of a vast amount of energy stored in a sheared filament. But the details of that particular flux emergence are subtle (Harvey 1983); it is by no means clear how the interaction between the filament and emerging flux should be conceived when the adjacent net photospheric flux decreases during the emergence. The experience with the 1980 June 25 flare, where adjacent emergent flux could not be found, should caution us that the flare triggering process is still elusive.

1.3.5.3 Summary and Recommendations for Studies of Emerging Flux

The vigorous advance of theory (Priest 1984a, 1984b) has brought into sharp focus the observational requirements to test the Emerging Flux Model. From an observational perspective, however, even the conceptual role of emerging flux in the flare process is clouded. Growth of magnetic flux is a necessary pre-condition for flares: small flares are common during the AFS stage of an active region: large flares often have their initial kernels rooted in new, rapidly growing flux. But the vast bulk of magnetic flux appears at the surface without producing flares as strong as a M1 event in X-rays. The published cases of flare-associated filament eruptions lack key facts which are needed either to validate the reconnection inherent in the Emerging Flux Model or to constrain the model in terms of our understanding of flux emergence in the absence of flares. One study of a flare-associated filament eruption on 1980 June 25, observed in detail for many hours at heights in the photosphere, chromosphere, transition zone and corona, rules out local emerging flux as either a driver or a trigger of the activation of that particular flare.

An important new result is the association of Cancelling Magnetic Features with Flares (Martin, 1984). These may have a similar role to emerging flux in triggering flares (Priest, 1985), since what is important is the interaction of flux, whether through material vertical or horizontal motions.

A major advance towards clarifying this situation would come from coronal observations aimed specifically at the problem of emerging flux. Jackson and Sheridan (1979) found general increases in activity of Type III radio bursts prior to flares, which imply that energy, originating in the emergence of new flux, is entering the corona on a time scale of many hours. We badly need to supplement the detailed chromospheric and photospheric observations of emerging flux, now available, with simultaneous multi-wavelength coronal observations of comparable spatial resolution (≈ 1") and comparable duration (many hours, even days, preceding the emergence). Target regions of emerging flux need to be followed long enough at all levels of the atmosphere to come to grips with the formation of AFS and field-transition arches, and in contrasting emergences of flux accompanied by their well-established signatures from simple appearances of new flux without those signatures. More than semantics are at stake; our concepts of the magnetic inter-

connections in the latter situation are woefully inadequate. Finally, we need to clarify the association between ephemeral regions and coronal bright points on an individual basis. In so doing, we should gain insight into the dissipative mechanisms which seem to occur with great frequency on a basic scale, and which might be applicable to ordinary flares.

1.4 CORONAL MANIFESTATIONS OF PREFLARE ACTIVITY


1.4.1 Introduction

Recent observations confirm the view that the initial release of flare energy occurs in the corona, with subsequent emissions arising from the interchange of mass and energy between different levels of the solar atmosphere. Knowledge of coronal preflare conditions is essential to understanding how energy is stored and then released in flares. Observational evidence for storage is, however, difficult to interpret owing to our inability to observe the three dimensional structure of the magnetic field and to the lack of coordinated observations with high resolution in space and in time.

More than sufficient energy to power flares can be stored in local magnetic fields on time-scales of hours. Long-term changes include emerging and evolving magnetic flux regions, satellite sunspots, sunspot motions, and velocity patterns (Martin, 1980; Section 1.3 these proceedings). Although such evolutionary changes are considered necessary for the storage of energy leading to especially large flares, it is very difficult to relate specific long-term changes to particular flares since similar changes occur in their absence.

More rapid changes can occur within minutes or a few hours preceding a flare, and they can be more unambiguously interpreted as flare precursors. Clearly, this distinction is arbitrary, but it does provide a useful operational definition of preflare patterns. These more rapid changes, especially in the corona, were the subject of the third subgroup of the Preflare Activity Team.

1.4.1.1 Review of Previous Studies of Coronal Precursors

Earlier searches for rapid flare precursors involving coronal phenomena recognized the physical importance of the corona for storage and release of flare energy. Reported coronal precursors have included X-ray brightenings associated with filament activations (Rust et al., 1975), expanding and brightening green-line arches (Bruzek and DeMastus, 1970), gradual enhancements and spectral hardening of soft X-ray and microwave flux (Webb, 1983), “forerunners” of white-light transients (Jackson and Hildner, 1978), changes
in circular polarization and intensity at centimeter wavelengths (Lang, 1974; Kundu et al., 1982; Willson, 1983), pre-burst activity at 1.8 cm (Kai et al., 1983) and preflare type III burst activity at meter wavelengths (Jackson and Sheridan, 1979).

Filament activations and associated manifestations, which are frequently observed with two-ribbon flares, have been the most readily observed and most studied forms of rapid flare precursors (Smith and Ramsey, 1964; Martin and Ramsey, 1972). The enhanced darkenings, organized motions and reconfigurations which constitute an "activation" were summarized by Smith and Ramsey (1964) and more recently by Martin (1980). The prevalence of the phenomenon is evident in the statistic (Martin and Ramsey, 1972) from a sample of 297 flares (importance > Class I) that about half the flares in that sample exhibited preflare filament activity. Prior to or during a filament activation, changes in certain photospheric and chromospheric structures occur, which have been taken as evidence of evolving or emerging magnetic flux (e.g., Rust, 1976).

Preflare observations in soft X-rays have been used in a number of studies. Culhane and Phillips (1970) observed 7 precursor events at 1-12 Å, one occurring 15 min before flare onset, using an OSO-4 full-sun detector. Thomas and Teske (1971) performed a statistical study using a full-sun detector on OSO-3 and found a tendency for the onset of X-ray events to precede those reported in Hz. For a small number of events Roy and Tang (1975) found specific enhancements in full-sun X-ray flux to be associated with different stages of preflare filament activity.

With better spatial resolution (20 arc-sec) Rust et al. (1975) identified OSO-7 EUV and soft X-ray enhancements with a filament activation 30 minutes before flare onset. Van Hoven et al. (1980) studied the preflare phase of a set of 12 flares observed by the same OSO-7 detectors with one-minute time resolution. Eight of the 12 showed definite enhancements in both X-ray and EUV 2-20 min prior to the onset. Interestingly, in 6 of these 8 cases the enhancements were observed simultaneously in both cool He II and hot Fe XXIV lines. Although the Skylab experiments had excellent spatial resolution (arc-sec), the operational modes limited the availability of preflare data to a few specific observations of EUV and soft X-ray precursors (see Van Hoven 1980 for details). Petrasso et al. (1975) and Levine (1978) observed pre-existing coronal loops to brighten 5-10 min before they flared. The XREA full-sun X-ray detector typically detected preflare enhancements 2-20 min before the impulsive phase. There was evidence for slight temperature increases in these events, and an increasing tendency for large flares to have associated precursors.

In more comprehensive, statistical studies, Vorpahl et al. (1975) found many cases where X-rays from the flare regions were enhanced prior to onset, but Kahler and Buratti (1976) and Kahler (1979) found that there were no systematic preflare X-ray brightenings at the locations of subsequent small flares, and therefore no requirement for coronal preflare heating of the flare loops. However, coronal preflare brightenings were observed in the Skylab X-ray data in areas of the active region adjacent to the flare site.

Recently, Webb (1983) studied similar sets of the AS&E Skylab X-ray data with the goal of determining whether X-ray precursors systematically occurred within the flare active region and what their characteristics were. The study differentiated between observations relating to the preheating of flare structures, and precursors which might have time and spatial scales and locations different from that of the flare. High time-resolution Hz and daily photospheric magnetograms were also used. A majority of the flares studied had preflare X-ray features, but typically not at the flare site, occurring within 30 minutes prior to onset. The X-ray precursors consisted of one to three brightened loops or kernels per interval, with Hz emission at the feet of the loops or cospatial with kernels. Electron pressures of a few dyne cm⁻² were derived for several typical coronal features. In half of the cases the X-ray precursors were associated with preflare Hz filament activity. The preflare and flare events occurred on or near the main active-region neutral line.

Using moderately resolved (arc-min) OSO-8 X-ray observations, Mosher and Acton (1980) and Wolfson (1982) reported no systematic enhancement in active regions in 20-minute intervals preceding flare onsets. But their detector was less sensitive to the lower energy, cooler precursors reported earlier from Skylab.

Radio observations provide important data on coronal emission and changing magnetic fields before flares. Individual observations of microwave preflare activity in the form of increased intensity and changing polarization have been reported in the past. With the increasing sensitivity and spatial resolution of such instruments as the VLA, these observations have become better defined, as discussed in Sections 1.4.2 and 1.4.5.

Green line (5303 Å) observations above the solar limb showed acceleration and expansion of coronal arches up to one hour before two flares (Bruzek and DeMastus 1970). Skylab observations of white light mass-ejection "forerunners" (Jackson and Hildner 1978) indicated that such activity might precede Hz flare onset. Recent SMM results, together with improved metric radio and lower altitude K-coronameter data (Wagner 1982) support the overall picture that a large volume of the corona can become activated up to an hour or so before a flare.

1.4.1.2 Objectives

Our objectives in studying preflare coronal phenomena were threefold: to select a suitable data set, to determine appropriate physical parameters, and to search for associations among events so as to identify the relevant physics in preflare phenomena.
A wealth of new information about active regions and preflare activity is now available from the coordinated observations conducted during the Solar Maximum Year by the Solar Maximum Mission satellite, by other spacecraft, and by ground-based observatories. The wavelengths accessible to a study of the preflare coronal condition range from centimeter-wavelength microwaves to hard X-rays. Table 1.4.1 summarizes the data that were used in our study by wavelength and instrument, and the references to publications of events covered in this report. Previous multi-wavelength studies of this sort (Martin, 1980; Van Hoven et al., 1980; Webb, Krieger and Rust, 1976; Rust, Nakagawa and Neupert, 1975; Webb, 1983; Kahler and Buratti, 1976) were more limited because of sporadic or slower image cadences, lower sensitivity, poorer resolution, or fewer wavelengths available. In addition to a broader range of data with better coverage, we also had the advantage of observing the sun at its maximum level of activity, with flares occurring six times more frequently than during the Skylab period.

Our approach was to assemble all available preflare data for a number of well-observed events and the results of several "cross-sectional" studies in specific wavelength ranges. We have selected good simultaneous observations at as many levels of the solar atmosphere as possible, from the photosphere through the chromosphere and transition region to the lower and middle corona. We concentrated on data with time resolution ranging from tens of seconds to minutes, collected over a time interval ranging from about one hour before the flare up to impulsive onset as defined in hard X-rays by HXRBS. In very few cases were observations at all levels of equally high quality, but a sufficiently large set of well-

### Table 1.4.1a

<table>
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<tr>
<th>Wavelength</th>
<th>Instrument</th>
<th>References Discussed</th>
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<td>Very Large Array: 2 cm, 6 cm, 20 cm</td>
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<td>(spatially resolved)</td>
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<td>Nobeyama Interferometer (17 GHz)</td>
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<td></td>
<td>Sagamore Hill</td>
<td>9, 73</td>
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<td></td>
<td>Ottawa/Penticton (2.8/2.7 GHz)</td>
<td>M. Bell, pers. comm.</td>
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<td></td>
<td>Toyakawa (1-9.4 GHz)</td>
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<td>Hα</td>
<td>Ottawa River Solar Observatory</td>
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<td></td>
<td>Solar Optical Observing Network</td>
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<td></td>
<td>Big Bear Solar Observatory</td>
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<td></td>
<td>Udaipur</td>
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<td>Meudon</td>
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<td>White Light</td>
<td>Mauna Loa</td>
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<td>Corona</td>
<td>SMM C/P</td>
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<td>P78-1 Solwind</td>
<td>J. Karpen, pers. comm.</td>
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<td>SMM XRP/FCS</td>
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<td>HXRBS</td>
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<td>Gamma Rays</td>
<td>GRE</td>
<td>73, 78</td>
</tr>
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Table 1.4.1b
References for Tables 1.4.1, 1.4.2

1. Martin 1980
2. Machado et al., 1982
3. Kundu et al., 1982
4. Kundu et al., 1985
5. Hurford and Zirin 1982
6. Lang 1979
7. Machado et al., 1982
8. Kundu et al., 1982
9. Kundu et al., 1985
10. Hurford and Zirin 1982
11. Lang 1979
12. Kundu 1981
13. Lang 1979
15. Kundu and Shevgaonkar 1985
17. Kosugi et al., 1985
18. Willson 1983
19. Woodgate et al., 1982
20. Woodgate et al., 1981
22. Sime et al., 1980
23. Harrison et al., 1985
24. Moore et al., 1984
25. Wolfson et al., 1983
26. Schmahl 1983
27. Gaizauskas 1984
28. Wilson et al., 1983
29. Gary et al., 1984
30. Schadee et al., 1982
31. Woodgate et al., 1981
32. Gary 1982
33. Sime et al., 1980
34. Harrison et al., 1985
35. Simon et al., 1984
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37. Rust et al., 1980
38. Zirin 1983
39. de Jager et al., 1983
40. Machado et al., 1983
41. Rock et al., 1983
42. Woodgate 1983
43. Enome et al., 1981
44. Hoyng et al., 1983
45. Kosugi and Shiomi 1983
47. Dwivedi et al., 1984
48. Duijveman et al., 1982
49. Strong et al., 1984
50. Oord et al., 1984
51. Simnett and Harrison 1984
52. Gosling et al., 1976
53. Gary et al., 1984
54. Schadee et al., 1983
55. Martin et al., 1983
56. Svestka et al., 1982
57. Gaizauskas and Schadee 1984
58. Wiehl et al., 1983
59. Hoyng et al., 1981
60. Dulk and Dennis 1982
61. Tandberg-Hanssen et al., 1983
62. Woodgate et al., 1983
63. Gabriel et al., 1981
64. Cliver et al., 1984
65. Bhatnager 1981
66. Poland et al., 1982
67. Neidig and Cliver 1983
68. Wagner 1982
69. Marsh et al., 1981
70. Duijveman et al., 1982b
71. McGee et al., 1983
72. Malherbe et al., 1983
73. Sturrock 1980, (especially p.413) in defining the “onset” of the flare as the time of the first rise in emission at the site of the flare itself. We adopt a somewhat more general definition of “precursor” than used in the Skylab studies (Sturrock, 1980). We take a “precursor” to be a transient event preceding the impulsive phase, possibly even before the onset and not necessarily at the precise site of the flare itself.

Among the questions guiding this study were:
• Where is the flare trigger located?
• Is flux emerging at the photospheric level a necessary condition for preflare coronal activity?
• Do flares “try” to start, fail, and “try” again?
• Do flare precursors have both thermal and non-thermal components?
• Are there two distinct classes of precursor, some associated with filament activation and some not?

We have organized material leading up to a discussion of these questions as follows. In the next section we define the onset phase and precursors and explain how we distilled our preflare data set. In Section 1.4.3 are presented several key events which illustrate the connections that we discovered among their preflare phenomena. In Section 1.4.4 we describe an important comparison of the location of preflare activity in FCS and UVSP images. In Sections 1.4.5 and 1.4.6 are reviewed the observations of certain radio precursors which are taken as evidence favouring preheating and non-thermal particle acceleration. Finally Sections 1.4.7 and 1.4.8 describe HXIS observations of X-ray precursors.
The initial sample of preflare events included 54 flares selected by Woodgate to have sufficient coverage in time by UVSP and BCS before the impulsive hard X-ray burst recorded by HXRBS. When multiple bursts occurred, the largest was taken to be the primary flare. In this respect, the study was similar to that of Webb (1983), in that "minor" flaring was included as "preflare" activity. From a combination of Woodgate's sample with 12 other events which showed interesting preflare activity in microwaves, Hα, white light and/or in X-rays, we selected 26 events which had the best overall coverage in data for concentrated study. These events along with key precursor observations and references to publications are summarized in Table 1.4.4.

1.4.2.1 The Onset Phase

We defined two onset times for each of the primary flares in Table 1.4.2. One was the impulsive onset observed in hard X-rays (HXRBS). The other was the soft X-ray onset, commonly defined as the start of the rise of the flare flux profile. Webb determined the onset time in this manner, using the full sun 1-8 Å X-ray flux recorded by the NOAA/GOES satellite for the events in this study. On average, the soft X-ray onset occurred ~ 2 minutes before the onset of the hard X-ray burst, in agreement with previous results (Svestka 1976). Schmahl, Strong and Waggett used background-corrected BCS light curves in a similar way to determine the soft X-ray onset times. These onset times and the hard-X-ray minus soft-X-ray time differences are shown in Table 1.4.2.

There was surprising agreement between the GOES and BCS (Ca XIX: ~ 3.2 Å) timings, with onsets rarely differing by 1 minute in the two X-ray regimes. When differences arose the BCS data were used since its 6' x 6' (FWHM) field of view minimized confusion from flares in other regions. Since Ca XIX is formed at ~ 1.5 x 10^7 K, the onset profiles indicate the existence of pre-impulsive plasmas as hot as ~ 10^7 K.

Harrison, Schadée and Schrijver plotted onsets for a number of flares using the softest channel (3.5-5.5 keV) of the HXIS instrument. Several onset profiles are shown in Figure 1.4.1a. The profiles of Figure 1.4.1a were integrated over the full coarse field of view (6'.2 x 6'.2), and therefore may represent the sum of more than one onset source. Figure 1.4.1b illustrates the comparison of onsets for the full field of view and for four areas of a few pixels each at and near the flare site, 18:17:19:03, 28 June 1980. We shall return to this flare later, but for now we note that the full field-of-view integration shows an earlier onset than the flare pixels themselves, suggesting preheating away from the flare site. Pre-onset activity has been noted outside of the flare structure before, especially in the Skylab data (e.g., Van Hoven 1980, Webb 1983, Kahler and Buratti 1976) and SMM data (e.g., Machado et al., 1982). However, at this stage it is not clear how to compare the results from Skylab and SMM. For instance, the X-ray filters on the Skylab AS&E experiment defined plasmas of lower temperature (~ 1-5 x 10^6 K for the softest filter) than the SMM BCS (> 8 x 10^6 K) and HXIS (greater than or about 10^7 K) experiments. There was no hard X-ray detector aboard Skylab so it was not possible to compare directly the distribution of soft X-ray to impulsive onsets. Since the Solrad or GOES maximum almost always followed the impulsive maximum by a few minutes, the Skylab onset times would have to be modified for comparison with this study.

The fact that a gradual onset in soft X-rays or microwaves is always present suggests a thermal origin for the first phase of flares (e.g., Svestka 1976). Machado et al. (1982) have suggested that the preflare gradual phase is a manifestation of the same phenomenon as the post-flare gradual phase. However, while this is conceivably true of the soft X-ray emitting regions, the gradual phase in microwaves shows remarkable differences (in polarization or source-size changes) preflare and post-flare (e.g., Kundu et al., 1985, Hurford and Zirin 1982). More study is required to determine the nature of the gradual onset of flares. We show below, in examples reported by Team members, several physical interpretations in terms of heating, upheavals or reconfigurations of magnetic flux.

1.4.2.2 Flare Precursors

The SMM data base is much more continuous than that of Skylab, and it is therefore possible to make stronger distinctions about flare precursors. In the more sporadic Skylab coverage (Webb, 1983; Kahler and Buratti, 1976; Kahler, 1979), it was more difficult to distinguish precursors from the onset phase. When such a precursor was observed, we defined the onset of the flare "conservatively" by the last pre-impulsive phase minimum of the light curve.

Since it is difficult to distinguish a true precursor signal from the flare onset or rise phase itself, when it occurs within a few minutes of the impulsive phase (Kahler 1979), we emphasized analysis of observations from about 60 to 5 minutes before impulsive onset. SMM images sometimes revealed precursors which were physically distinct from the flare, during what would otherwise be defined as the gradual onset phase.

X-rays. Precursors in the high resolution X-ray photographs from Skylab appeared as loops or kernels close to, but not necessarily, at the flare site. Often these sources were multiple and small (several arc-sec). In many cases, the precursors were closely associated with activated filaments (Van Hoven 1980, Webb et al., 1976, Webb 1983).

Examples of all of these effects are present in our SMM data set. In terms of the SMM X-ray light curves, gradual-rise-and-fall (GRF) precursor signatures were frequently detected in X-rays (Figure 1.4.1) and microwaves. Such a signature is considered indicative of coronal heating and is strongly associated with filament activations (Martin 1980,
### Table 1.4.2 Event Summary of SMY Precursors

<table>
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<tr>
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<tbody>
<tr>
<td>Mar 23</td>
<td>C7</td>
<td>1658.3 (4)</td>
<td>N</td>
<td>Y-1600; 1648</td>
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<td></td>
<td>Hα</td>
<td>Inc: 1648</td>
<td>Inc.+ Rev.</td>
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<td>10,47,78.</td>
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<td>Apr 6</td>
<td>C7</td>
<td>0716.5 (7)</td>
<td>N</td>
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<td></td>
<td></td>
<td>SXR,UV</td>
<td>Step: 0903</td>
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<td>Y-1600; 1648</td>
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<td>1551.3 (8)</td>
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<td>SXR, HXR, UV, Hα</td>
<td>Step: 1520</td>
<td>Inc.+ Rev. I, III</td>
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<td>Hα</td>
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<td>Dec.: 1619</td>
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<td>N</td>
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<td>Nov 5</td>
<td>C6</td>
<td>2252.9 (0)</td>
<td>Y for 2232</td>
<td>Active Fibrils</td>
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<td>C8</td>
<td>0626.3 (1)</td>
<td>N</td>
<td></td>
<td>SXR, UV</td>
<td>GRF: 0600-0630</td>
<td>III, V</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov 13</td>
<td>M1</td>
<td>1840.2 (7)</td>
<td>Y-1754, 1815</td>
<td></td>
<td>Hα</td>
<td>GRF: 1833-1922</td>
<td>Dec. I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 1, 83</td>
<td>M2</td>
<td>1840.2 (7)</td>
<td>N</td>
<td></td>
<td>Hα</td>
<td>GRF: 2051</td>
<td>Inc. I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**

1. GOES-2 I-8Å flux: Cl = 10^-6 w/m^2, M1 = 10^-5 w/m^2, X1 = 10^-4 w/m^2.
2. Time difference: HXRBS Impulsive onset minus SXR flare onset from BCS. GOES data used when BCS not available. GOES Data in ( ).
3. Time difference: HXRBS Impulsive onset minus earliest SXR precursor in BCS.
4. Ha subflare or flare, radio burst or X-ray peak in preflare interval. Y = Yes; N = No.
5. Preflare brightenings in active region: SXR = soft X-rays, HXR = hard X-rays (> 15 keV), UV = UVSP, Hα = from Hα images.
6. No Hα flare patrol: 1415-1515 UT.

1-53

**Microwaves.** In the cm-λ regime as observed with interferometers, precursors may appear in the preflare hour as changes in circular polarization (Lang 1974, 1979), enhancements in polarization and intensity (Kundu 1981, Kundu et al., 1982, 1985, Kundu and Shevgaonkar 1985) small impulsive prebursts (Kai et al., 1983, Kosugi et al., 1985), or gradual rises in intensity accompanied by a decrease in fractional polarization (Hurford and Zirin 1982). Simultaneous observations with the VLA and Westerbork Synthesis Radio Telescope (WSRT) (Willson 1983) have shown examples of preburst 6 cm heating near the footpoint of one of the loops which flared. However, other observations have shown that preburst changes are not usually detected, since only 1 out of 8 bursts observed at 2, 6, and 20 cm showed pre-burst activity at the burst site (Willson and Lang 1984), and only 8 of 27 10.6 GHz bursts showed preburst activity (Hurford and Zirin 1982). X-ray precursors were found a majority of the time in the flare active region (Webb 1983), namely, 17 out of 23 cases. So the question arises whether the lower rate of occurrence of microwave precursors is a selection effect, a threshold effect or a function of the pre-flare energetics or production mechanisms.

**Ultraviolet.** Some examples of UV precursors include preflare surging motions in C IV (Kundu et al., 1985, Woodgate et al., 1982), and rising loops (Woodgate et al., 1981); these enhancements will be discussed for individual events below. In Section 1.4.4 Waggett and Bentley report on the correspondence of precursors in ultraviolet and X-rays.

**Coronal White light.** Various observers (Gary 1982, Sime et al., 1980, Harrison et al., 1985, Gary et al., 1984, Wagner 1982) have discussed the early appearance of coronal mass-ejection transients. SMY observations of transients in the low (HXIS) and mid-corona (Mauna Loa) have given a manifestation of pre-onset activity, which is clearer than the Skylab “forerunners” (Jackson and Hildner 1978). The physics of the relation of coronal transients to flares and their respective precursors remains unclear but some preliminary concepts will be presented in Section 1.4.7.

**Common Precursor Factors.** The variety of precursors seen during the SMM period is surprisingly large but as we shall show, there appear to be common factors that connect them. Emergence of flux at the photospheric level is one such factor, but does not appear to be a necessary condition for the precursor, as shown by the discussion of the 25 June 1980 event in Section 1.4.3.1

A particularly important question for flares in which a filament eruption occurs is whether the uplift of the filament signifies a reconfiguration of the magnetic field that causes the main phase of the flare to begin. There is no question that, typically, a significant amount of energy is released before the impulsive phase begins and before the most violent part of the filament eruption (Webb et al., 1976, Martin and Ramsey 1972, Moore et al., 1984). But precisely where the preflare heating occurs, relative to the observed filament motions and the flare site, is a more central question. Several important flares with well-observed preflare activity are described below in an attempt to access the important parameters and common features of such activity. These features will be summarized in the last section.

### 1.4.3 Specific Illustrative Events

We have selected 12 well-observed events from our preflare study to illustrate the diverse physical phenomena observed in the corona before flares. These include data with the best imaging and spectral coverage. This selection rules out spurious instrumental effects or unwarranted interpretations that might arise from the data from a single instrument. In a few cases the preflare and flaring periods have been thoroughly analyzed, and the interpretations are not likely to change significantly. But for most of these cases, the analyses are still very preliminary. The reader is cautioned, therefore, that this discussion is only meant to provide some initial
Figure 1.4.1b Comparison of time profiles integrated over the coarse field of view and sets of 1 to 4 individual pixels of the HXIS instrument.
summaries and interpretations of these preflare coronal manifestations.

1.4.3.1 A Filament Eruption Without Emerging Flux (25 June 1980)

The initial source of interest in this event was the set of preflare microwave maps made at 6 cm using the VLA. In the hour before the flare onset (1548 UT), according to Kundu (1981), the region around the flare site showed intensification in several compact (less than or about 20") sources whose polarization increased up until flare onset. In the 15 minutes before onset, the polarization of one bipolar source reversed sign, and the subsequent 6 cm burst occurred at the site of that reversal (Kundu et al., 1982). It was deduced that magnetic changes were taking place during the pre-flare period (Kundu 1981). When he realized that the preflare period contained a well-observed filament activation, and that its subsequent eruption had been well observed in both on- and off-band Hα at the Ottawa River Solar Observatory (ORSO), Gaizauskas undertook an exhaustive analysis of the kinematics of the event (Kundu et al., 1985, Gaizauskas 1984). Woodgate (Woodgate et al., 1982), recognizing the significance of simultaneous C IV upflows before the same flare, also undertook a complete analysis of the UVSP dopplergrams. We briefly summarize the details of this event, which have been described at greater length elsewhere (Kundu et al., 1985, Schmahl 1983).

Figure 1.4.2 shows the time line of the preflare period as observed in hard X-rays, soft X-rays, Ultraviolet, Hα and microwaves. The main (1B) flare began at 1548 UT (HXRBS), with an earlier minor burst at 1522, which corresponded to an Hα subflare seen in the 1' x 1' UVSP field of view and recorded in the BCS Ca XIX and Fe XXV channels. (There were no imaging X-ray observations of this flare from either SMM or P78-1). Although the subflare had kernels within 20"-30" of the flare-associated filament, the filament motion was not affected. The filament showed steady transverse motion (see Figure 1.4.2) as early as ~ 3 hours before onset, with upward doppler shifts near its midpoint and axial flows and twisting motions along its length. Brightenings at 6 cm were seen in a 5 minute VLA map at the time of the subflare, but the source of emission was ~ 1" from the Hα and ultraviolet brightenings. It is likely that this prior radio brightening was related to the magnetic field changes taking place before the onset of the main flare. Just after the subflare, (15:33-15:38), a brightening and upflow occurred in the C IV dopplergram image, coincident with the rising portion of the Hα filament which also showed enhanced axial flows. The brightening and upflow reappeared more strongly from 15:42-15:46 in approximately the same location. Finally, a third brightening and upflow reappeared even more strongly at impulsive onset (15:49). By this time the transverse motion of the Hα filament had carried it further southward, so that the blue-shifted, impulsive, C IV brightening seen in the last UVSP image at 15:52 UT was clearly north of (and presumably below) the rising filament. In the last VLA preflare map (15:30-15:40) there was a polarity reversal in one of the bright active region components (“B” in Kundu et al., 1982). The location was cospatial with the subsequent ultraviolet and microwave impulsive onset at ~ 15:50. This was interpreted as possibly due to the interaction of new magnetic flux with pre-existing flux, creating increased 6 cm opacity through the gyroresonance process.

However, careful examination of the ORSO Hα films (Gaizauskas 1984, Kundu et al., 1985) and magnetographic data revealed no signature of emerging flux at the chromospheric or photospheric level (Section 1.4.3b). The main conclusion was that changes in magnetic field strength were mainly coronal, with photospheric changes being gradual or evolutionary in this event.
Gaizauskas (1984) has argued that the instability of the filament developed out of a major disturbance in a magnetically connected structure in the same active region. The slow upheaval of the entire structure exhibited enhanced axial flows leading to a rapid twist, consistent with the weak kink instability (Sakurai, 1976; Hood and Priest, 1979; Sung and Cao 1983).

The three preflare rising motions, seen in the ultraviolet, occurred beneath the \( \text{H}\alpha \) filament (see Figure 1.4.3), which responded with enhancements of axial flows from its midpoint towards the eastern footpoint. The first two episodes of rising motions in C IV were of lower velocity and density than the third. Kundu et al. (1985) have suggested that the coronal conditions were such that the first two uplifts were not sufficient to trigger the final disruption of the filament, but that the third one was. The restructuring of magnetic fields before 15:45 UT, suggested by the VLA map must be related to the rising, twisting motions of the filament and its supporting field lines.

1.4.3.2 Filament Eruption with Colliding Poles (22 June 1980)

The preflare activation of a filament on June 22, 1980 serves as an interesting counterpoint to the event of June 25. The region in which the activity occurred, Hale 16918, was studied extensively as part of an SMY FBS interval (Martin et al., 1983), and the filament activity was initially described by Malherbe et al. (1983). At the workshop, Simon presented results of a more complete study of the event with an interesting interpretation in terms of current sheets (Simon 1984).

The hard X-ray burst associated with this event was not recorded by SMM because of orbital night. (P78-1 Monex data may exist, but has not been reduced). The microwave impulsive phase of the event occurred between 13:03 and 13:06 UT. At 5.2, 8.4, and 11.8 GHz, an impulsive burst was recorded at Berne from 13:02:40 to 13:03:40. At 3.2 GHz (Berne) and 2.8 GHz (Ottawa) the strongest impulsive burst occurred about two minutes later (13:05:20). Almost simultaneously (±1 minute) another flare occurred in a neighboring region making the full-disk data difficult to interpret. This second flare occurred along the same neutral line and the two flares may have been related.

The \( \text{H}\alpha \) flare began in close coincidence with the impulsive bursts, with the central \( \text{H}\alpha \) intensity in the brightest kernel rising most rapidly from 13:03 to 13:06 UT (Malherbe et al., 1983). The \( \text{H}\alpha \) intensity and velocity profiles are shown in Figure 1.4.4. The filament associated with this flare showed activity as early as 12:36 UT in the form of red and blue shifts at various locations along its length (Figure 1.4.5).

Figure 1.4.5 shows the \( \text{H}\alpha \) intensity and velocity maps at 13:00 UT. Systematic blue shifts began at about 12:45 in the filament, where it passed through region designated "O" by Martin (1983). At the western end of the field of view, where the filament was darkest, the velocities were generally small but became redshifted during the main phase of the flare. At the opposite extremity of the filament (C2) on the other side of "O", blue shifts also changed to red shifts during the main phase. Near the midpoint (C1) of the filament and "O", the Doppler shifts became large toward the blue side. This behavior is qualitatively similar to that of the June 25 filament. The \( \text{H}\alpha \) profiles made north of the neutral line showed evidence of absorbing material moving transversely.

Figure 1.4.3 Rising motions and intensity fluctuations as shown in C IV dopplergrams and spectroheliograms for the preflare period, 25 June 1980. (Kundu et al., 1985).
(northward) away from the neutral line between 13:00 and 13:03. The transverse velocity was \(-35\, \text{km s}^{-1}\) and the vertical velocity was at least \(50\, \text{km s}^{-1}\). The ejected material remained connected to the filament at a point near "O" until 13:05, at the time of the impulsive phase.

During the rise of the filament, 12:59-13:04 UT, the brightest H\(\alpha\) knot near "O" moved systematically toward the neutral line with a transverse velocity of \(20\, \text{km s}^{-1}\). On the other side of the neutral line, the knots did not show significant motion. At the time of the H\(\alpha\) explosive phase (\(-13:06\)) the absorbing material north of the neutral line separated. The filament reformed soon after the flare, as it did on June 25. The moving knot was interpreted (Simon et al., 1984) as the foot of a current sheet separating emerging and pre-existing fluxes.

**Figure 1.4.4** Time profiles of H\(\alpha\) and microwaves for the preflare period, 22 June 1980 (Simon et al., 1984). Upper: H\(\alpha\) intensity. Middle: H\(\alpha\) velocity. Lower: Microwave flux.
Common Features of the June 22 and 25 Preflare Activity

Although the instrumentation observing the events of June 22 and 25 was different and the published descriptions emphasize different physical phenomena, it is clear that there were several common features in these events.

- **Filament Kinematics** – The upward motions of the filaments occurred near their midpoints, with downward motions near the ends. The driving force which lifted the magnetic arch apparently did not constrain the material from falling down the ends of the structures. In the analysis of both events it was concluded that not all of the filamentary material was ejected.

- **Multiple Motions** – Several kinds of motions were observed. In the June 25 case, there were axial and twisting motions as well as upflows and downflows. The upflows occurred as three successive events in the 20 minutes before onset. On June 22, upflows occurred during the preflare 25 minutes as three or four upheavals at the brightest point of the filament, but axial and twisting motions were not reported.
• **Exciting Agent** – The trajectory of the ejected material appeared to be directed away from a bright “exciting agent” at lower levels. On June 25, a bright surging feature was observed in the C IV line which could be inferred as triggering the eruption (Kundu et al., 1985, Woodgate et al., 1982). On June 22, the bright feature was an Hα knot which moved toward the neutral line as the dark absorbing structure on the other side moved away from it. The bright moving knot was interpreted as the footpoint of the current sheet between colliding lines of force (Simon et al., 1984). Although the two “exciting agents”, seen at lower levels, were morphologically different, a common interpretation in terms of moving magnetic fields is possible for both.

• **Filament Reformation** – In both events, the filament reformed within a few minutes of the impulsive phase. This implies that the boundary conditions of the configuration, especially in the photosphere, remained sufficiently similar that the preflare magnetic field structure was restored post-flare (Kundu et al., 1985).

• **Dissimilarities: Is Emerging Flux Necessary?** For the June 25 flare, a clear case has been made that no emerging flux existed below the filament. For the June 22 flare, the evidence is not so clear, but the colliding poles seen below the filament certainly are not characteristic of the classic emerging regions, which overlie diverging bipoles. However, such cancelling Magnetic Features (Martin, 1984) may have a similar effect to emerging flux in triggering flares (Priest, 1985). In both flares, the triggers for the eruptions may have been slow changes of magnetic field in the neighborhood of the filament. Similarly, one can ask whether the apparently different “exciting agents” (the surging C IV emission and the moving Hα knot) be interpreted by similar mechanisms. We return to this question after summarizing another event which shows both common and different features of preflare activity.

**1.4.3.3 Rising Loop at the Limb (April 30, 1980)**

Hα observers (e.g., Martin 1980, Rust et al., 1981, Rust et al., 1980, Webb 1983) have shown that Hα emission can precede the impulsive phase by a few to tens of minutes. The April 30, 1980 flare illustrates the case where the initial burst is preceded by a bright Hα mound at the site of developing new magnetic fields. (The flare occurred close to the limb where chromospheric footpoints typically are hard to detect.) The above-the-limb Hα emission was cospatial with a C IV loop (Woodgate et al., 1981) and was interpreted as an arch-filament system (Rust et al., 1981). Foreshortening at the limb, however, makes it impossible to determine the extent of the loop along the line of sight. For example, the loop might have been an elongated helical structure like a filament seen end-on, as suggested by line-of-sight flows seen in the UV, and by the fact that its southern footpoint was further onto the disk than the northern footpoint (Woodgate et al., 1981).

The preflare period for this event was well observed by all the SMM instruments and the details of the preflare activity were summarized by de Jager et al. (1983). Figure 1.4.6 shows the schematic UVSP loops (Woodgate et al., 1981) along with the HXIS light curves (de Jager et al., 1983). The two major HXIS structures in the flare, the “kernel” and the “tongue”, both appeared spatially coincident (±8") with the UVSP structures AB and DE (respectively). The brightenings in HXIS X-rays and in UVSP C IV were also in temporal coincidence as were the softer X-rays seen in the BCS Ca XIX and GOES 0.5-4 Å channels.

According to the HXIS observers (de Jager et al., 1983), after the maximum of the “kernel” precursor at 19:55 until
the onset of the flare at 20:22, the intensity decline was consistent with conductive losses (no radiative losses) of a gas at $T_e \approx 1.5-2 \times 10^7$ K and $n_e \approx 3.2 \times 10^8$ cm$^{-3}$. In the "tongue", particle energization occurred continuously from the onset of the precursor to the impulsive rise.

During the rise phase (20:17-20:22) of the burst, the Hα and soft X-ray emission increased, and material rose in the C IV loop leg, with Doppler shifts ($\approx 20$ km/s) toward the observer. At the time of the main burst, "breakout" occurred at the top of the loop where a new feature appeared in Hα. The question of the existence of emerging flux ribbons formed on either side of the neutral line. Immediately, much like one leg of an expanding loop, after which the eastern precursor was not obviously associated with any Hα activity. Several similarities in the preflare activity of the June 22nd, 25th and 26th events are discussed below.

1.4.3.4 X-ray Precursor Not at Flare Site (April 10, 1980)

The BCS Ca XIX and GOES flux started to rise at $\approx 09:00$, or about 20 minutes before the onset of the HXBS burst (09:16). During this rise there was a Ca XIX burst ($\approx 09:05$) which is considered a flare precursor. This peak was also recorded by HXIS (Machado et al., 1983) in the two softest channels. Preflare emission in N V was observed in three regions which were postulated (Machado et al., 1983) to be the footpoints of the subsequent flare loops. The 09:05 HXIS precursor appeared mainly at the southeastern and northern footpoints. The UVSP time profile in a 21"×21" raster centered on the western footpoint showed impulsive brightening at that footpoint. Woodgate, Waggett and Bentley found that the small UVSP raster precluded an analysis of correlations between preflare ultraviolet bright points and FCS activity.

The combined HXIS and UVSP data imply that the preflare activity occurred in loops displaced $\approx 8"\rightarrow 16$" away from the main hard X-ray brightening. Machado et al. (1983) estimated the emission measure ($\approx 5 \times 10^{47}$ cm$^{-3}$) and temperature ($\approx 1.3 \times 10^7$ K) for the precursor. The data permitted a multithermal interpretation, but counting statistics did not warrant the computation of differential emission measures.

The authors conjecture that the preflare gradual phase was a part of the overall gradual phase upon which the impulsive phase was superposed.

1.4.3.5 X-ray Preflare Emission From Filament Disruptions

On June 26 1980, Boulder Region 2522/30 produced what Martin classified as a "predictive filament" activation starting at approximately 23:30 UT. The BCS Ca XIX intensity showed a small precursor superposed on the rise at $\approx 23:33$. According to Harrison there were two precursors seen by HXIS at 23:35 (Figure 1.4.7), one located west (limbward) of the subsequent flare site and the other to the east. The BBSO Hα film showed that the precursor appeared as a subflare/surge in the penumbra of the leader spots to the west.

During liftoff (23:30-23:40) the activated Hα filament went from absorption into emission at 23:39:29 UT, close to the 23:39:35 impulsive onset. For the approximately two minutes of the Hα explosive phase, the filament rose rapidly, much like one leg of an expanding loop, after which ribbons formed on either side of the neutral line. Immediately following the flare, the filament reformed.

Preliminary coalignment suggests that the western HXIS precursor at $\approx 23:32$ coincided with the subflare/surge event. The eastern precursor was not obviously associated with any Hα activity. Several similarities in the preflare activity of the June 22nd, 25th and 26th events are discussed below.

On June 28, 1980 the leading portion of region 2522/30 was near the west limb and produced prominence and flare activity that was well observed at Mauna Loa Solar Observatory (MLSO) and by SMM. The first sign of activity in the hour before the flare was an eruptive prominence observed by MLSO from 17:12 - 18:44 UT (Rock et al., 1983). Subflares in the region occurred from 18:19 - 18:24. Associated activity was observed by UVSP in the Si IV line from 18:23 - 18:27. The flare itself appeared as two bright knots on the limb, seen in both Hα and Si IV. The preflare brightening occurred between the knots, then at the main flare site (18:23 - 18:27). Waggett and Bentley reported what may be an X-ray precursor in Mg XI inside the limb at $\approx 18:18$ 18:26 (Figure 1.4.8b-d) and then subsequently at the flare site at 18:27 (Figure 1.4.8). The same precursor at the flare site was observed by HXIS in maps prepared by Schadee and Schrijver.

Hα flare onset was at $\approx 18:24$ before the onset of hard X-rays and continued as an upflow until at least 18:34 UT. The onset of the flare in X-rays appeared to start at 18:37 in the soft HXIS channel. The Mg XI images (Figure 1.4.8)
Figure 1.4.7 HXIS images showing the 23:32 precursor before the 23:40 flare on 26 June, 1980. The arrows on the time axis of the burst profile show the times of the individual maps.
showed onset at later than or about 18:42 and a double flare. In Si IV a brightening occurred near the northern flare knot at \( \sim 18:41 \), maximizing at \( \sim 18:45 \), the time of the hard X-ray burst. The \( \text{H}\alpha \) upflows apparently continued through 18:54, with motion paralleling the previous prominence eruption. The outflowing prominence material moved above the MLO\( \text{S}\) occulting disk at \( \sim 18:59 \) at the same position angle as the previous eruption.

**Common Activity in the June Events**

In the June 26-28 events, preheating of the filament was inferred from X-ray brightening during its liftoff. Both events had \( \text{H}\alpha \) "double-ribbons"; the June 28th flare was also

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**Figure 1.4.8** Ne IX and Mg XI (XRP) images showing a precursor, onset and the main phase of the 28 June, 1980 flare. The last Ne IX image is replaced by a white light image. The main flare can be seen in the northwest quadrant of the Mg XI image at 18:44 UT (h). The onset can be seen at the same position at 18:40 UT (g).
double in ultraviolet and X-rays. Preflare brightenings were observed displaced from the flare site. On the 26th, two HXIS preflare brightenings occurred west and east of the flare site. On the 28th, the early Mg XI brightenings were displaced laterally and possibly above the limb flare. Both of these flares require considerably more analysis before firm conclusions can be drawn. Nevertheless, one striking similarity to the June 22 and 25 events stands out. In all four events preflare brightenings (in Hα on the 26th and in ultraviolet on the 28th) occurred beneath the filament or between the flare knots, suggesting that the flare was triggered from below. But the subflares preceding the June 25 and 26 flare, laterally and possibly above the limb flare. Both of these inclusions can be drawn. Nevertheless, one striking similarity to the June 22 and 25 events stands out. In all four events preflare brightenings were double in ultraviolet and X-rays. Preflare brightenings were observed displaced from the flare site. On the 26th, two HXIS preflare brightenings occurred west and east of the flare site.

1.4.3.6 Homologous Flaring – November 5, 1980, 22:26 and 22:32 UT

Woodgate (1983) suggested that a majority of flares might be homologous in the sense of having footpoints reappearing very near the same places. The importance of homologous flares is that differences in initial conditions between flares can be minimized in order to isolate which factors are significant in terms of the site of flaring, timing, field strengths and energy release.

The November 5, 1980 flares were a good example of well-observed, homologous events. The hard X-ray profiles were similar (see Figure 1.4.9), although the second burst was an order of magnitude stronger. The microwave burst profiles were also similar, but the second burst at 17 GHz (Enome et al., 1981) was ~ 40 times larger than the first. The first burst was observed by the VLA at 15 GHz (Hoyn et al., 1983) and by various patrols from 1-17 GHz. The microwave spectrum went as $p^{3.9±0.1}$ up to 17 GHz, and the maximum of the spectrum was therefore above 17 GHz. The patrol data (Nobeyama, Nagoya, and Toyakawa: (Enome et al., 1981, Kosugi and Shiomi 1983, S.G.D. 1981) show that the second burst had a very similar spectrum, also with a maximum $\geq 17$ GHz (but less than 35 GHz). The amplitudes of the two events were in rough proportions of ~ 40:1 at all frequencies from 1-17 GHz. Helium D3 film from BBSO showed that the two bursts were optically similar (see Chapter 5, §5A.5, Figure 5A.13). The bright D3 kernels of the impulsive phase appeared and disappeared with close simultaneity to the hard X-ray bursts, and the two “kernels” of the second event were cospatial with those of the first. One important difference between the two events was a weak “outlier” seen in D3 far from the main kernels.

According to Martin (see Chapter 5) the outlier appeared to correspond to the weak impulsive source reported by HXIS (Duijveman 1982). Both flares showed strong Ca XIX blue shifts (~ 300 km/s) during the impulsive phase (Antonucci et al., 1984). This bears on the question: did the first flare trigger the second? X-ray observations have shown (Strong et al., 1984) that a flare closely following a previous one can be affected by the presence of thermal electrons exceeding a certain critical density which are “quenched” in the flux tube where the impulsive acceleration of the second flare takes place. If the critical density ($\sim 3 \times 10^{13}$ cm$^{-3}$) is exceeded, the beam electrons will lose their energy at high altitudes, and no chromospheric evaporation will occur (as was the case in the double flare of August 31, 1980). The measurements of strong Ca XIX blue shifts in both flares on November 5 indicate that “quenching” of the second flare did not occur. Since the observations all suggest that the main components of the two flares were co-spatial (not including the outlier), it is likely that both flares occurred in one flux tube and that the critical density was not reached.

Longevity of the X-ray Loops

Martens et al. (1985) conjectured that two fairly stable loops in region 2776 dominated the HXIS emission from November 5, 12:30 to November 6, 03:50. These loops were labelled AB and BC (Figure 1.4.10). During this time loop AB flared twice at 22:26 and 22:34 UT with several other flare-like brightenings at 15:04, 17:20, 20:47 and 23:50 on November 5. In the second flare the footpoint C of the impulsive phase was connected to the common footpoint B of the two loops. Apparently, loop BC was quite long-lived (Martens et al., 1985) with small variations correlated with the brightenings in loop AB.

Because loop BC was stable in emission we can assume that it was in static thermal equilibrium. We can therefore use scaling laws (Rosner et al., 1978) to derive the electron
density \( n_e \) and the heating rate in the loop \( E_h \) from the observed loop length \( L \) and temperature \( T_{\text{obs}} \) from HXIS. (We note, however, that the usefulness of the static loop scaling law has been questioned by Roberts and Frankenthal (1980)). From the observed emission measure \( Y \) and the derived density an estimate of the emitting volume \( V_{\text{em}} = Y/n_e^2 \) of the loop could be made. This emitting volume was, surprisingly, much smaller than the observed volume \( V_{\text{obs}} = Lr^2 \) of the loop. The loop filling factor \( \phi = V_{\text{em}}/V_{\text{obs}} \) had an almost constant value of \( 10^{-3} \). These results are summarized in Table 1.4.3.

**Table 1.4.3**

<table>
<thead>
<tr>
<th>General Data on Loop BC, November 5/6, 1980</th>
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<tbody>
<tr>
<td>Mean Length ( (93.4 \pm 1.5) \times 10^8 ) cm</td>
</tr>
<tr>
<td>Mean Diameter ( (11.4 \pm 0.3) \times 10^8 ) cm</td>
</tr>
<tr>
<td>Mean Temperature ( (10.4 \pm 0.2) \times 10^6 ) K</td>
</tr>
<tr>
<td>Mean Electron Density ( (9.8 \pm 0.4) \times 10^{10} ) cm(^{-3} )</td>
</tr>
<tr>
<td>Mean Filling Factor ( (1.4 \pm 0.3) \times 10^{-3} )</td>
</tr>
<tr>
<td>Mean Heating Rate ( (0.64 \pm 0.04) ) erg cm(^{-3} ) sec(^{-1} )</td>
</tr>
</tbody>
</table>

Similar data on loop AB could not be derived, since it was unresolved by HXIS and its emission was highly variable. During quiescent periods loop AB had a temperature of \( 10^7 \) K and an emission measure per \((8'' \times 8'')\) pixel of about \( 1.5 \times 10^{46} \) cm\(^{-3} \). Duijveman et al. (1982) derived an electron density of \( 2.4 \times 10^{10} \) cm\(^{-3} \) from the observed temperature and an emission measure of loop AB by assuming a filling factor of unity, while FCS observations of Ne IX were used to derive \( n_e = 1.5 \times 10^{12} \) cm\(^{-3} \) (Wolfson 1983). Agreement between these observations is obtained by using a filling factor of \( 2.6 \times 10^{-4} \), which is of the same order of magnitude as that of loop BC.

Together these observations suggest the continuous dissipation of a current which is present in loops AB and BC, with the actual loss taking place in a very thin region. Clearly during flares the dissipation mechanism changes qualitatively in character.

It is still an open question whether the first and smaller burst late on November 5 triggered the second burst, or whether both were triggered by earlier events. The preflare manifestations of these flares have not yet been reported in sufficient detail to assess their significance. It appears, from the BBSO H\( \alpha \) film, that the first flare started in a fibril crossing the neutral line. This fibril went into emission at 22:23:29, approximately simultaneously with a rise in OV seen by UVSP, a small rise at 15 GHz (Hoyng et al., 1983) and a rise at 9400 MHz (Enome et al., 1981). Earlier sub-flares occurred on the same neutral line.

This double flare is important not only for the questions associated with homology, but as a possible test case for double flares in general. It has been estimated (Strong et al., 1984) that \( 43\% \) of the \( 200 \) largest flares seen by the XRP in 1980 were “multiple” (on the basis that the Ca XIX flux did not fall to background between maxima). The importance of such “multiple” flaring for preflare studies lies in their possible relation to precursors, triggering and the repeated “attempts” of a flare to start.

### 1.4.4 Comparison of Preflare X-rays and Ultraviolet

Waggett, Bentley and Woodgate compared BCS and UVSP images for those of the 26 events in the Table 1.4.2 that showed pre-impulsive activity in the UVSP images. As both the FCS and UVSP are capable of performing a vari-
ety of different size rasters within large fields of view it is possible for them to be looking at different areas within the same active region. Coalignment of the instruments’ fields of view left 10 events with good overlapping spatial and temporal coverage in both UVSP and FCS images.

Two time intervals were considered: the preflare period prior to the HXRBS onset and the impulsive phase prior to the HXRBS peak. The spatial separation of the UVSP preflare bright points and the FCS flare site were divided into three distance categories: less than 20" (adjacent to or at the flare site), between 20" and 40" (close to the flare site), and greater than 40" (far from the flare site). The results are given in Table 1.4.4 where the separation of the nearest preflare pixel is indicated by a ‘Y’ in the appropriate distance column. The BCS column indicates whether there was significant activity in the BCS Channel 1 light curve during the preflare period and the BDIP column indicates whether the preflare pixel brightened during the impulsive phase in the FCS data.

With only 10 events it is difficult to form meaningful conclusions. It is hoped that coordinated observations with special observing sequences during the SMM 2 mission will expand the sample. The inclusion of XRP data has improved the results of the UVSP analysis by confirming the position of the flare site and by removing events that were initially confusing. It is clear that the correlation of preflare UV bright point position and the flare site is good since 6 (possibly 7) of the nearest 10 preflare events are coincident with the subsequent flare site.

### 1.4.4 Preflare Microwave Intensity and Polarization Changes

We discussed in Section 1.4.3 some interferometer observations which showed preflare polarization changes.

<table>
<thead>
<tr>
<th>Date</th>
<th>Distance of Pixel</th>
<th>BCS</th>
<th>BDIP</th>
<th>UVSP Line</th>
<th>Pixel Size (arc sec)</th>
<th>Preflare Intensity (UVSP C/S)</th>
<th>Impulsive Phase Intensity (UVSP C/S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29/3/80 (2014 UT)</td>
<td>Y N N</td>
<td>CIV 3</td>
<td>1.42 x 10^4</td>
<td>3.42 x 10^4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27/4/80 (0106 UT)</td>
<td>Y(*) N</td>
<td>CIV 3</td>
<td>3.42 x 10^4</td>
<td>NOT SEEN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30/4/80 (2023 UT)</td>
<td>Y N N</td>
<td>CIV 3</td>
<td>6.13 x 10^3</td>
<td>2.76 x 10^4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/6/80 (0488 UT)</td>
<td>Y N N</td>
<td>CIV 3</td>
<td>2.92 x 10^3</td>
<td>2.34 x 10^4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29/6/80 (2022 UT)</td>
<td>Y Y N</td>
<td>CIV 3</td>
<td>1.08 x 10^4</td>
<td>1.66 x 10^4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/7/80 (2126 UT)</td>
<td>Y N Y</td>
<td>SiIV 3</td>
<td>4.07 x 10^2</td>
<td>7.00 x 10^4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/10/80 (1741 UT)</td>
<td>Y N N</td>
<td>OV 10</td>
<td>3.80 x 10^2</td>
<td>4.28 x 10^3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/11/80 (0211 UT)</td>
<td>Y N ?</td>
<td>OV 10</td>
<td>2.99 x 10^2</td>
<td>NOT SEEN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/11/80 (2054 UT)</td>
<td>Y Y Y</td>
<td>OV 10</td>
<td>9.06 x 10^2</td>
<td>1.63 x 10^3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/11/80 (2231 UT)</td>
<td>Y Y N</td>
<td>OV 10</td>
<td>1.46 x 10^2</td>
<td>2.59 x 10^2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Although it may be true (Hurford and Zirin 1982, Willson and Lang 1984) that preflare polarization changes at centimeter wavelengths are not generally detected, there is evidence (Hurford and Zirin 1982) that certain microwave signatures are relatively reliable predictors of flares.

In a study of a sample of 81 major flares observed at 10.6 GHz with the Owens Valley Radio Observatory (OVRO) interferometer, Hurford and Zirin (1982) found a variety of preflare behavior. The most common preflare signature was a step-like increase in signal amplitude I, accompanied by a decrease or reversal in the polarization signal V during the last 10 to 60 minutes before the flare. This signature was found in the first half of the data base (Feb. 19 – Sept. 1, 1980), and when applied by a computer program to the second half (Sept. 1, 1980 – March 31 1981) succeeded in “predicting” five out of 54 flares. This low success rate limits its practical value as a flare predictor but the microwave signatures do illustrate the coronal manifestation of some kind of magnetic activity. Figures 1.4.1a,b show two examples of flares observed at 10.6 GHz by OVRO on July 1 and October 11, 1980. The first shows a signature of increasing I and decreasing V, while the second shows only increasing V. Kundu (1981) suggested that the cause of microwave enhancements and polarization changes may be increasing magnetic field strength at the coronal level. The increasing magnetic field causes new loops to become optically thick at low harmonics (2nd, 3rd, and 4th) of the gyro-frequency. Depending on the relative orientation of the pre-existing and new loops, the polarization can increase (Lang 1974, 1979), flip (Kundu 1981, Kundu et al., 1982) or decrease (Hurford and Zirin 1982). Only two-dimensional interferometer (VLA) can resolve the loop geometry, and there are still too few examples from OVRO to infer the loop geometry statistically. Hurford and Zirin (1982) showed in 3 cases that microwave changes were associated with subflares or filament changes. The July 1 event illustrates an example of a preflare brightening in Hα (at ~ 16:18), near the start of the increase in one of the polarization channels. The June 25 flare reported above in Section 1.4.3.1 illustrated another association between microwave and Hα changes.

The gradual rise in preflare microwave intensity can be observed with patrol instruments, and is presumably associated with “preheating” and gradual rises in soft X-rays (see Section 1.4.2). These gradual increases in microwaves are frequently associated with filament activations (Webb et al., 1976, Sheeley et al., 1975, Webb and Kundu 1978) and were observed by patrol instruments for the June 22, 25 and 26 flares discussed above. The OVRO amplitude for the July 1 X-ray flare (Figure 1.4.11a) showed a preflare increase that was not observed by patrol instruments or in the Ca XIX time profile. Thus the heating effects may have been too small to be observed in X-rays, but a microwave increase was observed possibly because of the extreme sensitivity to the magnetic field in the cyclotron emission mechanism. More recently the OVRO system has been made into a microwave spectrometer, examining typically 30 – 40 frequencies from 1 – 18 GHz with a time resolution of seconds. With this system Hurford (1983) found that some microwave precursors were characterized by narrow-band spectra with sharp high and low frequency cutoffs. He has interpreted these data in terms of gradual loop heating.

1.4.6 Non-Thermal Precursors

Long before SMM, it was argued that non-thermal processes occurred during the “buildup” phase of solar flares (Kane and Pick 1976) and in the absence of flares (Webb and Kundu 1978). Several preflare team members presented new evidence and theoretical arguments for non-thermal, non-flaring activity as seen in radio waves. Kosugi summarized a number of preflare activities observed at 17 GHz using the Nobeyama interferometer. He and his co-workers (Kai et al., 1983) examined 25 pairs of bursts which occurred within 10 to 50 minutes of each other. These pairs were cospatial (in one dimension) to < 50” in 12 out of 15 cases. In most cases, the prebursts were impulsive, and therefore were not likely to be signatures of gradual preflare heating. However, they also noted that in more than half of the cases, Hα flaring started before the “preflare” burst, which argues in favor of preflare heating. They suggested three possible mechanisms for prebursts:

- A process related to the main energy release such as joule heating in current sheets.
- Pre-acceleration of electrons prior to the main acceleration.
- Manifestation of “leakage” of accelerated electrons.

They pointed out that the “leakage” mechanism is probably not consistent with the long time interval between bursts. Kosugi also showed evidence for statistical association in the number of type III (meter wave) bursts within minutes of prebursts at 17 GHz (Kosugi et al., 1985). No spatial locations were available for the type III bursts. Finally, Jackson reported that a study of spatially located type III’s observed at Culgoora showed a statistically significant tendency to occur an hour or so prior to large Hα flares. If these associations between prebursts at 17 GHz, Hα flares and type III’s are valid, then the mechanism of pre-acceleration appears to be favored.

Harrison presented a model (Simnett and Harrison 1984) of precursors in which $10^3$-$10^4$ keV protons heat a high coronal loop, destabilize the pressure balance and heat the chromospheric plasma to produce the precursor X-rays. The acceleration mechanism is a small shock, which primarily heats protons within a large-scale magnetic loop. The model is directed primarily at the situation where precursors are widely separated preceding a coronal mass ejection with or without a flare.
Figure 1.4.11a The July 1, 1980 flare time profiles at 10.6 GHz (Owens Valley Radio Observatory, Hurford and Zirin 1982) showing the "onset" signature of increasing I and decreasing V. The middle panels show the amplitudes of R and L (right and left circular polarizations); V = (R - L) / V.

Figure 1.4.11b The Oct. 11, 1980 flare time profiles at 10.6 GHz (OVRO, Hurford and Zirin 1982).
There is evidence for electron acceleration in the absence of flares. Chiuderi-Drago pointed out that sometimes bright non-flaring sources (\(T_b > 5 \times 10^6\) K) appear on microwave maps, and these sources may be explained (Chiuderi-Drago and Melozzi 1984) in terms of gyrosynchrotron emission from accelerated electrons trapped in coronal loops, where they may survive for \(\sim 10^2\) sec. This is consistent with the lifetime of some precursors, and if continual acceleration occurs, the mechanism could explain some long-lived microwave sources. If the number of electrons is sufficiently high, then the gradual-rise-and-fall events commonly associated with filament disruptions (Webb et al., 1976, Sheeley et al., 1975), can be explained by a thermalization process (Webb and Kundu 1978) which follows the precursor acceleration.

### 1.4.7 Precursors of Coronal Mass Ejections

Although most of the SMM preflare data are for disk events, three coronal transient events on June 29 were well observed as region 2522/30 near the limb.

All of these limb events were observed by HXIS and C/P (Harrison et al., 1985) and the 02:33 and 18:22 events were also well observed by XRP and UVSP. These were possibly homologous events because the flares occurred in the same location and had similar X-ray profiles with GRF precursors and long flare decay times (Stewart, 1984; Woodgate et al., 1984).

Figure 6.5.1a,b (Chapter 6) shows the HXIS flux profile for June 29 and the extrapolated C/P coronal transient onset times for two of the three events. The detailed HXIS data and their interpretation are presented in Chapter 6 and only summarized here.

A long-lived 160 MHz noise storm preceded the 02:33 flare but ended at 02:21 (Gary et al., 1974). The flare was associated with two moving white-light loops whose height-time profile extrapolated back to the surface about 6-8 minutes before flare onset. The HXIS precursor began at about 02:10. Shine prepared Figure 1.4.12 which shows the preflare period 02:17– 02:29 in Si IV and O IV rasters, as well as the flare itself (02:33– 02:37). At the time of the first UVSP preflare rasters, the BCS, FCS and HXIS all recorded a brightening at the flare site at 02:19. Later, the point brightened again at \(\sim 02:28\), but was not visible in X-rays. The onset of the Si IV/ O IV burst was at 02:33:56 and appeared as multi-pixel brightenings within \(\sim 10''\) of the preflare UV brightenings.

The 10:40 UT event was not well observed by the C/P or UVSP, but a preflare He I "jet" was observed (Schmahl 1983). The white-light loop transient associated with the 18:22 flare had a projected surface start before 18:15 (Sime et al., 1980, Harrison et al., 1985). A small Hα and X-ray flare occurred at 18:05 at a position slightly displaced from the later flare site. The UVSP observed a preflare OV loop and Fe XXI brightening (Poland et al., 1982), and BCS analysis revealed turbulent line broadening up to 4 minutes before onset (Antonucci et al., 1982).

The relationship between coronal mass ejection (CME's) transients and flares is far from clear, and it is fairly well established that one may have CME's without flares and vice versa.

However, Harrison et al. (1985) argue that the flare precursor and the mass ejection precursor may be one and the same. In Section 3 of Chapter 6 Harrison gives examples in which the X-ray precursor of the mass ejection may be very small, as large as a flare, or "a lone precursor", without a following flare. At this stage of the analysis it is premature to assess the reality of the possible relationships among precursors of flares and CME's, but research along these lines may well provide a broader understanding of the role precursors play in the energy release process.

### 1.4.8 Short-Lived and Long-Lived HXIS Sources as Possible Precursors

Owing to its low background, particularly in its lowest energy band (3.5– 5.5 keV), HXIS is capable of detecting very weak X-ray sources. The X-ray precursors reported by HXIS observers (Sections 1.4.3.3, 1.4.4 above) have been interpreted as thermal events, with temperatures \(1–2 \times 10^7\) K. HXIS images often showed (Schadee et al., 1983) short-lived sources (SLS) and long-lived sources (LLS) in the 3.5–5.5 keV band. The short-lived sources (lifetime less than or about 15m) appeared indistinguishable per se from HXIS precursors but did not always precede flares. The long-lived (hours-days) sources were of larger scale. Both had band-ratio temperatures of \(\sim 10^7\) K.

In the context of our study, HXIS LLS's preceded two large flares with precursors, namely, May 21 20:55 and the June 22 flare discussed in Section 1.4.3.2. Although not part of this study, the May 21 X1 flare is one of the best analyzed SMM flares and is discussed elsewhere in this monograph. As in the June 22 case, it was preceded by a compression of pre-existing flux. See Section 3.5.4(iii), Harvey (1983). Discrete LLS's cospatial with the curving filament persisted for many hours on May 20 and 21. One source was located near the site of the EFR where the filament broadened then parted 10 minutes before impulsive onset.

Figures 1.4.13a (coarse FOV) and 1.4.13b (fine FOV) show accumulated HXIS images during 20 hours preceding a two-ribbon flare on June 21, 00:55. LLS's were frequently present, cospatial with the neutral line and filament curving from SE to WNW through the center of the FOV. LLS's occurred along the filament until its eruption before the flare of June 22, ~ 13:04. Even though the filament soon reformed, no further LLS's were observed after this event.

As evidenced by Figure 1.4.13, long-lived sources extend over a large area, often persisting for several hours.
June 29, 1980  2:34 GMT
M2 Flare on West Limb

preflare large rasters

Si IV 1402  O IV 1401

2:17 to 2:21 GMT

small rasters during flare

Si IV 1393A and O IV 1402A  
each 7 x 7 raster covers 28" x 28"

preflare event

Figure 1.4.12 Preflare and flare images in Si IV and O IV (UVSP), 02:17-02:37, 29 June 1980.
Figure 1.4.13 Long-Lived HXIS sources seen preflare June 22, 1980. Post-flare images do not show these sources. Coarse field-of-view maps are shown on the left and fine field-of-view maps are shown on the right.
The characteristics of LLS's are: durations of tens of minutes to hours; temperature \( \sim 10^7 \) K; and emission measures of \( \sim 10^{46} \) cm\(^{-3}\). They often show gradual intensity changes.

Most LLS's appear to result from activity along neutral lines. They may represent the high temperature tail of the thermalized plasma associated with filament activity as observed during Skylab (e.g., Webb et al., 1976, Webb and Kundu 1978, Kahler 1977). The Skylab soft X-ray filament enhancements had emission measures an order of magnitude higher and temperatures an order of magnitude lower than the HXIS LLS's.

If the LLS's originate beneath the filament, then the model of Kopp and Pneuman (1976), Van Tend-Kuperus (1978) and Hood and Priest (1980) may be applicable. In that model the convergence of magnetic flux towards the neutral line in the photosphere results in energy dissipation by reconnection below the filament in the corona. Interestingly, other observations (Athay et al., 1984) show evidence of magnetic flux converging at the neutral line in the Martin region. They suggest a process of continuing reconnection. At this stage it is not clear whether the X-ray emission results from filament activation, from continuing reconnections, or both.

1.4.9 Summary: Are all the Blind Men Looking at the Same Elephant?

We have reported a variety of coronal manifestations of precursors or preheating for flares and have found that almost everyone with a telescope sees something before flares. Whether an all-encompassing scenario will ever be developed is not at all clear at present. The clearest example of preflare activity appears to be activated filaments and their manifestations, which presumably are signatures of a changing magnetic field. But we have seen two similar eruptions, one without any evidence of emerging flux (Kundu et al., 1985) and the other with colliding poles (Simon et al., 1984). While the reconnection of flux is generally agreed to be required to energize a flare, the emergence of flux from below (at least on short timescales and in compact regions) does not appear to be a necessary condition. In some cases the canceling of magnetic flux (Martin, 1984) by horizontal motions instead may provide the trigger (Priest, 1985).

We have found many similarities and some differences between these and previous observations. The similarities, besides the frequent involvement of filaments, include compact, multiple precursors which can occur both at and near (not at) the flare site, and the association between coronal sources and activity lower in the atmosphere (i.e., transition zone and chromosphere). Because of differences in instrumentation and improvement in multi-wavelength coverage with high time resolution, we have been able to identify several new aspects of preflare activity in the SMY data. These include the facts that: precursors were observed over a wide range of temperatures and heights; there were long-lived, hot (\( > 10^7 \) K) X-ray sources preceding some flares; and there was evidence for high energy phenomena, particularly electron and possibly proton acceleration before flares. The fairly rapid reformation of some filaments after their explosive eruption suggests that the photospheric boundary conditions remain unchanged, at least after some flares. Concerning filament-eruption flares, we saw suggestive examples in Section 1.4.3 of a flare exciting agent (at least as detected by its emission) first arising under the central portion of the filament.

Finally, our results leave us with several important questions. We have shown examples of preflare X-ray enhancements and small impulsive-like bursts. Are these signatures of an incremented instability, in which the flare "tries to start and fails" or are they signatures of a separate process that energizes the corona first with the flare following as a separate phenomenon?

Is the preflare gradual phase caused by the same mechanism as the postflare phase? Alternatively, does the gradual preheating occur through thermalization of an energetic population signified by nonthermal prebursts? Do microwave signatures signify changing coronal magnetic fields during the preflare hour, and (if so) what can we learn of the field strength and configurations? While the observational analysts continue to wrestle with the study of the vast SMM data store, the theoreticians must continue to synthesize and interpret these diverse phenomena in a consistent fashion.
1.5 REFERENCES


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