ST1.3 - Blowing in the Solar Wind: Understanding Solar Transients and their Heliospheric Impact EGU2019-13712

Forecasting the arrival of ICMEs throughout the heliosphere

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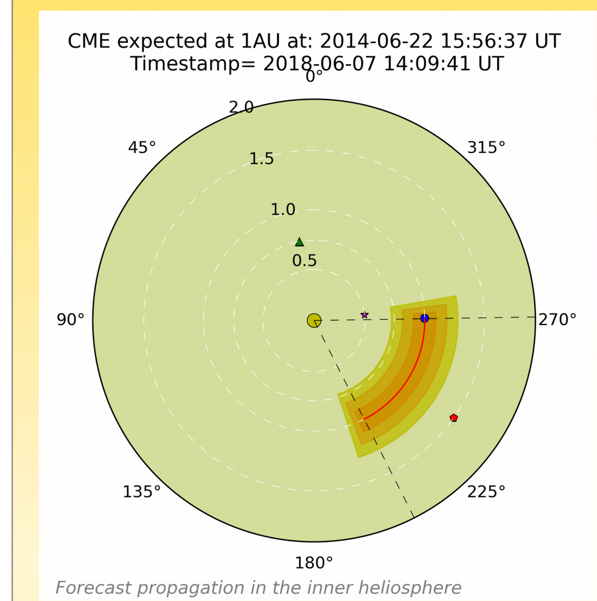
Abstract: ICME (Interplanetary Coronal Mass Ejection) are violent phenomena of solar activity that affect the whole heliosphere and the prediction of their impact on different solar system bodies is one of the primary goals of the planetary space weather forecasting. We realized a procedure based on the Drag-Based Model (Vrsnak et al., 2013, Napoletano et al. 2018) which uses probability distributions, rather than exact values, as input parameters, and allows the evaluation of the uncertainty on the forecast. We tested this approach using a set of CMEs whose transit times are known, obtaining extremely promising results.
We present some further results from the application of this model to propagate a sample of ICMEs from their sources on the solar surface into the heliosphere. We made use of recent works from Prise et al. (2015) and Witasse et al. (2017) who tracked the ICMEs through their journeys using data from several spacecraft, tracing the ICMEs trajectory farther than Earth. Considering the extremely short computation time needed by the model to propagate ICMEs, it is a promising candidate for Space Weather application and to forecast ICME arrival to planetary bodies in the whole heliosphere.

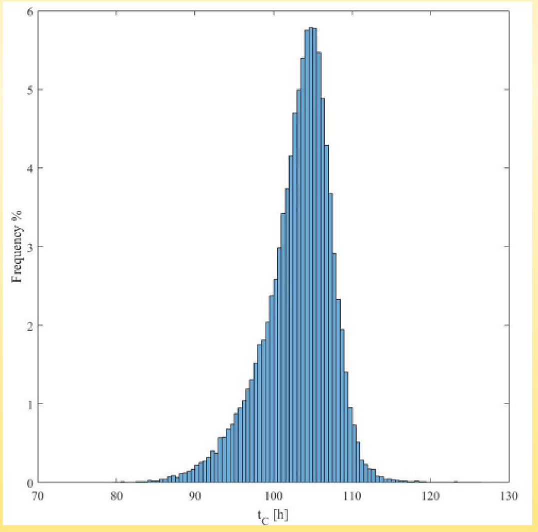
PROBABILISTIC DBM:



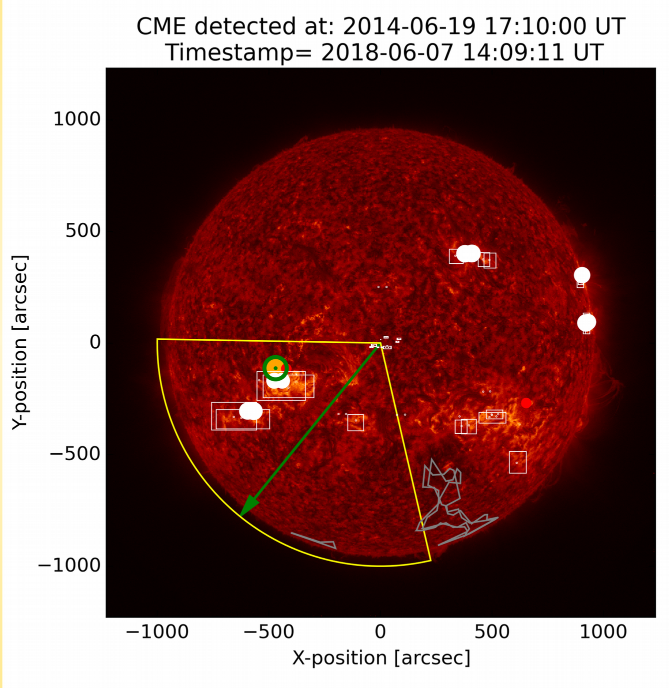
Above: Graphical output of the CME propagation algorithm. The inner part of the solar system is drawn at the most probable arrival time at 1AU of the CME. The estimated CME propagation path is represented by dashed lines, and the CME itself is represented by different shades of colors, representing different confidence levels of the CME extension: yellow=10% probability, light orange=50% probability, dark orange=90% probability.

Probabilistic approach:
N initial condition sets [r_0, v_0, w, γ] are randomly generated
N different [t@position, v@position] are computed

Obtain:
t_arrive ± t_error
v_arrive ± v_error.



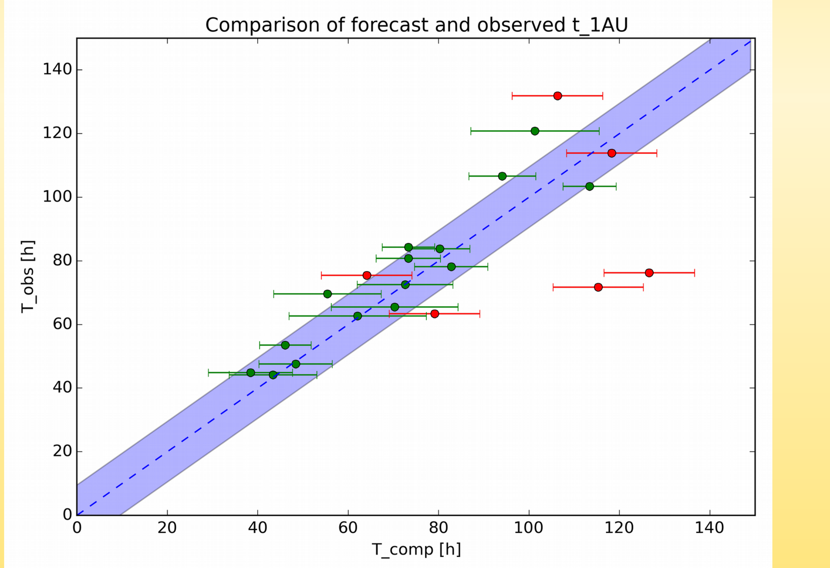
Above: The probability distributions used in the P-DBM are derived from past data: a Log-Normal PDF for the drag parameter, Gaussian PDFs associated to the measure errors for the CME initial position and velocity, two different Gaussian PDFs for the solar wind, one in case of fast or slow solar wind (decided checking for coronal holes in the proximity of the CME source). From the ICME arrival condition sets, we compute our best estimate and the associated error for ICME time and velocity at arrival.



Above: Graphical output of the CME source finding algorithm. We visualize several characteristics of the CME over a SDO/AIA 0304 image of the Sun: the green arrow shows the CME POS angle, the yellow sector shows the angle subtended by the CME POS width, the white boxes and circles, and the red dots shows the ARs and recent flare locations, respectively, taken into account to estimate the CME onset location (shown as a green circle). The gray polygons show the position of coronal holes at the time of the CME onset.

How to get useful PDFs?
PDF(r_0) ← $r_0 \pm \Delta r_0$
PDF(v_0) ← $v_0 \pm \Delta v_0$
PDF(γ) ← past statistics
PDF(w) ← past statistics
+ positions of Coronal Holes

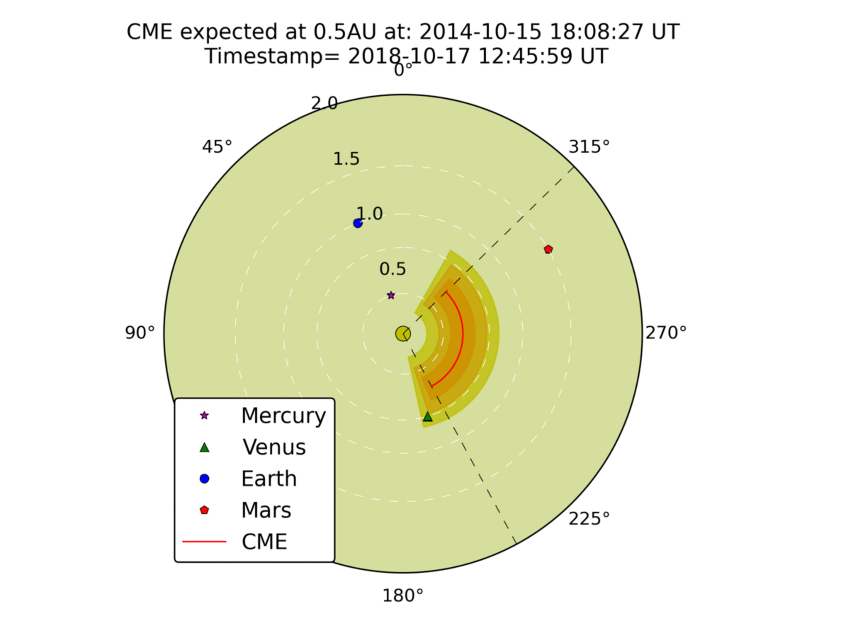
N initial condition sets [r_0, v_0, w, γ]



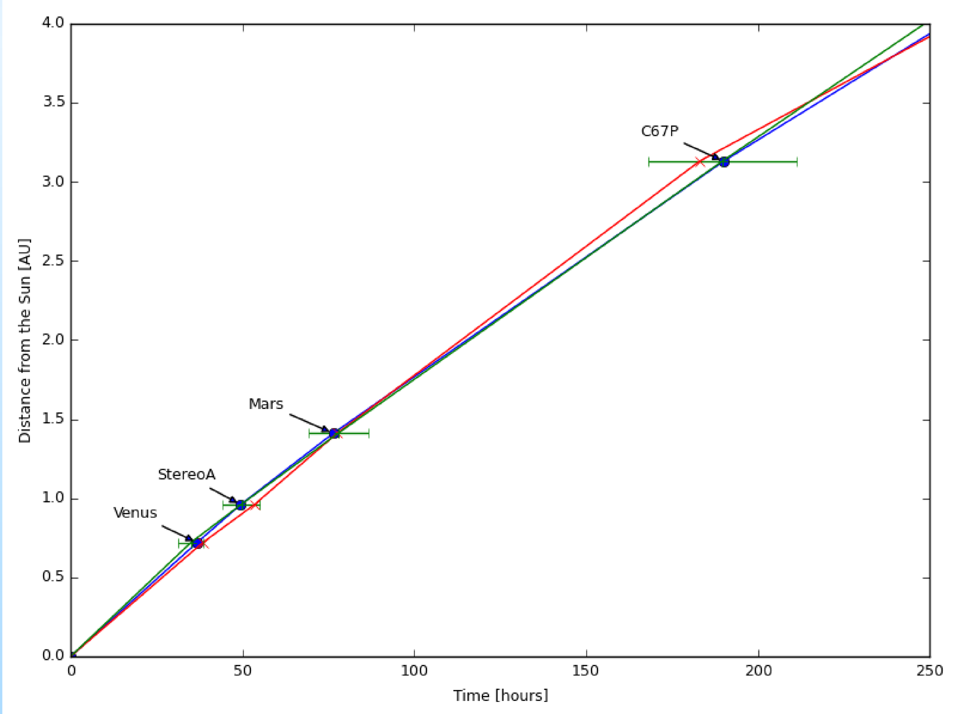
Above: Dots with error bars are the observed transit times versus forecast transit times from the Shi et al., 2015 dataset: in green the restricted sample and in red the CMEs originally excluded from that sample. The dashed line shows the perfect match expectation, with the 1σ travel time measure error zone shaded in blue.

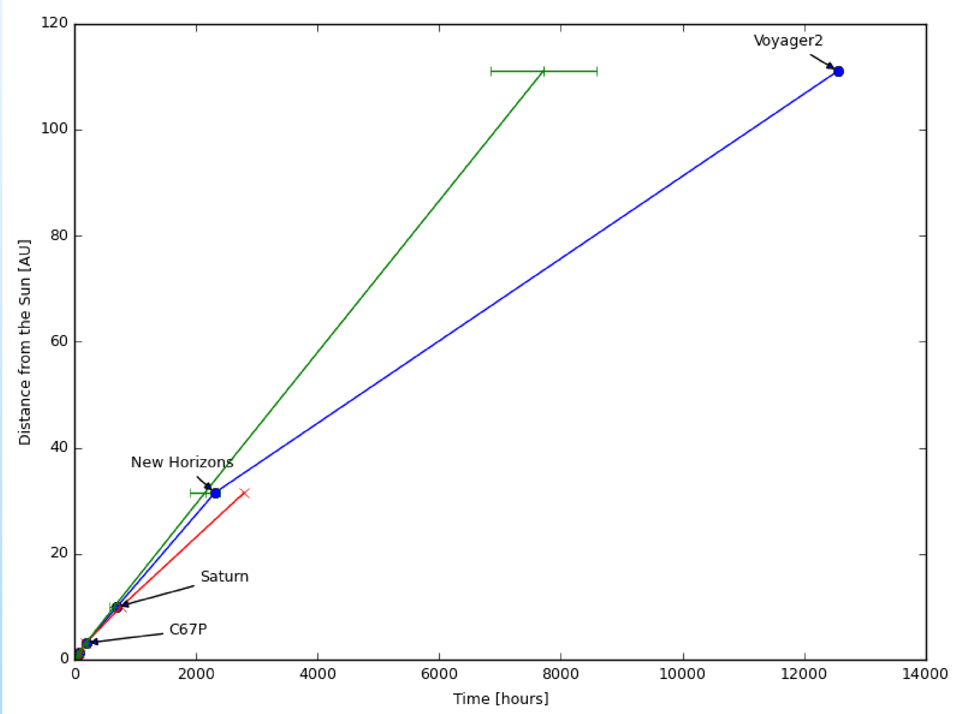
P-DBM to C67P & Beyond:

P-DBM applied on data from "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"



Below: The estimated CME propagation path is represented by dashed lines, and the CME itself is represented by different shades of colors, representing different confidence levels of the CME extension: yellow=10% probability, light orange=50% probability, dark orange=90% probability. Planets are represented by colored symbols.





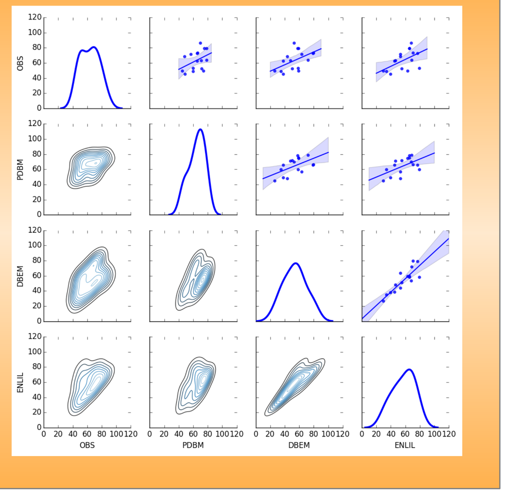
Left: Comparison between ICME transit times at different targets in the heliosphere. In blue the measured times, in red the time forecast by the WSA-Enlil model, in green (with error bars) the time forecast by the P-DBM.

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

P-DBM & Others DBM:

P-DBM applied on data from "The Drag-based Ensemble Model (DBEM) for Coronal Mass Ejection Propagation"

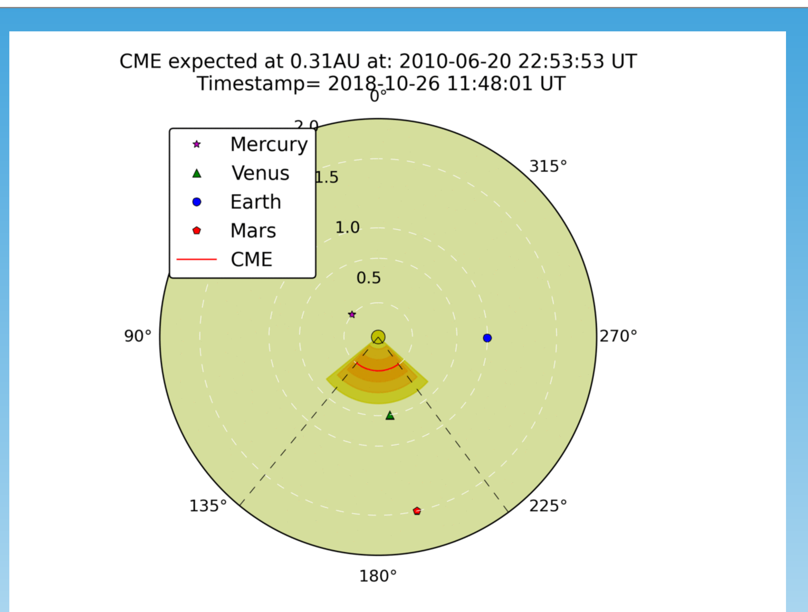
Right: Comparison between ICME transit times at 1 AU. Using observed times (OBS), P-DBM forecast (PDBM), WSA-Enlil forecast (ENLIL) and DBEM forecast (DBEM), we computed a vorrelation matrix, with distribution plots (on the diagonal), kernel density plots (on the upper half), and scatter plots with linear regression and (on the lower half).



Data from Dumbovic et al., 2018 https://doi.org/10.3847/1538-4357/aaaa66

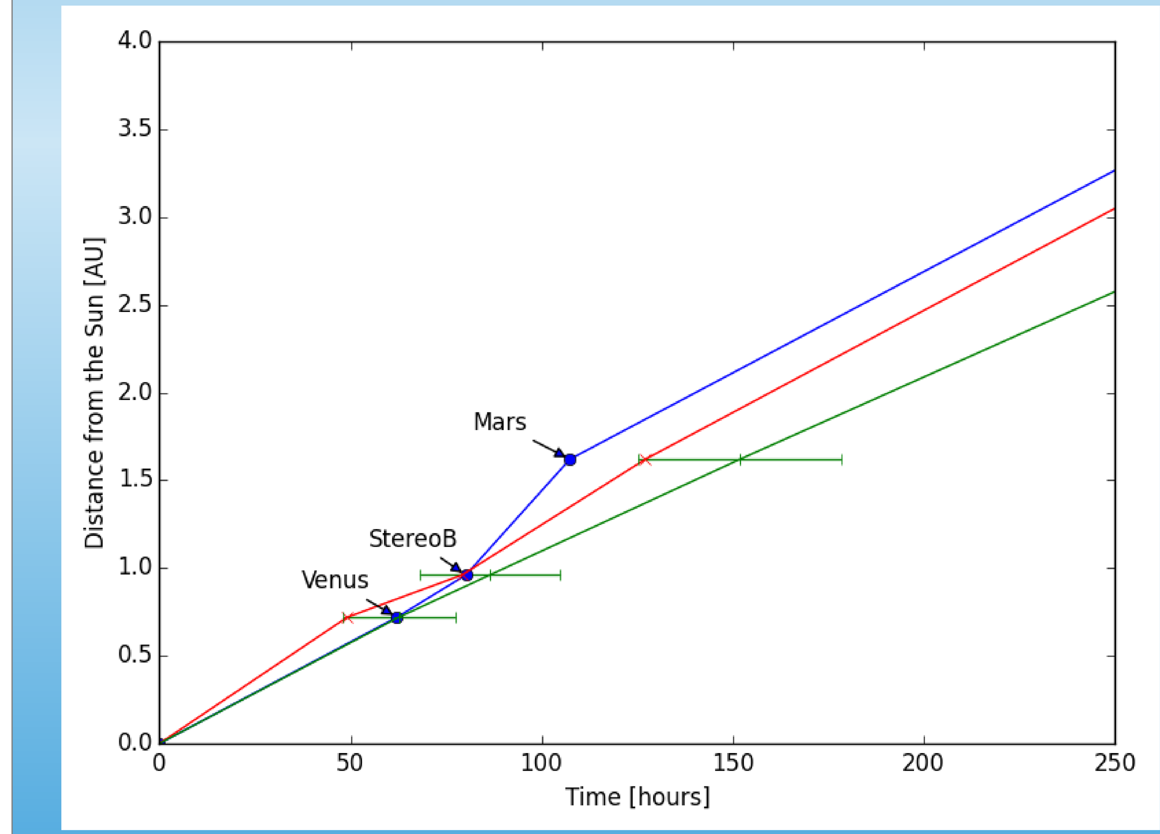
P-DBM to Mars & Saturn

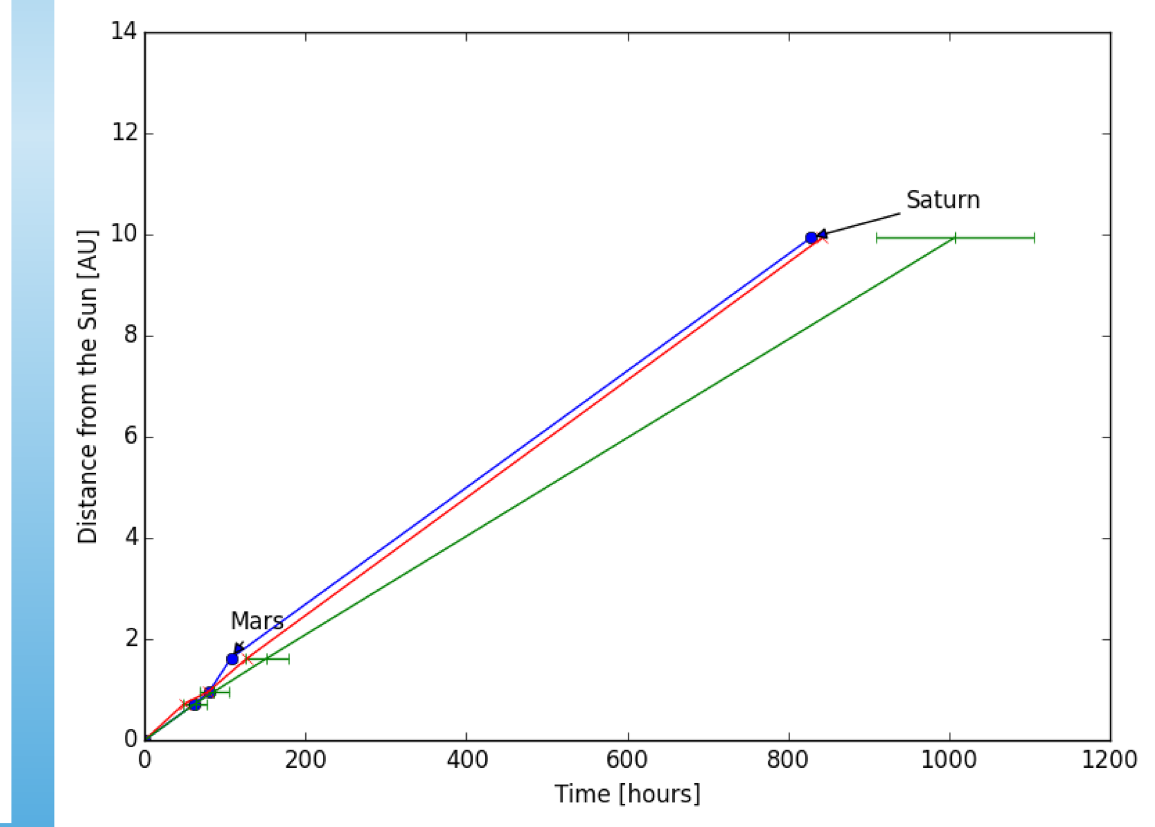
P-DBM applied on data from "Analysis of a coronal mass ejection and corotating interaction region as they travel from the Sun passing Venus, Earth, Mars, and Saturn"



Left: The estimated CME propagation path is represented by dashed lines, and the CME itself is represented by different shades of colors, representing different confidence levels of the CME extension: yellow=10% probability, light orange=50% probability, dark orange=90% probability. Planets are represented by colored symbols.

Below: Comparison between ICME transit times at different targets in the heliosphere. In blue the measured times, in red the time forecast by the WSA-Enlil simulation, in green (with error bars) the time forecast by the P-DBM.

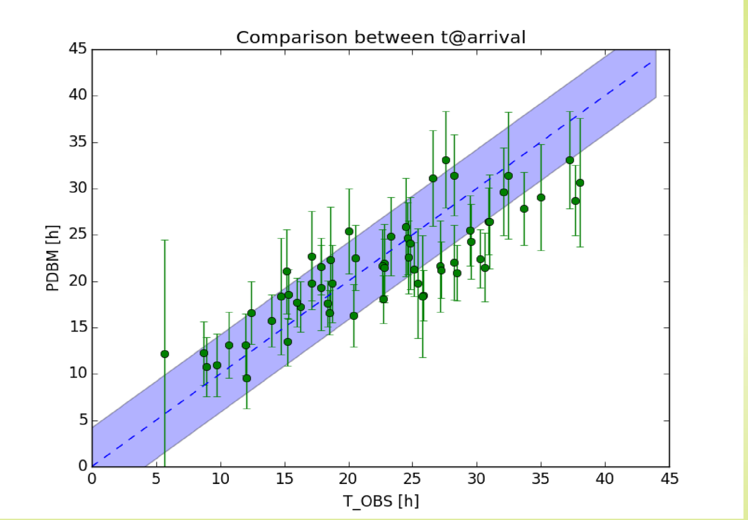




Data from Prise et al., 2015 https://doi.org/10.1002/2014JA020256

P-DBM to Mercury:

PDBM applied on data from "Interplanetary coronal mass ejections from MESSENGER orbital observations at Mercury"



Above: Dots with error bars are the forecast transit times versus observed transit time of the ICME observed by the Messenger mission orbiting Mercury during 2011-2015. The dashed line shows the perfect match expectation, with the 1σ travel time measure error zone shaded in blue.

Data from Winslow et al., 2015 https://doi.org/10.1002/2015JA021200

Biblio:

Del Moro et al., 2019
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