IL NUOVO CIMENTO **42 C** (2019) 39
DOI 10.1393/ncc/i2019-19039-4

Colloquia: SoHe3 2018

The Probabilistic Drag Based Model for ICME propagation

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received 28 December 2018

Summary. — 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 present some results from the application of the P-DBM (Probabilistic Drag Based Model) to propagate a sample of ICMEs from their sources on the solar surface into the heliosphere. We made use of recent works who tracked the ICMEs through their journeys using data from several spacecraft, tracing the ICMEs trajectory further than Earth. Considering the extremely short computation time needed by the P-DBM to propagate ICMEs into the whole heliosphere, and its accuracy in reproducing the observations, we remark that it is a promising candidate for ICME Time of Arrival computation for Space Weather applications and for the need of present and future interplanetary missions, since it could be used as quick tool to forecast the arrival of ICME to planetary bodies in our Solar System other than the Earth.

1. – Introduction

Among the many manifestations of the so-called Space Weather (e.g.: [1]), the Coronal Mass Ejection (CMEs) and their Interplanetary counterparts (ICMEs) are responsible for major consequences at Earth and on spacecrafts [2,3], consequently the prediction of their impact on different solar system targets is one of the primary goals of the planetary space weather forecast (e.g.: [4-6]).

Several forecasting methods have been proposed over the last two decades and they can be roughly divided into three classes:

- Purely empirical/statistical methods making use of relationships established between coronagraphically measured parameters and measured heliospheric propagation characteristics of past ICMEs (e.g.: [7, 8]).

- Numerical MHD-based models of the heliospheric propagation of the ICME (e.g.: [9-12]).

- Kinematic models that apply a somewhat simplified description of the main interaction the ICME is subject to during its interplanetary journey (e.g.: [13-16]).

In this work we employ a model belonging to the last category, the Probabilistic Drag-Based Model (P-DBM, hence-forth - [17]) and show some results of its application for the forecasting of the arrival time and speed to target other than Earth.

2. – The P-DBM model

To model the CME propagation in the interplanetary space, the P-DBM makes use of probability distribution functions instead of exact values as input parameters. This allows us to evaluate the ICME arrival times and velocities along with the uncertainties on the forecast. The P-DBM returns a statistical evaluation of the time of arrival and velocity of the ICME at a chosen distance from the Sun, transforming the probability or error distribution functions associated to the input parameters into probability distribution functions (PDFs) for the output results. This allows computing the best estimates and the errors for both the time of arrival and the velocity of a given ICME. For each CME whose initial position (r_0) and velocity (v_0) are measured with an error, we generate thousands of different [r_0, v_0, w, γ] initial conditions sets (w is the solar wind speed and γ is the drag parameter in eq. (2) of [17]), randomly chosen from the associated PDFs, to compute the transit time and the velocity at the target position R. This process generates the PDFs associated to t_R and v_R, which can be used to estimate the ICME most probable time of arrival and velocity and their associated uncertainties at R. More details about the implementation and an extended description are in [17].

3. – The P-DBM at Mercury

For a first application of the P-DBM to targets other-than-Earth, we used the catalog of ICME events observed from 2011 to 2014 by the MESSENGER spacecraft [18], in orbit around Mercury, created by [19]. Here, we use this catalog to test the P-DBM itself and its capability to provide a forecast of the ICME arrival at Mercury with an useful lead time. In figure 1, we report the travel time from the Sun to Mercury computed by the P-DBM for the 61 ICME in the catalog, against their actual travel time. The forecast are plotted as green dot with error bars, the error bars representing the arrival time forecast uncertainty estimated by the P-DBM. The red and orange shadowed areas represent two different lead time regimes. The red one represents the minimum time needed to acquire the information about the CME launch parameters (i.e. to download and analyze the images from the SOHO/LASCO instrument [20], compute the CME characteristics and propagate the ICME in the inner heliosphere). This time can not be reduced, and therefore no useful warning could be cast about the ICME that arrived at Mercury in just 6 hours. The orange area represents the duty cycle of the CME detection algorithm, which is at present updated every six hours. This could be instead reduced by creating a dedicated real-time detection algorithm. Beyond 15 hours, a useful warning about an ICME impacting on Mercury could be issued, to alert any observer and operator that could be interested by the event.

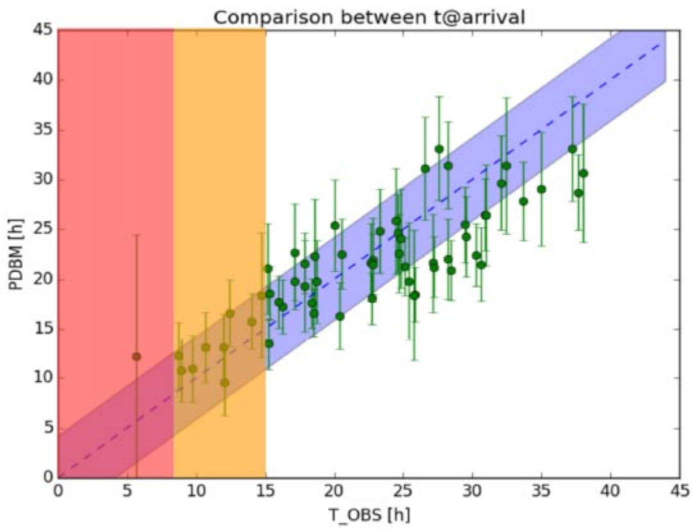

Fig. 1. – Green dots with error bars: forecast vs observed travel time for 61 ICME detected at Mercury. Shaded areas represent the uncompressible and compressible lead times.

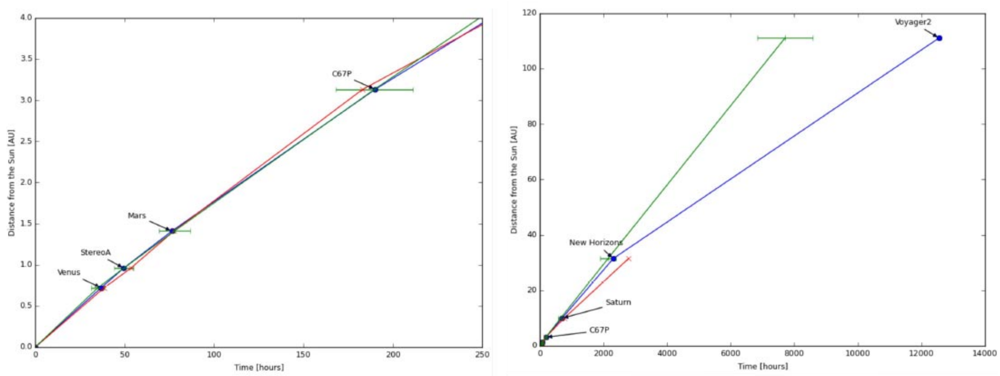

Fig. 2. – An ICME propagation in the whole heliosphere. In blue the travel times measured by [22], in red the travel times computed by an Enlil [10] propagation, in green with error bars the travel times computed by the P-DBM. In the left panel the inner heliosphere (from 0 to 4AU), with Venus, Stereo-A spacecraft, Mars, and comet C67P Churyumov-Gerasimenko positions; in the right panel the outer heliosphere (from 0 to 120 AU), with comet C67P Churyumov-Gerasimenko, Saturn, and the New Horizons and Voyager-2 spacecraft positions.

4. – The P-DBM to Mars and Beyond

In a limited amount of cases, the ICME journey in the heliosphere has been tracked by means of multi-spacecraft measures. Since the P-DBM computational needs are extremely limited, we could simulate the ICME propagation of two of those cases, where the ICME were tracked from the Sun to Saturn [21], and to the position of the New Horizons mission (at that time close to Pluto) and, possibly, to Voyager 2 [22]. In the first case (not reported here), the CME interacted with a Corotating Interaction Region and the P-DBM succeded in describing properly its propagation up to 1AU only. In the second case, the P-DBM performed exceptionally well, and its simulation was consistent with the ICME transit time observations up to the position of the New Horizons spacecraft. Since the computational effort was minimal, we also propagated the ICME to Voyager 2 position, which is considered to be close to (or even beyond) the heliopause, a distance where the P-DBM approximations are evidently no longer valid.

5. – Conclusions

To conclude, the accurate prediction of the Time of Arrival of an ICME to any place of the Heliosphere is of critical importance for our space-faring society and for any future manned exploration of the solar system. Considering the extremely short computation time needed by the P-DBM to propagate ICMEs into the whole heliosphere, it could be used for quick forecasts of the arrival of ICME to any planetary body and interesting location in our Solar System. We think that the P-DBM is a promising tool for Space Weather applications and for the need of present and future interplanetary missions.

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