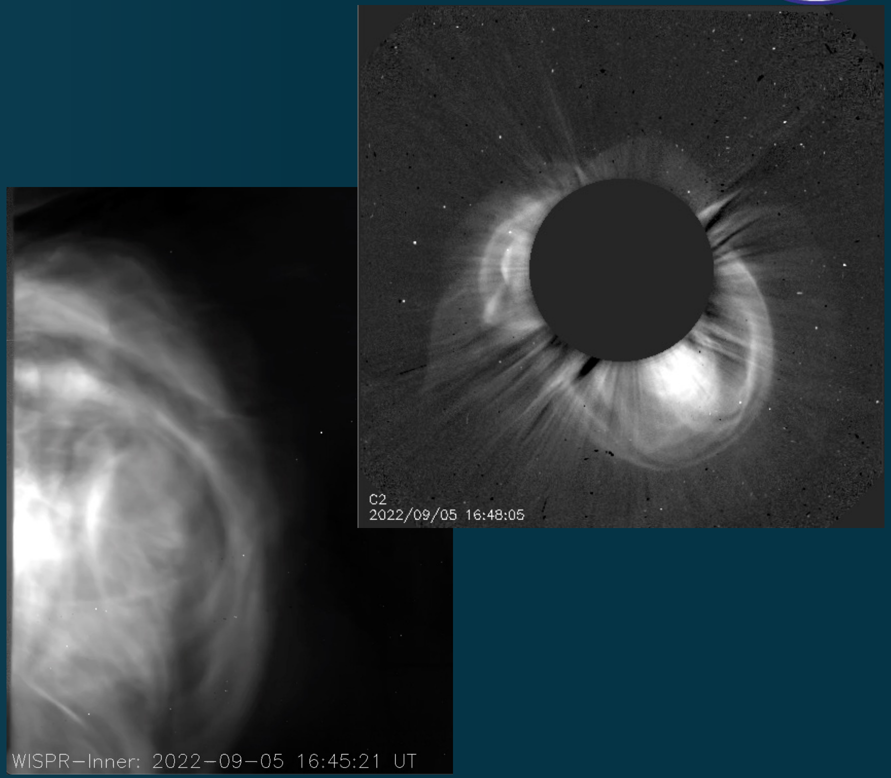
STEREO Science Highlight

The Space Weather Context of the First Extreme Event of Solar Cycle 25, on 2022 September 5

Paouris, E., Vourlidas, A., Kouloumvakos, A., Papaioannou, A., Jagarlamudi, V. K., and Horbury, T., (2023) *ApJ*, **956**,1, 2023. DOI: 10.3847/1538-4357/acf30f

Background

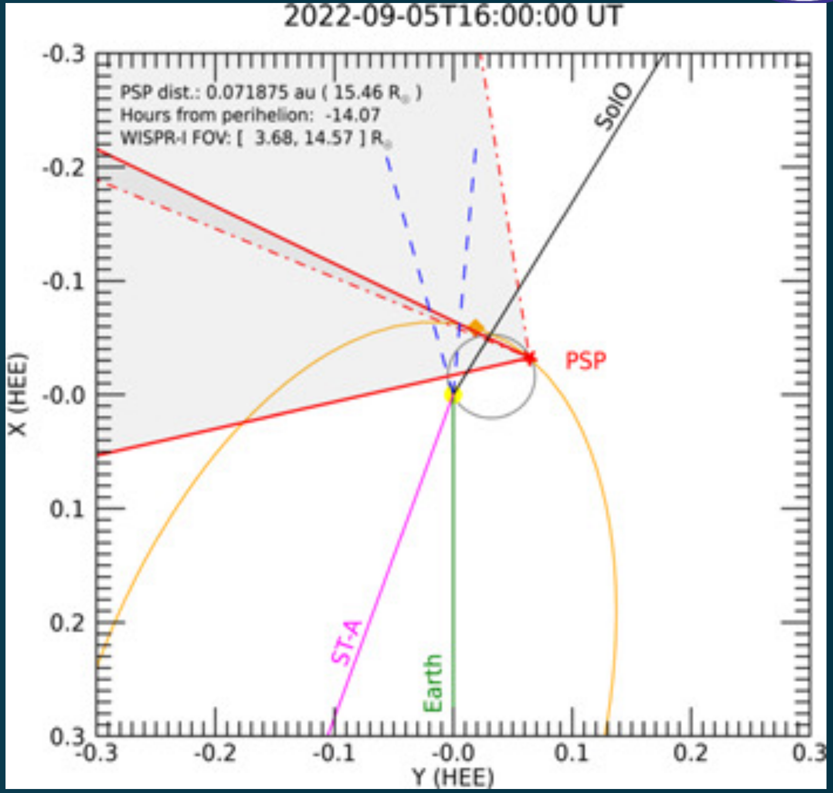
- Coronal Mass Ejections (CMEs) are the main drivers of intense space weather, causing significant effects to human technology, including power systems, spacecraft and communications.
- CMEs produce space weather effects in different ways, including via the acceleration of Solar Energetic Particles (SEPs), which create a radiation hazard in space, and also by the interaction of CMEs with Earth's magnetic field leading to geomagentic storms.
- However, the detailed connections between the CME dynamical/kinematic properties and their space weather impacts remain unclear, particularly for the rare Earth-directed events with extreme properties.
- Predicting which CMEs will be geoeffective and why are key space weather goals



Top right: The backside CME captured by LASCO/C2 from 1 AU as a halo with a sheath surrounding the occulting disk. **Bottom left**: the same CME captured by PSP/WISPR inside the solar corona (at 14 solar radii).

The Event

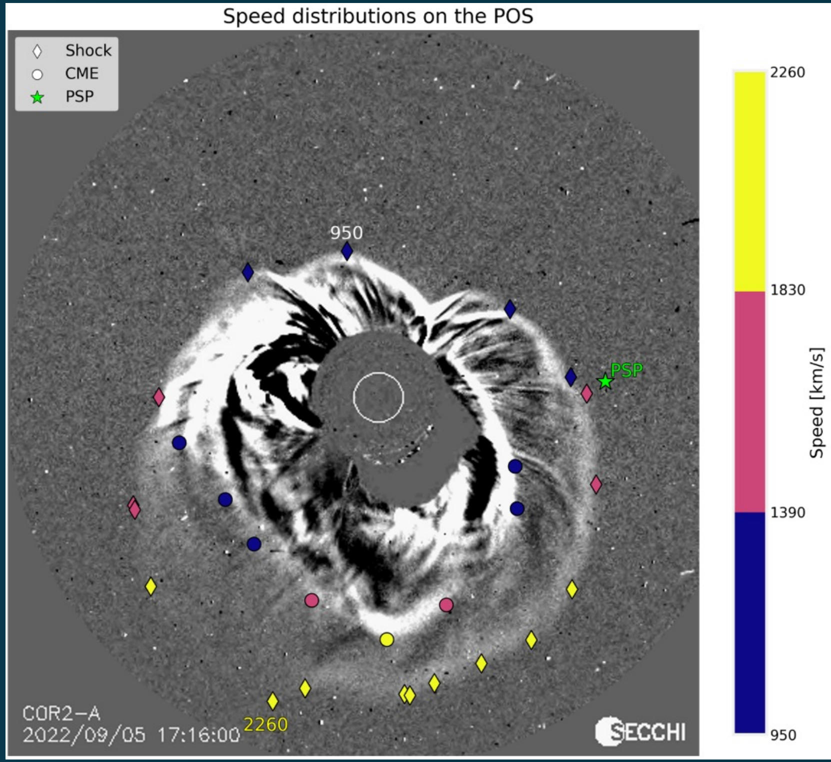
- The September 5, 2022 Coronal Mass Ejection (CME) was an extreme event in terms of speed, mass, and kinetic energy (in the top 1% of all CMEs observed since 1996). It was directed away from Earth.
- It was analyzed with data obtained from Solar Orbiter (SolO), Parker Solar Probe (PSP), STEREO-A (ST-A), and SOHO (near Earth), which were distributed across the inner heliosphere at different radial distances. This multi-spacecraft analysis was key to understanding the event.



Location of various observatories at the time of the eruption. The Dashed blue lines show the propagation of the CME. The light gray shaded area shows the PSP/WISPR field of view. Paouris et al. (2023)

Analysis and Results

- Paouris et al. (2023) derived the speed, mass, kinetic energy, direction and size of the CME and used an empirical kinematic algorithm (Heliospheric Reconstruction and Propagation Algorithm (HeRPA); Paouris and Vourlidas, 2022) to forecast the arrival of the event at Solar Orbiter with an error of only a few minutes (~5 mins). They extrapolated the measured properties at Solar Orbiter (~0.7 AU) to forecast the CME parameters at 1 AU and the subsequent storm levels that would have occurred if it had encountered Earth.
- They found that despite the high speed and mass of the event, it would have not caused an intense geomagnetic storm if it had been Earth-directed.
- They also developed a machine learning logistic regression model to assess the Solar Energetic Particle (SEP)-potential of this event based on its kinematics. They find that the CME would produce a high-energy (E>100MeV) SEP with a probability of 98%



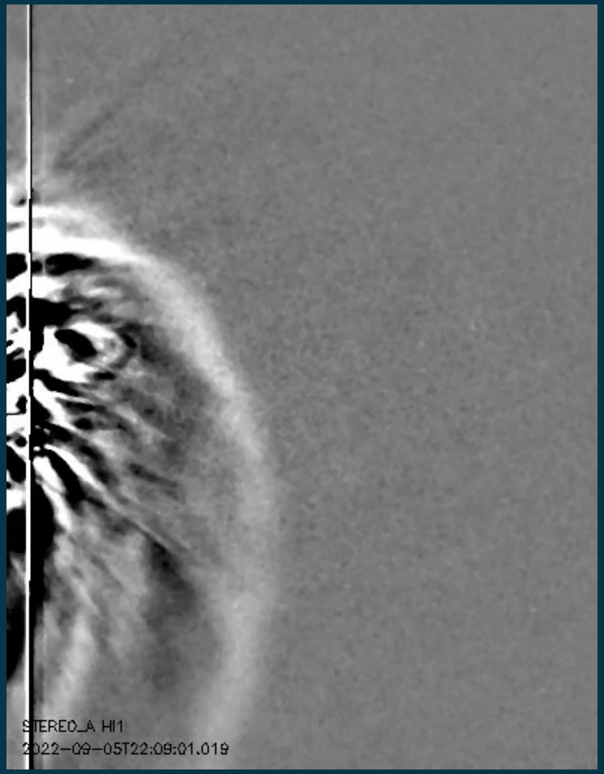
Above: Distribution of the calculated speeds for the shock (diamonds) and CME (circles) on top of a STEREO-A/COR2 image at 17:16 UT. Paouris et al. (2023)

Findings

- The September 5, 2022 Coronal Mass Ejection (CME) was an extreme event in terms of speed, mass, and kinetic energy (in the top 1% of all CMEs observed since 1996).
- Paouris et al. (2023) show the event would have a high probability of producing dangerous Solar Energetic Particles (SEPs).
- However, their analysis also showed that it would *not* have caused an intense geomagnetic storm if it had been Earth-directed.
- The precise intersection of Earth through the incoming transient seems to be more important for Space Weather than any parameter that describes the event as a whole.

Impacts

- The study found that the geoeffectiveness of an event depends more on the trajectory of the CME over Earth, than the solar (or even interplanetary) properties of the event.
- The disconnect between extreme eruptive events and their potential geo-impacts, as was demonstrated for 2022 September 5 CME, points to the need for a properly designed systems approach to space weather.
- Extreme-ultraviolet and white-light coronal observations of CMEs from the Sun-Earth line, while forming the foundation of operational forecasting systems, are insufficient for properly assessing the geoeffectiveness of solar transients.
- Off Sun-Earth line multi-viewpoint imaging in the inner heliosphere and multipoint in situ measurements, upstream of L1, are needed to increase the horizon and accuracy of space weather forecasts.



Above: STEREO HI-1 image of the CME at 22:09 UT, showing the preceding shock and a part of the CME flux rope underneath.

References

Paouris, E., Vourlidas, A., Kouloumvakos, A., Papaioannou, A., Jagarlamudi, V. K., and Horbury, T., (2023) *ApJ*, **956**,1, 2023. DOI: 10.3847/1538-4357/acf30f

Paouris, E. and Vourlidas, A. (2022), Space Weather, **20**, 7, e2022SW003070 doi: 10.1029/2022SW003070