On the Drag parameter of CME propagation models

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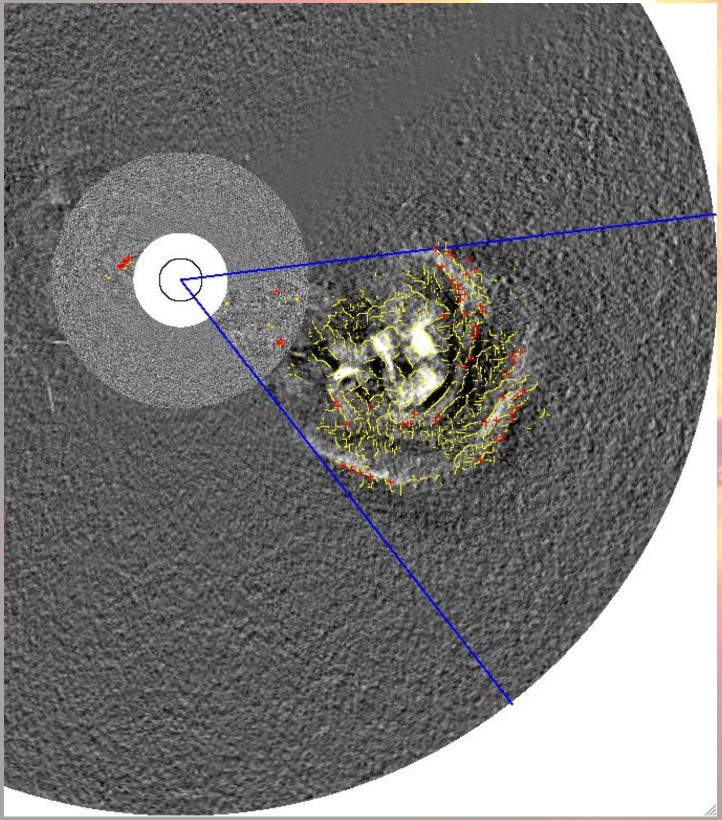
INTRO:

ICME (Interplanetary Coronal Mass Ejection) are violent phenomena of solar activity that affect the whole heliosphere and the prediction of their impact on different solar system bodies is one of the primary goals of the planetary space weather forecasting.

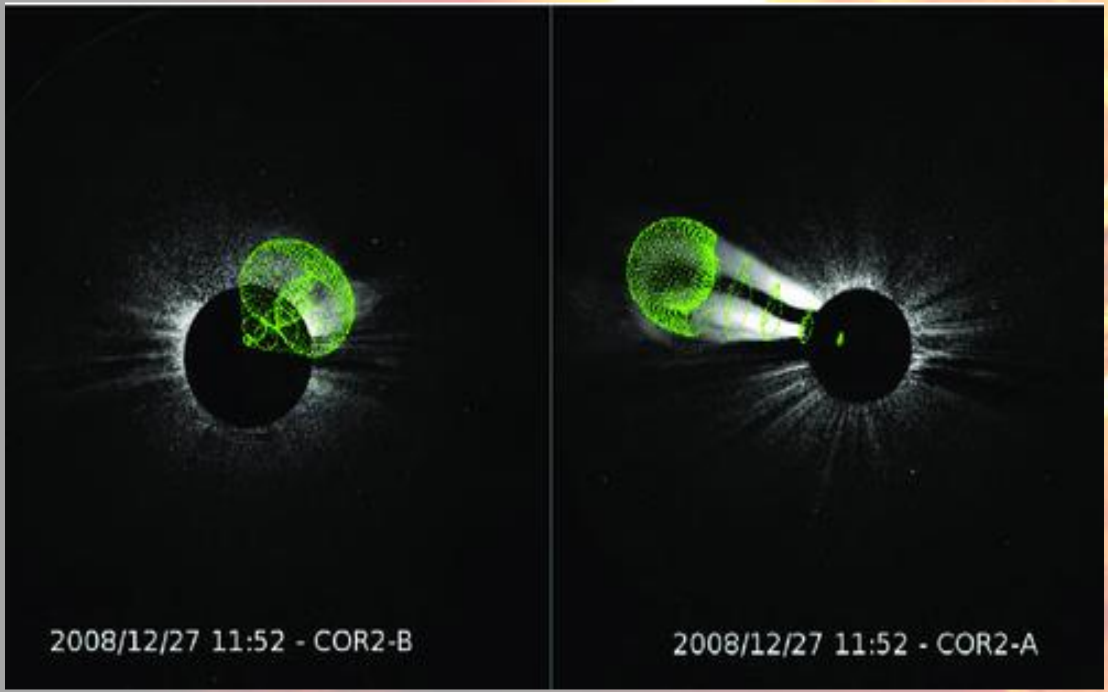
What: an exploratory work on **how** the **drag** parameter **depends on** the physical **parameters of the ICME**, to verify and extend the work by Vršnak et al. (2010).

Scope: a more robust definition of the **PDF** of the drag parameter that could be used in the various approaches to ICME propagation forecasting.

Methods for CME detection and characterization

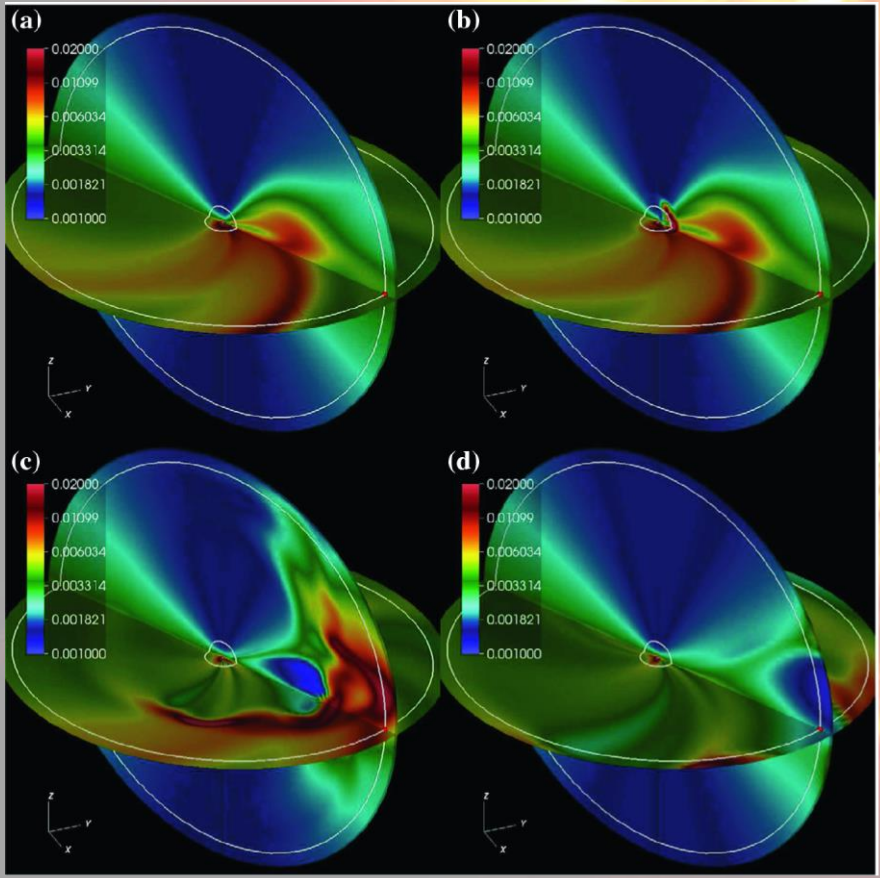


Predictions of the arrival of ICMEs in geospace are produced through use of **CME geometric models** combined with ICME propagation models, **constraining** these models with the **available Coronagraph and Heliospheric Imager** data.



Often, geometric models provide inconsistent results because assumptions inherent to each model are being invalidated

Models for ICME propagation



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The DBM equation and assumptions

- Self-Similar expansion
- Evolution entirely governed by fluid dynamics (i.e. the interplanetary magnetic field plays no role)
- Constant solar wind speed and drag parameter

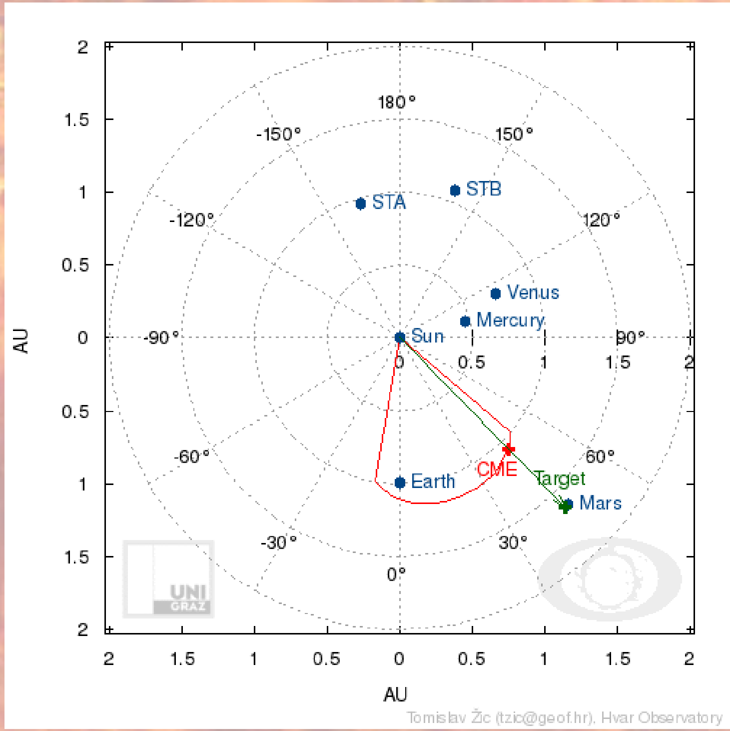
The **Drag Based Model** approach is based on a simple equation for the ICME acceleration as

$$\frac{d^2r}{dt^2} = -\gamma\left(\frac{dr}{dt} - w\right)\left|\frac{dr}{dt} - w\right|$$

where w is the ambient solar-wind speed and $\boldsymbol{\gamma}$ is the so-called drag parameter (Vršnak et al., 2013).
In this framework, $\boldsymbol{\gamma}$ depends on the ICME mass and cross-section, on the solar-wind density and, to a lesser degree, on other parameters.

The typical working hypothesis for DBM implies that both $\boldsymbol{\gamma}$ and w are constant far from the Sun.

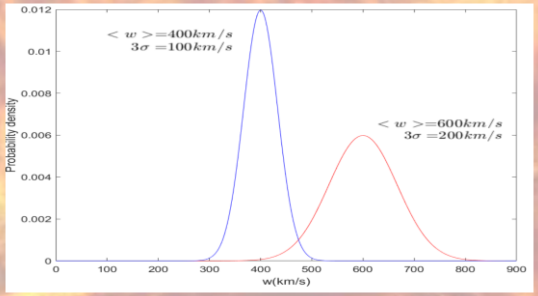
To run the codes, forecasters use empirical input values for $\boldsymbol{\gamma}$ and w.

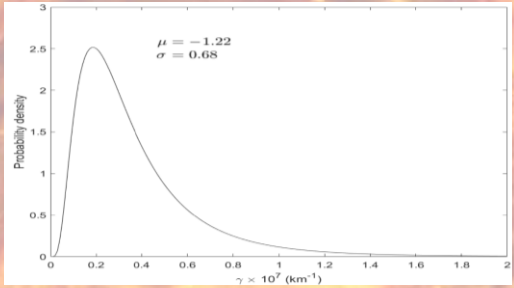


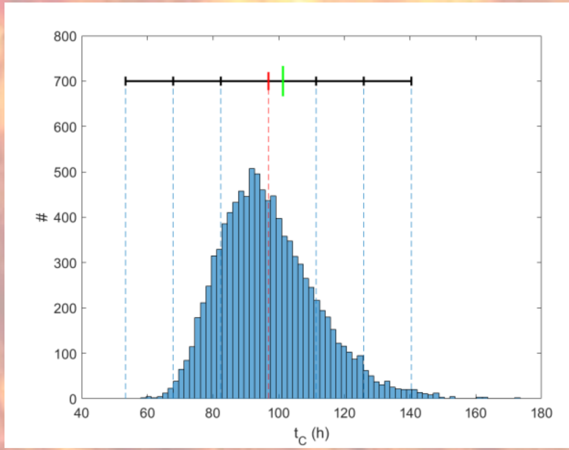
The P-DBM : the PDFs.

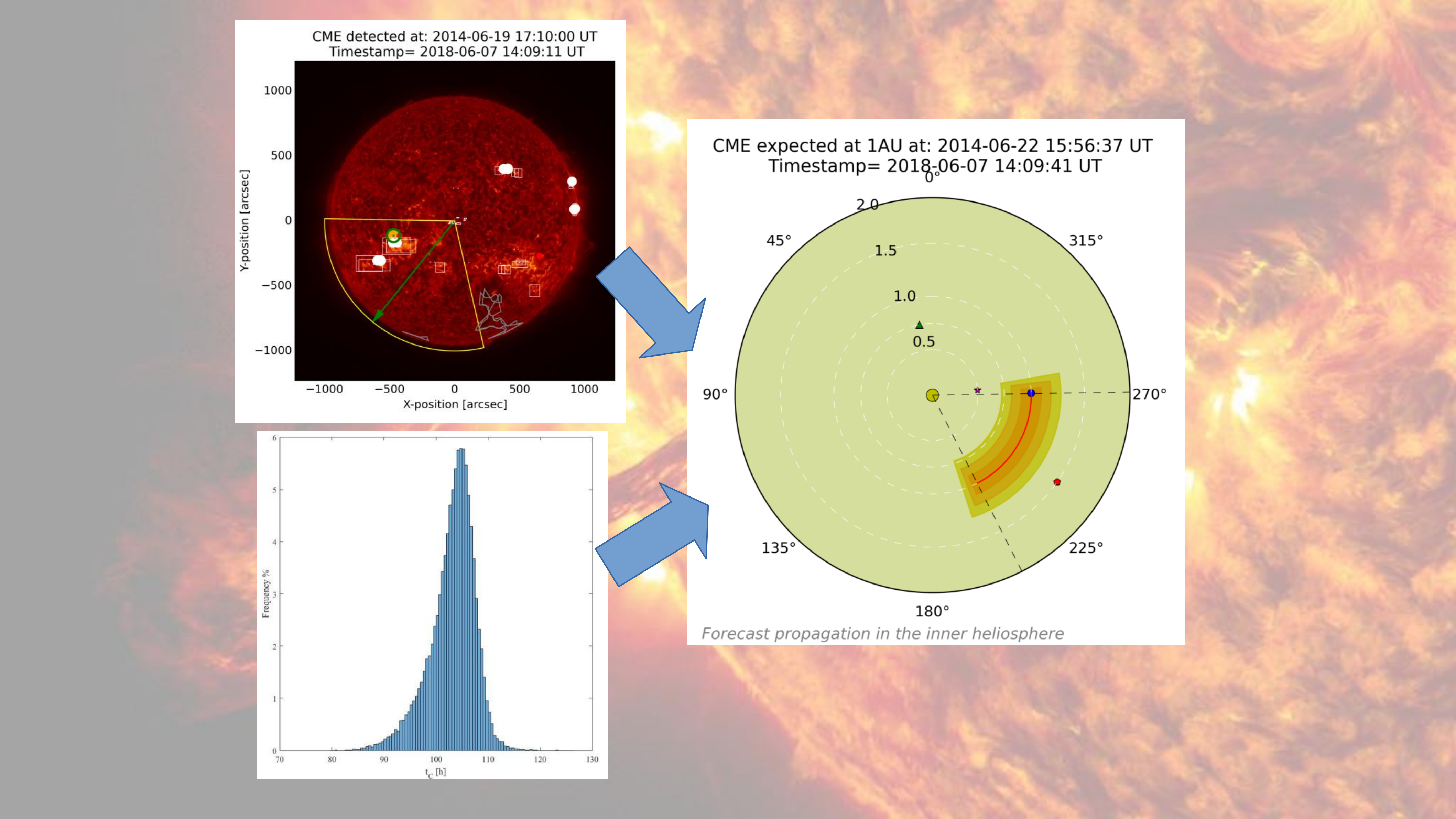
In the DBM 'Ensemble' approaches (Dumbovich et al., 2018; Napoletano et al. 2018), the uncertainty about the actual values of such inputs are rendered by **Probability Distribution Functions** (PDFs), accounting for the values variability and our lack of knowledge.

Among those PDFs, that of $\boldsymbol{\gamma}$ is poorly defined due to the relatively scarce statistics of recorded values.





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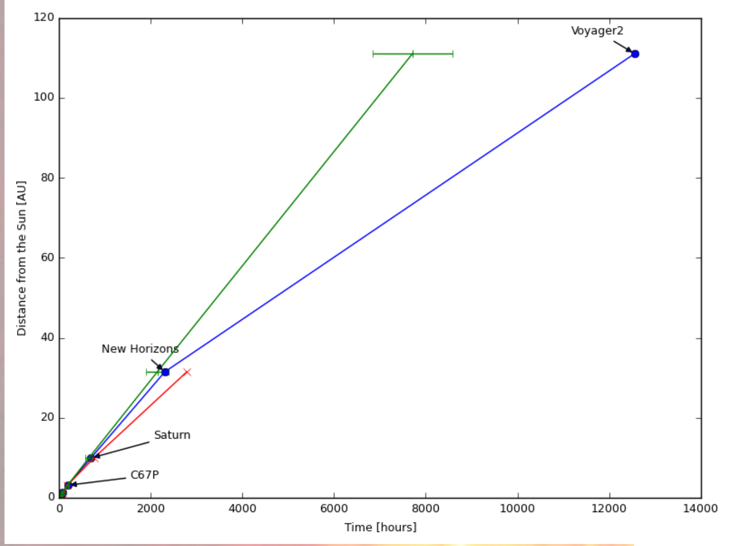
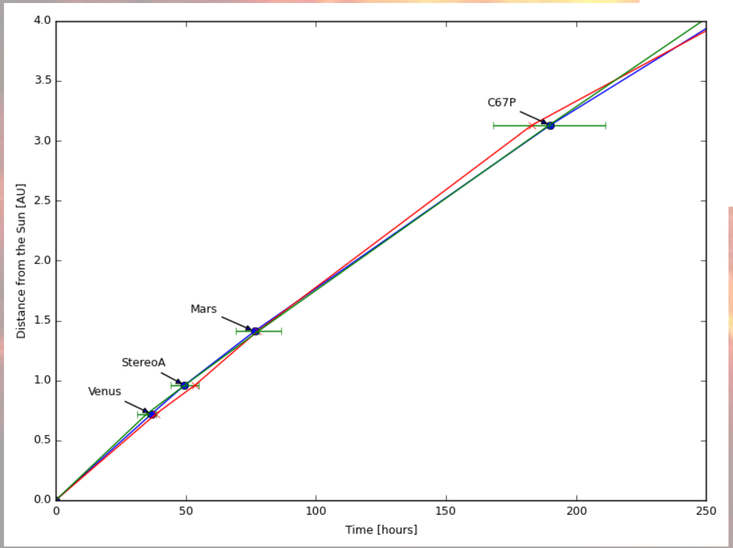
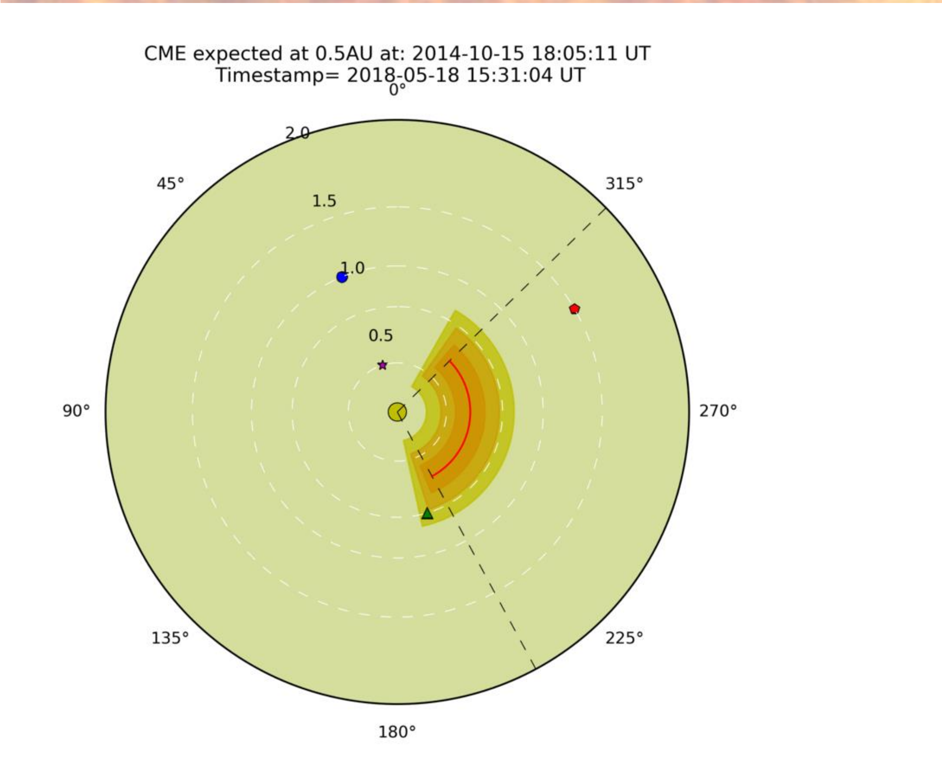
Timestamp= 2018-06-07 14:09:11 UT
Y-position [arcsec]
X-position [arcsec]
1000
500
0
−500
−1000
−1000
−500
0
500
1000
Frequency %
t_C [h]
70
80
90
100
110
120
130
0
1
2
3
4
5
6
CME expected at 1AU at: 2014-06-22 15:56:37 UT
Timestamp= 2018-06-07 14:09:41 UT
0°
2.0
1.5
1.0
0.5
45°
315°
90°
270°
135°
225°
180°
Forecast propagation in the inner heliosphere







"Interplanetary coronal mass ejection observed at STEREO-A, Mars, comet 67P/Churyumov-Gerasimenko, Saturn, and New Horizons en route to Pluto: Comparison of its Forbush decreases at 1.4, 3.1, and 9.9 AU"

Witasse et al., 2017 https://doi.org/10.1002/2017JA023884

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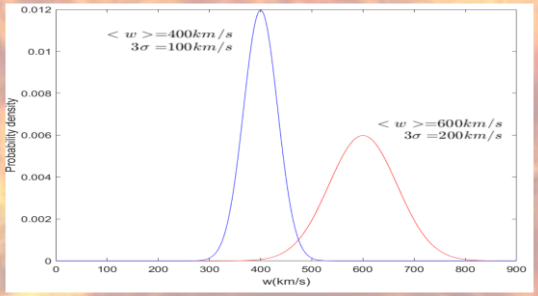
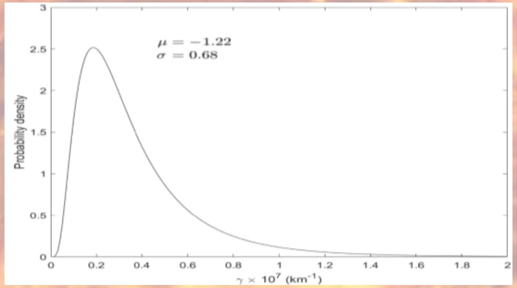
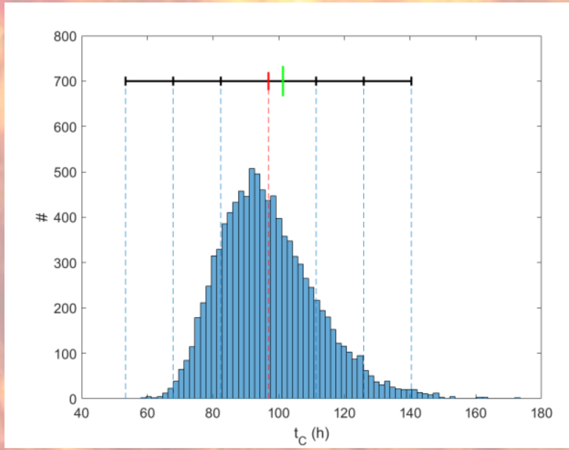


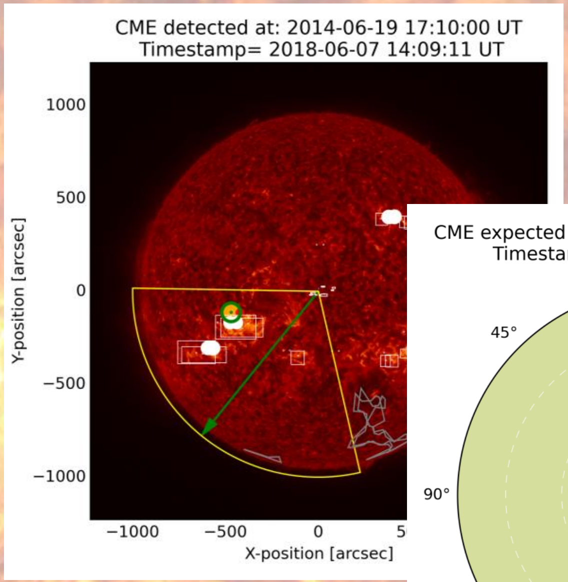


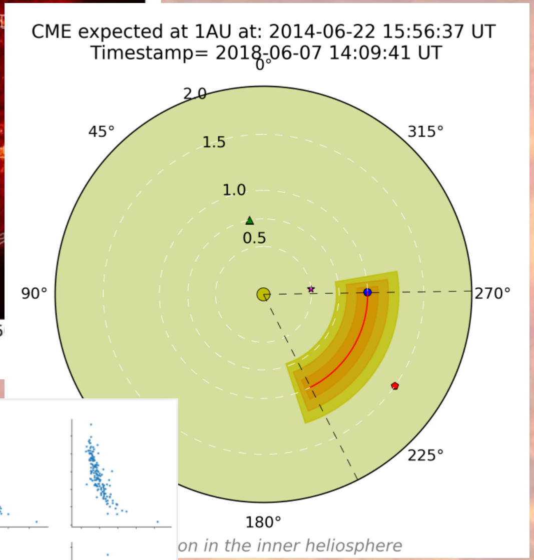


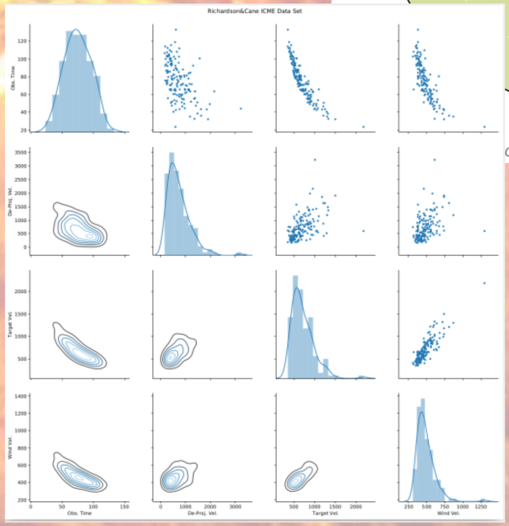
Our works: stats from R&C and our algorithms

Taking advantage of the large data-set of ICMEs registered by Richardson & Cane (2010), we computed how **γ** depends on SW velocity...

$$\pm\gamma = \frac{(v_0 - v_1)}{(v_1 - w)(v_0 - w)T}$$

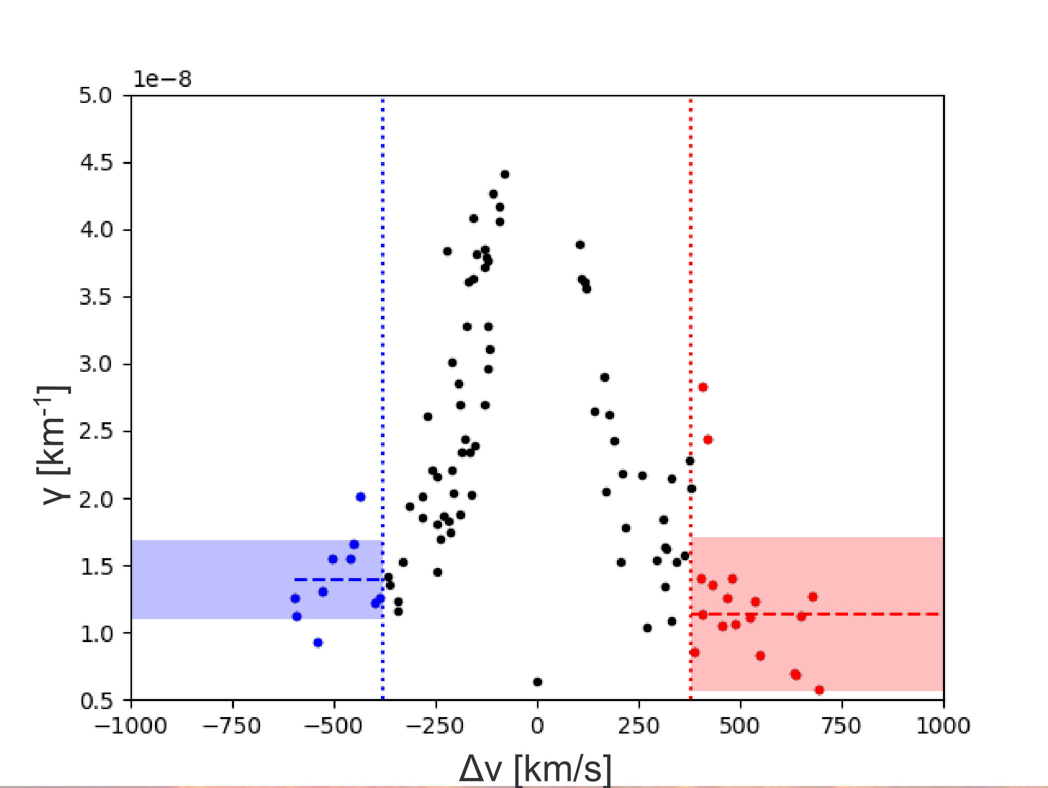






The hypothesis: γ(Δv) → Simulations

...found evidence of a variation in the **γ** PDF if the SW is accelerating or braking the ICME propagation.
By using a set of simulations of an ICME structure into the SW fluid, we try to link this change to the structure of the ICME.



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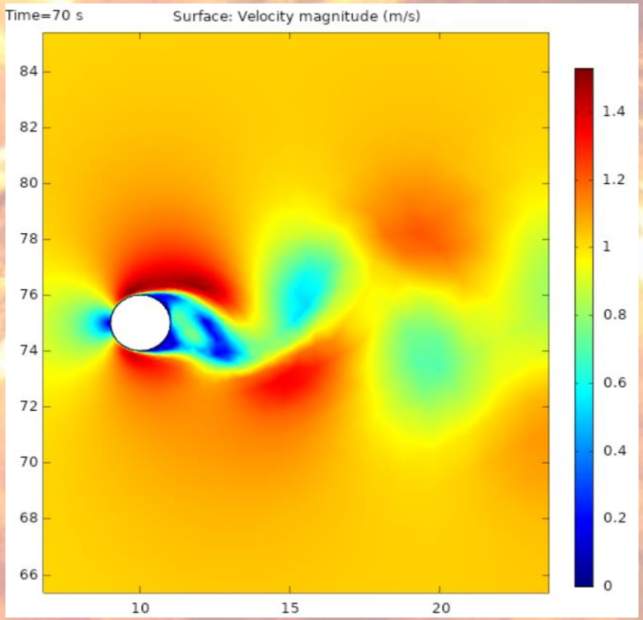

ICME simulation results:

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#	Shape	C_d^F	C_d^B	γ^F $(\times 10^{-7}\text{km}^{-1})$	γ^B $(\times 10^{-7}\text{km}^{-1})$
1		1.3	-	$0.25 \div 2.5$	-
2		2.0	-	$0.4 \div 4$	-
3		1.7	-	$0.35 \div 3.5$	-
4		1.0	1.5	$0.2 \div 2$	$0.3 \div 3$
5		2.2	3.6	$0.45 \div 4.5$	$0.7 \div 7$

Conclusions:

A dependence of γ on Δv is possible/likely, but we are at the very limit of what can be obtained by available data.

We are striving to refine the dataset to get further statistics

We are working on upgrading the simulation framework.

More information needed:

Other in-situ measurements

e.g. @Mercury

New fitting models

more imagers

more info from images