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Study of a Large Helical Eruptive Prominence Associated with Double CME on 21 April 2001

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Abstract. Here we present a preliminary analysis of a helical eruptive prominence at the east limb of the Sun on 21 April 2001. Unusually this eruption is associated with a double CME. We have tried to study the morphology of the event, energy budget of the prominence and associated CMEs. Our analysis shows that the prominence and first CME started simultaneously from the limb and prominence carries sufficient energy to feed both the CMEs. Moreover, it is also concluded that CMEs are magnetically driven and internally powered.

Key words. Sun: prominence, Coronal Mass Ejection.

1. Introduction

Solar prominences are ribbons of cool (~ 8000 K) dense gas ($\sim 10^{-11}$ gcm^{-3}) embedded in the hot tenuous corona, which forms the outer atmosphere of the Sun. Magnetic fields play an important role in supporting the prominence against gravity and insulating it from the hot surrounding corona. Normal and inverse polarity models of the prominences have been proposed by Kippenhahn & Schlüter (1957) and Kuperus & Raadu (1974) respectively. The relationship between prominence eruption and CMEs has been investigated by many authors (Schmieder *et al.* 2002; Gopalswamy *et al.* 2003; Lin 2004, and the references therein). But the trigger mechanism as well as the overall association between prominence eruption and CME is not well understood. In the present study, we have tried to explore the association between prominence eruption and two CMEs of 21 April 2001.

2. Observations

To carry out the present study, we have used Hα images taken from 15 cm coude refractor equipped with CCD photometric camera and Bernhard Halle Hα filter from ARIES Nainital, SOHO/EIT (195 Å) and LASCO C2 and C3 white light coronagraph data. The spatial resolution of Hα images is 1.3".

3. Analysis

3.1 *Morphology and height-time analysis*

The prominence eruption as well as the eruption of two associated CMEs occurred during the decay phase of NOAA AR 9433 on 21 April 2001. Since the prominence was not located at the active region no flare or radio burst was found to be associated with this eruption. The spatial correlation between prominence and CMEs can be understood with the help of Hα filtergrams, EIT 195 Å difference image and LASCO observations of CMEs (Fig. 1). Comparing the position of prominence eruption with the position angle of CMEs suggests that these events are spatially correlated. To study the temporal relationship between these events the height-time profiles of these events are plotted and compared (Fig. 2).

In Fig. 2 (left) the height-time profiles of the prominence and the leading edge of the first CME are plotted. At 07:50:47 UT the leading edge of the prominence was at 1.02 R_{sun} whereas the extrapolated height of the first CME at 07:50 UT was at 1.0 R_{sun}. The plot reveals strong temporal association between these two phenomena. The height-time profile of the second CME is plotted in Fig. 2 (right). The position

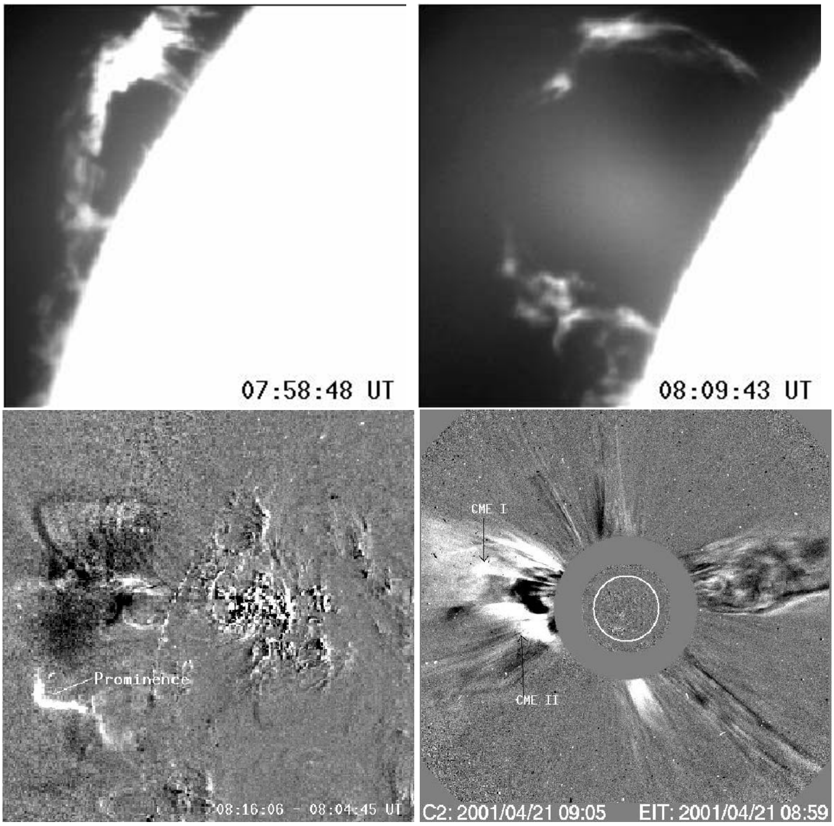

Figure 1. Evolution of Hα (333" $\times$ 333") prominence **(top panel)**, prominence eruption in EIT (195 Å) difference image (910" $\times$ 910") **(bottom left panel)** and associated CMEs **(bottom right panel)**. North is up and west is towards right.

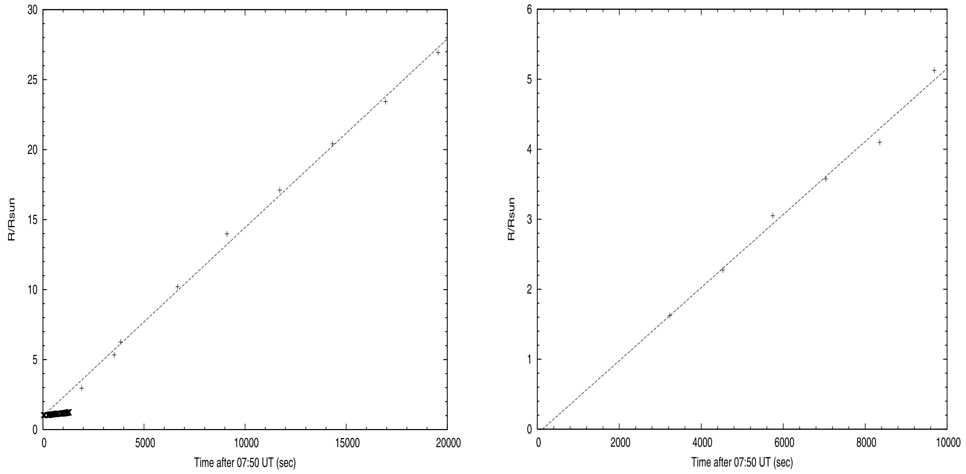

Figure 2. Height-time profiles of first CME (+) and prominence (x) **(left)** and height-time profile of second CME **(right)**.

angles of the second CME and the location of SE foot-point suggests that they are spatially correlated with each other. Since the eruption was so huge that it was not possible to keep the entire prominence in the field of view. Thus the rise of SE foot-point could not be covered properly. But whatever information we could gather from our data, suggests that the second CME and burst of SE foot-point are temporally associated with each other within the range of ± 10 minutes. Thus the first CME is spatially and temporally associated with the prominence eruption while the second CME shows good spatial and temporal association with the burst of SE foot-point.

3.2 *Energetics*

3.2.1 *Energy of prominence*

The calculation of the energy of prominence is carried out according to the model of Martens (1987). The parameters of prominence are directly derived from Hα filtergrams. The momentum equation of an active filament/prominence in Gaussian units is given by (Martens & Kuin 1989),

$$m\frac{d^2h}{dt^2} = \frac{lI^2}{c^2h} - \frac{lIB}{c} - \frac{mg_sR_s^2}{(R_s+h)^2}, \tag{1}$$

where R_s is the radius of the Sun, g_s is gravitational acceleration at the solar surface, h is the height above the limb of the Sun, and $B(= B_0 e^{-\frac{\pi h}{D}})$ is the background magnetic field, which is potential in nature. B_0 is the magnetic field in the photosphere and is taken as 50 gauss (Khan *et al.* 1998). D is the half of foot-point separation as measured to be 8.5×10^9 cm. When $(d^2h)/(dt^2) = 0$, the balance current is derived (Van Tend & Kuperus 1978) for equilibrium height, $h = 1.02 \times 10^{10}$ cm. The loop length of the prominence at this height is measured to be, $l = 2.9 \times 10^{10}$ cm and mass, $m = 0.5 \times 10^{15}$ g. Using these values the strength of equilibrium current is about 0.4×10^{21} stat ampere (s.a.).

The energy stored in the prominence/filament is given as (Martens 1987)

$$E = \frac{1}{2}LI^2 + \frac{1}{c}\phi I, \tag{2}$$

where L is the self inductance of the circuit and ϕ is the magnetic flux of the background field through the circuit. Using the techniques of Wu *et al.* (2002) for the calculation of L and ϕ, the pre-eruptive available energy of the prominence comes out to be 1.2×10^{32} erg.

3.2.2 *Energy of CMEs*

We examine the energetics of coronal mass ejections (CMEs) with data from LASCO C2 and C3 coronagraph. The enthalpy and thermal energy are so small that they can be

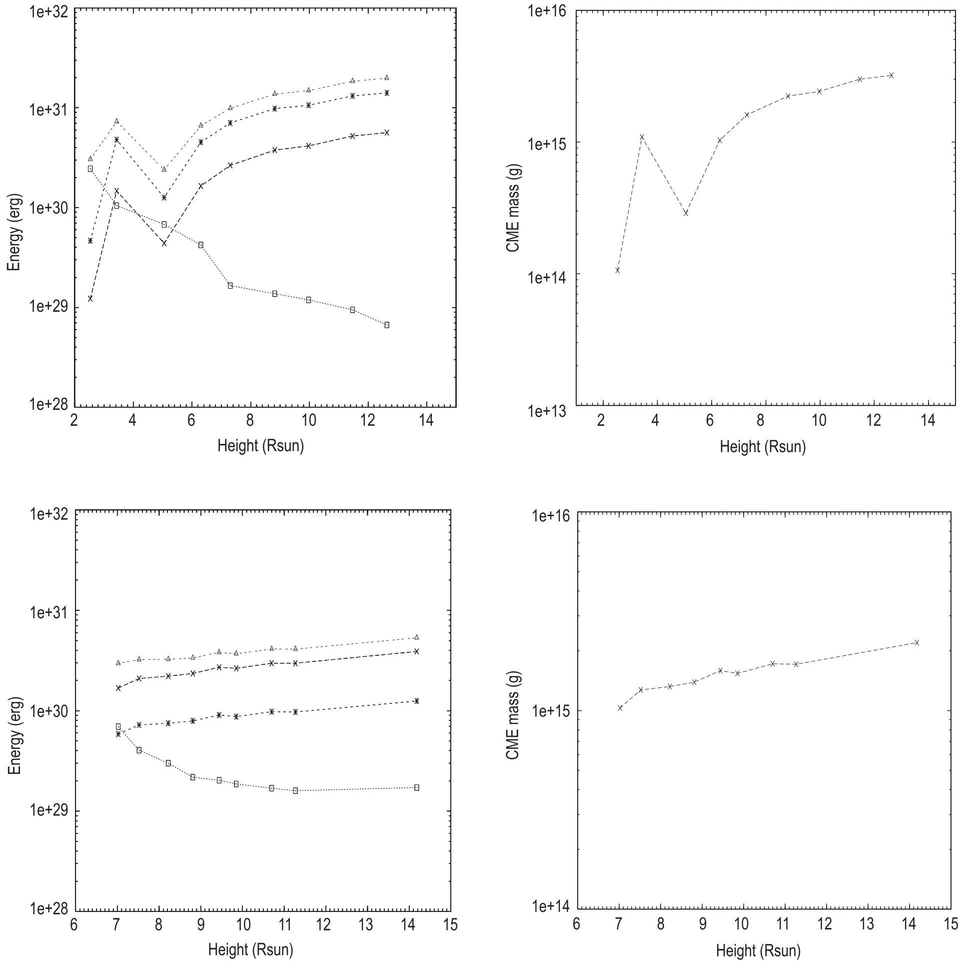

Figure 3. Left panels: Variation of potential ($\times$), kinetic ($\star$), magnetic ($\Box$) and total ($\triangle$) energy of first (top) and second (bottom) CMEs. **Right panels:** Evolution of mass of first (top) and second (bottom) CMEs.

neglected without effecting the overall conclusions. The potential (E_p), kinetic (E_k) and magnetic (E_m) energies are given by (Vourlidas *et al.* 2000)

$$E_p = GM_s m \left(\frac{1}{R_s} - \frac{1}{R_s + h} \right), \tag{3}$$

$$E_k = \frac{1}{2} m v^2, \tag{4}$$

$$E_m = \frac{l}{8\pi} \times \frac{(B \times A)^2}{A}, \tag{5}$$

where A and l are the area and length of flux rope respectively. l is assumed as $l = r_{\mathrm{cme}}$ (heliocentric height of center of mass). The speeds of the first and second CMEs are 937 km/s and 373 km/s respectively. We have used average magnetic flux $(B \times A) = 1.2 \times 10^{21}$ Max (Wu *et al.* 2002). The variation of potential energy (E_p), kinetic energy (E_k), magnetic energy (E_m) and total energy of both the CMEs with their heliocentric height as well as the evolution of mass of the respective CMEs are shown in Fig. 3. The total energy of the first and second CMEs are 2×10^{31} erg and 5×10^{30} erg respectively.

4. Conclusions

The following conclusions are drawn from the study of prominence eruption and associated CMEs on 21 April 2001.

The spatial and temporal correlation between prominence eruption and initiation of first CME is found to be good. This analysis suggests that both the events are caused by a common disturbance.

The combined energy of both the CMEs is found to be 2.5×10^{31} erg, whereas the energy stored in the prominence is about 10^{32} erg. These values suggest that there was enough energy stored in the prominence to provide both the CMEs.

The total energy of both the CMEs remain constant within a factor of 2, which supports the view that CMEs are magnetically driven and internally powered (Vourlidas *et al.* 2000; Manoharan *et al.* 2001).

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