OPTICAL AND RADIO OBSERVATIONS OF THE 1980 MARCH 29, APRIL 30, AND JUNE 7 FLARES

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Received 1980 August 18; accepted 1980 December 1

ABSTRACT

Ground-based solar observations are analyzed for three of the flares discussed in the accompanying Solar Maximum Mission reports. The principal conclusions are that Hα begins to brighten several minutes before the impulsive, hard X-ray bursts, that the preflare heating and impulsive phases of the three flares occurred in loop-shaped structures of about 3500 km semidiameter, and that after the impulsive phase a much larger volume (~200 times) of flare plasma was present for the flare main phase. Evidence is presented for the escape 100-500 keV electrons into the larger volume and into the corona during the impulsive phase. For the April 30 flare, the inferred origin of the hard X-ray burst is near the feet of the magnetic loops.

Subject headings: Sun: flares — Sun: radio radiation

I. INTRODUCTION

Solar flares are transient phenomena affecting many layers of the Sun's atmosphere. Interpretation of the physical phenomena taking place requires optical and radio data on the ambient magnetic fields, the low-temperature chromosphere, and accelerated electron beams, in addition to the data provided by the Solar Maximum Mission (SMM) instruments. Table 1 shows the National Oceanic and Atmospheric Administration's GOES 1-8 X-ray classifications and optical and radio indices of the events discussed in the accompanying Letters by the SMM experimenters. The table shows that, even though the SMM events were powerful producers of hard X-rays, the events were relatively small in soft X-rays and Hα area. Other important characteristics emerge from analysis of high-resolution Hα and radio data.

II. INSTRUMENTATION

The four observatories of the US Air Weather Service Solar Observing Optical Network (SOON) provide full-disk Hα patrol and large-scale, high-resolution data for nearly 24 hr each day (Bailey and Starr 1980). The large-scale images frequently yield 1" resolution. A distinctive feature of each SOON installation is the video brightness analyzer which records Hα light curves for up to 15 separate solar regions. Preliminary results from the video brightness analyzer have already shown that Hα emission begins ~5 minutes before the impulsive phase of small flares (Rust et al. 1980). Flares discussed in the present Letter follow the same pattern.

Other data used in this Letter were obtained by the Hvar Observatory (Ambroz et al. 1977), the Culgoora Radioheliograph (Labrum 1972), the Nançay Radioheliograph Group (1977, 1981), the Zurich Radio Observatory (Perrenoud 1980), and the Owens Valley Radio Observatory (Zirin, Hurford, and Marsh 1978).

III. OBSERVATIONS

a) The Flare of 1980 March 29

Despite the fact that the 1980 March 29 hard X-ray burst was the largest single spike burst ever reported (Dennis, Frost, and Orwig 1981), the Hα flare area was so small that no flare patrol stations reported it. Images obtained at the Hvar and SOON observatories show that the event was one of a series of subflares associated with the emergence of a negative-polarity sunspot on the edge of a cluster of large
positive-polarity (leader) spots. The Hα pictures at 0918 UT show two intensely bright kernels connected by a faint loop (A in Fig. 1 [Pl. L15]) of ~3500 km semidiameter. The flare kernels are 2000 km in diameter and appear on either side of the boundary between the growing negative spot and the adjacent positive fields. One would conclude that the flare took place entirely in the loop connecting the old and new fields, except that an unusual diffuse brightening occurred 10,000 km to the NW of the flare loop. The loop was fading from 0919 UT and vanished by 0926 UT. The diffuse patch brightened NW of the flare loop. The loop was fading from 0919 UT and vanished by 0926 UT. The diffuse patch brightened NW of the flare loop. The loop was fading from 0919 UT and vanished by 0926 UT.

The 1980 April 30 flare (Plate L4) at 2017 UT was the last of a series of eight similar small flares ranging in X-ray peak intensity from C3 to M2 (3–20 × 10^22 ergs cm^{-2} s^{-1} in the 1–8 Å band). The flares occurred in AR 2396, which was decaying until late on April 27, when a group of new sunspots with positive magnetic fields grew rapidly on the NW edge of a large negative spot. All the flares occurred near the new magnetic fields. Comparison of the April 30 flare with the earlier flares suggests that it may have had two bright chromospheric foot points that could not be resolved so near the limb. The above-limb Hα emission came from an overlying loop or loops, possibly part of an arch filament system (Bruzek 1967) at the site of the new fields.

The film shows continuous preflare activity at the limb. A bright Hα mound coincides with the mound seen in C IV (Woodgate et al. 1981). At 2017 UT, the GOES soft X-ray monitors and the Hα mound brightness showed gradual increases, which continued until 2018:30 UT, when the rate of soft X-ray emission increased abruptly. Thus, the Hα and soft X-ray enhancements began ~4 minutes before the hard X-ray burst (curves [d] and [e] in Plate L3) at 2022 UT.

At 2020 UT, the bright Hα mound was rising at ~40 km s^{-1}. Then, at 2022 UT, it accelerated to ~100 km s^{-1}, rising to a point 17,000 km above the limb, where a bright knot appeared at the loop top (see Plate L4). At 2023 UT, the knot broke into smaller knots and threads of material stretching out to ~20,000 km beyond the initial knot. There was little further expansion after 2024 UT. In summary, the Hα loop expanded most rapidly during the impulsive rise in

### TABLE 1

<table>
<thead>
<tr>
<th>Date</th>
<th>Max (UT)</th>
<th>Active Region</th>
<th>Position</th>
<th>1-8 Å Peak</th>
<th>Hα Class.</th>
<th>Metric Bursts</th>
<th>SMM Refs</th>
</tr>
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<tbody>
<tr>
<td>March 29</td>
<td>0918</td>
<td>2363</td>
<td>N26 E43</td>
<td>C9</td>
<td>−B</td>
<td>III, V</td>
<td>2, 3, 7, 9</td>
</tr>
<tr>
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<td>0915.5</td>
<td>2357</td>
<td>N07 W10</td>
<td>M1</td>
<td>−B</td>
<td>III, V</td>
<td>9</td>
</tr>
<tr>
<td>April 7</td>
<td>0910.5</td>
<td>2372</td>
<td>N10 E03</td>
<td>M4</td>
<td>1B</td>
<td>I, III, IV</td>
<td>5</td>
</tr>
<tr>
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<td>0940</td>
<td>2372</td>
<td>N12 E01</td>
<td>M8</td>
<td>1B</td>
<td>III, IV</td>
<td>3</td>
</tr>
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<td>0922</td>
<td>2372</td>
<td>N12 W42</td>
<td>M4</td>
<td>1N</td>
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<td>6</td>
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<tr>
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<td>0926</td>
<td>2396</td>
<td>S13 W90</td>
<td>M2</td>
<td>−N</td>
<td>none</td>
<td>1, 3, 4, 6, 8</td>
</tr>
<tr>
<td>June 7</td>
<td>0313</td>
<td>2495</td>
<td>N14 W70</td>
<td>M7</td>
<td>1B</td>
<td>II, III, V</td>
<td>8, 10</td>
</tr>
</tbody>
</table>

*a Numbered by the Space Environment Laboratory, Boulder, Colorado.

b Most of the GOES-recorded emission at 0540 UT probably originated in a simultaneous flare in another active region.

Fig. 1.—Hydrogen alpha photograph of a loop-shaped subflare (A) on 1980 March 29 at 0920 UT. A diffuse patch (B) reached peak brightness 3 minutes later. Each leg of the L placed on the photograph for orientation corresponds to 36,000 km on the Sun (Hvar Observatory).

Rust et al. (see page L180)
Fig. 2.—Analog recording of the decimetric radio emissions from the 1980 March 29 subflare. The frequency range is 100-1000 MHz (top to bottom). Labels indicate where preflare DCIM and type III bursts occur and the impulsive phase type III bursts. The solid black curve shows the 26-139 keV X-ray burst (linear scale, intensity increases downward). Type V metric emission and 500-800 MHz decimetric continuum follow the impulsive phase burst (Zurich Radio Observatory and Goddard Space Flight Center data).

Rust et al. (see page L180)
Microwave observations of the April 30 flare were obtained at the Owens Valley solar interferometer. The time profile of 10.6 GHz emission (Fig. 3) shows a gradual flux increase starting at about 2017:30 UT. Since signals from discrete sources add vectorially to give the interferometer signal shown in Figure 3, the flux change at 2020:30 UT may indicate an increase in emission from a nearby source. The total power at 10.6 GHz actually increased between 2020 and 2022 UT. Then, the impulsive burst began; it peaked at 2022:48 UT, simultaneously with the first hard X-ray burst. A second burst, at 2023:40 UT, had a slower rise time, the opposite sense of circular polarization, and a position 2000 km west of the first burst. The 27.3 spacing of the Owens Valley interferometer fringes places the burst sources either just at the limb or ~20,000 km above it.

The postburst microwave emission (peak at 2030 UT) was unpolarized and characteristic of a thermal plasma. The emission curve (Fig. 3) closely resembles the 3.5–8 keV emission (curve [f] on Plate L3) from an extensive tongue above the limb (van Beek et al. 1981).

Postflare Hα observations showed a faint cloud above the flaring region, but it is impossible to resolve structure in the cloud for comparison with the C IV spectroheliograms that show postflare loops.

c) The Flare of 1980 June 7

The June 7 event (Chupp et al. 1981; Orwig, Frost, and Dennis 1981) was the largest of three M-class X-ray events from AR 2495, which appeared on the disk on June 4. AR 2495 grew rapidly on June 5, but appeared to be decaying when the June 7 flare oc-

![Figure 3](https://example.com/figure3.png)

**Fig. 3.**—Right circular (+) and left circular (−) emission at 10.6 GHz during the 1980 April 30 limb flare. The phase data indicate the relative east-west position of the centroid of the emission (Owens Valley Radio Observatory).
curred. The flare started at 0310 UT, according to the GOES 1–8 Å flare monitor. Because of the close proximity of the region to the limb, the Hα flare and the underlying magnetic fields were poorly observed. However, the Culgoora videotape record of the flare shows that Hα emission commenced at 0311 UT with a rapid increase from 0311:45 to 0313 UT, when the flare covered the umbra of a small spot containing fields of both polarities. At 0312:56 a surge erupted from the flaring area.

Hard X-ray emission commenced at 0311:50 UT and peaked at 0312:37 UT. Type III metric bursts occurred from 0310 UT to 0316 UT with a type V continuum at 0312–0325 UT. As in the March 29 flare, the hard X-ray peak was preceded by the decimetric radio peak. The decimetric emission was similar to that on March 29: spike bursts just before the hard X-ray peak and gradual-rise-and-fall continuum for about 3 minutes afterward. The June 7 flare was the more energetic, evidently, since the hard X-ray emission continued for 13 minutes, and there was a type II metric radio burst (0316–0335 UT).

The June 7 flare was similar to the March 29 and April 30 flares in that thermal emissions (Hα and soft X-ray) commenced a gradual climb prior to hard X-ray burst, and there is some evidence in the decimetric continuum and in the Hα images that the volume of the flaring region increased greatly at the peak of the impulsive phase. Although the Hα flare area was small (∼10⁻⁴ solar hemisphere), the hard X-ray emission peak count rate was extraordinarily high. Also, this was one of the strongest gamma-ray events in 5 months of SMM observations.

IV. DISCUSSION

We have compared familiar Hα and radio-band flare phenomena with UV and X-ray observations obtained by SMM. On April 30 the C iv emission features were generally similar to Hα features, especially during the preflare (2005–2015) and gradual rise (2017–2020) intervals. The description of the C iv mound as a rising loop is consistent with Hα observations of arch filament systems (Bruezk 1967). The growth rate of the C iv loop is in agreement with the expansion rate of the Hα loop (limb flare), but unfortunately the UVSP detector was shut down before the most rapid Hα growth, at 2022–2024 UT. No UVSP data are available for the other two flares we studied.

In each of the flares, an Hα loop brightened about 2 minutes before the hard X-ray burst. We infer that such gradual heating of the flaring structures may be a necessary prerequisite for impulsive acceleration of electrons to several hundreds of keV. Our results are consistent with the flare-trigger model of Heyvaerts, Priest, and Rust (1977).

Sudden upward acceleration of an Hα loop in the April 30 flare coincided in time with the hard X-ray burst. Rapid expansion of an Hα loop certainly implies that the magnetic field entraining the emitting material is unstable. The fact that the loop expanded most rapidly at the precise time of the hard X-ray burst indicates that changing fields within the loop are accelerating the electrons responsible for the X-ray and microwave bursts. Being guided by the temporal similarity between the second radio burst (Fig. 3) and the 8–16 keV emissions from the loop foot point (van Beek et al. 1981), we suggest that the second microwave burst occurred just at the limb, as did the corresponding X-ray burst. Since the first microwave burst coincided in time with the hardest X-ray burst (curve [d], Plate L3), we infer that the positions coincided, too, and came from within 2000 km of the foot of the flare. The knot at the top of the Hα flare loop that exploded in the impulsive phase may be a clue to the flare instability and to a “break out” to a larger volume, but we conclude that it is not the site of the hard X-ray emissions.

If we assume that the impulsive microwave burst at 2022:48 UT was characterized by the hard X-ray source temperature of 2 x 10⁸ K (Orwig, Frost, and Dennis 1981) and that the microwave source size was larger than 175, then the peak flux of 1.5 sfu implies that the microwave source was optically thin at 10.6 GHz. Under these circumstances, the relative strengths of the two senses of circular polarization depend only on the angle between the line of sight and the magnetic field in the emission region (Dulk, Melrose, and White 1979). We conclude that the microwave bursts at 2022:48 UT and 2023:40 UT came from two different loops at the foot of the flare. Furthermore, since the frequency of peak microwave emission was below 10.6 GHz, the microwave data imply that the magnetic field was less than 300 gauss and the field lines were almost orthogonal to the line of sight. Our results imply that the hard X-rays were the result of “thick-target” bremsstrahlung (Brown 1973) in the corona at the base of the flaring loop.

We suggest that the hard X-ray emitting structures are no bigger than the ∼3500 km Hα loops. Larger features did not participate in the flares until after the hard X-ray peak. The rate of emission and the volume involved increased sharply at the impulsive phase peak, and we find evidence for a “break out” of the flare from 3500 km structures to 20,000 km structures at the impulsive phase.

We are grateful to David Speich who supplied most of the NOAA data and to Ron Stewart (CSIRO) and Bruce Springer (Palehuan SOON site) for radio data. We are especially grateful to the observers of the US Air Force Solar Observing Optical Network for Hα films. The ready and very kind cooperation of the SMM experiment teams was essential for completion of this work. We thank Jim Ryan, Brian Dennis, and Jake Wolfson for their helpful comments on an early draft of this report.

REFERENCES


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No. 3, 1981

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