THE ASSOCIATION OF FLARES TO CANCELLING MAGNETIC FEATURES ON THE SUN

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Abstract. Previous work relating flares to evolutionary changes of photospheric solar magnetic fields are reviewed and reinterpreted in the light of recent observations of cancelling magnetic fields. In line-of-sight magnetograms and H-alpha filtergrams from Big Bear Solar Observatory, we confirm the following 3 associations: (a) the occurrence of many flares in the vicinity of emerging magnetic flux regions (Rust, 1974), but only at locations where cancellation has been observed or inferred; (b) the occurrence of flares at sites where the magnetic flux is increasing on one side of a polarity inversion line and concurrently decreasing on the other (Martres *et al.*, 1968; Ribes, 1969); and (c) the occurrence of flares at sites where cancellation is the only observed change in the magnetograms for at least several hours before a flare (Martin, Livi, and Wang, 1985). Because cancellation (or the localized decrease in the line-of-sight component of magnetic flux) is the only common factor in all of these circumstances, suggest that cancellation is the more general association that includes the other associations as special cases. We propose the hypothesis that cancellation is a necessary, evolutionary precondition for flares. We also confirm the observation of Martin, Livi, and Wang (1985) that the initial parts of flares occur in close proximity to cancellation sites but that during later phases, the flare emission can spread to other parts of the magnetic field that are weak, strong, or not cancelling.

1. Review of Previous Work

The association of flares with observed photospheric magnetic fields has been made previously in terms of configurations and evolutionary changes. The earliest studies of flare positions relative to photospheric magnetic fields by Severny (1958, 1960) showed that flares occurred near polarity inversion lines (previously also called neutral lines or $H = 0$ lines). The centering of flares around polarity inversion lines was confirmed by Martres *et al.* (1968a) and Smith and Ramsey (1967). Michard (1971) also noted that when the initial H-alpha brightenings have more than one knot, they are located on two different polarities, on both sides of the inversion line, rather than directly on it.

Specific flare-related magnetic field changes were reported by Martres *et al.* (1968a, b). They studied an active region in which all the flares occurred where magnetic flux was increasing on one side of the polarity division line while it was decreasing on the other side.

The frequent association of flares with emerging magnetic flux regions was first noted by Rust (1972, 1974), verified by Vorpahl (1973), and subsequently elaborated on by these and many other authors (Martin *et al.*, 1983; Priest *et al.*, 1986; and references

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therein). When opposite polarity fields come into close contact because of the emergence of new magnetic flux in pre-existing active regions, a steep magnetic field gradient builds on the magnetic inversion line between the new flux and the pre-existing flux. The association of flares with high magnetic field was also made by Severny (1960) and confirmed by Martres, Michard, and Soru-Iscovici (1966).

Although many flares happen in association with new flux, it is also known that flares occur in the absence of emerging flux (Martin *et al.*, 1984). Martin, Livi, and Wang (1985) studied a decaying region and found that all of the observed flares began at sites where magnetic flux was cancelling. Cancellation is the gradual and mutual decrease of magnetic flux at the boundary between closely-spaced opposite polarity magnetic fields as seen in line-of-sight photospheric magnetograms (Martin, 1984; Livi, Martin, and Wang, 1985). Magnetic flux is observed to gradually decrease in both polarities as the magnetic fields migrate together and a high magnetic field gradient is observed as long as the fields are cancelling. In many cases the fragment with less magnetic flux completely disappears. To date cancellation has only been observed in magnetograms of the line-of-sight component which leaves the physical interpretation of cancellation open to several possible interpretations (Zwaan, 1987).

2. The Data

We illustrate examples of flares and cancelling magnetic fields from observations taken from 8–11 July, 1988 in an active region that crossed the central meridian during this interval. The data obtained on this active region are especially well-suited for the study of magnetic field changes and flares because: (1) the magnetograms were of high quality due to good seeing; (2) collaborative observations of the magnetic fields were taken at the Huairou Solar Observing Station of the Beijing Astronomical Observatory and at the Big Bear Solar Observatory; (3) the active region was located near the Sun's central meridian which is favorable for the acquisition and interpretation of line-of-sight magnetograms; and (4) the active region produced many small flares and a few large ones during the observing hours at Big Bear Solar Observatory.

The magnetograms used in the illustrations are mostly from the Big Bear Solar Observatory because the study is centered around flares observed at the Big Bear Solar Observatory. Unfortunately, Hα filtergrams are not yet taken at the Huairou Observatory. However, the videomagnetograms taken at Huairou are important in the evaluation of long-term changes before and after major flares; magnetograms from both sites have been matched in scale and sensitivity during the processing of the data. On all of the magnetograms negative magnetic polarity is presented in black and positive in white. Observing hours at Huairou Observatory are from approximately 01:00 until 12:00 UT and observing hours at Big Bear Observatory are from approximately 15:00 until 02:00 UT during the early summer.

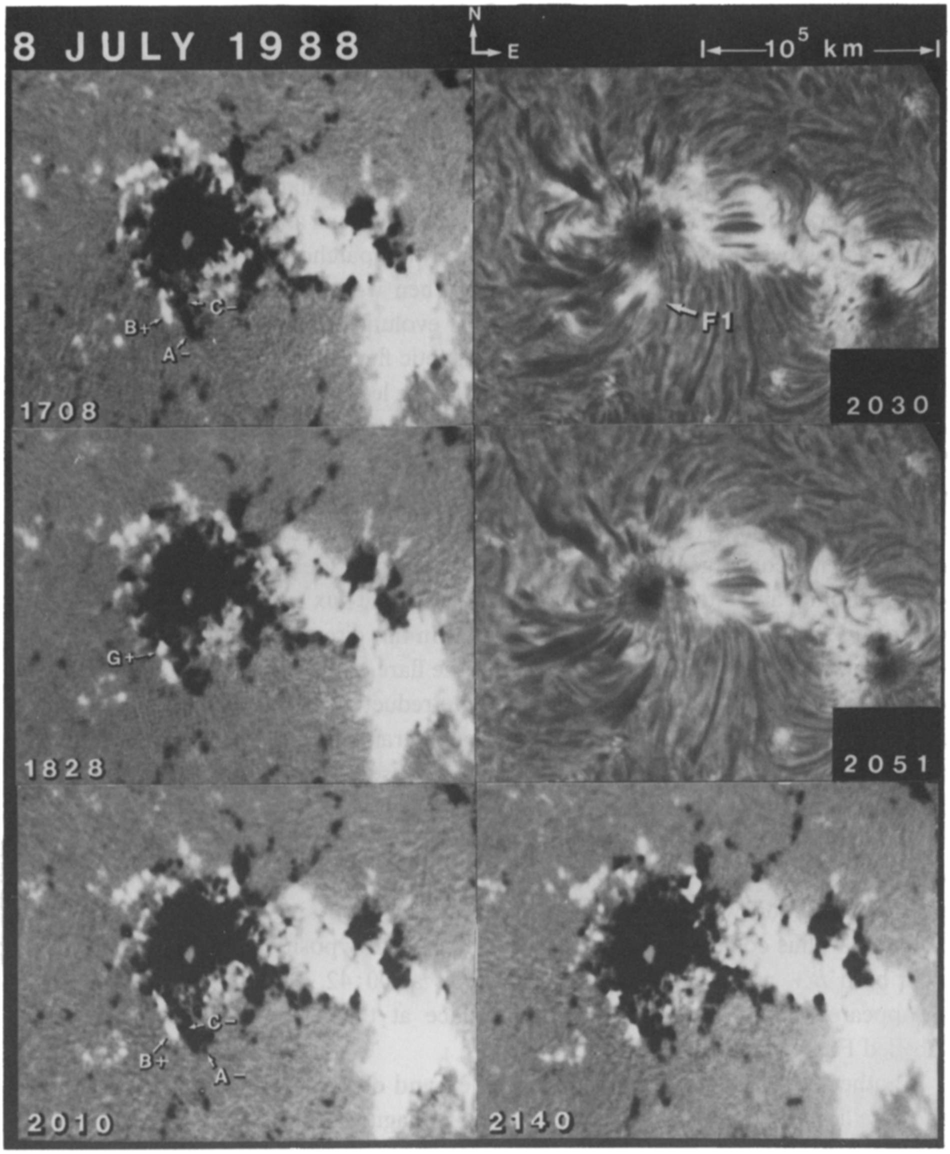

Fig. 1. The flare, F1, in the upper right frame, corresponds in position to the site of converging patches of magnetic field labelled $A-$, $B+$, and $C-$. All of these patches of flux are identified as part of a system of Moving Magnetic Features (MMFs) which originate near the penumbral boundary and flow approximately radially away from the associated sunspot. As they move away from the sunspot, $A-$, $B+$, and $C-$ converge. $B+$ and $C-$ begin to cancel each other when they come into contact but the slow reduction in magnetic flux becomes apparent only in the continuation of this series in Figure 2 where it is seen that the area of $B+$ is decreasing. The expected equivalent loss of flux in $C-$ is not seen because it merges with $A-$ and other negative magnetic flux closer to the sunspot.

3. New Examples of Flares and Their Relationship to Cancelling Magnetic Fields

In Figure 1, Hα filtergrams in the upper right and middle right reveal a flare, labelled F1, at 20:30 UT and the aftermath of the flare at 21:40. The flare occurs just below the sunspot near the middle of the images. The videomagnetograms in the left side show the magnetic field configuration for over 3 hours prior to the flare. The final magnetogram in the lower right corresponds to approximately one hour after the flare. We have put arrows and labels on the illustrations to identify the patches of photospheric magnetic flux that correspond to the site of the flare. Then we trace the same magnetic fields backward and forward in the time to see their evolution before and after the flare. The flare, F1, occurs above the photospheric magnetic flux patches marked $A-$, $B+$, and $C-$. Our system of labelling in this paper is to use letters to designate specific patches of magnetic field and to follow the letter with + or − to eliminate any ambiguity about whether the arrow points to a positive polarity patch (white) or a negative polarity patch (black). Tracing $A-$, $B+$, and $C-$ back in time we see that a convergence of these elements occurs between 17:08 and 18:28. This convergence brings $B+$ and $C-$ into contact. The convergence of magnetic flux of opposite polarity usually leads to cancellation at about the time that patches of magnetic flux appear to come into contact (Martin, 1984; Martin, Livi, and Wang, 1985). In this circumstance in Figure 1, it is not clear that cancellation has begun until after the flare. Although the visible effect of the cancellation is marginal in Figure 1, a definite reduction in the area of $B+$ is evident in the continuation of this time series of magnetograms in Figure 2. The cancellation is not yet conspicuous in the negative polarity because of the convergence of additional negative flux from the sunspot moat.

In Figure 2, a second flare, F2, is visible at 23:04. One part of this second flare F2a coincides with flare F1 in Figure 1. In Figure 2 at 22:21, negative patch $D-$ has moved into juxtaposition with $B+$ to form a new cancellation site. At 23:41, another new patch, $E+$, has coalesced from smaller patches of new positive flux. $D-$ is cancelling with both $B+$ and $E+$. By the end of series at 00:42, $D-$ has almost completely disappeared. These changes are taking place at the site of the part of the flare labelled F2a.

Another part of the flare, F2b, is to the left and closer to the sunspot. This part of the flare lies above and adjacent to a cluster of magnetic fields that have also emerged in the sunspot moat. To the upper left of $E+$, lie two other patches, $F-$ and $G+$. Tracing the previous evolution of $G+$ back through the magnetograms in Figure 1, we see that it was previously adjacent to $B+$ at 18:28 but has moved nearly tangential to the spot and has initially gained flux. This behavior differs from most of the small positive and negative magnetic knots around the spot that are called Moving Magnetic Features or MMFs (Harvey and Harvey, 1973). Most MMFs form near the outer penumbra of the sunspot and flow radially away from the spot. We re-examined the time-lapse videomagnetogram film and found that $G+$ and $C-$ comprised a new bipole (an ephemeral region) whose + and − components move away from each other as their fluxes increase. Thus $G+$, while growing, was also moving perpendicular to the outward

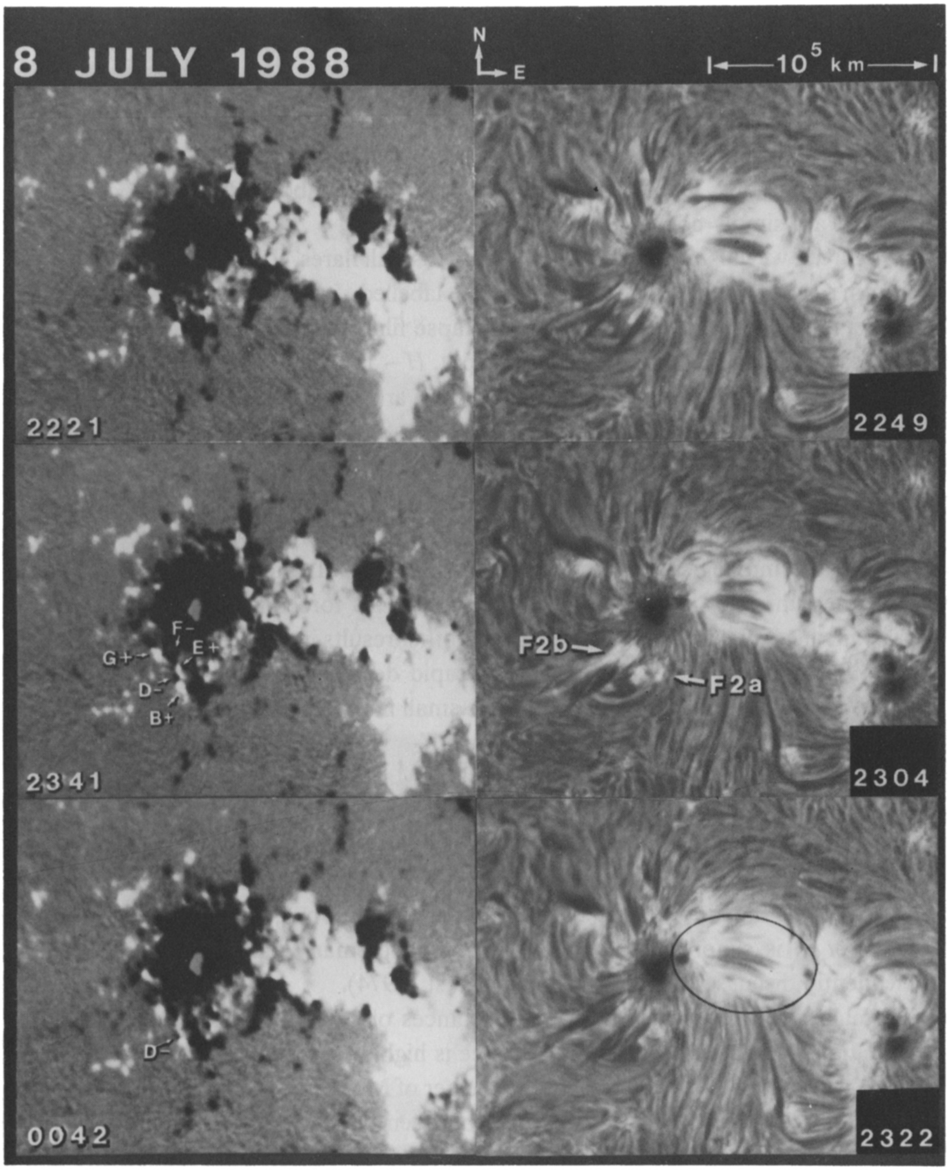

Fig. 2. Another flare, F2 at 2304, is seen at and adjacent to the site of the Flare F1 in Figure 1. The part labelled F2a is at the same site of cancelling magnetic features as in Figure 1. However, a new patch, $D-$, has moved into position to cancel with $B+$. $D-$ is also cancelling with another new patch, $E+$, and has almost disappeared by the end of the sequence. The other part of the flare, F2b, corresponds to magnetic patches $G+$ and $F-$. $F-$ is negative polarity Moving Magnetic Feature (MMF) that is flowing away from the sunspot. However, $G+$ is component of a small bipole, an ephemeral region, whose other initial negative pole is the patch labelled $C-$ in Figure 1. As the ephemeral region grows, its poles, $G+$ and $C-$, migrate in opposite directions approximately tangential to nearly circular moat of MMFs that radially emanate from the sunspot. G+, therefore, is moving approximately orthogonally to the MMFs that originate near the penumbral boundary. It encounters and cancels with negative polarity MMF labelled $F-$ before, during and after the flare.

flow of other patches within the moat. Since most of the nearby encountered flux is negative, we infer that $G+$ was probably growing and cancelling at the same time, as we have observed for ephemeral regions on the quiet Sun (Livi, Martin, and Wang, 1985; Martin, 1988). We conclude that this part of the flare, F2b, corresponds to a special dynamic circumstance within the sunspot moat including flux growth, flux cancellation and unusual motions. The other part of the flare, F2a, lies above photospheric magnetic fields that are simply converging and cancelling.

In Figure 3, we illustrate the sites of two other small flares, F3 and F4, in the H-alpha filtergrams. F3 coincides with flux patches, labelled $J+$, $I-$, and $H-$ in the first magnetogram before the flare. In the time-lapse film, we found that $J+$ and $I-$ are MMFs that are flowing away from the sunspot. $H-$ is a small part of the larger of two, magnetically complex emerging flux systems that are encompassed by ovals in the last H-alpha image. (The emerging flux system can also be identified in Figures 1 and 2 from the east–west aligned system of arch filaments. In the last H-alpha image in Figure 2 an oval is drawn around the emerging flux system.) $H-$ is growing and moving towards the sunspot to its left. As it does so, it encounters and merges with $I-$ moving to the right. $J+$, also moving to the right away from the sunspot, and $H-$, moving to the left toward the sunspot, also encounter each other. This forceful encounter of opposite polarity magnetic fields moving towards each other results in cancellation. This example of cancellation is very noticeable from the rapid decrease and disappearance of $J+$, respectively, during and after the time of the small flare. Any loss of flux in $H-$ during the encounter with $J+$ cannot be seen because $H-$ is a large and growing clump of flux. Hence, this example is like the cases studied by Martres *et al.* (1968a, b) in which they were able to associate flares with flux that was increasing on one side of a polarity inversion line and decreasing on the other. In observations from Big Bear Solar Observatory, we find the pattern observed by Martres to be the general case in situations where emerging flux develops in existing active regions. Thus, the association made by Martres *et al.* is synonymous to the association of many flares with emerging flux subsequently discussed and illustrated by Rust (1974).

We make the new point that in circumstances of emerging flux as just illustrated, cancellation also occurs and this occurrence is highly predictable. For example, in the last frame in Figure 3, we note that a new cluster of MMFs is approaching $H-$. Hence, a new cancellation site can be anticipated between the cluster of positive MMFs and the new flux $H-$. Figure 4 shows the development of the new cancellation site and a new corresponding patch of bright plage.

Flare F4, seen in the H-alpha filtergram at 18:39, corresponds to the tiny fragments $K+$ and $L-$ and $M-$. All are MMFs moving away from the positive-polarity trailing sunspot seen just above the time insert in the lower right of the H-alpha images. It appears that $L-$ and $M-$ simply overtake $K+$ and cancel with it. By approximately two hours after the flare, $K+$ no longer exists and only residual flux of $L-$ and $M-$ can be seen at the site of the little flare.

Flares F5 and F6 are shown in Hα filtergrams in the right side of Figure 4. Flare F5 has two components that lie near, but not on, a small cancelling field, $N-/O+$. The

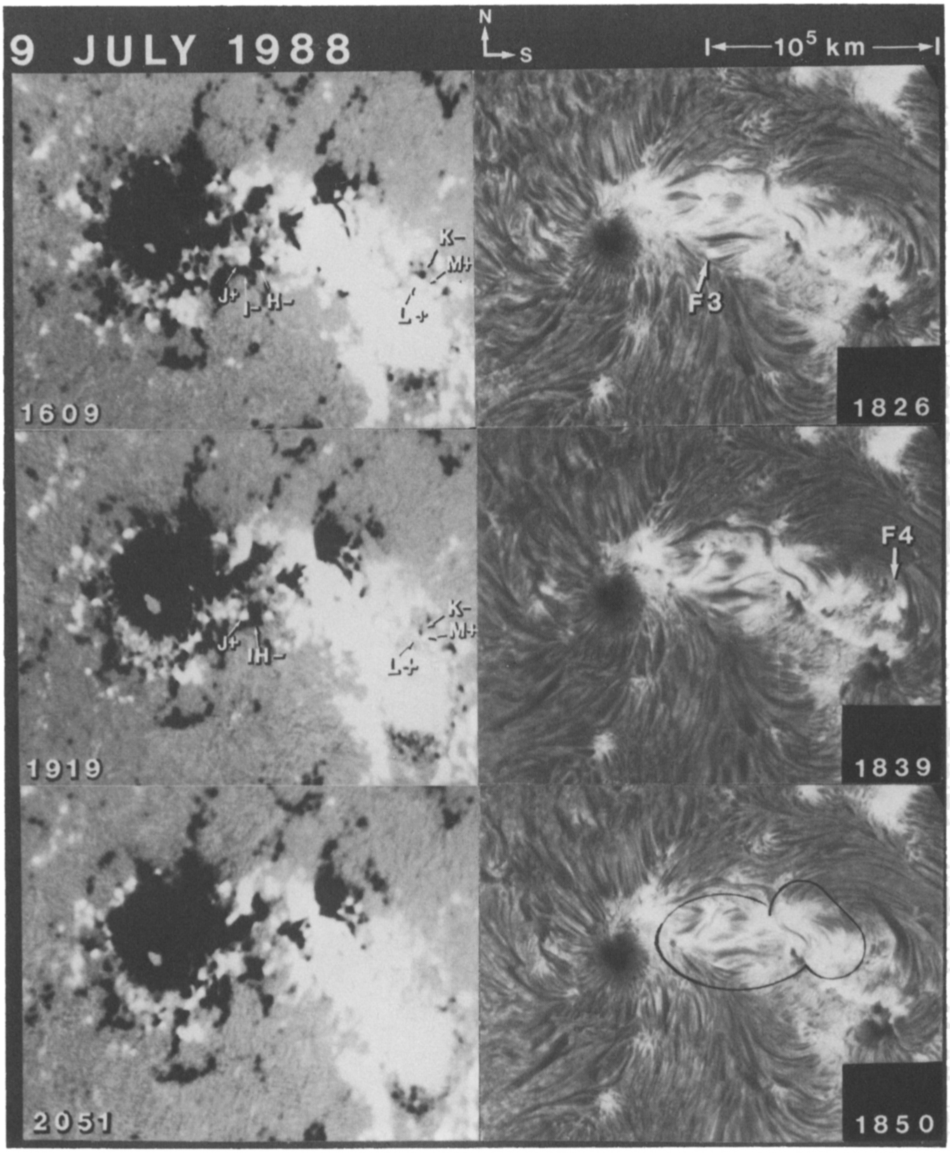

Fig. 3. Subflares F3 and F4 in the upper right and right middle frames are typical of other sites in this active region where small flares can occur. F3 corresponds to the magnetic field patches labelled $J+$, $I-$, and $H-$ in the first magnetogram. $J+$ and $I-$ are both MMF patches while $H-$ is part of the larger of two complex emerging flux systems that are enclosed within the ovals in the lower right. The larger emerging flux system was already present on the previous day and is the area within the oval in the lower right of Figure 2. The encounter of $J+$ with the merged fields of $I-$ and $H-$ results in flux cancellation which is seen by the reduction and disappearance of $J+$ by the time of the last magnetogram at 2051. Subflare F4 corresponds to the cancelling MMFs, $L+$ and $M+$ with $K-$. $K-$ also disappears completely by the end of the sequence.

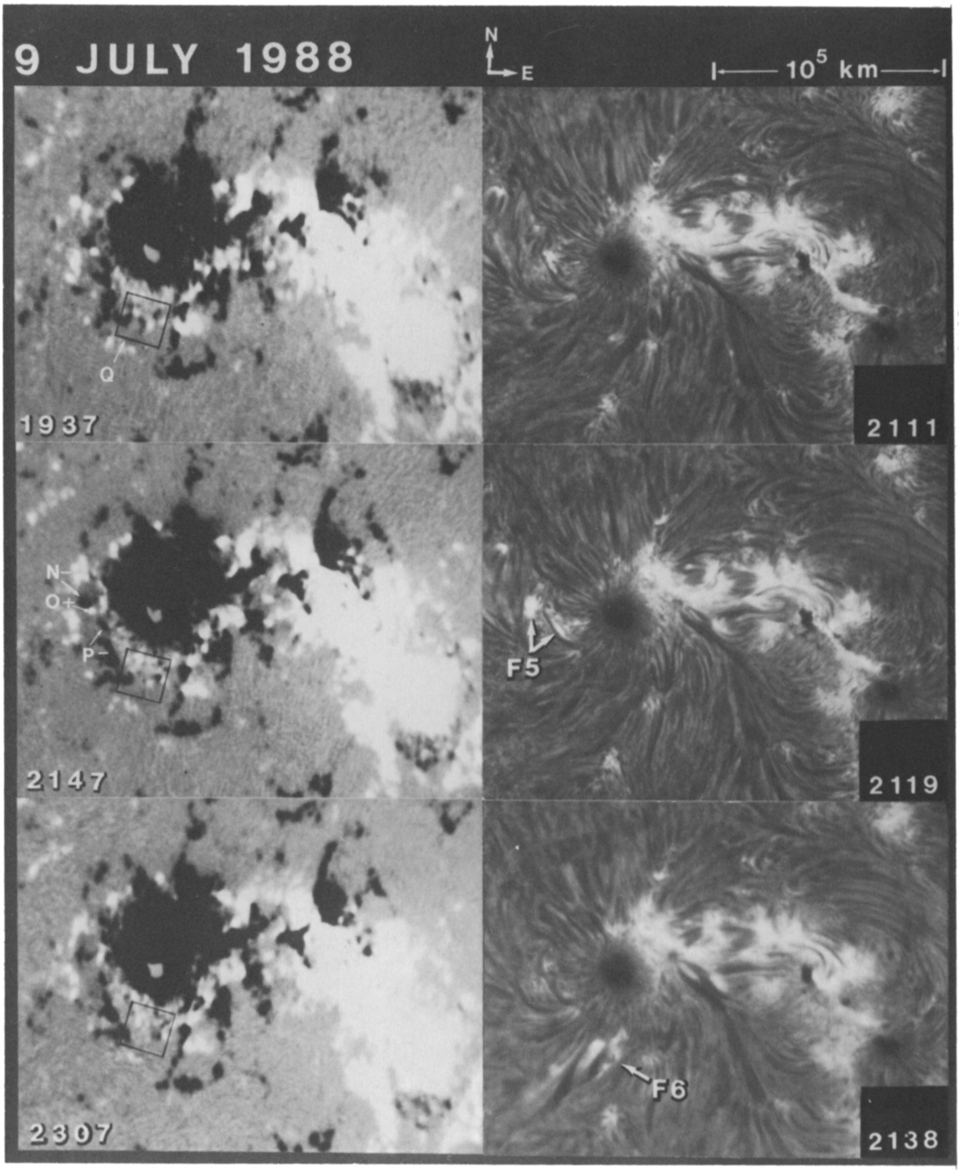

Fig. 4. The subflare F5 in the middle right is another example of a small flare which is related to changes in MMFs to the left of the negative polarity sunpot. The larger flare segment lies just to the left of cancelling feature, $N-/O+$, and the smaller segment corresponds to $P-$. Thus these two chromospheric components of the flare occur on opposite sides of a cancelling feature rather than coinciding with it. The other flare, F6, seen below the sunspot in the last frame, corresponds to a cluster of very small MMFs with the square labelled Q. Both of these examples, F5 and F6, show that flares are not necessarily coincident with strong magnetic fields.

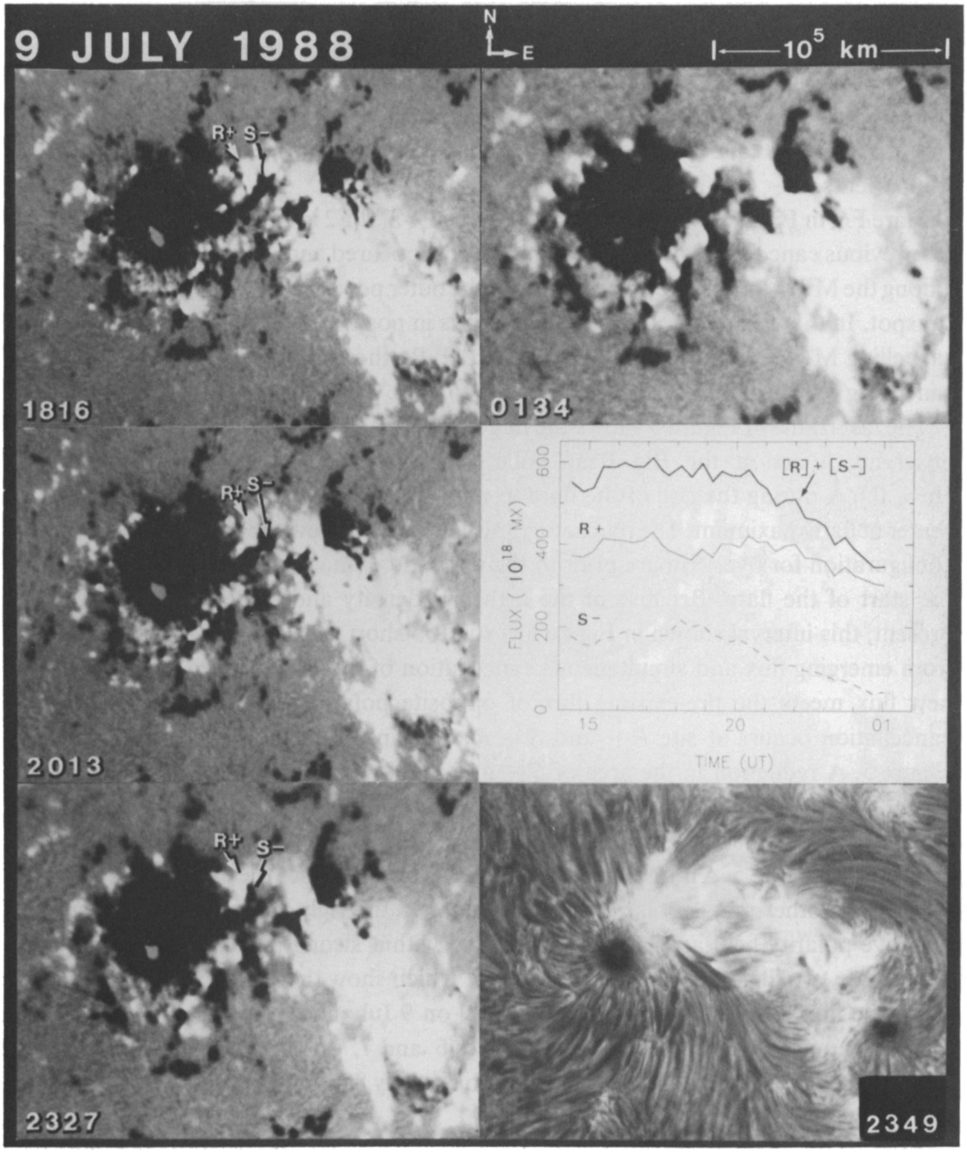

Fig. 5. The large flare in the lower right has spread to all of the areas of enhanced plage seen in the previous figures. It corresponds to all of the complex magnetic configuration within both emerging flux regions shown within the ovals in the lower right of Figure 2. In this illustration we label just two patches of magnetic flux, $R+$ and $S-$ that are cancelling during this flare. The loss of flux can be seen in the reduced area of $S-$ and the lower part of $R+$. Measurements of the rate of cancellation of $R+$ and $S-$ are shown in the graph. From 20:00 until 01:00 UT, the mean rate of cancellation in just this small area is 3×10^{19} Mx hr^{-1}.

left component of F5 lies just left of $N-$ where there appears to be no magnetic field. The time-lapse film, however, shows that this is a site of the convergence of weak positive flux. The other flare component corresponds to the negative fragment, $P-$. If the two chromospheric parts of this flare are connected by loops in the corona, then this flare straddles the cancelling feature, rather than coinciding with either or both cancelling components, $N-$ and $O+$.

Flare F6, in Figure 4, is near the sites of flares F1 and F2 in Figures 1 and 2. However, the previous cancelling fields have completely disappeared and new ones have developed among the MMFs that have emanated from the outer penumbral border of the associated sunspot. In the magnetograms, F6 corresponds in position to the cluster of small, weak cancelling MMFs within the square labelled Q. By the end of this series, only one tiny cancelling feature remains.

The last frame in Figure 5 shows the largest flare observed in this active region during observing hours at the Big Bear Solar Observatory. The image at 23:40 is at Hα – 0.6 Å during the rise of the flare to maximum and the image at 23:49 is at line center at flare maximum. The magnetograms in Figure 5 show the preflare magnetic field configuration for over 5 hours prior to the flare and a final image about one hour after the start of the flare. Because of the high flux density and the large amount of flux present, this interval shown in Figure 5 is still too short to illustrate most of the growth from emerging flux and simultaneous cancellation of flux at the boundaries where the new flux meets the pre-existing flux of opposite polarity. However, a conspicuous cancellation occurs at site $R+$ and $S-$ marked in the upper parts of the frames in Figure 5. A reduction in the area of $S-$ and the lower part of $R+$ can be seen. $R+$ and $S-$ are also sufficiently separated from adjacent flux that they could be measured. A gradual loss of flux at a mean rate of 3×10^{18} Mx hr^{-1} is shown in the graph on the right side of Figure 5. A much longer time series is needed to see the effects of cancellation around the other major polarity inversion lines to the right where two larger areas of negative polarity field are partially embedded within strong positive fields. Therefore, we include two illustrations, Figures 6 and 7, which show the long-term evolution of the magnetic flux for nearly 48 hours from early on 9 July until the end of 10 July. Using Figures 1 and Figure 8 along with Figures 6 and 7, one can trace the continuous evolution of the active region fields for approximately 80 hours except during a time gap during the first 15 hours of 11 July.

Figure 6 begins with images taken at the Huairou Solar Observatory and ends with images from Big Bear Solar Observatory nearly 24 hours later. Examples of the disappearance of magnetic flux are seen in negative polarity patches $T-$, $U-$, and $V-$. All three patches disappear before 16:09. Concurrently, several negative polarity patches grow in the middle of the region and converge to form the patch $W-$. Another new negative patch, $X-$, associated with the second new flux system, is first apparent at 20:13. $X-$ grows and merges with the large patch of negative flux to its upper left, while also cancelling with the intermediate area of positive flux. Note also in Figure 7, that $W-$ (from Figure 6) grows until about 15:27. Thereafter $W-$ begins to fragment and cancel with the adjacent flux. It is reduced in area by about 50% by the end of

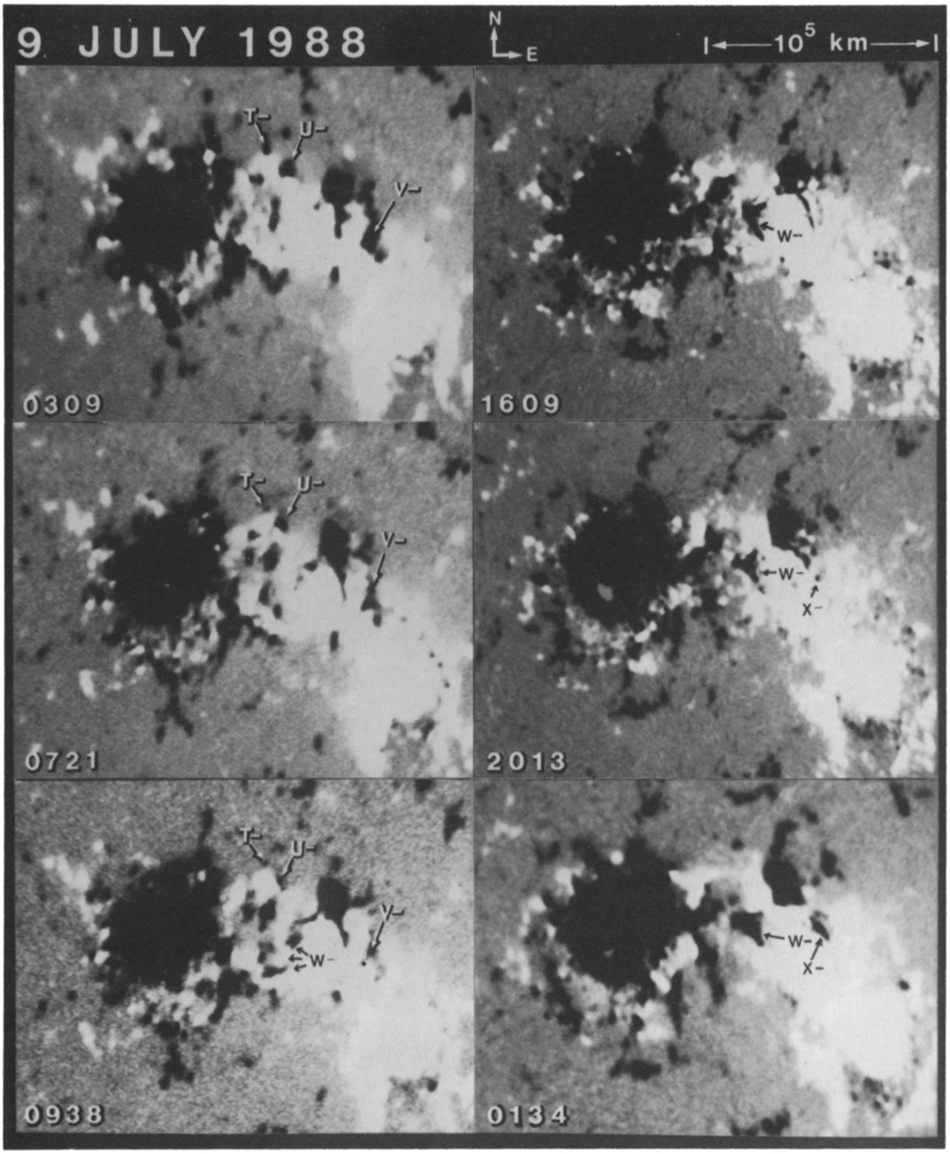

Fig. 6. This illustration encompasses a longer time interval around the major flare shown in Figure 5 in order to show the type of changes in flux that both precede and occur during that major flare. In this series from early on 9 July until early on 10 July, it is possible to identify many sites where the magnetic flux is either cancelling or growing because of the emergence of the new flux regions shown within the ovals in the lower right of Figure 3. Sites $T-$, $U-$, and $V-$ are negative field patches where the magnetic flux is decreasing and $W-$ and $X-$ are other negative patches where the magnetic flux is seen to increase. The first 3 images on the left are from the Huairou Observatory and the last 3 images on the right are from the Big Bear Solar Observatory.

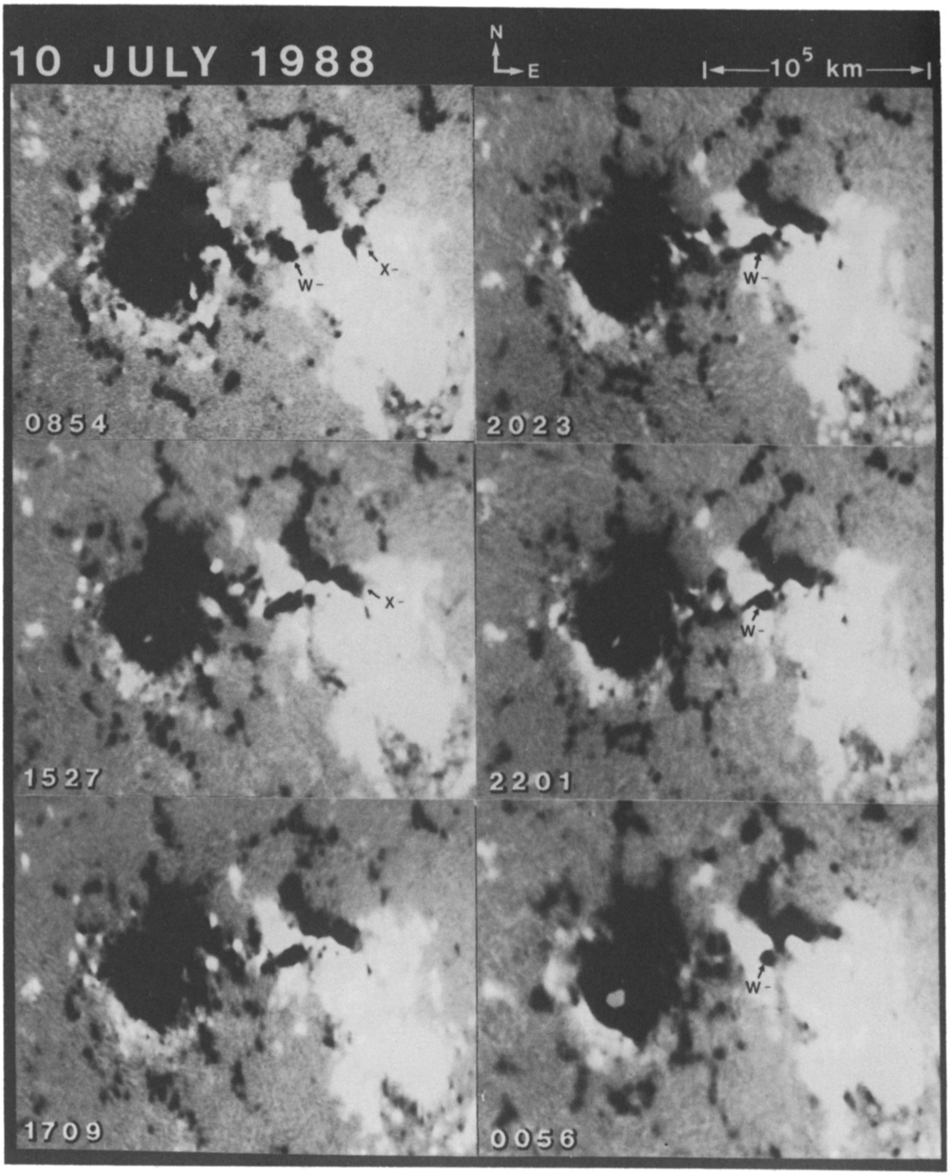

Fig. 7. This series of magnetograms continues from Figure 6. The area $W-$ continues to grow until about 15:27. Even during the growth stage, cancellation can be seen at the left border of $W-$, with small patches of neighboring positive polarity flux. Magnetic flux disappears to the left of $W-$ from about 20:13 in the preceding series in Figure 6 until the end of Figure 7. $W-$ ceases its overall growth at about 15:27 and thereafter it slowly shrinks as it is cancelled by the surrounding positive polarity flux. The comparable reduction in the positive flux around $X-$ is not conspicuous until the next day seen in Figure 8. Then it is seen in Figure 8 that most of the positive and negative flux in between the sunspots on the left and right has cancelled prior to the occurrence of the next observed major flare.

10 July. By the next day, 11 July, seen in Figure 8, it has completely disappeared along with the majority of the other negative polarity flux in the trailing polarity of this active region.

In Figures 6 and 7, we have labelled only the largest and most conspicuous sites of flux growth and disappearance. Many smaller sites of growth and disappearance can be found. The purpose was to show that much flux emergence and concurrent disappearance is taking place in the active region in the general area of the major flare shown in Figure 5. These changes are taking place before, during and after the major flare. In such complex situations as illustrated in Figures 6 and 7, it is not readily apparent that the magnetic flux disappears by cancellation of negative and positive flux. This process is much more clearly seen either in small active regions (Livi, Wang, and Martin, 1985) or during the decay phase of active regions (Martin *et al.*, 1985), illustrated in Figure 8 for example.

Figure 8 exemplifies the cancellation of flux associated with a major flare in a magnetically simple situation. Because the active region has decayed and the overall flux density is lower in the middle of the active region, we chose to make the final illustration from the original magnetograms. The contours are generated by reversing the color (black to white and *vice versa*) each time that the 8-bit memory is filled in the image processor. Hence, the polarity is determined by the color (black or white) outside of the lowest contour. Where the flux density is not too high, the original contoured magnetograms show the changes in magnetic flux just as well as the reduced magnetograms for which the contours have been removed.

In Figure 8, positive patch $AA+$ and negative patch $BB-$ slowly and simultaneously diminish during the 7-hour interval shown. As they diminish, tiny fragments such as $a1+$ and $a2+$ break away from the patch $AA+$. Other tiny fragments from neighboring patches of opposite polarity flux similarly separate from larger patches such as $CC-$ and $DD-$. Examples are $c1-$, $c2-$, and $d1-$.

All of these fragments except $c2-$ have cancelled with neighboring flux by the end of the day: $c2-$ migrated toward $BB+$ as $c1-$ was cancelling; $c2-$ then replaced $c1-$ and began cancelling with $BB+$ between 20:17 and 22:28. The study of Martin *et al.* (1985) demonstrated that this process of fragmentation and cancellation can take place continuously along a primary polarity inversion zone within a decaying active region. Where the flux density and magnetic field gradients are high, such as between $AA+$ and $BB-$, the fragmenting elements are usually not resolved. However, the rate of cancellation is measurable. The cancellation is then seen as simply a steady, slow decrease in the area and the magnetic flux. $AA+$ and $BB-$ clearly dminish throughout the day while maintaining approximately the same magnetic field gradient across their common boundary.

The flare in Figure 8 began around the primary cancellation site in the middle of the active region. Then the flare spread to the areas of single polarity both east and west of the cancellation site.

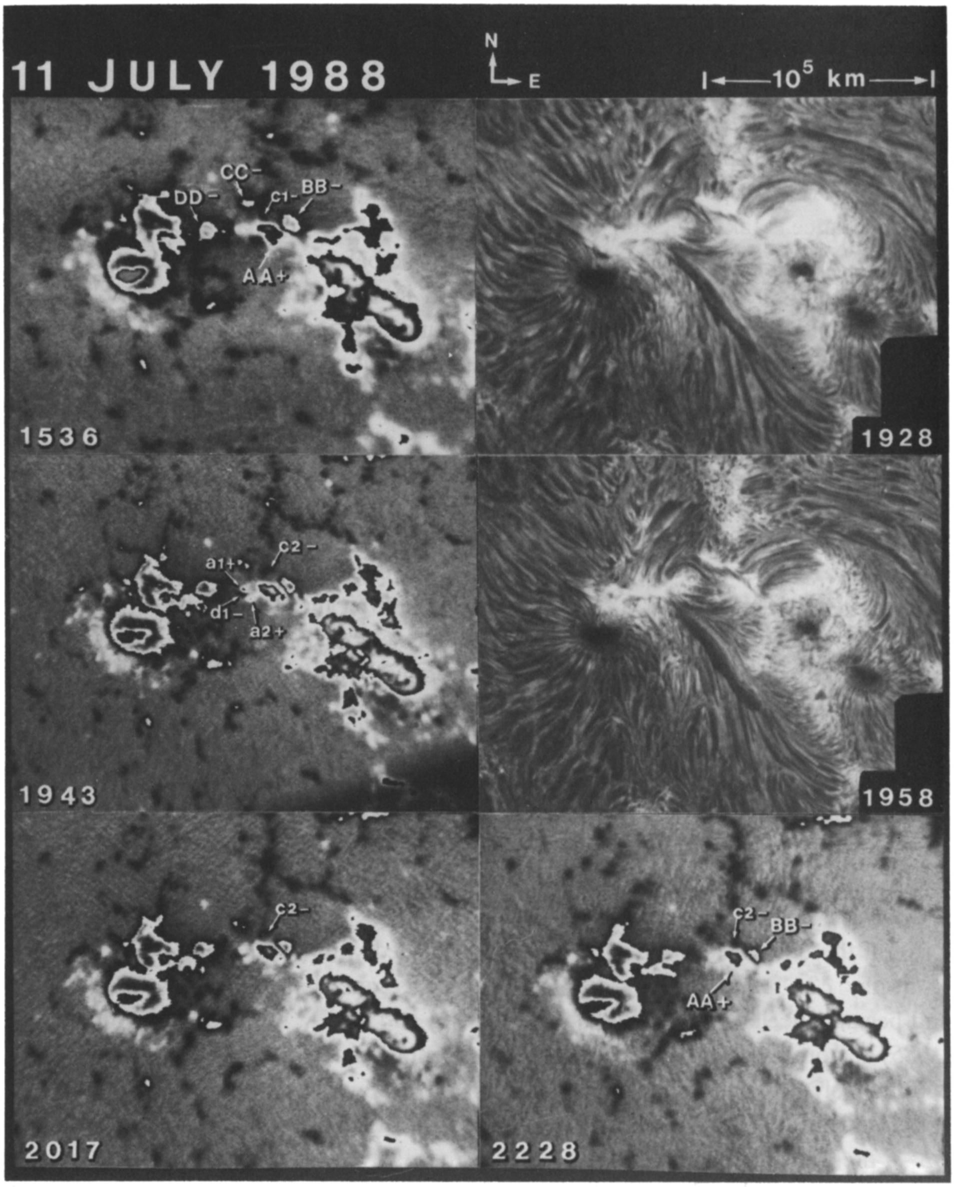

Fig. 8. This series continues from Figure 7 but the magnetograms are shown in their original format as taken at the Big Bear Solar Observatory. The strongest fields of each polarity lie within the contours which are created by reversing the color from black to white at successive levels of saturation of the magnetograph signal. Hence, the polarity is determined by whether the area around the perimeter of each contour is white (positive) or black (negative). The major flare in the upper right is shown at maximum at 19:28 and in its decaying phase at 19:58. The one remaining major site of cancellation is between $AA+$ and $BB-$. The cancellation is seen from the shrinking of the contours within $AA+$ and $BB-$. In addition, minor cancellation sites develop around the periphery of $AA+$ and $BB-$ as very small magnetic field fragments split off of $AA+$ and $BB-$ and from the neighboring areas such as the ones labelled $CC-$ and $DD-$. The cancellation of $d1-$ with $a1+$ and $a2+$ is seen to the left of $AA+$. The successive motion of small fragments, $c1-$ and $c2-$, toward $AA+$ are seen prior to their cancellation with $AA+$.

4. Discussion

The different circumstances that have been previously considered relevant in flare production might appear contradictory or irrelevant: adjacent decreasing and increasing evolving magnetic features (Ribes, 1969), emerging magnetic flux (Rust, 1974), cancelling magnetic flux (Martin, Livi, and Wang, 1985), magnetically complex regions (Smith and Howard, 1968), high magnetic field gradients (Severny, 1960), bright regions (Dizer, 1969), delta spots (Zirin and Liggett, 1987), sunspot motions (Zirin and Lazareff, 1975), to cite just a few early representative papers. However, there are common factors in all of these situations: they either indicate cancellation sites or show the collision of opposite polarity features which will lead to cancellation. Tanaka (1975), referring to flares in August 1972 and July 1974, writes: 'all sunspot motions indicate a collision between the two polarities'. Evidence now suggests that sunspot motion or emerging flux alone will not lead to flares. Their role is the forcing together of opposite polarity fields which in turn induces cancellation. Higher cancellation rates are expected with faster motions and higher concentrations of magnetic flux.

As illustrated above, a spatial relationship between cancellation and flares is now becoming more clear: flares begin at or near opposite polarity features that are cancelling. Flares often occur when magnetic flux is emerging, but now we think that they only occur if emerging fields also collide with opposite polarity leading to cancellation. Previous observations of emerging flux regions were unable to reveal the loss of flux that occurs on the same side of a polarity inversion line where growth or increase is also seen; they could only show the loss in flux on the opposite side of the polarity inversion line from the emerging side (Martres *et al.*, 1968a, b; Ribes, 1969). It was, therefore, observed that flares occurred around the polarity inversion lines where flux increased on one side and decreased on the other. The many previous associations of flares with emerging flux and the more specific association of flares at sites of both increasing and decreasing flux are entirely valid and still apply to many of our present-day observations, as in some of the examples above, which have saturation effects, inadequate resolution or inadequate sensitivity to detect the decrease in flux on both sides of polarity inversion lines. The new association of flares with cancelling magnetic fields thus does not invalidate previous results. It is only a more general association that encompasses the previous associations.

Since the paper of Martin, Livi, and Wang (1985), which first discussed the association of cancelling fields to flares, we have not yet found any flares at sites where cancellation was not observed or inferred, provided that we have acquired observations with sufficiently high resolution and sensitivity (on order of 10 G). Therefore, we propose that cancellation is a necessary, evolutionary condition for the occurrence of flares. This does not imply that all cancellation necessarily leads to flares nor that it is the only necessary condition.

The significance of the association of flares to cancelling magnetic fields is most clearly understood by studying flares that happen at cancellation sites in the absence of emerging flux and comparing these to circumstances when emerging flux is present.

From these comparisons, we have come to understand that emerging flux is not the primary reason for flares but that in many circumstances it plays an important, but secondary, role in forcing opposite polarity flux together. It is not yet known when a flare should happen during the cancellation process or if flares happen in all circumstances where cancellation takes place.

We speculate that gradual releases of energy might happen in all cancellation sites because they tend to be brighter than similar isolated magnetic features of single polarity. It might be that cancellation leads to flares only in special circumstances. There might be other necessary conditions such as a sheared magnetic configuration which has not been discussed in this paper. This is even expected because of the observation that filaments also form at cancellation sites (Martin, 1986) and filaments are generally recognized to represent sheared magnetic field configurations. In addition, there are many studies that have shown associations between filament orientation, sheared configurations, filament eruptions, and flares. These topics are outside the scope of this paper but are still fertile areas of research in understanding flare build-up (Gaizauskas and Švestka, 1987).

A new theory on the formation and eruption of prominences by van Ballegooijen and Martens (first presented at this Colloquium; unpublished) was stimulated by previous observations of cancellation and the formation of filaments at cancellation sites. By interpreting cancellation as magnetic reconnection at the photosphere, van Ballegooijen and Martens developed a model whereby part or all of the disappearing photospheric line-of-sight component is reconfigured into an increased transverse magnetic field component and, hence, disappears.

The site of increased transverse component becomes the filament. With continued cancellation, the magnetic field in the filament expands outward, eventually becomes unstable, and erupts. The instability that triggers the eruptions can be the same instability that results in solar flares. In this scenario, cancellation is a key part of the preflare build-up. At present, this theory and our observations of the relationship of cancelling fields to solar flares are remarkably consistent.

5. Summary

The examples cited above and many others found during our search through the time-lapse movies from the Big Bear Solar Observatory, show that cancellation happens with magnetic fields spanning a wide range of magnetic field strengths. It is shown that flares of all magnitudes begin adjacent to cancellation sites, whether the associated active region as a whole is developing or decaying. Both small and big flares are initiated near cancelling sites, from the microflares associated with ephemeral regions to the kernels of the great flares.

By reinterpreting previous results on emerging or increasing magnetic flux regions in terms of their possibility to induce cancellation, the apparent conflict between the various circumstances of flares with changing magnetic fields is resolved. Cancelling magnetic flux is observed or deduced to be the common denominator among all observed associations of flares to changing magnetic fields. In particular, flares have been observed when cancellation has been observed or inferred to occur concurrently with emerging magnetic flux, as well as in circumstances of verified absence of increasing magnetic fields during the decay of active regions. Additionally, flares cease occurring in decayed active regions when cancellation sites disappear. Therefore, we propose cancelling magnetic fields to be a necessary evolutionary condition for the initiation of solar flares. However, cancellation is still considered an indirect precondition to flares because the time-scale of cancellation is slower than the time-scale of flares. More studies will be necessary to know if all flares are preceded by cancellation and if observed cancellation corresponds to physical processes that result in stored energy which can be later released in flares.

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References

Dizer, M.: 1969, *Solar Phys.* **10**, 416.
Gaizauskas, V. and Švestka, Z.: 1987, *Solar Phys.* **114**, 389.
Harvey, J. H. and Harvey, K. L.: 1973, *Solar Phys.* **28**, 61.
Livi, S. H. B., Wang, J., and Martin, S. F.: 1985, *Australian J. Phys.* **38**, 855.
Marsh, K.: 1978, *Solar Phys.* **59**, 105.
Martin, S. F.: 1980, *Solar Phys.* **68**, 217.
Martin, S. F.: 1984, S. Keil (ed.), *Small-Scale Dynamic Processes in Quiet Stellar Atmospheres*, p. 30.
Martin, S. F.: 1986, *Coronal and Prominence Plasmas*, NASA Conf. Publ. 2442, p. 73.
Martin, S. F.: 1988, *Solar Phys.* **117**, 243.
Martin, S. F., Livi, S. H. B., and Wang, J.: 1985, *Australian J. Phys.* **38**, 929.
Martin, S. F., Dezsö, L., Antalová, A. Kučera, A., and Harvey, K. L.: 1983, *Adv. Space Res.* **2**, 39.
Martin, S. F., Bentley, R. D., Schadee, A., Antalová, A., Kučera, A., Dezsö, L., Gesztelyi, L., Harvey, K. L., Jones, H., Livi, S. H. B., and Wang, J.: 1984, *Adv. Space Res.* **4**, 61.
Martin, S. F., Livi, S. H. B., Wang, J. and Shi, Z.: 1985, *Measurements of Vector Magnetic Fields*, NASA Conf. Publ. 2374, May 1984, Marshall Space Flight Center, Alabama, NASA, Washington, DC, p. 403.
Martres, M. J., Michard, R., and Soru-Iscovici, I.: 1966, *Ann. Astrophys.* **29**, 249.
Martres, M. J., Michard, R., Soru-Iscovici, I., and Tsap, T.: 1968, in K. O. Kiepenheuer (ed.), 'Structure and Development of Solar Active Regions', *IAU Symp.* **35**, 318.
Martres, M. J., Michard, R., Soru-Iscovici, I., and Tsap, T.: 1968b, *Solar Phys.* **5**, 187.
Michard, R.: 1971, in R. F. Howard (ed.), 'Solar Magnetic Fields', *IAU Symp.* **43**, 359.
Priest, E. R., Gaizauskas, V., Hagyard, M. J., Schmahl, E. J., and Webb, D. F.: 1986, *Energetic Phenomena on the Sun*, NASA Conf. Publ. 2439, pp. 1-1 to 1-79.
Ribes, E.: 1969, *Astron. Astrophys.* **2**, 316.

Rust, D. M.: 1972, *Solar Phys.* **25**, 141.
Rust, D. M.: 1974, *Flare-Related Magnetic Field Dynamics*, HAO Conference held in Boulder, Colorado, p. 243.
Severny, A. B.: 1958, *Izv. Krymsk. Astrofiz. Obs.* **20**, 22.
Severny, A. B.: 1960, *Izv. Krymsk. Astrofiz. Obs.* **22**, 12.
Smith, S. F. and Howard, R. F.: 1968, in K. O. Kiepenheuer (ed.), 'Structure and Development of Solar Active Regions', *IAU Symp.* **35**, 33.
Smith, S. F. and Ramsey, H.: 1967, *Solar Phys.* **2**, 158.
Tanaka, K.: 1975, *Solar Phys.* **47**, 247.
Vorpahl, J.: 1973, *Solar Phys.* **28**, 115.
Zirin, H.: 1988, *Astrophysics of the Sun*, Cambridge University Press, Cambridge, p. 343.
Zirin, H. and Lazareff, B.: 1975, *Solar Phys.* **41**, 425.
Zirin, H. and Liggett, M. A.: 1987, *Solar Phys.* **113**, 267.
Zwaan, C.: 1987, *Ann. Rev. Astron. Astrophys.* **25**, 83.