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The Role of Magnetic Loops in Solar Flares [and Discussion]

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The role of magnetic loops in solar flares

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X-ray and ultraviolet observations of flares have provided much important information on their spatial structure and magnetic topology. The early observations from *Skylab* emphasized the role of simple loops and loop arcades, but later observations from the *Solar Maximum Mission* have greatly complicated this picture. Flares appear in a multitude of loops with complex spatial and temporal interrelations. In many cases, interactions between different loops appear to play a crucial role. The inferred magnetic topology of solar flares will be reviewed with emphasis on the implications for processes of energy release and transfer. It will be shown that the spatial resolution of the observations obtained so far is still inadequate for solving many basic questions of solar flare research.

1. Introduction

Nearly ten years ago, in December 1981, the Royal Astronomical Society organized a one-day meeting in London to discuss solar flares. On that occasion, I was asked to give a talk on observations of loops in flares, i.e. the same topic that I am asked to cover again in this paper. In those early days, in-depth analysis of *Solar Maximum Mission* (*SMM*) data had barely started and we were still capitalizing on the previous *Skylab* results. It was natural, therefore, to put the emphasis on single loops and loop arcades and on the modelling of solar flares within simple loop structures (Pallavicini 1982).

In the ten years since then, a great change has occurred in our appreciation of solar flare morphology, mainly as a consequence of X-ray and ultraviolet (UV) observations obtained by *SMM*. The emphasis is now on multi-loop structures and loop interactions and it is questionable whether the concept of a single loop can help understand flares. Why is there such a difference between the *SMM* and *Skylab* results, despite the fact that *Skylab* had typically a better spatial resolution than *SMM*?

There are several reasons that could explain the apparently contrasting results obtained by the two missions. The most important, perhaps, are the low temporal resolution of many *Skylab* observations and the fact that *Skylab* did not cover adequately the early phases of flares. During the decay, solar flares are often dominated by relatively simple X-ray structures. The situation is usually more complex during the impulsive phase.

In spite of these undeniable reasons, I think that the difference between *SMM* and *Skylab* was also due to the different emphasis put on the interpretation of the data. *Skylab* was the first mission to demonstrate the paramount importance of magnetically confined loops in all regions of the solar atmosphere, except coronal

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holes. Loops appeared to be the building blocks of coronal phenomena, including flares: it was natural, therefore, to study the physics of these elementary structures and to neglect, perhaps incorrectly, all other complicating aspects (like multi-loop structures) that could possibly distract from the elementary processes at work.

SMM, on the contrary, had a spatial resolution insufficient in most cases to show directly the loop structures: it had, however, a better temporal resolution, as well as a wider wavelength coverage and a better coordination of space-borne and ground-based observations. The complex morphology that *SMM* was able to reveal required a greater interpretative effort, but resulted in a far richer picture in which magnetic loops of various sizes and topologies coexist and often interact during the various phases of a flare. To understand whether these complex relations between different flaring structures play a crucial role in the flare energy release process is a difficult observational and theoretical task that can only be partly addressed with present data.

In this paper, I first recall briefly the early *Skylab* results, showing that even the *Skylab* picture was more complex than usually thought. Then I move to *SMM* observations, and I show what kind of evidence we have for multi-loop structures and loop interactions. Next, I discuss the physical implications of these observations by focusing on the magnetic topology and the processes of energy release and transfer in multi-loop structures. Finally, I conclude by stressing the limitation of the present observations to answer basic questions of solar flare research.

2. The *Skylab* picture: simple loops and loop arcades

One of the fundamental results of *Skylab* was that flares are of two different types: compact, short-lived events (now called *confined* flares) and large, long-duration events (now called *dynamic* or *ejective* flares (Pallavicini *et al.* 1977; Priest 1981; Svestka 1986)). This classification should not be taken too rigorously, since the two classes are likely to represent only extreme cases in the large variety of different conditions that occur in solar flares. I will use this classification only for the purpose of organizing the discussion.

Compact flares take place in magnetically confined structures that, apparently, remain unchanged throughout the flare evolution. They might be produced by rapid energy release through instabilities which occur inside an isolated stressed magnetic flux tube (Spicer 1977; van Hoven *et al.* 1981); energy could also be released through external reconnection in neutral sheets that form when different flux tubes come into close contact (Heyvaerts *et al.* 1977; Priest, 1985). It is often stated that compact flares are simple flares or, even more incorrectly, that they are *single-loop* flares. Although this may seem to favour internal reconnection, it is not what *Skylab* really showed us.

The *Skylab* images revealed many different kinds of compact flares. In most cases, the observed structure was quite complex, with bundles of loops flaring simultaneously or in succession (as for instance in the flare of 15 June 1973 (cf. Pallavicini *et al.* 1975)). Only in a few cases (e.g. the flare of 5 September 1973 (cf. Cheng & Widing 1975)) it was possible to isolate a simple flaring loop arching between regions of opposite magnetic polarity.

Kahler *et al.* (1976) called attention to the presence in several X-ray flares of bright short-lived 'kernels' often located near one extreme of a more extended loop-like structure. They argued that the kernels were small unresolved loops which decay faster because of larger radiative and conductive losses. Their presence near one extreme of a larger loop was taken as evidence in favour of the emerging flux model of Heyvaerts *et al.* (1977). Pallavicini *et al.* (1977) described a complex event at the limb (10 June 1973) where brightenings occurred in both small and large structures over a period of several hours. The brightening of a low-lying compact loop also produced brightening of a larger loop with one footpoint in, or close to, the compact structure. This is similar to a topological configuration often observed by *SMM* in limb flares (Woodgate *et al.* 1981; Poland *et al.* 1982). A case of possible loop interaction seen by *Skylab* in the 21 January 1974 flare was discussed by Widing & Hiei (1984) and Cheng & Widing (1990). All this indicates that complex morphologies were not uncommon in the *Skylab* data. It would be interesting to go back to the old *Skylab* observations with the new insights gained from the analysis of *SMM* observations.

The other class of flares mentioned above comprises large-scale long-duration events which are typically associated with filament eruptions or major activations, and are often accompanied by white-light transients (Pallavicini *et al.* 1977). Two-ribbon flares like the famous events of 29 July 1973 and 7 September 1973 observed by *Skylab* (Moore *et al.* 1980) are a subgroup of this class. These flares show typically an arcade of X-ray loops, brighter at their top, which grow in height as time progresses. Below the X-ray loops, cooler loops are observed in UV lines and in Hα. A global magnetic restructuring appears to be necessary in this case. According to current interpretations they are produced by magnetic reconnection in a Y-type neutral point, where field lines, originally torn open by a disruptive event, relax back to a closed configuration (Kopp & Pneuman 1976; Pneuman 1981).

It is worth mentioning that in addition to the better-studied two-ribbon flares, there are many other large-scale long-duration events observed in X-rays. A common occurrence are X-ray brightenings observed after filament disappearances outside active regions. These events are often not accompanied by Hα brightenings (Webb *et al.* 1976). A major problem is whether these phenomena can also be explained by the reconnection model proposed for two-ribbon flares. The *Skylab* observations left this issue largely unsolved.

3. The *SMM* picture: multi-loop flares and loop interactions

A very comprehensive summary of flare observations obtained with the hard X-ray imaging spectrometer (HXIS) on *SMM* has been presented recently by Machado *et al.* (1988*a*). Their sample comprises 23 flares from several active regions (ARS): many of them occurred in two well-studied regions, AR 2372 observed in April 1980 and AR 2779 observed in November 1980. HXIS had a maximum spatial resolution of 8 arcsec and covered the spectral range 3.5–30 keV.

AR 2372 consisted of two spots of opposite polarities aligned in the E–W direction, and a region of reversed polarity between the spots. The magnetic configuration, therefore, was of the type minus–plus–minus–plus, with three N–S neutral lines separating the various polarities. Extrapolations of photospheric fields under the potential approximation show that a complex system of loops connects the opposite polarities, as schematically shown in figure 1. An X-type neutral point exists above the central reversed region: this is a likely place for initial energy release and particle acceleration (Machado *et al.* 1983).

Analysis of the flares which occurred in AR 2372 from 6 April to 10 April 1980

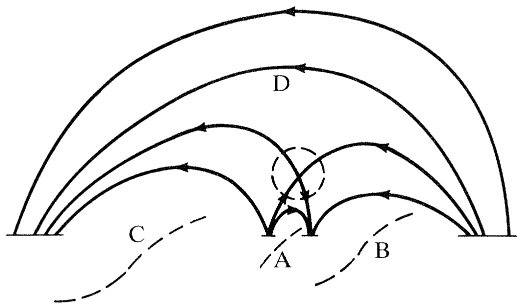

Figure 1. Schematic representation of the magnetic field configuration of AR 2372 in April 1980. A, B and C are photospheric neutral lines overlayed by coronal loops connecting opposite polarities. A, B and C also indicate the three interacting bipoles in which X-ray flares originated. The small dashed circle indicates the position of an X-type neutral point (from Machado *et al.* 1988*a*).

showed consistently that the X-ray events started in the general vicinity of the central neutral line, i.e. above the central bipole A, in a region of highly stressed magnetic fields. X-ray emission then rapidly extended to nearby regions, presumably involving loop structures across the outer neutral lines B and C (cf. figure 1). In the late decay, even larger magnetic structures were observed connecting the two main spots (as loop D in figure 1).

These observations clearly indicate that a complex magnetic topology was involved in the flares, with a series of loops that became excited at different times. There were differences from one flare to another, but the general topology and the sequence of events remained apparently the same. Machado *et al.* (1988*a*) argue that the proximity of different magnetic bipoles, with one bipole impacting over the adjacent one, was the cause of the flares. Energy could be released at the central X-ray neutral point (as originally suggested by Machado *et al.* (1983)) or in neutral sheets that form when the central bipole impacts over either one of the outer bipoles. Alternatively, non-potential energy stored in the magnetic flux tubes could be released internally when the different bipoles come in contact. In this case, the interaction of different bipoles would act simply as a trigger for the release of internally stored energy.

In contrast to disc flares, flares at the limb do not allow the observed structure to be related precisely to the underlying photospheric magnetic field, but have the advantage of showing directly the vertical structure of flares. Several authors have described events at the limb observed with *SMM* (Woodgate *et al.* 1981; Poland *et al.* 1982; Machado *et al.* 1983; de Jager *et al.* 1983; Kundu *et al.* 1984; Veck *et al.* 1985). In all cases, a small low-lying loop was apparently rising up and impacting against a much larger system of pre-existing loop structures. Although the magnetic polarities are not known in this case, and hence the nature of the loop 'interaction' remains obscure, these observations suggest a qualitative agreement with the emerging flux model of Heyvaerts *et al.* (1977). Apparently energy was released initially in the compact low-lying structure and only later in much larger adjacent loops. Whether this transfer of energy between different flux tubes occurred through a reconnection layer or through a common footpoint remains unclear. It is also possible that flaring of small and large structures occurred independently, and at successive times, in response to a common perturbation (e.g. shear motions at the base of field lines).

Evidence for multi-loop structures and possible loop interactions has also been

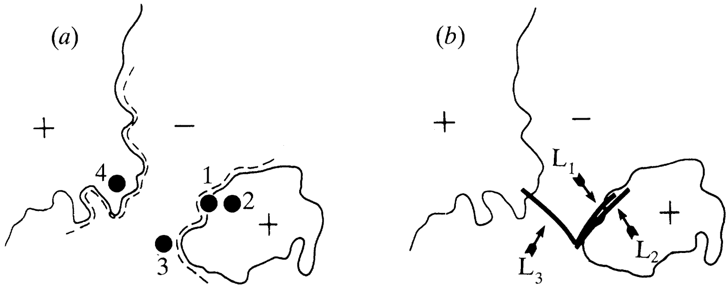

Figure 2. Magnetic topology inferred for the 12 November 1980 flare at 02:50 UT. The right-hand panel (*a*) shows the location of the bright O^{V} kernels relative to the magnetic neutral lines. The left-hand panel (*b*) shows the possible loop connections (from Cheng *et al.* 1985).

provided by simultaneous observations in O^{V} and Fe^{XXI} obtained at 10 arcsec spatial resolution with the ultraviolet spectrometer and polarimeter (UVSP) on board *SMM*. Cheng *et al.* (1985) discussed a flare which occurred in AR 2779 on 12 November 1980 at 02:50 UT. In the late flare decay, when transition region O^{V} emission (at $T \approx 2 \times 10^5$ K) had already faded away, the flare appeared in Fe^{XXI} emission (at $T \approx 10^7$ K) as a simple loop. Comparison with the underlying photospheric magnetic field shows, however, that the Fe^{XXI} feature cannot be a single structure, since otherwise its footpoints would be rooted in regions of the same polarity. The presence of a multi-loop structure is clearly evident if we follow the entire evolution of the flare from the onset to the decay phase and we use the O^{V} emission to identify the loop footpoints (see figure 2).

It is well known that impulsive brightenings in UV lines (Si^{IV}, O^{IV}, O^{V}) are well correlated in time (to within *ca.* 1 s) with hard X-ray bursts (Cheng *et al.* 1981; 1984). These brightenings are interpreted as streams of accelerated electrons impinging upon the transition region at the footpoints of loops. By using the O^{V} kernels observed in the 12 November 1980 flare, Cheng *et al.* (1985) arrived at the magnetic topology illustrated in figure 2. The flare consisted of three main systems of loops (L_1, L_2, L_3). The initial brightenings occurred in the highly sheared loops L_1 and L_2, while loop L_3 became visible only later and was in fact the dominant feature in the late decay. Cheng *et al.* (1985) attributed the onset of the flare to the 'interaction' of loops L_1 and L_2 (either mechanically or inductively) and explained the later brightening of the Fe^{XXI} loop L_3 as a consequence of chromospheric evaporation from the common footpoint area K_3 (cf. figure 2). Although the magnetic topology and the presence of a multi-loop structure seem well established in this case, the nature of the initial 'interaction' between the loops L_1 and L_2 remains obscure. At any rate, they were connected to the other loop L_3 and 'interacted' with it, probably through the common footpoint area K_3 (see also Cheng & Pallavicini (1987) for a discussion of the magnetic topology of this flare in relation to two other homologous events that occurred in the same region a few hours earlier).

HXIS observations of the 12 November flare show basically the same pattern as the UV observations, with X-ray brightenings first occurring to the West of the region (where loops $L_1 + L_2$ are located) and later on extending also to the East (where we have loop L_3). In spite of this, significantly different magnetic topologies have been derived by different observers who have analysed independently the HXIS observations. This is a clear indication of the many uncertainties inherent to the derivation of magnetic topologies from data of modest spatial resolution.

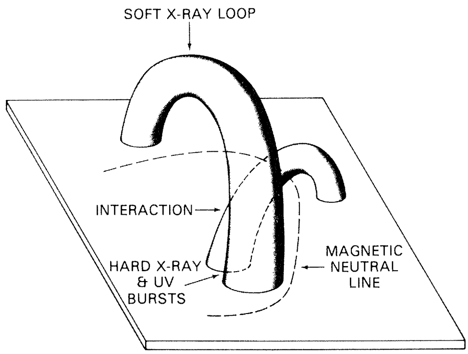

Figure 3. Schematic representation of the magnetic field configuration involved in a large filament-associated event observed on 22 November 1980. A small emerging loop probably perturbed an overlying highly sheared loop structure (from Cheng & Pallavicini 1984).

For instance, de Jager & Boelee (1984) concluded that the 12 November flare occurred in a bundle of loops running in the E–W direction from our kernels K_1+K_2 to kernel K_4 (cf. figure 2). While an alignment error in the location of the footpoints with respect to the magnetic neutral line can make their configuration possible (by shifting our footpoints K_1+K_2 to a region of negative polarity), the presence of the additional footpoint K_3 (as inferred by us from the O^{V} kernels) make our interpretation more likely. Machado *et al.* (1988*a*) noticed that the magnetic configuration of AR 2779 was similar to that of AR 2372 and hence concluded that also the flare topology should be similar (i.e. involving three interacting bipoles crossing the neutral lines A, B and C, as in figure 1). While the central and Eastern bipoles (i.e. our loops L_1+L_2 and L_3 in figure 2) are clearly apparent in both the HXIS and UVSP data, we do not find evidence for a third bipole to the West in our O^{V} and Fe^{XXi} images.

Finally, another example of a possible loop interaction was discussed by Cheng & Pallavicini (1984). We studied a large-scale filament-associated event which appeared as a very large X-ray feature extending along the magnetic neutral line at the periphery of an active region. Comparison with simultaneous Hα pictures shows that this large feature was not an unresolved arcade of loops nearly perpendicular to the neutral line, as might have been expected from the classical picture of large-scale long-duration events. Rather, it was a single highly sheared loop nearly parallel to the neutral line. Ultraviolet brightenings and Hα data provided evidence for the presence of an additional smaller loop below the main X-ray feature and at a small angle with it. This is shown schematically in figure 3. The brightening of the large sheared loop may have been produced by 'interaction' with this smaller underlying feature, probably because the smaller loop perturbed the overlying highly sheared configuration and caused release of non-potential energy.

4. Physical implications of the observed morphology

Ideally, one would like to use the above observational results to constrain the processes of energy release and transfer in solar flares. Unfortunately, this is not an easy task and many fundamental problems have to remain unsolved at present. A few specific examples will be given here.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

(a) *Is loop interaction a necessary condition for the occurrence of flares?*

This is equivalent to asking whether single-loop flares exist. Of course, a flare may look simple when observed at low resolution, while showing a complex structure at higher resolution. *Skylab* gave a few examples of flares which at a resolution of a few arcsec appeared to consist of a single loop (cf. Cheng & Widing 1975; and §2 above). Cheng & Pallavicini (1988) used O^{V} and Fe^{XXI} observations of flares from *SMM* searching specifically for simple events. In a sample of more than 20 events, they identified two point-like flares and two simple-loop flares. The first ones were very compact and short-lived events: they occupied only one or two 10 arcsec pixels and Fe^{XXI} emission followed O^{V} emission very closely in time. We argued that these flares occurred in a small high-density loop. On the contrary, in the two simple-loop flares we identified, the O^{V} emission was initially concentrated in two bright kernels, while Fe^{XXI} emission was delayed and eventually filled the region between the O^{V} kernels. We interpreted this as evidence for high-temperature material filling the loop as a consequence of chromospheric evaporation. In all other cases, the structure of the flare was much more complex. Thus, simple flares may possibly exist (we cannot exclude their existence on the basis of the present observational evidence), but they are certainly not common in the *Skylab* and *SMM* data (see also a similar conclusion in Machado *et al.* (1988*a*)).

(b) *Is energy released at the interface between contacting loops or internally in the loops?*

This is another question that is difficult to answer, because, as predicted by many theoretical models (see, for example, Priest 1985), current sheets have widths that are orders of magnitude smaller than the presently observable scale-lengths. Thus, it may be that we are just observing the heating of regions that are much larger than the original energy release site. Machado *et al.* (1988*a*) have argued on the basis of non-equipartition of thermal energy in adjacent flux tubes, that most of the energy is released internally rather than at the interface between contacting loops. They classified interacting bipoles as either active or passive according to the degree of magnetic stress (defined as the product of field strength and degree of shear). A highly stressed flux tube will release its internally stored energy when perturbed by an adjacent bipole; a weakly stressed loop, on the contrary, may be only the depositary of energy released in adjacent, more stressed loops. In this interpretation, loop interaction, though necessary, acts simply as a trigger for the flare process, rather than being directly responsible for the energy release. Although attractive for many reasons, this interpretation remains largely speculative in view of our basic ignorance of the microphysics of the energy release process. The observations do not allow us to discriminate between energy dissipation via internal instabilities and reconnection at the boundary between two contacting flux tubes.

(c) *How is energy transferred from the original energy release site to other regions?*

Whatever the mechanism of magnetic energy release might be, we expect that energy will be transferred from the initial site to other regions. Energy transport can occur in a variety of ways, including accelerated particles, thermal conduction, shock waves and mass motions. To identify the relevant transport processes is not straightforward and ambiguities are often present in the interpretation of the data. In any case, the magnetic field will provide a preferred direction by channeling the mass and energy flow along field lines. This has direct consequences for our understanding of flare loop geometry, since it provides a means of inferring the flare topology from the observed distributions of surface brightness.

Hoyng *et al.* (1981) and Duijveman *et al.* (1982) identified hard (16–30 keV) X-ray kernels observed by HXIS during the impulsive phase of some flares as evidence for beams of accelerated electrons impinging upon the chromosphere. Although interpreting these kernels as a proof of thick-target emission may be questionable when proper account is made of instrumental effects and noise level (McKinnon *et al.* 1985), they have often been used to infer the flare magnetic topology and to resolve possible ambiguities (see, for example, the cases discussed in Duijveman *et al.* 1982). Clearly, the derived topology depends critically on the assumption that hard X-ray kernels represent footpoints of loops and on their detectability in HXIS images. A similar approach has been followed by Cheng *et al.* (1985) and Cheng & Pallavicini (1987, 1988) when using the localized O^{V} brightenings observed during the impulsive phase of flares.

Evidence for bulk motions (at velocities of a few hundred kilometres per second) that could be interpreted as chromospheric evaporation inside loop structures has been presented by a number of authors (see, for example, Acton *et al.* 1982; Antonucci *et al.* 1982). I have already mentioned the behaviour of Fe^{XXI} emission with respect to O^{V} emission in simple flares (cf. Cheng *et al.* 1985; Cheng & Pallavicini 1988). Peres *et al.* (1987) showed that the temporal evolution of soft X-ray lines in a relatively simple flare (discussed by MacNeice *et al.* 1985) was well reproduced by the hydrodynamic response of the chromosphere to heat flux conducted downward from the loop top. Evaporation, however, could also occur if the chromosphere is heated by non-thermal particles, and it is not obvious how to distinguish between these two possibilities.

There is also evidence that energy is sometimes transferred through loop connections to very large distances from the flare site. Rust *et al.* (1987) have discussed several of these cases observed in HXIS images. They interpreted fast moving perturbations (at velocities of the order of *ca.* 10^3 km s^{-1}) as thermal conduction fronts propagating from the flare site along magnetic loops. Hα eject at much lower velocities are also observed in some of these structures (Martin & Svestka 1988). The interpretation of the optical and X-ray data together requires a large spectrum of energy transport processes, including transport by non-thermal electrons, shock waves, heat conduction and chromospheric evaporation (Machado *et al.* 1988*b*).

As a whole, the interpretation of energy transport processes in flares is on a somewhat better footing than points (*a*) and (*b*) mentioned above. Unfortunately, secondary flare processes provide little information on the primary release mechanism and on the associated magnetic topology.

(*d*) *Is there evidence for magnetic reconnection in two-ribbon flares and other long-duration flares?*

Long-duration events, and in particular two-ribbon flares, are currently interpreted as produced by reconnection in a disrupted magnetic topology which relaxes back from an open to a closed configuration (Kopp & Pneuman 1976; Pneuman 1981). This interpretation is in good agreement with *Skylab* results. *SMM* has substantially confirmed the *Skylab* picture of two-ribbon flares and has provided further evidence that magnetic reconnection may by a plausible interpretation (see, for example, de Jager & Svestka 1985; Svestka 1986). Svestka & Poletto (1985) have argued that direct evidence for the reconnection process can be found in HXIS observations of the 21 May 1980 flare.

It is still uncertain, however, whether all large-scale long-duration events observed in X-rays, including those outside active regions, could be interpreted in the same way. The X-ray morphology shown by *Skylab*, and even more that of the lower-resolution *SMM* data, were inconclusive in this respect. The observed X-ray features could be due either to an arcade of unresolved loops across the neutral line (as thought to occur in two-ribbon flares) or to the brightening of preexisting filament material heated to X-ray temperatures (Pallavicini *et al.* 1977) or to some other as yet poorly understood mechanism. The soft X-ray event discussed by Cheng & Pallavicini (1984; cf. §3 above) shows that at least in some cases energy could be released internally in a large sheared loop rather than being produced by magnetic reconnection in an originally open field configuration.

5. Conclusion

There is ample evidence from *SMM* and previous *Skylab* results that flares are often, perhaps predominantly, formed by complicated magnetic structures, with a variety of loops taking part in the flare phenomenon at various stages. The actual topology may be even more complex than has been revealed by the relatively low resolution X-ray and UV observations obtained so far. Whether this complex structure is directly responsible for energy release in flares, and how this may occur, is still to be determined. The existence of simple flares which involve only one single structure cannot be excluded. It is still possible, therefore, that energy is released in a highly stressed magnetic flux tube without any significant perturbation from nearby structures. On the other hand, the flaring flux tubes are not isolated and may be strongly affected by the surrounding fields as well as by fluid motions in the dense layers where they are rotated.

The evidence for reconnection in neutral sheets at the interface between different flux tubes is only circumstantial. The observations show simultaneous and/or successive brightenings in adjacent loops that sometimes cross each other. However, it is unclear whether these brightenings are due to reconnection between separate flux tubes coming in contact, or rather to the destabilization of a stressed magnetic configuration by emerging flux or by nearby moving fields. It is also possible that brightenings in separate, adjacent structures are not causally related but simply due to a common destabilizing cause (e.g. shear motions at the footpoints).

There is evidence that energy released at the flare site is transferred to other, sometimes very distant regions through magnetic connections. Energy can be transferred in a variety of ways including particles, heat conduction, shock waves and bulk motions. Energy is transferred not only from one point to another inside the same flux tube, but also from one flux tube to other, adjacent ones. This energy transfer could occur either through a common reconnection region or through common footpoints. The observations do not allow a choice between these different possibilities. The identification of the relevant energy transport processes is often difficult, but is essential if we want to use the observed brightness distributions to infer the magnetic topology of flares.

SMM has confirmed the *Skylab* picture of two-ribbon flares being produced by magnetic reconnection of fields lines that relax back from an open (disrupted) configuration to a closed one. However, there are still uncertainties as to whether all large-scale long-duration X-ray brightenings are produced by the same mechanism. Dissipation of internally stored free energy and/or heating of pre-existing filament material could also play a role in these events.

To summarize, X-ray and UV observations from space, particularly those from *SMM*, have greatly increased our knowledge of the magnetic topology and loop structures in flares. However, the analysis of the data is still to some extent a matter of personal judgement. The spatial resolution of most observations obtained so far is simply too low to allow us to understand the physical causes of flares and to discriminate between different competing mechanisms. Recent X-ray observations of the solar corona with sub-arcsecond spatial resolution (Golub *et al.* 1990) indicate the direction in which substantial progress may be expected in the coming years. The two-ribbon flare observed by Golub *et al.* (1990) in a rocket flight on 11 September 1989 shows not only the usual X-ray loops arching between the Hα ribbons, but also substantial X-ray emission from the ribbons. More intriguingly, each ribbon appears to be formed in X-rays by loop structures, in a way that completely defies any present interpretation. How many similarly puzzling results will be obtained when high-resolution observations of this type will become available on a routine basis?

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Discussion

E. R. Priest (*The University, St Andrews, U.K.*). (i) We developed the emerging flux model for flares in response to the observation of widely spaced Hα patches occurring simultaneously, one of them being at the location of emerging flux. It is therefore interesting to see the more comprehensive observations of these widely spaced brightenings in other lines. Of course the model applied equally well to *interacting* flux. In the examples you showed, is there evidence from the motion and evolution of magnetic sources and the Hα structures for the emergence or interaction of neighbouring flux? (ii) A key point of the emerging flux model was the suggestion that the type of flare that results depends on the properties of the neighbouring magnetic structure with which the flux interacts or into which it emerges. If the neighbouring flux is unsheared with little stored magnetic energy in excess of potential, then one finds a small flare as only the energy of interaction is released. But, if the neighbouring flux is highly sheared with a lot of stored energy, then the interaction or emergence can lead to the release of this energy and the appearance of a large flare. Have any of the studies been able to confirm this scenario?

MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES
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R. Pallavicini. (i) The emerging flux model was, and still is, a very promising model to explain energy release in flares. With respect to the original picture, the *SMM* results add the possibility that interaction of preexisting flux tubes (presumably due to motions at their footpoints) may produce flares even in cases in which no new flux really emerges. In either case, however, the observations support this picture only marginally. Many observations are consistent with new emerging flux and/or interaction of flux tubes; however, to the best of my knowledge, there is no single observation of moving magnetic or Hα structures that inequivocally proves that the flare was initiated by the interaction of one bipole with an adjacent one or with newly emerging flux. Even less proven is that energy release occurs through reconnection of adjacent field lines. The interaction, if it occurred, may have acted simply as a trigger for the release of internally stored energy. (ii) The scenario proposed by Machado *et al.* (1988*a*, *b*) on the basis of *SMM* HXIS data is precisely along these lines. They actually go a step further by claiming that most of the energy release in flares is *in all cases* energy stored internally in stressed magnetic configurations. Whether this is really brought out by the observations is largely a matter of personal opinion. I think that the observational evidence that this is the case is still scanty, although the observations are certainly consistent with such an interpretation.

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