



Analytical model for expansion speed for Limb CMEs

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Abstract: Expansion speed for limb CMEs has been shown to be a good approximation to determine the radial speed. In this work we present an analytical model to obtain from lateral expansion the radial propagation speed of CMEs. We found that the relation between expansion and lateral speeds depends as well on the angular width. We compare the results of the analytical model with the parameters of limb CMEs registered by LASCO-SOHO from 1997 to 2005.

Introduction

Coronal Mass Ejections are known to be one of the most important coronal phenomena contributing to interplanetary solar wind disturbances. Dynamical parameters of CMEs are directly involved on the possible effects on Space Weather conditions [5]. One of the most important of these parameters is CME's speed; from speed, the amount of energy carried by the ejecta can be evaluated as well as the possible evolution, transit time and related effects on Space Weather [6].

Most of the information of the dynamical parameters of CMEs come from white light coronagraph images of the solar Corona. Nevertheless CMEs observations come only from two dimension images (plane of the sky) CMEs are three dimensional feature. In fact, CMEs are defined for coronagraph observations as "an observable change in coronal structure that occurs on a time scale between a few minutes and several hours and involves the appearance of a new, discrete, bright white-light feature in the coronagraph field of view moving outwards from the Sun" [2], [4].

To determine the speed of a CME the usual procedure is choosing one point on the structure considered as the CME. Locating the position of the same point on subsequent images the speed is evaluated

using a linear fit position versus time. Acceleration and speed on different height is frequently obtained when a second order fit is performed. It is evident from coronagraph observations that a CME does not move as a solid body, instead it is usual that different parts of the structure have different speeds. A common selection of a point to be followed is the so called "fastest feature" which is usually part of the heading of the structure and, as is inferred from the name, the point moving fastest on the CME.

The position and subsequent parameters evaluated from coronagraph images are not the actual values but the projection on the plane of the sky (POS) or the real ones. When the CME is originated on the limb the position on the POS closely represents the position of the selected point, but as the CME source locates closer to the line of sight, the component of the speed on the plane of the sky approaches zero as the largest value is on the component perpendicular to the POS.

Considering that a CME has a different shape than a single point, Dal Lago et al. [1] showed that the radial speed of a CME is related to the ratio of expansion of the entire structure (Figure 1).

Measuring radial and expansion speed on 57 limb CMEs, Dal Lago et al. found a correlation between them, represented in Equation (1).

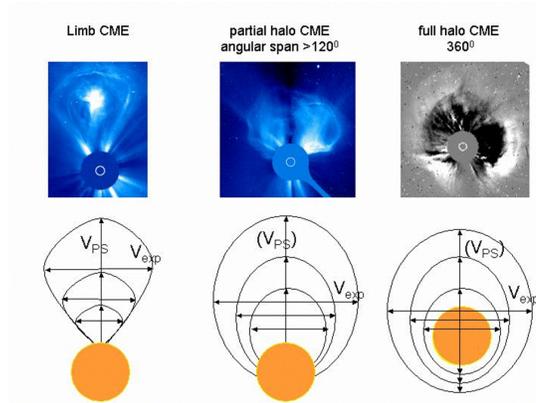


Figure 1: Measuring the Speed on the Plane of the Sky for different projections of CMES. Expansion Speed is evaluated on the borders of the CME on a line perpendicular to the previous (image from Schwenn et al. 2005 [3]).

$$V_{rad} = 0.88V_{exp} \quad (1)$$

This is an empirical relation obtained from a linear fit between radial and expansion speeds for the 57 Limb CMEs analyzed.

Geometric relation between Expansion Speed and Radial Speed

In order to represent a simple geometry of a CME, we considered self-similarity of CMES, this means, the shape and opening cone angle are maintained in the first stages of the CME evolution registered in coronagraph images.

The drawing in Figure 2 shows the relation between the radial position (r) and the lateral expansion (Δh) on a scheme representing the cone angle of a CME. We consider only values of the angular width (α) smaller than 90° .

From the figure, the relation for radial position and the opening cone angle is given by

$$r = l \cos(\alpha/2)$$

on the other hand, the lateral expansion is related to the opening angle as well,

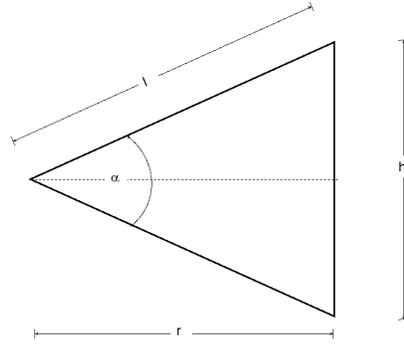


Figure 2: Considering the CME as a cone preserving the opening angle α , the frontal and lateral expansions are related.

$$h = 2l \sin(\alpha/2)$$

Radial and expansion speed, are then given by the equations:

$$v_{rad} = \frac{d}{dt}(l \cos(\alpha/2)) = l' \cos(\alpha/2)$$

$$v_{exp} = \frac{d}{dt}2(l \sin(\alpha/2)) = l' \sin(\alpha/2)$$

Therefore, the relation between radial and expansion speed, as a function of the opening angle is

$$\frac{v_{rad}}{v_{exp}} = \frac{1}{2}(\cot(\alpha/2))$$

$$v_{rad} = \frac{1}{2}(\cot(\alpha/2))v_{exp} \quad (2)$$

Hence, the coefficient in equation (1) is not constant but changes with the opening angle value of the CME involved. This result implies that the correlation coefficient can take value smaller or larger than one. According to equation (2), the coefficient of 0.88 obtained by Dal Lago et al. (equation (1)) corresponds to an opening angle of approximately 60° .

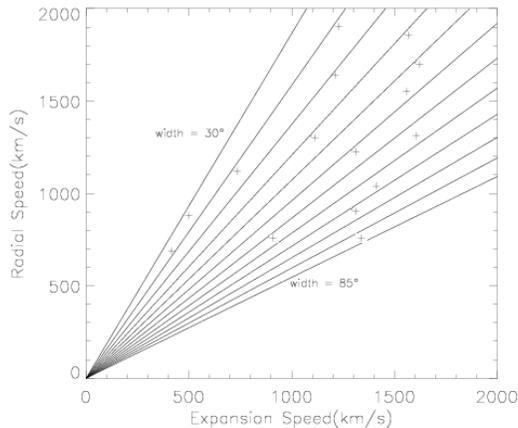


Figure 3: Relationship between Expansion Speed (V_{exp}) and Radial Speed (V_{rad}) from Equation 2 when the Angular Width takes values from 30° to 85° .

Comparison with SOHO data

In order to evaluate the accuracy of the model we analyzed CMEs registered by LASCO coronagraphs C2 and C3. To find Limb CMEs we observed LASCO-EIT composed images published on the LASCO-SOHO CME CATALOG on line, looking for CMEs related to eruptive events (flare or eruptive prominence) localized close to the solar limb. Once a CME was identified as a possible limb event, we measured directly from LASCO C2 images the angular width and, from LASCO C3 images, the POS Speed (Radial Speed, V_{rad}) of one frontal point on the structure and the Expansion Speed (V_{exp}) following two lateral points [1]. The plot on Figure 3 shows the relation between Radial Speed and Expansion Speed for different values of the Angular Width. The values corresponding to observed limb CMEs are represented on the same plot.

Conclusions

In this work we studied the geometric correlation between Radial Speed and Expansion Speed for Limb CMEs. For CMEs with an angular opening value lower than 90° , we found this correla-

tion to depend on the angular width of the CME. We evaluated the three parameters involved (α , V_{rad} and V_{exp}) directly from the images, for a group of CMEs registered by LASCO coronagraphs on board of SOHO from 1997 to 2005. We found that more than two thirds of the events identified as Limb CMEs have Angular Width less than 90° and were used to compare with the model.

As proposed by other authors [1] [4] Expansion Speed is a good proxy of Radial Speed for events on the solar disc for which the POS Speed does not correspond to the radial one. Particularly useful is in the case of Halo CMEs, when the largest component of the velocity vector is directed towards the line of sight. Accuracy on the determination of V_{rad} in these particular cases is important in order to predict the possible arrival time of CMEs to the Earth neighborhood and, eventually, the relation to geomagnetic storms and other effects on Space Weather.

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