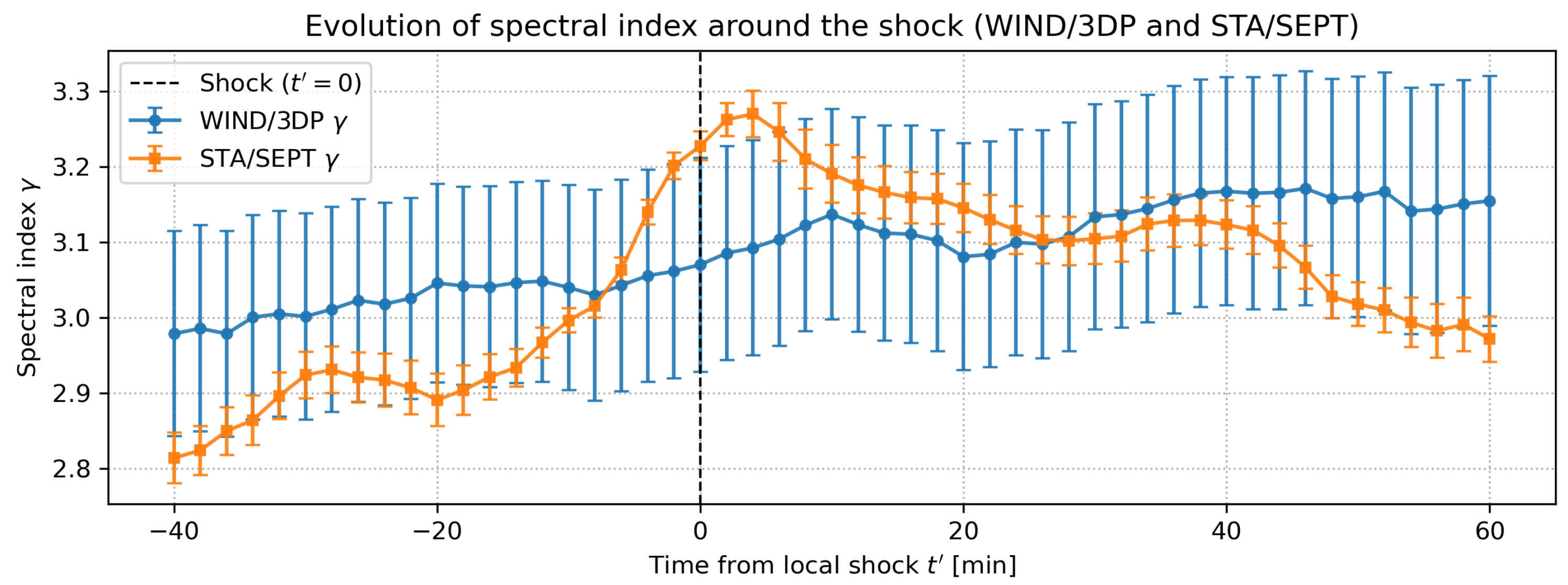

Figure 2. Temporal evolution of proton spectral index γ for WIND (blue) and STEREO-A (orange), as a function of time relative to each local shock time. At WIND, γ remains nearly constant around values between about 3.0 and 3.5, with no clear signature of local acceleration. At STEREO-A, γ shows a transient softening around the shock, consistent with a weak ESP enhancement.

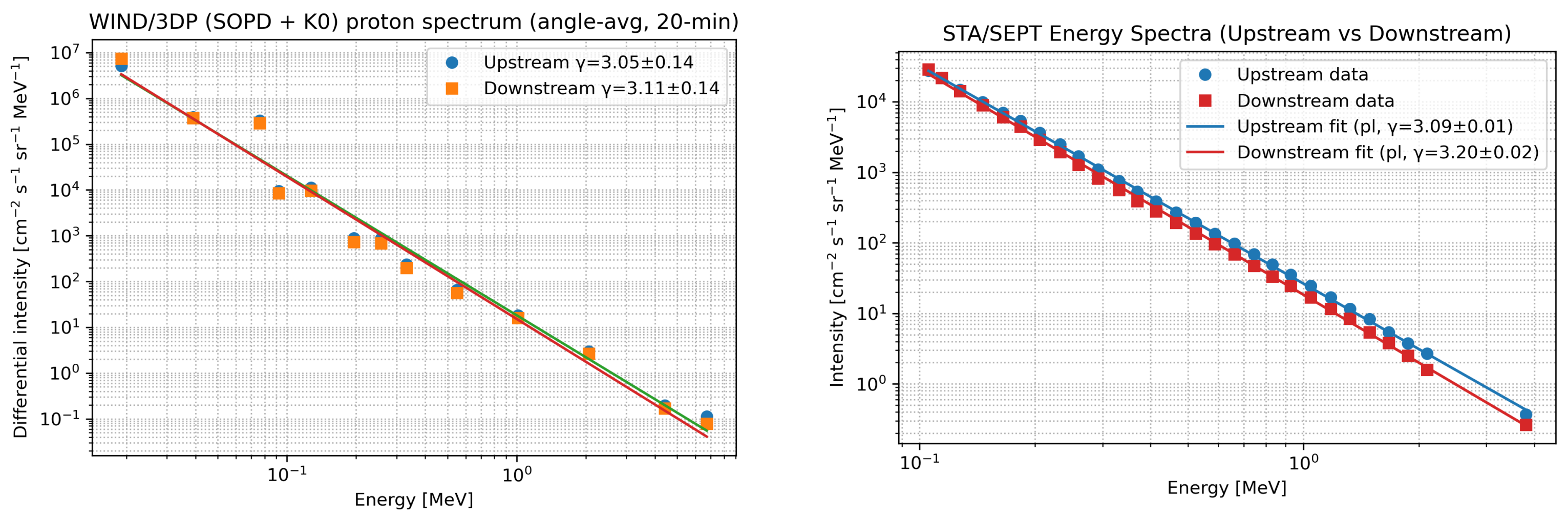

Figure 3. Comparison of upstream and downstream proton spectra at WIND (left) and STEREO-A (right) using 20-minute windows before and after the 2023-11-12 shock.

At WIND, upstream and downstream spectra almost overlap, with spectral indices $\gamma_{\rm up} \approx 3.05$ and $\gamma_{\rm dn} \approx 3.11$, and no significant change in normalization. The lack of spectral hardening or downstream enhancement confirms that WIND did not observe local ESP acceleration.

At STEREO-A, both spectra are well described by power laws, with $\gamma_{\rm up} \approx 3.09$ and $\gamma_{\rm dn} \approx 3.20$. The downstream spectrum steepens at higher energies and diverges gradually from the upstream one, consistent with a weak ESP signature at the shock.

4. CME Global Context (WSA–ENLIL)

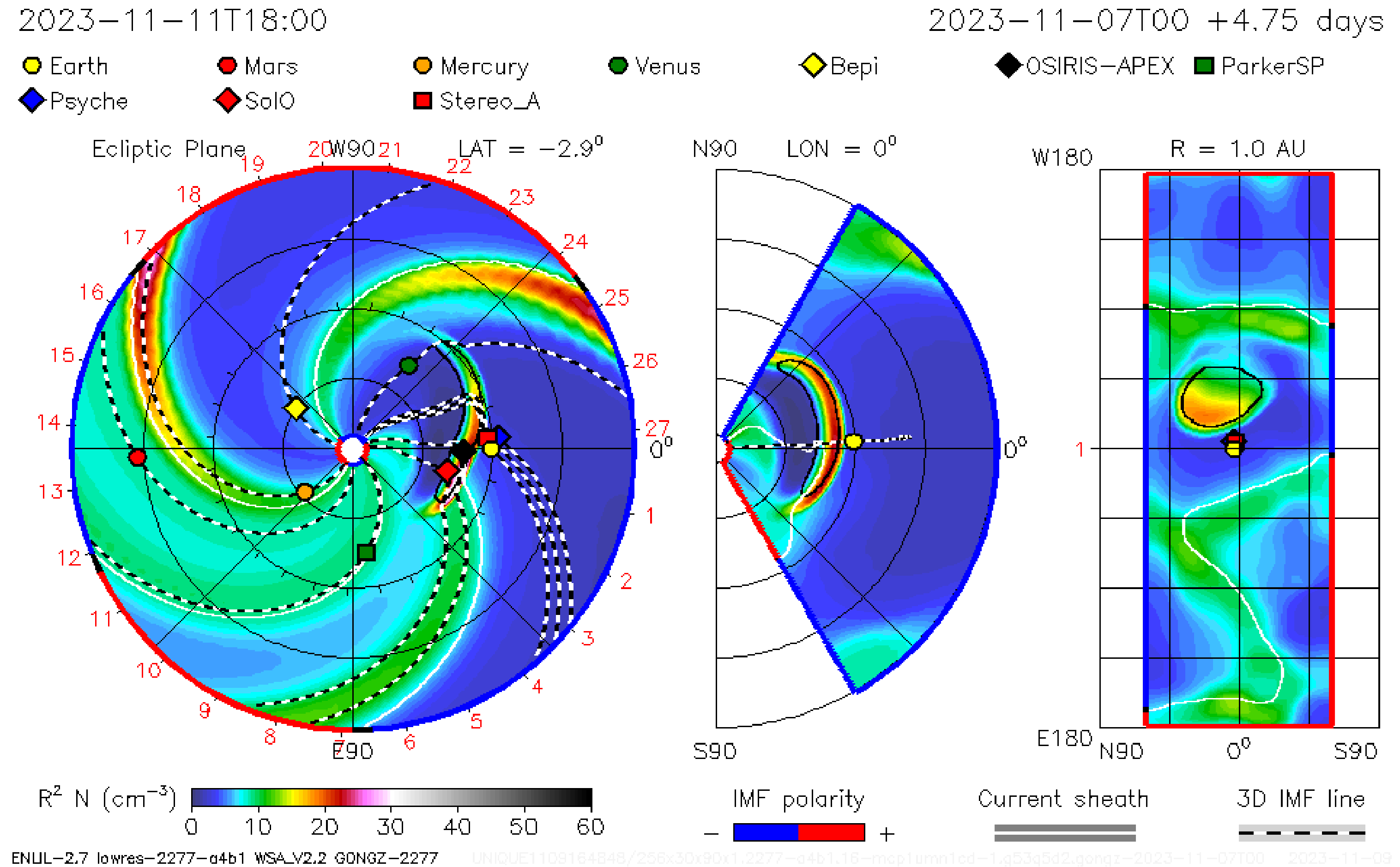

Figure 4. WSA–ENLIL+Cone simulation for the 2023-11-09 CME (input: Lon = 10°, Lat = 14°, speed = 782 km s^{-1}, half-angle = 45°) from CCMC/DONKI. The model predicts shock arrivals at Earth and STEREO-A with lead times of order 8–10 hours relative to the observed shocks on 2023-11-12. In longitude, the CME apex at about 10° places WIND (0°) about 10° west of the nose and STEREO-A (6°) about 4° west, consistent with STEREO-A being magnetically closer to the strongest region of the shock.

5. Shock Parameters at WIND and STEREO-A

Parameter	WIND	STEREO-A
Shock normal (GSE/RTN)	$[-0.94,\ 0.34,\ -0.10]$	$[-0.89,\ -0.36,\ -0.28]$
θ_{Bn} [deg]	57.7	72.3
r_n (density jump)	2.34	2.06
r_B (magnetic jump)	2.70	2.08
V_A [km s^{-1}]	20.7	49.3
ΔV [km s^{-1}]	65.4 (normal)	58.9 (radial)
$M_A^{(\rm pseudo)}$	3.16	1.19
Parker footpoint shift [deg]	52.6	49.6

Table 1. Comparison of shock properties at WIND and STEREO-A. WIND observes a stronger density and magnetic compression, whereas STEREO-A has a larger θ_{Bn} and higher upstream Alfvén speed. These differences, together with the different magnetic connectivity relative to the CME apex, contribute to the contrasting ESP signatures. $M_A^{(\rm pseudo)} = |\Delta V|/V_A$ in the spacecraft frame. For WIND we use the jump in the shock–normal component (ΔV_n); for STEREO-A we use the radial component (ΔV_R), since only V_R is available from plasma data. For STEREO-A, upstream and downstream averages of density and radial velocity are computed in 10-minute windows separated by a 10-minute gap around the shock to avoid contamination from the gradual transition (shock ramp).

6. Conclusions

- The 2023-11-12 CME-driven shock produces qualitatively different SEP/ESP behavior at WIND and STEREO-A.
- WIND shows no significant local ESP enhancement, neither in time profiles nor in upstream/downstream spectra.
- STEREO-A, only a few degrees away in HEEQ longitude, exhibits a weak but clear ESP signature, both in time profiles and in the transient softening of the proton spectrum.
- In a CME-centered frame, WIND is about 10° west of the CME apex, while STEREO-A is only about 4° west, placing STEREO-A magnetically closer to the shock nose.
- Shock geometry, local plasma parameters and detailed magnetic connectivity, rather than simple longitudinal proximity, control the presence or absence of ESP signatures at nearby spacecraft.
- Multi-spacecraft observations are crucial to constrain SEP acceleration and transport, and to improve space weather forecasts that usually rely on single-point measurements.
- The shock parameters alone cannot yet explain why STEREO-A observes ESPs while WIND does not; future work will examine additional physical and connectivity-related factors.

7. Acknowledgments

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