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CORONAL MASS EJECTION SPEEDS MEASURED IN THE SOLAR CORONA USING LASCO C2 AND C3 IMAGES

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ABSTRACT

In this work we present height-time diagrams of 2 halo coronal mass ejections, observed on September 28th, 1997 and June 29th, 1999. The CMEs were observed by the Large Angle and Spectroscopic Coronagraph (LASCO), which observes the solar corona from 2 to 32 solar radii. To obtain these diagrams we divide the LASCO images of a given sequence in angular slices, transform them into rectangular slices (their width chosen proportional to the time distance to the next image) and place them side by side. Thus, the speed profile of any pattern moving in the particular latitudinal slice can be derived. With this method we were able to identify even minor speed changes in several angular positions for the chosen events. This technique is particularly appropriate to identify acceleration or deceleration of structures in halo CMEs.

INTRODUCTION

Coronal mass ejections (CME) are expulsions of solar plasma from the gravitational field of the sun observed in the corona (Hundhausen et al., 1984; Schwenn, 1996; Hundhausen, 1997). These observations are made by instruments called coronagraphs that record the photospheric radiation (or white light), scattered by electrons in the ionized coronal plasma (Bruckner et al., 1995). Taking a temporal sequence of these observations it is possible to identify these coronal outflows. The most recent coronagraphs in operation are those from the Large Angle and Spectroscopic Coronagraph (LASCO) experiment onboard of the Solar and Heliospheric Observatory (SOHO) satellite, which is a joint project from the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). LASCO provides plane of sky observations of the dynamics of the solar corona made by two coronagraphs named C2 and C3, which image the corona from 2 to 6 and 4 to 32 solar radii, respectively. When a coronal mass ejection happens to occur toward (away) the line of sight of the satelite (sun-earth line), it appears as a halo structure expanding in all directions, the so called "halo CMEs" (Howard et al., 1982).

When coming in the earth direction, these halo CMEs may produce geomagnetic storms (Gosling, 1990). One of the difficulties experienced by the scientific community has been to quantify the observations provided by the LASCO images. In this sense we present a new technique applied in 2 halo CMEs, the September 28th, 1997 and the June 29th, 1999, that helps to quantify these images. This technique has already been presented by Dal Lago et al. (2002) and it is in some ways similar to the one presented by Sheeley et al. (1999), but with some basic differences that we shall point out. The June 29th, 1999 has also been studied by Sheeley et al. (2000), which allows us to compare the results and the technique used here.

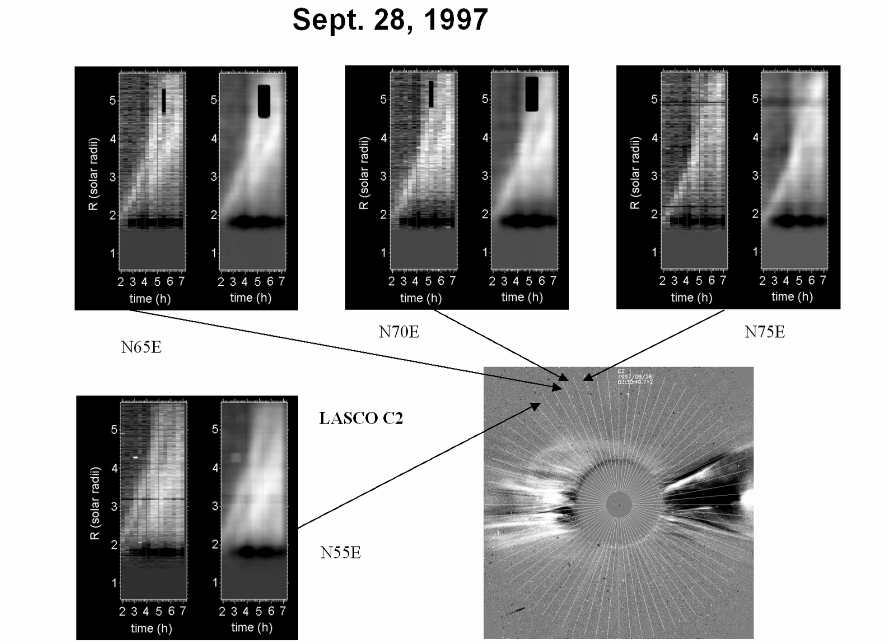

Fig.1. A LASCO C2 single image taken on September 28th (1997) at 0330 UT showing four positions over the north-east pole, N75E, N70E, N65E and N55E. The respective height-time diagrams obtained using our technique are places around the image, each one with a smoothed version beside it.

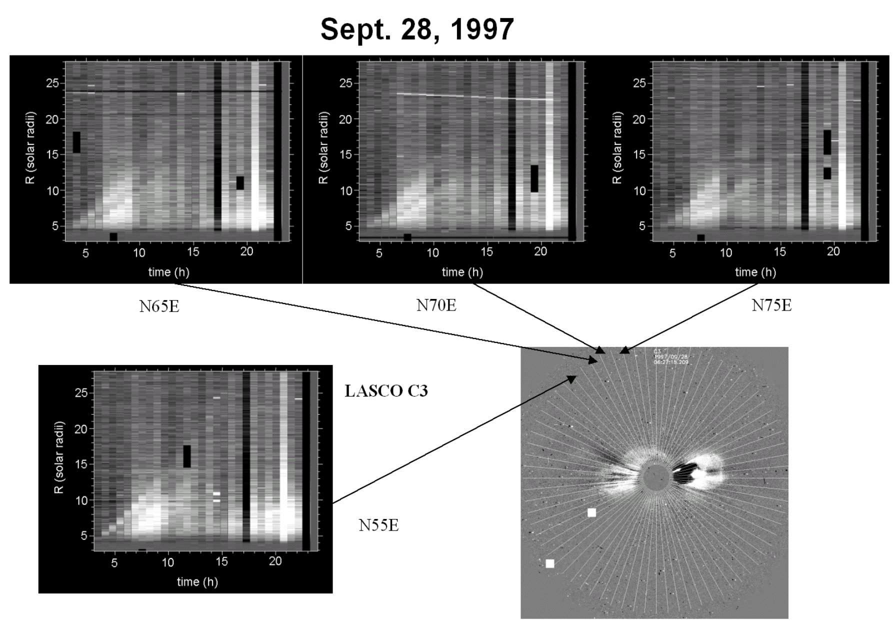

Fig.2. A LASCO C3 single image taken on September 28th (1997) at 0627 UT showing the same four positions of Figure 1 over the north-east pole, N75E, N70E, N65E and N55E. The respective height-time diagrams obtained using our technique are places around the image.

THE TECHNIQUE

The technique consists in dividing each LASCO image in angular sectors and performing an angular integration producing radial profiles in all directions. Since halo CMEs have approximate circular symmetry, no information is lost in this integration. Placing side by side several profiles taken in different times for the same position we are able to produce a clear height-time diagram for each angular position and then obtain height-time scatter plots. The angular integration compensates the fading of the structures as they expand, making them visible at long distances in the corona. It is important to point out that a fixed pre-event image is subtracted from the sequence of images of a given event. This means that no running difference images are used and no further processing is performed on the images. Sheeley et al. (1999) have presented a technique that also provides very good height-time diagrams for halo CME images, which does not do angular integration. This other technique uses running difference images as input and requires some intensity adjustments to compensate the radial fading out of the mass density. Our procedure does this job of increasing intensity with radial distances from the sun through the angular integration. Of course, the CME angular motion information is lost with the integration, but we assume that halo type CMEs do have circular symmetry. The radial speed information is preserved. Detailed information on the technique used in this paper is presented by Dal Lago et al. (2002).

THE SEPTEMBER 28TH (1997) HALO CME

The Sept. 28th (1997) halo CME was a front side full halo CME event. It was first seen in the C2 field of view at 0149 UT and lasted until 1155 UT in the C3 field of view. We applied our technique for the positions N75E, N70E, N65E and N55E. Figure 1 shows a LASCO C2 single image taken on Sept. 28th (1997) at 0330 UT. For all the positions mentioned above we applied our technique and the resulting height-time images are shown in Figure 1. In each of these height-time diagrams the “x” axis is time (hours) and the “y” axis is radial distance from sun center (solar radii). Smoothed diagrams were also included beside each of the original ones to better qualitative recognition of the structures. This event shows an acceleration indicated by the upward curvature of the leading edge in all chosen positions. It is also possible to observe a double structure in the positions N55E and N65E, being the left most the leading edge of the CME and the right most the following inner structure of the CME. The acceleration of this inner structure is not so evident as for the leading edge. Figure 2 shows, for the same positions in Figure 1, the height-time diagrams as seen in the C3 field of view. Note that the double structure becomes clear in all four diagrams. Qualitatively one can observe that the acceleration is not as pronounced as it was in the C2 field of view. Figure 3 shows scatter plots obtained from the diagrams of Figures 1 and 2. A second order fitting was added and the acceleration values were calculated for each position. In fact if one considers just the C3 field of view, a linear fit would be reasonable, which means that all the acceleration took place in the C2 field of view.

This CME was front side and it produced a shock wave in the interplanetary medium, which reached earth 71 hours later, on October 1st (1997). The ejection accompanying this shock wave caused an intense geomagnetic storm at earth with peak Dst index -98 nT in this same day.

THE JUNE 29TH (1999) FULL HALO CME

The June 29th (1999) was a back side full halo CME extending all around the sun. It was first observed in the C2 field of view at 0754 UT and lasted until beyond 1800 UT in the C3 field of view. It was very circular symmetric with the source probably in the back side of the sun. Figure 4 shows a single C3 frame with the height-time diagrams for the positions N70E, N30E, S05E, S85W, S35W and N60W. Qualitatively analyzing these diagrams one can recognize a very little deceleration of the leading edge in all chosen positions. It is also possible to recognize, especially in the N70E and N60W directions, a double structure traveling with different speeds, the leading edge being the faster one. Like for the previous event these diagrams were used to obtain the corresponding scatter plots, which are shown in Figure 5. A second order fitting function was added to each of the plots, indicating a small deceleration in all directions.

Since it was a back side event, no geomagnetic activity was related to this CME.

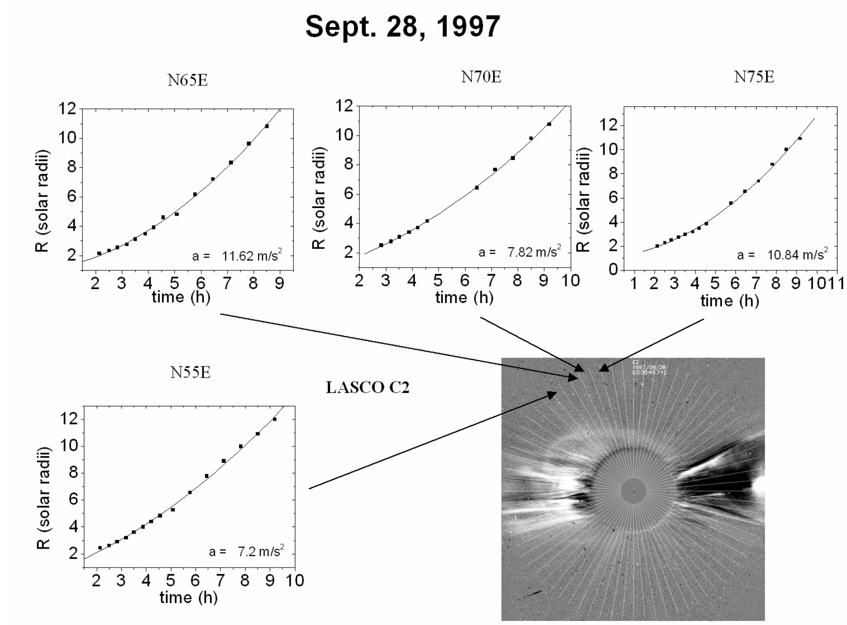

Fig.3. Corresponding scatter plots obtained from the combination of Figures 1 and 2 for the four positions over the north-east pole, N75E, N70E, N65E and N55E.

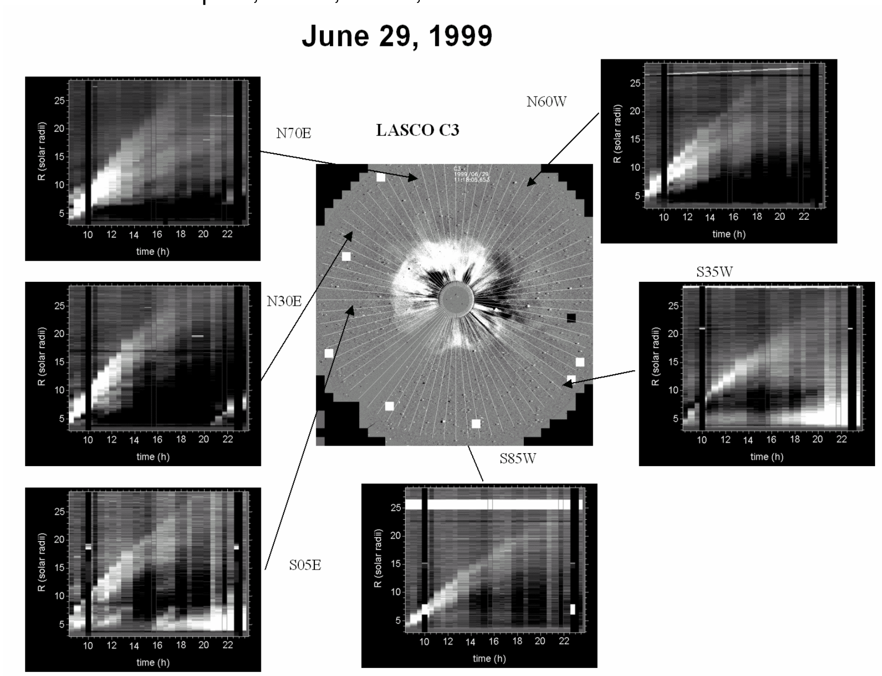

Fig.4. A LASCO C3 single image taken on June 29th (1999) at 1118 UT showing six positions around the sun, N70E, N30E, S05E, S85W, S35W and N60W. The respective height-time diagrams obtained using our technique are places around the image.

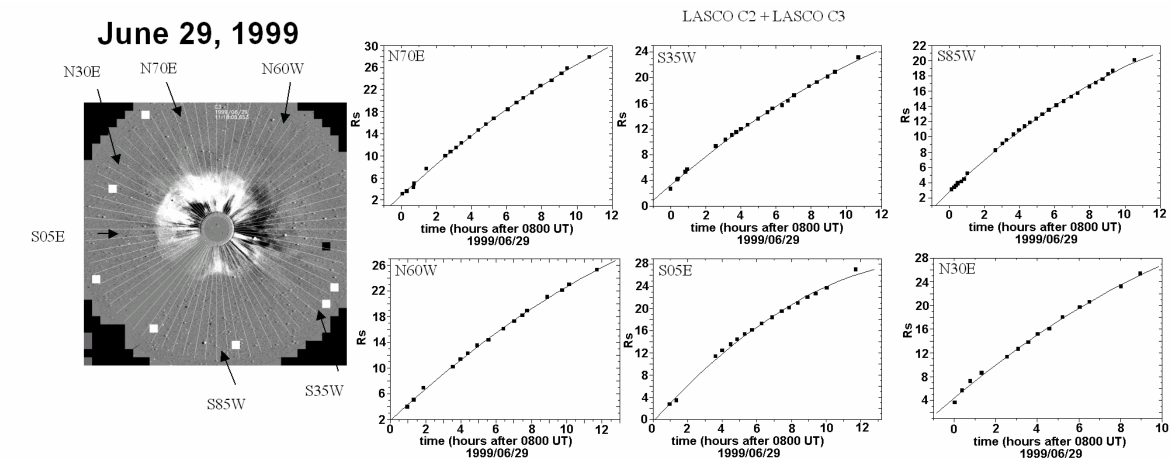

Fig.5. Corresponding scatter plots obtained from Figure 4 form the six positions around the sun, N70E, N30E, S05E, S85W, S35W and N60W.

Table 1 gives the initial and final speeds, as well as the acceleration/deceleration measured for each of the events in the respective directions for which the height-time diagrams were obtained.

Table 1. Initial/final speeds, and acceleration/deceleration measured for the events

September 28th, 1997				*June 29th, 1999*			
	V_0 (km/s)	V_f (km/s)	a (m/s^2)		V_0 (km/s)	V_f (km/s)	a (m/s^2)
N70E	107	402	10.8	N60W	486	274	-5.1
N65E	161	353	7.8	S35W	458	249	-5.1
N60E	130	416	11.6	S85W	435	187	-6.2
N50E	178	374	7.2	S05E	648	192	-11.0
				N30E	578	321	-7.5
				N70E	578	329	-6.0

CONCLUSION

Height-time diagrams for 2 full halo CMEs, September 28th (1997) and June 29th (1999), were obtained from a new technique which permits easy visualization of radial outward movements in the solar corona. Height-time images obtained with this technique have shown clearly the halo CME movements for all the chosen directions in both events. The technique, which performs an angular integration in the LASCO images, permitted the visualization of faint structures far in the corona.

From the analysis of these 2 events we conclude that: (a) the CME observed on September 28th,1997, started very slowly, with initial speeds ranging from 107 to 178 km/s, and accelerated in the C2 field of view reaching final constant speeds of 352 to 400 km/s in the C3 field of view; (b) the CME observed on June 29th, 1999 started with initial speeds from 435 to 650 km/s, and it decelerated smoothly in the C3 field of view and reached a variety of speeds ranging from 150 to 330 km/s, depending on the direction around the sun. These results are in good accordance with a previous work done by Sheeley et al. (2000).

It is interesting to mention that these 2 CMEs were associated with different solar disk source positions, being one a clear front side event (Sept. 28th, 1997), and one back side event (June 29th, 1999). Both produced full halo CMEs on LASCO images. The September 28th (1997) halo showed an acceleration, which was taking place mainly inside the LASCO C2 field of view. We must have in mind that we are able to observe only the plane of sky projection speed of the CME, and, as it was a halo CME, it must have had a strong component of its speed in the sun-earth line direction. In the June 29th (1999) event, the deceleration was observed to take place only in the LASCO C3 images. The deceleration in the sun-earth line direction probably occurred beyond 30 solar radii, because of projection effects.

Concerning geomagnetic activity, only the front side event (Sept. 28th, 1997) was observed to be related to a shock wave observed at the earth and a following intense geomagnetic storm.

We propose that the technique presented in this paper is appropriated to identify whether there is acceleration or deceleration on halo CMEs near the sun.

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REFERENCES

Brueckner, G. E., R. A. Howard, M. J. Koomen, C. M. Korendyke, D. J. Michels, J. D. Moses, D. G. Socker, K. P. Dere, P. L. Lamy, A. Llebaria, M. V. Bout, G. M. Simnett, D. K. Bedford, and C. J. Eyles, The large angle spectroscopic coronograph (LASCO), *Solar Phys.* **162**, 357-402, 1995.

Dal Lago, A., R. Schwenn, G. Stenborg, W. D. Gonzalez, A. L. C. de Gonzalez, L. E. A. Vieira, E. Echer, F. L. Guarnieri, and N. J. Schuch, Deceleration observed on the July 25th (1999) coronal mass ejection, *Geofisica Internacional*, in press, 2002.

Gosling, J. T., Coronal mass ejections and magnetic flux ropes in interplanetary space, in *Physics os magnetic flux ropes*, edited by C. T. Russel, E. N. Priest, , and L. C. Lee, **58**, pp.343-364, AGU, Washington, DC:, 1990.

Howard, R. A., D. J. Michels, N. R. Sheeley Jr., and M. J. Koomen, The observation of a coronal transient directed at Earth, *Astrophys. J.*, **263**, 101-104, 1982.

Hundhausen, A. J. An introduction, in *Coronal mass ejections*, edited by N. Crooker, J. A. Joselyn, and J. Feynman, **99**, pp1-7, AGU, Washington, DC, 1997.

Hundhausen, A. J., C. B. Sawyer, L. L. House, R. M. E. Illing, and W. J. Wagner, Coronal mass ejections observed during the solar maximum mission - latitude distribution and rate of occurrence, *J. Geophys. Res.*, **89**(A5), 2639-2646, 1984.

Schwenn, R. An essay on terminology, myths, -and known facts: solar transients – flare – cme – driver gas – piston – BDE – magnetic cloud – shock wave – geomagnetic storm, *Astrophys. J.*, **243**, 187, 1996.

Sheeley, N. R., Jr., J. H. Walters, Y. -M. Wang, R. A. Howard, Continuous tracking of coronal outflows: two kinds of coronal mass ejections, *J. Geophys. Res.*, **104**(A11), 24739, 1999.

Sheeley, N. R., Jr., W.N. Hakala, Y.M. Wang, Detection of coronal mass ejection associated shock waves in the outer corona, *J. Geophys. Res.*, **105**(A3), 5081, 2000.

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