Statistics and parameters of solar coronal mass ejections in the inner heliosphere: what to expect for Parker Solar Probe?

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Key points

Solar storms, known as coronal mass ejections (CMEs), play a pivotal role in space weather and heliophysics.

The *Parker Solar Probe* (PSP) will observe CMEs in situ where no man-made object has gone before (< 0.29 AU). In order to anticipate CME observations by PSP, we clarify the dependence of basic parameters of CMEs for both the heliocentric distance and the phase of the solar cycle. We derive CME statistics to be observed by PSP which seem likely from the point of view of the current progress in solar cycle 24.

This is done with the most extensive catalog of in situ observed CMEs to date, with 686 events observed at heliocentric distances from 0.31-1.67 AU at Mercury, Venus, Earth and Mars and in the solar wind. This is an outcome of the European Union HELCATS project, with data taken from *MESSENGER, STEREO, Venus Express, Wind* and *MAVEN.*

These results provide baselines for in situ observations not only by PSP but also for *Solar Orbiter, Bepi Colombo* and the Cubesat for Solar Particles, *CuSP*.

HELCATS products

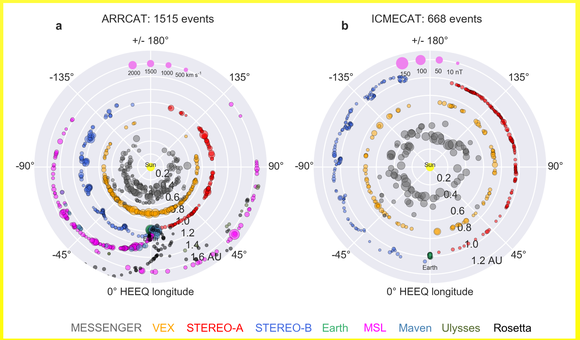
http://www.helcats-fp7.eu/products.html

Catalogs available for **CMEs in HI and COR, ICMEs, radio bursts, Files as ASCII, JSON, VOtable.** Some catalogs are on my *figshare* page: (.txt, .sav, header) and can be cited with their *doi*, see also *Möstl et al. 2017 (Space Weather, open access).*

ICMECAT: interplanetary CME catalog, based on in situ magnetometer and plasma observations in the heliosphere. **668 events** 2007-2015, VEX, MESSENGER, Wind, STEREO-A/B

ARRCAT: 1995 impacts, 2007-2014, targets EARTH-L1, STEREO-A, STEREO-B, VENUS, MESSENGER, MARS, SATURN, ULYSSES, MSL, MAVEN, ROSETTA

The .sav files can be read directly in IDL ("restore" function) and python ("scipy.io.readsav").



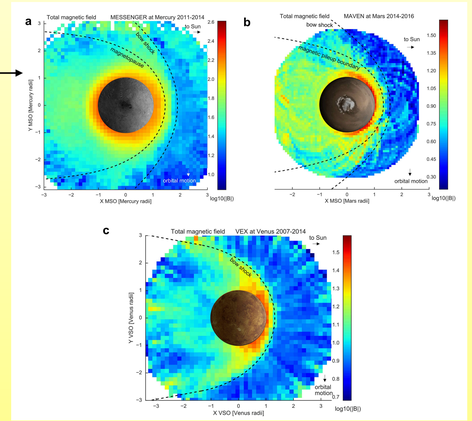
HELCATS WP4 catalogs overview. Left: each dot is a CME arrival predicted with STEREO/HI, **Right:** each dot is an in situ observed ICME.

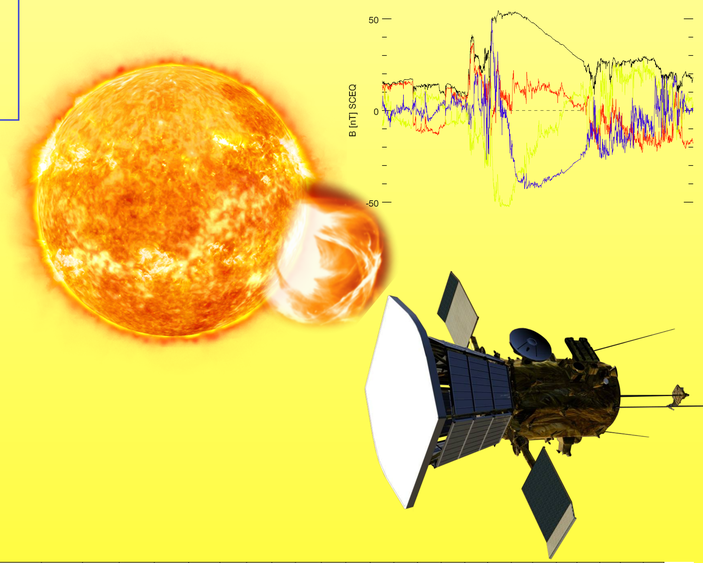
Data

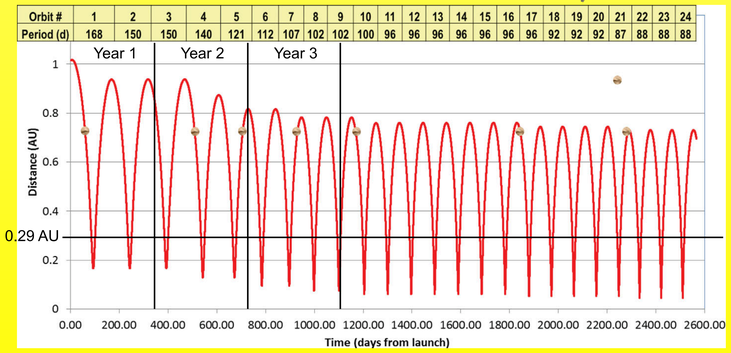
Total magnetic field around Mercury, Mars and Venus.

We have made solar wind only datasets for each mission, removing all data inside the bow shocks, see *Winslow et al. (2013), Edberg et al. (2008), Zhang et al. (2008).*

ICME lists were gathered from *Simon Good, Reka Winslow, Teresa Nieves-Chinchilla* and merged in the HELCATS ICMECAT.







Heliocentric distance versus time of ***Parker Solar Probe*** with launch date 31 July 2018. Adapted from ***Fox et al. 2016, Space Science Reviews.***

Results for Parker Solar Probe

(1) Impact frequency

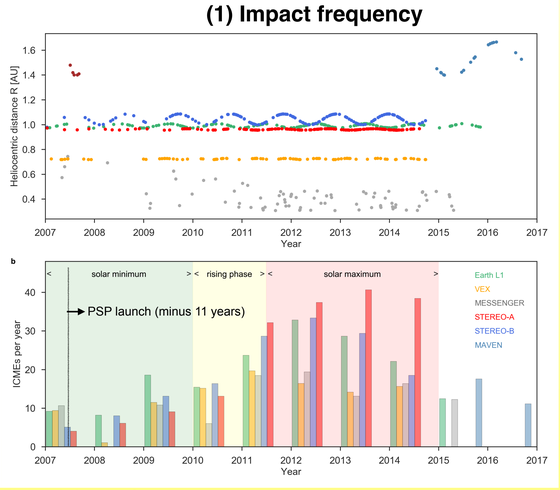


Figure 1: **Impact frequency**
Overall: solar minimum/rise phase/maximum 10/19/25 ICMEs per year.
VEX, MESSENGER: smaller rate, reason likely more difficult identification (no plasma).
***Parker Solar Probe* is in unknown in situ territory < 0.29 AU** for about 15% of the time during one orbit, for the first 3 years (~8 orbits) these are about 150 days, with 1 ICME per month **about 4 to 5 ICMEs are expected to be observed < 0.29 AU to mid-2021.**

(2) Duration

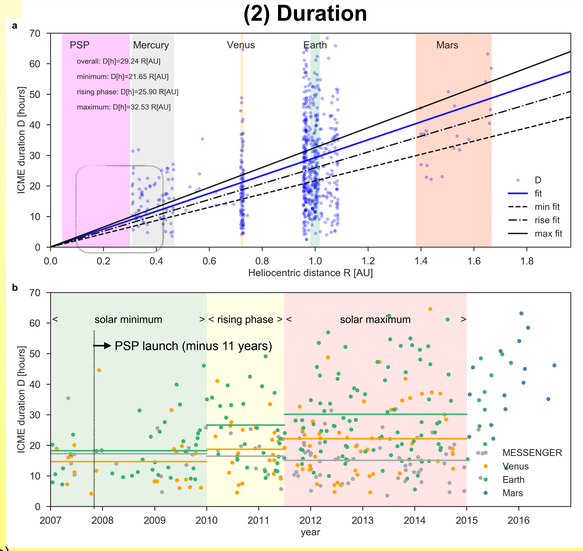


Figure 2: **CME durations in unknown territory: 0.044 AU - 0.29 AU**

Derived from linear fits: **mean 5 +/- 2 hours, range 1 to 9 hours for full shock, sheath, flux rope structure.**

Wide distribution around mean for each location!

Close to the Sun the durations are not to be expected to depend much on the solar cycle.

(3) Magnetic field

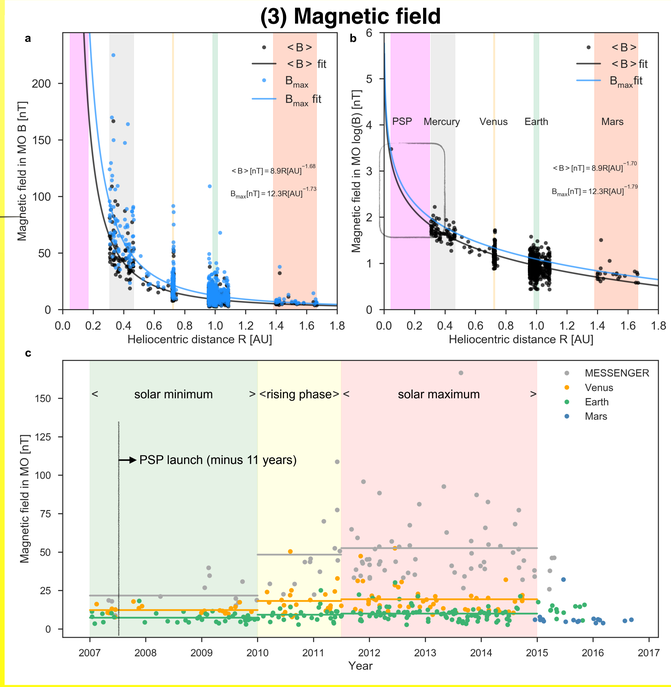


Figure 3: **CME flux rope magnetic field in unknown territory: 0.044 AU - 0.29 AU:**

Predicted from power law fits: **mean field** in flux rope: **360** +/- 416 nT, range 70 to **2100** nT, **maximum field** in flux rope **538** +/- 636 nT, range 100 to **3250** nT
Included data point 3000 nT at 10 Rs (*Patsourakos & Georgoulis, 2016 A&A*).

Conclusions

- We have used a large database from HELCATS with ICME parameters for predicting the **ICME impact frequency, their duration and magnetic field strength at *Parker Solar Probe (PSP)*.**
- **Assuming a similarity to the previous solar minimum,** *PSP* should observe roughly **0.5 to 1 ICMEs per month.**
- For each orbit, the **probability of observing an ICME in uncharted territory at < 0.3 AU is about 50%.**
- **ICME durations** are expected to be on average **5 hours at < 0.29 AU**, ranging from 1 to 9 hours
- The **power law describing the CME flux rope mean and maximum magnetic field** seems valid up to the solar corona, with an **exponent of -1.7.**
- Magnetic fields in the ICME flux rope will vary on average roughly between 100 nT (0.3 AU) to > 3000 nT (close approaches at 0.044 AU)
- **A paper on CME statistics at the four terrestrial planets with a note on these results is in preparation *Möstl et al. (2018, journal tbd).***

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