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# II. THE ACTIVE SUN AND TRANSIENT EFFECTS

## Activated solar filaments and flares

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[Plates 1 and 2]

Activations and disruptions of dark Hα filaments are very common phenomena on the Sun. They precede the most powerful two-ribbon solar flares, but they also appear far from any active region without any chromospheric flaring. Therefore, until very recently, filament disruptions were considered as interesting, but physically insignificant, flare precursors. Only Skylab observations have shown that the filament disruptions actually represent one of the basic and most important mechanisms of solar activity.

These observations have revealed (1) that many coronal transients originate in eruptive filaments without chromospheric flares, (2) that Bruzek's slow-mode waves originate in disrupted filaments and not in flares themselves, and (3) that many coronal X-ray enhancements outside active regions are also tops of newly formed loops, similar to the post-flare loops observed after filament disruptions in active regions.

An interpretation of these data stems from Kopp & Pneuman's theory of post-flare loops: the process that disrupts a filament opens the magnetic field and causes a greatly enhanced mass-flow along the field lines. The open field lines subsequently reconnect, starting from the bottom of the corona and proceeding upwards. This process can last for many hours. Hot loops are first seen in X-rays, later in extreme ultraviolet (e.u.v.) lines, and, after an appropriate cooling time, in Hα as the loop prominence systems. The visibility of loops depends on plasma density.

Several observed properties of solar flares indicate that the primary acceleration occurs as the field lines reconnect. Thus the process of particle acceleration in two-ribbon flares can last for hours. Because reconnection is accomplished after essentially all filament disruptions, 'disparitions brusques' outside active regions should also accelerate particles.

### 1. FILAMENT CHANNELS

The most characteristic feature of the decaying phase of active regions in Hα light is a dark filament, called a quiescent prominence when seen at the limb (figure 1, plate 1). A comparison with solar magnetograms shows that all these filaments occur at the boundary between two opposite magnetic polarities; it means they always extend along the zero line of the longitudinal magnetic field, $H_{\parallel} = 0$.

The X-ray picture in figure 1 well shows the filament channel along which the filament extends, being bridged by higher-lying hot coronal loops which connect the opposite magnetic polarities. Observations of the corona made on the limb, which extend far from the Sun, then often show a streamer overlying the filament channel. Thus the whole configuration looks like the schematic drawing shown in figure 2: a cool gas condensation, seen as a dark filament in Hα, forms at the top of low-lying field lines connecting the opposite polarities; it is supported against gravity by the magnetic field and is overlain by higher hot coronal loops. At the top the magnetic field opens into a coronal streamer.

This configuration is best developed in remnants of old active regions. But it starts to develop in any young region, and the first Hα dark filaments are usually seen in a new active region within a few days of its birth. One can often see several intense and extensive dark filaments in fully developed active regions, and a clearly marked filament channel becomes an outstanding characteristic feature in old active regions without spots (as in figure 1). Even after the active region completely dissolves and disappears, the filament channel survives and marks then the boundary of magnetic polarities at the place where solar activity was eminent a few rotations earlier. The common appearance of dark filaments in essentially all active regions, and the longevity of the filament channels, make this particular configuration extremely common on the Sun, both in the active and quiet parts of its surface.

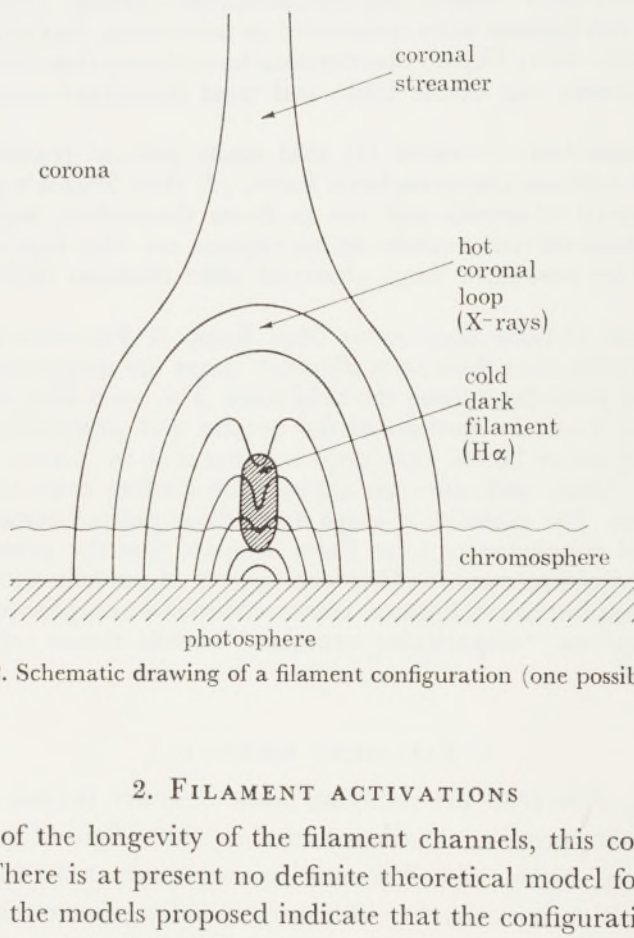



FIGURE 2. Schematic drawing of a filament configuration (one possible model).

## 2. Filament activations

However, in spite of the longevity of the filament channels, this configuration appears to be rather unstable. There is at present no definite theoretical model for the filament channel (cf. Anzer 1979), but the models proposed indicate that the configuration in figure 2 is metastable against lateral perturbations. That means that any trigger that deforms the symmetry of the supporting magnetic field may lead to a straightening of the field lines, removal of the condensed gas, and generally to a simplification of the magnetic configuration. We see it then in Hα as a gradual activation of the dark filament which begins to rise into the corona and eventually disrupts and completely disappears. In soft X-rays (figure 3, plate 1), we see a brightening above the place where the filament just disappeared, and this brightening can often last for hours.

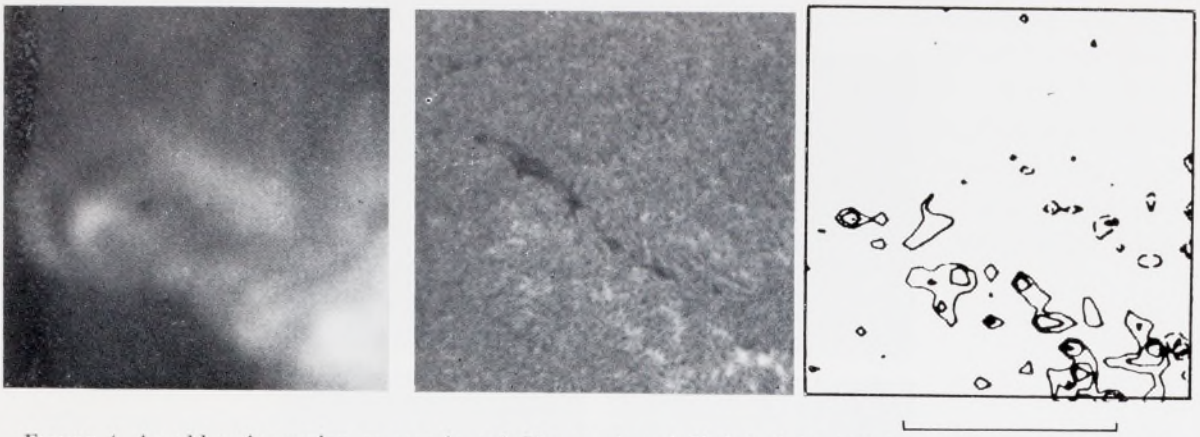
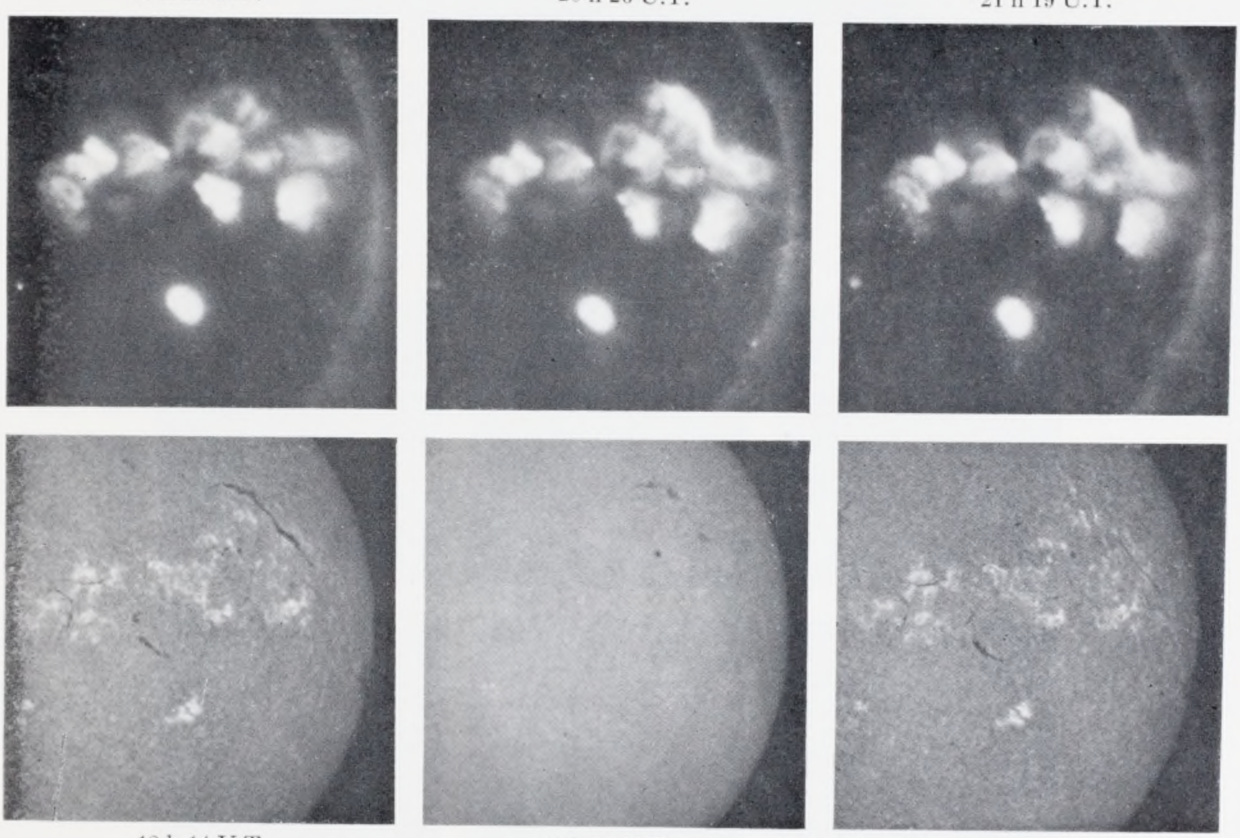


FIGURE 1. An old active region as seen in soft X-rays aboard Skylab (left; 14 h 01) and in Hα light on the ground (centre; 10 h 45). The magnetic field distribution is shown on the right (17 h 55–19 h 50). A dark filament, seen in Hα, runs along the line that divides the magnetic polarities. It is bridged by hot coronal loops (left) rooted in the opposite magnetic polarities. McMath 12673, 20 November 1973. The bar represents 5′. (All X-ray pictures are by courtesy of American Science and Engineering, Inc., Cambridge, Mass., U.S.A.)

18 h 14 U.T. 20 h 26 U.T. 21 h 19 U.T.



18 h 14 U.T. 19 h 58 U.T. 21 h 18 U.T.

FIGURE 3. The left and right pictures show the situation before and after the disruption of a filament (Švestka 1976*b*, p. 230). Soft X-ray pictures are above and Hα photographs below. The central frames show the situation during the process of activation (the Hα picture is out of the line centre thus emphasizing the Doppler-shifted moving parts of the activated filament).

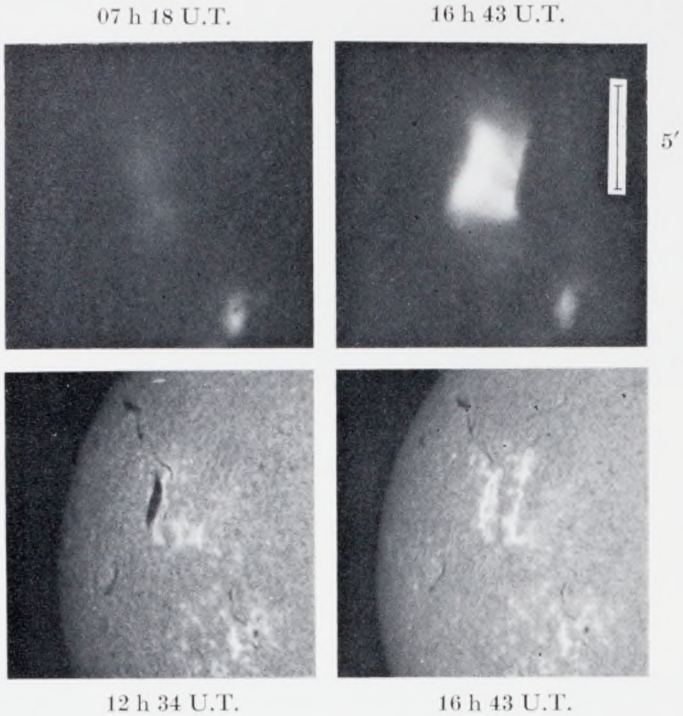



FIGURE 4. Images of the corona (soft X-rays, top) and the chromosphere (Hα, below) before and during the two-ribbon flare of 29 July 1973. The hot X-ray loops, with maximum brightness and temperature at the top, are rooted in the chromospheric bright ribbons that extend along both sides of the disappeared dark filament (Rust 1976).

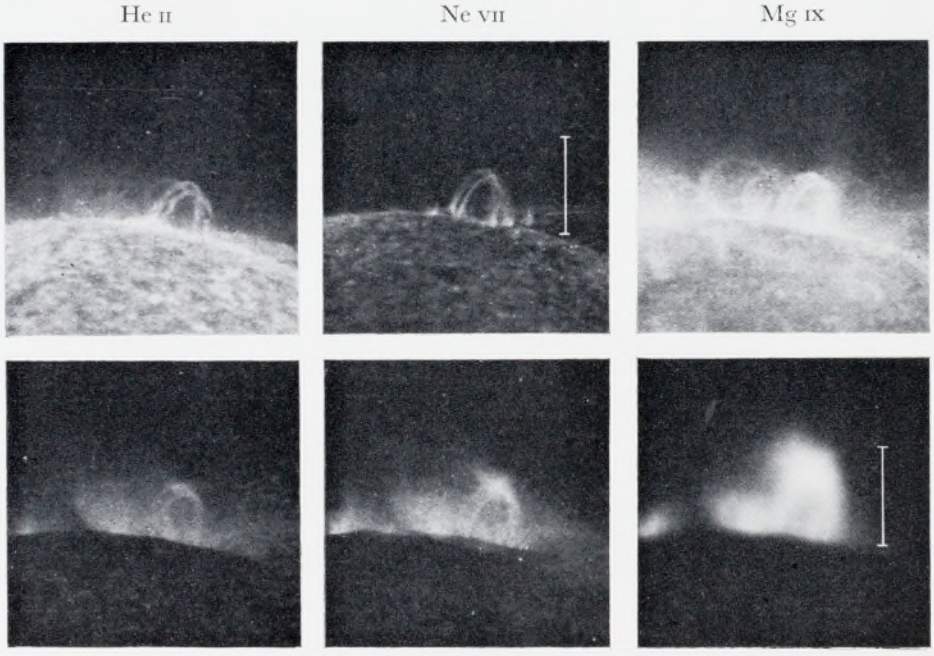



FIGURE 7. Simultaneous e.u.v. images and an X-ray image of a system of loops seen on the limb after a filament disruption (14 August 1973; 01). All images are on the same scale. The vertical line on the Ne VII and X-ray images shows the much higher extension of the X-ray loops. 1 Å = $10^{-10}$ m = $10^{-1}$ nm. (MacCombie & Rust (1979).)

The trigger that causes this instability may be, for example, a newly emerging magnetic flux nearby, which changes the whole magnetic configuration, or the growth of a coronal hole, which opens the magnetic field, or a travelling disturbance from another part of the Sun, which hits the magnetic-field configuration and deforms it. However, after the disruption the filament channel is usually restored. After a few hours or days, plasma again begins to condense at or near the place where it was seen before. A filament is formed, and it eventually erupts once again. Only in rare cases does the filament channel completely disappear, for example along the borders of growing coronal holes.

## 3. Two-ribbon flares

The most outstanding example of filament activation is a two-ribbon flare. This phenomenon occurs when a filament is activated inside a growing, or not yet much decayed, active region (figure 4, plate 2). After the filament disappears, we see in X-rays a system of growing loops, with maximum brightness at their tops, where temperature exceeds $10^7$ K. In Hα we see two bright ribbons running parallel to the $H_{\parallel} = 0$ line along the footpoints of the hot coronal loops, and some time later a system of cool loops, with temperatures of the order of $10^4$ K, rooted at the inner edges of the bright ribbons. This loop system grows and at the same time the two ribbons at the loop foot points drift apart (cf. Švestka 1976*a*, fig. 6). However, the loops do not expand; the growth is due to successive appearance of progressively higher loops, while the old ones, at lower altitudes, cease to be visible.

In a growing or fully developed active region these flares produce enormously hot coronal loops, brilliant Hα ribbons, and dense systems of cold loops (cf. Švestka 1976*a*, fig. 7). They are seats of the strongest particle acceleration on the Sun, capable of accelerating protons up to gigaelectronvolt energies in the most outstanding events. They are also a source of shock waves propagating through the corona and interplanetary space all the way up to the Earth and behind it.

Also in decaying active regions, still compact and bright in the chromosphere and corona, but without any sunspots, the two-ribbon flares are very characteristic events. However, temperature and density in the coronal loops are then lower, with the result that the cool Hα loops are only faintly seen, or are entirely invisible, and all the effects of particle acceleration and shock production are less intense. A very good example of such a flare occurred during the Skylab mission on 29 July 1973, and was studied in detail at the A.T.M. Flare Workshop in 1977/8 (Moore *et al.* 1979; Švestka *et al.* 1979*b*).

## 4. The flare of 29 July 1973

This major two-ribbon flare in a spotless active region is the best example of a big two-ribbon flare observed on Skylab (figure 4). Unfortunately, the soft X-ray observations there started only 3 h after the onset of the flare. Nevertheless, they still showed very well the growing system of coronal post-flare loops, with temperatures at the top in excess of $5 \times 10^6$ K (Nolte *et al.* 1979; Petrasso *et al.* 1979).

Though the cool Hα loops were weak, one could measure for about 3 h their altitude and development (Martin 1979) and compare them with the hot loops (figure 5*a*). Only for a short time one could measure simultaneously both the hot and cool loops, but measured velocities of separation of the bright ribbons, in which the hot loops were rooted, made it possible to extrapolate the X-ray observations backwards.

It appears to be clear that the Hα loops are the cooled remnants of hot coronal loops which were visible in X-rays in the same position some time earlier. By comparing the altitude variations of the two kinds of loops, one can determine the cooling time for the individual loops.

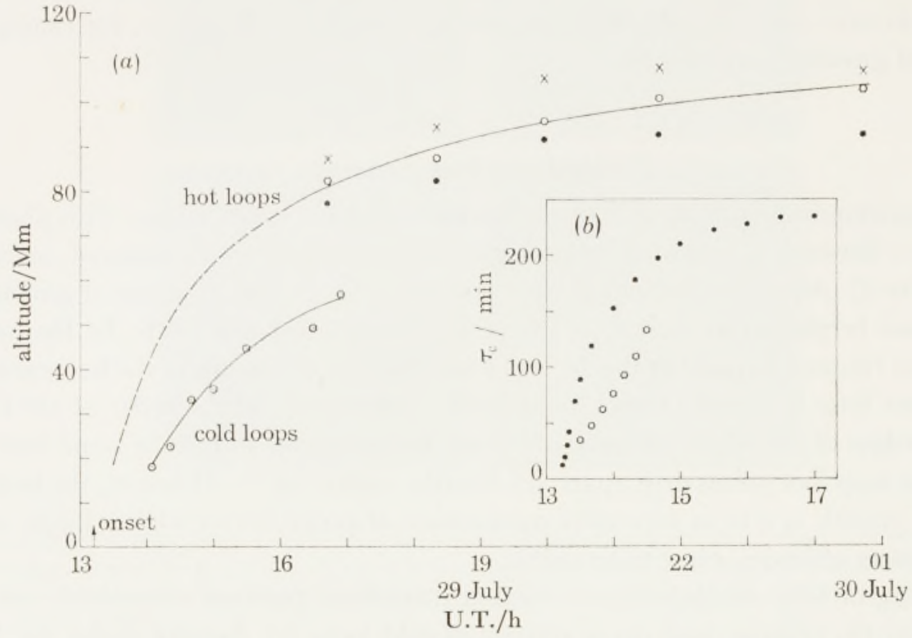



FIGURE 5. (*a*) Growing altitudes of the hot (X-ray) and cold (Hα) loops in the flare of 29 July 1973. The arrow shows the Hα flare onset time. (*b*) Cooling time, $\tau_c$, of the individual loops as deduced from the loop growth in (*a*) (open circles) and from the growing Hα ribbon width (dots). (Moore *et al.* (1979).)

This cooling time is shown in figure 5*b*: obviously, at the beginning the cooling time is short, of the order of 10 min, because the loops are dense (hence the radiative cooling is fast) and short (hence also the conduction is very effective). The subsequently formed loops become progressively longer and their plasma density decreases so the cooling time grows; however, as figure 5*b* shows, it never exceeds 4 h. Because this system of loops was seen growing in X-rays for 12 h or more (possibly as long as 30 h; see Nolte *et al.* 1979), this is clear evidence that new loops must still have been formed in the corona 8 h or more after the flare onset!

All this time, the highest temperature was formed at the top of the loops (Petrasso *et al.* 1979), with a rather steep temperature gradient from the top to the loop footpoints (5.1–$3.5 \times 10^6$ K at 16 h 40 U.T. on 29 July). Thus energy seems to be added to the loop system at the top.

A comparison of the X-ray loops with the Hα ribbons has shown that the brightest patches in the ribbons coincide with the footpoints of the brightest loops. The loop brightness, as Petrasso *et al.* demonstrated, varies with plasma density throughout the loop system, whereas temperature at a given altitude appears to be the same everywhere. Thus the chromospheric brightening obviously appears at those places where very dense hot coronal loops are rooted.

It should perhaps be emphasized that flares of the two-ribbon type may also occur without being preceded by filament activation, namely in very young active regions where the filament has not yet become visible. An example of it was the famous flare of 7 July 1966 studied during the Proton Flare Project (Stickland 1968). This demonstrates clearly that the filament itself actually is not important. The cool condensed plasma is only a visible tracing of what happens to the magnetic field before the two-ribbon flare occurrence – like the iron filings a teacher uses to demonstrate the existence of magnetic field at school. If the plasma condensation is not yet cool and dense enough to be seen, this visible demonstration of the rearrangement of the magnetic field is missing, but the process is still the same.

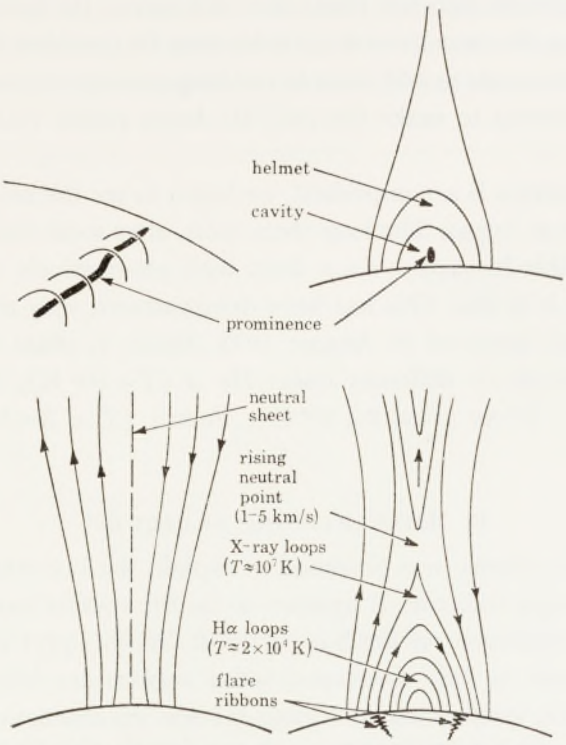



FIGURE 6. The Kopp & Pneuman (1976) model of filament (prominence) disruption. The quiet situation (top) is similar to that shown in figure 2 (the filament is embedded in a coronal cavity below a helmet of higher-lying coronal loops). An instability opens the magnetic field and the filament disappears (lower left). After some time the open field lines begin to reconnect starting from below (lower right). The hottest loops are the newly formed ones at the top whereas the lower loops have cooled and are now seen in Hα. (Pneuman (1979).)

## 5. Kopp & Pneuman's theory

There seems now to be a general agreement that the filament disruption and the subsequent appearance of a two-ribbon flare can be explained as an opening of the magnetic field and its successive reconnection, a process first suggested by Kopp & Pneuman in 1976. The filament disruption marks an opening of the originally closed magnetic field (figure 6). Solar wind begins to flow along the opened lines so that gas pressure inside the opened filament cavity decreases. Thus magnetic pressure prevails and drives the open field lines towards the neutral sheet in the centre of the disrupted cavity, where the field lines begin to reconnect. The reconnection starts at the bottom of the disrupted configuration and the neutral point then propagates upwards, creating progressively higher loops. The process of reconnection is very fast in its initial phase, but it progressively slows down as the neutral point rises with decreasing speed through the corona.

When a bunch of field lines reconnects and a new coronal loop is formed, the upward streaming along the field lines is suddenly stopped. In consequence, a shock is produced at the top of the loop which travels downwards and can heat the loop to some 3 or $4 \times 10^6$ K. In addition, the loop is heated at the top – where the reconnection was accomplished – by the reconnection process itself, most probably through ohmic dissipation of the magnetic field energy at the reconnection site (Pneuman 1979). The heat is conducted downwards, heats the chromosphere and produces the two bright chromospheric ribbons. Some part of the heated chromospheric gas evaporates into the loop, thus enhancing its density, and in this process of chromospheric heating also accelerated particles may be involved (Kopp & Martin 1979; Švestka *et al.* 1979*a*). One needs to add mass to the loop system, because otherwise there is not enough plasma in the corona to make the cool Hα loops visible (Kleczek 1963; Jefferies & Orrall 1963).

Soon after the reconnection is accomplished, we begin to see the newly formed coronal loop in soft X-rays (Moore *et al.* 1979). The loop then cools, after some time ceases to be visible in X-rays and becomes visible in various e.u.v. lines with progressively decreasing temperature. At the end, one can see it in Hα. This has been demonstrated very nicely by MacCombie & Rust (1979) for the limb event of 13 August 1973 (figure 7, plate 2), where simultaneous observations were available in different lines: He II ($T < 10^5$ K), Ne VII ($T \approx 5 \times 10^5$ K), Mg IX ($T \approx 9 \times 10^5$ K), Fe XV ($T \approx 2 \times 10^6$ K), Fe XVI ($T \approx 3 \times 10^6$ K) and soft X-rays ($T \gg 1.5 \times 10^6$ K).

## 6. 'Disparitions brusques'

The Kopp & Pneuman theory was proposed to explain the two-ribbon flares. However, as recent observations strongly indicate, it appears to be the correct explanation for essentially all filament disruptions observed on the Sun (Rust & Webb 1977; Pneuman 1979; Švestka 1979). Disrupted filaments in fully developed active regions are followed by powerful two-ribbon flares; in decaying spotless active regions we see less intense, but still very extensive flares of the type seen on 29 July 1973 (§4); as the region further decays, filament disruptions are followed by less conspicuous chromospheric brightenings which may, but need not be reported as flares; finally, disruptions in very old filament channels, often called 'disparitions brusques', usually do not produce any chromospheric brightening at all (Howard & Švestka 1977; Švestka 1979). Still, even in these cases we can see a striking brightening in soft X-rays which is similar in shape to the dark filament that was seen in the Hα light before the disruption (cf. figure 3).

We see in these cases in X-rays only the tops of the loops, because density is too low to make also the legs of the loops visible. But the basic process is all the time the same: opening of the closed field lines when the filament disrupts, and subsequent field-line reconnection creating sequential loops of progressively higher altitude. The speed of growth of the loop tops decreases from more than 10 km s$^{-1}$ in the onset phase to a value close to 1 km s$^{-1}$ a few hours later (Rust & Webb 1977). In X-rays and on radio microwaves these events are typically characterized by gradual rise-and-fall bursts (Teske 1971; Sheeley *et al.* 1975; Kahler 1977).

## 7. Travelling coronal disturbances

Until quite recently, filament activations were considered for interesting, but energetically rather insignificant phenomena. In association with flares, they were described as precursors, manifesting preflare rearrangement of the magnetic field, but the really important matters were supposed to happen only when the real flare – that is heating of the corona and brightening of the chromosphere – began to be seen. When no flare was observed, the 'disparition brusque' was considered to be a very minor coronal disturbance (see, for example, Švestka 1976*b*). The Skylab observations, however, and their evaluation during the last 2 or 3 years, have forced us to change radically our opinion about the importance of the filament disruptions.

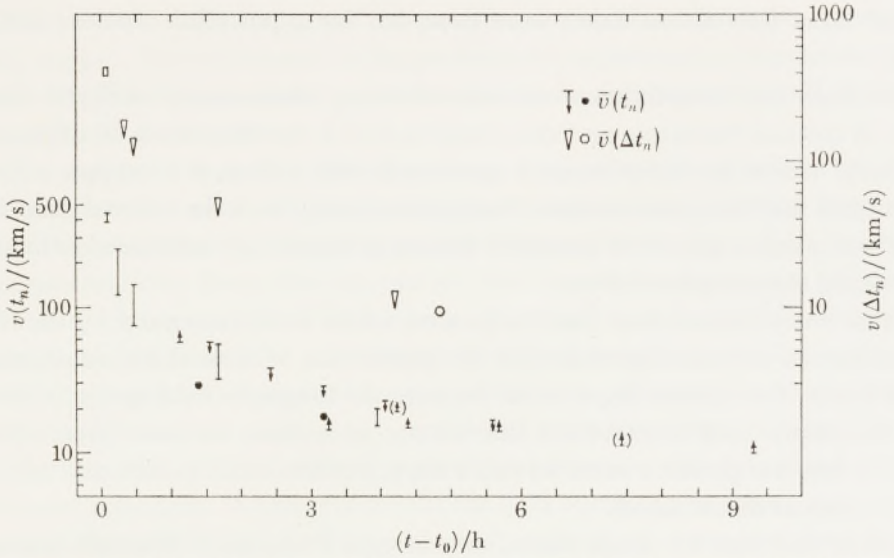



Figure 8. Composite diagram of velocities of the slowly moving disturbances detected in soft X-rays (Rust & Švestka 1979): $(t-t_0)$ is the time elapsed from the filament disruption; $\bar{v}(t_n)$ is the average speed during time $2t_n$, whereas $\bar{v}(\Delta t_n)$ is the average speed during a shorter interval $(t_n-\Delta t,\ t_n+\Delta t)$ in case the X-ray pictures were obtained more often. Arrows are used when only the maximum or minimum speeds could be determined.

The white-light coronagraph on Skylab detected 77 coronal transients that were identified as mass ejections coming from the lower parts of the solar atmosphere (Munro *et al.* 1979). Twenty-five of them could be definitely associated with observed chromospheric phenomena, and twenty of these events, i.e. 80% of them, were clearly associated with the activation and disruption of a filament, mostly seen as a prominence activation on the limb. Out of these twenty events only five were also associated with a chromospheric flare. It is true that some flares just on the limb and behind it were certainly missed and not reported. But six of these filament disruptions occurred outside any active region so that one can be fairly sure that no significant chromospheric flaring was associated with them. Still, even these filament disruptions without flares produced coronal transients that carried energies of $10^{29}$ erg ($10^{22}$ J) or more, i.e. an energy comparable with energies released in moderate flares.

In soft X-rays, Rust & Švestka (1979) detected slowly moving disturbances that caused sequential brightenings of distant stationary (pre-existing) coronal structures. The disturbance starts with a speed of *ca.* 400 km s$^{-1}$, but is damped to 50–60 km s$^{-1}$ after 1 h, and to *ca.* 10 km s$^{-1}$

after 4 or 5 h of propagation (figure 8). In extreme events the effects of the disturbance can be followed more than 18 h up to a distance in excess of 600 000 km. This disturbance appears to be identical with the slow-mode wave hypothesized from Hα observations long ago by Bruzek (1952, 1959) and confirmed by Yajima (1971); according to these authors (see also Öhman & Öhman 1953) the (invisible) slow-mode waves cause instabilities in distant quiescent filaments.

However, there is one significant difference between the Hα and X-ray results: Bruzek and Yajima supposed that this kind of disturbance originated explicitly in flares, particularly in major flares. In X-rays, however, this appears not to be true: in at least three cases the source of the slowly moving disturbance was an activated filament that was not associated with any reported flare. In two other cases the apparent source of the disturbance was a major flare. But both of these two-ribbon flares were preceded by a powerful filament activation and disruption.

Therefore, both the white-light corona and soft X-ray observations on Skylab show that the real source of coronal transients and slow-mode waves is the disruption of a filament and not the flare itself. When the disturbance is associated with a flare, it is because a filament activation preceded the flare phenomenon. And, quite clearly, both the coronal transients and the slow-mode waves can originate in disrupted filaments that are not associated with any reported (i.e. big enough) chromospheric flare.

All of these observations show that the process which is characterized by the filament disruption is a process of basic importance for the production of coronal transients, wave disturbances, and flares. Two-ribbon flares occur because the magnetic field opens – this we see as a filament disruption – and reconnects – this we see as a flare. In some cases the process of reconnection does not produce what we call a flare, but the whole process still can be a source of powerful coronal disturbances.

It is possible that also the shock waves, seen as type II bursts or Moreton waves, originate during the phase of the filament disruption. But this kind of disturbance, as far as we know, is indeed associated always with a flare. Thus it might also be the consequence of a powerful particle acceleration accomplished during the flare flash phase as Lin & Hudson (1976) suggested.

## 8. Particle acceleration

Two-ribbon flares are the sources of the most energetic particle acceleration on the Sun; relativistic electrons and protons up to gigaelectronvolt energies are recorded in Space after the most outstanding flares of this type. Therefore, a powerful acceleration must be accomplished during the flare process.

The appearance of impulsive hard X-ray and microwave bursts during the initial, flash phase of the flare reveals that the acceleration process starts very close to the onset of the flare development. Almost simultaneously with the hard X-rays, with a delay shorter than 1 min, major flares also emit the γ-ray line at 2.2 MeV (Hudson 1978). However, this (neutron) line needs atomic nuclei with energy in excess of 30 MeV for its production (Ramaty *et al.* 1977), and its formation must be delayed, because of the atomic processes involved, by at least 30 s (Wang & Ramaty 1974). Thus the acceleration process in the earliest phase of the flare development should be able, in extreme cases, to accelerate protons to energies in excess of 30 MeV.

A question arises, then, of which process this initial acceleration is accomplished by. There are essentially two alternatives: either the acceleration occurs when the filament disrupts, in which case current interruption and shock-associated acceleration seem to be the most likely processes, or the acceleration starts when the first loops are formed, in which case it should be associated with the process of reconnection.

The fact that the impulsive bursts are seen only after the onset of the visible flare, i.e. after the reconnection has started, strongly favours the second alternative. Besides, simultaneously with the $\gamma$-rays we also see the flare white-light emission (H. S. Hudson 1979; L. Dezsö 1979, personal communications) which is caused by accelerated particles penetrating to the low chromospheric layers (Švestka 1970; Najita & Orrall 1970; Hudson 1972). The white-light flare patches are clearly the foot-points of one or more coronal loops (cf. Švestka 1976*a*, fig. 9). Thus a significant fraction of the accelerated particles must be confined in the flare loops and this can most easily happen if the particles are accelerated at the reconnection site (Švestka *et al.* 1979*a*). Then a fraction of the particles is trapped in the reconnected loop while another part (cf. figure 6) propagates upwards and can be accelerated to still higher energies in the flare-produced shock wave.

Thus one can suppose that at any time when a new loop reconnects, particles are accelerated to enhanced energies. The most energetic particles are produced when the first loops are formed very low in the corona; after that the peak energy of the accelerated particles decreases as the reconnection process slows down. But one can see that the whole acceleration process proceeds for hours. In long-lasting post-flare loop events, like that of 29 July 1973 already discussed (§4), some particles would still be accelerated 12 h (and possibly even 30 h) after the flare onset (Švestka *et al.* 1979*a*, *b*). This offers a completely new picture of the acceleration process in flares which until now has been usually considered to be impulsive and short-lived.

However, there is still another interesting conclusion that one can draw from the described model of filament activation. We have seen that the field opening and subsequent reconnection is common to all disrupted filaments. Either the field opening or, more probably, the field-line reconnection is the process that accelerates particles. This clearly implies that particles should be accelerated not only in the two-ribbon flares, but also during any other process of 'disparition brusque'. One has to expect, of course, that the peak energy of particles accelerated in 'disparitions brusques' without flares would be low, of the order of 1 MeV or less. But this actually is what has been observed. Essentially all particle events in Space that involve protons with energies greater than 10 MeV can be successfully associated with flares occurring on the Sun or supposed to appear in known active regions behind the solar limb (cf. Švestka & Simon 1976). As soon as we go to lower energies, however, the number of 'unexplained' particle events greatly increases. In particular, many $\lesssim 1$ MeV proton enhancements in space set in when a magnetic-sector boundary crosses the Earth, in spite of the fact that inside the corresponding sectors on the Sun no obvious acceleration took place, often for tens of days before (Švestka *et al.* 1976). These particles might be accelerated in Space; however, nobody has checked the occurrence of 'disparitions brusques' on the Sun in relation to these particle streams. It is certainly difficult to do it, because there are no regular patrol observations of this kind of solar activity. Nevertheless, filament activations occur very frequently in some particular old active regions (see, for example, Howard & Švestka 1977) and along the borders of growing coronal holes (see, for example, Webb *et al.* 1978). Thus they might indeed be powerful enough sources of low-energy protons on the Sun.

## 9. Compact flares

The ATM Flare Workshop has shown that not all flares are of the two-ribbon type (Moore *et al.* 1979). There are many other flares (and actually most flares may belong to this other kind) in which we cannot recognize any two-ribbon structure and in which the chromospheric Hα emission does not exhibit any drifts. In soft X-rays these flares seem to represent a brightening of mostly pre-existing and stationary coronal loops, and no filament activation and disruption can be seen before the flare. These phenomena have been called 'compact flares'.

They also differ from the two-ribbon flares in another essential aspect: whereas, as we saw in §4, the theoretical cooling time in two-ribbon flares is much shorter than the flare lifetime, in compact flares the predicted cooling time roughly corresponds to their duration. Thus, evidently, in this case essentially all energy is released at the onset of the flare, in constrast to the long-lasting sequential reconnection in the two-ribbon flares.

As noted earlier, the compact flares may perhaps occur more often on the Sun than the two-ribbon flares. However, and this is a very important fact, essentially all major events on the Sun (producing coronal disturbances and high-energy particles) are of the two-ribbon type. Therefore, an interpretation of the two-ribbon flares and of filament activation in general is of basic importance for our understanding of the most powerful activity events on the Sun.

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### *Discussion*

K. H. J. Phillips (*S.R.C. – Astrophysics Research Division, Culham Laboratory, Abingdon, Oxon. OX*14 3*DB*). I should like to draw attention to some work Dr Zirker and I did two years ago on the formation of Hα loop prominences from hot X-ray loops (in *Solar Physics* **53**, 41, 1977). Our model was a completely static one involving a nest of coronal loops heated impulsively at the flare flash phase, thus contrasting with Kopp and Pneuman's in which there is a continuous energy input by magnetic reconnection processes high in the loop. We allowed the nest of loops to cool by conduction and radiation, and found that the cooling time increased with increasing loop length, rather as observed (though admittedly the exact observed dependence was not reproduced). We consider this to be still a valid alternative to models such as Kopp & Pneuman's in which there is a continuing supply of energy into flare plasmas long after the initial release of energy.

Z. Švestka. I do not think so. I demonstrated that the observed cooling time on 29 July 1973 was always shorter than 4 h, whereas the X-ray loop system continued to grow for 12 h or more. Thus new loops must be formed still 8 h (or more) after the flare onset, and these new loops still have $T$ at the top in excess of $4 \times 10^6$ K.