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Eruptive Prominences of 1980 April 27 Observed during STIP Interval–X

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Abstract. Observations and analyses of two similar eruptive prominences on the north-east limb observed on 1980 April 27 at 0231 and 0517 UT, which are associated with the Boulder active region No. 2416 are presented. Both the eruptive prominences gave rise to white-light coronal transients as observed by C/P experiment of High Altitude Observatory on the Solar Maximum Mission. Type II and moving type IV radio bursts are reported in association with the first Hα eruptive prominence at 0231 UT.

Both the Hα eruptive prominences showed pulse activity with a quasi-periodicity of about 2–4 min. We estimate a magnetic field in the eruptive prominence of about 100 G and a build-up rate ~ 10^{26} ergs^{-1}. The high build-up rate indicates that the shearing of the photospheric magnetic field, which fed the energy into the filament, was rapid. It is proposed that fast-moving Hα features must have initiated the observed coronal transients. From Hα, type II and coronal-transient observations, we estimate a magnetic field of 2.8 G at 1.9 $R_\odot$ from the disc centre, which agrees well with the earlier results.

Key words: Sun—eruptive prominences—mass ejection—coronal transients—magnetic field

1. Introduction

Time-lapse Hα observations of two eruptive prominences at the northeast limb of the Sun were made from the Vedhshala, Udaipur Solar Observatory on 1980 April 27, at 0231 and 0517 UT. These two eruptive prominences were associated with the Boulder active region No. 2416. Both the eruptive prominences gave rise to white-light coronal transients observed at 0241 and 0538 UT by C/P experiment of High Altitude Observatory (HAO) on the Solar Maximum Mission (SMM) satellite. The Culgoora Radio Observatory has also reported type II and moving type IV radio bursts associated with the eruptive prominence of 0231 UT.

In this paper, we present a detailed study of the development of these two eruptive prominences with a view that a comprehensive study could be made in collaboration with radio, coronal-transient and interplanetary traveling-wave observations.

2. Observations

2.1 *Eruptive Prominence at 0231 UT*

Time-lapse observations of the eruptive prominence at the northeast solar limb were made at an interval of 6 and 10 seconds in the Hα line centre, through a Halle filter of 0.5 Å passband in conjunction with a 15-cm aperture solar spar telescope. A total of 172 frames were obtained for the event. This eruptive prominence was perhaps associated with the Boulder active region No. 2416 behind the eastern limb. The observations were started at 023141 UT, when the mass ejection had already started and thus the beginning of the event was missed. This event gave rise to a coronal transient observed with C/P experiment and also type II and type IV radio bursts were recorded at Culgoora. Development of the eruptive prominence in Hα is shown in Fig. 1 and line drawings of this activity are shown in Fig. 2. The prominence motion also has a component in line of sight, but as mentioned earlier, the observations were made using a 0.5 Å passband Hα filter, so measurement for height and velocity refer to the sky plane. In the first frame of our observations at 023141 UT (Fig. 2) a huge mass A rose to a height of about 26320 km above the solar limb. At 023159 UT the top half of the feature A fragmented into small pieces as shown in Fig. 2. Within 30 s, at 023228 UT, all the small features seem to have vanished. The top of the remaining part of feature A, indicated as ‘a’ in Fig. 2, also fragmented into small pieces at 023234 UT. After about 23 s, all the small fragmented features vanished.

This eruptive prominence activity continued until 024630 UT, a total duration of about 20 min. Our time-lapse observations show various features which shot out from the prominence. Among all these features, e and f attained the highest velocity of ejection of about 770 km s^{-1}, whereas feature h attained velocity of about 540 km s^{-1}. On the other hand, features i, n and m were observed as a coronal condensation; they were showing a downward motion towards the solar surface. During the 20 min period of observations at least 4 distinct ‘pulses’ of activity took place in the underlying active region, which gave rise to four kinks in the diagram of maximum height *vs* time (Fig. 3). The beginning of these pulses appeared at 023153, 023417, 023533 and 023821 UT, thus indicating that a recurring pulse activity with a quasi-periodicity of 2–4 min was responsible for the observed repeated eruptions of the prominence material.

2.2 *Eruptive Prominence Activity at 0517 UT*

On 1980 April 27, the same Boulder active region No. 2416 again gave rise to a violent eruptive prominence activity about three hours after the first manifestation, beginning around 0517UT. The Hα filtergrams and line drawings of the development of the prominence activity are shown in Figs 4 and 5 respectively. At 051728 UT the prominence material A rose to a height of about 54100 km. Over and above the mass A, features b and c were seen at 051754 UT. The feature b vanished from the frame at 051813 UT. The feature c was seen to have expanded in size before it fragmented into a number of small pieces at 051849 UT. One of the pieces of this fragmented material, designated as c rose to a maximum height of about 27800 km with a velocity of 270 km s^{-1}, whereas another piece e moved upwards with velocity of 510 km s^{-1} and vanished at 051923 UT. The maximum height and velocity attained by various features in this

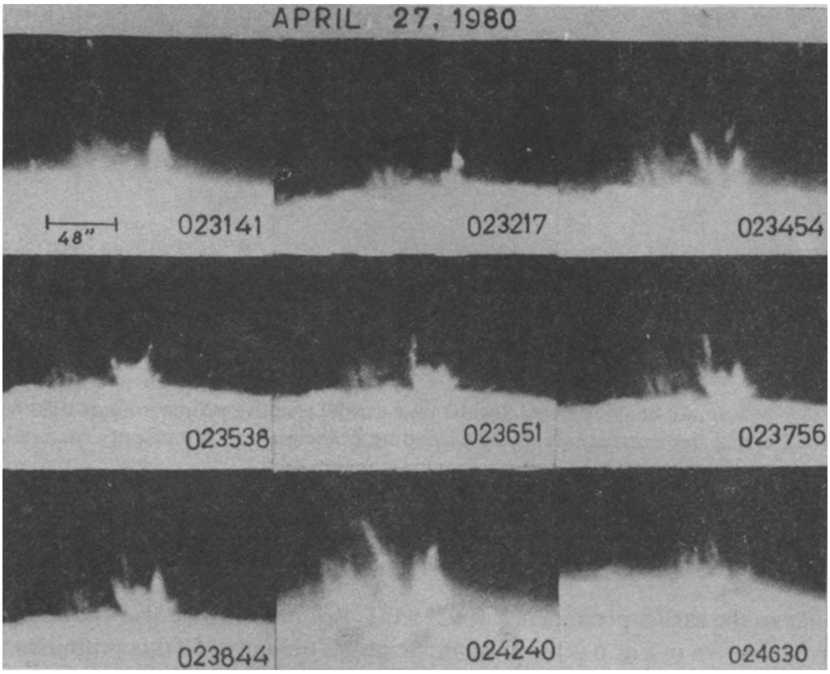

Figure 1. Sequence of Hα filtergrams, showing the development of the eruptive prominence of 1980 April 27 at 0231UT.

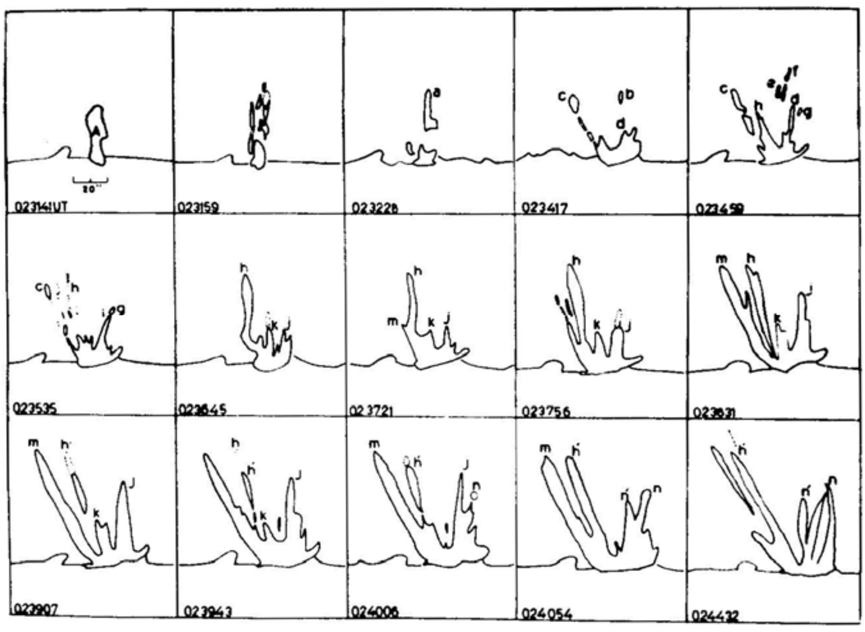

Figure 2. Line drawings of the sequence of the eruptive prominence activity of 0231 UT.

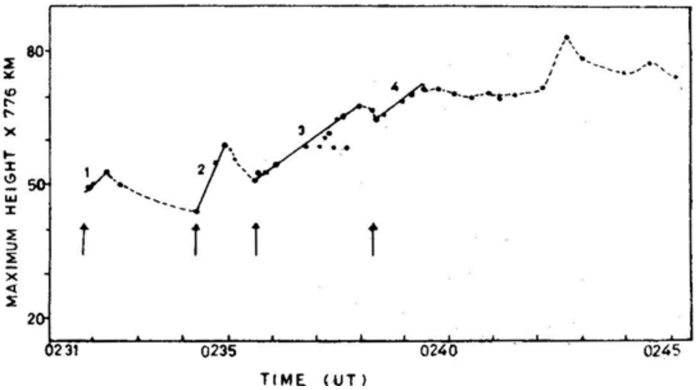

Figure 3. Maximum height plotted against time for the eruptive prominence of 1980 April 27 at 0231 UT. Solid line correponds to the ascending branch of the prominence material. Four distinct kinks are indicated.

eruptive prominence observed through the 0.5 Å passband H*α* filter are given in Table 1.

Similar to the earlier prominence at 0231 UT, this prominence also showed 'pulses' of activity. Shown in Fig. 6 is a maximum height *vs* time plot. In this prominence, five distinct pulses of activity were observed with a quasi-periodicity of 2–4 min which is similar to the earlier prominence.

3. Estimation of magnetic field and energy

The strength of the magnetic field in the eruptive prominence may be estimated from the fact that its outward acceleration increased steadily through the period of observations (Engvold, Malville & Rustad 1976). Thus the eruptive prominence material could not have been on a ballistic trajectory but must have been driven and

Table 1. Maximum height and velocity attained by different features in the prominence at 0517 UT.

Features	Maximum height 10^3 km	Velocity km s^{-1}	Remarks
c	78	270	erupted from A
e	74	510	detached from C
h	84.5	582	erupting feature from a
g	101.0	770	
f	66	910	shot out from A
t	61.5	780	shot out from A
s	48.3	145	
i	108.7	360	the tip of B; detached from it
j	62.6	220	newly rising spike in the region
k	117.5	300	rising from A

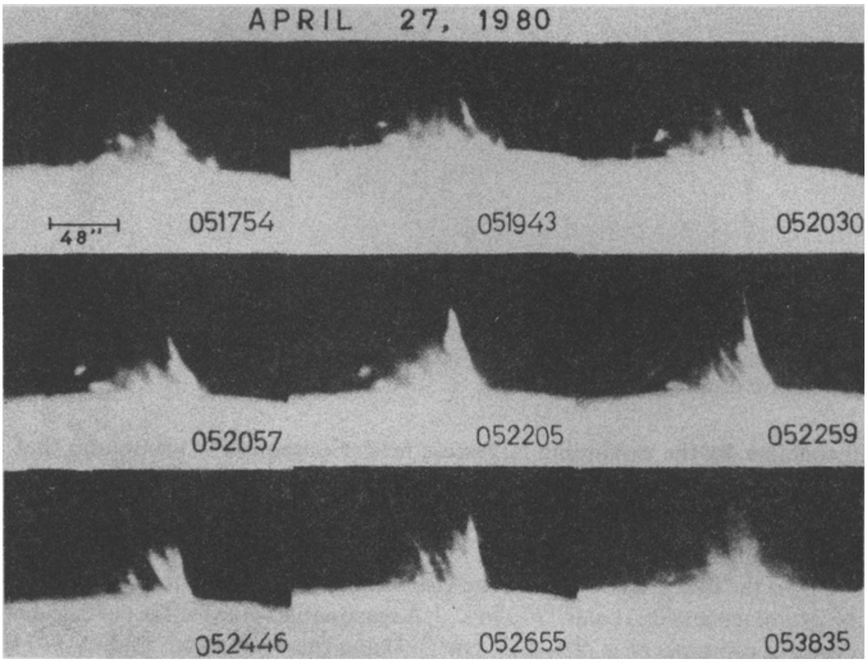

Figure 4. Sequence of Hα filtergrams of the eruptive prominence of 1980 April 27 at 0517 UT.

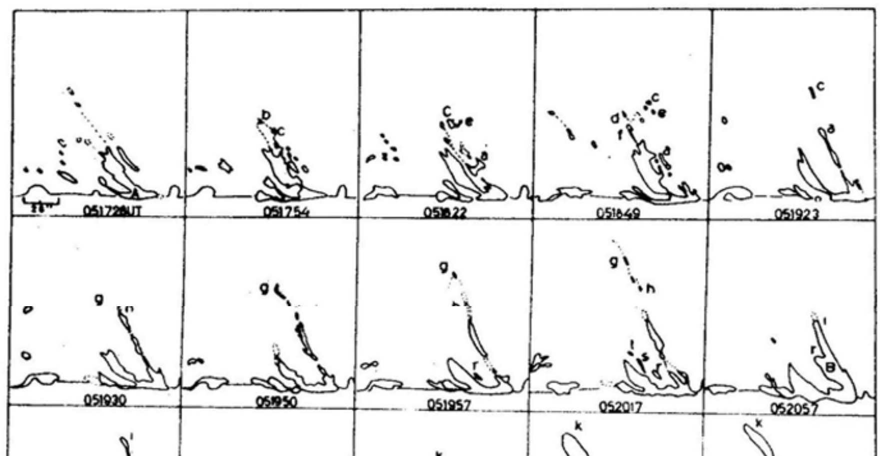

Figure 5. Line drawings of the sequence of the eruptive prominence activity of 0517 UT.

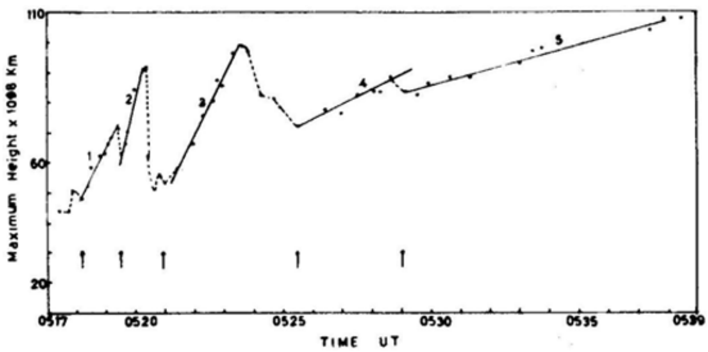

Figure 6. Maximum height plotted against time for the eruptive prominence event at 0517 UT indicating five distinct 'kinks'.

held together by the expanding largescale field. Consequently we require that

$$\frac{B_0^2}{4\pi\rho v^2} > 1 \tag{1}$$

where B_0 is the field associated with the visible material. The greatest projected velocity in the prominence at 0231 was 770 km s^{-1} . A reasonable value for the particle density in an eruptive prominence is $N = 10^{11}$ cm^{-3}. Using these values we find $B_0 > 113$ G in the prominence at 0231 UT and $B_0 > 133$ G in the prominence at 0517 UT.

The eruptive material with a velocity greater than V_{esc} cannot be contained by the magnetic field of strength ~ 100G because to control an object with velocity V_{esc} requires a magnetic field of at least 275 G (Tandberg-Hanssen 1974).

The two eruptive prominences of 1980 April 27 appear to have been similar events. We estimate the total mass (M_{prom}) of each prominence as seen in Hα from

$$M_{prom} = V_{prom}\rho \tag{2}$$

where V_{prom} is the volume of the prominence deduced from Hα line-centre data.

We determine the true height of the prominence above the limb to be 101750 km at 0533 UT. The width of the prominence is about 63000 km. Taking into account the fine structure of the prominence, we estimate its effective thickness to be about 1200 km. Thus we get $V_{prom} \simeq 7.3 \times 10^{27}$ cm^3. If the particle density $N = 10^{11}$ cm^{-3}, we get a total mass of 1.24×10^{15} gm as seen in Hα.

The initial velocity of mass ejection is 230 km s^{-1}. According to the mass estimate given above, the kinetic energy in the Hα prominence would be

$$E_{kin} = 4.5 \times 10^{29} \text{ erg}, \tag{3}$$

and the potential energy at a height 111750 km above the photosphere

$$E_{pot} = 3.8 \times 10^{29} \text{ erg}. \tag{4}$$

The fact that two similar prominences erupted in the same region, on 1980 April 27, would mean that a build up of energy of 10^{30} erg took place in a time interval of 2 h 46min ($\simeq 10^4$ s). This corresponds to an energy buildup rate

$$\frac{dE}{dt} \simeq \frac{10^{30}}{10^4} \simeq 10^{26} \text{ erg s}^{-1}. \tag{5}$$

This high build-up rate indicates that the shearing of the photospheric magnetic field which feeds the energy into the filament was fast.

4. Discussion

Munro *et al.* (1979) reported a good correlation between high-speed flare-associated Hα phenomena and mass ejections observed in white light during the Skylab mission. The flares, associated with coronal transients were accompanied by high-velocity ejections, sprays or eruptive prominences. Many coronal transients are associated with dynamic phenomena in the chromosphere which occur without flares. Over 70 per cent of all observed coronal transients are known to be associated with the eruption of solar prominences (Pneuman 1980). Thus in some Hα mass ejections, some parts can be thrown off with very high speed in various directions and can be seen in the centre of the Hα line as far as 3×10^5 km above the photosphere and much farther in the white light corona.

HAO's C/P experiment on the SMM satellite observed two white light coronal transients at 0241 and 0538 UT on 1980 April 27, which may be associated with observed Hα eruptive prominences at 0231 and 0517 UT, respectively. The coronal transients associated with the eruptive prominences at 0231 UT and at 0517 UT were at position angle 100° and 92° as reported by Research Observatory results for solar events selected for collaborative study by the Solar Maximum Year (SMY) study coordinators on 1981 August 31. The coronal transient associated with prominence at 0231 UT was a rising loop with a dark curved edge which moved with a velocity of ~ 610 km s^{-1}. In Hα, the observations of the eruptive prominence in the sky plane showed that several bits and pieces of material were moving outwards. However, many of them returned to the solar surface. On the other hand, a few pieces moved with a very high speed. In the case of prominence at 0231 UT, the feature b fragmented at 023447 UT into small bits e and f which shot out with a velocity of about 774 km s^{-1}. Similarly, in the eruptive prominence of 0517 UT many features (h, g, f & t) showed velocities ranging from 580 to 910 km s^{-1}. The velocities of these features are similar to the observed velocities of the coronal transients.

Our Hα time-lapse observations indicate that prominence material or fragments of material shot out recurrently to great heights. At least 4 and 5 distinctive 'thrusts' are clearly identified which might have taken place in the active region during the first and the second prominence respectively. We suggest that the recurrent rise of prominence material was caused by these thrusts or 'pulses' injected into the corona. These pulses showed a quasi-periodicity of 2 to 4 min.

Type II (0245–0253) and moving type IV radio bursts in metric band were observed at the Culgoora radio observatory. The optical disturbances seen in Hα moving with a very high speed and attaining greater heights (coronal transients) produce shocks which could be observed as type II radio bursts. Gosling *et al* (1975) have reported type II events in association with coronal transients and Hα mass ejections. The observed velocities of fragments of material (feature e and f) are sufficient to generate a shock which might have produced type II burst at 0245 UT. An eruptive prominence can give rise to a moving type IV burst (Robinson & MacQueen 1975). The moving type IV bursts are associated with sprays as seen in Hα and as expanding loops, arches, or bottles in the white-light corona. The observed coronal transient, in association with the prominence at 0231 UT, was an expanding loop. It seems that both type II and moving type IV radio bursts were generated by the eruptive prominence at 0231 UT. Assuming that the observed type II burst at 0245 UT in the metric band was produced by the shock generated by the eruptive prominence material e and fat 023417 UT, we estimate the velocity of shock to be about 1100 km s^{-1}. The electron density at a height 0.9 $R_\odot$ above the photosphere where the type II burst was observed by Culgoora radio observatory is estimated to be 10^8 cm^{-3}. Type II bursts are usually interpreted as originating in weak shocks, of magnetic Mach number $M \leqslant 2$ (Smerd, Sheriden & Stewart 1975). If we assume M = 1.8, we obtain an Alfvén velocity V_A = 611 km s^{-1}, which corresponds closely to the speed (610 km s^{-1}) of the rising loop observed in the associated coronal transient. This supports the results of Smerd, Sheriden & Stewart that type II bursts originate in weak shocks. Further, taking V_A = 611 km s^{-1} and N_e = 10^8 cm^{-3}, we estimate the magnetic field to be B = 2.8 G at 1.9 $R_\odot$ from disc centre, a value which falls well within the range of magnetic field strengths (1.0–10.0 G) derived from radio observations at 2.0 $R_\odot$ from the disc centre by Dulk & McLean (1978).

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