AN ACTIVE ROLE FOR MAGNETIC FIELDS IN SOLAR FLARES

(Invited Paper)

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Abstract. Magnetic fields in the low corona are the only plausible source of energy for solar flares. Other energy sources appear inadequate or uncorrelated with flares. Low coronal magnetic fields cannot be measured accurately, so most attention has been directed toward measurements of the photospheric magnetic fields from which coronal developments may be inferred. Observations of these magnetic fields are reviewed. It is concluded that, except possibly for the largest flares, changes in the photospheric magnetic fields in flaring centers are confined to evolutionary changes associated with emergence of new magnetic flux. Flare observations with the 10830 Å line of helium, in particular, are discussed. It is concluded that the brightest flare knots appear near points of emergent magnetic flux. Pre-flare activation and eruptions of Hα filaments are discussed. It is concluded that the rapid motions in filaments indicate unambiguously that the magnetic fields in the low corona are severely disrupted prior to most flares. The coronal signature of Hα filament eruptions is illustrated with soft X-ray photographs from the S-054 experiment of the NASA Skylab mission. An attempt is made, by studying X-ray flare morphology, to determine whether flares grow by reconnections between adjacent or intertwined magnetic elements or by triggering, in which each flaring loop drives adjacent loops to unstable states. It is concluded that successive loop brightenings are most easily interpreted as the result of magnetic field reconnections, although better time resolution is required to settle the question. A model of magnetic field reconnections for flares associated with filament activation and emerging magnetic flux is presented.

1. Introduction

Questions about the behavior of magnetic fields before and during flares underlie any discussion of flare build-up and of possible similarities between flares and magnetospheric substorms. In the Earth's magnetotail it is possible to measure the magnetic fields *in situ*, but the means available to us for probing solar magnetic fields are few and depend upon arguable assumptions. In most cases, also, the measurements suffer from temporal and spatial resolution which are inadequate to deal conclusively with the flare problem. Flares occur on a time scale much shorter than that required to scan the underlying magnetic fields. And, they apparently start in the low corona, where no high resolution magnetic field observations are available. Nevertheless, we know that magnetic fields provide the only source of energy dense enough to fuel a flare, and we know that all flares occur in regions threaded by magnetic fields. Therefore, a close examination of the association of magnetic fields with flare activity is in order.

2. What is the Role of the Magnetic Field in Flares?

In the past, it has been argued that the role of the magnetic fields in flares is mostly passive, serving only to guide or trap the energy released, whether it be in

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the form of non-thermal particle streams (Elliot, 1974) or hot plasma (see Švestka, 1976, for a review of models). For purposes of discussion at this conference I will assume that magnetic fields play an active role in providing flare energy. This assumption is supported by the close correlation found long ago (Giovanelli, 1939) between the magnetic complexity of sunspot groups and the frequency of flares. Additionally, other energy sources appear inadequate and uncorrelated with flares.

The observational evidence for flare-associated changes in the magnetic fields has been reviewed recently (Rust, 1976). Some points of that discussion are summarized below. Results from the Skylab flare observations are added to help clarify this basic question: is the active role of magnetic fields effected by reconnections in current sheets at neutral lines or by changes in the electric currents within force-free loops? Also, we will find it necessary to ask whether the observations show *reconnection* between loops or *triggering* in which one flaring loop drives an adjacent loop to an unstable state. But first, we must treat briefly the question of whether changes in the photospheric fields can be related to flare activity.

Inferences of the magnetic field intensity in flaring regions have been drawn generally from measurements of the longitudinal Zeeman effect in photospheric absorption lines. Because of the difficulties involved in interpretation, few measurements have been made with lines formed in the chromosphere. Full vector magnetic field measurements have been neglected for the same reason. Therefore, most measurements refer to the vertical component of the magnetic fields in and around the sunspots that lie beneath flares. Using daily maps of these fields and theoretical models for their force-free extension into the corona, Tanaka and Nakagawa (1973) have inferred that magnetic energy in the very large spot-group of August, 1972 increased before each of the major flares there and decreased afterwards. It is important to remember, however, that the typical daily change for sunspot fields in flaring and non-flaring regions is of the order of 500 G. This is enough to mask any energy build-up or loss associated with a flare. More frequent observations are required, but even hourly observations may not yield conclusive evidence on field changes associated with flares, since 'seeing' variations and other sources of error limit the precision of individual measurements to ± 200 G, at best.

To establish the proper baseline for the study of flare-associated field changes, we must know how fields usually vary. Cowling (1946) found that the rate of increase of field in spots is about 50 G h^{-1}, and the rate of flux increase is about 1.5×10^{16} Mx/s^{-1}. The normal rate of decay is about 0.5×10^{16} Mx/s^{-1}. This rate may be compared with the flare-associated changes found by Severnyi and his co-workers (Severnyi, 1963, 1969; Zvereva and Severnyi, 1970). They find that major flares are accompanied by flux changes of $3\text{–}10 \times 10^{16}$ Mx/s^{-1}. Similarly, Rust (1973) found that the fields in the region that produced the proton flare of 1972, August 7 decreased at the rate of 6×10^{16} Mx/s^{-1} in $1\frac{1}{2}$ h following flare onset, and Livingston (1974) inferred a decrease in field strength of $\sim$300 G/h^{-1} following the 1974, July 4 proton flare. These rates are somewhat larger than the rates of change usually found with magnetograph observations during minor flares (Rust, 1968, 1972; Ribes, 1969). These give rates of 10^{15}–10^{16} Mx/s^{-1} in small spots underlying flare knots. Thus, *except possibly in those rare cases of the largest proton flares,* the rates of change in sunspot fields do not differ from normal growth or decay rates.

There are many reports in the literature to indicate that photospheric fields do not change when flares occur (Wiehr, 1972; Harvey *et al.*, 1971; Howard and Babcock, 1960; Michalitsanos and Kupferman, 1974), but these reports should be viewed with the same caution as the positive reports. The observations have suffered from insufficient sensitivity (e.g., Harvey *et al.* and Howard and Babcock) or from insufficient time resolution (e.g., Wiehr) or from both (Michalitsanos and Kupferman).

3. What is the Role of Emerging Fields?

Improvements in resolution in the past years have made possible a better understanding of how flares are related to photospheric magnetic fields. The emphasis has moved from attempts to show that the magnetic fields weaken in flares to attempts to find whether the photospheric field changes have any relationship to flare occurrence at all. Ribes (1969) found that flares occur when the magnetic flux in one pole of an evolving magnetic feature is decreasing while the flux in the opposite pole is increasing. Ogir and Shaposhnikova (1965) and Martres *et al.* (1966), 1968) found that flares tend to occur in regions of growing sunspots. Also we know that the surges associated with small flares occur near growing pores on the boundaries of large spots (Ogir, 1971; Koval and Stepanyan, 1972). Roy (1973) has studied these events most thoroughly, and he concludes that if the magnetic map reveals a satellite polarity (Rust, 1968), the brightening will occur over it. The presence of a *visible* satellite sunspot is not a necessary condition for surges, however. The most important photospheric determinant, and probably a necessary pre-condition for surge flare activity is the emergence of magnetic flux of one satellite polarity into a region dominated by opposite polarity.

Ramsey and Martin (1974) studied flares in the D_3 line of He I and showed that the brightest flare knots often occur near the changing pores. Recent observations with the Diode Array at Sacramento Peak extend their results. Rust and Bridges (1975) studied 12 sub-flares that occurred in McMath 12848 and 12849 on1974, April 10–14 and in McMath 12906 on 1974, May 4–8. In every case the flares were marked by one or more emission knots above the continuum level at λ10830. Figure 1 shows two examples of the flares studied by Rust and Bridges. The λ10830 flare knots are seen in sharp relief. We postulate that they are connected directly along magnetic fieldlines to the invisible point of flare origin in the upper chromosphere or lower corona.

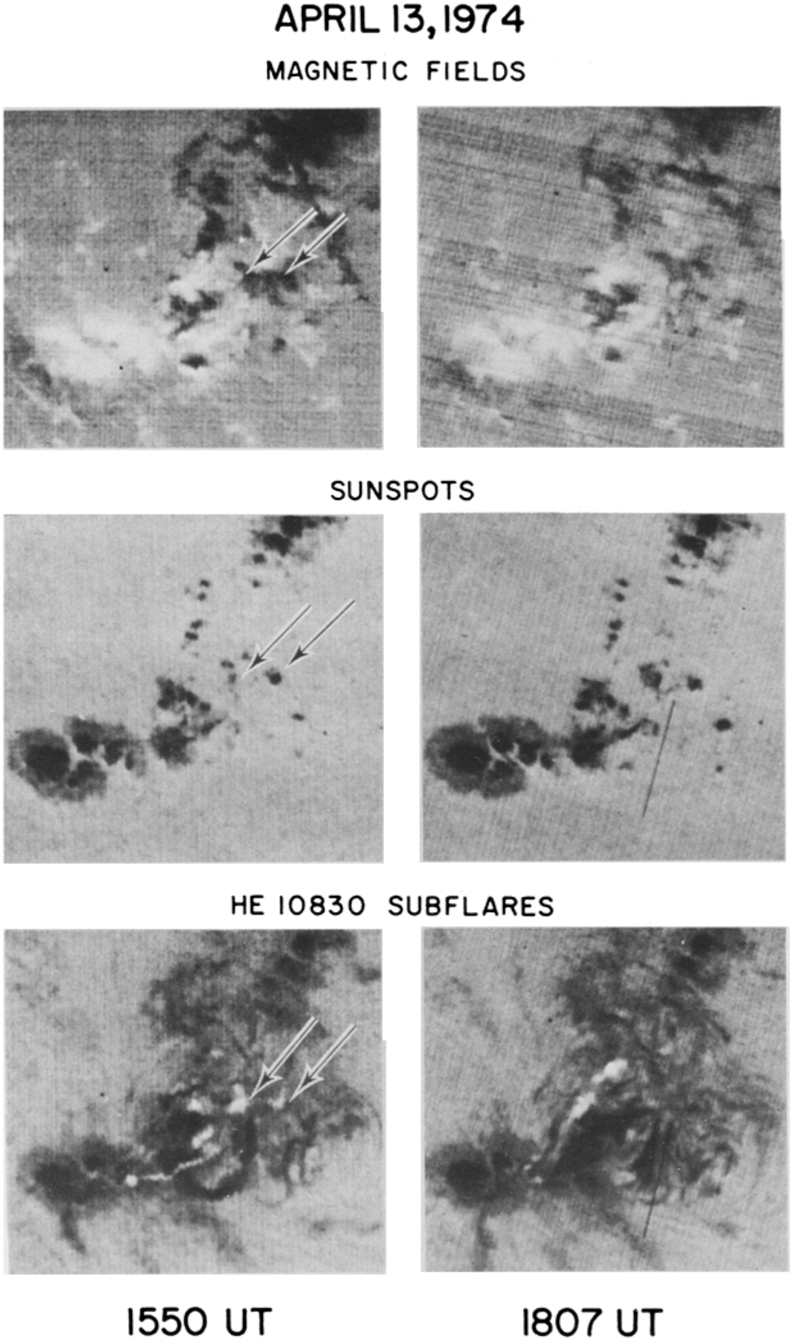

Fig. 1. Flare knots (bottom), growing pores (middle) and magnetic fields (top) in McMath region 12848 at S12 W34 on April 13, 1974. North is down in this picture and west is to the left. Arrows indicate flare knots and growing pores for the subflare at 1550 UT.

With the Diode Array, magnetograms and sunspot images with 1–2″ resolution were obtained simultaneously with the flare observations. This made possible the sort of comparison shown in Figure 1, where it may be seen that each of the helium knots lies just off the center of a sunspot umbra. Careful study of long sequences of spectroheliograms revealed that many of the umbrae kissed by flare knots were growing or changing shape rapidly.

In 8 cases out of the 12 studied by Rust and Bridges (1975), at least one of the flare knots brightened within 3–5″ of a clearly identifiable patch of emerging magnetic field. The emerging fields revealed their presence in two ways: as 5″ patches on the magnetograms and as darkening pores in the photosphere. For example, examine the behavior of the magnetic fields, the sunspots and the He 10830 chromosphere in Figure 1. Two of the emergent poles are marked by white arrows. The pattern of λ 10830 emission shown in the figure was imitated by many of the other flares, but the intimate association between the emergent fields and the bright knots is clearest in the April 13 data.

In 3 of the 4 cases where we could not establish an unambiguous association between the λ 10830 knots and emerging fields the observations lasted for less than an hour or the flaring region was near the limb. Even in these cases, however, it was clear that the flare occurred over a 'peculiar' magnetic field – a complex region where magnetic poles 5″ or smaller were closely packed in a 'salt and pepper' pattern. The Diode Array data revealed that all of the flares occurred over such complex regions. Complex fields are characteristic of emerging flux regions (Frazier, 1972), so we concluded that the brightest knots of the flares were occurring within a few arc sec of emergent field. Furthermore, the flux emergence occurred within 10″ of a neutral line, in agreement with Moreton and Severnyi's (1968) early results.

4. What is the Role of Hα Filaments?

In a review of flare observations, Kiepenheuer (1963) drew attention to the many similarities between flares and filaments. Both lie along the boundary between regions of positive and negative magnetic field in the photosphere; the Hα flare mimics the shape of the filament, except that it appears as two ribbons rather than one; there are flares without filaments but close examination usually shows that the chromospheric fine structures separating the flare ribbons have the typical organization that distinguishes filament channels; filaments often become darker just before a flare; and, many flares break out in the midst of an activated or rising filament. Since that review, further observation and theory have established that filaments are supported by magnetic fields. The activation and eruption of the filament is indicative, then, of a major disruption of the magnetic field just prior to the flare. Let us examine evidence for this important conclusion in more detail.

Martin and Ramsey (1972) studied 297 Importance 1 or larger flares and found that 53% of them were preceded by filament darkening in the blue wing

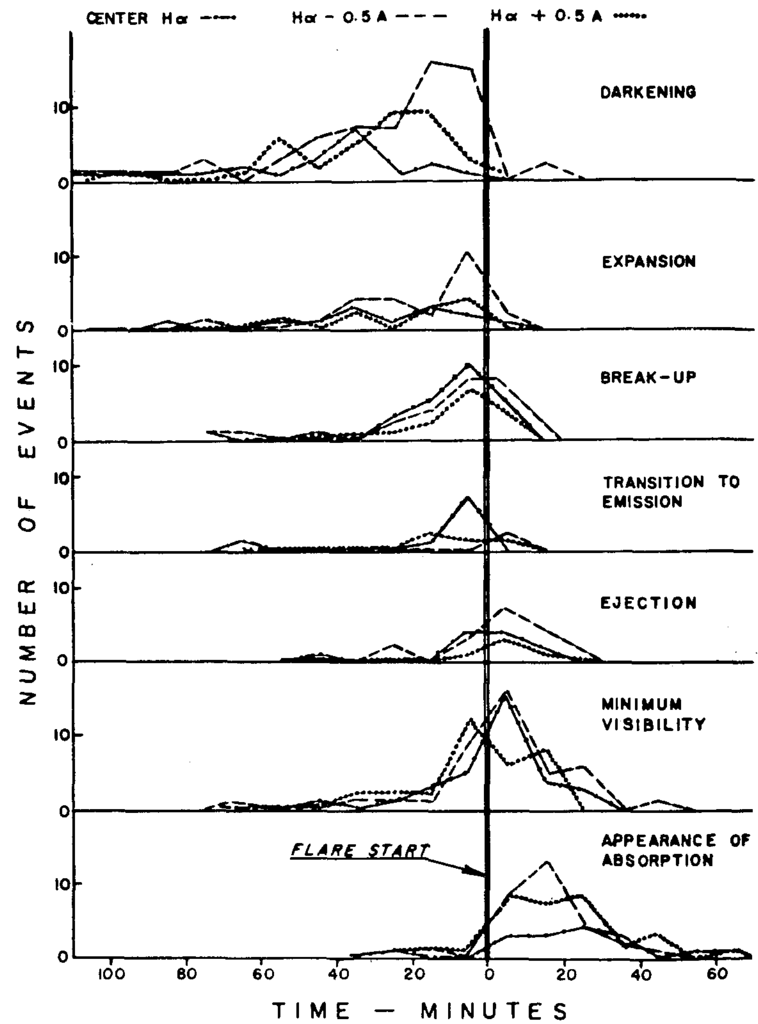

Fig. 2. Distribution of observed changes in filaments and other absorption features relative to the starting time of flares. Times preceding flare start appear to the left of the double line (from Martin and Ramsey, 1972).

(indicating upward motion). Filament activation could be seen in the red-wing in 44% of the cases and on-band Hα in 12% of the cases. While there was considerable overlap among these cases, we may conclude that a majority of flares are preceded by filament activation. Martin and Ramsey found that pre-flare filament activations followed a definite pattern, as summarized in Figure 2. Filaments darken markedly ~60 min prior to flare start. The effect is most obvious 10–20 min before a flare. Then, after expansion and break-up, many filaments brighten ~2 min before the chromospheric flare patches appear. This is the same average time by which Thomas and Teske (1971) found that soft X-ray emission in 283 events preceded the first Hα brightenings. These results must be viewed with some caution, however, because onset times reported for X-ray and Hα emission are susceptible to errors caused by inadequate or variable instrumental sensitivity. In spite of this possible difficulty, it does seem that soft X-ray emission, like filament activation, precedes the chromospheric flare in many cases. The results beg the following question: does energy release actually begin in or near magnetic fields erupting with the moving filament material? One answer to this question was provided by Roy and Tang (1975) in a recent paper concerning six flares observed with very high resolution Hα cinematography and with the OGO-5 and OSO-7 satellites. The data available to Roy and Tang were of considerably higher quality than those available for the earlier studies mentioned above. The resolution at Hα was $\sim 1''$. Martin and Ramsey's study was made with $5''$ data.

Roy and Tang confirmed that pre-flare filament activation is accompanied by a slight X-ray enhancement. Further, they concluded that the X-ray emission was synchronized to phases in the filament activations, with a rapid increase in soft X-ray flux accompanying the fastest filament expansion. Plateau or slow decay phases in the X-ray light curve were associated with slowing and termination of filament expansion. Roy and Tang suggested that this correlation was due to compression of the corona by the expanding filament, but another possible explanation is heating by the currents generated in the moving magnetic fields.

Detailed studies of the sequence of events in a few well-documented flares complement the statistical surveys mentioned above. For examples, the reader should see the papers by Neupert *et al.* (1974), Foukal (1970), Zirin and Tanaka (1973), Pallavicini *et al.* (1975), Thomas (1975) and Widing (1975).

Prior to the Skylab mission, only rarely were simultaneous observations available of photospheric magnetic fields, Hα activity, and spatially resolved EUV and soft X-ray emission. One such set of observations (Rust *et al.*, 1975) was obtained at the Sacramento Peak Observatory and aboard the OSO-7 satellite. Although the spacecraft observations were limited to $20''$ resolution, we found that the pre-flare increase in soft X-rays observed on 1972, January 19, appeared to start in an erupting filament. The pre-maximum evolution of the studied flare is shown in Figure 3. The Hα filament was a thin, vertical line at 1619 UT; by 1625 it broadened and some Hα emission appeared amidst the dark threads. A sequence of off-band pictures showed that the filament was untwisting, apparently, and erupting with an upward velocity of at least 100 km s^{-1}. Simultaneous with this filament activation, a low level of EUV (Mg VIII and Mg IX) and soft X-ray (Mg XI, Mg XII + continuum) enhancement occurred at the same location. By the time of flare onset the dense filament material was rising uniformly at the center (point A in the figure) and falling at the ends (points B and C). Rising and falling material were not intertwined at 1636 as they were at 1619. We interpreted the Hα data as showing that the filament was untwisting before the flare. The photograph at 1636 UT indicates that the twist disappeared and the filament was erupting at the center.

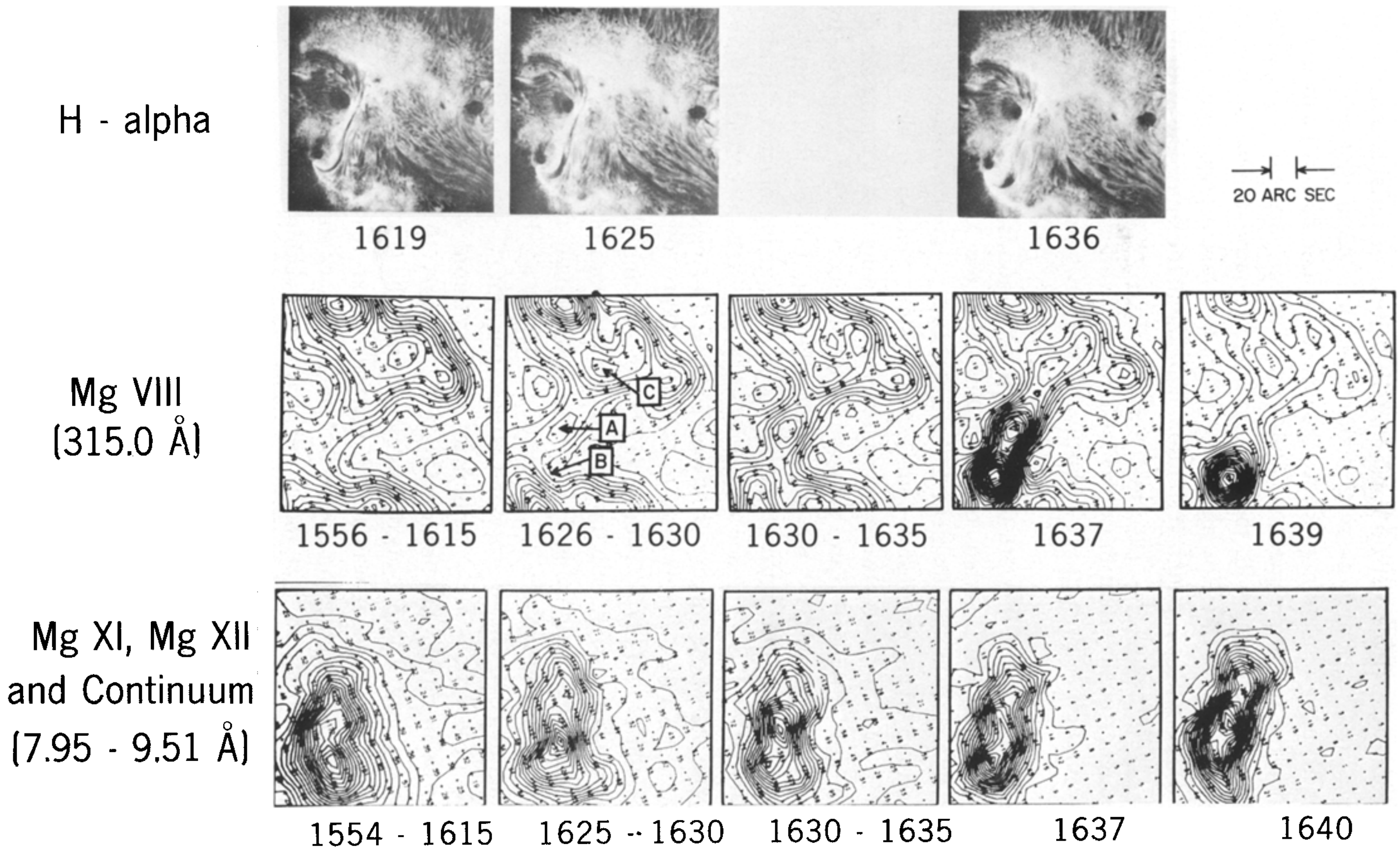

Fig. 3. Comparison of Hα, Mg VIII and soft X-ray observations prior to and during the flare of 1972, January 19. Points A, B, and C, the sites of successive EUV brightenings, are indicated. Weak soft X-ray emission was observed in the region of the activating filament before the beginning of the event.

It is not at all unusual to observe twisting motions in a filament just before a flare. Zirin and Tanaka (1973) show a similar photographic subtraction revealing twist in the filament that lay over the neutral line of the 1972, August 7 proton flare region. Many flare-associated eruptive prominences seen at the solar limb show a pronounced spiral structure (Rompolt, 1975). The point of discussing these observations in the present context is that *erupting, untwisting filaments are unambiguous evidence for restructuring of the field associated with flares.* The material in filaments is constrained to move with the magnetic lines of force, and it becomes a 'tracer' as the fields change. We conclude that changes in the magnetic fields in the midst of the majority of flares are obvious.

Not all flares are accompanied by obvious field disruptions. Filaments need not appear in a young active center before the first flares occur. Or, the filaments may be so narrow, wispy or optically thin in Hα that they are not detected on flare patrol films. Or, it may be that no filament has appeared in the region since a previous flare. In these cases, we have no conclusive evidence for magnetic field changes.

Frequently, the chromosphere surrounding such a flare region is subtly changed, but with low resolution observations it is impossible to infer that any change in the magnetic fields has or has not taken place. However, Zirin (1974), Bruzek (1975) and Tanaka (1975) have inferred from high resolution Hα pictures that some structural changes occurred in the magnetic fields near selected flares. Similarly, the before-and-after pair of Hα pictures shown in Figure 5 are inferential evidence for a rearrangement of the chromospheric field during the previously discussed flare of 1972 January 19. Rust *et al.* (1975) interpret the observations shown in Figure 5 to indicate that the lines of force linking sunspots that emerged beneath the filament disturbed the equilibrium of the supporting fields. They conclude that reconnection took place between the fields in the filament and the fields of an emerging flux region. The calculated reduction in available magnetic energy that would result from such a reconnection was $\sim 10^{31}$ erg–sufficient energy to account for the observed flare phenomena.

The soft X-ray emission that precedes many slow flares may help us to probe the pre-flare magnetic field configuration now that high resolution images of this emission are available from the Skylab experiments. Figure 4 shows the dramatic effect upon the appearance of the low corona that accompanied the sudden eruption of one Hα filament. The filament is shown before the '*disparition brusque*' and at 1958 UT when its emission was shifted 3 Å to the blue wing. We interpret this as a Doppler shift indicative of an upward velocity of about 150 km s^{-1}. A faint trace of the elongated filament appears on the 1814 soft X-ray picture, but an exposure at 1946 UT (not shown) shows the beginning of the linear brightening most evident in the frame at 2026 UT (middle frame). Pictures after the filament eruption show the X-ray cloud becoming more diffuse and fading. The Hα picture at the same time shows flare-like brightenings in the form of two faint ribbons on either side of the vacated filament channel. The X-ray

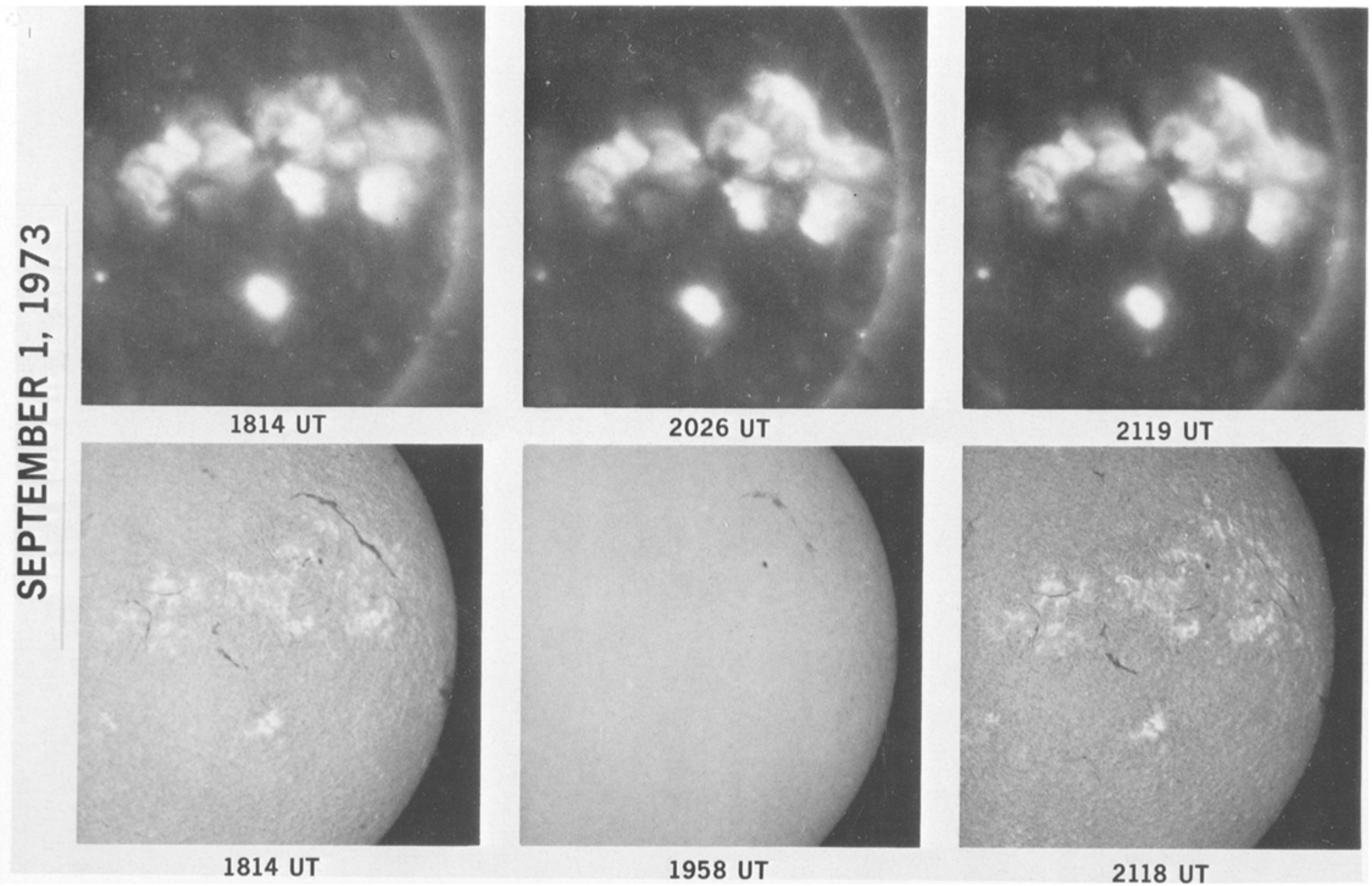

Fig. 4. Development of a bright coronal filament associated with a *disparition brusque*. The dark Hα filament became active between 1800 and 1930 UT. The northern part of it disappeared between 1946 and 1958 UT. This figure shows the Hα filament before eruption and at the maximum phase (1958 UT) when it is moving outward at $\sim$150 km s^{-1} (lower middle frame). The corona shows only a faint thread of emission at 1958 UT. The upper middle frame reveals that the coronal filament has brightened greatly by 2026 UT. The images on the right show a fading coronal filament (top) and a double ribbon flare-like brightening in the chromosphere (bottom) where the Hα filament disappeared.

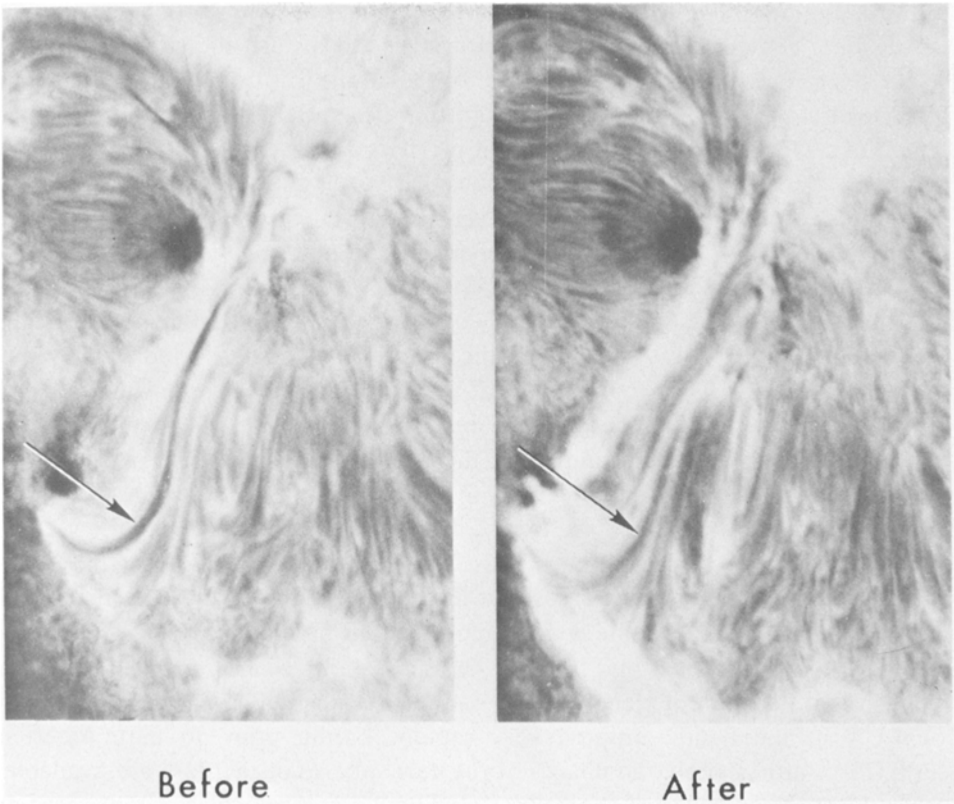

Fig. 5. Two enlarged Hα pictures of the region that flared on 1972, January 19. The arrows pointing to the lower end of the eruptive filament before (1619 UT) and just after (1727 UT) the flare show how the long dark filament curving northwest (to the upper left) changes from being part of the filament *before* to being part of an arch filament system (right) *after* the flare. We may infer from these pictures that fields from the lower sunspot reconnected to the emergent fields underlying the arch filament system.

feature was coincident with the Hα filament to within an estimated error of 10″ and the brightest part in X-rays was coincident with the apparent region of fastest ejection. Loops intersecting the X-ray filament are enhanced and appear to have footpoints in the chromosphere at the flare patches (Webb *et al.*, 1976).

In a study of filament disappearances during the Skylab mission (May, 1973–February, 1974), Webb *et al.* (1976) found that most, perhaps all, were associated with coronal brightenings similar to that shown in Figure 4. But, most of the events showed no chromospheric brightening. Webb *et al.* selected only events that took place outside active centers where the magnetic fields are usually an order of magnitude weaker. We may speculate at this point that filament disappearances in weak magnetic field regions may lead to 'coronal flares' in which the soft X-ray emission is well below the threshold for detectability by full-disk monitors. Hα emission would not appear because the coronal flare would not develop enough heat or accelerated particles to disturb the chromosphere.

The temporal resolution of the Skylab observations was usually quite poor, but Pallavicini *et al.* (1975) did have sufficient time resolution during the Importance 1 flare of 1973, June 15 to establish that pre-flare soft X-ray emission came from a linear feature resembling an Hα filament that erupted prior to the flare. During the impulsive phase of that flare, however, the linear feature was outshined by a bright arcade of X-ray emitting loops spanning the line occupied by the filament (the 'filament channel'). Widing (1975) found Fe XXIV emission there, which indicates that it may be the hottest point, and perhaps the core of the flare. Widing also found that the EUV images of the erupting filament showed a Doppler-shifted spike there. The Doppler shift at that point indicated an upward velocity of 460 km s^{-1} in the filament as seen in the lines of He II, Fe XIV and Fe XV. Unfortunately, no further examples of the pre-flare and impulsive phases of an Importance 1 or larger event are yet available.

There are many observations of the late phases of flares from the Skylab mission and from optical flare records. These show that the largest flares are characterized by an arcade of loops that link positive and negative magnetic field patches. An excellent example is the Importance 3B flare of July 29, 1973, shown in Figure 6 in soft X-rays and in Hα. The figure shows clearly that the arcade of loops in that flare ran the length of the dark Hα filament. The filament, shown at 1234 UT in the figure, erupted very rapidly 10 min prior to flare onset at 1300 UT. Unfortunately, no images of the early phases of the flare are available, so we do not know whether the flare started with a narrow soft X-ray filament or with an arcade of small loops.

5. What is the Role of Magnetic Loops?

Apparently, the immediate pre-flare state is a soft X-ray brightening along a line where a large scale magnetic field, as outlined by low temperature Hα filamentary material, is severely disrupted. Then, as shown by Kahler *et al.* (1975), Petrasso *et al.* (1975), Wilding and Cheng (1975), Brueckner (1976) and Vorpahl *et al.* (1975), successive brightenings develop rapidly in one or more loops bridging the neutral line*. In the hardest X-ray filters used by the Skylab investigators and in the emission from the most highly excited ions observable (Fe XXIV and Fe XXV), it appears that the hottest part of the flare starts at some point along a single loop whose dimensions are below the present resolution (5″).

Details of loop brightenings before and during subflares appear in several of the papers presented at the Flare Build-up Study Workshop. How are the loop brightenings and other changes in the morphology of X-ray emitting structures to

* As used in this paper, 'neutral line' is shorthand for the boundary between patches of positive and negative fields as detected with a magnetograph measuring the longitudinal component of the photospheric field.

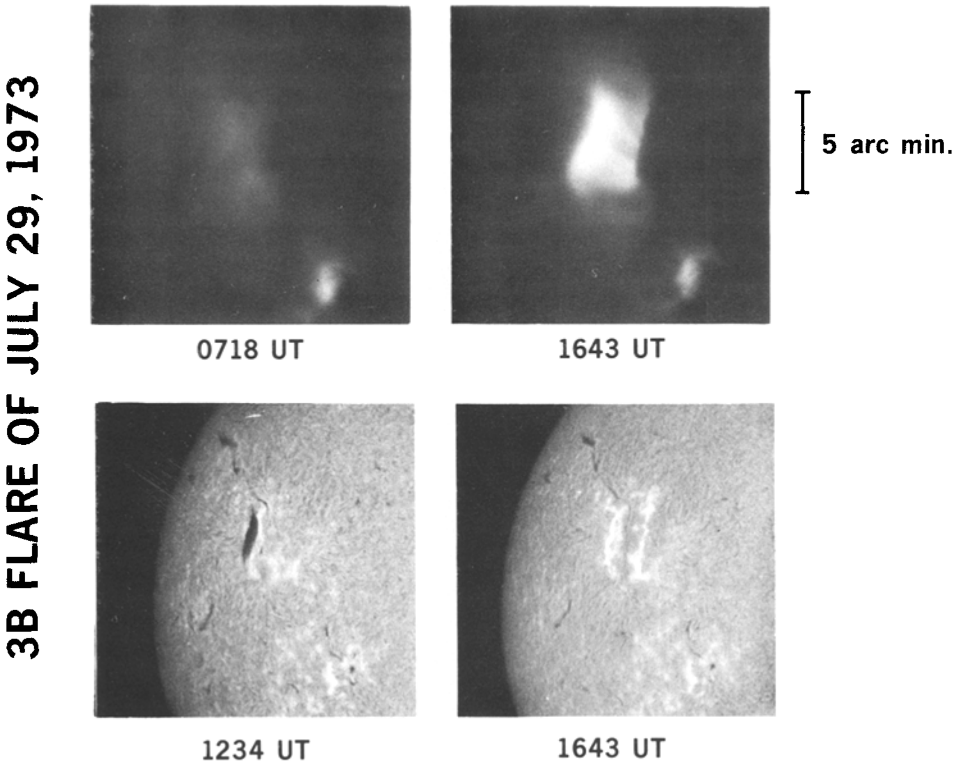

Fig. 6. Images of the corona and the chromosphere before and after the two ribbon flare of 1973, July 29. The X-ray pictures (top) show only a very faint diffuse cloud above the region marked in the chromosphere by a very dark Hα filament. Afterwards, a system of loops at a temperature of about 10^7 K surmounts the chromospheric flare. Brightening is most intense at the top of the arcade of loops, which appear rooted in the chromospheric flare ribbons.

be interpreted in terms of magnetic field developments? Successive brightenings in a family of loops may be evidence for the spread of a magnetic field reconnection point from one field concentration to the next. Or, there may be many metastable loops in an active region. A flare in one loop may then trigger flares in other loops by pressure waves or MHD shocks. This problem may be clarified some by considering the curious events shown in Figure 7. As the figure shows, the solar disk is covered by tiny X-ray faculae, called 'X-ray bright points' by Golub *et al.* (1974), who have studied their properties carefully. Beneath each X-ray facula, there is an 'ephemeral active region' (Harvey *et al.*, 1975). These consist of magnetic flux which emerges through the photosphere in 2″ clumps and vanishes, apparently by diffusion or sudden weakening of the fields, in about 8 h, on the average. In about 10% of these regions, an X-ray flare occurs, and thereafter the region dies out rapidly (Golub, private communication). For about 10% of the flaring faculae, an adjacent loop of very large dimensions brightens also (Figure 7). These larger loops are always part of large scale coronal structures that live for weeks or months.

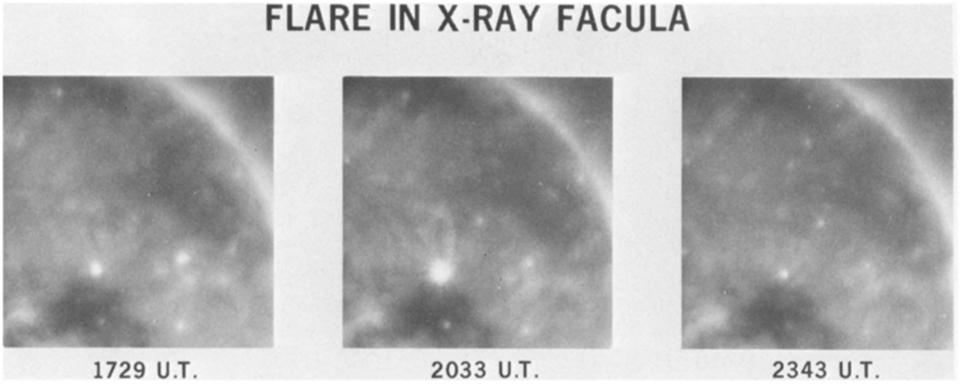

Fig. 7a. Sequential images of a flaring X-ray facula (bright point) on 1973, August 17. Notice the faint brightening (center picture) in the large loop that is apparently part of the long lived (~2 weeks) coronal background. The X-ray faculae usually fade away after only ~8 h, as may be judged from this sequence.

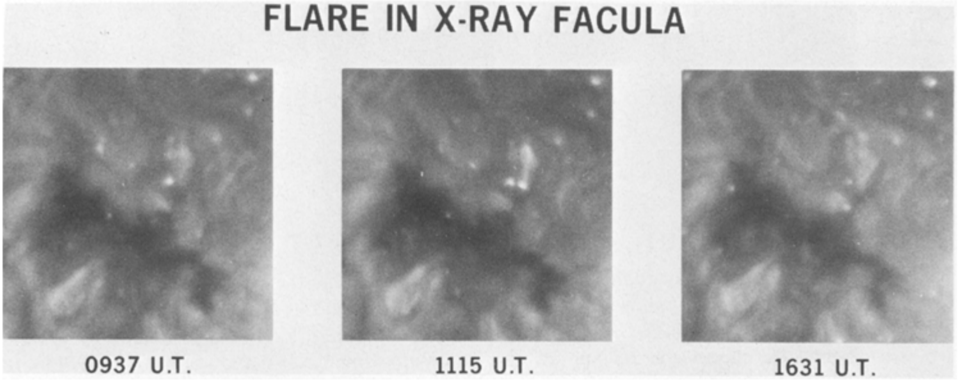

Fig. 7b. Sequential images of a flaring X-ray facula (bright point) on 1973, September 17. After the brightening at 1115 UT, the facula fades completely. The dark area (center left) is a coronal hole included here to indicate the scale of the loop brightening. The loop is about 100 000 km long.

The puzzle presented by these events is this: does the facular brightening trigger the brightening (a kind of flare, too, since it is short-lived) in the larger loop? Or, does reconnection occur between the emergent fields and the ambient field with subsequent energy release into both fields? Earlier in this review, I said that inferences about the role of the magnetic field in flares were based on arguable evidence, and certainly, interpretation of X-ray coronal morphology is arguable. However, it seems to me unlikely that large loops in the quiet corona, as pictured in Figure 7, are in metastable states waiting for a flare to occur close enough to trigger release of their energy. It seems much more plausible that the emerging fields reconnect to the old fields at the time of the flare. Unfortunately, none of these events has been found yet during Skylab observations with high time resolution, so the answer to this question will have to wait until better observations are available.

6. Summary and an Empirical Model

The eruption of an Hα filament in the minutes before a flare indicates that a major restructuring of the magnetic fields is taking place about 10 000 km above the chromosphere, where it is generally conceded that flares start. Often, this eruption apparently is triggered by the emergence of new magnetic fields through the photosphere just below. Observations show that the brightest knots of the chromospheric component of the flare appear within 3–5″ of these emerging fields. This may indicate that the larger flaring structure is reconnecting with the emergent flux, or, it may mean that the hot kernel, as discussed by Brueckner (1975) and Widing (1975), for example, is entrained in the fields at the point of flux emergence. In this view, the destabilization of the Hα filament is incidental to the central energy release mechanism of the flare. Direct observations of the magnetic fields in the coronal flaring structures themselves are needed to clarify this point. But, they will not be available until very sophisticated instruments are launched with the Space Shuttle nearly a decade from now. Until then, we must rely upon interpretations of field morphology from Hα, EUV and X-ray pictures.

On the basis of the Skylab and OSO-7 results, and on the basis of the very high resolution Hα pictures that have become available only in the past decade, it appears that flares may well be taking place in a region of fieldline reconnection. To see how this might be occurring, we examine briefly an empirical flare model first discussed by Canfield *et al.* (1974). Since observations (see Tandberg-Hanssen, 1974, for a review) show that the magnetic field in an active center filament is predominantly parallel to the long axis and the overlying coronal fields are perpendicular to it (Vaiana *et al.*, 1973), Canfield *et al.* supposed that the lines of force in and around filaments take the form sketched in Figure 8a. If new flux

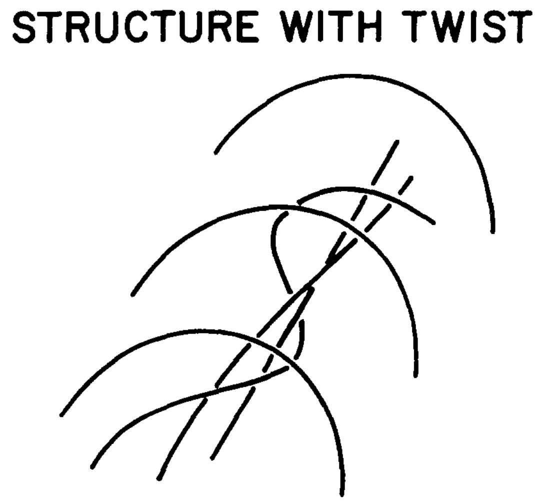

Fig. 8a. Sketch of the lines of magnetic force over an active center. The straight and the slightly twisted lines are assumed to thread an Hα filament, while the loops arch through the corona over the filament.

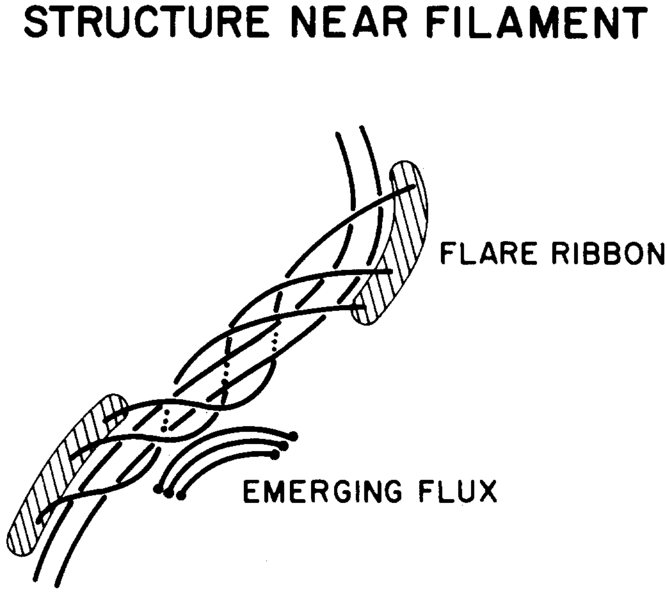

Fig. 8b. Sketch of the lines of magnetic force and the flare ribbons in the initial stages of a flare triggered by the emergence of new fields below a filament.

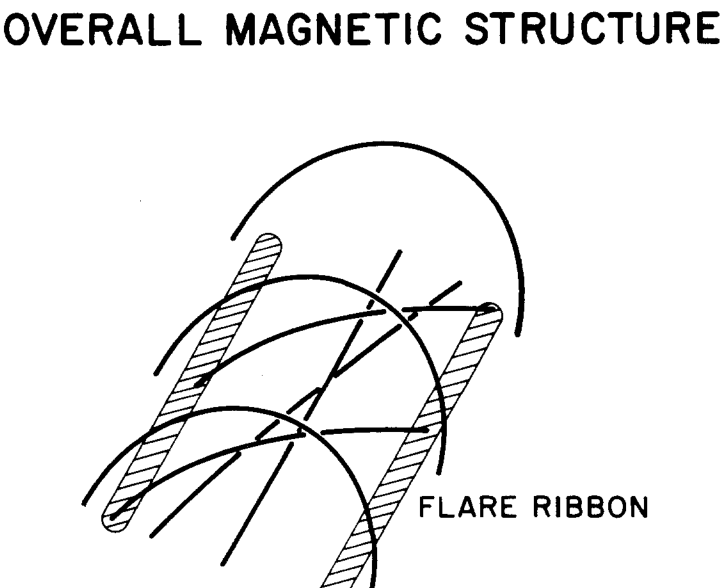

Fig. 8c. Sketch of the lines of magnetic force and the flare ribbons in the post-maximum of a double ribbon flare.

emerges (Figure 8b) from just below the filament, it may have the effect of destabilizing the supporting fields, which are thought to be otherwise quite stable (Kuperus and Raadu, 1974). Reconnection will take place at a slow rate in a 'quiet' current sheet and some heating will occur, leading to a slow increase in soft X-rays. At some critical stage the electrical resistivity in the current sheet increases by a large factor and allows the onset of much more rapid (Sonnerup, 1972) magnetic field reconnection in an 'active' current sheet. Charged particles are accelerated to high energies by the electric field involved in the reconnection process. They travel along the field lines from the current sheet to the chromosphere, where they produce flare knots. In general the fields in the emerging flux loop and the filament will certainly not be antiparallel, but they will intersect at any angle. Nevertheless, magnetic field reconnection can occur, as demonstrated by Priest and Sonnerup (1975). The flare spreads by rapid reconnections within the twisted fields in and near the filament. The resulting structure is sketched in Figure 8c. The degree of twist remaining in the interior fields sketched there is uncertain although it has been the object of a number of observational investigations (e.g., Tanaka and Nakagawa, 1973; Rust and Bar, 1973).

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Discussion

PATTERSON: You've shown several pictures of X-ray flares that didn't show up in SOLRAD observations. Do you have a definition for what you would call a flare, in terms of brightness or temperature, or do you call all X-ray brightenings flares?

RUST: We do not know where to draw the line between flares and whatever other kinds of transient brightenings there may be. I do not believe the definition should include a reference to any particular wavelength, such as Hα. It appears that our real problem is in differing instrumental thresholds, and that as sensitivity increases, so does the number and frequency of transient brightenings.

VORPAHL: In the analysis of flares observed with the Aerospace/MSFC soft X-ray experiment, only events with intensity sufficiently high to register on the SOLRAD scale have been used. Many hundreds of observed events that were below this intensity were not included in the study. We feel it is extremely important to define some reference so that other observers may do comparative studies with our data. This is not possible if any brightening is used as a flare. Furthermore, it has not yet been established that a smooth curve results when frequency of events is plotted versus intensity. If this curve turns out to be single peaked, we could accept lower intensity events as 'flares'. Until then, it is very important to have a common acceptance among solar astronomers of what is defined to be a 'flare' and what is 'flare-like'.

HONES: Before coming to this conference, I thought the current sheets in the magnetotail and in flaring structures were similar. But, now I am not so sure, because you have emphasized twisted structures. Do you see any evidence for flares in a helmet-shaped structure such as that described by Sturrock?

RUST: No. I do not think the observations support the helmet streamer model over active centers. Flares appear to start in very low-lying structures. A matter not entirely resolved yet, I think, is whether the magnetic fields there are twisted or sheared. But, there are no observations that I am aware of to indicate a collapsing neutral sheet high in the corona similar to that in the magnetotail. The neutral sheets that are inferred from helmet streamer images over quiescent prominences appear to be quite stable.

TANDBERG-HANSSEN: The different flare-manifestations you mention indicate, I believe, that we may have to do with more than *one* flare mechanism. Consequently, if we try to find a mechanism that can explain all flares, we may be on the wrong path, and we make our task impossibly hard.

I would not want the magnetospheric physicists here to go away with the impression that there is only one kind of flare. You have shown several different kind of flares and I don't think one model will fit them all. I just offer this word of caution against attempts to see all flares in terms of only one model or mechanism.

DODSON: Did you actually observe emerging magnetic flux associated with the 1973, July 29 flare?

RUST: No. The observations were inadequate for that.

DODSON: Then, I would like to issue a caution against assuming that the magnetic fields in all flares are changing and complex. That flare was a very unusual and very great flare in a spotless region – an active center in its death throes and the magnetic fields in such regions are usually simple and dying.

RUST: I am sorry if I implied that emerging fields were observed in that particular flare. I was reasoning by analogy with observations of some other spotless region flares for which we did have adequate observations. In one case studied by René Roy and myself, we found growing pores at one of the flare knots. They were not visible on the flare patrol films. In fact, the region that produced the July 29 flare showed sunspots the next day. This resurgence may have started on July 29 and escaped notice. Since emerging fields may be very limited in area, high resolution is required.

BRUECKNER: In how many cases do you have growing magnetic fields in plages without a flare occurring? And, how often are prominences twisted in the manner you describe? We need to know what is a sufficient condition for a flare in addition to all these conditions you seem to imply are necessary.

RUST: No one has done a comprehensive survey of how many filaments have the twisted structure, but Rompolt, for example, finds twisted structures to be very common. My own experience, and I believe that of Sara Martin and of the workers at the Big Bear Solar Observatory, too, is that filaments always appear twisted when examined with sufficiently high resolution in on-band and off-band Hα filtergrams.

In reference to your first question, it is clear that emerging fields are not a sufficient condition for a flare, since active centers are changing all the time. The important point in the observations, however, is that the few chromospheric bright knots in each flare are *intimately* associated with pores that show marked growth in the half-hour before the flare. In the January 19 flare, for example, the only changing spots were those beneath the apparent flare initiation site, and they were within 10″ of the first flare knots.

BRUECKNER: In how many cases do you see flares, then, when there is a prominence eruption? Is there sufficient evidence that an erupting prominence always preceeds a flare?

RUST: That is a question of definition, really, because preliminary results by Webb indicate that every erupting prominence is accompanied by some transient coronal brightening. Are these not X-ray flares? Now, whether the chromosphere brightens also in each case is another question. Examination of flare patrol films with about 5″ resolution did not reveal chromospheric brightenings in most of Webb's cases. But, he deliberately avoided *disparitions brusques* that occurred in active centers.

Some flares, expecially small ones, do not have an obvious prominence eruption preceding them. It is not the prominence material itself that is particularly important for the flare process, but rather the magnetic fields in the prominence. If no material has collected in the magnetic fields, then we cannot examine their behavior.

BRATENAHL: I think we should be very careful in interpreting two-dimensional pictures of filaments in terms of twisted ropes.

RUST: I agree that we should be very cautious with interpretations of single filtergrams in terms of 3D structures, but in the cases studied by myself and Varda Bar, for example, we relied on filtergram movies and on Doppler shift measurements. If Doppler shifts and transverse motions are examined over a significant portion of a filament's evolution, I think we can obtain a reliable interpretation of the 3D structure. After all, we have two spatial dimensions and three velocity dimensions in these observations.

VORPAHL: I'm a believer in helical field lines also, but I'm wondering if the twist you discuss could merely be the result of looking at several different, individual filaments along the same line-of-sight. Would you comment on this.

RUST: I suppose that is possible in unusual cases, but any ambiguity usually can be removed by examining a sequence of pictures.