Longitudinal Spread and Variability of SEPs: Impact of Interplanetary Structures (Multi-Spacecraft Observations, Dec 7-10, 2024)

F. Carcaboso (UMBC NASA GSFC), L.Y. Khoo (Princeton University), D. Lario (NASA GSFC), R. Gómez-Herrero (UAH), F. Espinosa Lara (UAH), I. Cernuda (UAH), E. Palmerio (PSI), D. Pacheco (USTC), G. Martín (UAH), B. Sánchez-Cano (University of Leicester), C. Lee (SSL UC Berkeley), A. Szabo (NASA GSFC), B. Lynch (SSL UC Berkeley), W. Wei (SSL UC Berkeley)

Abstract

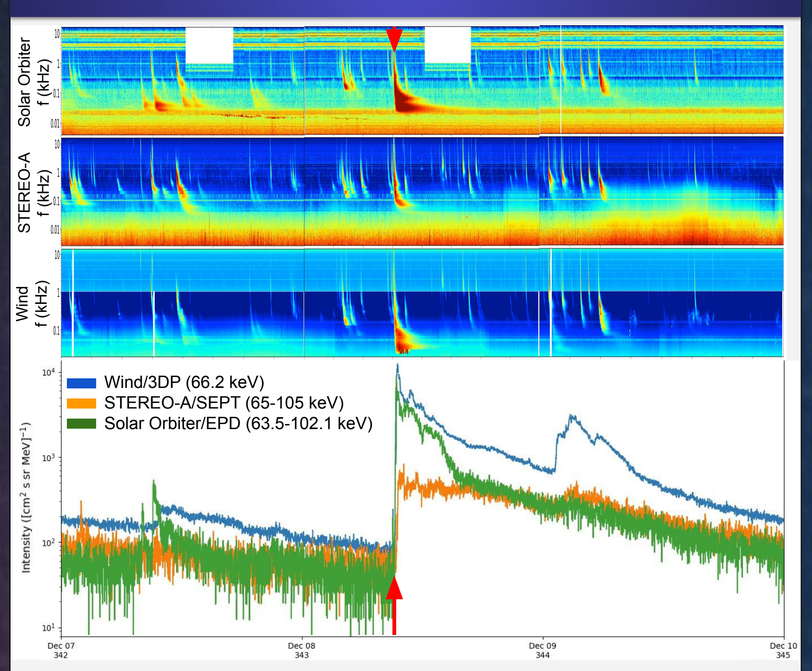
A series of solar energetic particle (SEP) events occurred in close succession between December 7 and December 10, 2024. The most significant of these originated from Active Region 13912, associated with an X2.3 class solar flare. These events were encountered by a constellation of spacecraft —Solar Orbiter (SolO; 0.9 au, -6° in longitude from Earth), BepiColombo (Bepi; 0.3 au, +5°), Earth-orbiting missions (~1 au), MAVEN (at Mars; 1.6 au, +22°), and STEREO-A (STA; 0.97 au, +28°)— which were immersed in diverse interplanetary solar wind conditions at that moment. Some of the events were not observed by all the spacecraft, while the most prominent was.

Notably, at Solar Orbiter, the most intense event showed a clear peak from the north-pointing telescope, observing ions exceeding 50 MeV and electrons above 7 MeV. The spacecraft was located within what appears to be a small-scale flux rope embedded in a Stream Interaction Region (SIR), while Wind at Earth's L1, was found outside this structure at the onset of this event.

This study presents preliminary work focusing on the longitudinal distribution of these SEP events and the impact of large-scale interplanetary structures on their propagation. We will compare observations from various longitudinally separated spacecraft to investigate these aspects. Preliminary findings on the main event's anisotropy, particularly its directional nature at Solar Orbiter and its relation to local structures, and the presence/absence of observations in the different spacecraft during the rest of the events underscore the importance of considering detailed interplanetary conditions for understanding SEP propagation and improving space weather prediction models.

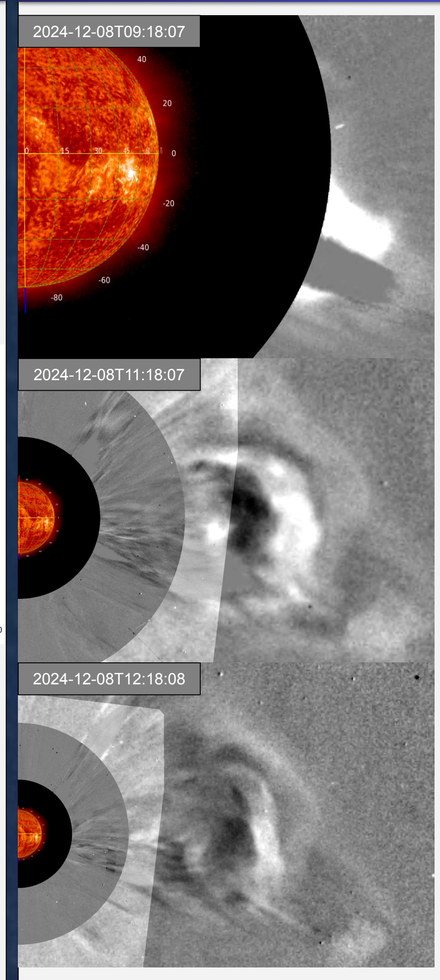
Observations

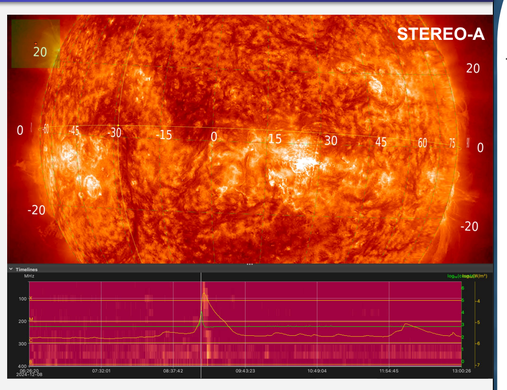
Radio and electrons



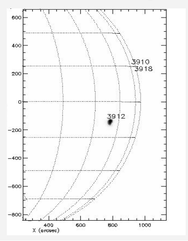
Trains of Type III radio bursts were observed throughout the December 7–10 period. Despite Wind's central location, bursts appeared more clearly at Solar Orbiter and STEREO-A in some cases. The most intense radio emission coincided with the largest SEP event, while no Type II bursts were detected. Langmuir waves were observed at Solar Orbiter and Wind, but were absent at STEREO-A.

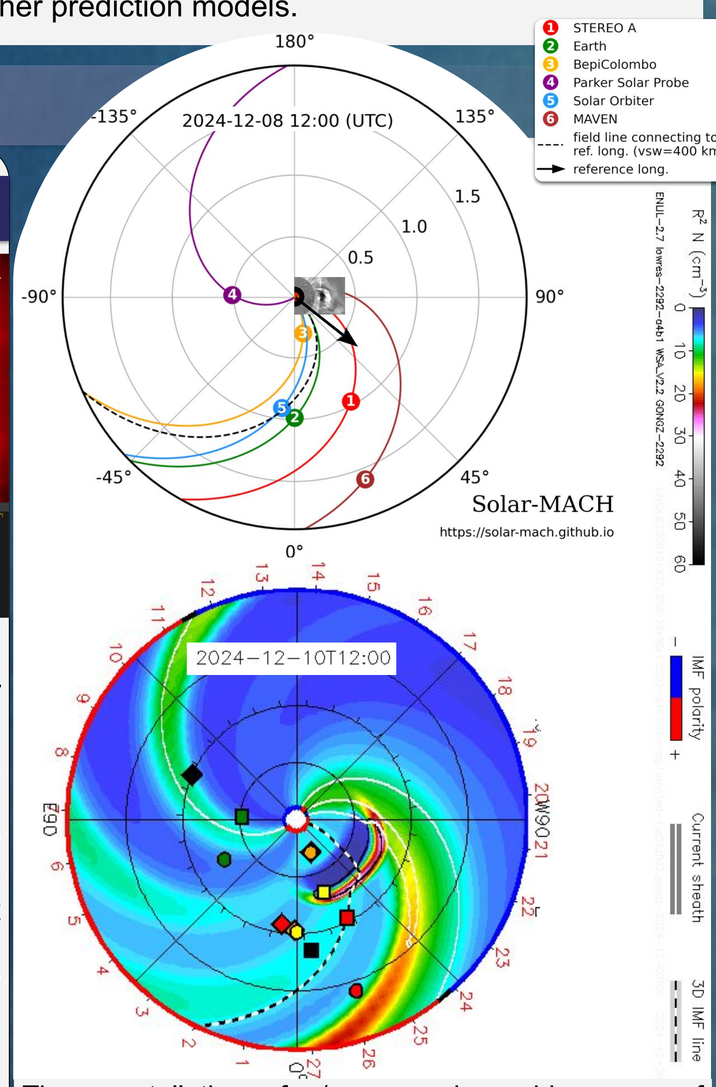
Flare and CME





An X2.3-class flare from AR 13912 (S08W53) occurred on December 8, directly facing STEREO-A. The flare was associated with a CME launched at 09:24 UT, with a speed of ~677 km/s (728 km/s as per the LASCO CME catalog) and a central longitude of 51°, consistent with the flare location. This CME is linked to the most intense SEP event observed during the period.

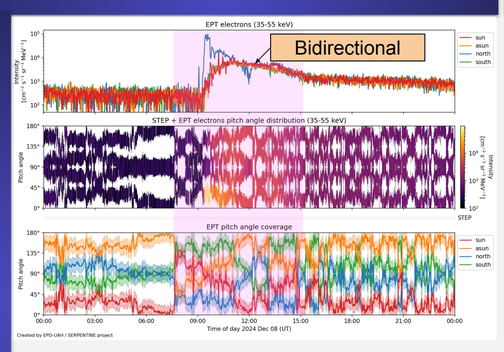




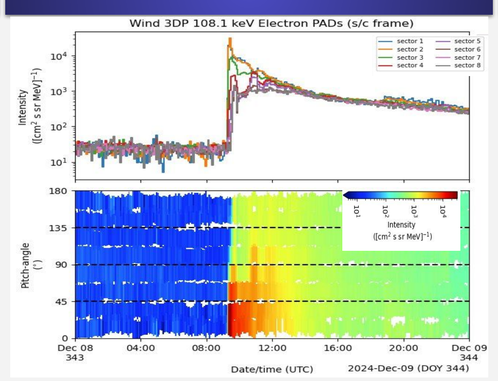
The constellation of s/c covered a wide range of longitudes (-92° to +28° from Earth) and heliocentric distances (0.3–1.6 au), offering a valuable multi-point view. ENLIL simulation shows varying solar wind conditions, with Solar Orbiter and MAVEN embedded in a fast stream, while STEREO-A was in slower wind.

Electron pitch angles

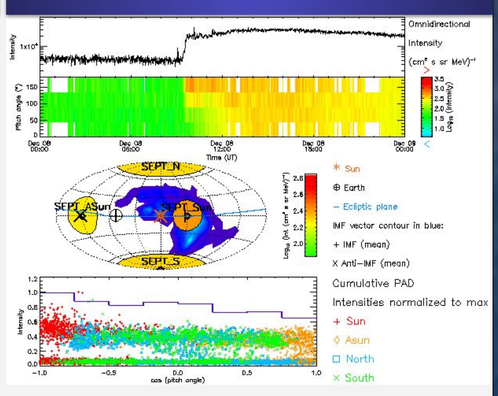
Solar Orbiter



Wind

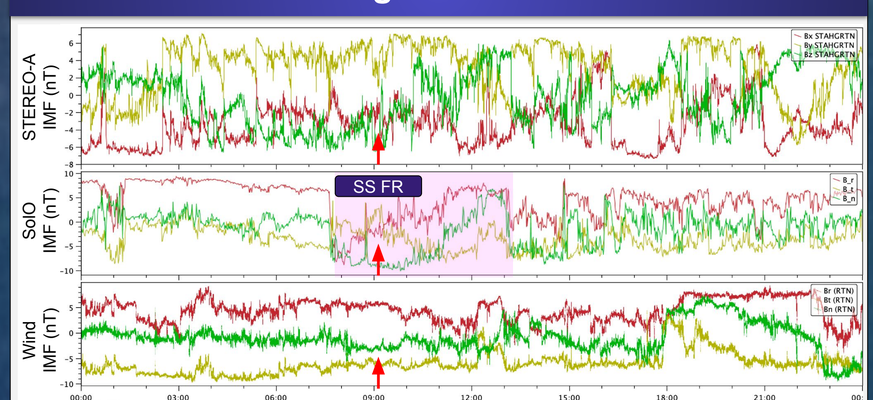


STEREO-A



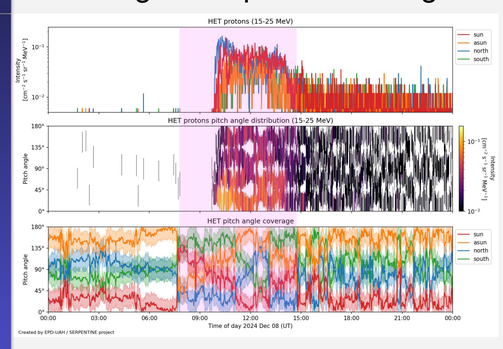
Strong anisotropies were observed at Solar Orbiter, Wind, and STEREO-A. At Solar Orbiter and Wind, electrons arrived parallel to the local magnetic field, while at STEREO-A they propagated anti-parallel likely due to the heliospheric current sheet (HCS) present between. At Solar Orbiter, field polarity pointing south caused electrons to arrive from the north, with a brief period of bidirectional streaming and strong depletion, indicating a complex local magnetic structure.

Magnetic field

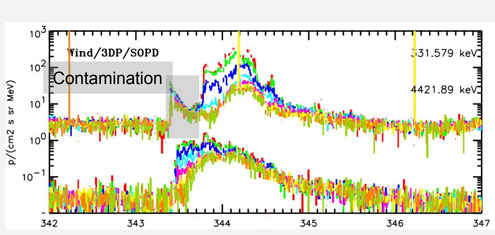


During the main event, Solar Orbiter/Earth (STEREO-A) observed outward (inward) polarity. At Solar Orbiter, there is a clear south-to-north rotation (SS FR) coinciding with the event onset.

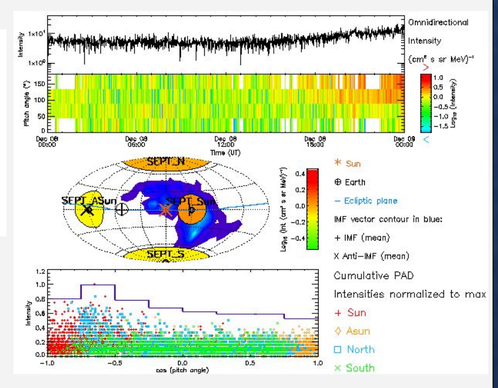
Ions



Intense and anisotropic ion onset with good pitch-angle coverage. The decay phase was notably abrupt before the end of the small-scale flux rope, suggesting rapid magnetic disconnection.



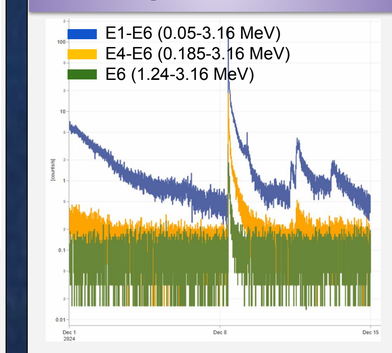
Ions display strong anisotropy and a delayed onset ~1.5 hours after the electrons, consistent with energy-dependent transport. The decay phase is more gradual compared to Solar Orbiter, indicating differing magnetic connectivity or local scattering. Additionally, low-energy electrons show signatures suggestive of local shock acceleration (not shown).



STEREO-A higher-energy ions arrived ~3 hours after the initial electron onset and the anisotropy is less clear. This timing delay suggests different propagation effects or injection. It also shows a clear velocity dispersion (not shown).

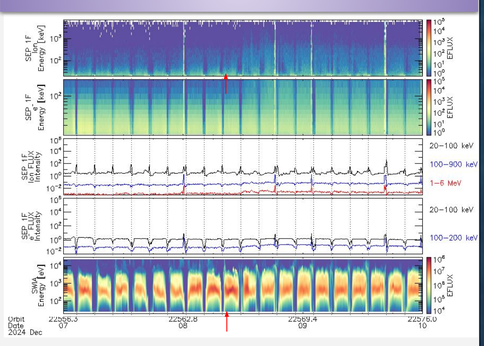
Other locations

BepiColombo



BepiColombo registered an intensity enhancement during the period of the main SEP event reaching >1 MeV electrons and 9 MeV protons (not shown).

MAVEN



MAVEN (1.6 au) also detected the main SEP event. This highlights the event's efficient particle transport under varying solar wind conditions.

Acknowledgements

The authors acknowledge the open policy of the data for the different missions. We acknowledge use of NASA/GSFC's Space Physics Data Facility's CDAWeb service. This work has been possible thanks to the scientific discussions within the LASSOS-Goddard group. Project PID2023-150952OB-I00 funded by MICIU/AEI/10.13039/501100011033 and by FEDER, EU.

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Cofinanciado por la Unión Europea
AGENCIA ESTATAL DE INVESTIGACIÓN