ORIGIN AND DEVELOPMENT OF SOLAR FLARES

C. de Jager
The Astronomical Institute
Space Research Laboratory
Beneluxlaan 21
3527 HS UTRECHT,
The Netherlands

ABSTRACT

A review is given of knowledge on solar flares with particular emphasis on progress made during the international Solar Maximum Year (1979-1981).

The pre-flare structure is described by a flux tube model or a circuit model. The instability leading to a flare may occur by a disturbance of the field topology (mostly: field emergence) followed by field-line reconnection (circuit coupling). In the first, impulsive, phase of a flare this causes jets of energetic electrons, originating near the top of the flux tube, to bombard lower chromospheric regions: footpoint heating. In the second ('gradual' or 'diffuse') phase heated gas from the footpoints ascends convectively upward producing a large cloud of hot gas. Consequent shock wave phenomena cause moving fronts and associated waves in the high parts of the corona; these show up in coronagraphic or radio-observations. In some cases it happens that several hours after a large flare extended loop-like structures appear of fairly high temperature (> 6 MK), emitting a very faint X-ray flux. They are the basic structures of a more extended configuration, visible on metric radio waves, and pointing out from the area where the flare occurred. They may extend to distances of $\approx 10^6$ km or more from the solar surface.

1. INTRODUCTION

Since the early part of this century solar flares have been observed, initially by means of spectro-heliographic Hα images, mainly by Hale at Mt Wilson and by Deslandres at Meudon. Obtaining a flare image was in that period a matter of good luck because of the time needed to build up the solar image with the spectroheliographic technique. Things changed when in the thirtees Lyot (and independently Öhman) developed the monochromatic filter, enabling one to obtain full-disk pictures in a fraction of a second and nearly with any desired operational frequency. Routine observations of the Sun in Hα are nowadays made daily at many observatories, and allow one to monitor solar variability almost uninterruptedly.

Richard M. West (ed.), Highlights of Astronomy, Vol. 6, 53–71.

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

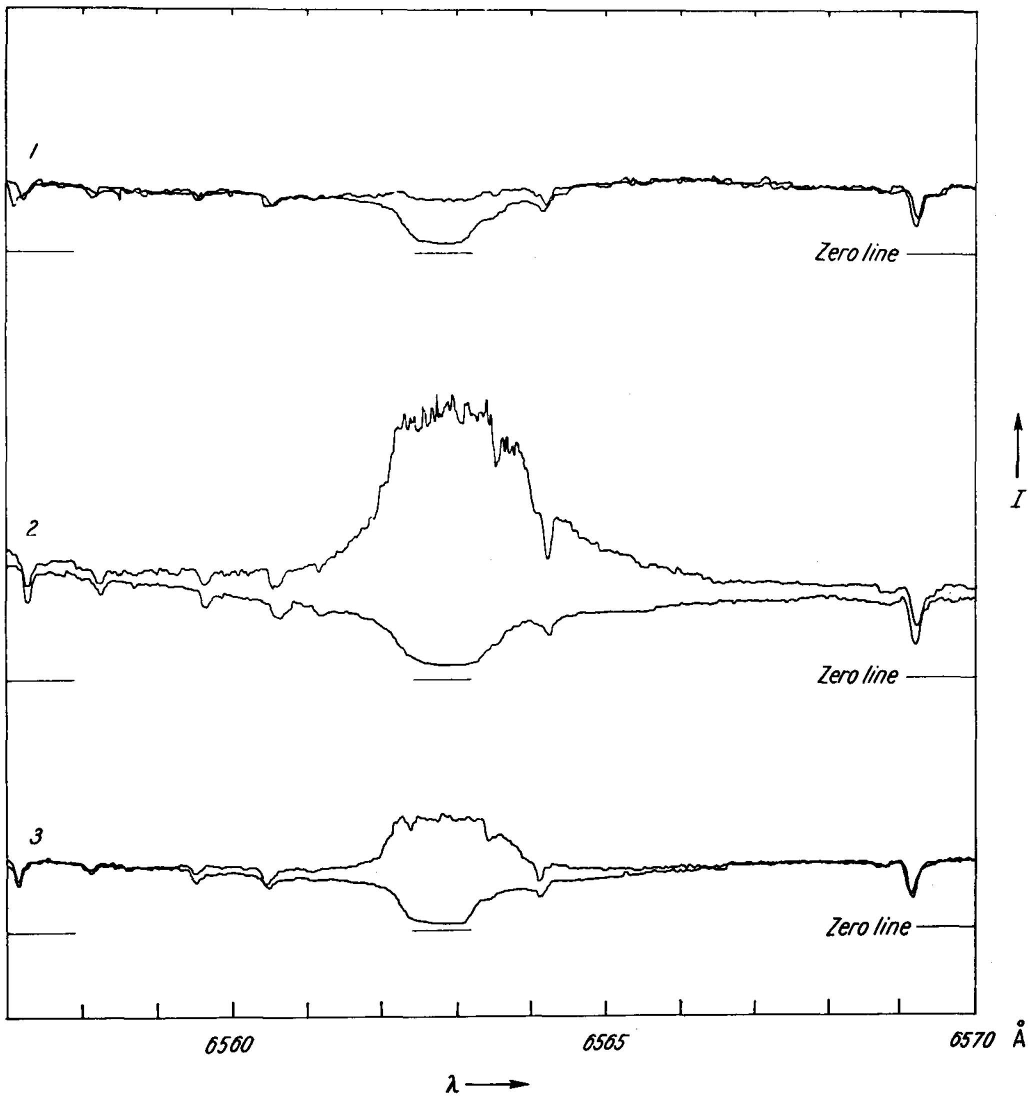

Figure 1. Spectra of the strong flare of August 31, 1956, taken by the author with the Utrecht spectrograph. The flare was of importance 3^+ and lasted from 12:33 UT till about 15 UT. The tracings give direct intensities; each lower one gives the undisturbed Hα profile, the upper one shows the flare profile. 1. 12:36:22 UT, during the onset; 2. 12:40:31 UT, during the flash phase; 3. 12:44:10 UT, during the decline.

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

Such observations are made preferably in light of the Hα line because 'white light flares' are rare. Yet the first flare ever seen was a white light flare observed by Carrington in 1859. This flare, which may have been one of the largest flares of the last 150 years, was detected by accident in a projected image of the Sun.

Flares are best seen in Hα because a flare's spectrum is an emission line spectrum with a very faint or absent continuum. Yet, this latter observation poses a problem because the observed weak continuum can only be reconciled with the known physical parameters of a flare when the effective geometrical thickness of a flare is of the order of at most a few tens of km only (Svestka, 1965). Combined with the observed thickness of a limb flare ($\approx 10^3$ km) this means that the 'filling factor' of a flare is of the order of 10^{-2}. Hence, when once seen with much higher resolution than nowadays possible from the ground, a flare may appear to differ greatly from the customary picture and may show striae, knots, filaments, and what more.

Flares show an enormous variety of shapes. Yet, some general aspects return: flares appear always in the vicinity of sunspots, and prefer complicated magnetic patterns. They tend to show as bright patches on either side of the 'inversion line' (or: 'neutral line') being the curve on the solar surface where the line-of-sight component of the magnetic field vector is zero. These patches are often connected by a 'light-bridge' crossing the inversion line at a small angle. Later we show that this bridge may be the seat of an electric current. Strong flares often appear as two bright ribbons running more or less parallel to the inversion line and at either side of it: the two-ribbon flare.

These general features tend to fade away when one is confronted with modern high resolution pictures of flares, and their development. The view of a flare movie, where the development of a flare in Hα light is shown at accelerated speed, leaves the spectator with the impression of a bewildering diversity in which it would be hard to find coherence and system.

2. A FLARE AS A CIRCUIT; A HISTORICAL REVIEW

An important step towards the beginning of understanding of the flare mechanism was made when Giovanelli (1939) found that the probability for flares to occur is proportional to the rate of increase of the area of the associated sunspot group. Since a change of area implies a change of magnetic flux B, this finding associates flares with an electric field E since

$$\frac{\delta\vec{B}}{\delta t} = - \operatorname{curl} \vec{E} \quad ,$$

and hence with an electric current density $\vec{J} = \sigma \vec{E}$.

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

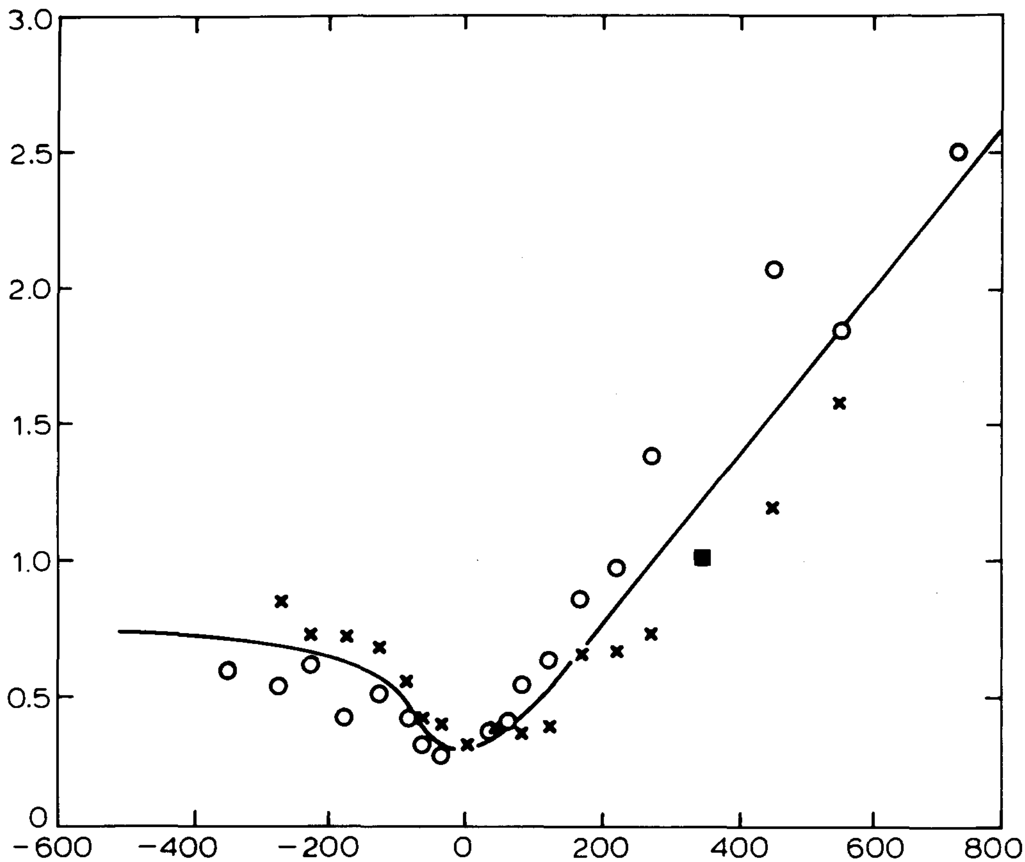

Figure 2. The probability for a flare to occur (ordinate) as a function of the changes of the sunspot area during the days preceding (circles) and following the flare (crosses). Areas are in 10^{-6} visible hemisphere. (Giovanelli, 1939).

The electric current density can be measured when vector magnetograms of the flaring area are available, since

$$\vec{J} = \text{curl } \vec{B} \quad .$$

This was done for the first time by Moreton and Severny (1968) who found that the bright flare patches on either side of the inversion line are seats of oppositely directed electric currents of the order of 10^{11} Ampère It looks then reasonable to assume that these two currents are connected and form a *circuit* bridging the inversion line and - evidently - also closed beneath the photospheric surface.

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

Thus the circuit model of a prospective flare was proposed (Alfvén and Carlquist, 1967; Alfvén, 1981; Spicer, 1982). Schematically it is as shown in Figure 3. It is thought that the seat of the electromotive force V, driving the current, is in the solar convection zone, and is due to dynamo effects in that region. The electric resistivity in the solar photosphere is by a factor 10^4 to 10^5 larger than in the chromospheric-coronal plasma where flares occur; this is schematized by including the resistance R in the circuit. In addition, any closed circuit will have a certain inductance L. Finally, Alfvén (1981) has mentioned the possibility that electric double layers may form in the coronal region of the circuit and this is formally described by the capacitance C in the circuit.

One may thus conclude that a preflare consists of a (system of) current(s) flowing through a highly conductive plasma above a turbulent

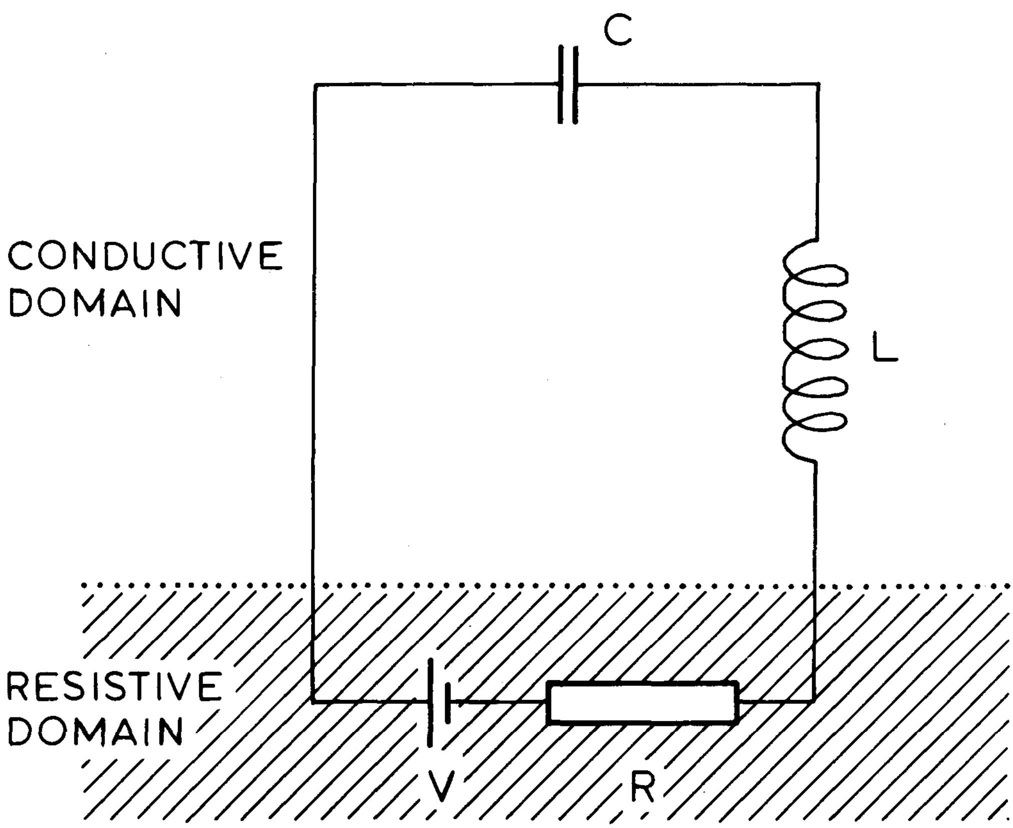

Figure 3. A circuit model of a preflare loop.

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

resistive medium where the currents originate. In order to maintain themselves the currents must be driven continuously, in other words: there is continuous energy input into a preflare loop system. As soon as energy input (i.e. the electromotive force V) would stop, the circuit would disappear.

In order to yield a flare the circuit has to be on the verge of instability and the immediate question is how it becomes unstable and gives rise to a flare.

An indication where to look for the answer is given by the observation of the X-radiation emitted by flares and discovered by Friedman *et al.* (1957). The X-ray emission is observed over a wide range of energies up to several times 10^4 or 10^5 eV, but in high energies ($10^5 - 10^6$ eV) it occurs only in bursts during the very first phase of a flare, and associated with Hα emission in the 'bridge' connecting the two flare patches , as shown first by De Jager (1967). Hence, high energy particles are emitted during the onset of a flare and persist only briefly, while a hot plasma can stay during a larger part of the flare's lifetime. One should not forget, though, that during all phases of the flare there is simultaneously a cool Hα emitting (hence $T \approx 10^4$ K) plasma.

So far we have described in this 'historical' review the *model* of a flare, and we have shown evidence where to look for the *onset*. Another question is then how flare energy is *accumulated*. To that end shearing motions may be essential. The considerable differential motions, sometimes observed in sunspot groups, many hours before a flare, already indicate the importance of energy storage through $\vec{v} \times \vec{B}$ motions in a plasma. This was stressed in a suggestive way by Tanaka *et al.* (1980) for flares of July 1974. They found that the curve showing the time-dependence of the accumulated shearing energy in the flaring region was very similar to the curve giving the accumulated radiated energy (Figure 4).

Later in this paper we will refer to the importance of field emergence as the process leading to the *onset* of a flare.

3. INTERNATIONAL GEOPHYSICAL YEAR; THE SOLAR MAXIMUM YEAR

In order to study irregularly occurring short-lived transient phenomena with the most chance for success worldwide coordination is needed. To that end the International Geophysical Year was organized (1957-1958), after two previous fine examples, the First (1882) and Second (1932) International Polar Years. Presently (1982) we commemorate the 100^{th}, 50^{th} and 25^{th} anniversaries of these truly international and very successful enterprises.

The recent *Solar Maximum year* (1979-1981) was established following these earlier examples but it deviated in some aspects. Its aim was the study of the origin, development and aftermaths of solar flares and thus

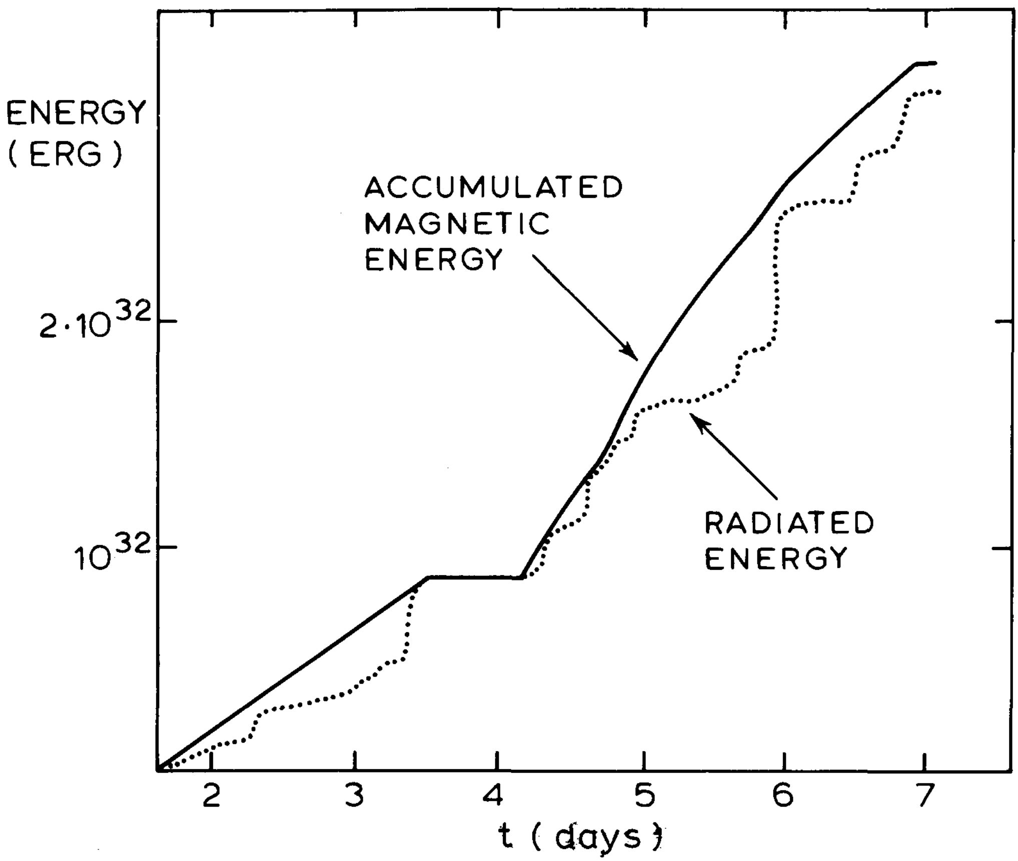

Figure 4. Comparison of the accumulated magnetic energy and the radiated energy in the region of the large flares of July 1974 (Tanaka et al., 1980).

the SMY consisted of three subprograms: the Flare Build-up Study; the Study of Energy Release in Flares, and the Study of Travelling Interplanetary Disturbances. Ground and space observations took primarily place in declared intervals and cooperating institutes were alerted by the coordinating center in Meudon (France), from where also close contacts were maintained with Goddard Space Flight Center (USA) where a considerable group of scientists was collecting and studying data from NASA's Solar Maximum Mission, a large multi-instrument spacecraft launched February 14, 1980.

Other important instruments that contributed to the success of the SMY are the Japanese solar satellite Hinotori, and ground-based radiotelescopes like the U.S. Very Large Array, the Netherlands Synthesis

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

Radio Telescope at Westerbork, the Australian Radioheliograph at Culgoora. Altogether scientists from more than 30 countries joined in the SMY. The results obtained during the 18 months of cooperative research have not yet been fully digested; yet they have already greatly improved our views on solar flares.

4. THE FIRST (IMPULSIVE) PHASE OF A FLARE

It makes sense to look for the origin of flares in radiation of high energy, since such radiation is likely to be emitted by the high energy plasma that is apparently originating at the very onset of flares and that shows its existence by peaky bursts in hard X-rays. Indeed, there is a marked difference between the X-ray light curves obtained in soft ($\lesssim$ 10 keV) and hard ($\gtrsim$ 20 keV) X-rays, the first being smooth, gradual, the latter being spiky, and restricted to the initial phase of the X-ray event (Figure 5). One therefore speaks of the *impulsive* and the *gradual* phases of a flare, but the figure shows that the two phases overlap, the gradual one going on all the time.

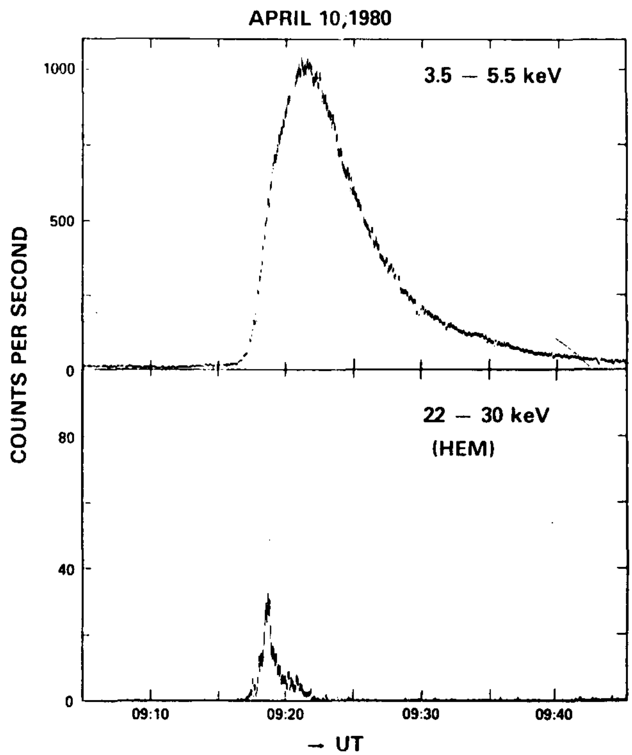

Figure 5. Integrated X-ray light curves of the flare of April 10, 1980; 09:20 UT obtained by HXIS aboard SMM. The graphs show the gradual development in low energies (upper figure) and the impulsive character of the high energy light curve (Duijveman et al., 1982).

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

The next obvious question is *where* the impulsive spikes originate. Observations made with the Hard X-ray Imaging Spectrometer (HXIS) aboard SMM have shown that these are always emitted by small areas situated on either side of the inversion line (Figure 6). These areas coincide often with the bright patches seen in Hα in the early phase of a flare and are often suggestively called 'footpoints'. Let us elaborate on this theme with a few well-studied examples.

The flare of 21 May 1980, one of the largest that occurred during the period of operation of SMM, was a typical two-ribbon flare. The ribbons ran parallel to an inversion line-filament that disrupted during the flare. The impulsive phase occurred at ca. 20:55 UT (Figure 7). At that time two small bright spots originated in HXIS images obtained in hard ($\gtrsim$ 16 keV) X-rays; they were situated at a mutual projected distance of $\approx$ 40 000 km and did not last longer than about one minute. Their occurrence appeared to be related to emergence of field ('upwelling of plasma')

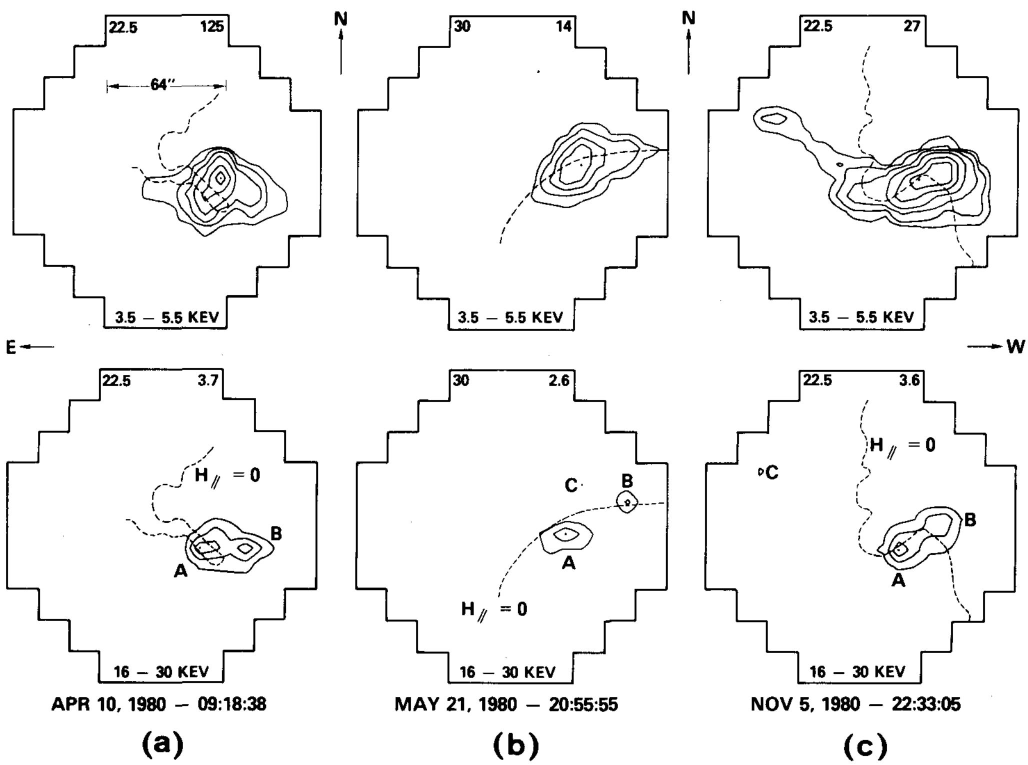

Figure 6. HXIS observations of three flares during the impulsive phases in low energies (upper diagrams) and in high. The lower diagrams demonstrate that during the impulsive phase the radiation is restricted to a pair of patches on either side of the inversion line (dashed curves) (Duijveman et al., 1982).

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

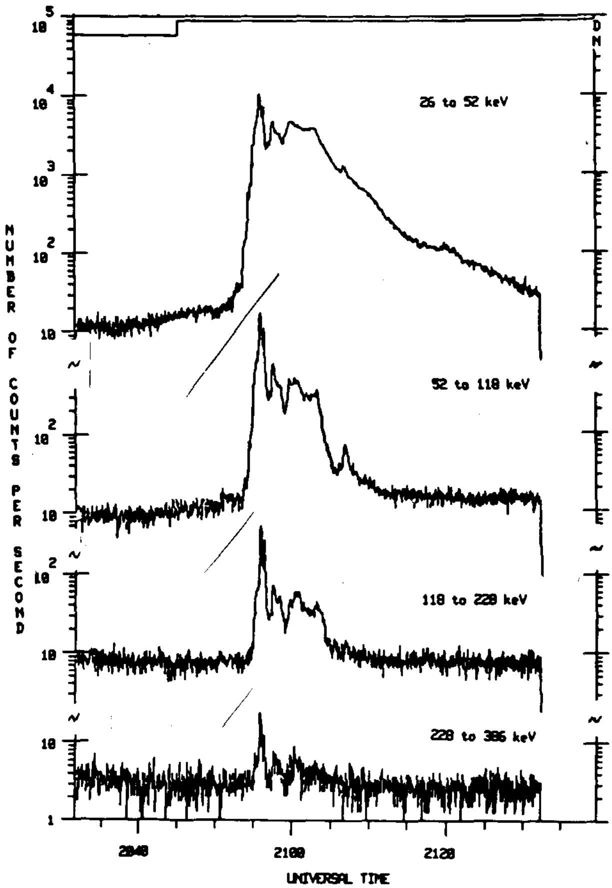

Figure 7. X-ray light curves of the great flare of 21 May 1980, obtained with the Hard X-Ray Burst Spectrometer (HXRBS) in five energy channels. Note the impulsive burst at 20:55 UT. (Hoyng et al., 1981).

near one of the bright spots, and therefore it seems likely that this disturbance significantly modified the field line arcade that held the inversion line-filament at its place. These events caused the filament to erupt and thus the flare was started (Figure 8).

The observation that *two* small areas flare up simultaneously at either side of the inversion line is not unique nor was their distance very large. Westerbork observations showed a case of two flare-associated centimetric radio sources, 2×10^5 km apart, flaring up within a second. More examples can be given. In view of the expected travel time of any kind of wave motions or of jets of electrons such observations can only be understood when the two burst sources are connected by a flux tube, with the source of the disturbance situated somewhere in the middle of the tube, so that a disturbance, most probably a stream of energetic electrons

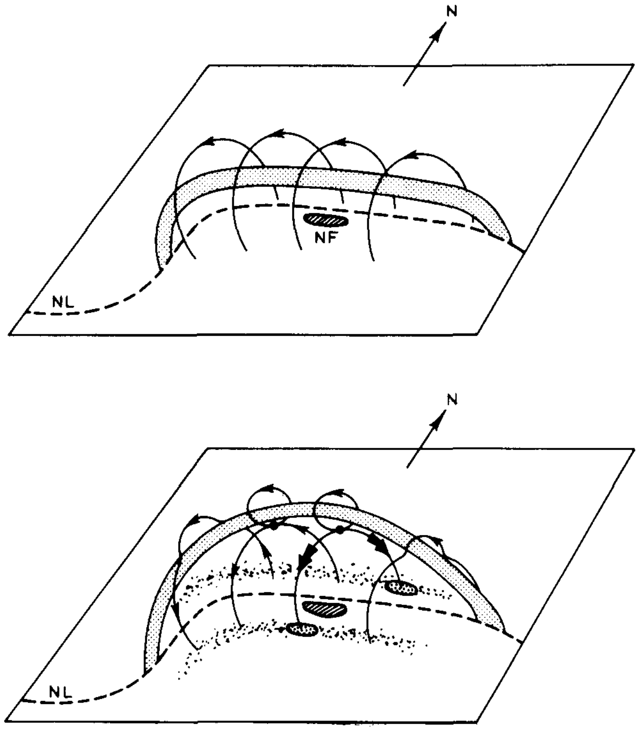

Figure 8. Scenario of the events leading to the flare of 21 May 1980. NL = neutral line; NF = new flux. (P. Hoyng, unpublished)

would need the same time to reach either footpoint. The question is whether there is any observation supporting this idea. X-ray observations on the disk invariably show *no* hard X-ray source in top of the loop.

The clue to the answer may be given by VLA observations. For the flare of 5 November 1980; 22:26 UT these show a 2 cm radio emission source over the inversion line (Figure 9). The high degree of circular polarization identifies the radiation as gyro-synchrotron emission, originating in top of the loop, where the ambient density is small, while the particle energy is too large to produce a measurable amount of X-emission.

Yet there is at least one case in which the point of initial ignition, coinciding with the top of a loop, has been seen in X-rays. The Queens' Flare (so called because it occurred on the day of abdication of Queen Juliana and of the inauguration of Queen Beatrix of the Netherlands) was a limb flare, which started its main development in X-rays and in Hα simultaneously at 20:20 UT on April 30, 1980. However, observations made with the Ultra Violet Spectrometer Polarimeter (UVSP) aboard SMM showed that field emergence started already some five minutes earlier. The flaring area at that time showed at least two loops (Figure 10), the smallest being near the area of field emergence. The integration of X-ray observations over periods of 30 s during a ten min. period prior to the

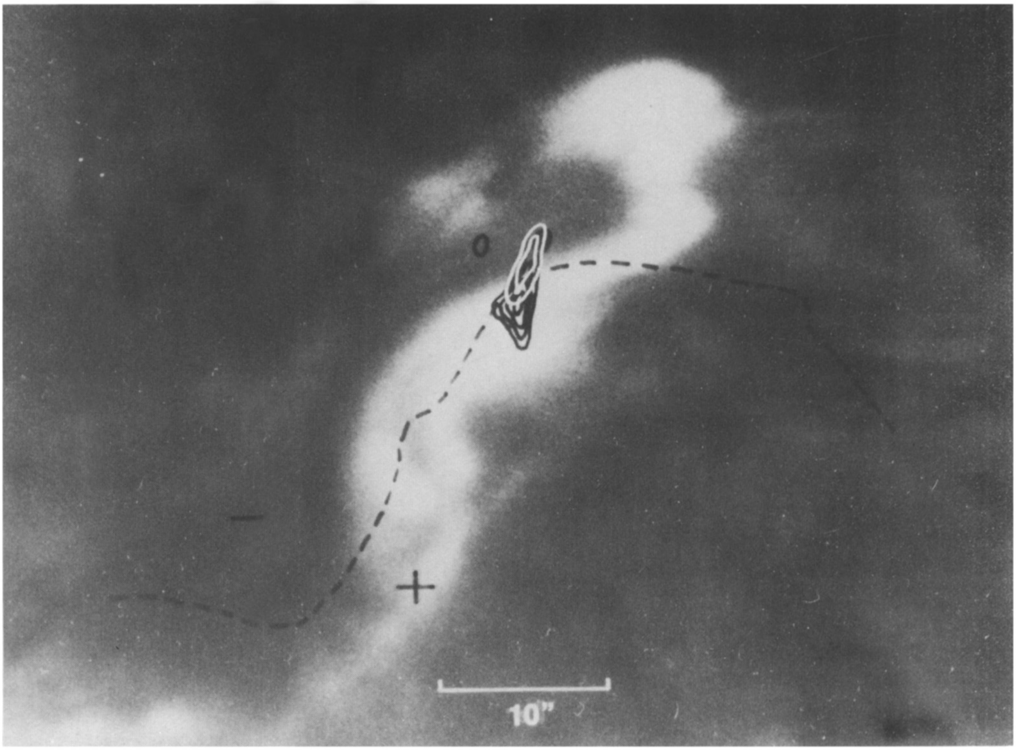

Figure 9. VLA map at 2 cm in right circular (black) and left circular (white) polarization for the flare of 5 November 1980 at 22:26:26 UT, superimposed on the corresponding Hα picture (Hoyng et al., 1982).

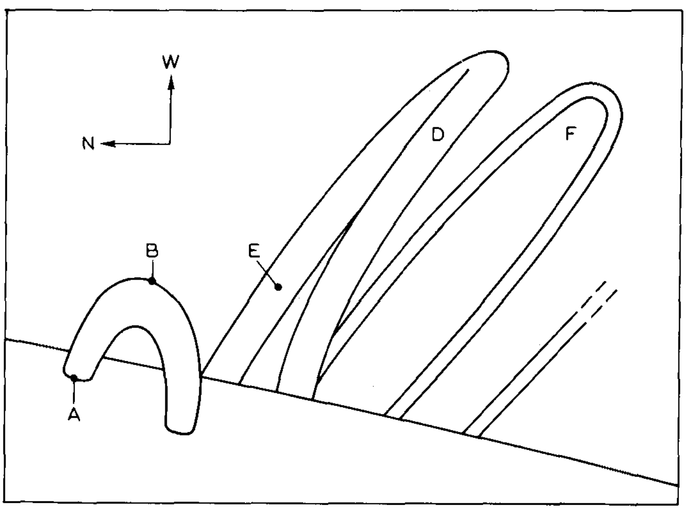

Figure 10. Loop structure in the limb area where the Queens' Flare originated on April 30, 1980, 20:20 UT. (De Jager et al., 1983)

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

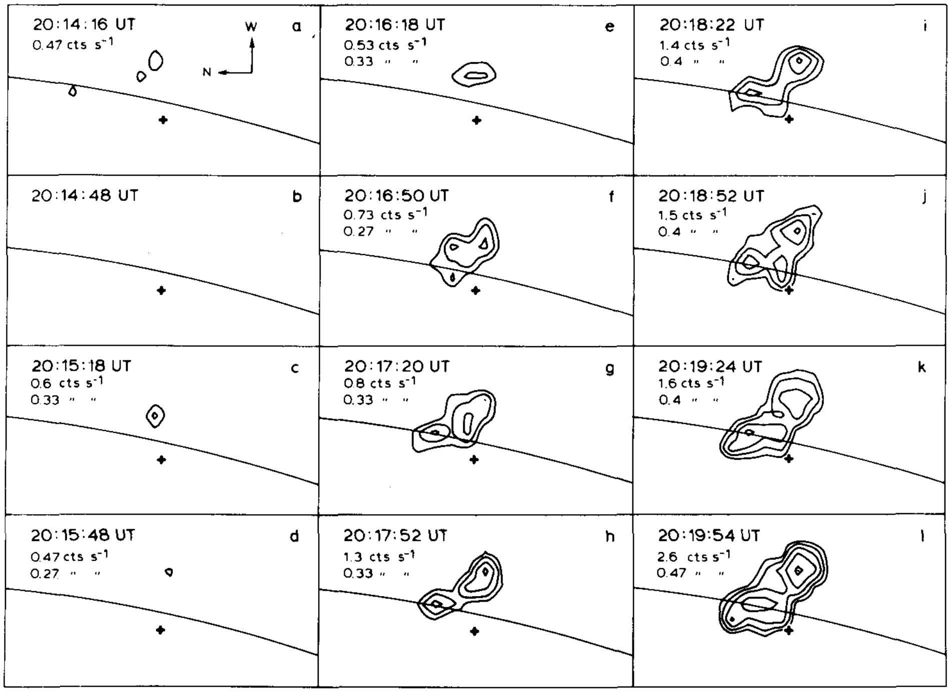

Figure 11. Preflare development, in HXIS X-ray pictures, of the Queens' Flare. Each picture is the result of 30 seconds count integration, which shows that the X-intensity is very faint. Note that first brightening occurs above the limb, about in the top of the small loop shown in Figure 10. It occurred simultaneously with the first field emergence. (De Jager et al., 1983).

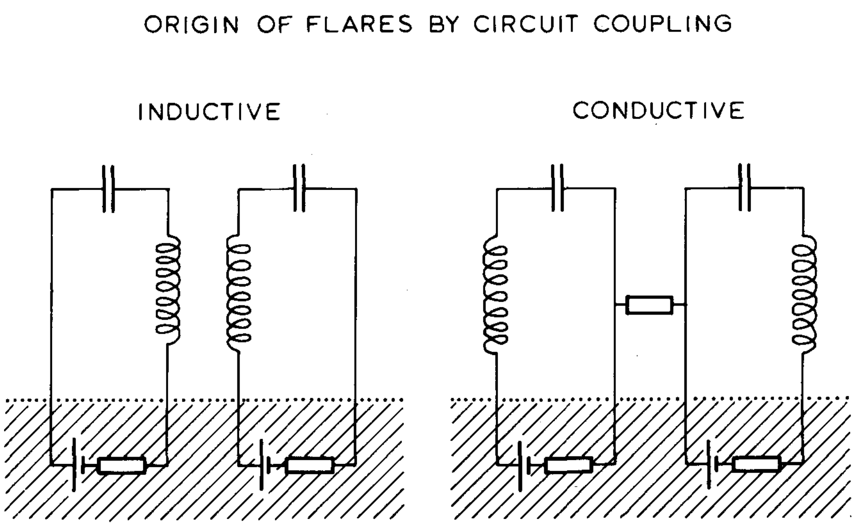

Figure 12. Circuit coupling.

flare (Figure 11) showed that the first - faint - X-ray emission was indeed observed some 10^4 km above the limb, approximately at the position of the top of the smallest loop. It occurred at the moment when UVSP observations showed the first signs of field emergence. Only a few minutes later a lower kernel started to brighten up; this was most probably a footpoint or leg of the small loop. Still later, at 20:23:45 the emerging matter (as seen in Hα) reached the height of first X-ray ignition, and at that time a strong radio burst was observed, together with a sudden increase in temperature and emission intensity of the X-ray kernel, as well as a sudden sideward expulsion of the upwelling Hα surge.

Remembering that a flare loop can be described by an electric circuit it is not difficult to interpret the above-described phenomena by the coupling of two electric circuits, a coupling initiated by the disturbing upwelling matter. This circuit coupling can either be inductive or conductive (Figure 12), a decision is hard to make. In terms of magnetic fields the interactive process is called field-line reconnection.

5. VERY HIGH ENERGY EMISSION DURING THE IMPULSIVE PHASE

The impulsive phase should not only be identified with the specific X-ray bursts that occur during that phase, but rather with the whole period of energy injection. This period appears to last as long as bursts are observed. In a well-studied case (a flare observed by SMM on 12 November 1980) the impulsive phase, thus defined, lasted 8 min, and there was an average net energy input of 10^{27} erg s^{-1}, with burst-associated fluctuations.

The *Gamma Ray Experiment* (GRE) aboard *SMM* has made several observations of gamma-ray spectral lines during flares (Chupp, 1982). The lines occur in the energy range 0.5 - 10 MeV and are due to nuclear interactions of various kinds. They are emitted in bursts with durations of one to several minutes. In addition neutron emission has been observed during the impulsive phase of one flare (Chupp *et al.*, 1982). These various observations lead to the interpretation that energetic ions and electrons, with energies up to 10^2 MeV, are accelerated (or released) during these bursts, and interact with matter during a very brief period.

6. THE GRADUAL (OR: DIFFUSE) PHASE

While the X-ray images in the impulsive phase are marked by their patchiness, showing 'footpoint illumination', the emitting area becomes more diffuse and amorphous in the later phase of a flare. This is illustrated by Figure 13 which shows the X-ray image of the flare of 12 November 1980 during the impulsive and gradual phases respectively. This figure shows the flaring area seen from *above*, which evidently confuses the interpretation. Therefore it makes sense to consider a flare seen from *aside* like the Queens' Flare (Figure 14). In that case one initially observes mainly footpoint heating followed by the development of a large diffuse

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

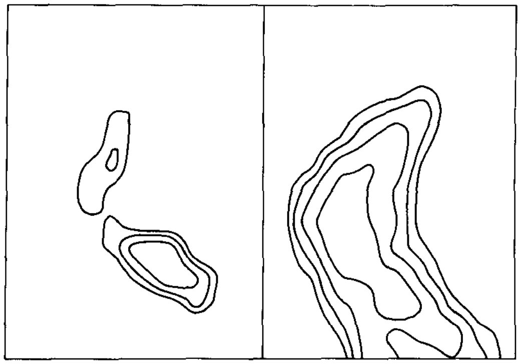

Figure 13. The impulsive (left) and the diffuse, or gradual (right) phases of the flare of 12 November 1980. Left: 02:50:02 UT; right: 02:57:02 UT; 5.5 - 8.0 keV. (Boelee and De Jager, 1983)

cloud at greater altitudes. The cloud originated nearly immediately, and reached its largest dimensions ca. 10 minutes after the first intensity maximum of the bright kernel, and occurred at an average height of 20 000 km above the limb.

These observations suggest that the diffuse cloud that occurs in the later phase of a flare is the consequence of upward rising *convective motions*. There are several observations that support this hypothesis. First of all, the Bent Crystal Spectrometer (BCS) aboard SMM noted upward velocities of the order of 400 km s^{-1} during the impulsive phases of flares. Such a velocity fits to the observed elevation of the diffuse cloud (2×10^4 km) and a time of ascent of about one minute. In addition,

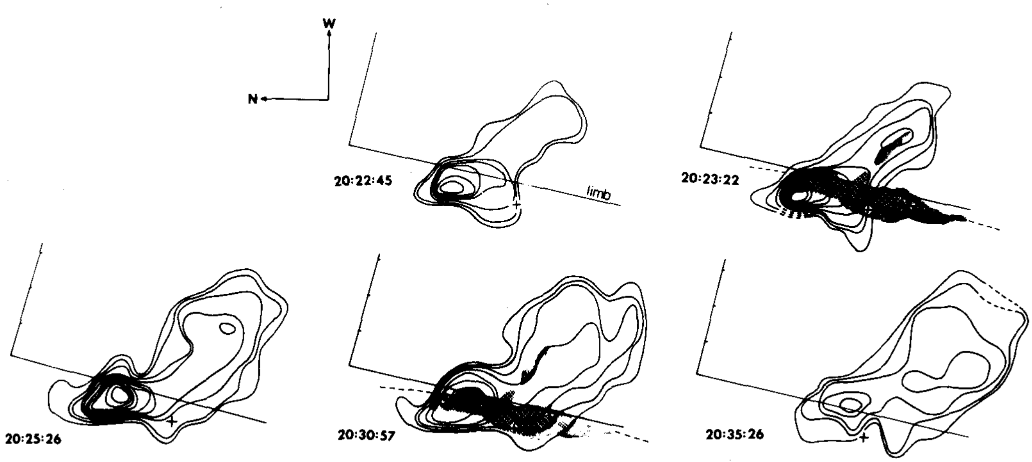

Figure 14. Development of the Queens' Flare (30 April 1980; 20:20 UT) as seen in X-rays. (Van Beek et al., 1981)

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

HXIS has observed that during the first few minutes after its origin the diffuse cloud is hotter by a few million K than the average footpoint gas. This suggests that the hottest elements of gas ascend quickest. These various observations (temperature difference, velocity, height) are apparently all in accordance with simple convection theory.

7. THE LAST PHASES OF A FLARE

The rapid rising of heated gas during the gradual phase of a flare must cause shock phenomena in the corona and these have indeed been observed as 'white light ejecta', by Skylab observations and by the white light coronameters aboard SMM and the US satellite 1-P78. The associated wave phenomena, induced by such shocks produce radio emissions that have indeed been observed.

A new aspect, hitherto unknown, was brought forward by HXIS aboard the SMM. Integration of X-radiation over intervals of 30 min *after* the flare of 21 May 1980 has revealed the existence of an extremely faint X-ray structure that must be interpreted as a giant arch, about 150 000 km high, with its footpoints situated near the endpoints of the flare-filament that disrupted during the flare (Figure 15). The arch must have had a temperature of at least 6×10^6 K, otherwise it would not have been observable by HXIS. Its X-ray intensity, though, was very small, less than 10^{-4} of the flare at maximum.

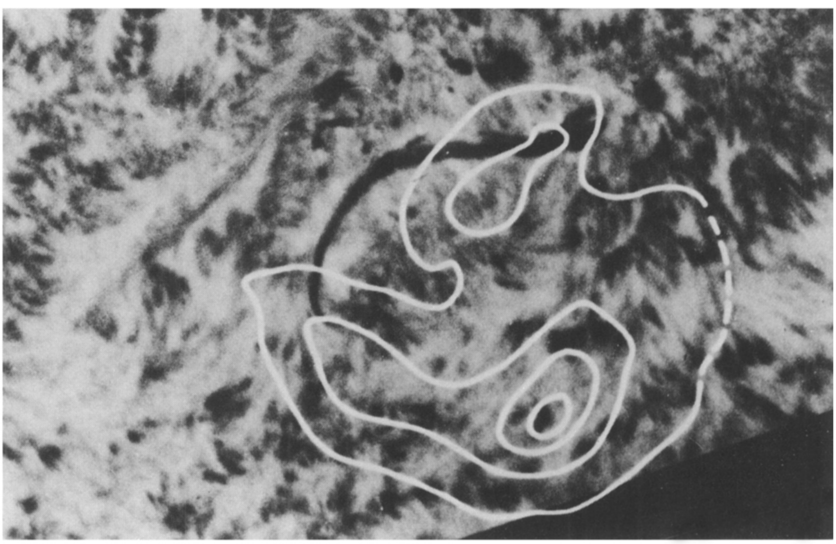

Figure 15. The giant arch observed in X-rays six hours after the flare of 21 May 1980, projected on a Hα picture of the Sun. (Svestka et al., 1982)

https://doi.org/10.1017/S1539299600004986 Published online by Cambridge University Press

Simultaneous observations with the Culgoora Radio-heliograph showed that this structure was the lower part of a larger one, the upper part of which being observable as noise storm sources in radio-frequences (Figure 16). This whole structure, extending over at least 10^6 km, must contain energetic electrons trapped in a large magnetic bottle. Only in the lower part, where the density is sufficiently large, X-rays can be emitted with a just detectable flux.

How can such a structure originate? A possible mechanism is through reconnection in a system of extended arches, combined with shearing motions which make one leg of every arch to reconnect with the other of the 'following' arch. Thus a spiral-like configuration originates that would be able to contain the current system observable as the giant X-ray arch (Figure 17).

Concluding this review, the reviewer should express his embarrassment about all that has *not* been told: so much fascinating data is available that would complete the present picture, which necessarily has to be a simplified one. Certainly, in flare research great progress has been made but, I believe that the most surprising discoveries are still ahead of us. They dawn upon us in Very Long Baseline Observations showing the existence of flare elements of only 50 km diameter; in the remarkable observations of nuclear reactions in flares; in the observation of solar millisecond radiobursts....

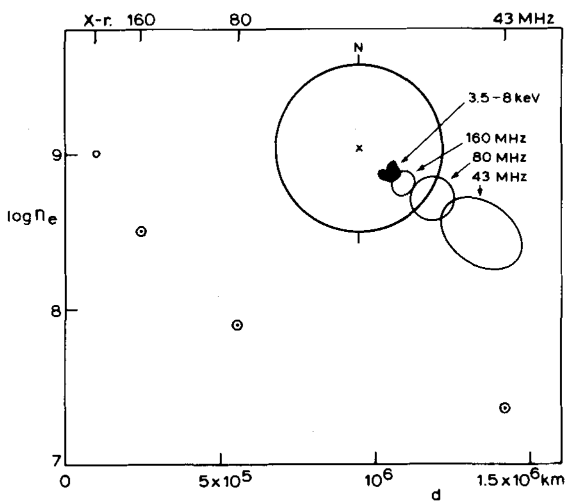

Figure 16. Structures observed after the large flare of 21 May 1980.
Black: the X-ray structure shown in Figure 15.
Open ovals: location of sources of noise storms observed with the Culgoora Radio-heliograph.
(Svestka et al., 1982)

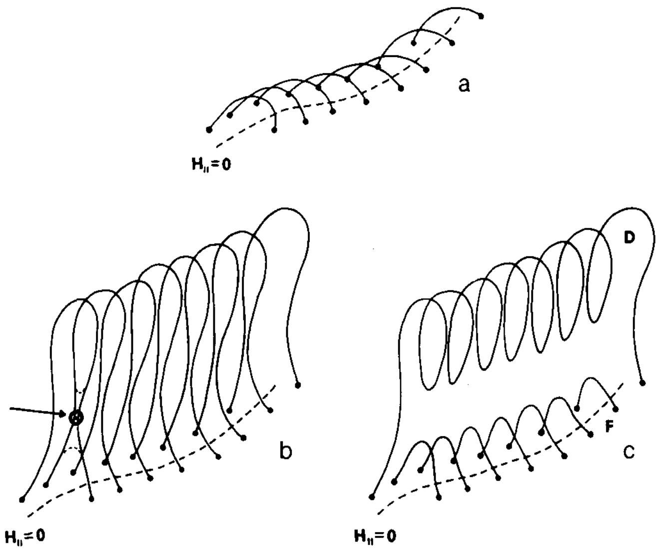

Figure 17. Possible scenario of the field line configuration leading to the giant X-ray arch. (Svestka et al., 1982)

ACKNOWLEDGEMENTS

This invited Discourse was illustrated by two films specially prepared for this occasion. One of these showed flare development in Hα and was produced at Big Bear Solar Observatory under the directorship of Dr. Hal Zirin. The other showed the development of solar flares in X-rays observed by HXIS aboard SMM and was due to Dr. Dave Rust. Several other colleagues provided slides and/or preprints. I am grateful to my near colleagues Peter Hoyng and Zdenek Svestka for a critical discussion of first versions of the paper and for many stimulating remarks. The fine cooperation with other members of the HXIS team and with members of other SMM groups was stimulating at any time.

REFERENCES

Alfvén, H. : 1981, Cosmic Plasma, Reidel, Dordrecht.
Alfvén, H. and Carlqvist, P.: 1967, Solar Phys. 1, 220.
Boelee, A., De Jager, C.: 1983, Solar Physics, in preparation.
Chupp, E.L.: 1982, *Solar Energetic Photon Transients*, Proceedings Amer. Inst. Phys. 77, 363.
Chupp, E.L., Forrest, D.J., Ryan, J.M., Heslin, J., Reppin, C., Pinkau, K., Kanbach, G., Rieger, E., Share, G.H.: 1982, Astrophys. J. (Letters), submitted.
De Jager, C.: 1967, Solar Phys. 2, 327.
De Jager, C., Machado, M.E., Schadee, A., Strong, K.T., Svestka, Z.,

Woodgate, B.E., Van Tend, W.: 1983, Solar Phys., accepted.
Duijveman, A., Hoyng, P., and Machado, M.E.: 1982, Solar Phys. 81, 137.
Friedman, H., Chubb, T.A., Kupperian, J.E., Kreplin, R.W., Lindsay, J.C.: 1958, Int. Geophys. Year Rocket Rept. Ser. 1, 183.
Giovanelli, R.G.: 1939, Astrophys. J. 89, 555.
Hoyng, P., Duijveman, A., Machado, M.E., Rust, D.M., Svestka, Z., Boelee, A., De Jager, C., Frost, K.J., Lafleur, H., Simnett, G.M., Van Beek, H.F., Woodgate, B.E.: 1981, Astrophys. J. (Letters) 246, L155.
Hoyng, P., Marsh, K.A., Ziring, H., Dennis, B.R.: 1982, Astrophys. J., submitted.
Moreton, G.E. and Severny, A.B.: 1968, Solar Phys. 3, 282.
Spicer, D.S.: 1982, Space Sci. Rev. 31, 351.
Svestka, Z.: 1965, Adv. Astron. Astrophys. 3, 119.
Svestka, Z., Stewart, R.T., Hoyng, P., Van Tend, W., Acton, L.W., Gabriel, A.H., Rapley, C.G., Boelee, A., Bruner, E.C., De Jager, C., Lafleur, H., Nelson, G., Simnett, G.M., Van Beek, H.F., Wagner, W.J.: 1982, Solar Phys. 75, 305.
Tanaka, K., Smith, Z., Dryer, M.: 1980, in: M. Dryer and E. Tandberg-Hanssen (eds): *Solar and Interplanetary Dynamics*, Int. Astron. Union Symp. 91, 231.
Van Beek, H.F., De Jager, C., Fryer, R., Schadee, A., Svestka, Z., Boelee, A., Duijveman, A., Galama, M., Hoekstra, R., Hoyng, P., Imhof, J.P., Lafleur, H., Machado, M.E., Maseland, H.V.A.M., Mels, W.A., Schrijver, J., Simnett, G.M., Van der Laan, J.J.M., Van Rens, P., Van Tend, W., Werkhoven, F., Willmore, A.P., Wilson, J.W.G., Zandee, W.: 1981, Astrophys. J. (Letters) 246, L157.