Science Highlights

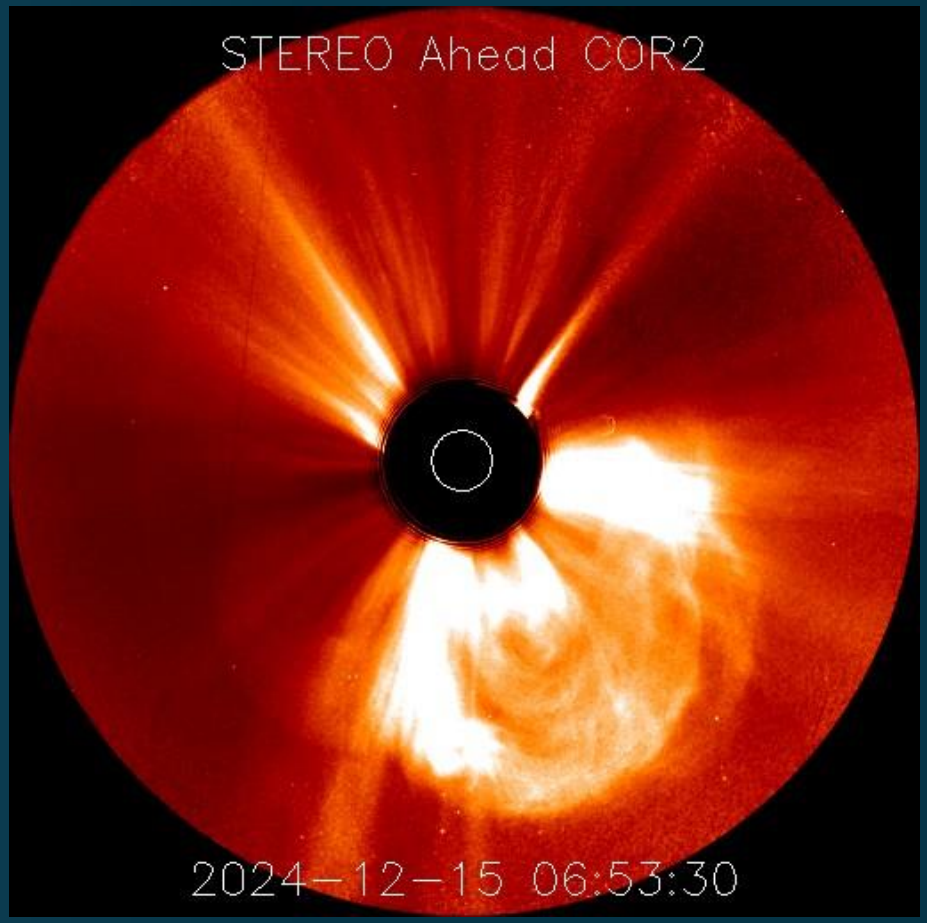
The structure of a complex, asymmetric coronal mass ejection revealed by 17 spacecraft across the inner heliosphere

A. Luspay-Kuti, D.L. Turner, E. Paouris, A. Vourlidas, A.B. Crew, R.L. McNutt, J.H. Westlake, S. Raptis, C.J. Cochrane, X. Jia, C.A. Raymond, H. Korth, D. Heyner, K. Hanley, A. Rahmati, J.R. Gruesbeck, J.S. Halekas, S.M. Curry, H.T. Smith, M.L. Stevens, E.Roussos, K.E. Mandt, M.G. Kivelson, J.A. Slavin, D. Waller, K.K. Khurana, T.A. Nordheim, C.S. Paty, A.M. Rymer, J. Saur, and N. Krupp

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Background

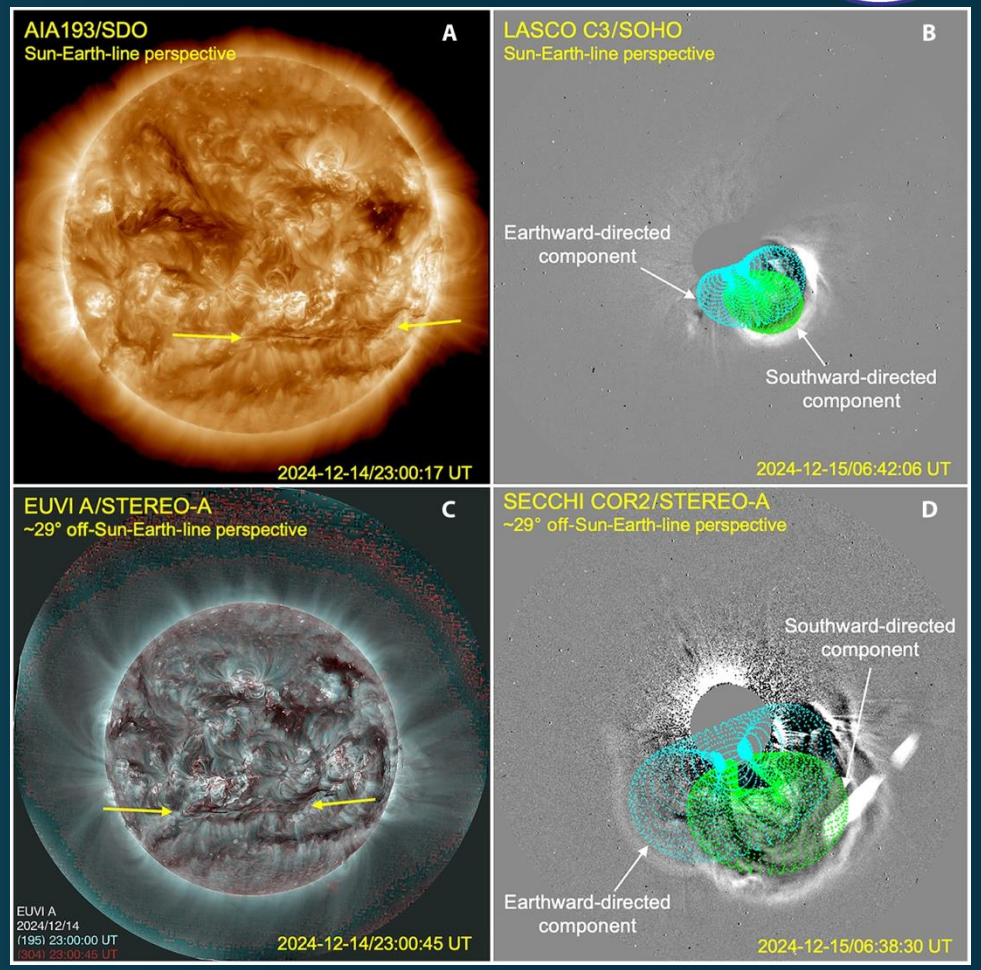
- Coronal mass ejections (CMEs) are enormous bursts of plasma and magnetic field from the Sun that propagate explosively through the Solar System.
- Fast CMEs often drive interplanetary shocks capable of accelerating solar energetic particles (SEPs) to high energies. These particles can penetrate spacecraft shielding and pose acute radiation risks to astronauts during interplanetary transit or lunar surface operations.
- In addition, enhanced dynamic pressure and magnetic disturbances can disrupt spacecraft systems and communication.
- Understanding CME structure and how they move through the Solar System is key to understanding their effects.
- Forecasts missing Earth- or Mars-directed CMEs have direct implications for crew safety and operational planning.



Above: CME as observed with STEREO-A/Cor2
Credit: NASA, STEREO/SECCHI

Analysis

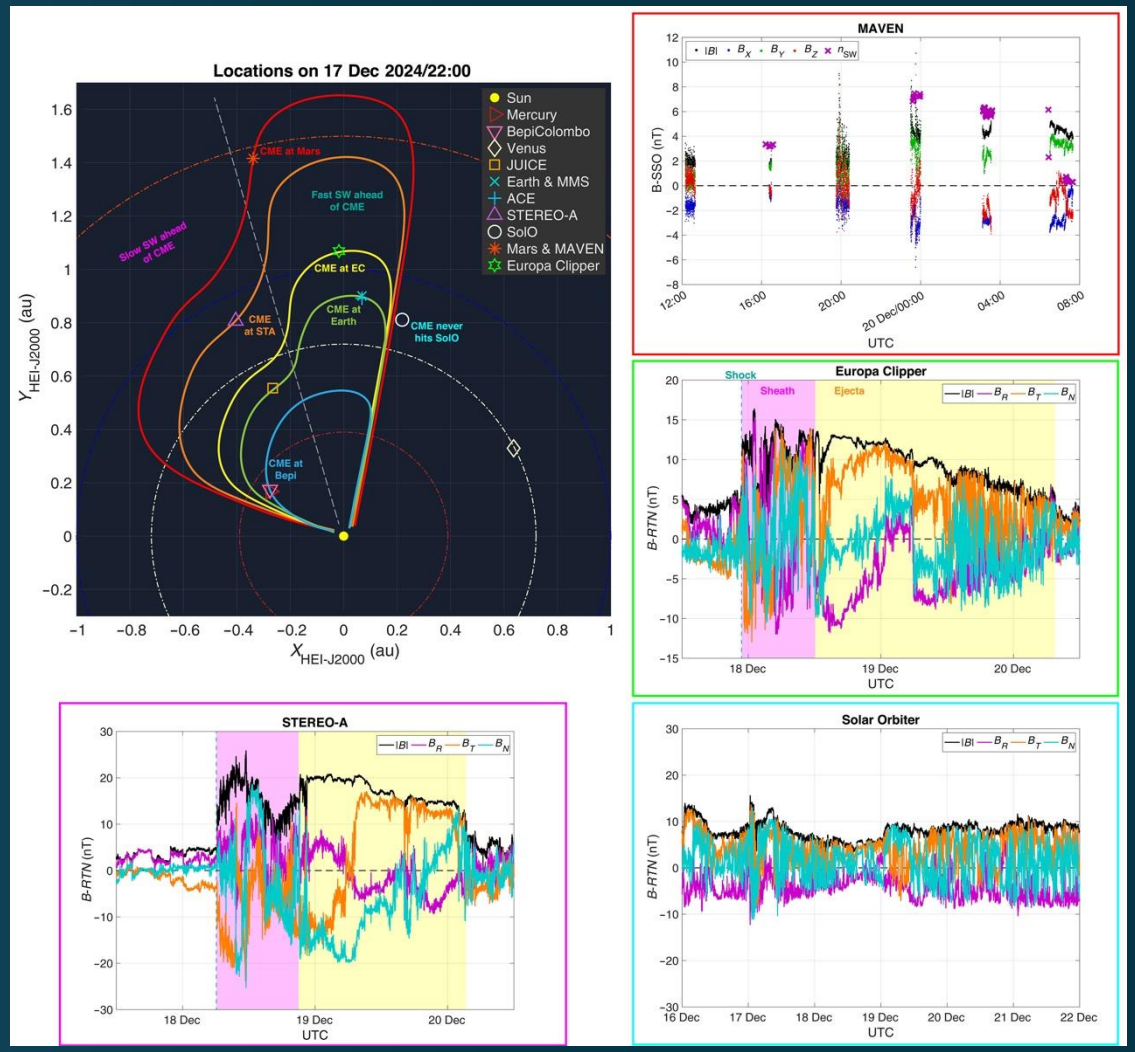
- On December 14, 2024 a CME erupted from the Sun and headed into interplanetary space.
- Data from an unprecedented network of 17 spacecraft across the inner Solar System were used to analyze the event, including *ACE, ARTEMIS* (2), *BepiColombo, DSCOVR, Europa Clipper, GOES, MAVEN, MMS* (4), *SDO, SOHO, Solar Orbiter, STEREO-A*, and *Wind.*
- These data revealed a complex two-part structure with a hidden Earth-directed component that propagated asymmetrically and could not have been predicted without off-Sun-Earth-line observations.
- This component also affected Mars and Europa Clipper (in its cruise phase), demonstrating how a missed forecast of this kind could endanger a crewed mission.



Above: (a) and (c): Extreme ultraviolet images from SDO and STEREO-A highlighting the extended filament that produced the CME. (b) and (d): Running difference images of coronagraph observations from SOHO and STEREO-A with superimposed models of the two flux rope structures needed to model this complex coronal mass ejection. Credit: Luspay-Kuti et al 2026

Findings & Impacts

- Together, the observations reveal two geometrically distinct aspects of the Earth-directed CME component: a fast lobe passing through the Sun-Earth-Mars sector and a slower longitudinal flank sampled by STEREO-A. These lobes represent different portions of the same asymmetric CME rather than separate events.
- STEREO-A's crucial off-axis coronagraph observations revealed the otherwise hidden Earth-directed component, while its in situ measurements helped establish the pronounced longitudinal asymmetry within that component.
- The CME shock reached STEREO-A approximately 25 hours after near-Earth spacecraft, despite their similar distances from the Sun, while Solar Orbiter, only ~10° east of Earth, did not encounter the CME. These observations demonstrate the CME's pronounced longitudinal asymmetry.
- These findings highlight the importance of sustained *in situ* measurements from planetary missions during cruise, alongside dedicated heliophysics missions, to improve our understanding of CME propagation and support space-weather forecasting and mission planning.



Above: Top left: Locations of the CME as it moved through the Solar System, revealing two lobe-structure. Other panels show in-situ magnetic field data from MAVEN, *Europa Clipper, STEREO-A*, and *Solar Orbiter*. Credit: Luspay-Kuti et al 2026

Additional Info

- Publication information

  The structure of a complex, asymmetric coronal mass ejection revealed by 17 spacecraft across the inner heliosphere

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