Multispacecraft Observations of interacting CME flux ropes

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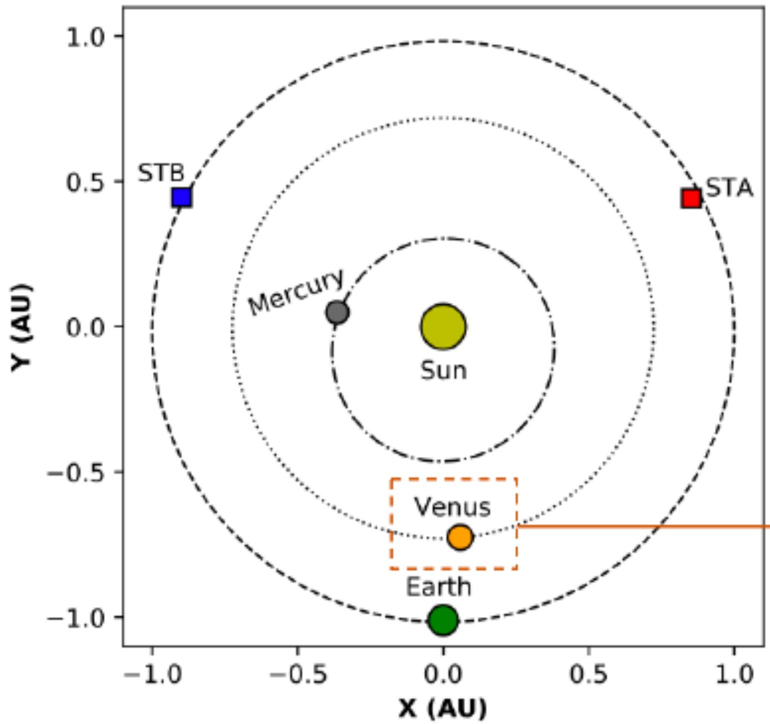
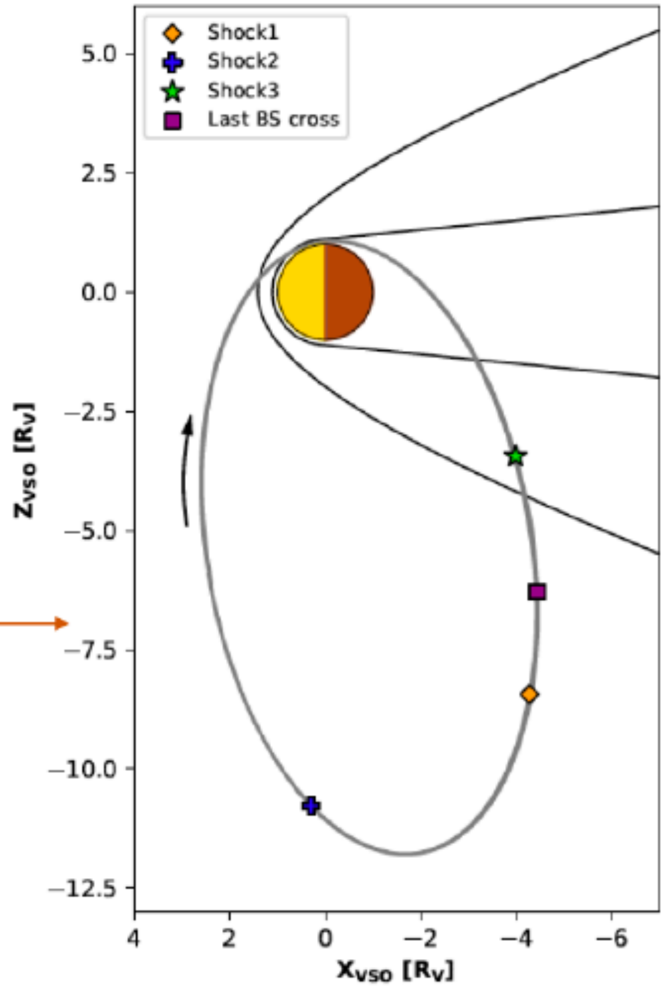
Motivation Interactions between successive coronal mass ejections (CMEs) in interplanetary space can greatly modify their properties and evolution → significant modifications to their space weather response. The nature of interactions and the outcome varies considerably depending on the relative speed and launch direction of CMEs involved, as well as the magnetic configuration of their flux ropes. One of the challenges in studying interactions is the lack of observations in heliosphere at different radial distances as well as lack of realistic information of intrinsic CME parameters to coronal and heliospheric models.

Results shown We present here results of the analysis of three CMEs that erupted from the Sun between June 12-14, 2012. They were observed by almost radially aligned Venus Express and near-Earth spacecraft (Wind used). Observations showed at Earth a weak edge encountered CME ejecta and one coherent flux rope CME with high peak magnetic field (~ 40 nT). Measurements at Venus however revealed that the big flux rope at Earth was composed of two separated CMEs. Observational analysis is complemented by modelling using EUHFORIA (*Pomoell & Poedts*, 2019) and heliospheric imaging from STEREO.

Kilpua et al., Multipoint Observations of the June 2012 Interacting Interplanetary Flux Ropes, Frontiers in Astronomy and Space Sciences, doi: 10.3389/fspas.2019.00050, 2019

Spacecraft Locations



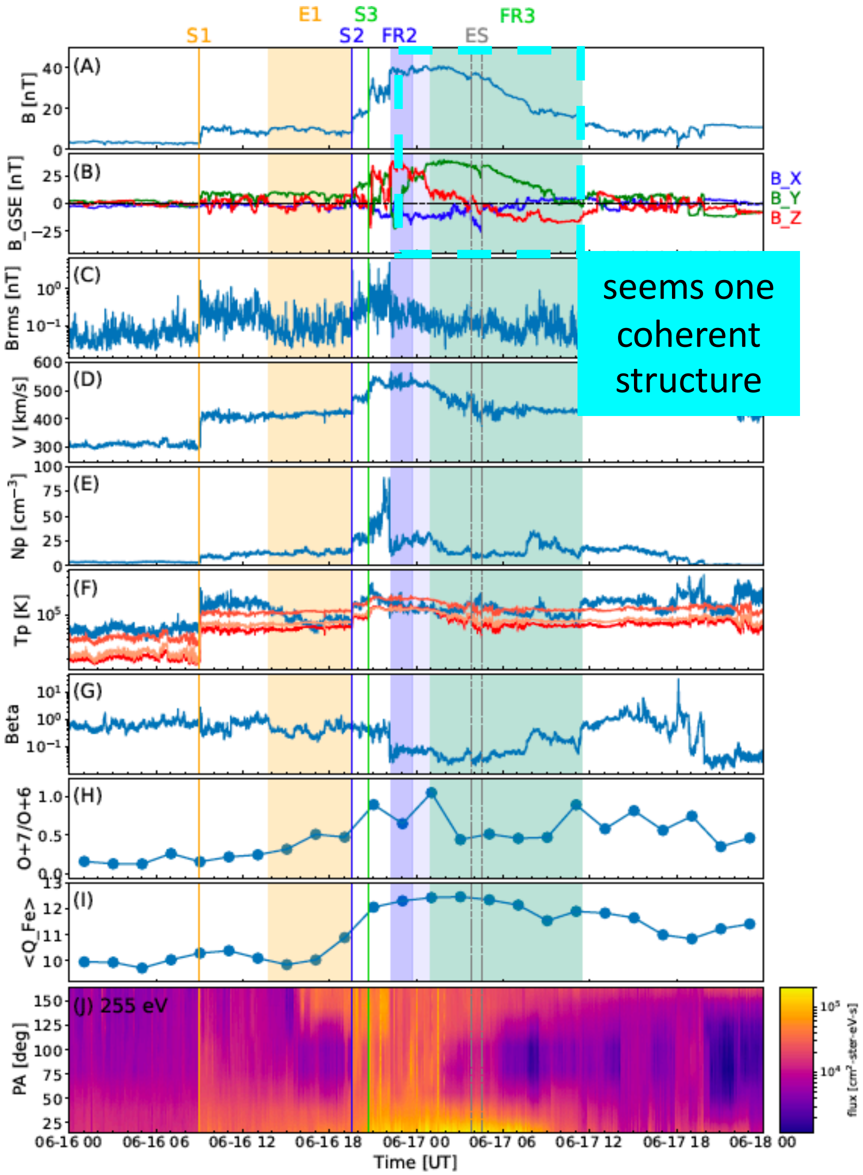


Venus Express and Wind separated by 5.4° in longitude and in 0.2° latitude

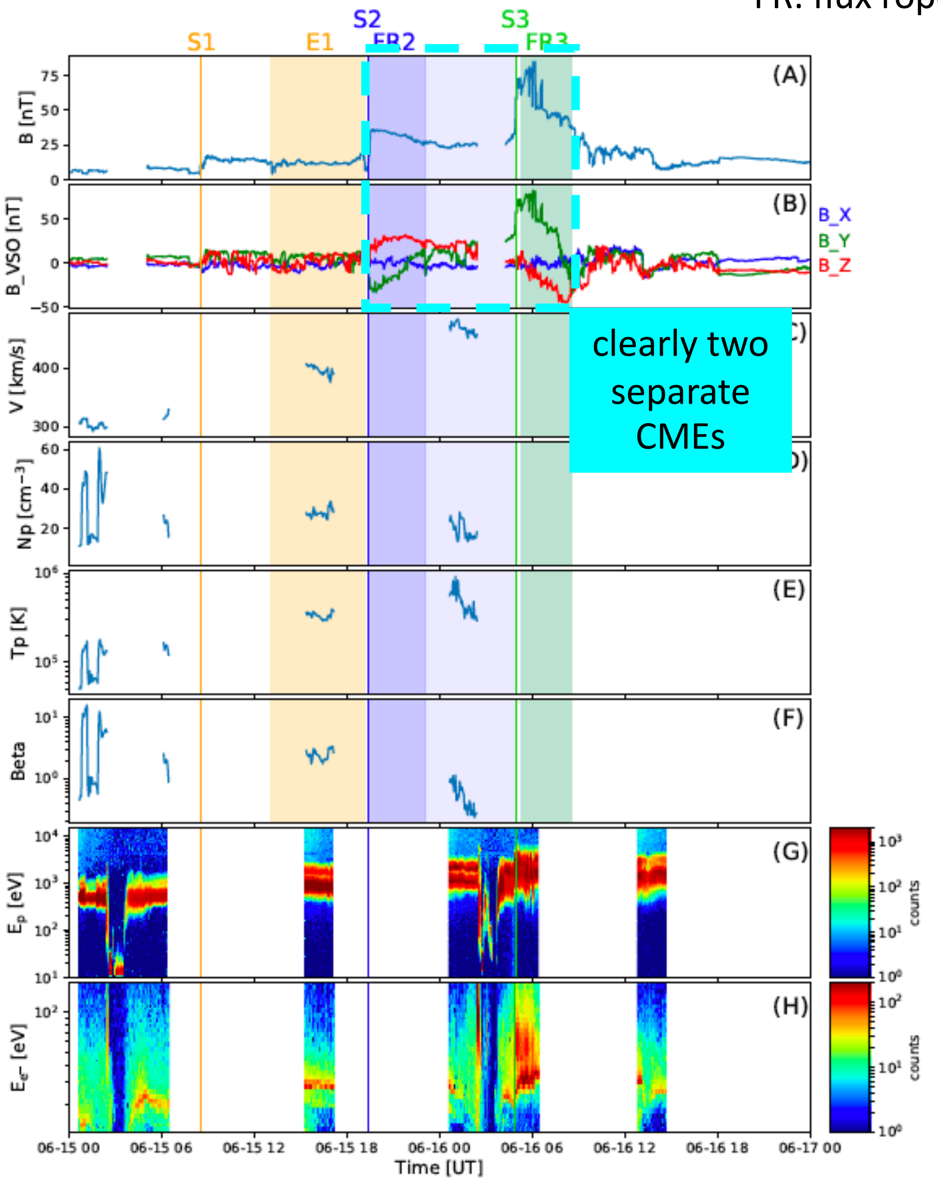
Solar wind observations

S: shock
E: ejecta
FR: flux rope

Near-Earth solar wind (L1, Wind)



0.72 AU (Venus Express)



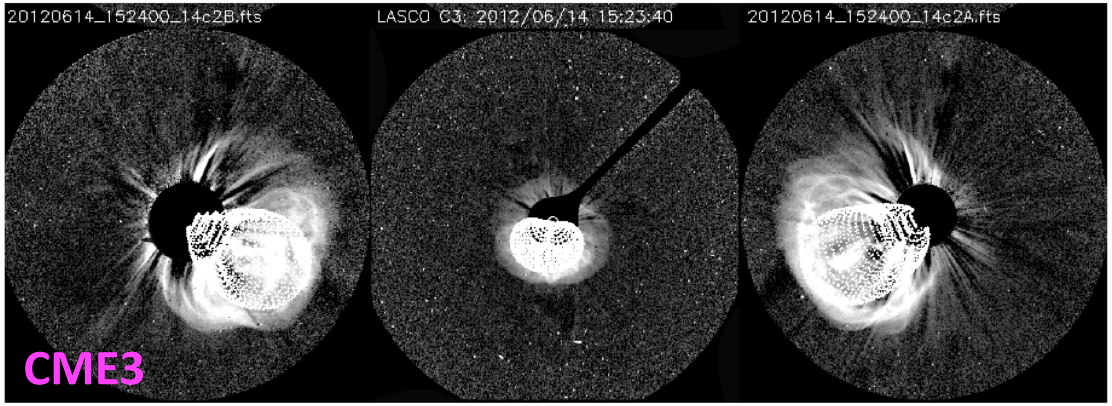
Solar observations

- Three CMEs erupted June 12-14, 2012: 1) June 2012, 17: 24 UT (**CME1**), 2) June13, 2012, 14:09 UT (**CME2**), 3) June 14, 2012, 14:24 UT (**CME3**)

- Geometric and kinematic CME parameters determined using Gradual Cylindrical Shell (GCS) fitting

- CME magnetic parameters (helicity and axial field direction) were determined using the observational scheme described in *Palmerio et al*. 2017; 2018 for CME2 and CME3. They had **NES** – type magnetic flux rope (i.e. field rotating from North to South, being East at the axis). CME1 was too complex to perform the analysis, it originated from two sympathetic eruptions that merged very early on to produce complex ejecta.

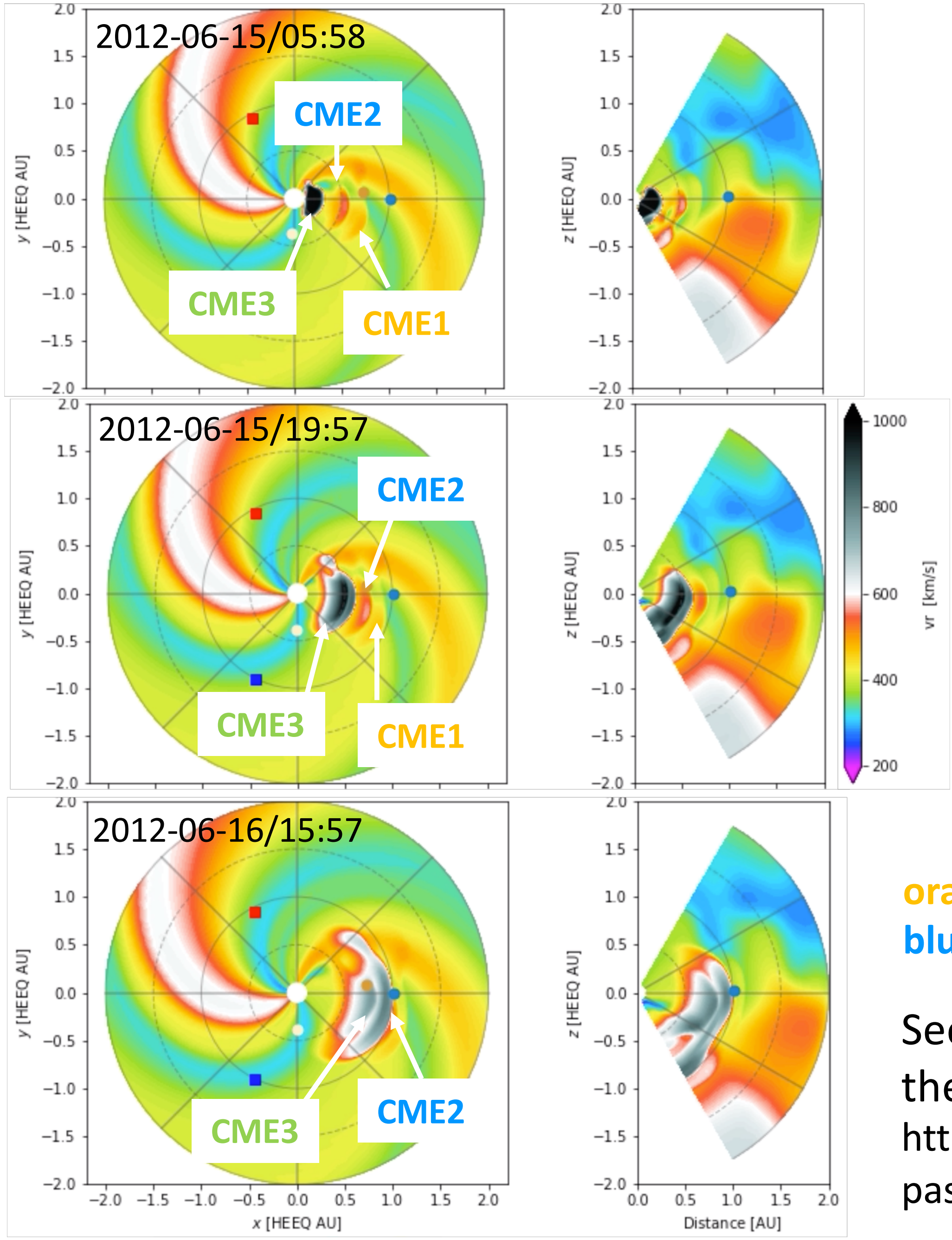
- EUHFORIA was run for all three CMEs with the cone model using parameters from GCS.



CME	Time at 0.1 AU [UT]	Θ [°]	Φ [°]	$\omega/2$ [°]	V [km/s]
CME1	6/13 00:35	0.0	-5.0	27.5	521.8
CME2	6/13 19:54	-35.0	-10.0	38.6	657.0
CME3	6/14 17:18	-28.0	-5.0	57.0	966.3

Θ: latitude
Φ: longitude
$\omega/2$: half angle

EUHOFRIA run results

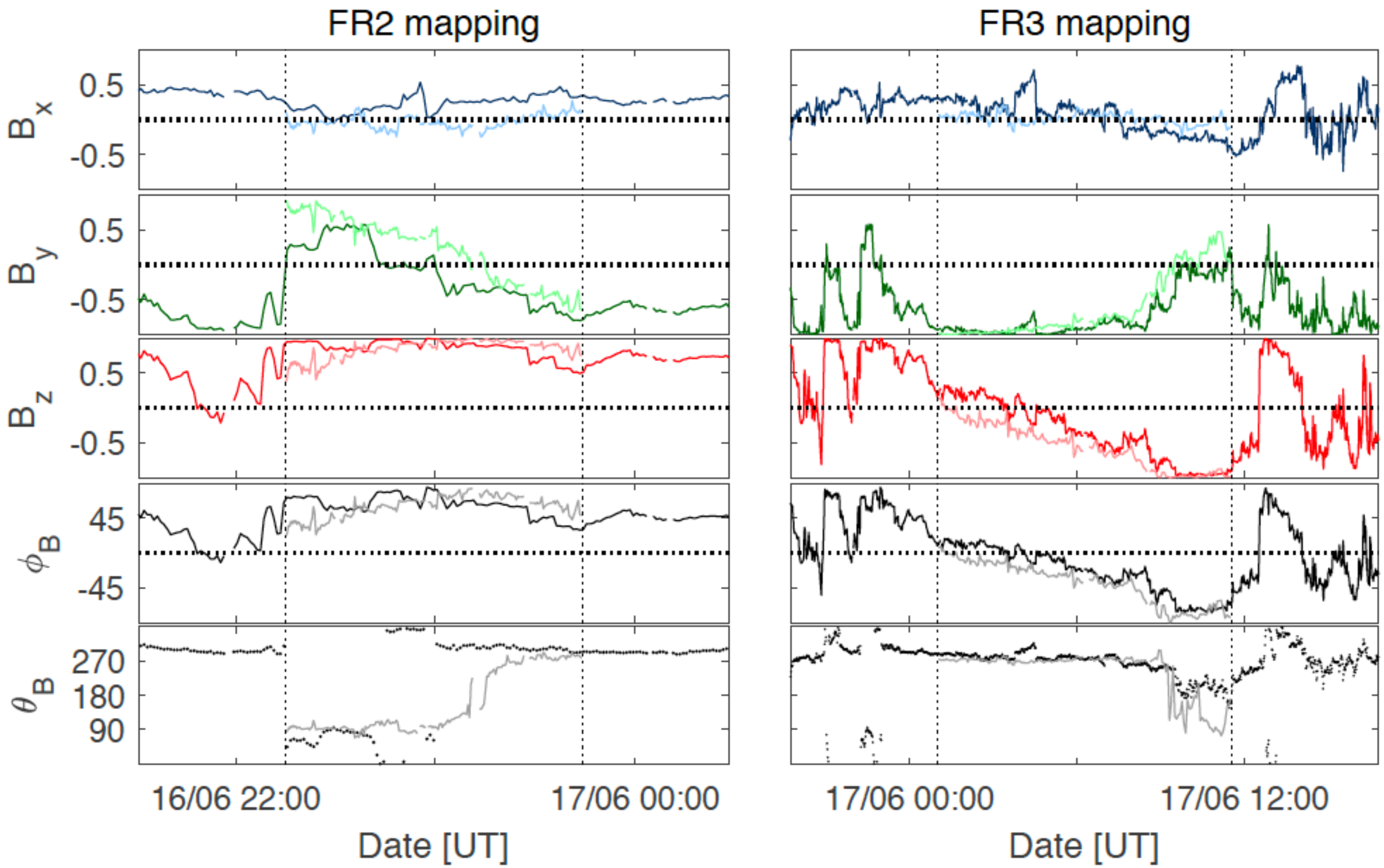


- CME1 arrives first both to Venus and Earth. It makes only a glancing encounter and is much weaker than two other CMEs
- CME2 and CME3 were still separate at the orbit of Venus, but catch and merge while reaching the Earth → consistent with double shock feature at Earth
- Arrival times match well with in-situ observations as well as STEREO Heliospheric Imager movie

orange dot: Venus
blue dot: Earth

See Supplementary Kilpua et al., 2019 for the full EUHFORIA and for the HI movie: https://www.frontiersin.org/articles/10.3389/fspas.2019.00050/full#supplementary-material

Venus vs. Earth comparison



- Mapping technique (*Good et al*., Sol. Phys., 2018) between Venus (pale-coloured curves) and Earth (darker-coloured curves) show close match for magnetic field components of the flux ropes related to CME2 and CME3 (FR2 and FR3) between two locations

Interpretation

- CME1 was related to merging of two sympathetic eruption forming a complex and weak ejecta in interplanetary space

- CME2 reached CME3 about at the orbit of Venus with two separate flux ropes and well separated shocks visible. Flux rope related to CME3 was observed as compressed in the Venusian magnetosheath.

- CME3 propagated in the wake of CME2, experiencing thus very little drag, maintain thus its high speed and strong magnetic field.

- Significant interaction occurred between Venus and Earth (in about 0.3 AU distance): CME3 and CME2 interacted and shock of CME3 propagated through CME2. (consistent with simulation studies showing merging of CME shocks, e.g., Odstrcil et al., 2003; Lugaz et al., 2013). Flux ropes were of similar polarity (NES) → CME3 mainly compressed CME2 with little merging (e.g., Schmidt&Cargill, 2004) → one seemingly coherent structure at Earth.

Discussion

- CME-CME interactions can drastically affect CME properties and evolution
- Drastic interactions can occur over relatively small radial distances (here ~0.3 AU)
- Spacecraft observations of radially (almost) aligned spacecraft with varying heliospheric distances are crucial for studying interactions and making correct interpretation of data
- This study highlights the importance of heliospheric simulations (such as EUHFORIA, ENLIL, SUSANOO-CME) with realistic CME input parameters and heliospheric imaging to get the global understanding of the situation
- Future joint observations by L1 spacecraft, STEREO-A, BepiColombo, Solar Orbiter and Parker Solar Probe provide interesting possibilities for radial and longitudinal multi-spacecraft studies of interacting CMEs (e.g., Bepi BepiColombo multispacecraft coordinated observations working group).