Study of the evolution of interplanetary coronal mass ejections in the inner heliosphere

C. Larrodera (@Solar_mole), M. Temmer

Institute of Physics (Heliospheric Physics Research Group), University of Graz, Austria

Abstract

The launch of new spacecraft such as Parker Solar Probe or Solar Orbiter allow us to measure in-situ at different radial distances the physical magnitudes of ICMEs. With that, we are able to quantify the evolution of ICMEs and their substructures at a specific radial distance in order to better understand the interaction processes that occur with the background solar wind. Using multiple spacecraft covering the inner heliosphere, we extract plasma and magnetic field parameters from several ICMEs to relate the physical processes responsible for the formation of the different substructures. We present first results for some ICME parameters that prepare for a large statistical analysis.

Introduction

- We have gathered ICMEs from **13 catalogs** at different radial distances from 1975 until 2022.
- After removing overlaps, the final number of ICMEs is **2163 ICMEs**.
- According to the catalogs, **56%** show clear **sheath structures** followed by a magnetic ejecta.
- The rest consists only of magnetic ejecta structures.

Breakdown of events

Spacecraft	Min date	Max date	Min dist (AU)	Max dist (AU)	Events
Helios	1975-01-08	1980-07-21	0.29	0.98	95
ULYSSES	1991-03-05	2007-09-06	1.35	5.42	185
Wind	1995-02-07	2022-09-30	0.97	1.02	606
ACE	1997-09-21	2022-09-12	0.97	1.00	531
STEREO-B	2006-12-14	2014-09-25	0.98	1.09	157
STEREO-A	2007-01-14	2022-10-21	0.96	0.97	292
VEX	2007-02-13	2014-09-26	0.72	0.73	93
MESSENGER	2007-05-04	2015-04-22	0.31	0.74	87
MAVEN	2015-01-18	2017-07-04	1.39	1.66	10
Parker Solar Probe	2018-10-30	2022-02-16	0.25	0.91	36
Bepi Colombo	2019-03-25	2022-09-27	0.35	1.03	32
Solar Orbiter	2020-04-16	2020-09-06	0.42	1.01	39

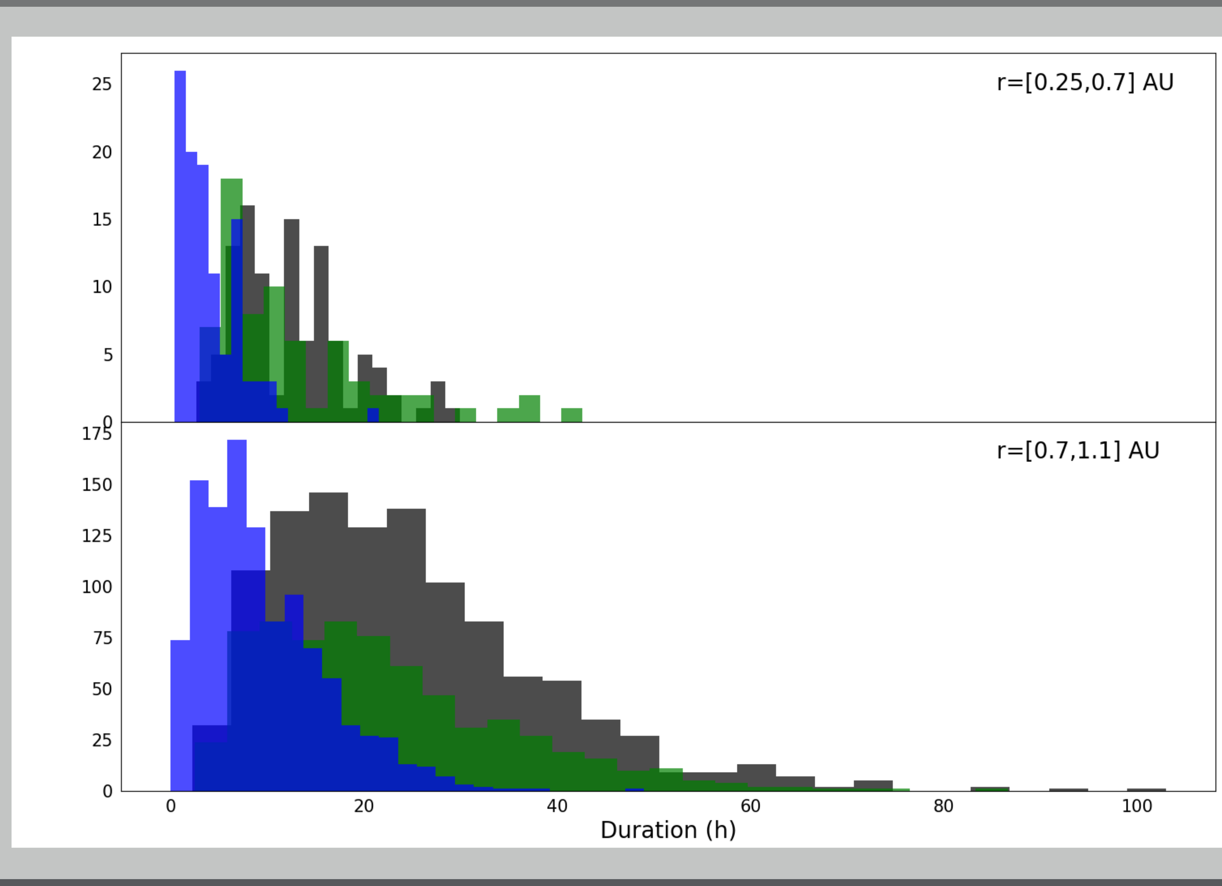
Spacecraft conjunction

- We search for spacecraft conjunctions in order to find ICMEs seen by more than one spacecraft.
- The requirements are ICMEs detected within a range of $\pm$**5** days and $\pm$**20** of longitude.
- As a validation of our methodology, we found conjunctions already studied, e.g. Kilpua et al. (2021); Möstl et al. (2022)
- We found **25 events** as a set for analyzing the case study

Substructures duration

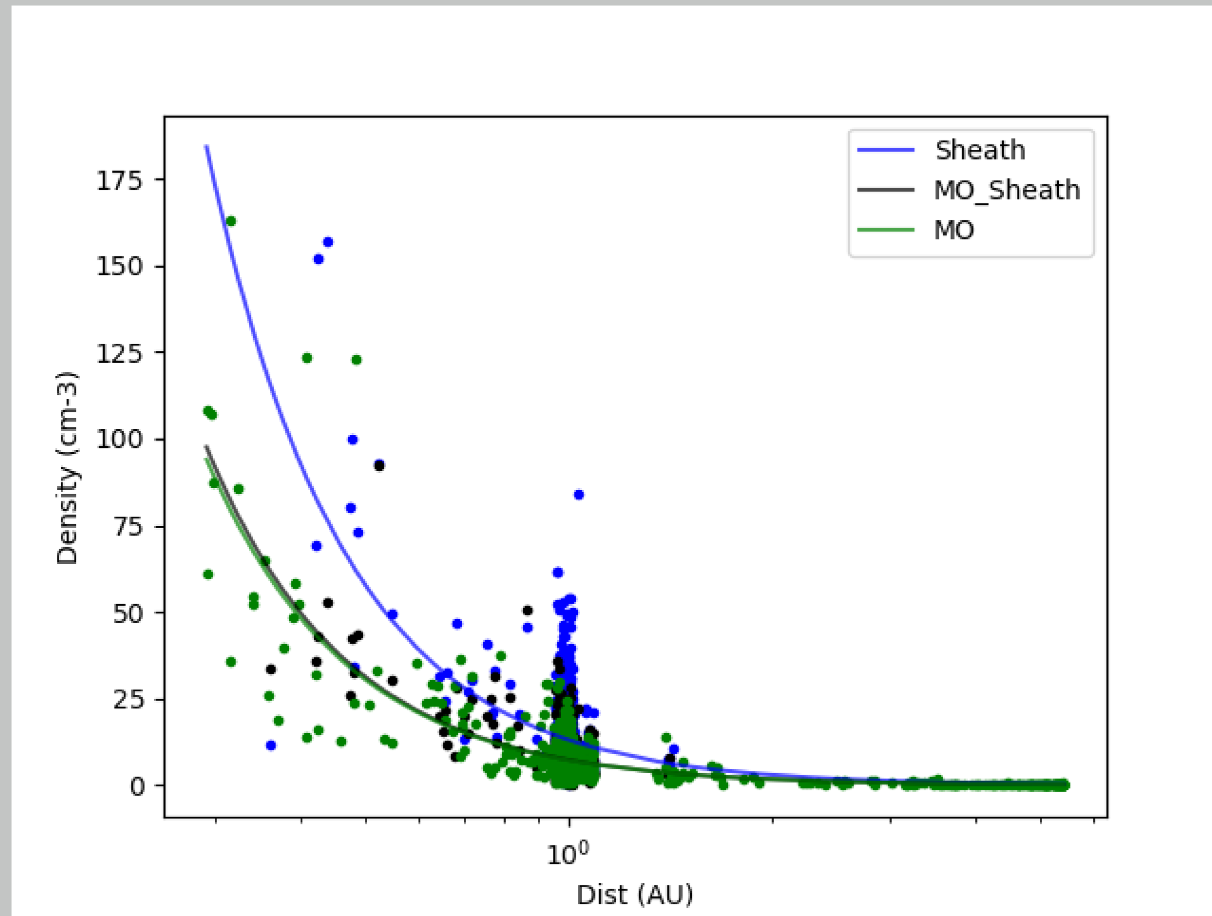
- Temmer and Bothmer (2022) derive a duration of **5.2h** and **17.7h** for **sheath** and **ME** for r<0.7 AU.
- The duration for r>0.7 AU is **6.8h** and **26.5h**
- Kilpua et al. (2013) obtained **9.1h** and **20.6h** at 1 AU

Substructure	$r = [0.25, 0.7)$	$r = [0.7, 1.1]$
Sheath	4.1±3.1	9.6±6.5
MO (Sheath)	12.6±6.0	24.5±13.8
MO	12.8±8.8	22.1±12.9



ICME substructure density evolution

- The evolution has been fitted by $N = \delta r^{\beta}$
- For the **magnetic ejecta** following the sheath:
  - Schwenn and Marsch (1990); Temmer and Bothmer (2022); Leitner et al. (2007) obtained β=-2.4
  - The value from our research is β=-2.07
- For the **sheath**:
  - Temmer and Bothmer (2022) with measurements from Helios 1/2 and PSP, obtained β=[-1.5,-1.7].
  - Our result is β=-2.14.
- Kilpua et al. (2017), using measurements from ICMEs between 0.3 AU and 11 AU, obtained β=-2.21



References

E. K. J. Kilpua, A. Isavnin, A. Vourlidas, H. E. J. Koskinen, and L. Rodriguez. On the relationship between interplanetary coronal mass ejections and magnetic clouds. *Annales Geophysicae*, 31(7):1251–1265, July 2013.

E. K. J. Kilpua, S. W. Good, N. Dresing, R. Vainio, E. E. Davies, R. J. Forsyth, J. Gieseler, B. Lavraud, E. Asvestari, D. E. Morosan, J. Pomoell, D. J. Price, D. Heyner, T. S. Horbury, V. Angelini, H. O'Brien, V. Evans, J. Rodriguez-Pacheco, R. Gómez Herrero, G. C. Ho, and R. Wimmer-Schweingruber. Multi-spacecraft observations of the structure of the sheath of an interplanetary coronal mass ejection and related energetic ion enhancement. *Astronomy & Astrophysics*, 656:A8, December 2021.

Emilia Kilpua, Hannu E. J. Koskinen, and Tuija I. Pulkkinen. Coronal mass ejections and their sheath regions in interplanetary space. *Living Reviews in Solar Physics*, 14(1):5, November 2017.

M. Leitner, C. J. Farrugia, C. Möstl, K. W. Ogilvie, A. B. Galvin, R. Schwenn, and H. K. Biernat. Consequences of the force-free model of magnetic clouds for their heliospheric evolution. *Journal of Geophysical Research (Space Physics)*, 112(A6):A06113, June 2007.

Christian Möstl, Andreas J. Weiss, Martin A. Reiss, Tanja Amerstorfer, Rachel L. Bailey, Jürgen Hinterreiter, Maike Bauer, David Barnes, Jackie A. Davies, Richard A. Harrison, Johan L. Freiherr von Forstner, Emma E. Davies, Daniel Heyner, Tim Horbury, and Stuart D. Bale. Multipoint Interplanetary Coronal Mass Ejections Observed with Solar Orbiter, BepiColombo, Parker Solar Probe, Wind, and STEREO-A. *Astroph. Journal letters*, 924(1):L6, January 2022.

Rainer Schwenn and Eckart Marsch. *Physics of the Inner Heliosphere I. Large-Scale Phenomena*. 1990.

M. Temmer and V. Bothmer. Characteristics and evolution of sheath and leading edge structures of interplanetary coronal mass ejections in the inner heliosphere based on Helios and Parker Solar Probe observations. *Astronomy & Astrophysics*, 665:A70, September 2022.