CORONAL CHANGES ASSOCIATED WITH
A DISAPPEARING FILAMENT

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Abstract. This paper describes Skylab/ATM observations of the events associated with a disappearing filament near the center of the solar disk on January 18, 1974. As the filament disappeared, the nearby coronal plasma was heated to a temperature in excess of \(6 \times 10^6\) K. A change in the pattern of coronal emission occurred during the 1½ hr period that the soft X-ray flux was increasing. This change seemed to consist of the formation and apparent expansion of a loop-like coronal structure which remained visible until its passage around the west limb several days later. The time history of the X-ray and microwave radio flux displayed the well-known gradual-rise-and-fall (GRF) signature, suggesting that this January 18 event may have properties characteristic of a wide class of X-ray and radio events.

In pursuit of this idea, we examined other spatially-resolved Skylab/ATM observations of long-duration X-ray events to see what characteristics they may have in common. Nineteen similar long-lived SOLRAD X-ray events having either the GRF or ‘post-burst’ radio classification occurred during the nine-month Skylab mission. Sixteen of these occurred during HAO/ATM coronograph observations, and 7 of these 16 events occurred during observations with both the NRL/ATM slitless spectrograph and the MSFC-A/ATM X-ray telescope. The tabulation of these events suggests that all long-lived SOLRAD X-ray bursts involve transients in the outer corona and that at least two-thirds of the bursts involve either the eruption or major activation of a prominence. Also, these observations indicate that long-lived SOLRAD events are characterized by the appearance of new loops of emission in the lower corona during the declining phase of the X-ray emission. However, sometimes these loops disappear after the X-ray event (like the post-flare loops associated with a ‘sporadic coronal condensation’), and sometimes the loops remain indefinitely (like the emission from a ‘permanent coronal condensation’).

1. Introduction

The original purpose of this paper was simply to describe Skylab/ATM observations of the events associated with a disappearing filament near the center of the solar disk.

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Since disappearing filaments usually correspond to eruptive prominences when seen at the solar limb (Tandberg-Hanssen, 1974), we felt that this would complement the more frequent limb observations made with coronagraphs. In particular, we hoped that this description would help to clarify the way in which the disturbances in the outer corona and interplanetary medium (Gosling et al., 1974) are generated.

However, subsequent study has produced the unexpected bonus that this event is apparently not isolated, but instead is characteristic of a wide class of long-duration X-ray and microwave events. Now it seems that the Skylab/ATM observations of this and other long-duration events may help to clarify our understanding of flares as well as coronal transients, as will be discussed within the text.

In this study we shall describe the disappearing filament event of January 18, 1974 using XUV spectroheliograms, X-ray filterheliograms, Hα spectroheliograms, and photospheric magnetograms. The XUV spectroheliograms were obtained with the Naval Research Laboratory's Skylab/ATM instrument, S-082A. The X-ray filterheliograms were obtained with the joint NASA Marshall Space Flight Center and Aerospace Corporation Skylab/ATM instrument, S-056. Descriptions of these instruments and the ATM observing programs have been given by Reeves et al. (1972), Tousey et al. (1973), and Underwood et al. (1975). The Hα spectroheliograms were

![Figure 1](image-url)  
Fig. 1. A sequence of Fe 284 Å spectroheliograms (negative prints) showing the evolution of the F81 region on January 16–19, 1974. (In this and all subsequent figures, solar north is up and west is to the right.)
obtained from the ground-based patrol telescopes of the National Oceanic and Atmospheric Administration (NOAA) and the Air Weather Service (AWS). The photospheric magnetograms were obtained at the Kitt Peak National Observatory, and supplied by courtesy of J. W. Harvey and W. C. Livingston.

2. The Observations

The time-lapse sequence of Fe xv 284 Å spectroheliograms in Figure 1 shows that a spatial change occurred in the lower corona between 1407 UT on January 18, 1974 and 1146 UT on January 19, 1974. (In this paper, all Skylab/ATM photographs are displayed as negative prints with solar north up and east to the left.) In particular, by January 19 a loop-like configuration of emission had become visible for the first time, apparently arching across the sinuous emission feature that was conspicuous near the center of the field of view during January 16–18. (The sinuous emission feature is indicated by an arrow on the Januray 17 spectroheliogram. For definiteness, we shall refer to this feature as feature 1.)

As the loop-like configuration of coronal emission developed, the region of locally-reduced coronal emission west of feature 1 contracted into a narrow channel. The

![Fig. 2. A sequence of KPNO magnetograms showing the evolution of the photospheric magnet fields in the F81 region during January 15–19. Lighter-than-average features correspond to posit line-of-sight polarity (directed toward the observer), and darker-than-average features correspond negative polarity. (The positive field in the umbra of a large sunspot appears black due to a saturation of the magnetogram display system in the strong field of the umbra.)](https://example.com/fig2.png)
comparison between the January 19 Fe xv spectroheliograms in Figure 1 and the January 19 photospheric magnetogram in Figure 2 shows that this channel falls within a large area of predominantly negative (black) magnetic polarity separating two large areas of positive (white) polarity. In fact, the Fe xv channel tends to divide the region of negative polarity in half. Apparently the Fe xv channel shows the parting of the coronal magnetic field lines as they extend from the negative region of the photosphere on their way to the two different positive regions nearby.

Also, a comparison between the Fe xv spectroheliograms in Figure 1 and the corresponding magnetograms in Figure 2 indicates that feature 1 is located along the magnetic neutral line separating the large region of negative polarity from the positive region to its east. This observation, together with the fact that feature 1 is relatively intense, leads us to suppose that this feature consists of an unresolved arcade of low-lying loops joining elements of opposite magnetic polarity along the neutral line.

Finally, the magnetograms in Figure 2 do not show the emergence of new magnetic flux through the photosphere in this area during the time that the loop-like coronal structure was forming. (Instead, the sequence of magnetograms shows the decay of a small sunspot of positive polarity on the eastern edge of this neutral line during the January 15–19 period.) Thus, the January 18 event seems to be different from the familiar development of coronal emission associated with the emergence of a new bipolar magnetic region (Sheeley et al., 1975a, b).

![H-Alpha Images](image_url)

**Fig. 3.** A sequence of Hα spectroheliograms showing the general development of the F81 region during January 16–18, and the detailed changes in F81 on January 18.
The time-lapse sequence of Hα filtergrams in Figure 3 shows that the reconfiguration and eruption of a filament accompanied the changes in the lower corona. On January 16 and 17, an Hα filament (F81) is visible winding around the west side of a small sunspot and extending northward. This filament lies along the same neutral line that we have already associated with feature 1. For this reason, feature 1 and the southern segment of F81 tend to have the same shape and location. However, the Hα filament extends approximately 200,000 km farther to the north where it bends to the east and extends for another 200,000 km in the shape of a large 'number 7'.

On January 18, the northern segment of F81 erupted. Figure 3 shows that by 1632 UT the north-south and east-west segments had become disconnected, and by 1801 UT the north-south segment was bent westward toward a newly-emerging flux region in the northern hemisphere. By 1823 UT most of the filament was Doppler-shifted out of the Hα line center, and was strongly visible as far as 1 Å into the wings of the line. At 1920 UT the only remaining evidence of the Hα filament occurred at 0.9 Å to the violet of line center. Minutes later, the filament had disappeared completely.

We shall see in Figure 4 that the entire filament was visible in the He II 304 Å chromospheric image at 1852 UT as a curved absorption feature arching to the north-west, despite the fact that most of the filament was no longer visible in Hα. Apparently the unrestricted bandpass of the S-082A slitless spectrograph allowed us to observe the filament against the disk as it was in the process of erupting.

Figure 4 contains a time-lapse sequence of 6–22 Å X-ray filterheliograms which show the development of the new coronal structure during the period 1837–2015 UT. Figure 4 includes an Fe xv 284 Å spectroheliogram and a He II 304 Å spectroheliogram taken simultaneously at 1852 UT during the rising phase of the soft X-ray emission and within 2 min of the X-ray filterheliogram at 1854 UT. Although the coronal structure was the most intense feature on the Sun in soft X-rays, it was not even as intense as nearby active regions in Fe xv. At 1852 UT the only evidence of any activity in He II was the erupting filament visible in absorption against the disk.

Applying filter-ratio techniques to the S-056 observations, we obtained a temperature of \((6\pm 1)\times10^6\) K for the intense coronal structure. This is consistent with its faintness in the Fe xv and Fe xvi XUV images which suggests a temperature of at least \(6\times10^6\) K (Jordan, 1969). This temperature is also consistent with the fact that the coronal structure is not visible in any of the very high temperature XUV lines such as Fe xxiv 192, 255 Å which require \(15\sim20\times10^6\) K for their formation (Widing and Cheng, 1974). Finally, we mention that the new coronal structure was not visible either at 1852 UT in any of the other lines of the shortwave portion of the NRL S-082A XUV spectrum or during 1907–1918 UT in representative coronal, transition-region, and chromospheric lines of the HCO S-055 EUV spectrum (Schmahl, 1975).

Presumably the relatively great intensity of this coronal feature in the 6–22 Å region results from a combination of line and continuum emission at a temperature in the \((6\sim10)\times10^6\) K range which is not covered by lines in the S-082A XUV spectrum. The 6–22 Å spectral region does contain the resonance lines of ions such as Si xiii (6.7 Å) and Mg xii (8.4 Å) which have their maximum abundance at \(9\times10^6\) K, as well as
prominent lines of O viii, Mg xi, and Fe xvii which have their temperature of maximum abundance at approximately $5 \times 10^6$ K (Silk et al., 1975). Furthermore, according to Tucker and Koren (1971) and to Walker (1975), at a temperature in excess of $5 \times 10^6$ K, the effect of radiative recombination as well as thermal bremsstrahlung should produce an enhancement of the soft X-ray continuum relative to the XUV (300 Å) continuum. However, Silk et al. (1975) estimate that for temperatures 'characteristic of the decay phase of flares', the contribution from the continuum is less than 15% in the 6–22 Å region.

A straightforward measurement of the X-ray photographs in Figure 4 gave $(7 \pm 1)$ km s$^{-1}$ as the speed at which the western boundary of the new coronal structure moved westward (relative to the active region to its east) during the 1837–1908 UT period
that the X-ray flux was increasing. A corresponding measurement gave an equal value of (7 ± 1) km s⁻¹ as the speed with which the eastern boundary of emission moved eastward (relative to the same active region) during the same time period. These motions are consistent with an interpretation of this event as the formation and apparent outward expansion (at 7 km s⁻¹) of an arcade of coronal emission over feature 1.

This interpretation is consistent with the observations in Figure 5 which shows the soft X-ray development of the event from 1418 UT on January 18 to 1156 UT on January 19. (The filterheliogram at 2150 UT on January 18 is not strictly comparable with the three other filterheliograms because it was obtained with a longer exposure time through a filter having a different passband (6–16 Å).) This figure shows that the hot coronal feature was still visible at 2150 UT on January 18, more than two hours after both the Hz filament had disappeared and the X-ray flux had reached maximum. In Figures 4 and 5 it is difficult to characterize the detailed spatial structure of the X-ray feature prior to 0120 UT on January 19 because its great intensity had overexposed the film. However, Figure 5 shows that by 0120 UT the X-ray intensity had decreased sufficiently that one can recognize the fainter pattern of emission that developed into the loop-like structure visible in the X-ray and Fe xv photographs later on that day. Furthermore, this comparison of the X-ray images at 2150 UT on January 18 and 0120 UT on January 19 shows that the apparent increase in the size of the emission feature during the X-ray sequence in Figure 4 is a real spatial change, and is not the result of over-exposure due to the increasing brightness of this feature.

14:18 JAN 18, 1974  (6-22Å)  21:50 JAN 18

Fig. 5. A sequence of 6–22 Å filterheliograms illustrating changes in the X-ray corona during the period 1418 UT January 18 – 1156 UT January 19.
Fig. 6. The time history of the integrated solar flux in the soft X-ray and microwave-radio spectral bands illustrating the gradual-rise-and-fall (GRF) signature of this disappearing filament event. The traces shown are from the Skylab X-ray event analyzer 6.1–20 Å and 2.5–7.25 Å bands, the SOLRAD-9 8–20 Å and 1–8 Å bands, and the combined Ottawa-Penticton 10-cm radio emission. For each curve, dashes indicate intervals for which X-ray flux observations were not obtained, either because the respective satellite was in the Earth’s shadow, or because Skylab was not configured for ATM observations. Note that the XREA fluxes are given in counts cm\(^{-2}\) s\(^{-1}\), whereas the SOLRAD fluxes are given in erg cm\(^{-2}\) s\(^{-1}\). Although each of these curves seems to reach its maximum sometime in the unobserved interval near 1950 UT, the high-energy fluxes begin their decline sooner than the low-energy fluxes.

Figure 6 shows the soft X-ray and microwave solar flux as a function of time during the January 18, 1974 disappearing filament event. Such flux observations have been studied for many years, and have been called long-duration X-ray events (Kreplin et al., 1962; Teske, 1971) and gradual-rise-and-fall (GRF) radio bursts (Covington, 1959; Kundu, 1965), respectively. Thus, we might expect to increase our understanding of the January 18, 1974 event both by comparison with previous studies of such flux
observations, and by comparison with ATM observations of similar events that may have occurred during the nine-month Skylab mission. The next section of this paper describes the results of both of these comparisons.

3. Discussion

It was a simple matter to determine systematically all of the major, long-duration X-ray events that occurred during the Skylab mission using the SOLRAD X-ray flux data published in the NOAA Comprehensive Reports of Solar-Geophysical Data. Of course, this excluded some weak events which were visible in spatially-resolved ATM X-ray observations. We included SOLRAD events whose durations were at least comparable to the $4\frac{1}{2}$ hr duration of the January 18, 1974 event. With one exception (September 15), we excluded SOLRAD events that were complicated by the presence of simultaneous or near-simultaneous events. (The September 15 event followed an earlier X-ray event by only 30 min, but we retained it in our list because originally we thought that the ATM observations of this event provided a unique and puzzling counter example worthy of special consideration. However, this special consideration has subsequently revealed that the ATM observations of this event do not provide a counter example, but are consistent with the observations of the other events to be described here.)

**TABLE I**

<table>
<thead>
<tr>
<th>Date</th>
<th>Start</th>
<th>Max.</th>
<th>End</th>
<th>$\Delta T_R$</th>
<th>$\Delta T_P$</th>
<th>HAO report</th>
<th>NOAA report</th>
</tr>
</thead>
<tbody>
<tr>
<td>161</td>
<td>June 10</td>
<td>0830</td>
<td>0920</td>
<td>1500</td>
<td>0:50</td>
<td>5:40 ($3 R, 80^\circ$) 0929</td>
<td>Eruptive prominence (EP) (20°N, 90°E) 0815–0900</td>
</tr>
<tr>
<td>170</td>
<td>June 19</td>
<td>2300</td>
<td>0100*</td>
<td>0630*</td>
<td>2:00</td>
<td>5:30 ($3 R, 270^\circ$) 2357</td>
<td>No observations (clouds)</td>
</tr>
<tr>
<td>183</td>
<td>July 2</td>
<td>1300</td>
<td>1420</td>
<td>2000</td>
<td>1:20</td>
<td>5:40 ($2 R, 250^\circ$) 1341</td>
<td>EP 1245</td>
</tr>
<tr>
<td>210</td>
<td>July 29</td>
<td>1320</td>
<td>1340</td>
<td>1600*</td>
<td>0:20 ~27:00</td>
<td>($\sim 6 R$, 90°) Faint 1632, (previous obs. 0619)</td>
<td>M-7 flare (12°N, 43°E) 1312 following disappearing filament</td>
</tr>
<tr>
<td>225</td>
<td>Aug 13</td>
<td>1800</td>
<td>2120</td>
<td>0600*</td>
<td>3:20</td>
<td>8:40 ($3.5 R, 260^\circ$) 2137</td>
<td>EP (25°S, 90°W) 1740</td>
</tr>
<tr>
<td>233</td>
<td>Aug 21</td>
<td>1350</td>
<td>1450</td>
<td>1950</td>
<td>1:00</td>
<td>5:00 ($2.5 R, 50^\circ$) 1441</td>
<td>EP (13°N, 90°E) 1319</td>
</tr>
<tr>
<td>250</td>
<td>Sept 7</td>
<td>1140</td>
<td>1210</td>
<td>2100</td>
<td>0:30</td>
<td>8:50 Chaos (210°–310°) 1306</td>
<td>X-1 classic double ribbon flare with filament activation (18°S, 46°W) 1130</td>
</tr>
<tr>
<td>254</td>
<td>Sept 11</td>
<td>1750</td>
<td>1940</td>
<td>0400*</td>
<td>1:50</td>
<td>8:20 ($2 R, 300^\circ$) 1744</td>
<td>'Active prominence' (28°N, 90°W) 1540–2017</td>
</tr>
</tbody>
</table>

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Table I (continued)

<table>
<thead>
<tr>
<th>Date</th>
<th>Start</th>
<th>Max.</th>
<th>End</th>
<th>$\Delta T_R$</th>
<th>$\Delta T_F$</th>
<th>HAO report</th>
<th>NOAA report</th>
</tr>
</thead>
<tbody>
<tr>
<td>258</td>
<td>Sept 15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2350</td>
<td>0130*</td>
<td>0530*</td>
<td>1:40</td>
<td>4:00 1. Streamer re-arrangement of east limb, 2, (2.5 R, 270°) 0139*</td>
<td>'Active prom.' (30°S, 90°E) 0133–0405 (19°S, 90°W) 0158–0400</td>
</tr>
<tr>
<td>268</td>
<td>Sept 25</td>
<td>0010</td>
<td>0120</td>
<td>0500</td>
<td>1:10</td>
<td>3:40 1N flare (29°N, 73°E) 0034–0132 following filament-prominence</td>
<td>activation at 2340</td>
</tr>
<tr>
<td>293</td>
<td>Oct 20</td>
<td>1820</td>
<td>2230</td>
<td>0600*</td>
<td>3:50</td>
<td>7:30 (4.0 R, 90°) 0054* Previous obs. 1359</td>
<td>Prominence activity (09°S, 90°E) starting 1740</td>
</tr>
<tr>
<td>302</td>
<td>Oct 29&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0040</td>
<td>0120</td>
<td>0900</td>
<td>0:40</td>
<td>7:40 No transient</td>
<td>No disappearing filament</td>
</tr>
<tr>
<td>303</td>
<td>Oct 30</td>
<td>1430</td>
<td>1510</td>
<td>2200</td>
<td>0:40</td>
<td>6:50 1'-N' flare (16°S, 33°W) 1443, 0142*</td>
<td>X-ray flare 16°S, 17°W 0140&lt;sup&gt;e&lt;/sup&gt; ('-N' flare at 16°S, 17°W) 0445</td>
</tr>
<tr>
<td>307</td>
<td>Nov 3</td>
<td>0010</td>
<td>0030</td>
<td>1300</td>
<td>0:20</td>
<td>12:30 Chaos (270°) 0107</td>
<td>X-1 flare 13°S, 82°W 0014–0100, post flare loops 0014–0255</td>
</tr>
<tr>
<td>017</td>
<td>Jan 17&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1900</td>
<td>2000</td>
<td>2400</td>
<td>1:00</td>
<td>4:00 (2.0–2.5 R, 280°) 01943</td>
<td>EP (07°N, 90°W) 1925–1945</td>
</tr>
<tr>
<td>018</td>
<td>Jan 18</td>
<td>1830</td>
<td>1950</td>
<td>2300</td>
<td>1:20</td>
<td>3:10 No transient</td>
<td>'F' flare (17°S, 12°E) 1903 following disappearing filament</td>
</tr>
</tbody>
</table>

NOTES TO TABLE I

- From NOAA Solar-Geophysical Data (Comprehensive Reports) and the Scientific Data Analysis Guide for the HAO/ATM Coronagraph Experiment as reported by Ross (1975).
- This GRF event occurred at (10°N, 70°E), but was complicated by another event at 260° on the west limb. The event at the west limb reached its maximum phase at 2200 UT. Also, Rust (1975) reports a filament eruption at (08°S, 54°E) at 2200 UT.
- There is doubt about the identification of this event as a SOLRAD GRF event because during the fall phase the flux decreased to approximately the pre-event level in only one hour. Following this sudden decrease, 8 additional hours were required to reach the pre-event level.
- A relatively weak SOLRAD event, but apparently a relatively energetic S-082A event.
- Private communication of ASE/ATM S-054 observations by Rust (1975).
- Indicates the following day.

The result was a list of 19 events, 16 of which occurred during the operation of the HAO/ATM coronograph. (The 3 events that were not observed occurred on July 23, November 4, and November 6, 1973.) These 16 events are described in Table I. Seven of these 16 events occurred during operation of both the NRL/ATM slitless spectrograph and the MSFC-A/ATM X-ray telescope. Although the X-ray observations have not yet been reduced to tabular form, the XUV observations are described in Table II.
### TABLE II

S-082A coverage of 7 events in Table I

<table>
<thead>
<tr>
<th>Event Date</th>
<th>Time Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 13 (225)</td>
<td>1800 – 2120 – 0600*</td>
<td>Loops at west limb in coronal lines. ‘Knots’ of emission at the loop tops of the higher temperature coronal lines (e.g., Fe xvi)</td>
</tr>
<tr>
<td>2016–2045</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0050–0051*</td>
<td></td>
<td>Loops at west limb in chromospheric, transition region and coronal lines</td>
</tr>
<tr>
<td>1314–1356*</td>
<td></td>
<td>Loops at west limb have ‘expanded’ and are ‘faint’, present in transition region and chromospheric lines, but not coronal lines</td>
</tr>
<tr>
<td>August 21 (233)</td>
<td>1350 – 1450 – 1950</td>
<td></td>
</tr>
<tr>
<td>1313</td>
<td></td>
<td>Fe xv silhouette of prominence at east limb</td>
</tr>
<tr>
<td>1442–1533</td>
<td></td>
<td>He II eruptive prominence at east limb, Fe xv silhouette gone; Fe xv, xvi loops developing</td>
</tr>
<tr>
<td>1615–1658</td>
<td></td>
<td>He II prominence gone, but Fe xv, xvi loops bright</td>
</tr>
<tr>
<td>1835</td>
<td></td>
<td>Loops now present in transition region lines</td>
</tr>
<tr>
<td>September 7 (250)</td>
<td>1140 – 1210 – 2100</td>
<td></td>
</tr>
<tr>
<td>1221–1311</td>
<td></td>
<td>Loops visible in transition region and coronal lines, including Fe xxiii, xxiv. Classic 2-ribbon flare in He ii at (18°S, 46°W). Fe xv, xvi ‘filament activity’ in southeast part of region</td>
</tr>
<tr>
<td>1402</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1848</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0046*</td>
<td></td>
<td>Characteristic behavior of post flare loops, including ‘expansion’ of the loops</td>
</tr>
<tr>
<td>September 11 (254)</td>
<td>– 12 (255) 1750 – 1940 – 0400*</td>
<td></td>
</tr>
<tr>
<td>0108–0109*</td>
<td></td>
<td>Loops at northwest limb in coronal, transition region and chromospheric lines</td>
</tr>
<tr>
<td>September 15 (258)</td>
<td>– 16 (259) 2350 – 0130* – 0530*</td>
<td></td>
</tr>
<tr>
<td>0129–0130*</td>
<td></td>
<td>Loop configuration at (10°N, 70°E) in coronal lines, especially Fe xv, Fe xvi. Some loops also visible in Mg ix and Ne vii</td>
</tr>
<tr>
<td>January 17, 1974</td>
<td>1900 – 2000 – 2400</td>
<td></td>
</tr>
<tr>
<td>1945–2010</td>
<td></td>
<td>Eruptive prominence at west limb in chromospheric and transition region lines</td>
</tr>
<tr>
<td>2046</td>
<td></td>
<td>He II prominence still visible</td>
</tr>
<tr>
<td>January 18</td>
<td>1830 – 1950 – 2300</td>
<td></td>
</tr>
<tr>
<td>1405–1407</td>
<td></td>
<td>Fe xv spatial structure beginning to change at (17°S, 12°E)</td>
</tr>
<tr>
<td>1852–1854</td>
<td></td>
<td>Spatial change of Fe xv, xvi corona in progress at (17°S, 12°E), but no significant enhancement of intensity (S-056 X-ray intensity of this region now brightest on disk). Erupting filament visible against disk in He ii 304 Å</td>
</tr>
<tr>
<td>1146*</td>
<td></td>
<td>‘Permanent’ loop-like structure now visible in Fe xv, xvi</td>
</tr>
</tbody>
</table>

* Indicates the following day.
The first 4 columns of Table I give the date (day of year), and the universal time for which the SOLRAD intensity began to rise, reached maximum, and returned to the pre-event level, respectively. Since the SOLRAD coverage was periodically interrupted for intervals of approximately 30 min due to the satellite's passage into the Earth's shadow, the times quoted here are sometimes guesses based on an interpolation of the data. When the satellite was not in the Earth's shadow, the times are eye-estimates, accurate to \( \pm 10 \) min. Although it may be possible to measure these times more precisely, we think that the present estimates are sufficient for the exploratory purposes of this paper.

Columns 5 and 6 give the rise time \( (\Delta T_R) \), and fall time \( (\Delta T_F) \), respectively, for each event. These times were obtained by comparing the numbers given in columns 2, 3, and 4. Columns 7 and 8 summarize the HAO coronagraph observations and the solar activity record (either obtained directly from the NOAA Solar-Geophysical Data Comprehensive Reports or indirectly from the HAO Data Analysis Guide (Ross, 1975)). In column 7 the numbers in parenthesis are the ploar coordinates of the observed coronal transient, where the azimuthal angle is measured from north toward east. The 4-digit numbers outside the parenthesis are the universal times that the observations were made.

Table I is presented to show that long-duration SOLRAD events seem to be accompanied by coronal transients, and to permit the reader to compare these results with his own observations. Column 7 shows that coronal transients were observed for 13 of the 16 SOLRAD events, and a comparison between columns 7 and 8 shows that the three remaining events (October 29, 1973 (16°S, 17°W), October 30, 1973 (17°S, 34°W), and January 18, 1974 (17°S, 12°E)) occurred much closer to the center of the disk than the other 13 events. Only 2 of these 13 events originated appreciably inside the limb, and these were the flares of July 29 (M-7 at (12°N, 43°E)) and September 7 (X-1 at (18°S, 46°W)). Thus, it appears that coronal transients may also have occurred on October 29, 30, and January 18, but that they did not produce effects that were visible beyond the occulting disk of the HAO/ATM coronagraph. It is interesting that the January 18, 1974 event described in this paper was one of these 3 events.

Next we consider the distribution of rise times and fall times of the events in Table I. Column 6 indicates that all of the remaining events have fall times greater than the 3 hr 10 min fall time of the January 18 event, and in this sense they are indeed long-duration events. Column 5 indicates that 5 events have rise times outside the interval (40 min–2 hr). Three of these 5 events have rise times of 30 min or less, and correspond to the major flares of July 29 (M-7), September 7 (X-1), and November 3 (X-1). An impulsive burst of hard X-rays and microwave radio emission usually occurs during the rising phase of such major, long-duration events, and for this reason these events are usually distinguished from gradual-rise-and-fall (GRF) events by the special radio classification of 'post-burst increases' (Covington, 1959; Kundu, 1965). This distinction is not made in Table I because the selection of events did not involve an examination of the rising phase of the SOLRAD flux with high time resolution. Furthermore, it is not clear that such a distinction is physically meaningful since weak impulsive
bursts could well accompany GRF events but be undetectable without sufficient sensitivity and spatial resolution.

The remaining two events have rise times of 3 hr and 20 min (August 13) and 3 hr and 50 min (October 20). We can think of two possible effects, either of which might have produced the relatively large rise times of these two events. First, the large rise times may correspond to the gradual appearance of coronal emission associated with the emergence of new bipolar magnetic flux in these regions. (These events occurred at or behind the solar limb so that associated magnetic field observations were unavailable. However, the comparison of magnetograms obtained during both the preceding and following disk passages of these respective regions indicates that, in each case, a major new bipolar magnetic region had emerged while its fields were unobservable either at or behind the limb.) Second, the actual rise phase of these two events may have been obscured by the solar limb, so that the long rising phase of the SOLRAD observations may indicate emission from ‘post event loops’ as they expand into view above the limb during the actual falling phase of the event.

S082A observations were obtained during at least some phase of 7 of the 16 SOLRAD events listed in Table I. Table II is an abbreviated summary of these observations. The 7 events are listed in chronological order with the SOLRAD ‘start’, ‘max’, and ‘end’ times included for reference. The numbers listed under each event are the universal times for which S082A spectroheliograms were obtained. The descriptions listed opposite these times summarize the general appearance of spectroheliograms obtained in lines of the 150–630 Å XUV spectrum. We refer to ‘coronal’ lines (e.g., Fe xv 284 Å, Fe xvi 335, 361 Å), ‘transition region’ lines (e.g., Ne vii 465 Å), and ‘chromospheric’ lines (e.g., He ii 304 Å). Of course, this is an oversimplification because there are lines which fall between these categories, such as Mg ix 368 Å which could be regarded as either a low-temperature coronal line or a high-temperature transition region line.

Table II suggests that during long-duration SOLRAD events the visibility of sharply-defined loops of emission begins initially in the high-temperature lines of the corona (e.g., Fe xvi 335, 361 Å), and subsequently passes to progressively lower-temperature lines of the transition region (e.g., Ne vii 465 Å) and chromosphere (e.g., He ii 304 Å) as the hot plasma cools. Observations were obtained during the falling phase of 4 of the 7 events in Table II, and all 4 of these events (August 13 and 21, September 7 and 11) indicate the formation of loops in the transition-region and chromospheric lines. Furthermore, observations of the August 13, August 21, and September 15–16 events indicate that such loops become visible first in the relatively high-temperature coronal lines (e.g., Fe xvi 335, 361 Å).

These sharply-defined XUV loops resemble the transient Hz and Fe xiv 5303 Å loops that seem to follow major chromospheric flares in complex sunspot groups (Dodson, 1966; Jefferies and Orrall, 1961, 1964; Bruzek, 1964; Zirin, 1966). In contrast, the loop-like coronal structure that formed during the January 18, 1974 event had the diffuse appearance characteristic of a ‘permanent coronal condensation’. Although only a minor Hz subflare was reported in association with the January 18,
1974 event ('-- F', Solar-Geophysical Data, 1974; Zirin, 1975), we do not know whether the XUV analogue of post flare loops appeared during the falling phase of the X-ray flux because no S-082A observations were obtained during this period. This leads us to wonder whether possible differences between the January 18 loops and the classic post flare loops may be simply a matter of degree, determined, for example, by the strength of the associated magnetic field. This raises the additional question of whether or not events which occur outside the sunspot belts such as the classic dispersion brusque of a quiescent filament or the possibly related X-ray enhancement accompanying the disappearance of a filament cavity (Vaiana et al., 1974) are limiting cases of this process when very weak fields are involved.

Tables I and II indicate that prominences (filaments) erupted during the initial phase of 8 of the 15 events for which chromospheric observations were obtained. Also, some kind of prominence activity was reported during 4 of the remaining 7 events. One of the remaining 3 events (November 3) involved an X-1 flare with post flare loops so that major filament activity may well have occurred but may not have been reported. No filament activity was reported for the remaining two events (October 29 and 30, 1973). Eventually, we hope to learn whether the few apparent exceptions reflect insufficient observations or the fact that major prominence activity did not occur for these events.

Previous studies of GRF events are consistent with the ATM observations. Kreplin et al. (1962) reported a rising limb prominence in association with a long-duration X-ray event having the GRF signature. Like many others, this limb event was not accompanied by a visible Hα flare. Bell (1972) has reported enhanced microwave radio emission at 2.2 cm and 10.7 cm from a limb prominence whose eruption on February 8, 1972 apparently produced the coronal transient (and associated microwave GRF) described by Tousey and Koomen (1972a, b) and Tousey (1973). This event also showed the GRF signature in the SOLRAD X-ray data, although it was somewhat blended with the decreasing emission from a prior event. Recently, Covington (1974) has described a major microwave GRF event associated with a disappearing Hα filament. However, in this case, an enhancement of Hα chromospheric emission to flare intensity accompanied the filament disappearance. In a study of thermal radiation from the corona, Newkirk (1961) found that the microwave emission from a GRF event may be interpreted as thermal radiation from a dense, hot, loop-prominence region. More recently, Teske (1971) has described major systems of loop prominences which appear during the fall-phase of long-duration soft X-ray events. In a study of X-rays from OSO-4, Krieger et al. (1972) described 'long-enduring brightenings' whose properties are similar to those of a GRF event. In particular, using certain assumptions, they estimate $7 \times 10^6 \text{K}$ for the peak temperature of a typical long-enduring X-ray event.

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References

Gosling, J. T., Hildner, E., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: 1974, J. Geophys. Res. 79, 4581.


