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# Estimating arrival time of 10 October 2010 CME using STEREO/SECCHI and in-situ observations

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**Abstract.** The prediction of arrival time of Coronal Mass Ejections (CMEs) at the Earth is one of the prime objectives of solar-terrestrial physicist. In the present work, we applied the tie-pointing method on STEREO/SECCHI coronagraph (COR2) images to obtain the true 3D coordinates of CME feature of 10 October 2010 and estimated its arrival time at 1AU. Further, we tracked this CME in the interplanetary medium using COR2 and HI images from SECCHI instruments and obtained its true kinematics using geometric triangulation technique. In order to estimate the arrival time of the CME, the drag based model is used for the remaining distance where CME could not be tracked with good accuracy in HI field of view. We identified the interplanetary counterpart of 10 October 2010 CME in in-situ data and marked its arrival time which is then compared with the arrival time estimated using remote sensing observations. It is shown that a better prediction of arrival time and transit velocity of CME at 1AU is possible by implementing geometric triangulation technique on HI observations combined with drag based model than using only SECCHI coronagraph images.

*Keywords* : ICME – STEREO – heliospheric imager – solar wind

## 1. Introduction

Coronal Mass Ejections are huge magnetized plasma eruptions from the Sun into the interplanetary (IP) medium. They play an important role in producing non-recurrent disturbances in earth's magnetosphere, shock wave disturbances and solar energetic particle events in interplanetary medium (Gosling 1993). We could observe and study

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the evolution of CMEs using SOHO coronagraph observations up to 30 $R_\odot$ in the projection images, therefore, we lacked information about true kinematics of CMEs. Also most of the earlier studies suffer from two point measurements, one near the Sun and other near the Earth. The possible deflection of the CMEs, interaction between two or more CMEs and inexact value of drag force experienced by a CME in the interplanetary medium may result in incorrect association between CME and its corresponding ICME. Thus, this results in inaccurate estimation of travel time of a CME. It is required to track and estimate the kinematics of CMEs continuously throughout its journey in the IP medium for better understanding of the evolution of CMEs. In this work, we applied the geometric triangulation technique (Liu et al. 2010) on the COR and HI images and estimated the kinematics of 10 October 2010 CME in the IP medium. The estimated true velocity was used as input in the Drag Based Model (Vršnak et al. 2013) to estimate the arrival time of CME at 1 AU. The estimation of arrival time of this CME at 1 AU using only tie-pointing method (Thompson 2009) is also compared with in-situ observations of ICME.

## 2. Observations and analyses

The twin STEREO spacecraft A and B, drifts away from the earth at a rate of about 22.5 degree per year. The on-board instruments on STEREO/SECCHI package are EUVI (FOV: 1.0-1.7 $R_\odot$), COR1 (FOV: 1.5-4.0 $R_\odot$), COR2 (FOV: 2.5-15.0 $R_\odot$), HI1 (FOV: 15-90 $R_\odot$) and HI2 (FOV: 66-318 $R_\odot$) which together image a CME from 0.4° to 88.7° in solar elongation angle. All these imaging instruments have sun-centred field of view, except HI1 and HI2 which are off-pointed from the Sun at solar elongation of 14° and 53.7° respectively (Eyles et al. 2009).

**CME of 10 October 2010:** A slow and partial halo CME was observed by SOHO/LASCO at 22:12 UT on 10 October 2010. This CME was associated with a filament eruption located on south-east quadrant of the Sun. The evolution of this CME as observed by STEREO-A COR2, HI1 and HI2 is shown in Figure 1. To estimate the true dynamics of CME in the SECCHI/COR2 FOV, we carried out the 3D reconstruction technique on the leading edge of CME using tie-pointing (Thompson 2009) method.

It is very difficult to identify and track a particular feature of CME in the HI field of view because of weak Thompson scattered signal. To overcome this, a method developed by Sheeley et al. (1999) for LASCO images, which is also known as time elongation map (J-map), was used to track the CME in the IP medium. We constructed the J-map along the ecliptic plane using the images taken by COR2, HI1 and HI2 instruments on-board both the twin STEREO/SECCHI. J-map constructed from STEREO-A observations for the CME of 10 October 2010 is shown in Figure 2.

Independent elongation of a moving feature is estimated simultaneously from two view points and used as inputs in the geometric triangulation technique (Liu et al. 2010) to obtain the kinematics of CME in IP medium, which is shown in Figure 3.

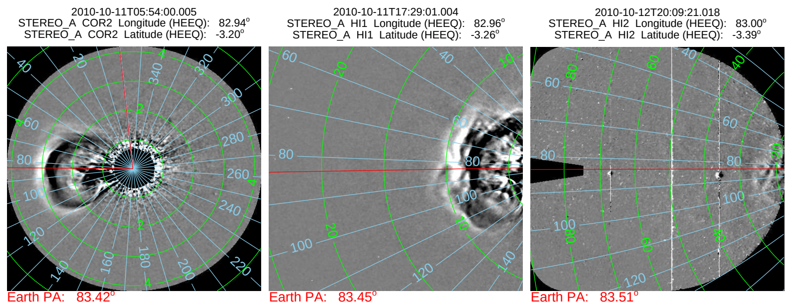


**Figure 1.** Left, middle and right figures show the running difference image of COR2, HI1 and HI2 respectively taken by STEREO A/SECCHI with over drawn contours of elongation angle (green) and position angle (blue). The horizontal red line is along the ecliptic at the position angle of Earth. In the left panel, the vertical red line marks the zero degree position angle.

Velocity is calculated from the adjacent distances by using numerical differentiation with three point Lagrange interpolation method.

**Estimation of arrival time and in-situ measurement of ICME:** Using tie-pointing method on CME leading edge, the true velocity was estimated as 566 km s$^{-1}$ at 14.5 $R_\odot$ at 06:50 UT on 11 October 2010. Assuming that the speed of CME is constant beyond COR2 field of view, the predicted arrival time is 14 October 2010 at 02:33 UT at 1AU. The kinematics of CME using HI observations could be studied up to 120 $R_\odot$. We assume that after such a large distance the propagation of CME will be governed by the aerodynamic drag. We used the Drag Based Model (DBM) of the Vršnak et al. (2013) combined with inputs from the average of last few data points obtained at the farthest distance from the Sun using geometric triangulation scheme in HI FOV. The inputs parameters are, the take-off date and time of CME as 13 October 2010, 09:33 UT, take-off distance 120.65 $R_\odot$, take-off velocity 354 km s$^{-1}$. On taking the extreme values of statistical range of drag parameter $0.2 \times 10^{-7}$ - $2.0 \times 10^{-7}$ km$^{-1}$ (Vršnak et al. 2013) and ambient solar wind speed as 350 km s$^{-1}$, the predicted arrival time is at 12:23 - 12:30 UT on 15 October 2010 with transit velocity of 354 - 353 Km s$^{-1}$ at 1AU.

Near the Earth, interplanetary counterpart of this CME is identified by a combination of various signatures (Zurbuchen & Richardson 2006). We analysed the OMNI in-situ data and identified the sheath region for the ICME which started at 04:30 UT on 15 October 2010 and sheath trailing edge at 01:38 UT on 16 October 2010.

## 3. Results and conclusions

In the J-map, we tracked the leading edge of the CME having positive inclination. Bright feature in the J-map corresponds to enhanced density feature in the solar wind.

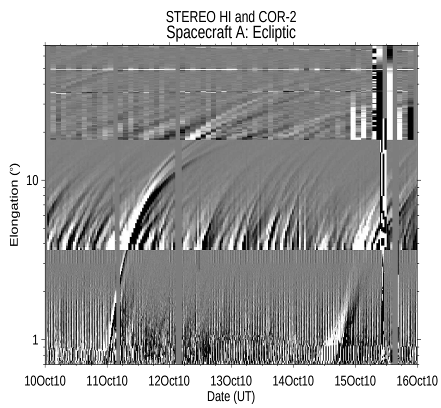


**Figure 2.** Time elongation map (J-map) constructed from the COR2, HI1 and HI2 images of STEREO A/SECCHI for the interval of 10 to 16 October 2010 is shown.

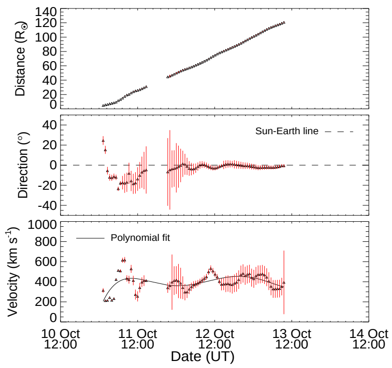


**Figure 3.** The solid line in third panel is the polynomial fit of actual velocity data points. The red vertical lines show the error bars. The data gap is due to singularities in the estimation scheme.

The actual arrival time of CME at 1AU is taken as the time when first maximum enhanced density feature is observed by the in-situ instruments nearly at 1AU. The estimated arrival time of CME at 1AU using only tie-pointing method is 26 hours earlier than the leading edge of the ICME region as observed in-situ. Using HI observations combined with DBM the estimated arrival time of CME at 1AU is 6.3 hours later than the actual arrival. Using HI observations, we predict the transit velocity at 1AU of the CME taken in our study within errors of 50 km $s^{-1}$. We therefore conclude that estimation of arrival time, and transit velocity, and identification of ICME at 1AU can be improved by combining the inputs from HI observations with the Drag based model for the CME evolution.

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