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Coronal Mass Ejections travel time

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Abstract. Coronal mass ejections (CMEs) are the main source of intense geomagnetic storms when they are earthward directed. Studying their travel time is a key-point to understand when the disturbance will be observed at Earth. In this work, we study the CME that originated the interplanetary disturbance observed on 2013/10/02. According to the observations, the CME that caused the interplanetary disturbance was ejected on 2013/09/29. We obtained the CME speed and estimate of the time of arrival at the Lagrangian Point L1 using the concept of expansion speed. We found that observed and estimated times of arrival of the shock differ between 2 and 23 hours depending on method used to estimate the radial speed.

Keywords. coronal mass ejections (CMEs), halo CMEs, interplanetary disturbances, magnetic clouds

1. Introduction

Coronal mass ejections (CMEs) and their corresponding structures in the interplanetary medium (known as ICMEs) are of great importance because they cause most of the intense geomagnetic storms (Gosling *et al.* 1990; Gonzalez *et al.* 1990). Those events are frequently called geoeffective CMEs when they have direction of propagation close to the Sun-Earth line (Möstl *et al.* 2014).

In this work we identify the CME that caused the ICME observed on 2013/10/03 and then estimate its travel time using only the speed extracted from coronagraph observations.

2. Identifying the CME and estimating its travel time

In order to identify the CME associated to the interplanetary disturbance, we used simultaneous observation from three white light coronagraphs onboard at three different spacecraft: the twin STEREO (Solar TErrestrial RElations Observatory, Kaiser *et al.* 2008) spacecraft and SOHO (Solar and Heliospheric Observatory, Domingo *et al.* 1995). While the later is located in the Lagrangian point L1, the STEREO probes were located approximately 1 AU away from the Sun, one ahead of the Earth orbit by 147° and the other behind by 139° during the ICME observation period. Their separation angle was approximately 73°.

First, we inspected white-light coronagraph observations from the LASCO -C3 (Brueckner *et al.* 1995) onboard SOHO looking for identification of any CME possibly directed toward the Earth. Those CMEs are seen as halos or partial halos surrounding the occulting disk. From previous studies, we know that the travel time of the CME ranges basically from 1 to 5 days (Gopalswamy *et al.* 2001, Schween *et al.* 2005). From our analysis, the unique CME observed as a partial halo on the period was first seen on the LASCO coronagraph C2 at 2013/09/29 22:12. No full halo event was identified.

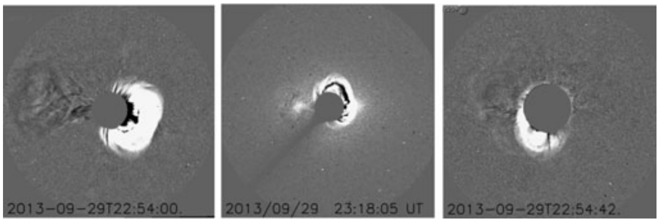

Figure 1. The observation of the CME on 2013/09/29 on both COR2 A (left), COR2B (right) and LASCO -C3 FOVs.

Secondly, we identified the corresponding CME observed on the COR2 coronagraphs onboard the STEREO spacecraft. Due to its viewpoint, a CME directed toward the Earth is observed as a eastward limb on COR2A and as a westward limb on COR2B. From this analysis we confirm that the CME observed on 2013/09/29 22:12 is directed toward the Earth and must be the cause of the ICME (Fig. 1).

According to the in situ observation from the instruments MAG and SWEPAM onboard the ACE spacecraft (located at the Lagrangian Point L1), an interplanetary shock was observed on 2013/10/02 01:18, more than 50 hours after the first observation of the CME on the solar corona. The solar wind increased to approximately 600 km/s and the interplanetary magnetic field reached values of 32 nT. On the first half of 2013/10/03, a structure with magnetic cloud (MC) signatures was observed, in accordance with the criteria from Lepping *et al.* (2005)

The definition of the CME time of arrival (ToA) at L1 will depend on the specific signature observed in situ interplanetary data and there is no consensus about the parameter to be used (see, e.g., Gopalswamy *et al.* 2003). Beyond the time of the shock observation, other parameters used are: (a) the peak magnetic field intensity associated to the shock (2013/10/02 04:24); (b) the beginning time of the MC (2013/10/02 22:35) and (c) peak density (2013/10/02 03:58).

The ToA can be estimated using the expansion speed, a speed perpendicular to the radial direction of the CME (Dal Lago *et al.* 2003). The CME travel time T_{travel} can be estimated by an optimum fit function (from Schwenn *et al.* 2005): $T_{travel} = 203 - 20.77 \ln(v_{exp})$ where T_{travel} is given in hours and v_{exp} is the expansion speed (given in km/s). Using the pseudo-automatic segmentation of the CME from CORSET methodology, we derived $v_{exp} = 837km/s$ (the reader is referred to Braga *et al.* 2013 for details). In this case the travel time estimated is 63 hours and the ToA is 2013/10/02 13:25. When we do not have the expansion speed, it can be derived from from the fit between the v_{exp} and v_{rad} obtained by Dal Lago *et al.* (2004): $v_{exp} = v_{rad}/0.88$.

We took the radial speed derived by CME catalogs such as the CDAW CME catalog (Yashiro *et al.* 2004), CACTus (Computed Aided CME Track, Robbrecht & Berghmans 2004) and SEEDS (Solar Eruptive Event Detection System, Olmedo *et al.* 2008). By estimating the expansion speed from the radial speed, we calculated the ToA. In the specific case of CORSET, the ToA was calculated in two ways: (i) using the expansion speed provided from the method ignoring the radial speed and (ii) ignoring the expansion speed and using the radial speed to estimate it.

Among all methods cited in the upper paragraph, the ToA estimated differs from the shock observation time the least when using the radial speed from CDAW catalog. In this case, the estimated ToA is 2013/10/02 03:39, approximately 2 hours later than the observed shock. When using the results from CORSET, the difference increases to approximately half a day: 2013/10/02 13:25 using the expansion speed, and 2013/10/02

12:29 using the radial speed to estimate the expansion speed. The speeds from fully automatic catalogs (CACTus and SEEDS) resulted in estimated ToA 20 hours later than the shock (2013/10/03 04:17 and 2013/10/03 00:04, respectively). Notice that these two ToAs lie in the first hours of the MC-like observation. One possible explanation for the best ToA estimation obtained when using the speed derived by CDAW catalog is the similarity between the methodology used in this catalog and the one adopted by Schween *et al.* (2005) and Dal Lago *et al.* (2004): both methodologies identify the CME by eye. On the other methodologies, the CME speed is derived using automatic or pseudo-automatic identification.

3. Final remarks

The ToA of the CME observed on 2013/09/29 was estimated using the methodology from Schween *et al.* (2005) and taking plane-of-sky projected speed measurements from LASCO-C3 derived using several methods. For all radial speeds considered here, the estimated ToA was found to be latter than the actual shock observation and the difference ranges from 2 to 23 hours, depending on the method used.

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