IL NUOVO CIMENTO **42 C** (2019) 36
DOI 10.1393/ncc/i2019-19036-7

Colloquia: SoHe3 2018

Measuring the 2D distribution of the expansion speed of solar eruptions: A first test based on synthetic coronagraphic data

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received 28 December 2018

Summary. — The determination of the propagation speed of Coronal Mass Ejections (CMEs) is usually done by tracking the motion of isolated brighter parcels of plasma embedded in the body of the eruption in coronagraphic and heliospheric imagers. In this work we explore the possibility to derive the 2D map of the instantaneous velocity distribution in the body of a CME. To this end, in this first test we analysed synthetic coronagraphic observations, to compare the derived CME speed with the expanding speed of the simulated eruption. First results are presented here.

1. – Introduction

Coronal mass ejections (CMEs) are large scale eruptive phenomena of the Sun, which are one of the most important drivers of geomagnetic storms on the earth. The Large Angle Spectroscopic Coronagraph (LASCO) [1] on board the Solar and Heliospheric Observatory (SOHO) mission successfully demonstrated that these coronagraphic instruments can provide real-time information on the properties of solar eruptions, such as the kinematics, masses, velocities of CMEs and other parameters. The major part of the brightness signal of white-light coronagraphic images is yielded by Thomson scattering. A lot of studies concentrate on the estimate of CME masses, and subsequently on deriving the kinetic energies from coronagraphic observations [2-4]. However, these kinetic results are associated with CME's unidimensional propagation speed obtained from tracking the movement of bright features, such as the CME core and front, so that it is hard to understand how the plasma moves within the CME body. Therefore, the measurement of the two-dimensional (2D) velocity map of the CME is important to reveal the plasma kinematics and energy distribution of the CME body.

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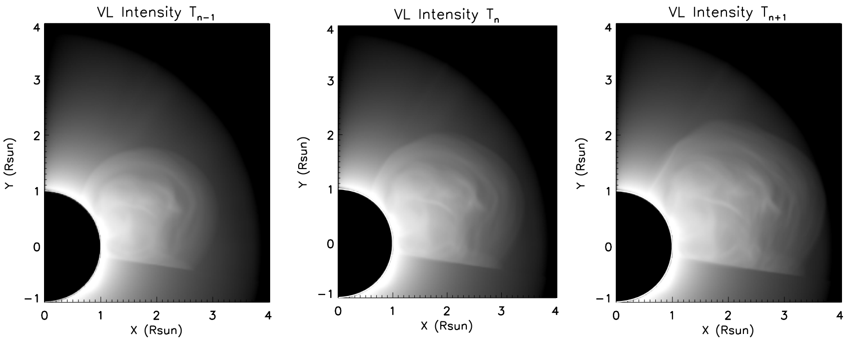

Fig. 1. – Resulting simulated total brightnesses of a CME in coronagraphic images acquired in the VL channel. $T_{n-1} \simeq 23$ minutes, $T_n \simeq 26$ minutes and $T_{n+1} \simeq 29$ minutes. The time interval is 174 seconds.

In our paper, we find a possible way, through tracking the evolution of the CME structure along the radial direction pixel by pixel in visible-light (VL) images, to derive the 2D radial velocity distribution in the body of a CME.

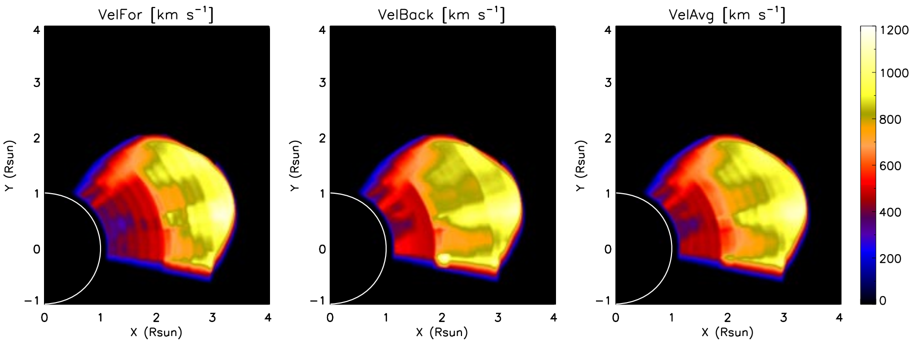

Fig. 2. – 2D images of the measured radial velocities of the CME from the VL images by FS, BS and AS methods.

2. – Construction of the CME synthetic VL images

In this work, we generate synthetic VL observations of a CME as recently done by Bemporad et al. [5] based on the MHD simulation by Pagano et al. [6].

In this MHD simulation, the spherical 3D parameters are interpolated onto Cartesian grid. These 3D cubic parameters provided by the MHD model include proton density, ρ, radial velocity, v_r, and temperature, T. In the same way as Bemporad et al. [5], we compute the VL total (tB) and polarized (pB) brightnesses from each simulated plasma element by integrating the contribution along a given light of sight and then obtain the synthetic tB and pB images. The resulting sequence of VL coronagraphic tB images is shown in Fig.1. These three synthetic VL images are at three simulated times $T_{n-1} \simeq 23$, $T_n \simeq 26$, $T_{n+1} \simeq 29$ minutes, respectively.

3. – Method of the velocity measurement

We use three VL images (at T_{n-1}, T_n, T_{n+1} times) of CME to measure its radial velocity at the T_n. In the first step, we convert VL images from Cartesian to polar coordinates. For each fixed latitude, we extract the radial VL intensity distribution of the three moments. Then we divide our method into three small steps: forward step, backward step and average step. In the forward step (FS) we determine pixel by pixel the radial shift maximizing the cross-correlation between the signal in the actual frame (at T_n) extracted in a symmetric radial window and the signal in a shifted radial window extracted in the next frame (at T_{n+1}). The backward step (BS) has the same procedure as the FS, but we just need to determine the maximal cross-correlation between the frame at the T_n and the frame at the T_{n-1}. In the average step (AS) we average results from the FS and BS. Fig.2 shows the 2D velocity images from these three steps. From Fig.2, we can find that the speed distribution of the CME's body is quite inhomogeneous, which is due to the fact that different parts of the CME plasma propagate with different speeds.

4. – Conclusions

We use simulated data from the MHD model to reconstruct the synthetic VL images. Then, by comparing these three synthetic VL images and calculating their cross-correlation values, we estimate the displacements of the CME plasma pixel by pixel along the radial direction. These results sequentially allow us to compute the velocity distribution of the CME body. The next step is to compare the measured radial velocity with the simulated velocity on the plane of sky to check the reliability of the measured radial velocity distribution from our method, and to develop a method to determine also the tangential (latitudinal) speed and use it to estimate the transverse (longitudinal) expansion speed. In the future, we also plan to apply this method to the study of a real CME event observed in the coronagraphic data.

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SOHO is a mission of international cooperation between ESA and NASA. This work was supported by NSFC grants (11522328, 11473070, 11427803, U1731241) and by CAS Strategic Pioneer Program on Space Science, Grant No. XDA15010600, XDA15052200, XDA15320103, and XDA 15320301. L.F. also acknowledges the specialized research fund from the State Key Laboratory of Space Weather for financial support.

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