SOLAR FLARES FROM SPACE: IMPLICATIONS OF SPATIALLY RESOLVED XUV OBSERVATIONS(*)

Roberto PALLAVICINI
Osservatorio Astrofisico di Arcetri
Firenze

Abstract

Recent X-ray and EUV observations of solar flares obtained with the Apollo Telescope Mount/Skylab and the Solar Maximum Mission are reviewed. Flares are subdivided into two physically distinct classes: I) compact flares and II) large-scale, long-decay events. The physical processes pertaining to these two classes are discussed with special attention to the space and time dependence of the energy release process as well as to the source of mass filling the flaring structure. It is suggested that flares of class II may comprise events of two different types: energetic two-ribbon flares and more gradual filament-associated events in and outside active regions.

With the advent of high spatial resolution XUV observations from rockets and satellites, it has become evident that flares possess a complex three-dimensional structure which extends from the chromosphere to the corona. We now know that their basic elements are constituted by magnetically confined loops of various sizes and life-times. These loops are most easily observable at X-ray and extreme-ultraviolet wavelengths, although occasionally loops can also be seen in Hα either in emission at the limb or as absorbing features on the disk.

In this paper, I shall try to summarize the main observational facts concerning flaring loops as seen from space. I shall put special emphasis on the spatial structure of the region and on the physical processes implied by the observed spatial structure. I shall illustrate the main points by using X-ray and EUV images obtained from Skylab and the Solar Maximum Mission. These two space missions, more than any other, have given us a new perspective of solar flares and have provided significant insights into the physics of transient phenomena in the solar atmosphere.

That flares occur inside magnetic loops was evident from the very first spatially resolved X-ray observations obtained in the late sixties. For instance, Fig. 1 shows an X-ray flare observed in 1968 from a rocket flight of an imaging X-ray telescope developed at American Science and Engineering (Vainana and Giacconi, 1969). Although there was some resemblance between the X-ray flaring region and the Hα structures, most of the X-ray emission originated in a bright loop crossing the magnetic neutral line and with the footpoints rooted in the two chromospheric ribbons. This early finding was later confirmed and extended by the many observations provided by Skylab (Kahler et al. 1975, Vorpahl et al. 1975, Pallavicini et al. 1975). A comparison between an X-ray flare observed from Skylab and the underlying chromospheric emission is shown in Fig. 2.

Fig. (3) shows EUV images of the flare of June 15, 1973 in the lines of He II and Fe XXIV, observed by the Naval Research Laboratory slitless spectrograph on Skylab (Widing and Cheng, 1974). The figure shows the relationship between the hot coronal component and the cooler chromospheric component in flaring regions. In this image the magnetic neutral
Fig. 1. The flare of June 8, 1968 observed at X-ray wavelengths from a rocket flight and at optical wavelengths from the ground. From top-left to bottomright: (a) X-rays; (b) Hα; (c) Ca II; (d) magnetogram (from Vaiana and Giacconi 1969).
Fig. 2. Comparison of Hα and X-ray images for the September 7, 1973 flare observed from Sylab (from Pallavicini and Vaiana 1980).
Fig. 3. X-ray and EUV observations of the flare of June 15, 1973. The upper part of the figure shows the time profile of the event as recorded by the Solrad 9 satellite. The approximate times at which various EUV lines maximize are also indicated. In the lower part of the figure the spatial configuration of the region observed from Skylab in the lines of Fe XXIV and He II is shown (from Widing and Cheng 1974).
line is drawn incorrectly, since it actually runs between the two He II ribbons. The interesting point is that the compact hot Fe XXIV region overlays a gap between the two He II ribbons suggesting that we are seeing in Fe XXIV the top of a loop which arches across the neutral line and whose ends are anchored in the He II (and Hα) bright ribbons. This is further supported by X-ray observations of the same flare (Pallavicini et al. 1975) and by a detailed comparison of the observed X-ray structures with the underlying photospheric magnetic fields. More generally, observations of flares in different EUV lines show that chromospheric and lower-transition region emission traces the footpoints of loops visible in high-transition region and coronal lines (Cheng and Widing 1975, Widing and Dere 1977, Withbroe 1978).

Fig. (4) shows the wide range of different sizes and time scales of flares observed in X-rays. Two different events are shown side by side at the same scale. On the left-hand side is the large flare of September 7, 1973, which was characterized during the decay phase by the development of an archade of large, growing loops. On the right-hand side is an essentially point-like event (August 9, 1973), unresolved even at the Skylab spatial resolution of a few seconds of arc. On the same figure, the temporal profile of the two events recorded by the Solrad 9 satellite is also plotted. It appears that there is a rough tendency of the spatial scale to correlate with the time-scale, longer flares occurring in larger structures. These two events are prototypes of the two main classes of flares (compact flares and large, long-decay flares) whose existence was first proposed by Pallavicini et al. (1977) and which are now generally regarded as a convenient way to describe different physical processes occurring in solar flares.

Let us concentrate our attention first on compact flares. Fig. (5) shows a particularly clear example of this type of event. The figure shows the temporal evolution of a compact flare which occurred in a single loop seen at the limb. By definition, these flares have relatively small dimensions (characteristic length ≈ 1 x 10⁴ km) and are usually located at the base of larger active region loops. In a limited number of cases (Petrasso et al. 1976, Schmahl et al. 1978), it has
Fig. 4. The spatial structure and time profiles of two X-ray flares observed simultaneously from Skylab and the Solrad 9 satellite. The left-hand side refers to the large, long-decay event of September 7, 1973. On the right-hand side the impulsive, compact flare of August 9, 1973 is shown for comparison (courtesy American Science and Engineering).
Fig. 5. The development of a compact X-ray flare from the preflare to the postflare phase. The spatial configuration of the region, which consisted of a single loop at the limb, is clearly visible in the image at the top-right (from Pallavicini et al. 1977).
been possible to demonstrate that the flaring loop was preexisting in the region, although in most cases it is difficult to recognize the flaring loop in the complex bundle of lower density loops which constitute the preflare active region.

An important observational characteristic of compact flares is the absence of any change or expansion of the flaring structure. The flaring loops persist essentially unchanged for the entire duration of the event, in contrast with the case of large long-decay events, which show the development of higher and higher systems of loops throughout the flare evolution. Another important difference is the absence of a bright region at the loop apex. When a single loop is observed, for instance at the limb, the structure tends to be more or less uniformly bright with a tendency to be brighter close to the footpoints rather than at the top. Large-scale long-duration events, on the contrary, show consistently a bright condensation at the top.

X-ray observations of compact flares indicate that they are generally quite complex in structure. Often, one or more bright knots are observed close to one end of the main flaring loop. Some examples of these X-ray knots observed in soft X-ray images from Skylab are shown in Fig. (6). Despite the terminology used in the figure headings, these soft X-ray knots should not be confused with the X-ray kernels observed recently by the Hard X-Ray Imaging Spectrometer (HXIS) on SMM (Hoyng et al. 1981a, b). For instance, the X-ray kernels observed by the HXIS experiment in the May 21, 1980 flare (see Fig. 7) are associated with Hα kernels and with the impulsive phase of flares and a convincing argument can be made that they are produced by beams of accelerated electrons which impinge into the dense chromosphere and emit X-rays by thick-target bremsstrahlung.

The soft X-ray knots which appear in Fig. (6), on the contrary, have no clear relation with the impulsive phase (as indicated by hard X-ray emission or impulsive microwave emission, cf. Kane et al. 1980) and are most likely unresolved loop-like structures at higher temperature and density, which cool more rapidly by both heat conduction and radiation. The presence of these knots close to one end of a larger loop is marginal evidence in favor of the occurrence of magnetic reconnection between a preexistent loop and a new small emergent
S-054 X-RAY FLARE KERNELS

Fig. 6. Soft X-ray bright knots observed in various flares during the Skylab mission. These knots are likely small unresolved loop-like structures at higher temperature and density and should not be confused with the hard X-ray kernels shown in the next figure (from Kahler et al., 1976).
Fig. 7. Hα observations of the two-ribbon flare of May 21, 1980 and comparison with the underlying magnetic fields. The drawing superimposes on the preflare Hα image at the top-left shows the position of the X-ray kernels detected by the Hard X-ray Imaging Spectrometer on SMM. The flare was probably triggered by the emergence of new magnetic flux at the locations A and B shown in the image at the lower-right. The X-ray kernels are interpreted as due to thick-target bremsstrahlung of supra-thermal electrons at the footpoints of magnetic loops (from Hoyng et al. 1981b).
magnetic region close to one of its footpoints (Kahler et al. 1976, Heyvaerts et al. 1977). Other interpretations, however, are equally possible. The main point is that all flares, including compact ones, are formed quite frequently by different loop-like features which evolve with different time scales. Under this respect, the term simple flares, often used to indicate compact events, may be totally misleading.

Fig. (8) shows monochromatic X-ray images of a solar active region obtained with the Flat Crystal Spectrometer (FCS) on SMM. The Figure refers to four successive days and shows the configuration of the region in the resonance lines of O VIII, Ne IX and Mg XI. White-light images are also shown for comparison. A number of both compact flares and large-scale events are visible in the Figure. The substantially lower spatial resolution of the FCS with respect to Skylab X-ray observations is compensated by a superior temperature discrimination, obtained observing simultaneously lines of ions formed over a wide range of different electron temperatures. With observations such as those shown in Fig. (8) it is possible to derive the detailed temperature-density structure of the emitting region and to compare the observations with predictions of hydrodynamic calculations of the response of a loop to various heating perturbations (e.g. Pallavicini and Peres 1982).

Some crucial problems related to the physics of flares are the detailed spatial and temporal dependence of the energy release mechanism and the source of the mass which is added to the flaring region during the transient event. In the case of compact flares, spatially resolved XUV observations have been unable so far to provide much information on the location and spatial extent of the energy release, simply because the time resolution of most observations (notably those from Skylab) is much longer than the characteristic time-scales for energy and mass transfer. The bright features which are seen in the XUV images are more likely the result of heat conduction and chromospheric evaporation rather than reflecting the spatial distribution of the heating process. This makes it extremely difficult to discriminate between different proposed flare mechanisms (current sheets, tearing-mode instabilities etc., cf. Spicer 1977, Priest 1980).

The situation is more promising with respect to
Fig. 8. Monochromatic X-ray images of a solar active region in the resonance lines of O VIII, Ne IX and Mg XI for four successive days (from November 6 to November 12, 1980). Both quiescent active region structures and transient X-ray brightenings appear in the images. White-light pictures of the same region are also shown for comparison (Courtesy X-ray Polychromator experiment on SMM).
duration of energy release and the source of mass. Considerable progress, in fact, has been made on the basis of the observations from Skylab, the P78-1 satellite and the Solar Maximum Mission. For instance, observations with the Bent Crystal Spectrometer (BCS) on SMM have shown evidence for the presence of mass upflows in compact events for a substantial fraction of the flare rise-time (Antonucci et al. 1982; see also Antonucci, this issue). These upflows, with velocities of up to a few hundred kilometers per sec, can be interpreted as due to evaporation of chromospheric material either as a consequence of electron bombardment of the chromosphere or as an effect of heat conduction from a thermal energy source high in the corona. The upflows cease just before flare maximum. The occurrence of evaporation of chromospheric material is an important prediction of hydrodynamic models of flaring loops, which consider a loop-like structure with the footpoints anchored in the dense chromospheric layers and which allow mass and energy transfer between the chromosphere and the corona (Nagai 1981, Cheng et al. 1981, Doschek et al. 1981, Pallavicini and Peres 1982).

Another important result derived from Skylab observations is that compact XUV events are consistent with no energy supply after the flare maximum (Krieger 1978). This result contrasts with the case of large long-decay events, which require prolonged heating during the decay phase (Pallavicini and Vaiana 1980). Recent analysis of SMM data for the flare of April 10, 1980 (Machado et al. 1982) has provided evidence for a continuous energy release limited to the flare rise-phase, with the production of very hot thermal regions (T \(\approx 1 \times 10^8\) K). This gradual energy release lasts substantially longer than the impulsive non-thermal phase indicated by hard X-ray emission.

The picture which is gradually emerging as a result of SMM observations regards the production of high temperature regions in the corona, with subsequent heat conduction and evaporation of chromospheric material, as a direct consequence of a gradual energy release process operating during the rise phase of compact events and ending before flare maximum. In addition to this thermal phase, a non-thermal phase may be present in some flares. The non-thermal process gives rise to hard X-ray emission (Dennis et al. 1981, Orwig et al.
1981), HXIS flare kernels (Hoyng et al. 1981a, b), and ultraviolet impulsive brightenings in the transition region (Cheng et al. 1981b). These latter brightenings have been shown to originate at different locations in the flare region and to be temporally coincident with spikes of hard X-ray emission, as shown in Fig. (9). At present, the role of non-thermal processes in the overall energetics of flares is uncertain. The relative duration and time sequence of different phases in flares, as well as preliminary estimates of the energy involved, suggest that the non-thermal phase may be insufficient to account for the entire radiative output of flares in most cases.

Before leaving the subject of compact flares, it should be mentioned that Skylab observations have shown the existence of a large number of essentially point-like featureless events. An analysis of the physical properties of these events and comparison with the properties of compact flares occurring in loops, show no significant differences, except the spatial scale, between the two groups. The most likely conclusion is that point-like flares are simply small unresolved loop structures (Pallavicini et al. 1977), the same conclusion reached for the soft X-ray knots mentioned above (Kahler et al. 1976). Point-like flares, in fact, can be regarded as events in which only one knot is prominent. In this respect, flares of bright-points may be a low-energy version of this kind of flares. It is well known, in fact, that X-ray bright-points occur in small bipolar magnetic regions and consist most likely of unresolved loops (Golub et al. 1977, Sheeley and Golub 1979).

Let us consider now a different type of flares, those which occur in large structures and which are characterized by long time-scales. Two examples of this kind of flares are shown in Fig. (10) which compares preflare and flare X-ray images obtained with the same exposure time. In both cases, the development of an arcade of large loops with the top brighter than the lower sections is observable. These flares, which extend often to heights of the order of $1 \times 10^9$ km, are usually referred to as either Long Duration Events or Long-Decay Events (LDE's).

If one considers a large number of X-ray flares and compares their physical characteristics, such as height, vol-
Fig. 9. Impulsive UV brightenings in the resonance line of Si IV at 1402 Å observed during the flare of October 14, 1980 by the Ultraviolet Spectrometer and Polarimeter on SMM. The UV bursts are shown to originate from different spatial elements which brighten up sequentially. The individual UV bursts are temporally coincident with different peaks of hard X-ray emission recorded by the Hard X-Ray Burst Spectrometer on SMM. Images in the intersystem line of O IV at 1401 Å are also shown for comparison (from Cheng et al. 1981).
Fig. 10. Two examples of X-ray flares characterized by long-decay times and large arcades of loops. Both events are observed at the limb and are compared with pre-flare images obtained in the same spectral band and with the same exposure time (from Pallavicini et al., 1977).
ume, rise and decay times, energy density and so on, one is led (Pallavicini et al. 1977) to a natural separation of flares into two groups, the larger one being composed of compact flares (class I), and the smaller one by flares of the type illustrated in Fig. (10) (class II). An example of this kind of separation is shown in Fig. (11) where energy density is plotted vs peak intensity in the Solrad 1-8 A band for a number of X-ray events. This morphological separation into two groups, which is valid only in a statistical sense, suggests the possibility that some fundamental physical differences may also exist between flares of the two classes. Such differences in fact do exist, including different associations with prominence eruptions and white-light transients, different spatial and temporal dependences of the energy release process, different magnetic field configurations at flare onset (Sheeley et al. 1975; Kahler 1977, Pallavicini et al. 1977, Pallavicini and Vaiana 1980).

Before going into discussing these differences, I would like to stress two points with the aid of Fig. (11). First, it is very difficult, and in fact practically impossible, to draw a sharp dividing line between these two classes of flares, in the sense that there is always some overlap of the two groups with regard to spatial extent, time scales, energy density and so on. It is more likely that the flares we characterize respectively as compact events and large-scale long-decay events are actually the extreme cases of an otherwise continuous distribution, with all possible intermediate conditions in between. For instance, the well studied flare of June 15, 1973, observed from Skylab, shares many properties of both classes (Pallavicini et al. 1975).

The second point is that in the discussion of flares of class II much attention has been paid in the literature to strong, energetic flares such as for instance the classical two-ribbon flares of July 29 and September 7, 1973 from Skylab, or the May 21, 1980 flare from SMM. It should be born in mind, however, that most large-scale long-duration events are in fact weak flares in terms of X-ray peak intensity, they have often a much more gradual rise phase than the energetic events mentioned above, and further they appear to be related to a class of X-ray enhancements associated with filament disappearances outside active regions (Webb et al. 1976),
Fig. 11. Plot of energy density $3 \, n \, k \, T$ vs peak flux for a number of X-ray flares observed at the limb. Crosses and circles indicate respectively flares occurring in compact loops and point-like events. Diamonits indicate flares characterized by long-decay times and large arcades of loops. The two straight lines are least-square fits for compact flares and large flares, respectively (from Pallavicini et al. 1977).
which are so weak energetically that generally they are not
detectable in full-disk X-ray measurements and do not produce
any appreciable Hα brightening at chromospheric level. In oth-
er words, the large two-ribbon flares may be only a part of
the whole story.

With this caution in mind, let us see in Fig. (12) a well
known example of class II flare (July 29, 1973). A dark
filament is present in the region before the flare and the
event starts with the disappearance of the filament, that is
with the rise and eventual eruption of the prominence sitting
along the magnetic neutral line. This is a general characteris-
tic of all long-decay events. High X-ray loops with the top
brighter than the legs are observed during the decay phase
(Petrossa et al., 1979, Nolte et al., 1979, Moore et al., 1980).
These loops anchored in two Hα ribbons. Detailed comparison
of X-ray and Hα images shows that the footpoints of the
X-ray loops are rooted in the middle and outer edges of
the Hα ribbons (Moore et al., 1980). During the flare develop-
ment the two Hα ribbons move apart with a velocity decrea-
sing from about 10 km/sec early in the flare to less than
1 km/sec late in the decay (Martin 1979). Dark absorbing
features between the two ribbons indicate the presence
of Hα loops bridging the magnetic neutral line and anchored
in the inner edges of the Hα ribbons.

Simultaneously with the expansion of the ribbons, the
X-ray loops grow in size with a velocity comparable to the
velocity of separation of the two Hα ribbons (MacCombie
and Rust 1979, Pallavicini and Vaiana 1980). Fig. (13) shows
the apparent expansion velocity of the X-ray loops in a number
of class II flares. The expansion of the whole structure is a
distinctive property of long-decay flares and may be inter-
preted as indicating the successive formation of different
loops at progressively increasing heights. An analogous phenom-
enon, although at a lower height, occurs at optical wave-
lengths, as indicated by observations of Hα loop promi-
nence systems at the limb (Bruzek 1964). Formation of X-ray
loops at increasing heights occurred presumably for the flares
of May 21 and April 30, 1980 observed by the instruments on
SMM (van Beek et al. 1981, Woodgate et al. 1981, Gabriel et
al. 1981). Recently, a similar phenomenon has been observed
also at microwave wavelengths during gradual rise and fall
Fig. 12. X-ray and Hα observations of the two-ribbon flare of July 29, 1973 observed from Skylab. Images taken during the early flare decay are compared with pre-flare images of the same region. A high resolution off-band Hα image obtained at the Big Bear Solar Observatory during the main phase of the flare is shown at the bottom (Courtesy American Science and Engineering).
Fig. 13. Plot of maximum height of X-ray loops vs time for a number of large-scale long-duration events preceded by filament eruptions. All events were observed in 1973 by instruments on board Skylab (from MacCombie and Rust 1979).
Fig. 14. EUV and X-ray observations of loop systems observed from Skylab during a long-duration event on August 13-14, 1973. The monochromatic EUV images are in five spectral lines which form at different temperatures over the range from $4 \times 10^4$ to $3 \times 10^6$ K (from MacCombie and Rust 1979).
bursts (Nakajima 1982).

Fig. (14) shows observations of a long-duration flare (August 13-14, 1973) in different EUV spectral lines (MacCombie and Rust 1979). The loops appear sharper in transition zone lines than in broad-band X-ray images, as expected from the fact that EUV line observations respond to a much narrower range of electron temperatures than broad-band X-ray images. Detailed comparison of the observed spatial structure in different EUV lines shows that the cooler transition region loops are not coaxial with the hotter X-ray loops, but are nested several thousand kilometers below the X-ray loops (Withbroe 1978, MacCombie and Rust 1979). At still lower heights there are loops at chromospheric temperature such as loops in HeII and Hα (Moore et al. 1980).

A characteristic property of all long-decay events is the enhanced brightness at the apex of the loop arcade. Analysis of a number of different events has shown that the increased brightness at the top cannot be attributed to an increased path-length along the line-of-sight, but must be due to increased temperature or density or both at the loop apex. Quantitative analysis of broad-band X-ray images from Skylab (MacCombie and Rust 1979), as well as more recent monochromatic images obtained with the Flat Crystal Spectrometer on SMM, indicate that the increased brightness at the top is due to a significantly higher temperature at the apex with respect to the temperature in the legs, while the density remains approximately constant throughout the structure. In any case, the X-ray surface brightness in images such as those shown in the Figures above is proportional to the square of the pressure integrated along the line of sight (Kahler 1976). The increased brightness at the loop top in large long-decay events indicates that the pressure at the top is a factor of two higher than in the legs and that a pressure gradient exists within the structure. This is an important observational constraint, which appears to be characteristic of only class II flares, and which has significant physical consequences.

The increased brightness at the top of loop archades in large long-duration events lasts for a time much longer than the characteristic times for heat conduction and mass transfer from the top of the loop to the footpoints. Moreover, the decay time of long-duration events is much longer not only of
the conduction time but also of the radiative time, as shown for instance by quantitative analysis of the September 7, 1973 flare (Withbroe 1978, Pallavicini and Vaiana 1980). All these facts taken together imply that continuous energy release must occur in class II flares for a substantial fraction of the flare decay and well after the intensity peak. The increased temperature at the loop apex is strong argument in favor of the location of the heat source at the apex of loops, possibly as a result of magnetic reconnection subsequent to the disruption of the field configuration at flare onset, as in the model first proposed by Kopp and Pneuman (1976) and later developed by Pneuman (1981).

We have already mentioned that flares of class II are always preceded by filament eruptions or major activations. We also know that they are correlated with white-light transients (Munro et al. 1979). Both facts indicate a disruption of the magnetic configuration at flare onset in contrast with the case of compact flares, in which the magnetic configuration remains closed and unchanged throughout the flare evolution. According to the Kopp and Pneuman (1976) model, the magnetic field lines, torn open by the filament eruption, relax again to a closed configuration producing magnetic reconnection and localized heating at the loop apex. As higher and higher loops form, the reconnection point moves upwards with decelerated motion. The loops cool by radiation and conduction producing the observed structure with the two Hα ribbons at chromospheric levels and with cool loops nested below hot loops at any given time.

A difficulty related to long-duration events is the source of the mass which fills the observed structure during the transient phenomenon. We have seen that for compact flares there is convincing evidence that the mass comes from the chromosphere through an evaporation process. That the same thing occurs for large long-decay events, as usually assumed (cf. Pneuman 1981), is much less clear from the observations.

In the case of class II flares we observe X-ray loops with the top at higher pressure than the legs. In the absence of a sustaining mechanism, one should expect mass flow from the loop apex down to the footpoints, rather than upflows. In any case, even if chromospheric evaporation is occurring, material must move upwards against a pressure gradient and...
this situation lasts for hours during the decay of long-dura-
tion events. This phenomenon is difficult to interpret. As far as the observations are concerned, downflows are observed rather than upflows at both optical and EUV wavelengths. For instance, it is well known that mass is seen streaming down-
wards along both legs of post-flare loop prominence systems in Hα (Bruzek 1964, Michalitsanos and Kupferman 1974). Mass downflows of material at transition-region temperatures can also be inferred from Skylab EUV observations (Levine and Withbroe 1977, Pallavicini and Vaiana 1980). These downflows presumably result from the cooling process which makes the loops too heavy to sustain themselves against gravity.

If material is convected from the chromosphere to the corona, this process must occur therefore in the hot X-ray loops. Unfortunately, no spectroscopic measurements of Doppler shifts at X-ray wavelengths exist so far to test this possibil-
ity. I wish to point out, however, that if the blue shifts observed by the Bent Crystal Spectrometer on SMM indicate chromospheric evaporation (Antonucci et al. 1982), and if chromospheric evaporation occurs in large long-decay events as well, one should observe blue shifts for an extended period of time, well after the intensity peak. BCS observations of the large long-decay event of May 21, 1980 do not seem to support this interpretation.

Another possibility is that material is continuously sup-
plied at the top of the observed loop structures. The mass involved is very high, of the order of $10^{15} - 10^{16}$ gr (Pallavicini and Vaiana 1980, Lantos et al. 1981) and occasion-
ally even higher (Pneuman 1981). This mass cannot come from condensation of coronal material, because the coronal volume needed to produce this amount of mass is quite large and one should observe a large coronal depletion around the flaring loops ($M_{cor} \lesssim 2 \times 10^{17}$ gr). A suggestion which I put forwards some years ago (Pallavicini et al. 1977) is that at least part of the mass is evaporated from the associated prominence, which is always present in long-decay events. Order of magni-
tude estimates show that the mass observed in the flaring loops is comparable to that of prominences (Tandberg-Hanssen 1974), although precise mass estimates for specific events are quite uncertain and should be considered with caution. The objection that prominence material is not available because it
is expelled from the Sun, may not be correct, because only a fraction of the filament mass is observed to be expelled in most cases (Schmahl and Hildner 1977). Moreover, a number of cases have been reported from Skylab and SMM in which filaments appear to dissolve gradually in place, rather than erupting (Kahler et al. 1980, Lantos et al. 1981). Finally, it is well known that the bulk of the material in white-light coronal transients does not come from the prominence, but is coronal material located originally above the filament (Hildner et al. 1975).

Despite the theoretical difficulties of envisaging a model in which mass is supplied to the flaring loops from the activated filament, one should pay more attention to the role of the filament in the mass and energy budget of large long-decay events. Let me illustrate this point with a specific example from SMM. Fig. (15) shows a sequence of monochromatic images of a filament-associated X-ray event observed by the Flat Crystal Spectrometer on SMM. The X-ray brightening followed a filament disappearance which occurred on November 22, 1980 along the magnetic neutral line separating two active regions at central meridian passage. As appears from the figure, the main configuration is that of an extended loop-like structure which follows very closely the location and spatial configuration of the preexisting filament. Comparison with simultaneous Hα images supports the view that the X-ray structure is a single loop which lies almost parallel to the filament, rather than an arcade of unresolved smaller loops at right angles with respect to the filament. Within an hour from the filament disappearance, the filament reformed at the same place and with essentially the same configuration.

This is not an isolated example. There are a number of cases observed from Skylab and SMM which show that loops which first appear in long-duration events tend to lie parallel rather than perpendicular to the filament, indicating a strongly sheared magnetic field configuration. For instance, the events studied by Kahler et al. (1981) is clearly of this type. A similar situation also occurred in the event of March 30, 1980 discussed by Lantos et al. (1981) and found to be associated with a white-light transient and a Type I noise storm. In both cases, the filament was described as gradually fading in place, rather than erupting. Kahler (1981) has
Fig. 15. Monochromatic images of a filament-associated X-ray event observed on November 22, 1980 by the Flat Crystal Spectrometer on SMM in the resonance lines of O VIII, Ne IX, Mg XI and Si XIII. The characteristic temperature of formation of the line increases from left to right over the range from $2 \times 10^6$ K to $10 \times 10^6$ K. The four rows of images refer to four successive times. Contours levels drawn over each image (Courtesy X-Ray Polichromator experiment on SMM).
recently suggested that flares of class I and II may be distinguished also on the basis of the orientation of the early flaring X-ray loops with respect to the associated filament. In compact flares, the loops which first brighten are nearly perpendicular to the filament and the filament does not disappear, while in events of class II the early loops are nearly parallel to the filament and the flare disappears.

Finally, it should be mentioned that a close morphological relationship exists between filament-associated events in active regions and large-scale long-duration enhancements associated with prominence eruptions outside active regions (Webb et al. 1976). Several examples of events of this kind were observed by the FCS experiment on SMM; one is visible in the third row of images in Fig. (8), south of the active region. Another example from Skylab is shown in Fig. (16). The X-ray cavity which is associated with the filament during the preflare state, brightens up in X-rays at the time of the filament disappearance. The morphology of the brightening X-ray loops resembles closely that of the erupting filament. In some events, Hα brightenings are observed in association with the X-ray event. In most cases, however, as in the case illustrated in the figure, no Hα brightening occurs. It is hard to believe that chromospheric evaporation plays a relevant role in the mass supply of these transient X-ray brightenings, given the absence of any chromospheric emission simultaneous with the X-ray event. For a specific event of this type, Webb et al. (1976) estimated that the mass involved in the X-ray brightening was only 10% of the mass of the preexisting filament. One possible explanation for these more gradual events may be direct magnetic heating of the cool filament material.

In conclusion, either X-ray enhancements associated with prominence eruptions outside active regions, as well as most filament-associated events in active regions, are quite different from the better known energetic two-ribbon flares, or we have difficulties in reconciling all observations with the notion of mass supply via chromospheric evaporation and with the classical reconnection model of Kopp and Pneuman. Flares after all may be much more complex than suggested by the schematic subdivision in just two classes.
Fig. 16. X-ray and Hα images of a large-scale long-duration X-ray enhancement associated with a filament disappearance outside active regions (from Webb et al., 1976).
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