Multi-Spacecraft Observations of the Evolution of ICMEs Between 0.3 and 2.2 AU: Conjunctions with Juno

Emma E. Davies[1,2], Réka M. Winslow[1], Camilla Scolini[1,3], Robert J. Forsyth[2], Christian Möstl[4], Noé Lugaz[1], Antoinette B. Galvin[1]

1. University of New Hampshire, USA. 2. Imperial College London, UK. 3. CPAESS, UCAR, USA. 4. Space Research Institute, Austrian Academy of Sciences, Austria.

University of New Hampshire

Motivation

- **To better understand the magnetic structure and evolution of interplanetary coronal mass ejections (ICMEs) in situ, it is useful to track individual ICMEs measured over varying scales and separations.**
- **Previous studies have utilised ICME catalogues to search for conjunctions between spacecraft observing the same event within 1 AU (Good et al. 2019, Salman et al. 2020).**
- **A recent catalogue of ICMEs identified at Juno (Davies et al. 2021) during its cruise phase to Jupiter (1-5.4 AU) provides an opportunity to study ICMEs over wider heliocentric distance separations.**

Outline

- **In this study, we identify ICME conjunctions with Juno by matching features in the magnetic field data with those observed by MESSENGER, Venus Express (VEX), STEREO, and Wind, covering 0.3 to 2.2 AU.**
- **We identify a total of 35 conjunction events, 7 of which had not been identified in Davies et al. 2021.**
- **We investigate the global expansion of ICMEs by tracking how the magnetic field strength changes with distance and compare this to the local expansion measured at 1 AU. For events with magnetic flux ropes, we investigate the orientation of the flux rope axis as they propagate.**

1. Identification of Multi-Spacecraft Events

- Back-propagated events identified at Juno by Davies et al. 2021.
- Also worked forwards from previously catalogued events (Helio4CAST, Salman et al. 2020, Richardson et al. 2010) to establish links with signatures in the Juno magnetic data that may not have been previously identified.

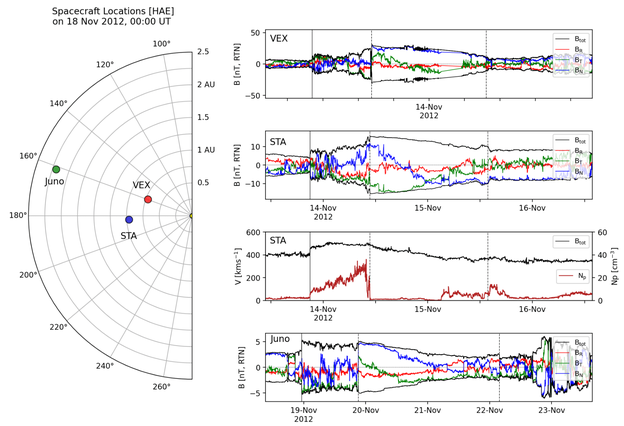


Figure 1: Overview of spacecraft positions and in situ data for an example event observed by Venus Express, STEREO-A, and Juno in November 2012.

2. Event Separations

- 35 multi-spacecraft events were identified: 34 were observed by a spacecraft near 1 AU, 7 were also observed by either VEX or MESSENGER.
- Widest radial separation between VEX and Juno of 1.48 AU.
- 31 of 42 conjunctions longitudinally separated by less than 10°.

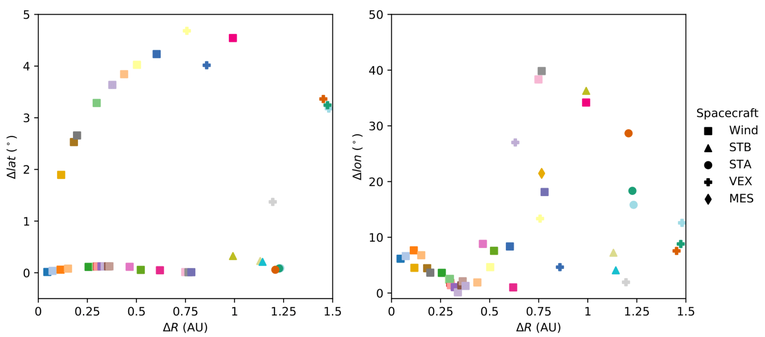


Figure 2: Overview of latitude (left) and longitude (right) separations with radial separation between Juno and corresponding spacecraft.

3. Event Properties with Heliocentric Distance

- The variation of ICME magnetic field strength with heliocentric distance provides a measure of global expansion.
- Statistical relationship of mean magnetic field strength: radial dependency, α = -1.40, consistent with previous studies conducted using Ulysses data e.g. Richardson et al. 2014, Liu et al. 2005, and Wang et al. 2005.
- The mean of all individual fits (positively expanding): α = -1.46 ± 0.53.
- High standard deviation demonstrates the large spread in radial dependencies calculated for individual events.

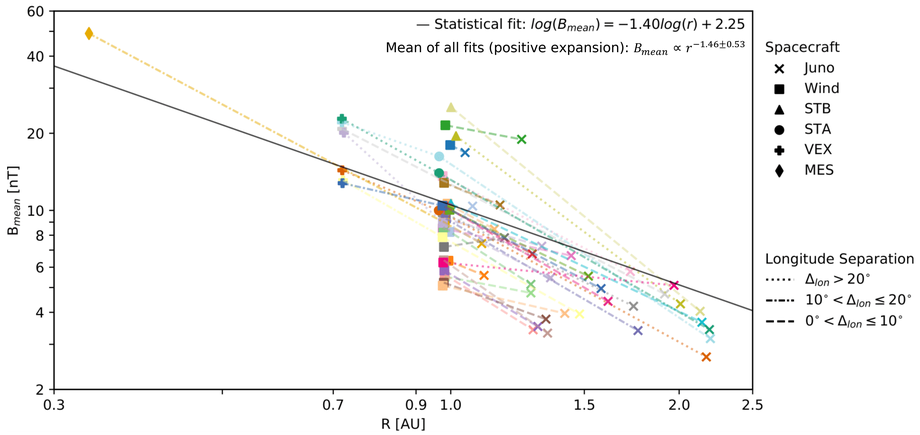
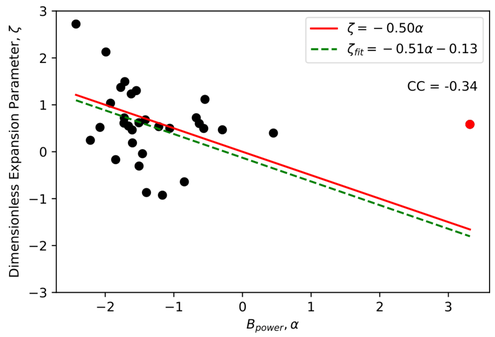


Figure 3: Variation with heliocentric distance of the mean magnetic field strengths of each event observed at Juno and at least one other spacecraft.

4. Comparing Local and Global Expansion Measures



- The dimensionless expansion parameter provides a measure of the local expansion of an ICME: $\zeta = \frac{\Delta v}{\Delta t}\frac{r_H}{v_c^2}$
- ζ is independent of distance and found to be related to the global expansion as $r^{-2\zeta}$.
- Despite the best fit following the expected relationship between the two parameters, they are weakly correlated.

Figure 4: Dimensionless expansion parameter at 1 AU, ζ (local expansion) vs. the radial dependency of the mean magnetic field with heliocentric distance for each event pair, α (global expansion).

5. Events with Magnetic Flux Ropes

- 10 events with magnetic flux ropes were identified and fit using a linear force-free model.
- 40% display a significant change (|Δθ|> 45° or |Δϕ| > 60°) in flux rope orientation with increasing heliocentric distance.
- This is consistent with 38% of flux rope events found to have significant changes in orientation between MESSENGER and 1 AU by Scolini et al. 2021.

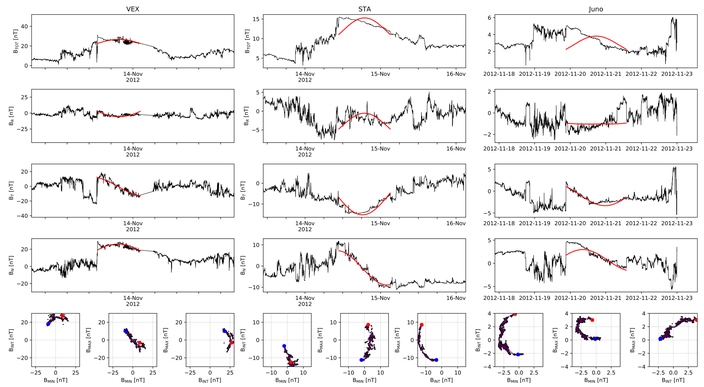


Figure 5: The linear force-free (LFF) flux rope fitting results (red) and magnetic hodograms for the same example event presented in Figure 1.

6. Summary

- We have identified 35 multi-spacecraft ICME events. Most were observed by Juno and one other spacecraft at 1 AU (Wind, STEREO-A, or STEREO-B), 7 of which were observed by a third spacecraft (MESSENGER or Venus Express).
- There is a large variability in radial dependencies calculated for individual events.
- Local and global expansion parameters are weakly correlated.
- 40% of ICME flux ropes identified display a significant change in orientation as they propagate beyond 1 AU.

JUNO ICME CATALOG

MULTI-SPACECRAFT ICMEs

emma.davies@unh.edu