RADIO AND VISIBLE-LIGHT OBSERVATIONS OF A CORONAL ARCADE TRANSIENT

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Abstract. We discuss simultaneous visible-light and radio observations of a coronal transient that occurred on 9 April, 1980. Visible-light observations of the transient and the associated erupting prominence were available from the Coronagraph/Polarimeter carried aboard SMM, the P78–1 coronagraph, and from the Haleakala Observatory. Radio observations of the related type III–II–IV bursts were available from the Clark Lake and Culgoora Observatories. The transient was extremely complex; we suggest that an entire coronal arcade rather than just a single loop participated in the event. Type III burst sources observed at the beginning of the event were located along a nearby streamer, which was not disrupted, but was displaced by the outmoving loops. The type II burst showed large tangential motion, but unlike such sources usually do, it had no related herringbone structure. A moving type IV burst source can be associated with the most dense feature of the white-light transient.

1. Introduction

Simultaneous, spatially resolved observations of coronal transients in visible light and at radio wavelengths have been reported for about ten events. Reviews of the observations up to the beginning of the Solar Maximum Mission have been given by Dulk (1980), and Stewart (1980) among others. The observations of an event which occurred after the launch of the SMM Satellite was reported by Wagner et al. (1981). Work on other transients which occurred during SMM is in progress.

In this paper we discuss a coronal transient which occurred on April 9, 1980. The

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event was observed in Hα at the Haleakala Observatory of the University of Hawaii, in visible light by the Coronagraph/Polarimeter (C/P) experiment aboard SMM, as well as the coronagraph aboard the US Air Force P78–1 satellite, and at meter-decameter radio wavelengths by the Clark Lake and the Culgoora Radio Observatories. Although the coverage provided by any single observatory was less than complete, the observations enable us to draw some interesting conclusions regarding the event.

The transient was very complex. This is clearly shown by the white-light pictures which strongly suggest that an entire coronal arcade and not just a single loop became unstable. The event was also interesting, because it was associated with a type II radio burst. To date very few spatially resolved observations of type II bursts associated with transients have been made. The type II burst showed large tangential movement and a very low drift rate. Such bursts have been described by Weiss (1963) and have been commonly associated with herringbone structure (Stewart and Magun, 1980) which was absent, however, in this case. Finally, a moving type IV burst was observed, along with several stationary sources. The moving IV source was clearly associated with a high electron density region observed in visible light.

2. Observations

A. The eruptive prominence

Observations at Haleakala on April 9, 1980, included full disk Hα (0.5 Å) filtergrams and limb exposures with the 10-cm coronagraph which incorporates and Hα interference

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Fig. 1. (a) Tracings of the erupting prominence are shown in pairs. The tracing corresponding to the latter time in each pair is shown by the dashed line. (b) Height vs time and (c) velocity vs time diagram of the features identified in (a).
filter (FWHM = 7.5 Å). The coronagraph program was commenced at 22:25 UT with exposures made at 1 min intervals; a break in the observations occurred between 22:41 and 22:58 UT. These observations show the development of the eruptive prominence in the low corona in association with the transient. The first indication of activity was seen at 22:12 UT as a small limb brightening at PA 263°. The prominence, which had two branches, gradually extended in nearly radial direction with the bright footpoint of the northern branch being detectable against the visible disk. Observations on previous days show that the underlying chromosphere was in the forward part of a weak, decaying active region, although a small feature at the position of the brightening had become considerably enhanced on Ca-K line filtergrams one day earlier.

Figure 1a shows tracings of the prominence in pairs to indicate its growth, and identifies the measured trajectories of ejecta. The tracing corresponding to the later time in each drawing is shown by the dashed lines; it is repeated in full line in the following pair. With the exception of e and g, the trajectories shown are those of isolated features until their disappearance; e and g follow the upper boundaries of the two main portions of the prominence. Height vs time, and velocity vs time for the features identified are plotted in Figures 1b and 1c, respectively. Height is measured along the radial direction in solar radii from Sun center. Similarly, the velocity indicates a change in height with time, rather than speed along the trajectory. The error bars show the estimated accuracy of measurements for individual fragments, but the errors could be greater for prominence boundaries where material may be evaporating.

The prominence, with a chromospheric base extending from 258°–264°, consisted of two distinct parts (N and S) which we discuss separately.

The N portion was the more massive and shorter lived. The bulk rose to a maximum height approaching 1.15 \( R_\odot \) at 22:34 UT, while it also unfolded to the north with a whipplike motion, in such a way that the position of the northern boundary at the chromospheric level remained fixed. Trajectory e shows the path of a point at the top of the prominence and is representative of how most of the material moved. After 22:34 UT most of the material was seen to fall back towards the solar surface. The exception to this pattern was a protrusion identified at 22:26 UT which became detached and accelerated outwards, divided into two parts (b and e), of which c continued accelerating and reached a velocity of 400 km s\(^{-1}\) before it faded from view at a height of 1.23 \( R_\odot \) (160 000 km above the limb) at 22:33 UT.

The S portion with its base behind the limb developed more slowly, but with some initial acceleration. The trajectory g shows the path of the top of this feature. Between 22:39 UT and 22:41 UT new and distinct knots (p-t) appeared near the top and showed structural changes within 1 min intervals, as they rose in height. At the same time the rest of the material fell back to the chromosphere; the first 4 frames taken after 22:58 UT revealed a higher faint knot moving in the same general direction.

Summarizing the H\(\alpha\) observations, the interesting features of the prominence eruption have been:

1) The footpoints of the two branches remained stationary with a spread of \( \sim 6° \). The two branches of the prominence evolved differently, although the general appearance
was that of an expanding arch inclined to the plane of the sky, with footpoints in front of and behind the limb.

(2) Branch N opened upwards and outwards, then fell back, but there was at least one accelerating ejection from the top. On the other hand, branch S appeared to move almost radially; most of the material also appeared to fall back to the chromosphere.

(3) A short string of knots developed at the top of branch S in the later stages of the eruption but the observations were insufficient to follow them in detail. The few observations of a high knot indicate that some mass moving out into the corona is likely to have originated in branch S.

B. THE WHITE-LIGHT CORONA

Observations in visible light were obtained with the Coronagraph/Polarimeter carried on board the Solar Maximum Mission Satellite (MacQueen et al., 1980). The transient discussed by us was one of several events which occurred at approximately the same location. The first took place on March 26 before 00:45 UT, at which time the legs of a transient were observed on the east limb. Two transients were observed on April 9. The starting time derived for the first one was 11:48 UT. No flare was reported to have taken place at this time (Solar Geophysical Data, 1982). The first bright loop appeared at PA 265°, and was followed by an arcade of six or seven loops, stretching from PA 247° to PA 298°. Pre-existing streamers at PA 205° and 312° were displaced outward. A second transient occurred, approximately ten hours later. Although similar to the earlier event, the two events were not strictly homologous. The later transient was brighter, had a more outstanding and distinctive major wide loop and a brighter diffuse envelope. The last event of the series consisted of a white light transient which lay over a long-lasting Hα prominence. It rose high into the corona at PA 275°, at 09:47 UT on May 6. In this paper we confine our discussion to the second event of April 9, 1980.

The evolution of the transient, as observed by the C/P is shown in the sequence of Figure 2. The center of the disk is at the lower left corner, and west is indicated on the 1 $R_\odot$ circle in each picture. The last pretransient image of the corona (Figure 2a), obtained at 20:11.5 UT shows the west limb north of the site where the transient was subsequently observed to be very bright. The C/P experiment team received alerts of the erupting prominence from Sacramento Peak Observatory, and of the Hα limb brightening and meter wavelength radio event from Culgoora and responded with a ground command that reached the spacecraft at 22:33 UT, just before spacecraft sunset at 22:35 UT. The first observation of the transient was obtained during the next orbit at 23:16 UT (Figure 2b). It showed bright material extending over the range of position angles 230° to 295°, and reaching from the occulting disk at 1.5 $R_\odot$ to heights as great as 3.75 $R_\odot$. The complex structure suggests multiple loops with some similarity to the arcade of loops seen at the same position angle ten hours earlier. The multiple loops could also be observed at 23:20 and 23:39 UT (Figure 2c). At these times the loops appeared expanded and more separated. By 00:49 UT (Figure 2d), April 10 no closed loops could be seen, as the tops of the loops moved out of the field of view. The
Fig. 2. The evolution of the coronal transient as observed by the C/P aboard SMM. The images have been obtained at: (a) 20:11 UT; (b) 23:16 UT; (c) 23:39 UT; (d) 00:49 UT, April 10.

transient legs appear to be slightly curved still, however. By 02:35 UT the transient legs were very nearly radial.

Figure 3 shows an enhanced false color image of the event taken at 23:20 UT. Its festooned appearance illustrates the multiple loop character of the transient. A broad, somewhat diffuse loop appears to enclose the whole arcade. Its height/width ratio is 0.94.

The feature that stands out clearly and that can be followed to the greatest heights is an asymmetrical loop that moved out radially with apparent velocity 300 km s\(^{-1}\) (identified by the \(Y\) on Figure 3). As it expanded from 23:20 to 23:57 UT, this loop
Fig. 3. A highly enhanced image of the coronal transient as observed by the C/P at 23:20 UT. Notice the multiple loop character of the transient, as indicated by its jagged appearance. We also indicate the position of the bright blob ($X$) and the asymmetric loop ($Y$).

maintained a ratio of height (above the limb) to width in the range 2.0 to 2.3. Four other loops that could also be traced at 23:20 UT had height/width ratios ranging from 6.5 to 9.3, with average value 7.4. The other remarkable feature seen on the difference image is the enhancement slightly to the north of the asymmetrical loop, identified by the $X$. Its dimensions are approximately $0.3 \, R_\odot \,(2 \times 10^5 \, \text{km})$ along the loop, and half this value in the radial direction. The blob moved with a velocity similar to that of the other features and passed out of the field of view after 23:23 UT. It appeared to be situated within a loop, and to be related to a structure which consisted of a number of overlapping, optically thin loops. The question arises then, if the enhancement might not have been due to individual loops overlapping along the line of sight. The blob is not located at
such an intersection however, and there are no other features of similarly high brightness among the complex and seemingly overlapping structures. Consequently, we believe it to be a genuine density enhancement.

A bright streamer, located at PA 205°, south of the transient was seen to move away from it by about 0.4 $R_\odot$, an unusually large displacement. Existing coronal structures have often been seen to be pushed aside during the passage of a transient, but usually only by a fraction of this amount. During this event the corona over an entire quadrant was affected by the transient passage.

Observations of the late phase of the transient have been obtained also by the Naval Research Observatory coronagraph, flown aboard the P78–1 satellite. The field of view of the NRL coronagraph extends from $\sim 2.5 R_\odot$ to $10 R_\odot$, its angular resolution is
1.25 arc min. The operation of the coronagraph has been described by Michels et al. (1980). Figure 4 shows the NRL observations of the transient. The Sun and corona are occulted to 2.5 $R_{\odot}$, and the outer field is masked to 8.5 $R_{\odot}$. The dark annular ring is polarizing material that admits only the radial component of polarization. The figure shows a pre-event image, taken at 08:10 UT and the next image, obtained at 23:42 UT when the transient was already in progress. We recall that the C/P aboard SMM observed another transient at about 11:48 UT at the same site. In the three lower images, the pre-event image has been subtracted to show the transient clearly. While the multiple loop structure of the transient is lost on this scale, its large extent can be well appreciated, and at least two lobes filled with material can be distinguished. The bright streamer south of the transient may also be seen. Unsubtracted images show that this streamer narrowed between 08:10 and 23:42 UT, the side next to the transient being compressed. It is possible, of course, that this compression was due to the earlier transient. Evolutionary changes in streamers are frequently seen on this time scale. Later images show the compressed streamer temporarily displaced away from the transient, the displacement being greatest at 01:28 UT on 10 April, at the time when the lateral spread of the transient was greatest. Finally, it is interesting to note that at 23:42 UT a bright ray can be seen on the subtracted image at the site of the streamer. Alongside and to the south of the bright ray a dark ray has also appeared at this time. This dark ray could barely be detected 20 min earlier on the SMM C/P image. As the event progressed, the streamer grew darker; this process can be clearly seen on the subtracted images at 23:52 and 24:02 UT. The appearance of a dark feature alongside a bright one in the differenced images may be attributed to the lateral displacement of the streamer. Alternately, it is conceivable that the streamer was progressively depleated of its electron content. It did not disappear entirely, however, and was still visible at 08:22 UT on 10 April.

C. THE RADIO BURSTS

Type III, type II and moving type IV sources were associated with the transient, and were observed at the Clark Lake (CLRO) and Culgoora radio observatories. CLRO observations consisted of swept-frequency recordings with a time resolution of 1 s in the 20–110 MHz frequency range. These recordings allow us to determine the two-dimensional positions and sizes of the radio sources. Radio spectrograph, as well as heliograph observations of the late phase of the event were available from Culgoora. The spectrograph observations started after 22:30 UT, in the 8 to 8000 MHz range. Heliograph observations at 43, 80, and 160 MHz were taken after 22:45 UT, approximately. The spatial resolution of the CLRO interferometer and of the Culgoora heliograph are similar at the overlapping frequencies and the observations complement each other, allowing us for instance to detect ionospheric refraction effects and attempt to correct for them when present.

The radio event started with a group of type III bursts at 22:29 UT. This group was followed by a type II burst in the 56–30 MHz range, which lasted from about 22:36 to 22:43 UT. The Culgoora radiospectrograph started operating at 22:35 UT; it observed
the type II burst in the 55 to 25 MHz range from 22:36.5 to approximately 22:45 UT. There was no sign of harmonic structure in the type II burst, but there was a very weak second band of emission at frequencies about 10 MHz higher than the main burst. Traces of this second band may also be seen on the CLRO record, but the burst was too faint for accurate position measurements to be made. The only other activity observed on the radiospectrograph were type I noise storm bursts in the frequency range 75 to 220 MHz. This noise storm began before 22:35 UT and was still in progress after 23:35 UT.

There were only two occasions on which a definite radio source was observed by the Culgoora radioheliograph at 43 MHz. These were at 22:49 UT, immediately after observing started, and at 22:58 UT. At other times either the source was too weak to be observed, or else the level of radio interference was too high. The source brightness was \( \approx 7 \times 10^7 \) K at 22:49 UT and \( \approx 3 \times 10^7 \) K at 22:58 UT. It is not possible to determine if the source positions were affected by ionospheric refraction, but soon after 22:58 UT (23:02 to 23:08 UT) the north–south arm of the Clark Lake array measured source positions at 40 MHz which were very close to the 43 MHz Culgoora source position. The two sets of independent measurements suggest that ionospheric effects were not important at 22:58 UT, and measurements at 160 and 80 MHz by the Culgoora heliograph tend to confirm this conclusion. (Although ionospheric refraction was important at other times at 160 and 80 MHz, at 22:58 UT the observed positions were close to the corrected positions.)

The Culgoora radioheliograph did not detect 80 MHz radio sources until \( \approx 22:55 \) UT, when the Sun began to drift into the aerial beams. From 22:55 UT until \( \approx 00:00 \) UT at complex of six distinct sources were observed (Figure 5). After correcting for ionospheric effects by using the known type I noise storm source A as a reference, it was found that all these sources remained stationary in position to within a source diameter, except for one (source E) which moved outwards from \( \approx 2.4 \) to \( \approx 3.0 \) \( R_\odot \) with a projected speed \( \approx 500 \) km s\(^{-1}\). Both sources A and E were partially polarized in the RH sense (\( A \approx 50\% \), \( E \approx 30\% \)) whereas sources B, C, D, and possibly F were partially polarized in the LH sense (\( \approx 30\% \)). B increased in polarization (from \( \approx 30\% \) to \( \approx 80\% \)) during this period. It was probably also a type I source, C or D may have been type I sources because a partially LH polarized noise storm was present below C and D on the previous day. To summarize, A and B were persistent sources, most likely of type I. C and D were very intermittent and may have been type I sources also. E was a moving type IV source. The nature of source F is not clear. It appeared to be related to the 43 MHz source, but it was weak and was observed only briefly at both frequencies. Possibly, it was a moving type IV, since the 43 MHz source was observed to move with the CLRO instrument. The 80 MHz sources were not observed at CLRO, possibly because of a combination of several factors. The sources were faint, (the peak brightness temperature of all sources, except B, remained below \( 10^7 \) K) and the sensitivity of the instrument is low at this (late) time of the day. Further, the interference level is high in the neighborhood of the 80 MHz frequency range.

The early part of the transient, including the type IV moving source (if it emitted at
160 MHz), was not observed by the Culgoora radioheliograph. The 160 MHz observations are affected more strongly by gain effects than the 80 MHz observations, because the primary antenna pattern is half as wide at 160 MHz than at 80 MHz. 160 MHz sources were strongly attenuated before $\approx 23:30$ UT. The only source observed before 23:07 UT was the intense RH polarized type I source $A$. After 23:07 UT sources $B$, $C$, and $D$ were also observed. These were all partially LH polarized. As at 80 MHz, it seems likely that $B$, $C$, and $D$ were type I sources.

3. Discussion

Figure 5 shows a sketch of the prominence, some of the white light loops and the faint outer envelope of the transient at 23:16 UT. The stationary radio sources $A$, $B$, $C$, and $D$ and the moving sources $E$ and $F$ are also shown. The complexity of both the radio and the visible light sources suggest strongly that the transient is not a simple loop

![Composite sketch of the visible light features and radio sources observed during the transient. The stationary radio sources $A$, $B$, $C$, and $D$ observed at 160 and 80 MHz with the Culgoora heliograph are shown. The motion of the centroid of the type II burst at frequencies between 60–50 MHz, 50–40 MHz, and 40–30 MHz is represented by the triangles, crosses, and squares, respectively. We also show typical source sizes in the 60–50 MHz and 40–30 MHz ranges, and the position of the moving source, $E$ (at 22:52 and 23:07 UT) and $F$ observed at Culgoora and at Clark Lake. The location of the prominence on the limb (N and S), of the white-light loops, the white-light blob (at 23:16 UT), the outer edge of the transient and the streamer south of the transient are indicated. The open and full circles show the approximate location of the type III bursts which started at 44 and 55 MHz, respectively.](image-url)
oriented in the plane of the sky, but rather an arcade of loops with its axis inclined to
the north−south direction. The western footpoints of the loops appear to be located
beyond the limb. The transient event of 9 April was therefore much more complex than
the one of 7 April, which had the appearance of a single loop with its southern leg near
our source B (Wagner et al., 1981). Trottet and MacQueen (1980) studied the relation-
ship of transients and eruptive prominences and concluded that "loop-like transient
events have their origin in low-lying coronal loops over the filament, inclined only a small
angle with respect to the filament axis". An east−west orientation of the loops seen
during the present event is consistent with their observation. The erupting prominence
was inclined with respect to the heliographic north−south direction. Its southern leg was
located behind the visible limb, while the northern leg was rooted on the disk. The Hα
synoptic chart for Carrington rotation 1693 (Solar Geophysical Data, 1980) shows a
filament channel inclined some 20 degrees to the N−S direction, but twisted at the solar
equator.

Radio evidence for east−west loops is also strong. The highly polarized RH and LH
sources A and B can be explained by fundamental plasma emission. Source B may have
been located at the 80 MHz plasma level in the plane of the sky at the top of a magnetic
loop where the field direction was towards the observer, hence explaining the great
height of the source (≈2.0 R⊙) and the sense of circular polarization (≈80% LH).
There would seem to be no way of explaining such a high degree of polarization other
than by assuming that we are looking more or less directly along the field line. Source
A was located at PA 330°. It is therefore possible that it was not directly related to the
loops comprising the transient, which was confined to position angles ≤300°. It could
have been associated with active region Boulder 2372 which was very active during disk
passage. That source A and perhaps also source B (located at PA 315°) were unrelated
to the transient is supported by the fact that these were the most persistent radio sources.
On the other hand, the noise storm sources C and D appear to have been associated
with the legs of transient loops. Both were weak, and intermittent in intensity. When
the radio observations started, the top of the loops had already passed the 80 and
43 MHz plasma levels. The polarization of sources C and D may be explained if they
were located near the stretched out legs of east−west loops. Their height was about
1.6 R⊙, lower than that of source B, and close to the normal 80 MHz plasma level. Such
sources have been observed in conjunction with other loop transients (Dulk et al., 1976;
Gergely et al., 1979).

At meter wavelengths, the event started at ≈22:28.6 UT with a group of type III
bursts which ended by ≈22:32.6 UT. The times given refer to a frequency of 35 MHz.
The starting frequencies of the bursts in one group shifted from a low of ≈44 MHz to
a high of ≈54 MHz, between 22:28.6 UT and 22:30.2 UT. Similar shifts in the
starting frequencies of flares associated type III's occurring in groups have been observed
by Kane and Raoult (1981) at decimeter wavelengths. During the event discussed here
a reverse shift took place from the high starting frequency of ≈54 MHz to the initial
low of ≈44 MHz after 22:31.2 UT. Kane and Raoult (1981) interpreted the shift to
higher frequencies in terms of a downward shift of the electron acceleration-injection
region. Kosugi (1981) found that some type III groups are made up of distinct subgroups, and that the electron acceleration site for these different subgroups shifts to different locations within the flaring region. Our observations lend some support to Kosugi's finding. The type III bursts which had starting frequencies of \( \sim 44 \) MHz (before 22:30.2 UT and after 22:31.2 UT) differed in position from those which had a starting frequency of \( \sim 55 \) MHz (22:30.2–22:31.2 UT). The centroids of groups of type III bursts at 35 MHz (the highest frequency at which positions could accurately be measured for all bursts) are shown on Figure 5. Open circles indicate the position of the bursts with a starting frequency of \( \sim 55 \) MHz, closed circles show the position of the bursts starting at \( \sim 44 \) MHz. The energetic electrons which must be responsible for exciting these bursts have probably propagated along different open field lines. It is obvious from the figure that at least some of the type III's did not lie in the direction of the erupting loops, but were located in the direction of the nearby streamer which was pushed aside by the transient loops. Because of the low height of the type III sources (except for one) it is also possible that they propagated in a direction inclined to the plane of the sky, close to the line of sight. Nevertheless, we feel that the type III group must have been related to the transient source, since:

- The dynamic spectrum of the event shows a typical type III–II–IV sequence. The delay between the type III group and the type II burst is 5–6 min, a rather typical delay.
- The starting frequencies of the type III group (\( \sim 55 \) MHz, considering the highest starting frequency) and the type II burst (\( \sim 70 \) MHz) were close. In fact, the discrepancy was in all likelihood due to small differences in the intensity of the burst. The CLRO swept frequency interferometer barely detected the type II at 65 MHz, while it showed up strongly at the next lowest frequency fringe, at \( \sim 55 \) MHz. The type III burst may have been just below detection level at \( \sim 65 \) MHz, while at 55 MHz its intensity was comparable to that of the type II. Unfortunately, the Culgoora spectrograph started operating at 22:34 UT, during the period between the type III group and the type I, and therefore no comparison of the starting frequencies of the bursts could be made with this instrument.
- While the streamer centered on \( \sim PA \) 205° did not become part of the transient directly, it is clear that it was affected by it. It was displaced laterally towards the south pole about 0.4 \( R_\odot \) by the erupting loops.

The type II burst was observed with the CLRO arrays and with the Culgoora spectrograph. The time evolution of the burst is shown in Figure 5, in relation with the white light transient. The direction of motion of the centroid of the source at several frequencies is indicated by the arrows. The triangles, crosses, and squares represent the actual centroid positions in the 50–60 MHz, 40–50 MHz, and 30–40 MHz ranges, respectively. In the 50–60 MHz range, the positions shown were determined between the onset of the burst and 22:39.5 UT, at approximately half minute intervals. At 40–50 MHz the burst lasted longer, and positions were determined until \( \sim 22:41 \) UT. In the 30–40 MHz range the positions were determined at the onset of the burst and at about 22:40 UT and 22:41 UT. Typical source sizes at the 5% intensity above the noise level are also shown, at 22:37.8 UT (50–60 MHz) and 22:40.1 UT.
Fig. 6. Height-time diagram for the 9 April, 1980 coronal transient. We indicate the motion of the forerunner, as observed by the P78-1 satellite of the NRL, the motion of the white-light blob (X), the asymmetric loop (Y), and the leading edge of the material (Z) observed by the C/P. We also show the positions of the IVm source E, the initial heights of the type II in the 60–50, 50–40, and 40–30 MHz range, and the motion of the prominence material. The dashed curve shows the extrapolated trajectory of the Hα knot e, under the assumption of constant acceleration. The extrapolated trajectories of the various visible light features suggest that the transient began between 21:40 and 22:00 UT, well before the motion of the prominence started. The start of the Hα event is also indicated.

(30–40 MHz). At any given frequency, the source moved towards the disk, the lower frequencies being displaced further to the south.

The figure also shows the half power source size of the moving type IV burst at 80 MHz at 22:52 and 23:07 UT, and the bright blob observed by the C/P in visible light at 23:16 UT. For the blob we have drawn the approximate location of the 50% increase in brightness over the post-event corona at 01:24 UT. We estimate a plasma frequency of $\sim 40$ MHz at the 60% contour, and $\sim 23$ MHz at the 50% level. On the basis of Figure 5 and the height-time diagram (Figure 6) we associate the moving type IV source with the excess matter contained in the bright blob. It is unfortunate that early observations of the white light transient are missing. While the association of the radio source and the white light blob is evident, the origin of the ejecta is far from established. While a firm association may not be made on the basis of our data, it is interesting to note that if the Hα knot a continued its outward motion with constant acceleration after 22:33 UT it would have ended up close to the position where the IVm source was first seen (dashed curve on Figure 6).
Finally, we show on Figure 5 the location of the 43 MHz source $F$, observed at 22:58 UT by the Culgoora heliograph. The lines intersecting the source represent the displacement in the N–S direction of the centroid of the source at 40 MHz between 23:02 and 23:08 UT observed with the Clark Lake array. The arrow indicates the direction of the motion. The motion of sources $E$ and $F$ is reminiscent of the moving sources at 80 and 43 MHz observed by Wagner et al. (1981) in course of the earlier transient on April 7, 1980. During both events the 80 and 40 MHz sources were narrow band, and their motion appeared to be unrelated, i.e. the 80 MHz source moved nearly radially, while the 40 MHz source moved laterally, following the motion of the leg of one loop in one case, and the expansion of the arcade in the other.

The filled circles on the height-time diagram, derived from the P78–1 coronagraph observations refer to the very faint material, which may be seen to move outwards between PA 250°–260° on Figure 4. We identify this faint material as the forerunner described by Jackson and Hildner (1978) or an outer faint transient loop. It precedes the densest portion of the transient by about 1.5 $R_\odot$ and its velocity matches closely that of the other coronal features. In fact, the velocities of all visible light features are found to be very similar, approximately 500 km s$^{-1}$. Extrapolating the trajectories of the coronal features to the disk, the beginning of the disturbance is found to have occurred between 21:40 and 21:55 UT, at about the same time when the 1–8 Å X-ray flux started to rise, while the earliest Hα activity was detected at 22:12 UT. The early start of the transient, when compared to the beginning of chromospheric activity appears to be fairly common (Wagner, 1983), and quite possibly indicate that the transient is triggered high in the corona rather than by surface activity (e.g. Jackson, 1981).

We discuss now possible radiation mechanisms for the IVm source $E$. The high degree of polarization of the source ($\sim 30\%$ RH) rules out second harmonic plasma emission. This leaves the possibility of fundamental plasma or gyrosynchrotron radiation. The source was not too bright to rule out the latter. However, if the plasma frequency was $\gtrsim 40$ MHz then Razin suppression would apply. Since the white light source may have expanded and the true size of the IVm source might be smaller than the 60% contour size, it is reasonable to conclude that the plasma frequency must have exceeded 40 MHz, at the time of the 80 MHz observations. Hence we believe that the source radiated at the fundamental plasma frequency. Less information is available for the $\sim 40$ MHz IVm source. Due to its position, south of the 80 MHz source, we believe it to be a different source altogether. While no conclusive evidence is available, we suggest that the 40 MHz IVm source observed by CLRO as well as Culgoora may have been related to another loop in the southern part of the arcade (Figure 5).

4. Conclusions

We have described and discussed a coronal transient, observed in visible light and at radio wavelengths. The event was very complex; unfortunately its early evolution was missed by the coronagraphs. The transient was associated with a prominence eruption above a weak and decaying active region. Most of the ejected prominence material fell

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back into the Sun, but some of the ejecta were observed to accelerate and possibly escaped. The angular extent of the coronal disturbance was very wide compared to the prominence, which was located between PA 258°–264°, while the white light loops were observed between 230° and 295°. Further, the prominence was located near the extrapolated photospheric location of one of the legs of the central loop of the arcade. We emphasize that both the visible light and the radio evidence point to the fact that this transient may best be described geometrically as an erupting arcade of loops. This shows that a coronal transient may occur in three-dimensional forms, other than a bubble.

Activity in the corona was first observed in the form of a group of type III bursts, with low starting frequencies. While these III's were clearly related to the event, the burst sources were located along a nearby streamer, which was displaced but not disrupted by the transient. It is not clear how the energetic electrons responsible for the type III bursts, and which are likely to have been produced near the site of the prominence ejection, reached the streamer. Type III production along a streamer close to a transient in progress has been observed recently by Trottet et al. (1982). As in the case described by us, Trottet et al. noticed that type III production occurred along the streamer on the transient side but not on the other side of the streamer, which appeared to mark the boundary of the type III source region. Events like this one also show that caution must be exercised in interpreting type III sources which do not lie above the acceleration site (flare or prominence ejection) in terms of non-radial propagation.

A type II burst started before the first visible light images of the transient were obtained. The burst was characterized by large tangential source motions and a very low drift rate. The joint occurrence of low drift rates and large tangential motion in some type II bursts has been first pointed out by Weiss (1963). Further, it was noted by Stewart and Magun (1980), that such bursts often show herringbone structure as well. This was not the case for the present burst, which had a well defined low frequency edge during the first two minutes, and then became patchy but had no herringbone structure at any time. The slow drift and large tangential motion of these bursts has been attributed to a shock wave propagating transverse to open magnetic field line in the corona. Such an explanation accounts for the herringbone features by means of electrons escaping along open field lines (Stewart and Magun, 1980). While we have no simultaneous images of the type II sources and of the corona in visible light, their relative position is consistent with transverse propagation of the shock, possibly along the axis of the arcade of loops seen later in white light. Holman and Pesses (1983) recently proposed a shock drift acceleration mechanism for the origin of type II radio emission. Based on the geometry of the magnetic field and the shock they predict the circumstances under which type II bursts are expected to consist of a backbone only, or be associated with herringbone structure. They predict that only a backbone will be observed when the magnetic field is perpendicular to the electron density gradient. The type II burst observed by us did appear to propagate below the top or to the side of the loops, and appears to fit the scenario proposed by Holman and Pesses (1983).

Finally the moving type IV sources which were seen in course of the event may be
accounted for by fundamental plasma radiation. At least one of these may be identified with a dense blob observed in visible light.

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References


