A QUERY INTO THE SOURCE OF PROTON EMISSION FROM SOLAR FLARES

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1.0 INTRODUCTION

From the literature review conducted during this study it was concluded that no properties of flares or active centers have yet been found which uniquely identify a flare that produces protons in the vicinity of earth from one which does not. This conclusion does not disclaim the fact that there are certain properties of some flares and their active centers that are statistically correlated with the detection of very energetic protons. It merely means that exceptions have been found to every such statistical association.

Because of this apparent lack of unique proton flare properties, it is important to ask the question, "Are all major flares sources of proton emission?" Since the conditions of particle propagation in the interplanetary medium are not well enough known and the conditions of proton injection are even less well-known, there is at present no definitive answer to this question. However, for purposes of this study, it is assumed that the answer is likely to be, "Yes, all major flares eject protons." Accordingly, this report follows the recommendation in the literature review that information on the possible source of proton emission should be sought by studying the properties that all major flares may have in common.

The question of the possible source of proton emission is addressed herein by re-examining seven solar flares that were followed by major proton events. These seven events were chosen for this study because of the availability of high quality Hα observations prior to or during these events and because this sample of events includes very diverse flare characteristics. The dates and times of these events are listed in Table I.

2.0 PROPERTIES COMMON TO ALL MAJOR FLARES

Ground-based observations (references cited in reviews by Svestka, 1976; Martin, 1979; Report I of the subject contract) have shown that major flares invariably occur in active centers or complexes of active centers where the line-of-sight component of both the magnetic field and velocity field are zero. The chromospheric elements are divided into two or more emission segments, which are centered with respect to locations where $V_{||} = 0$ intersect or coincide with $H_{||} = 0$ lines. In addition, Hα structures and motion provide evidence that the direction of the magnetic field in the chromosphere and low corona is parallel or very near parallel to the $H_{||} = 0$ lines prior to the occurrence of major flares. This combination of conditions at the sites of solar flares is consistent with the geometry of either a current sheet or a field that is strongly sheared in a horizontal plane (a plane approximately parallel to the solar surface). The magnetic field geometry at flare sites is also similar to the geometry of "tangential discontinuities" in the interplanetary magnetic fields.

The Skylab ATM experiments revealed two more properties thought probably to be associated with all major flares: (1) the occurrence of coronal flare loops at x-rays and EUV wavelengths and (2) the occurrence of white light transients beyond 20 solar radii. (Obviously, transients were only observed for events sufficiently close to the solar limb.)

Under the assumption that all flares are proton flares, the <u>visible</u> flare characteristics which <u>could be somehow</u> related to proton acceleration

Table 1

Optical Flare						Proton Event*		
Date	Start	Max.	Duration (Min.)	Location	Imp.	Date	N Time	N Duration
2 Aug. 1972	1838	1844	18	N13E28	1B	4 Aug.	0200	0.5
2 Aug. 1972	1958	2058	218	N12E28	2B	4 Aug.	1400	7
7 Aug. 1972	1449	1534	152	N16W35	3B	9 Aug.	0000	5
29 Jul. 1973	1312	1239	>348	N14E45	3B	31 Jul.	0800	?
7 Sep. 1973	1141	1212	170	S18W46	2B	9 Aug.	0000	5
5 Jul. 1974	1506	1515	65	S14W23	1B	6 Jul.	1800	1-2
5 Jul. 1974	2123	2143	119	S17W26	2B	7 Jul.	1200	2-3

*Neutron Monitor Reports
All data in this Table is from Solar Geophysical Data

are reduced to:

(1) chromospheric flare elements adjacent to $H_{||} = 0$ lines

(2) flare loops

(3) coronal transients

3.0 DIVERSE CHARACTERISTICS AMONG MAJOR FLARES

3.1 The Range of Emission Features with Flares

In order to not be too simplistic, the diverse characteristics of flares need also to be considered. In the most general sense, a flare historically has been considered to be any brightening observed in Hα or other spectrum lines. In addition to the bright chromospheric flare elements which occur on opposite sides of the $H_{||} = 0$ line at the feet of the EUV and x-ray coronal loops, a number of other emitting flare elements are known. These have been identified as:

(1) Hα loops in emission (prior to loops in absorption)

(2) Peripheral chromospheric brightenings

(3) Emission traversing curved trajectories

(4) Faint diffuse moving emissions described variously as "emission front," "flare-halo" and "flare-veil"

(5) Bright surges or parts of surges

(6) Brightened filament mass

This multitude of flare features, particularly items (1)-(4), are often not separately distinguishable in low resolution films of flares and sometimes not even in the current higher quality, larger scale Hα images. If the various forms of flare emission are not distinguished, the properties that major flares have in common may also be obscured. Using the seven proton flares mentioned above, examples of the various forms of flare emission are discussed below, excluding surges and erupting filaments whose identification usually poses no problem.

3.2 Hα Loops

An exquisitely clear example of an Hα flare loop system in emission is seen in Figures 1 and 2 with the flare of 7 August 1972. In these illustrations from the Big Bear and Lockheed Solar Observatories, the tops of individual loops stand out as curvilinear emission arcs lying approximately midway between the chromospheric flare elements at 1555 UT and later. It is now well known that the arcs are sections of flare loops which join the inner boundaries of the chromospheric ribbons (Rust and Bar, 1973). The 7 August 1972 flare develops into a classical example of what is known as a "two ribbon" flare. The row of more or less parallel loops has been called the "third flare ribbon." It may be noteworthy that the spectra in Figure 2 reveal the Hα profiles of loops to be more broad than the chromospheric flare elements at the time shown! Unfortunately, the multislit Hα spectra were not obtained earlier in the flare.

Another example of a flare showing the classical two ribbon form is shown in Figure 3. This flare on 29 July 1973 occurred in a nearly "spotless" active region. When the 16 mm. copy of the film of this event is viewed on a motion picture projector, sections of very faint emission loops are seen prior to their changing to absorbing loops as seen in Figure 3. In narrow band filtergrams, such as these, one only sees the section of the loops which lie nearly perpendicular to the line of sight because Doppler shifted mass flowing along the loops renders the complete loops invisible unless one has the capability of tuning the passband of the filter into the wings of the Hα line.

In Figure 3, it is seen that the bright flare ribbons separate as a function of time. Both the separation and the duration of flare ribbons seems to be inversely proportional to the strength of the magnetic field at the flare site. As an example, the 29 July 1973 flare (Figure 3) shows a marked

BIG BEAR SOLAR OBSERVATORY
GREAT FLARE 8/7/72

Fig. 1. This bright flare develops into the classical "two ribbon" form between 1530 and 1555 UT. The tops of flare loops in emission are seen at 1555 UT as short arcs appearing to join the chromospheric flare ribbons. In the upper part of the flare at 1555 UT, some cooler absorbing loops have already formed.

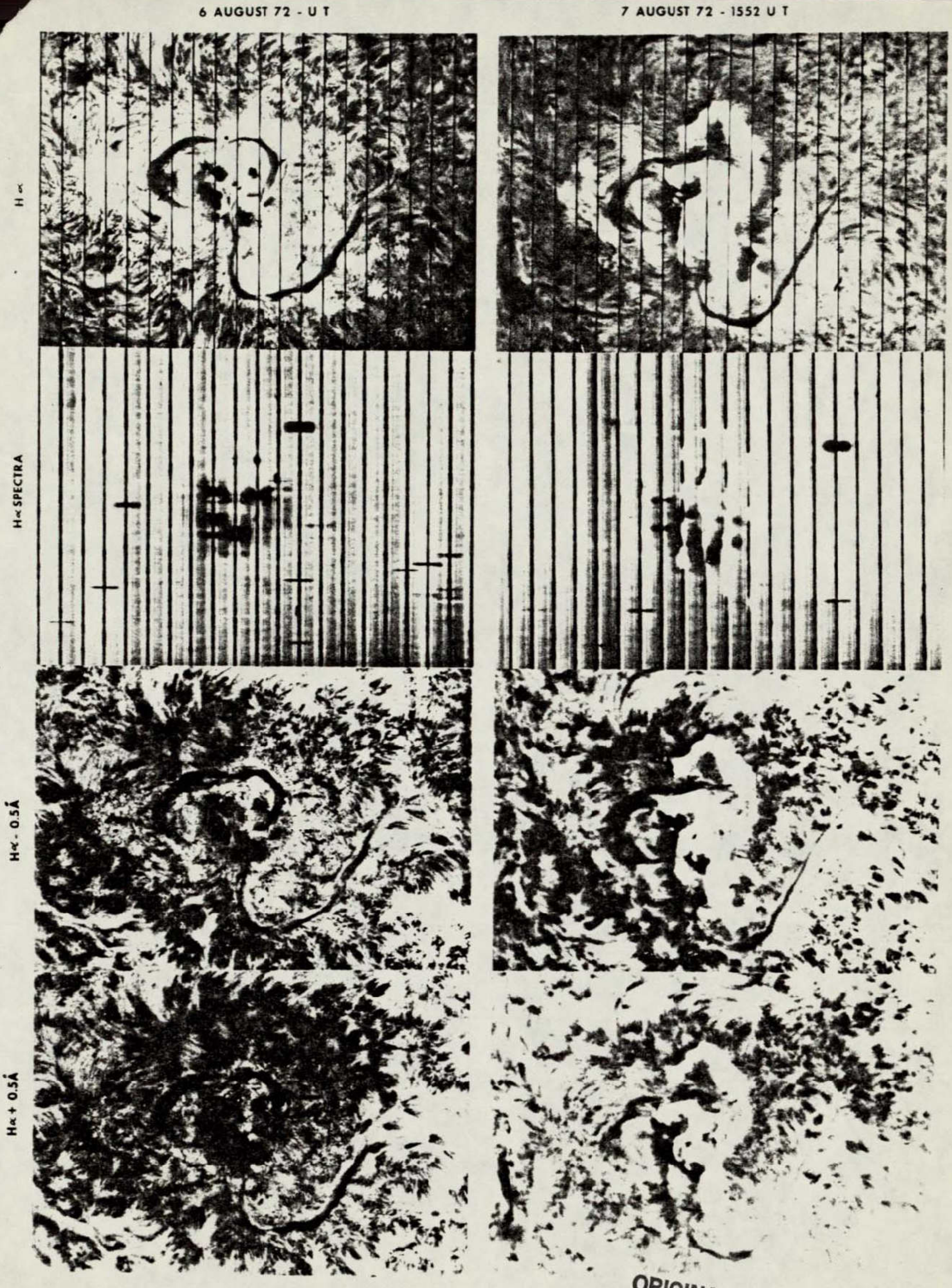


Fig. 2. The flare of 7 August 1972 photographed at the Lockheed Solar Observatory is compared with the active region filaments seen on the preceding day. The filaments around which the flare is centered erupted at the outset of the flare. The slit in the upper right frame which crosses the loops reveals a relatively broad Hα profile (3-4A) in contrast to the profile of chromospheric flare ribbons at the time shown.

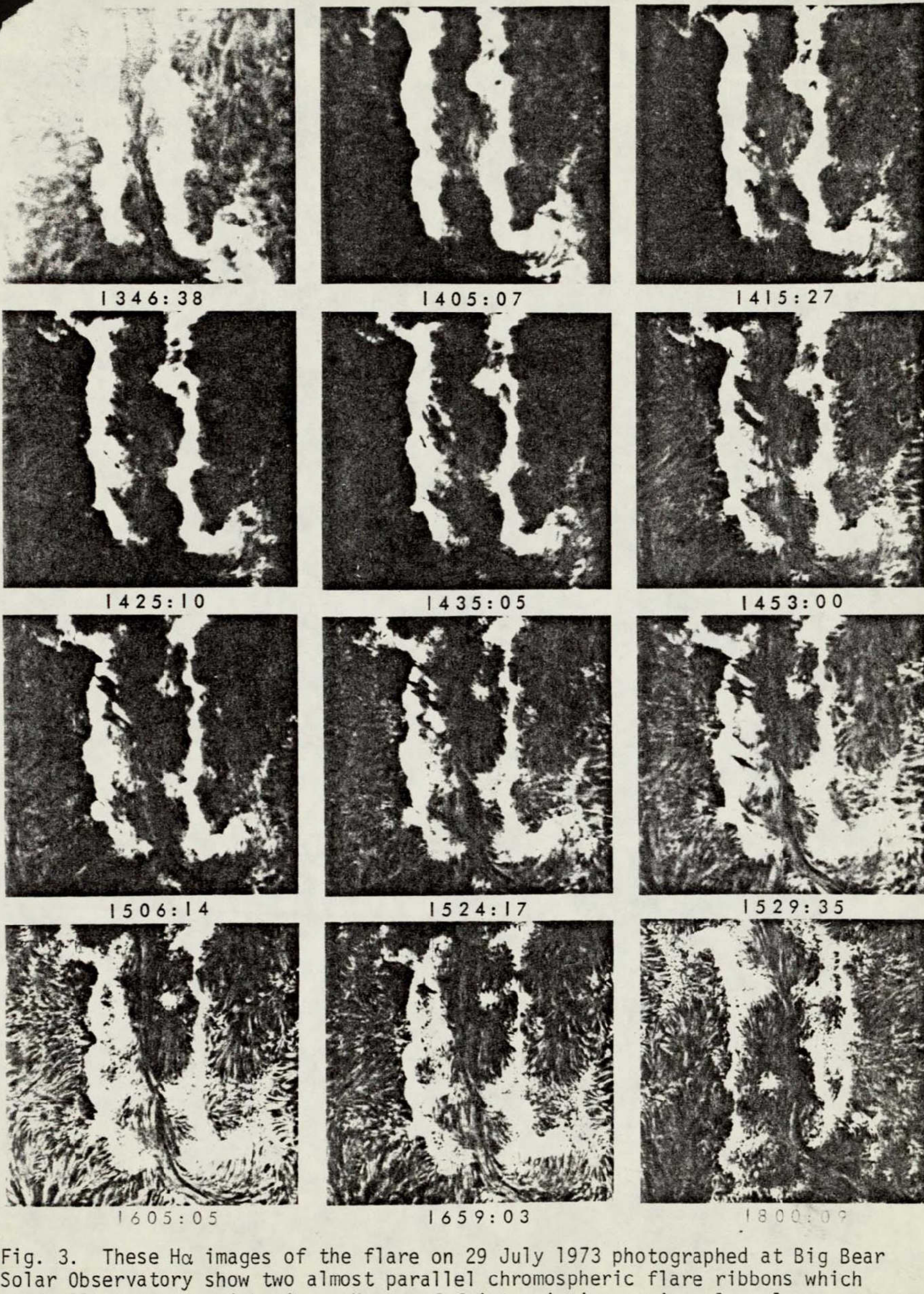


Fig. 3. These Hα images of the flare on 29 July 1973 photographed at Big Bear Solar Observatory show two almost parallel chromospheric flare ribbons which gradually separate with time. Knots of faint emission moving along loops are seen between the flare ribbons at 1415 UT and earlier. Subsequently, the visible sections of the flare loops are seen in absorption projected against the limbward ribbon.

separation of the flare ribbons and an extremely long duration, over six hours. In contrast, the 7 August flare occurred close to strong spots and revealed a lesser degree of ribbon separation and a shorter lifetime.

In many flares, however, the loops as seen in Figures 1, 2 and 3, may not be resolved and they may be superposed in projection against the bright chromospheric flare ribbons. In such circumstances, the two ribbon character of the chromospheric flare, as seen in the flare of 7 August 1972 (Figures 1 and 2) may not be evident. Such examples, where the separation of the chromospheric flare element is not clearly seen in Hα, are the two flares of 5 July 1974, shown in Figures 4 and 5. The bright core of the flares appear in the same position relative to the sunspots in Figures 4 and 5. Only in the D_3 HeI images in Figure 5 (or in the wings of Hα--not shown), is it seen that the flare has discrete chromospheric elements that separate around the $H_{||} = 0$ line. The motion of the flare ribbons in this case is apparently restricted greatly by the strong fields of the sunspots underlying the flare. At Hα line center one cannot, at the times shown in Figures 4 and 5, distinguish between Hα loops and Hα chromospheric emission. After flare maximum, however, as some of the emission is decaying, the bright arcs, as in the 7 August 1972 flare, become distinguishable in the center of the brightest emission seen in Figures 4 and 5. Thus, these flares on 5 July 1974 are in fact "two ribbon" flares.

3.3 Peripheral Chromospheric Brightenings

In addition to the bright flare core of the 5 July 1974 flares, seen in the lower left of each frame in Figure 5, smaller flare elements are seen in the upper part of each frame. This peripheral emission is readily seen in absorption in the D_3 HeI images in Figure 5. Such peripheral emission has also been identified in soft x-ray images (Rust and Webb, 1977). Unlike the flare

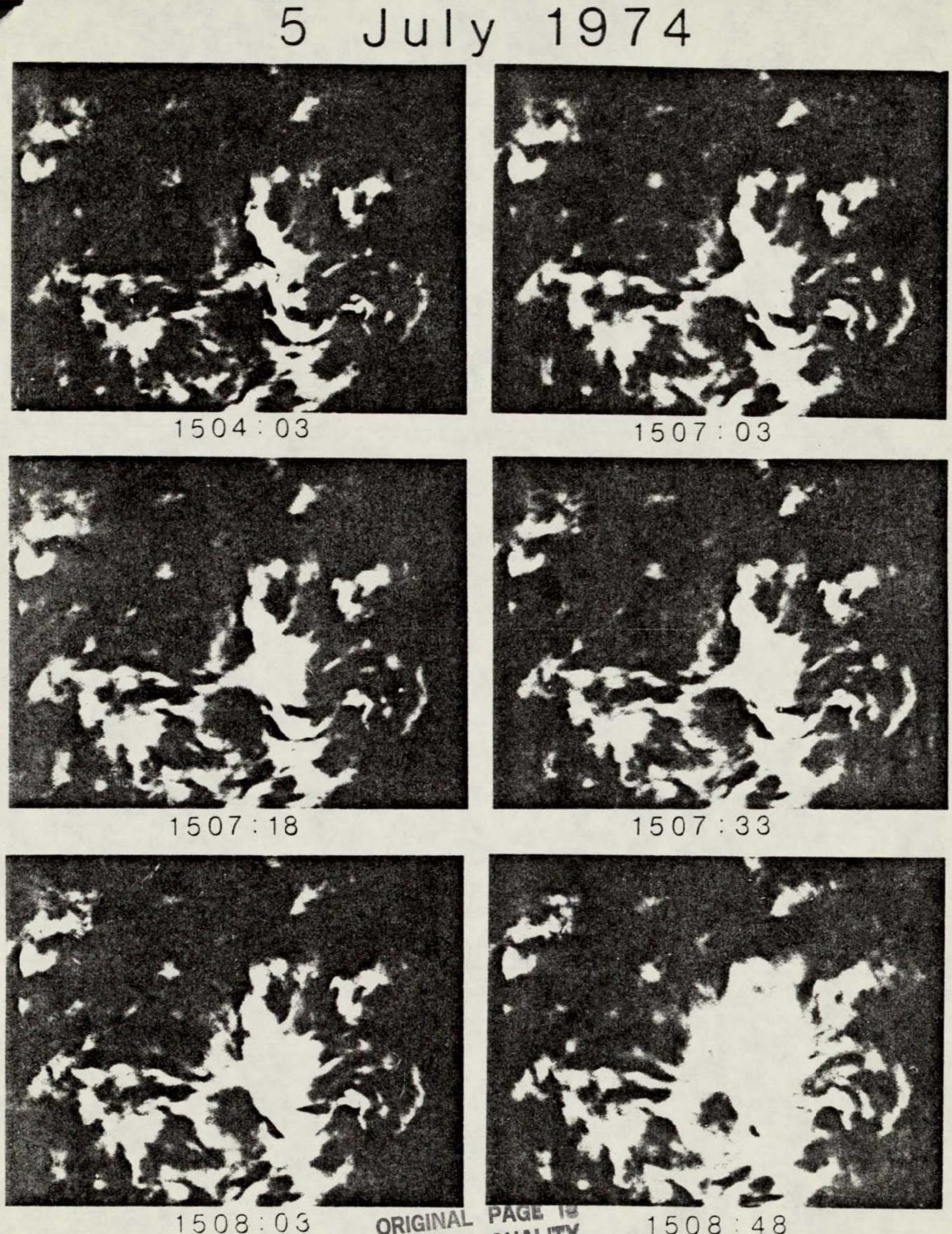


Fig. 4. Only the early development of this flare photographed at Big Bear Solar Observatory is shown. Initially the boundaries of the chromospheric flare appear to be very sharp. As the flare develops, a diffuse patch of emission appears near the center of the flare and suddenly expands to encompass the sunspot to the left of the flare. This is the flare "veil". Maximum extent appears at 1508:45 UT. Subsequently, the veil disappears and the flare boundaries again appear sharp.

Fig. 5. This second major flare on 5 July 1974 photographed at the Lockheed Solar Observatory developed almost identically to the flare in Fig. 4. This flare is shown at its maximum brightness (2142:00) and maximum size (2147:30) in Hα, (top row), Hα multi-slit spectra (middle row) and D_3 HeI (bottom row).

core and flare loops, the peripheral emission is not centered with respect to $H_{||} = 0$ lines. The initial appearance of the peripheral emission is also delayed with respect to the start of the flare core emission. The more distant elements of peripheral emission brighten last as if the emission were initiated by something emanating from the area of the flare core at its flash phase. It is similar to the chromospheric brightenings described by Smith and Harvey (1971) except that it occurs in this case within the active center of the flares. The peripheral emission is usually an enhancement of plage or network elements that were already slightly brighter than the average background. The elements show little or no apparent motion. The Hα spectra of the peripheral emission is always weak and very narrow in profile. In Figure 5 it is seen as a slight weakening of the Hα line.

3.4 Emission Traversing Curved Trajectories

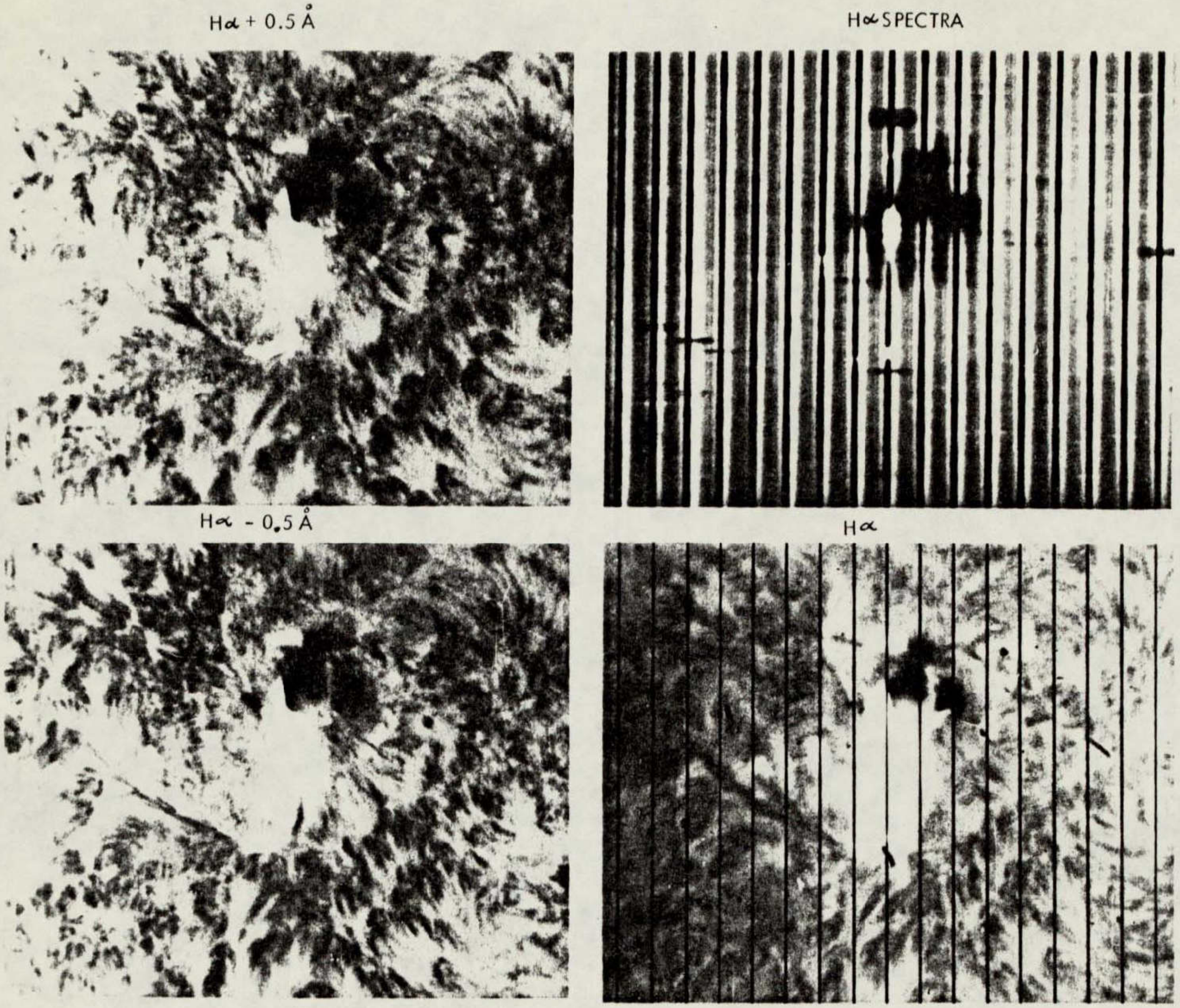
Emission traversing a curved path, apparently above the chromosphere, is another form of flare emission which is quite common but is rarely mentioned in the literature. One example was described by Smith and Ramsey (1967). In single pictures it is often difficult to differentiate this emission from the chromospheric flare elements. However, in cine-projection, this emission is readily distinguished by its relatively rapid motion in contrast to the slow development of chromospheric elements at the foot points of loops. Hence, if not superposed against a background of chromospheric flare elements, it is identifiable by its motion in the plane of the sky, by its relatively short duration, and sometimes by its Doppler shifts which may be either toward or away from the observer. The motions suggest that this emission is following specific curved paths defined by the magnetic fields of the corona overlying active regions. However, in Hα no pre-existing structures are seen along the trajectories of the moving emission. It may be relatively bright or very faint. An example of this moving emission appears in the lower right corner of the Hα images in Figure 5. One can see that rapid changes have taken place in this region while the flare core in the lower left corner seems to have simply expanded. The two Hα spectra in the lower right of the center frame of Figure 5 reveal some red shift and some blue shift. Also, the spectra show this moving emission to be less bright than the flare core emission, but relatively broad in profile. This emission probably corresponds to the dynamic parts of some flares seen very near the limb and gives us a clue to why limb flares and flares on the disk often appear to have such widely differing properties.

3.5 Veil Emission

A faint, diffuse veil of emission is seen with some bright flares. This emission has also been called the flare halo by Zirin and Tanaka (1973). The emission fronts described by Martin (1978) may also be the same type of phenomenon when seen offset from the flare core emission rather than superposed against it. In this report we choose to adopt the term "veil" or "veil emission" originally used by R. Hedeman at McMath-Hulbert Observatory because this term may imply an obscuration of background structures and irregular shape. The term "halo" is not used because "halo" implies that the phenomenon is stationary and symmetric with respect to the flare, which it generally is not.

The veil differs from the above-described emission in that it does not have well defined boundaries. It is an extensive flash of emission that appears in the vicinity of a flare and appears to emanate from around the flare core. It begins very close to flare start, increases in brightness and area during the flash phase of the flare and then rapidly fades from view. Examples of the veil emission are in Figures 4, 6 and 7. In the filtergrams in these illustrations, one notices only that the developing chromospheric flare boundary is not sharp. After the veil disappears from view, the expanding flare

2 AUGUST 1972



1840 UT

Fig. 6. In the wings of the Hα line (left) the flare shows two well separated flare elements. The Hα center-line image (lower right) shows a diffuse veil of emission overlying or surrounding the chromospheric emission elements. In the spectra (upper right) the veil appears as a slight overall decrease in absorption in the Hα line between the chromospheric elements.

BIG BEAR SOLAR OBSERVATORY
MULTIPLE FLARE 8/2/72

Fig. 7. The flare in Fig. 6 is also shown here in the first two frames in the left column. A second flare begins to develop less than an hour following the preceding flare. The second flare is much slower in development, much larger in area, and less impulsive than the previous flare. The second flare does not reveal a flare veil as seen for the earlier flare at 1839:26 UT.

boundaries again show distinct sharp or cerated edges. In both of the 5 July 1974 flares (Figures 4 and 5) and in the 2 August 1972 flare (Figure 6) the peripheral chromospheric flare elements appear immediately after the apparent rapid expansion of the veil as seen only in cine-projection. The properties and timing of the veil and the subsequent appearance of peripheral emission suggest that it is a transient coronal phenomenon which partially and temporarily obscures the underlying flare and surrounding chromosphere in the line-of-sight. For these reasons, Glackin and Martin (1978) proposed that this class of phenomena may be a visible aspect in the early development of a white light coronal transient. This is a debatable hypothesis because it implies the existence of neutral hydrogen in the low corona during and possibly before flares, for which there is yet little supporting evidence.

The spectra in Figure 6 show a low level brightening of the entire Hα lines where the slits in the filtergram (lower right in Figure 6) cross the veil where it is not superposed against the chromosphere parts of the flare. A distinct profile is not seen in the wings of Hα. The blue wing filtergram (lower left, Figure 6), however, shows the veil to be slightly brighter than in the red wing of the line (upper left, Figure 6). This is the only event in which the veil emission is bright enough to appear in the spectra and in the wings of the Hα line. The veil with the flare on 2 August 1972 is the brightest one detected to date. The associated flare is only a Class 1 flare, but it was very impulsive. The subsequent extensive Class 2 flare (Figure 7) which developed just south of this early flare at 1804 showed no sign of the hazy veil. This flare, though large, developed very slowly.

The above pattern, however, was not repeated for the pair of homologous flares on 5 July 1974 (Figures 4 and 5). In this case, the early flare showed an outstandingly bright flare veil, placed almost symmetrically around the flare core. The second flare developed a similar but much fainter veil. A peculiarity of the flares with the two brightest veils is that they are the smallest of the seven flares, and neither was associated with a clear cut filament eruption. The 2 August event, however, was associated with a mass ejecta --probably a bright surge. The later flare on 5 July, which showed a faint veil of emission, was associated with an erupting filament. In fact, the veil develops as the filament erupts. Thus, the flares which reveal veils do not seem to represent any distinct class of flare. Veils only have in common their association with relatively bright flares.

3.6 Emission Phases in Surges and Erupting Filaments

In addition to the forms of Hα flare emission discussed and illustrated above, flare-related surges and erupting filaments may also exhibit phases of emission. Sometimes surges begin as an emission feature and gradually make a transition from emission to absorption. The early flare on 2 August 1972 in Figure 6 is associated with such a surge. Erupting filaments always start as absorbing features when viewed against the disk. However, some filaments <u>in active regions</u>, make a transition from absorption to emission before the radial component of velocity shifts the filament out of the center of Hα. Part of the erupting filament with the second flare on 5 July 1974 became unusually bright before it moved out of the field of view of the telescope (not shown in Figure 5). Usually, the identification of surge or filament mass in emission is readily made by observing the apparent origin and trajectories of the mass.

3.7 Unidentified Forms of Flare Emission

Occasionally, an emission feature is observed that does not readily fit any of the above descriptions of the various common forms of flare emission. One such unidentified emission feature is seen limbward of the flare on

7 September 1973, illustrated in Figure 8. It most closely resembles a surge except that it is not seen to ever fall back into the sun. It originates with a small brightening close to a filament that subsequently erupts with the following major flare. The emission feature does not appear to be part of the filament which seems to remain in place until flare start. It appears to be too well defined to be a flare veil, and too cohesive to be an enhancement of successively brightened chromospheric elements. Hence, it remains for the present in the category of unidentified flare emission.

There are unusual aspects of the ejected emission with this flare on 7 September 1973 which are worth noting. First, it is a preflare phenomenon. It begins nine minutes prior to the start of the major flare. Secondly, it occurs in the location where a transient x-ray event appeared on the previous day. Third, it was followed by additional emission very close to the limb which somewhat resembles the slow-mode waves reported by Rust and Svestka (1977). A detailed comparison of this feature with x-ray and EUV data from Skylab would be worthwhile.

4.0 PROPERTIES IN COMMON AMONG MAJOR FLARES IN THIS STUDY

Although the flares discussed above include several diverse forms of emission, these events also have some properties in common. In all cases, the brightest elements of the flares are centered with respect to a preflare filament or filament channel. (Filament channels are recognized by paths of alligned fibrils in Hα (Martin, 1973).) Since filaments only form at boundaries between opposite polarity fields as seen on magnetograms of the line-of-sight component, we know that the core of these flares was centered with respect to lines where $H_{||} = 0$. These are also locations which Martres et al (1971) and Harvey and Harvey (1976) found to intersect or coincide with sites where $V_{||} = 0$.

Only two of the seven flares were not associated with the eruption of a

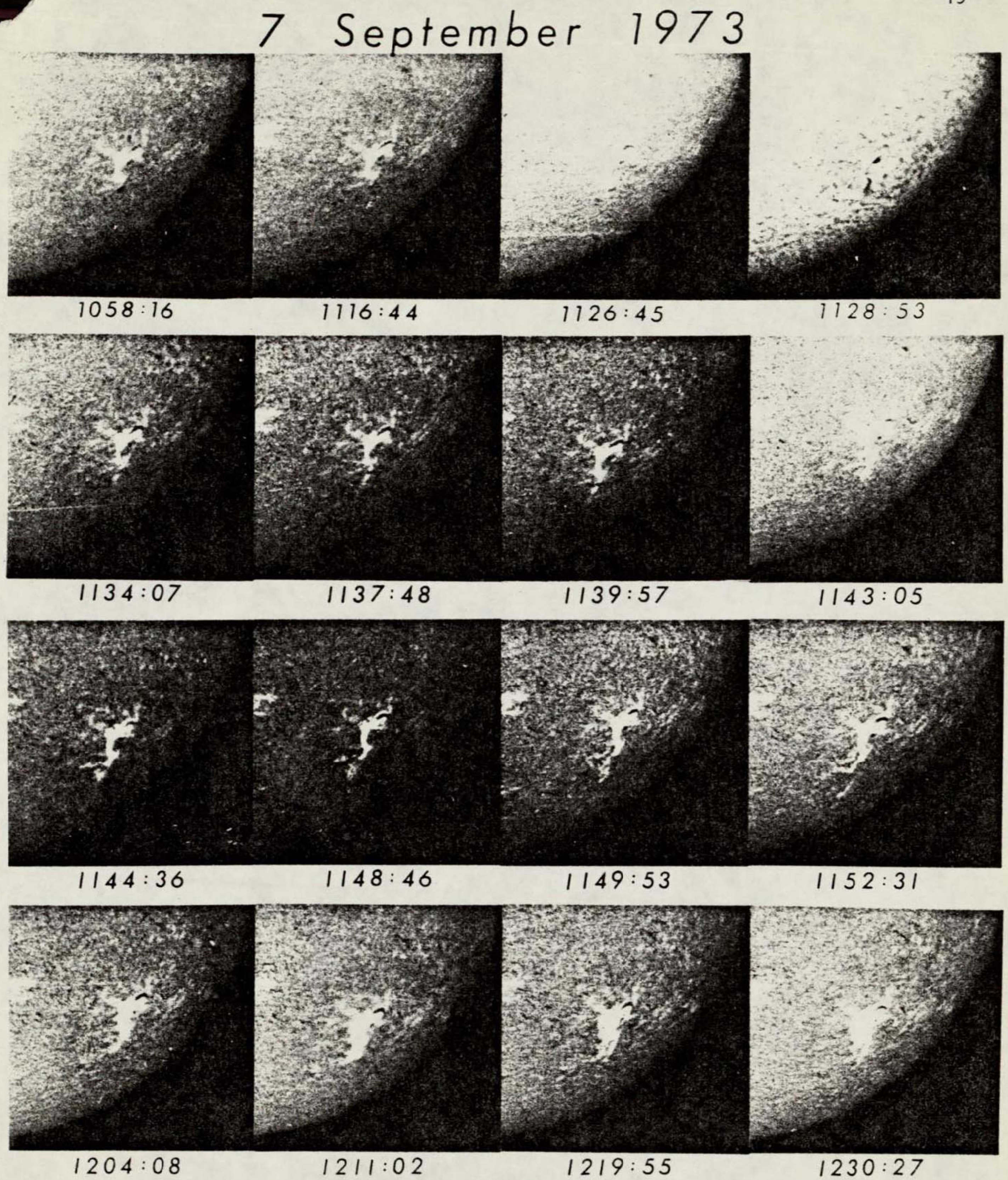


Fig. 8. This flare recorded by the flare patrol at Ramey AFB shows an unusual preflare and flare-associated emission feature. It begins following a small brightening at 1116:44 UT, is related to the absorbing feature seen in the blue wing of Hα at 1128:53, and is seen in emission at line center. From 1134:07 until 1152:31, the faint emission continues to move limbward as a major flare ensues at 1139:57.

filament. These were the earlier of the two flares on both 2 August 1972 and 5 July 1974. Both of these flares were followed on the same day by subsequent larger major flares that were accompanied by an erupting filament along the same polarity boundary ($H_{||} = 0$, the so-called neutral line) around which the core of the earlier flare was centered. This demonstrates that the earlier flares on 2 August 1972 and 5 September 1974 were the type that would have been associated with an erupting filament, if conditions had been favorable for the accumulation of filament mass in the filament channel before these flares occurred. Thus, one common property among these seven flares is the association of the flare core with a filament channel irrespective of whether filament mass occupied the channel prior to the flares.

Four of the seven flares were clearly associated with Hα loops in emission which subsequently changed to loops in absorption, as seen superposed against the solar disk at Hα line center. The flare on 7 September 1973 has been studied only in low resolution Hα films and its possible association with Hα loops remains uncertain. The two events which did not reveal loops in Hα were the two flares on 2 August 1972. The conditions for loop formation in Hα are unknown, although loops in emission are most often seen with flares which show an increasing separation of the chromospheric flare ribbons with time and occur in active regions with moderately strong magnetic fields. The earlier flare on 2 August 1972 did not show a marked separation of the flare ribbons with time. In fact, the flare elements were highly sheared with respect to the $H_{||} = 0$ line in the magnetograms. The second flare on 2 August 1972 was a more classic two ribbon flare but the flare developed extraordinarily slowly. This suggests that it was perhaps more like two ribbon flares in very weak active regions which are generally associated with erupting filaments but seldom with obvious loops in Hα.

Although the 2 August 1972 flares and the 7 September 1973 flare were not clearly associated with Hα loops, a very certain conclusion from the Skylab observations is that all flares are associated with coronal loops or coronal loop systems and these flares should be no exception. Thus, the existence of flare loops is another property common to these flares.

Coronal flare loops are known to join chromospheric flare ribbons (Rust and Bar, 1973; Svestka et al., 1979) which lie in opposite polarity line-of-sight magnetic fields. It follows that the progressive development of chromospheric flare elements, whether or not the elements distinctly separate from the neutral line, is evidence of formation of successive coronal loops. Since all of the seven flares examined here exhibited the successive development of chromospheric flare elements, this is further evidence that they all were associated with the development of coronal loop systems. This has been clearly demonstrated for the flares on 29 July 1973 (Svestka et al., 1979). In effect this means that all of these flares were "two ribbon" flares, even though the flares on 5 July 1974 and the early flare on 2 August 1972 departed greatly in appearance from the classic two ribbon form.

The events on 29 July 1973 and 7 September 1973 are known to be associated with white-light coronal transients. From the results of the HAO coronagraph flown on board Skylab, it is now known that essentially all major flares within 45° of the limb were associated with coronal transients. Thus, it is quite safe to assume that all of the flares in this study should have been associated with a coronal white-light transient also. Since coronal transients are also highly correlated with Type II radio bursts, the occurrence of Type II events with most of these flares is further evidence of the high probability of their association with coronal transients.

Three of the seven events in Table 1 were also associated with a coronal emission veil as described in Section 3.5. These are the early flare on

2 August 1972 and two flares on 5 July 1974. These three flares had the most impulsive development of all the flares in Table 1; that is, the period from flare start to flare max (maximum brightness) was shorter than for the other flares. Also, the total duration of these three events was shorter than for the other four flares. This suggests that, somehow, the impulsiveness is important in revealing this emission. Indeed if the veil emission is related to the development of a white light coronal transient, as proposed by authors (Martin, 1978; Martin and Glackin, 1978), it seems reasonable that the suddenness of energy release of a flare might be related to its visibility. It is perhaps like the relationship of Hα loops to coronal flare loops; the Hα loops are only visible under certain conditions even though the coronal loops are invariably present. The emission veil may require a certain minimum density, temperature, or energy (velocity) to render it visible.

5.0 CONSIDERATIONS ABOUT THE SOURCE OF PROTON EMISSION

5.1 Questions Concerning Proton Escape

The flares discussed above were selected because they are diverse in character and yet have the common property of being events for which protons were subsequently recorded at the earth by ground level detectors. Questions that are many times asked are, "When, how, and where during a flare does the proton acceleration take place?" It seems logical that the acceleration would take place during the flash phase of the flare (Krivsky, 1977) when the greatest amount of electromagnetic radiation occurs throughout the solar spectrum. However, it is not certain whether acceleration to such great energies can take place just during the flash phase. Various models of two-stage acceleration have been proposed to account for the long duration of proton events near earth.

5.2 White-light Transients

Kahler et al. (1978) propose that a mass ejection event (white-light transient) may be a necessary condition for the occurrence of prompt proton events. They suggest that the occurrence of mass ejection events facilitates the escape of protons and that there may exist a proton acceleration region around or above the outward moving mass ejecta far above the flare site.

The Kahler et al. (1978) assertion is in keeping with the quest of this study in searching for the source of proton emission among the properties that major flares have in common and my conclusion that the white-light transient would thus be considered a candidate for proton acceleration. However, the evidence of Kahler et al. (1978) is largely circumstantial. They offer no compelling reasons why proton acceleration must necessarily be accomplished in the vicinity of the white-light transient, and in any case, they do not postulate this association for the initial acceleration of protons. I have no evidence or reason either to suggest that either a first stage or second stage acceleration of protons should occur in association with white-light transients. Instead, I suggest that it is equally likely that the acceleration of the white-light transient (not observed) and the acceleration of protons could have a common cause--taking place well below the 2.0 solar radii occulting disk of the white-light coronagraph.

5.2 Chromospheric Flare Elements

The remaining candidates among the optical aspects of solar flares for a possible association with proton acceleration are the chromospheric flare elements and flare loops.

There is one property of chromospheric flare elements which strongly mitigates against these elements as being directly associated with proton acceleration. That property is the red-shift. It has long been known that flares are brighter in the red wing than the blue wing at equal distances from line center (Waldmeier, 1941; Ellison, 1943). Ellison (1952) described the red wing brightening as a "red wing assymetry" in which the peak of the flare emission profile is coincident with line center. Teske (1962), however, found a symmetric flare profile displaced a few tenths of an Angstrom into the red wing of Hα. This type of profile is hereafter referred to as the "red-shifted" profile. Confirmation of red-shifted profiles was established by Martin (1975) and Ramsey et al. (1975). It is still unknown whether all red wing excess brightening can be explained as due to red-shifted elements or whether separate true red wing assymetry (Svestka, 1976) also exists. In any case, the red wing brightening was found to be a property of virtually all newly forming chromospheric flare elements (Ramsey et al., 1978).

The flare red-shift is consistent and supportive of particle impact flare models (Brown, 1973; Canfield, 1974) even though initial attempts to theoretically reproduce observed flare profiles under the assumption of electron deposition in the chromosphere have not yet met with much success. The flare red-shift unmistakably implies that chromospheric elements are depressed by either high energy particles or shock waves. As such, the chromospheric flare elements are most likely to be a response to impact rather than themselves a primary source of proton acceleration, although we cannot yet exclude the chromospheric elements responding to particle bombardment as a possible second source of proton acceleration. However, the lack of magnetic field changes in the chromosphere coincident with flare elements (Harvey and Harvey, 1976) further mitigates against chromospheric elements as the primary site of proton acceleration.

5.3 Flare Loops

The last of our optical candidates for being a site of proton acceleration are flare loops. Hα flare loops have not been proposed as being related to proton emission because they are most typically seen during the late stages of solar flares. In fact, the common designation for Hα flare loops is "post-flare" loops. Actually, Hα loops, when in emission, never occur after the other parts of the flare emission have decayed. When the loops are in emission, as shown in Figures 1 and 2, they become apparent during or soon after flare maximum. Subsequently, they become absorbing loops before becoming invisible against the solar disk. However, at the limb the loop systems remain visible for hours after the chromospheric flare emission has disappeared (Bruzek, 1964). Hence, limb observations account for the term "post-flare" loops.

A theory of the formation of flare loops has been developed by Kopp and Pneuman (1976). The starting point of the Kopp and Pneuman model is the assumed opening of magnetic field lines during the rise of a solar flare. According to the Kopp and Pneuman model, the fields become closed again at lower elevations in the solar atmosphere by a sudden magnetic field reconnection. The reconnection results in loops which fill with ionized mass flowing up the reconnected field from the chromosphere. The mass cools and condenses at the tops of the loops and then is subsequently seen to flow down the legs of the loops back to the chromosphere.

This model by Kopp and Pneuman is well supported by ground-based observations. However, as originally proposed, it was not intended to explain the existence of high temperature flare loops above the Hα loops (McCabe, 1973; Svestka et al., 1979b). The model could be observationally consistent with coronal observations as well as ground-based observations if a minor modification to the model is made. The essential change would be assuming that the opening of field lines (stretching or elongating) <u>takes place prior to the start of the flare</u> and that the start of the reconnection process is coincident with flare start. With this modification, successive rapid reconnections take place during the flash phase and subsequently as long as new chromospheric flare elements are seen. With this proposed shifting of the sequence of events in the Kopp and Pneuman model to earlier times, the model becomes not just a "post-flare" loop model but a flare model as well. With this proposed change the model becomes consistent with additional flare properties and has the following advantages:

(1) reconnection provides a mechanism for creating loops at flare onset;

(2) reconnection provides energy for accelerating protons and electrons downward and outward to very high velocities;

(3) the red-shift of flare elements can be accounted for by the collision of accelerated particles into the chromosphere and photosphere from their initial positions along the lower half of the reconnected field;

(4) acceleration of particles along the upper half of the reconnected fields as well provides a mechanism for ejecting protons and electrons into the interplanetary medium;

(5) reconnection detaches a part of the coronal magnetic field from its former roots in the chromosphere and photosphere, thereby creating the outward moving confined magnetic field and associated mass known as the white-light coronal transient;

(6) the acceleration of protons through the upper half of the reconnected field (the white-light transient) provides an opportunity for some protons to charge-exchange with neutral atoms in the transient thereby creating the flare veil described in section 3.5.

If this modification to the Kopp and Pneuman model has validity, one would also expect in the future to find that:

(1) the maximum velocities of the white-light transients and erupting prominences should be proportional to the energy of reconnection;

(2) the red-shift of newly-formed chromospheric flare elements should be proportional to the energy of reconnection and hence would decrease gradually after the flash phase of a flare;

(3) from (1) and (2) it follows that the maximum red-shift of chromospheric flare elements should be proportional to the maximum velocity of the white light transient;

(4) the ascent of filaments before flares would be a visible response to the opening (distending) of coronal field lines above and around the filaments;

(5) the coronal fields as seen in 5303Å, EUV, and soft x-ray wavelengths should expand outward before the start of the chromospheric flare and flare loops.

6.0 DISCUSSION

According to the preceding arguments, the x-ray, 5303Å, EUV and Hα flare loops in the corona would be the aftermath of bombarding the chromosphere with high energy particles. The process of loop formation would be similar to that proposed by Kopp and Pneuman (1976) but the effects more cataclysmic due to the acceleration of particles trapped along the distending magnetic field.

In this suggested revision of the Kopp and Pneuman flare-loop model, the development of chromospheric flare elements would be indirect measures of the energy of reconnection and hence also indirect measures of the duration of proton and particle injection into the interplanetary medium. If protons and electrons are primarily accelerated at the instant of loop formation, particle injection could occur at least as long as new chromospheric flare elements are forming and possibly much longer since loop formation does not cease at the end of the chromospheric flare. This raises the question of whether or not protons continue to escape even during the true "post-flare" loop phase and also whether proton acceleration and escape occurs during filament eruptions when no chromospheric flare elements are visible. Webb and Kundu (1978) have already found evidence of electron events with such erupting filaments not accompanied by chromospheric flare elements.

Excluding for the moment the known effects of the interplanetary medium, and assuming that proton acceleration occurs primarily at the instants of magnetic field reconnection and loop formation, the arrival of protons at earth would be at least partially determined by:

(1) the time profile of the energy of reconnection, and

(2) the duration of loop formation until the energy is no longer sufficient to accelerate particles to escape velocities.

A profile of decreasing energy of reconnection throughout most of the duration of flares would serve to greatly stretch out the interval during which particles arrive at the earth in contrast to the duration of the solar event ejecting the particles. This would be such a substantial factor in determining the particle arrival times that there may be no need to invoke mechanisms for the storage of particles in the corona. The requirement instead is to supply particles into the coronal magnetic fields which are reconnecting.

Since loop systems may occupy an extensive volume of space over solar flares, this mechanism of reconnection for particle injection agrees with Lin and Kahlers' (1968) conclusions that particle injection does not occur at a point source.

7.0 CONCLUSION

From this analysis of the diverse and common properties of major flares, it is concluded that the most probable site of primary proton acceleration is cospatial with the site and instant of formation of coronal loops. Since loop formation occurs through the entire duration of major solar flares over significantly large areas of active centers, it is proposed that proton injection occurs from a relatively large volume of space in the corona of active centers and is continuous throughout, and possibly even after, the visible duration of the related chromospheric flare. A direct, short-lived manifestation of proton ejection may be the phenomenon described herein as the "flare veil". The flare veil is hypothesized to occur as a result of proton charge-exchange taking place in the white-light transient.

The Kopp and Pneuman (1976) model of loop formation by magnetic field reconnection is suggested to be an adequate and satisfactory model for all major flares with the provision that the beginning of the rapid magnetic field reconnection is coincident with flare start. This model could satisfactorily account for the red-shift of chromospheric flare elements and all loop formations throughout flares. It is also consistent with observations of erupting filaments and coronal transients with flares.

Since the Kopp and Penuman model requires an initial opening or distending of closed magnetic fields, it is predicted that coronal magnetic field changes should occur prior to all major flares. Such changes are very likely to be observable in 5303Å coronal observations, in soft x-rays and at EUV wavelengths as outwardly moving coronal structures such as reported by Bruzek and De Mastus (1970). The preflare ascent of filaments before they erupt with flares is thought to be a passive preflare response of filaments to the preflare distending of the coronal magnetic field surrounding and above such filaments.

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