A WHITE-LIGHT/Fe X/Hα CORONAL TRANSIENT
OBSERVATION TO 10 SOLAR RADII

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Abstract. Multi-telescope observations of the coronal transient of 15–16 April, 1980 provide simultaneous data from the Solar Maximum Mission Coronagraph/Polarimeter, the Solwind Coronagraph, and the new Emission Line Coronagraph of the Sacramento Peak Observatory. An eruptive prominence-associated white light transient is for the first time seen as an unusual wave or brightening in Fe X \( \lambda 6374 \) (but not in Fe XIV \( \lambda 5303 \)). Several interpretations of this fleeting enhancement are offered.

The prominence shows a slowly increasing acceleration which peaks at the time of the Fe event. The white light loop transient surrounding the prominence expands at a well-documented constant speed to 10\( R_\odot \), with an extrapolated start time at zero height coincident with the surface activity.

This loop transient exemplifies those seen above 1.7\( R_\odot \) in that leading the disturbance is a bright (\( N_e \)-enhanced) loop rather than dark. This is consistent with a report of the behavior of another eruptive event observed by Fisher and Poland (1981) which began as a density depletion in the lower corona, with a bright loop forming at greater altitudes. The top of the bright loop ultimately fades in the outer corona while slow radial growth continues in the legs.

1. Introduction

For the first time, data from three different observing facilities provide an especially complete record of a coronal transient from the surface of the Sun to 10\( R_\odot \) (from Sun center). The advantages of collaboration between different institutions in solar observations are especially evident when a comparison of data serves to verify what the individual data sets only suggest. Forbidden emission lines from million-degree material illustrate the behavior of the high temperature corona and possibly signal the passage of excitation/ionization waves. Balmer emission lines allow the tracking of cool prominence condensations. Thomson-scattered white light observations avoid the interpretive uncertainties inherent in emission line observations which necessarily involve parameters such as optical depth, temperature, ionization, or motion.

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This paper reports results of a study with these media of three aspects of the coronal transient of 15–16 April, 1980 which is associated with an eruptive prominence. First, for this rather typical white light loop transient, a careful tracking of excess mass trajectories shows constant velocity implying only small unbalanced forces on this mass. Less typical perhaps (Jackson and Hildner, 1978) is the coincidence of the start time of the outer corona white light transient (derived by an extrapolation to zero height) and the timing of the events at the surface of the Sun. Often, such a zero-height extrapolation provides the puzzling situation of the coronal loop transient starting before any Hα surface manifestations. For those transient events (unlike the present) with coronal forerunners (Jackson, 1981), this has been found to be unvaryingly true.

A second feature of this paper is the first verification of an observed coronal red line transient as truly solar in nature. Until recently, patrol cadence Fe X observations have been virtually non-existent. The frequent green emission line transients seen in λ 5303 from Fe xiv have been reviewed and classified by Dunn (1971) and Demastus et al. (1973). Such events bear little resemblance to the λ 6374 disturbance reported here, and, interestingly, have in themselves been extremely difficult to associate (Wagner and Demastus, 1977) with white light transients observed higher in the corona by the orbiting ATM coronagraph.

Finally, recent observations in the low corona of transients seen in Thomson scattering have been reported by Fisher and Poland (1981). These workers present data showing that an eruptive prominence-associated coronal transient is apparently launched from near the surface of the Sun as a density rarefaction which fills in, brightening with material above 1.7 \( R_\odot \). The analogous event we report consisted of a leading bright (density-enhanced) loop above 2.4 \( R_\odot \), as were previous events witnessed by the ATM and OSO-7 coronagraphs (see MacQueen, 1980). It is believed that this leading edge behavior (depletion/enhancement) may be an important clue providing insight into the kinematics of a coronal transient.

A brief description is given in the next Section of the observing facilities used in this study. The particular observations in Hα, forbidden visible lines, and in the visible continuum from free-electron Thomson scattering are described in Section 3. A discussion of the implications of the mutually-supportive data is offered in Section 4.

2. Instrumentation

The observations were obtained through the collaboration of one ground-based and two orbiting coronagraphs. These three coronagraphs provide overlapping coverage of the solar atmosphere from the top of the chromosphere to 10 \( R_\odot \). The Coronagraph/Polarimeter on the Solar Maximum Mission and the Solwind on the P87-1 spacecraft are externally-occluded coronagraphs using secondary electron conduction vidicon detectors. The Solwind instrument is similar to one described by Koomen et al. (1975). The Solwind data for this event covers the entire corona between 3 < \( r/R_\odot \) < 10 over most of the visible wavelength region. Polarization analysis is provided by a focal plane mosaic of concentric (transmission allowed) linear polaroid plus radial, approximately

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azimuthal, linear polaroid segments each covering about ninety degrees of position angle which form annuli at 5 and 8 \( R_\odot \).

The C/P instrument field of view encompasses more than a quadrant of the middle corona from \( 1.45 < r/\!R_\odot < 6 \) with six arc sec resolution. Wavelength discrimination is provided for this 15 April, 1980 event by a broadband (approximately 250 Å) green filter showing continuum radiation from Thomson scattering and by an H\( \alpha \) filter of 42 Å FWHA which transmits the Balmer line plus red continuum. A comparison of images through these filters confirms the presence of neutral hydrogen atoms and low temperatures which are maintained in eruptive prominence material (see House et al., 1981). Polarization analyses are permitted by use of successive data frames taken through three linear polaroids. To date, calibration has not been completed, thus precluding estimates of coronal densities. Details of the instrument are given by MacQueen et al. (1980).

The new Sacramento Peak Observatory Emission Line Coronagraph provides photographic data for this event from the low corona. With this instrument, coronal images are recorded in sequence in the emission of the \( \lambda \) 5303 line of Fe\( \text{XIV} \) and the \( \lambda \) 6374 line of Fe\( \text{X} \), as well as prominence and disk images in H\( \alpha \); the set of four exposures is repeated at one-minute intervals. The basic optical system consists of a 20-cm aperture, \( f/11 \) aspheric singlet objective and four secondary optical systems corresponding to each image channel (Smartt et al., 1981). Interference filters and a specially-designed Lyot birefringent filter isolate spectral bands of approximately 1 Å at the three wavelengths. The efficiency of this filtering and special construction features result in an exceptionally small amount of scattered light reaching the film plane. Coronal images can be recorded in skies some 2.5 times brighter than is typical for earlier designs of emission-line coronagraphs. Full-limb fields of view extend from 0.01 < \( r/\!R_\odot < 1.60 \).

3. The Observations

3.1. H\( \alpha \) Emission

A moderate-size prominence (50 000 km height) at latitude N 28 was seen to rotate onto the northeast limb, with a classical, but low, helmet streamer lying over it in the corona. This was only a mildly active prominence characterized by typical complex filamentary structure. About 21:30 UT on 15 April, 1980, the H\( \alpha \) limb record from the SPO coronagraph shows increased activity at the southern extremity of the prominence. A slowly accelerating eruption was observed from 21:20 to 21:50 UT as shown by images reproduced in Figure 1. Peak acceleration was noted in the period 21:55 to 22:12 UT. The maximum rate of propagation of the prominence material away from the solar surface, a slightly non-radial direction, is approximately 190 km s\(^{-1}\), a value in the middle range of prominence eruption velocities. The H\( \alpha \) material faded from view against the sky brightness at about 1.35\( \!R_\odot \) at 22:32 UT. The general form of the prominence was loop-like, a small central gap becoming more evident as the eruption
developed. As recorded by this coronagraph, the eruption consisted of a tangential spreading of the southern edge of the prominence in addition to the radial expansion.

3.2. CORONAL LINE EMISSION

Apparently as a direct result of the performance quality of the SPO Emission Line Coronagraph, some very faint short-lived enhancements have been identified on the coronal images that differ from those previously described in the literature. Caution is of course required in identifying all such faint features as necessarily of coronal origin, since scattering from airborne particulate matter can be recorded by such an extraordinarily sensitive device. However, where there is a close spatial and temporal association between such features and some limb event such as that considered here, the probability of their being non-coronal must be regarded as extremely small. Those enhancements identified (in a large data base) are usually recorded only in the red line image channel, and are characterized by having a short duration, less than two minutes.

Well after the start of the prominence eruption, and after many data frames showing moderately bright but static Fe X red emission line coronal structure, a single λ 6374 frame taken at 22:05:35 UT shows a very unusual phenomenon. As reproduced in Figure 2, a bright enhancement appeared with its highest point, at about 100 000 km above the limb, coinciding in position angle with the erupting northern segment of the prominence which is below the λ 6374 enhancement boundary. The original negative image is faint and has been electronically subtracted from the previous λ 6374 frame with the result displayed in Figure 3. A notable characteristic is the sharp outer boundary, with the suggestion of a double edge. Even more faint, and not evident in this figure, is a radial extension of the enhancement that reaches to about 400 000 km, with the ends appearing to loop back slightly towards the disk. The length of this red line transient is 500 000 km. Difference images were made of preceding and following frames in the λ 6374 channel, but no evidence of this phenomenon was seen either one minute before or one minute after 22:05 UT, although extremely subtle changes are evident. A series of difference frames was also checked in the green emission line λ 5303 data, but no similar transient nor, in fact, any evidence of temporal changes were found. This
Fig. 2. Green and red line images near the time of maximum acceleration of the eruptive prominence. The fleeting λ 6374 transient is just visible as a bright enhancement at 22:05 UT (bottom, center frame), extending about 40 degrees in position angle. No corresponding changes are seen in the λ 5303 images.
Fig. 3. A difference print of the red-line transient created by a video digitizer subtracting \( \lambda \) 6374 frames taken at 22:04 and 22:05 UT. Enhanced intensity at 22:05 UT is shown in white. Solar north is up. The eruptive prominence lay under the highest point of the northern portion of the enhancement.

disturbance in the emission from coronal ions was limited to a single data frame in only one stage of ionization, Fe X.

The validity of this image as having coronal origin rests heavily on the other bodies of evidence developed in this paper. This frame was recorded at 22:05 UT, coinciding in time within a few seconds with a type III U-burst recorded both at Culgoora (CSIRO) and at Fort Davis (HCO). No other U-bursts were seen by these observatories within
one day of this one. Since radio source position information is not available (the CSIRO radioheliograph was not operative at that hour), the origin of the radio event coinciding with the location of the red line enhancement cannot be established with certainty. The Fe X event occurred during the period of peak acceleration of the prominence, however, and (see below) at the extrapolated start time for the white light transient. None of the authors are aware of any previous report of so fleeting an event, limited to so narrow a range of ionization stages. This indeed may represent also the first observation (see Smartt et al., 1981) of an Fe X coronal transient.

3.3. Electron-scattered radiation

The first evidence in the SMM C/P record of unusual limb activity appeared at 23:07 UT when a green continuum filter image showed a full bright coronal loop transient. This transient and its development are shown in Figure 4. The loop extended across and beyond the boundaries of the helmet streamer which is apparently being destroyed.

![C/P White Light](image)

**Fig. 4.** Green continuum images of the transient in the middle corona. The C/P occulting disk radius is 1.45 \( R_\odot \). At 23:07 UT, the complete bright loop is seen with the underlying eruptive prominence (still neutral hydrogen at this time). Later, at 00:40 UT, the top of the white light loop has faded.

Behind the complete loop, which is bright because of an excess of entrained free electrons, a cavity, defined by much lower density, follows. This is more evident as a dark region in Figure 5 which displays differenced C/P images. In this cavity is found the eruptive prominence itself, with a slightly extended 'halo' of excess electrons. The prominence has disappeared by 01:30 UT of 16 April; no Balmer radiation is observed.
above $r/R_\odot = 3$. As the white light loop proceeds outward, it appears to open near the top of the loop (note the difference images from 23:43 and 00:40 UT). What remains are two bright legs which continue to expand and fade. Striated radial structure (loop transient legs) remains visible and recognizable as transient remnants until about 05:00 UT April 16. Note also in the difference images of Figure 5 that, for the first C/P observation, no coronal depletion leads the white light loop transient.

**C/P WL DIFFERENCES**

![C/P WL DIFFERENCES](image)

Fig. 5. Green continuum images formed by subtracting pre-event frames from event frames. Two different pre-event frames were required as bases due to changes in selected C/P sector mirror position during the event. Excess mass appears white; mass deficits dark. Note that no density rarefaction leads the bright excess mass loop transient here above 2.4$R_\odot$.

The Solwind coronagraph first observes the transient in continuum scattering at 00:33 on 16 April, when the highest portion of the transient has reached $R_\odot = 4$. Figure 6 shows data where in the upper row are direct reproductions of the images while in the second row are differences of the direct images from one obtained as 21:11 UT on 15 April. In these difference images, excess mass is shown in white. In the Solwind data the transient also shows an open top and more resembles two growing lags or pincers (Figure 7). Its visibility decreases as it crosses the interface between the orthogonal polaroid segments in the field of view.
SOLWIND WL

DIRECT

DIFFERENCE FROM 15 APR 2111

0033  0151  0648  0824  1000

16 APR 1980

Fig. 6. Continuum images of the white-light transient in the outer corona. The edge of the field of view of the Solwind coronagraph is 10R⊙. Direct images are shown (top), as well as subtracted images (below). Excess mass appears white.

4. Discussion

A height-time plot for the transient is shown in Figure 8. The highest points of two features are tracked in this diagram: the coronal material in the white light transient and the cool dense eruptive prominence. These features were easily distinguishable through the advantage of small amounts of continuum being included in the Hα filter passband. Data from the ground-based coronagraph are combined with those from the orbiting coronagraphs. Note the smooth blending of Solwind and C/P data from 1.8 to 6R⊙ which allows the fit of a line representing a constant speed of 257 km s⁻¹ to the white light transient observations. Some confusion exists for the far field points at 06:48 and 08:24 UT. The best analysis suggests that the front of the white-light transient has exited the Solwind field of view by these times and one only observes a trailing cloud which was the former prominence. If this thesis is correct, the prominence would have been traveling at about 205 km s⁻¹. In any case, for the well-documented trajectory of the white-light transient, there is no evidence for acceleration or deceleration.
Fig. 7. A collection of filtergrams showing the transient in the forbidden emission line (top, left), with the underlying eruptive prominence seen in Hα (top, right), to the same scale. Later, at different scales, the Thomson scattering from the density-enhanced transient appears in the data sets from the orbiting coronagraphs (bottom, left and right); and in Hα (from the C/P coronagraph) (bottom, center).

For better resolution of the height-time behavior and, especially, to inspect the timing of the lower coronal events, the scale of this diagram is expanded in Figure 9. The dots signify the trajectory of the fastest moving parts of the prominence. A hatched bar is drawn at the time and spanning the observed height of the λ 6374 transient. The dashed line represents an extrapolation of the progress (at 257 km s⁻¹) of the white light transient from outer corona data back to zero height. Note that other workers (see Jackson, 1981) suggest a height of origin of the white light loop transient above the chromosphere for other well-studied events. A picture allowing the coronal transient to be launched from a height above the chromosphere, but simultaneous in time with an event such as a flare or prominence eruption, avoids the postulation of deceleration in the inner corona of a white light transient initiated at the flare site. Such deceleration is rarely, if ever, observed. For the 15–16 April, 1980 event, if an elevated launch height is assumed, it would not be great because good agreement is obtained between a transient start time from the chromosphere at 22:04 UT and the appearance of the
fleeting $\lambda$ 6374 transient at 22:05:35 UT. This simultaneity of white light and forbidden line transient is one of the stronger pieces of evidence for the origin of the red line phenomena as solar. Unexplained is the fact that prominence activity began still earlier (at 21:20 UT), albeit maximum acceleration occurred only at the time of the white light/Fe X events.

Fisher and Poland (1981) have recently reported an observation of an eruptive-prominence associated coronal transient made with the new Mk III K-coronameter at the Mauna Loa Observatory. In the Mauna Loa event, a dark cavity or void is the earliest manifestation of the transient, and was visible as it rose from 1.4 to 1.7 $R_\odot$. Beyond 1.7 $R_\odot$, a bright loop slowly formed above the cavity. The C/P instrument with a field of view only down to 1.5 $R_\odot$ has to date only observed bright-loop-first transients, although for eruptive events, a dark void is enclosed behind the bright loop (House et al., 1981). In the event of 15–16 April, 1980, that we report, the loop first appeared at 2.4 $R_\odot$, as bright and continuous across the top. This work and that of Fisher and Poland (1981) indicate that there may be a basic difference for an eruptive prominence-associated coronal transient in its appearance in the inner versus outer corona.

Analyzing the $\lambda$6374 transient is difficult. It is seen only in Fe X and not Fe XIV; and it is fleeting. Let us first consider implications for a disturbance seen to extend from
Fig. 9. A magnified height-time plot of the initiating events of the coronal transient. An extrapolation of the white light transient trajectory from Figure 8 (dashed line) matches the occurrence of the FeX enhancement and the period of maximum acceleration (applied external force imbalance) of the erupting prominence. Significant prominence instability was detected as early as 21:35 UT.

the limb to 100,000 km for no more than 60 s (time between FeX exposures). The propagation speed implied for such an excitation wave would be 1670 km s⁻¹. Such a speed is high, but not unreported, at least for phenomenon such as shocks exciting type II radio bursts (Maxwell and Dryer, 1981). For the present event, however, no type II was detected at the Sun and the other optically-observed velocities are far lower.

The action of high energy electrons cannot be discounted, perhaps generated in the re-organization of the local magnetic field during the prominence eruption. The type III U-burst demonstrates that one such energetic population was present within seconds of the red line enhancement.

Another possibility which may explain the brief appearance of the FeX transient is that the phenomenon was only seen as the locus of interaction between a much slower disturbance and its surroundings. That is, an overhanging canopy of magnetic field or enhanced electron density brightened in situ when struck by the disturbance which travelled through the cavity. Such a suspended obstruction might represent the interior 'walls' of a prominence cavity.

The FeX exposure was made only 47 s after the FeXIV frame. If the emission line transient is observed only in the red line data, coronal temperatures must have been between 1.0–1.9 x 10⁶ K. The energy density of the disturbance may have been insufficient to ionize a coronal volume which was originally cool (the prominence cavity) beyond FeX stages.
One additional way to explain the transient being seen only in the red line data is to postulate that in fact only temporarily enhanced continuum radiation, not line emission, exists. The $\lambda$ 6374 channel operates in a mode which is closer to showing continuum than the green. That is, the equivalent width of the red line is generally observed to be somewhat less than that of the green and the filter bandpass is 1.5 times larger at $\lambda$ 6374 than at $\lambda$ 5303, or, the emission line 'signal' to Thomson continuum 'noise' is less for $\lambda$ 6374. This argument would imply that the white light coronal transient observed high in the corona by the C/P and Solwind was also recorded in Thomson scattering at the surface of the Sun by the SPO coronagraph. Credibility is lent to this argument by the fact that the typical green emission line transient reported by Dunn (1971) and DeMastus et al. (1973) resembles very little the appearance or behavior of the present $\lambda$ 6374 disturbance. In any individual data frame during the $\lambda$ 5303 transients nothing is ever visible which does not resemble normal stationary coronal structure. The Fe\textsc{x} transient of 15 April, 1980 more resembles a smooth wave.

Conversely, such an eruptive prominence-associated transient in the low corona, if it is continuum, according to Fisher and Poland (1981) would show a density rarefaction not an enhancement. Moreover, the integrated white light intensity, if represented by the intensity of the 6374 Å enhancement, for a 1.4 Å passband, would be exceedingly more intense than typical K-corona features. Yet such features have not been reported from K-coronameter observations.

5. Conclusions

An especially complete observing record of an eruptive prominence-associated coronal transient has been constructed allowing three principal conclusions to be inferred. First, there indeed is a class of transients which is well-timed with respect to their coincidence with solar surface activity. For this event of 15–16 April, 1980, a detailed height-time plot shows constant velocity of the loop transient to the outer edge of the Solwind coronagraph field of view, 10 $R_\odot$. An extrapolation earlier in time indicates an initiation of the coronal transient at the chromosphere simultaneous with the period of maximum acceleration (unbalanced force) on the erupting prominence. Such simultaneity, it should be stressed, of transient departure and chromospheric event is rare.

Further, we report a unique Fe\textsc{x} $\lambda$ 6374 enhancement, strikingly dissimilar to the well-known Fe\textsc{xiv} disturbances, which was recorded coincident with the extrapolated launch time of the white light transient, the prominence eruption, and a metric radio U-burst. The fleeting appearance of this forbidden coronal emission line feature may imply a very high speed ($1670 \text{ km s}^{-1}$) excitation wave, an illumination \textit{in situ} of thin walls of a prominence cavity by a slower excitation pulse. An even faster high energy electron excitation could have resulted from magnetic field changes with the prominence eruption. There remains the possibility that the $\lambda$ 6374 channel was 'leaking' a sharp increase in electron-scattered continuum, and hence recording the initiation of the outer corona white light transient.

Finally, this report should stand in contrast to a recent observation by Fisher and
Poland (1981) of the behavior of a white light transient in the corona below $1.7 R_\odot$. Both associated with eruptive prominences and both apparently signalling the local conditions they meet, the inner corona transient shows a leading electron depletion while the present transient above $2.4 R_\odot$ indicates the opposite – a bright loop of excess mass.

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