

AD-A207 876

STANDARD PROTONS AND THE IMPULSIVE PHASE OF SOLAR FLARES

S.W. Kahler
R.L. Moore
S.R. Kane
H. Zirin

DTIC
ELECTE
MAY 16 1989
S D
CD

The Trustees of Emmanuel College
400 The Fenway
Boston, Massachusetts 02115

Scientific Report No. 1


30 June 1988

Approved for public release; distribution unlimited

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731


89 5 15 048

"This technical report has been reviewed and is approved for publication"


EDWARD W. CLIVER
Contract Manager


E.G. MULLEN
Branch Chief

FOR THE COMMANDER


R.C. SAGALYN
Division Director

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify AFGL/DAA, Hanscom AFB, MA 01731-5000. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.

AD-A-7876

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS None	
2a. SECURITY CLASSIFICATION AUTHORITY N/A		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A			
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Scientific Report No. 1		5. MONITORING ORGANIZATION REPORT NUMBER(S) AFGL-TR-88-0165	
6a. NAME OF PERFORMING ORGANIZATION Emmanuel College	6b. OFFICE SYMBOL <i>(If applicable)</i>	7a. NAME OF MONITORING ORGANIZATION Air Force Geophysics Laboratory	
6c. ADDRESS (City, State and ZIP Code) 400 The Fenway Boston MA 02115		7b. ADDRESS (City, State and ZIP Code) Hanscom AFB MA 01731	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAF AFSC ESD PKR	8b. OFFICE SYMBOL <i>(If applicable)</i>	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F19628-87-K-0033	
8c. ADDRESS (City, State and ZIP Code) Hanscom AFB MA 01731		10. SOURCE OF FUNDING NOS.	
		PROGRAM ELEMENT NO. 61102F	PROJECT NO. 2311
		TASK NO. G4	WORK UNIT NO. BA
11. TITLE (Include Security Classification) Filament Eruptions and the Impulsive Phase of Solar Flares			
12. PERSONAL AUTHOR(S) S.W. Kahler, R.L. Moore, S.R. Kane, H. Zirin			
13a. TYPE OF REPORT Scientific No. 1	13b. TIME COVERED FROM 5/18/87 TO 5/17/88	14. DATE OF REPORT (Yr., Mo., Day) 88 June 30	15. PAGE COUNT 30
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	coronal mass ejection (CME)	
	SUB. GR.	filament eruptions	
		flares (continued on reverse)	
19. ABSTRACT (Continue on reverse if necessary and identify by block number)			
<p>We examine the observed development of filament eruptions in the impulsive phase of flares for evidence of how the eruption is driven. A one possibility sometimes adopted as a working hypothesis is that the filament eruption and accompanying coronal mass ejection are consequences of the energy release in the flare impulsive phase; they are taken to be ejecta in the explosion resulting from the pressure pulse from the plasma heating in the flare. We present evidence against this view. The evidence is from four flares in which, in the movies, from Big Bear Solar Observatory, a filament eruption was observed during the flare impulsive phase defined by the E at 30 keV hard X-ray emission observed with the the University of California at Berkeley detector on the ISEE 3 spacecraft. In each case we find (1) the well-known result that the filament eruption began before the onset of the impulsive phase; (2) that the eruptive motion is consistent with a smooth evolution through the impulsive phase, accelerating, but showing no new acceleration attributable to the</p> <p>(continued on reverse)</p>			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS <input type="checkbox"/>		21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Edward Cliver	22b. TELEPHONE NUMBER <i>(Include Area Code)</i> (617) 377-3975	22c. OFFICE SYMBOL AFGL/PHP	

A

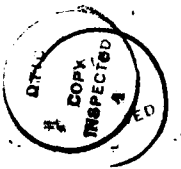
18. Subject Terms (continued)

impulse phase
magnetic field
x-ray emission

19. Abstract (continued)

impulsive phase; (3) that the brightening of the $H\alpha$ flare ribbons in the impulsive phase occurring in compact areas is much smaller than the overall span of the erupting filament; and (4) that the observed projected speed is on the order of 100 km/s^{-1} at the onset of the impulsive phase. These characteristics indicate that the filament eruption is not driven by the flare plasma pressure, but instead marks an eruption of magnetic field driven by a global MHD instability of the field configuration in the region of the flare. It appears that the filament eruption and the impulsive energy release are coordinated and driven by a common cause, the instability of the whole field configuration. A new mode of energy release, that of the impulsive phase, may be initiated when the eruptive motion surpasses some speed limit of order 100 km/s^{-1} .

*1/s. (code) **



Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

1. INTRODUCTION

A flare is an explosion in the solar atmosphere, a sudden burst of particle acceleration, plasma heating, and bulk mass motion. Because flares occur only in magnetic regions and strongly favor sites where the magnetic field is greatly deformed from its potential, minimum-energy configuration, it is likely that flares draw their energy from the free energy stored in the nonpotential magnetic field (Svestka 1976; Gary et al. 1987; Machado et al. 1987; Moore 1987).

The magnetic field in which a flare occurs is basically bipolar. The configuration consists of a single overall bipole or of two or more distinct bipoles impacted against each other, each bipole having its own internal polarity inversion line (the dividing line between the two opposite polarity domains of the bipole) (Moore et al. 1980; Machado et al. 1987). Many flares have a dominant bipole which is evidently nonpotential and in which most of the energy release occurs (Machado et al. 1987). In this bipole, the flare typically starts out closely straddling the inversion line and then spreads away (Svestka 1976; Moore et al. 1984).

A clear and common sign of nonpotential stress in a bipole is strong magnetic shear across the polarity inversion line; instead of connecting directly across the inversion line as it would if the field were potential, the field near the inversion line runs almost parallel to it (Hagyard, Moore, and Enslie 1984; Moore and Rabin 1985). Such sheared magnetic field is often marked by a filament of dark chromospheric material tracing the inversion line (e.g., see Figure 1). When a flare occurs in such a bipole, the inversion line and the sheared field traced by the filament are

embedded in the flare. In the onset and impulsive phases of such flares, chromospheric movies often show impressive eruptive action of the filament and hence of the field that carries it (Kiepenheuer 1964; Zirin 1970; Martin and Ramsey 1972; Moore et al. 1984).

In some flares the filament eruption is arrested and confined within the bipole (Svestka 1986; Machado et al. 1987; Moore 1987). In other cases the eruption opens the bipole, and the field in and around the filament is ejected out into the corona and escapes into the solar wind; such a filament ejection viewed in a chromospheric movie is called a flare spray (Tandberg-Hausen, Martin, and Hansen 1980). Viewed in coronagraph images, the filament material and the magnetic field traced by it are often seen to ride in the core of a coronal mass ejection (CME) (Webb and Hundhausen 1987). Because a filament ejection is an integral part of many CMEs, study of the initiation of filament eruptions may yield clues to how CMEs are launched.

One working hypothesis for numerical modeling of CMEs from flares has been that the mass ejection is basically the consequence of a pressure pulse generated by the sudden intense heating marked by the impulsive hard X-ray burst and steeply rising soft X-ray emission in the flare impulsive phase (Dryer 1982). Estimates of the total energy released, based on thick-target interpretation of hard X-ray bursts from large flares, give enough energy ($> 10^{32}$ erg) for even the largest CMEs (Lin and Hudson 1976). On the other hand, it is known that in most large flares with filament eruptions, the filament begins to erupt several minutes or more before the onset of the impulsive phase of the flare (Martin and Ramsey 1972). It is also fairly certain that many CMEs begin before the impulsive phase onset of the flares with which they are associated (Harrison 1986). The early

start of filament eruptions and CMEs casts doubt on the identification of the pressure pulse as the driver for CMEs; this raises the question of how the impulsive energy release is involved in the launching of filament eruptions and CMEs.

To investigate this question we have closely examined the filament motion through the onset of the impulsive phase in four flares for which the impulsive phase onset was well defined by an observed hard X-ray burst and in which the filament motion could be well followed in an H α movie. We find that in each of these flares the filament began to erupt minutes before the impulsive phase onset, and the motion evolved smoothly through impulsive phase onset, showing no basic change in character at that time. This indicates that the impulsive flare energy release is not the driver of the filament eruption, and hence is not the cause of filament ejections and CMEs.

II. DATA ANALYSIS

We began with a listing of all H α flares observed at Big Bear Solar Observatory (BBSO) and reported as 1B or larger (Solar-Geophysical Data 1979-1983) after the launch of the ISEE-3 spacecraft in August 1978. From over 200 candidate flares we selected for detailed examination four flares meeting the following criteria:

- (1) The BBSO H α photographic coverage was complete during the preflare and flare rise phases, and the motion of an eruptive filament in the flare region could be followed well into the impulsive phase before the filament disappeared from the observing bandpass. Both on-band and blue wing ($\Delta\lambda = -0.6 \text{ \AA}$) off-band images were used.
- (2) A well defined hard X-ray burst was observed by the UC Berkeley scintillator experiment on the ISEE-3 spacecraft (Anderson et al. 1978).
- (3) The flare occurred sufficiently far from the limb that the position of the impulsive phase H α brightenings relative to the erupting filament could be determined.

Many candidate flares lacked overlapping H α and hard X-ray coverage. In other cases the H α filament was faint or faded quickly from the H α bandpass when the flare began. The four selected events, listed in Table 1, were selected from a viewing of the H α movies. For each of the four events we selected images at appropriate times and made prints with a scale of 8700 km (12 arc sec) = 1 cm. The relative positions of the outermost parts of the erupting filaments were measured on each print. In addition, the positions of the impulsive phase H α brightenings were also traced out. For each event, discussed in detail below, we show in one figure images of the moving filament and a diagram of the positions of the

impulsive phase H α brightenings relative to the filament. A second figure shows the time series of the relative filament displacements (projected in the plane of the sky) and hard X-ray fluxes. In these figures the solid vertical line shows the approximate time of onset of the hard X-ray burst and the dashed vertical lines bracket the onset of the H α flash phase estimated from the H α movies.

a) The Flare of 1979 April 26.

The flare occurred in McMath plage region 15967, a large region with a bipolar magnetic structure. In Figure 1 we show the H α flare emission regions and the increase in the emission areas from early in the flare at 2001:08 UT to just after the peak of the hard X-ray burst at 2002:51 UT. The strongest impulsive brightenings were along the magnetic inversion line centered approximately under the filament. Some weaker enhancement of H α emission was also seen near the filament footpoints. Most of the H α brightenings near the northern footpoint occurred before the flare impulsive phase.

In Figure 2 the filament displacement measured from the H α images shows that the large filament structure was already moving eastward with a projected speed of $\sim 5 \text{ km}\cdot\text{s}^{-1}$ at 1956 UT. The hard X-ray burst began just before 2002 UT and peaked at 2002:36 UT, as shown in Figure 2. Before 2003 UT, the bandpass of the H α filtergrams was centered on the line; after 2003 UT, the images were made in the blue wing of the line. We found good agreement between the on-band and off-band displacements near 2003 UT, showing that the same filament feature was being tracked throughout the event.

b) The Flare of 1980 May 28.

The flare occurred in plage region 16863, a large bipolar region in its first solar rotation. The observations used here were obtained in the blue wing of $H\alpha$ (Figure 3). The impulsive phase of this event consisted of at least two separate bursts, the first peaking at 2338:16 UT, the second at about 2338:40 UT (Figure 4). The most prominent $H\alpha$ brightening associated with the first peak was centered under the arch of the erupting filament at point A (Figure 3). It was very bright in the 2338:20 UT image, but almost invisible in the images 10 sec before and 10 sec after that time. Subsequent brightenings appeared as bipolar features near the northern and southern footpoints of the filament. In addition, another large region of $H\alpha$ emission appeared well to the north of the filament region.

c) The Flare of 1980 June 25.

This flare occurred in plage region 16923, a new complex region joined to another region on its second disk passage. Observations were obtained in both the center of the $H\alpha$ line and its blue wing. The latter show the erupting filament burst (Figure 5). The $H\alpha$ brightenings during the onset of the impulsive phase show double ribbon features, particularly near the western end of the filament where the eruption proceeded most rapidly. The large displacement of the filament from the ribbon suggests that the filament overlay magnetic arches connecting the opposite polarities of the double ribbon. Another bright emission region lay well to the west of the filament. An isolated emission patch also appears in the spots to the east of the filament and may lie at the eastern footpoint of the filament. That

end of the filament was the more slowly moving part of the eruption. The hard X-ray profiles and filament displacements are shown in Figure 6.

d) The Flare of 1981 July 27.

The flare occurred in plage region 17760, a large bipolar region on its second disk passage. Zirin (1983) has studied the magnetic development of this region during the July 26-27 period of flare activity. His Figures 7 and 8 show the July 27 flare in H α and D $_3$ emission respectively. Our Figure 7 shows that the impulsive phase H α brightenings were widespread throughout the region. The D $_3$ regions mark the positions of the peaks of the hot thermal plasma presumed due to the most intense energetic electron precipitation. We show three such regions in this event. One is a large region lying partially in the sunspot to the east of the filament. A second is centered directly under the filament and appears to be a small bipolar structure on the magnetic inversion line. The third also appears as a bipolar feature near the northern footpoint of the filament.

Kattenberg (1984) has discussed the 2 cm maps of this event. He shows two small 2 cm structures at \sim 1724 UT, each of dimensions 2 arc sec by 10 arc sec and separated by 10 arc sec. One feature corresponds to our second region centered under the filament (his images are rotated 180° from ours and Zirin's). Kattenberg reports them to be small features oriented perpendicularly to the magnetic inversion line and interprets them as small low-lying loops possibly newly formed by reconnection. The filament displacements and hard X-ray profiles for this event are shown in Figure 8.

III. ANALYSIS OF THE FILAMENT MOTION

In all four cases the filament displacement is seen to undergo a smooth

evolution through the onset of the impulsive phase (Figures 2,4,6, and 8). The displacement profiles at those times show little change of slope in the 26 April and 25 June events, but the slopes steepen substantially in the 28 May and 27 July events. This suggests that the filaments of the latter two events may differ qualitatively in their motion from the former two events. We have fitted each of the profiles to an analytical trajectory in which we arbitrarily assume an acceleration a , which varies monotonically in time according to

$$a = ct^b, \quad (1)$$

where t is time and c and b are constants. The resulting displacement is

$$\Delta x = v_0 t + c(b+1)^{-1}(b+2)^{-1}t^{(b+2)}, \quad (2)$$

where v_0 is the speed observed at the beginning ($t = 0$) of the observations.

By estimating the initial slope of the points and requiring the curve to be a good fit near the middle and end of the observing interval, we evaluate the parameters b and c . The computed trajectories are shown as the smooth curve fits to the observed displacements at the bottoms of Figures 2, 4, 6, and 8. The power law exponent, b , of the acceleration equation (1) is definitely positive in all but the 25 June event, for which it was close to 0. All the filament displacements are well fitted by the curves through the onsets of the hard X-ray bursts and flash phases and show no evidence of any additional acceleration at those times. Hence, it appears that all four filament eruptions belong to a single family well described by smoothly varying acceleration.

The calculated filament displacements, speeds, and accelerations at the onsets of both the hard X-ray burst and the H α flash phase are shown in Table 2. Uncertainties are stated to reflect the range of possible

times for the H α flash phase. We note that the speeds at either the hard X-ray burst onset or the flash phase were all in the narrow range 30-180 km \cdot s $^{-1}$. This suggests that the impulsive phase energy release may not be initiated until a threshold speed of the eruptive filament has been achieved. The accelerations show a much broader range of values and, in view of the subjective nature of the fits to equation (2), must be considered to be less certain.

IV. DISCUSSION AND CONCLUSIONS

We have examined filament motions during the onset of the flare impulsive phase. The impulsive phase onset was established from the profiles of \sim 30 keV X-ray fluxes and the rapid flare brightenings characteristic of the H α flash phase. The general temporal and spatial association of these brightenings with impulsive hard X-ray bursts has been clearly established in previous studies (e.g., Diujveman, Hoyng, and Machado 1982; Diujveman and Hoyng 1983). We find the following:

- (1) The filament motion begins several minutes before the impulsive or flash phase of the flare.
- (2) No change occurs in the character of the motion of the filament during the onset of the impulsive phase of the flare.
- (3) The most common H α brightenings associated with the impulsive phase lie near the magnetic inversion line roughly centered under the erupting filament.
- (4) Filament speeds at the onset of the impulsive or flash phase lay in the range 30-180 km \cdot s $^{-1}$. Accelerations were in the range 0.2-9 km \cdot s $^{-2}$.

These results were derived from observations of only four events selected from a much larger sample of candidate events. They differed from

the other events only because of their comprehensive data coverage and clear delineation of the filament position and H α brightenings. We have no reason to think that they are uncharacteristic of filament eruptions in general; hence, the conclusions (1) to (4) should be general for most or all such events.

Our first observational result is consistent with results obtained in previous studies. For example, the motions of the filaments we found prior to the impulsive phases are manifestations of the early stages of filament activity found by Martin and Ramsey (1972) in their statistical study of 297 large flares. The early low speeds correspond to their phases of filament darkening, expansion, and breakup. This preflare activation was described earlier by Bruzek (1969) as a destabilization showing that the magnetic field had become unstable. As he put it, "Its (the activation of the filament) early start indicates that the magnetic field starts to change long before the onset of the optical flare. The final rise or eruption of the filament may then be considered as evidence of a catastrophic change of the magnetic field which simultaneously destroys the filament and generates the flare."

The important implication of the observational results (2) and (3) is that the rapid energy release in the impulsive phase does not cause, either directly or indirectly, the filament eruption. We have seen that the filament is already in motion well before the onset of the impulsive phase and that it continues to accelerate smoothly through the onset of the impulsive phase. No qualitative change of character of the motion occurs at that time. The H α brightenings that occurred in the impulsive phase usually lay close to the magnetic inversion line under the erupting filament.

A similar result for impulsive phase brightenings was found by Feldman et al. (1983) using He D₃ images of bright flares. The close proximity of the brightenings to the inversion line suggests that the impulsive energy release is confined to structures, probably magnetic bipoles, with size scales an order of magnitude smaller than those of the overlying filaments. If this is the case, it would not seem plausible that a pressure increase in the impulsive phase structures could result in a driving force adequate to propel the much larger overlying magnetic structure containing the filament. We conclude that the impulsive energy release is not a requirement for the eruption of the filament or of a CME in which the filament is an integral component (Webb and Hundhausen 1987). Rather, from our observations, it appears that the magnetic eruption traced by the erupting filament, as well as the impulsive energy release, are both driven by the MHD instability, or loss of equilibrium, of the overall magnetic field configuration in which the filament and flare are embedded.

Since the flare impulsive phase is not required for the occurrence of a filament eruption or a CME, there appears little reason to distinguish on physical grounds flare-associated CMEs from those associated with the eruptions of quiescent filaments. The more likely case is that all CMEs lie on a broad spectrum ranging from the quiescent filament eruptions in weak magnetic field regions to the flare filament eruptions from active regions with strong fields (Anzer and Pneuman 1982; Cane, Kahler, and Sheeley 1986; Moore 1987). Several additional observational results support this view. First, as pointed out by Bruzek (1969), many activated filaments remain stable and do not erupt, even when a flare occurs adjacent to or below the filament. This suggests that in many cases the impulsive

phase energy may not be adequate to propel the filament eruption. Second is the observation of large double-ribbon flares with no observed impulsive hard X-ray emission (Dwivedi et al. 1984) and the discovery of energetic proton flares with only small impulsive phases (Cliver, Kahler, and McIntosh 1983). A notable example of an energetic eruption occurring outside an active region was the event of 1981 December 5 in which a large filament eruption unaccompanied by any impulsive phase hard X-ray or microwave burst resulted in a CME, interplanetary shock wave, and solar energetic particle event (Kahler et al. 1984). Tandberg-Hanssen, Martin, and Hansen (1980) have shown that the trajectories of flare sprays and filament eruptions form a broad continuum rather than showing two classes as believed earlier (Valnicek, 1964). Finally, Cane, Kahler, and Sheeley (1986) found that CMEs associated with the eruption of quiescent filaments do not necessarily lie at the low end of an energy spectrum of eruptive events. Six quiescent filament eruptions they considered gave rise to interplanetary shocks and energetic particle events, phenomena usually presumed to be associated only with flare events. These several observational results indicate no requirement for an impulsive phase in an eruptive event.

Having shown that the flare filament eruption occurs essentially independently of the impulsive phase, one can ask what the relationship, if any, is between the two phenomena. We found (Table 2) that the onset of the impulsive phase seems to occur only during a limited range of filament speeds ($30-180 \text{ km}\cdot\text{s}^{-1}$) and accelerations ($0.2-9 \text{ km}\cdot\text{s}^{-2}$). These speeds are about one tenth the Alfvén speed, the most likely physically relevant speed. We speculate that these speeds are somehow critical for the

occurrence of the impulsive phase energy release. In agreement with this, we note that the speeds of eruptive quiescent filaments, events with no observed impulsive phases, are lower than $100 \text{ km}\cdot\text{s}^{-1}$ until after they leave the vicinity of the filament region ($h < 2 \times 10^5 \text{ km}$) (Schmahl and Hildner 1977, MacQueen and Fisher 1983). In addition, flare sprays, which originate from active region filaments and are probably always accompanied by flare impulsive phases, reach speeds of $> 500 \text{ km}\cdot\text{s}^{-1}$ within a few minutes of the start of the events (Tandberg-Hanssen, Martin, and Hansen 1980). We suggest that all eruptive events are due to the same physical cause and that those events characterized by a rapid ($< 5 \text{ min}$) acceleration to a speed of $> 100 \text{ km}\cdot\text{s}^{-1}$ will be accompanied by an impulsive phase. The impulsive phase, however, is only a secondary effect and plays no direct role in the eruptive event. In this sense the impulsive phase may perhaps be regarded as an effect of the eruptive event, a complete reversal of the roles previously attributed to these phenomena.

ACKNOWLEDGEMENTS

The work at Emmanuel College was supported by AFGL contract AF 19628-82-K-0039; at MSFC by the NASA Office of Solar and Heliospheric Physics and by AFGL through the Solar Research Branch of its Space Physics Division; and at BBSO by NASA grant NGL 05 002 034 and NSF grant ATM 8513577. At UC Berkeley the ISEE 3 data processing was supported by NASA grant NAG5-376, and the analysis was partially supported by NASA grant NGL-05-003-017 and by the Air Force Systems Command. The authors benefitted from their participation in the SMM Flare Workshop and thank E. Tandberg-Hanssen for his helpful comments.

TABLE 1

Characteristics of the Four Flares with Filament Eruptions

Date	H α Onset (UT) and Importance	Position	Region	GOES 1-8 Å Peak	Maximum 26-43 keV Flux (cts/sec)	8800 MHz Max Flux (s.f.u.)
1979 April 26	2001 1B	N11 E31	15967	C7	5.6×10^2	60
1980 May 28	1550 1B	S28 W29	16863	M6	1.4×10^3	270
1980 June 25	2338 1B	S16 W36	16923	M4	2.5×10^2	400
1981 July 27	1723 1B	S13 E10	17760	X1	$\sim 6 \times 10^3$	1800

TABLE 2

Characteristics of Filament Eruption at Impulsive Phase Onset

Date	IHXB ^a Onset (UT)	HFP ^b Onset (UT)	Displacement ^c (10^3 km)	Speed ($\text{km} \cdot \text{s}^{-1}$)	Acceleration ($\text{km} \cdot \text{s}^{-2}$)
1979 April 26	2001:46		17	88	0.31
		2001:55 \pm 35	18 \pm 3	91 \pm 12	0.32 \pm .06
1980 May 28	2338:03		5.9	75	1.30
		2338:10 \pm 10	6.5 \pm 1.0	85 \pm 15	1.50 \pm 0.25
1980 June 25	1549:56		7.8	91	0.25
		1550:25 \pm 15	10.8 \pm 1.8	98 \pm 10	0.22 \pm 0.01
1981 July 27	1723:16		2.4	28	0.26
		1723:55 \pm 15	4.2 + 2.0 - 1.0	85 + 92 - 40	3.95 + 4.8 - 2.3

a. IHXB = Impulsive Hard X-ray Burst (26-43 keV).

b. HFP = H α Flash Phase. The uncertainties given in the other columns are those resulting from the uncertainty in HFP onset.

c. Measured in the plane of the sky.

REFERENCES

- Anderson, K.A., Kane, S. R., Primbsch, J.H., Weitzmann, R.H., Evans, W.D., Klebesadel, R.W., and Aiello, W.P. 1978, IEEE Trans. Geosci. Elec., GE-16, 157.
- Anzer, U., and Pneuman, G.W. 1982, Solar Phys., 79, 129.
- Bruzek, A. 1969, in Solar Flares and Space Research, eds., C. de Jager and Z. Svestka (Amsterdam: North-Holland), p.61.
- Cane, H.V., Kahler, S.W., and Sheeley, N.R., Jr. 1986, J. Geophys. Res., 91, 13,321.
- Cliver, E.W., Kahler, S.W., and McIntosh, P.S. 1983, Ap.J., 264, 699.
- Dryer, M. 1982, Space Sci. Rev., 33, 233.
- Duijveman, A., Hoyng, P., and Machado, M.E. 1982, Solar Phys., 81, 137.
- Duijveman, A., and Hoyng, P. 1983, Solar Phys., 86, 279.
- Dwivedi, B.N., Hudson, H.S., Kane, S.R., and Svestka, Z. 1984, Solar Phys., 90, 331.
- Feldman, U., Liggett, M., and Zirin, H. 1983, Ap. J., 271, 832.
- Gary, G.A., Moore, R.L., Hagyard, M.J., and Haisch, B.M. 1987, Ap.J., 314, 782.
- Hagyard, M.J., Moore, R.L., and Emslie, A.G. 1984, Adv. Space Res., 4, 71.
- Harrison, R.A. 1986, Astron. Astrophys., 162, 283.
- Kahler, S.W., Cliver, E.W., Cane, H.V., McGuire, R.E., Stone, R.G., and Sheeley, N.R., Jr. 1984, Ap. J., 302, 504.
- Kattenberg, A. 1984, Ap.J., 283, 398.
- Kiepenheuer, K.O. 1964, in The Physics of Solar Flares, ed. W.N. Hess (NASA SP-50), p.323.
- Lin, R.P., and Hudson, H.S. 1976, Solar Phys., 50, 153.

- Machado, M.E., Moore, R.L., Hernandez, A.M., Rovira, M.G., Hagyard, M.J.,
and Smith, J.B., Jr. 1987, Ap.J., in press.
- MacQueen, R.M., and Fisher, R.R. 1983, Solar Phys., 89, 89.
- Martin, S.F., and Ramsey, H.E. 1972, in Solar Activity Observations and
Predictions, eds. P.S. McIntosh and M. Dryer (Cambridge: MIT Press),
p. 371.
- Moore, R.L. 1987, Ap.J., submitted.
- Moore, R., et al. 1980, in Solar Flares, ed. P.A. Sturrock (Boulder:
Colorado Associated University Press), p.341.
- Moore, R.L., Hurford, G.J., Jones, H.P., Kane, S.R. 1984, Ap. J., 276, 379.
- Moore, R., and Rabin, D. 1985, Ann. Rev. Astron. Astrophys., 23, 239.
- Schmahl, E., and Hildner, E. 1977, Solar Phys., 55, 473.
- Svestka, Z. 1976, Solar Flares (Boston: Reidel).
- Svestka, Z. 1986, in The Lower Atmosphere of Solar Flares, ed. D.F. Neidig
(National Solar Observatory), p.332.
- Tandberg-Hanssen, E., Martin, S.F., and Hansen, R.T. 1980, Solar Phys., 65,
357.
- Valnicek, B. 1964, Bull. Astron. Inst. Czech., 15, 207.
- Webb, D.F., and Hundhausen, A.J. 1987, Solar Phys., in press.
- Zirin, H. 1970, in Report UAG-8, ed. J.V. Lincoln (World Data Center A),
p.30.
- Zirin, H. 1983, Ap. J., 274, 900.

FIGURE CAPTIONS

Figure 1. Top: The H α flare of 26 April 1979 before (upper left, on band) and during (upper right, blue wing) the impulsive phase. Bottom left: Diagram of the impulsive phase brightening of the event. Shaded regions trace the filament. The heavy lines show the regions of new H α brightenings present during the impulsive phase image at 2002:51 but not observed in the earlier image at 2001:08 UT. Thin lines indicate the extent of the H α flare regions in the earlier image. The dashed line shows the estimated magnetic inversion line. The arrow shows the outer extreme of the erupting filament used in measuring the displacement shown in Figure 2.

Figure 2. Top: Counting rates of the 26-78 keV X-rays during the 26 April 1979 flare. Bottom: The relative filament displacements are shown by circles; filled circles are from on-band images, and open circles are from off-band images. Vertical arrows show the filament displacements at the times of the H α images of the top of Figure 1. The solid vertical line marks the X-ray onset of the impulsive phase. The dashed lines show the earliest and latest possible onset of the H α flash phase as determined from the movie.

Figure 3. Top: The H α flare of 28 May 1980. Details are similar to those described in Figure 1 except that both images are in the blue wing of H α . Point A in the lower diagram was the brightest region during the first peak in the impulsive phase.

Figure 4. X-ray counting rates and filament displacements for the 28 May 1980 flare. Details are similar to those of Figure 2.

Figure 5. The H α flare of 25 June 1980. Details are similar to those

described in Figure 1 except that both images are in the H α blue wing.

Figure 6. The X-ray counting rates and filament displacements for the flare of 25 June 1980. Details are similar to those in Figure 2.

Figure 7. The H α flare of 27 July 1981. Details are similar to those described in Figure 1 except that both images are in the H α blue wing and we show as dotted areas the regions of the D₃ emission at 1724:35 UT (Zirin 1983).

Figure 8. The X-ray counting rates and filament displacements for the flare of 27 July 1981. Details are similar to those in Figure 2.

POSTAL ADDRESSES

S. W. KAHLER: AFGL/PHP, Hanscom AFB, MA 01731

**S. R. KANE: Space Sciences Laboratory, University of California, Berkeley, CA
94720**

**R. L. MOORE: Space Science Laboratory, NASA/Marshall Space Flight Center, ES52,
Huntsville, AL 35812**

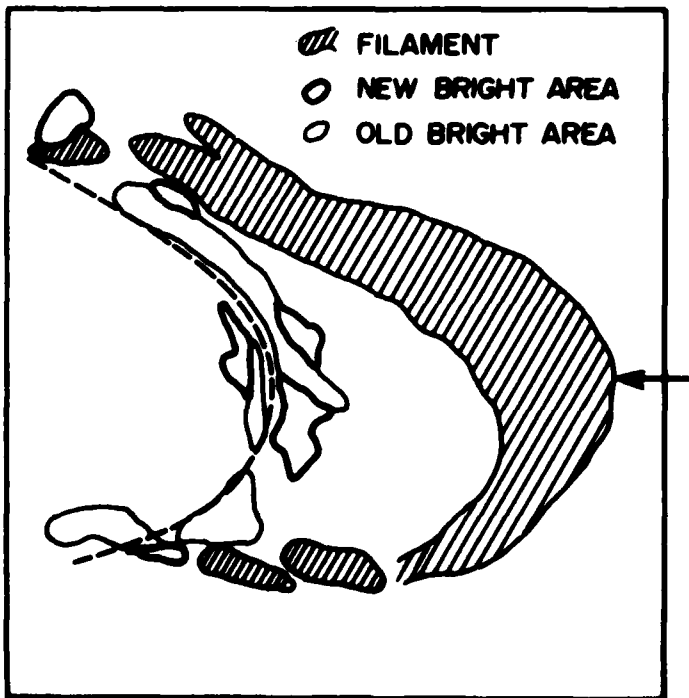
H. ZIRIN: Mt Bear Solar Observatory, Caltech, Bldg 264-33, Pasadena, CA 91125



1956:07 UT

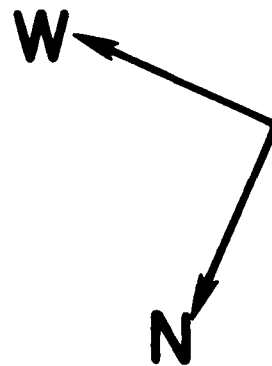


2003:43 UT

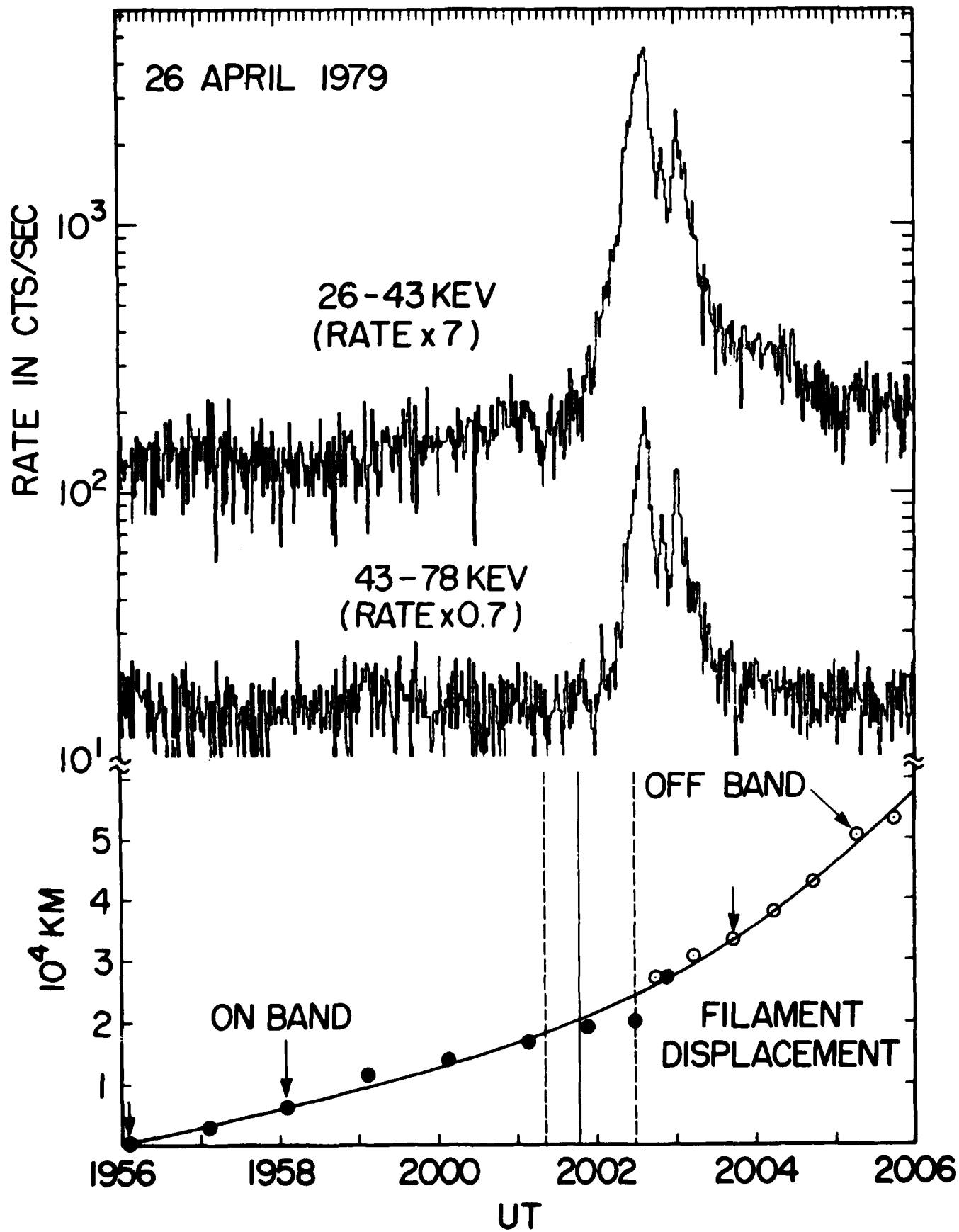


2002:51-2001:08
UT

4.35×10^4 km



APRIL 26, 1979
BBSO H α

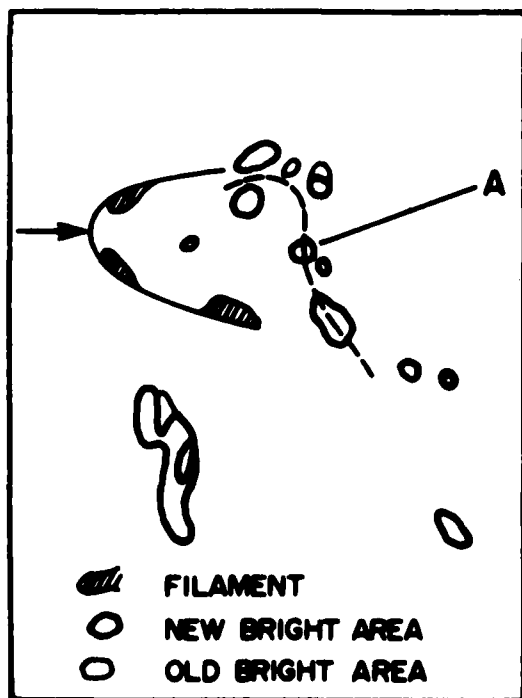




2335:20 UT

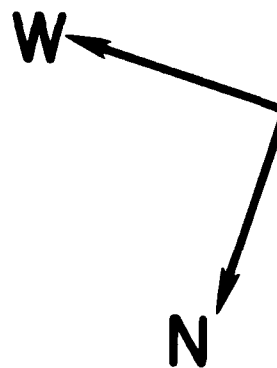


2338:50 UT



2338:50-2338:10
UT

4.35×10^4 km



MAY 28, 1980
BBSO H α

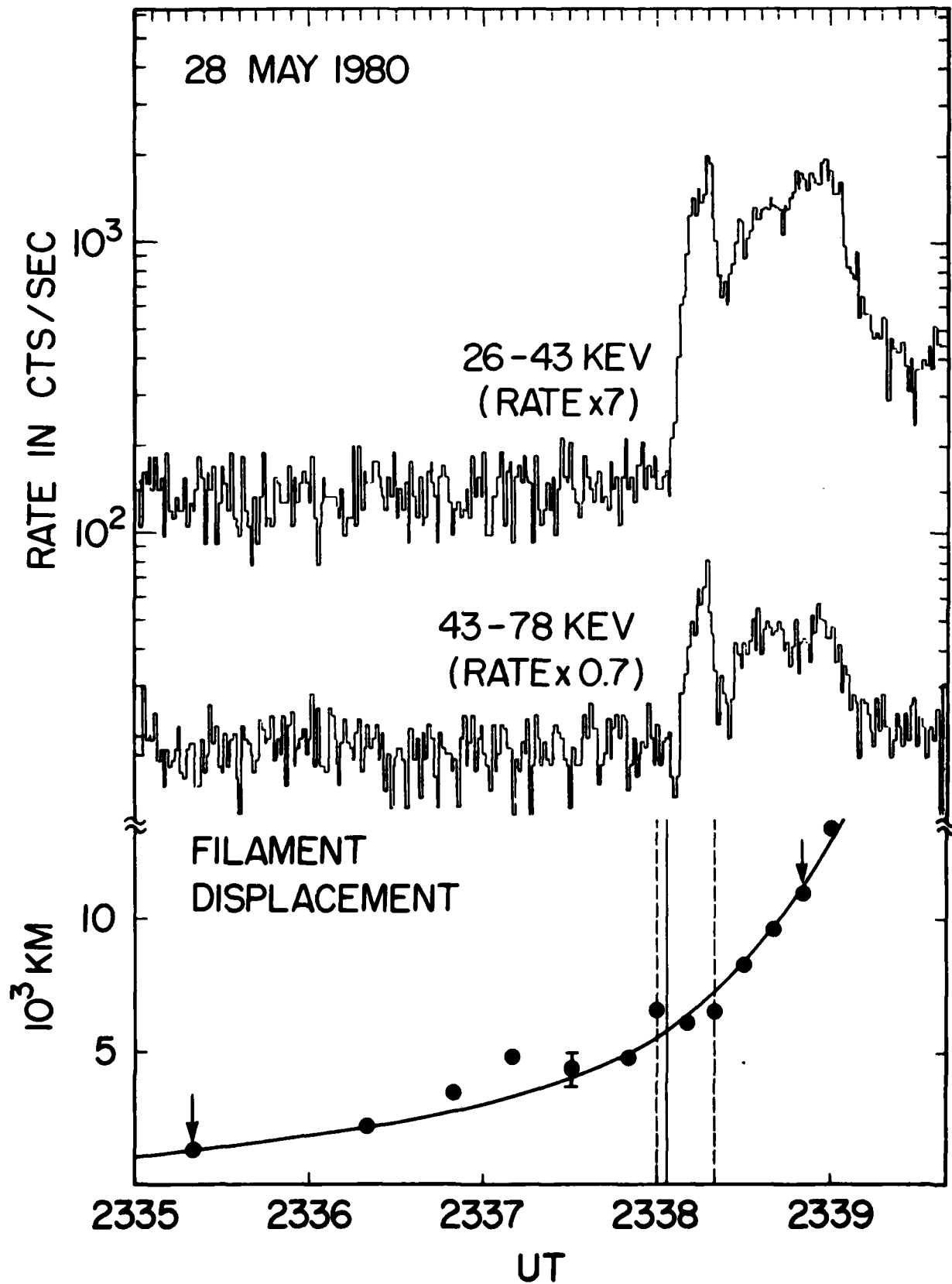
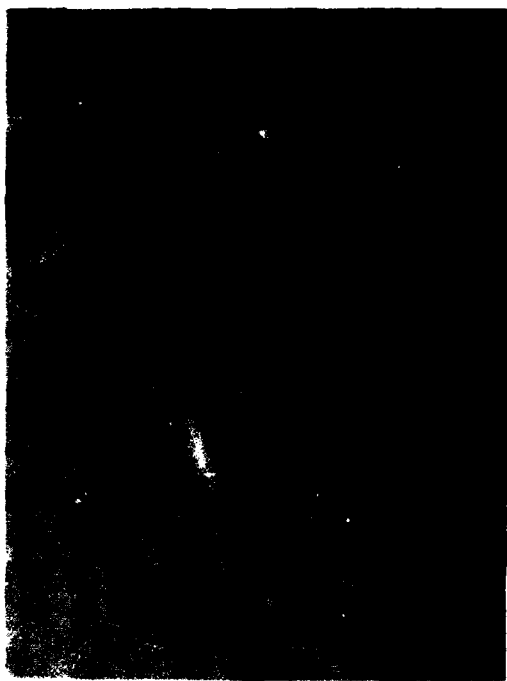


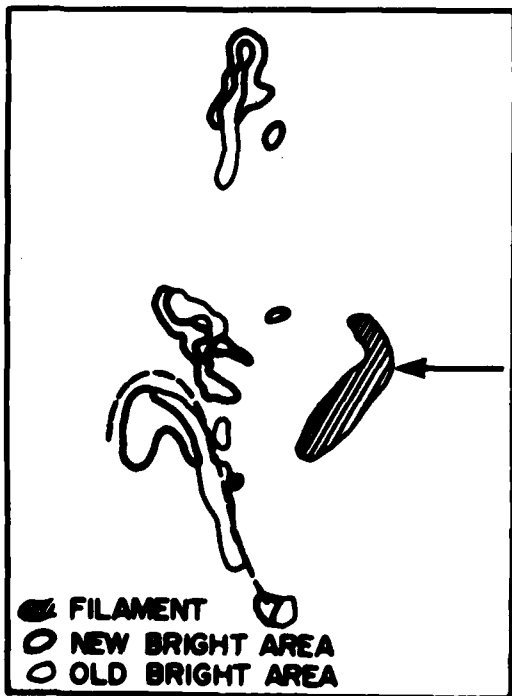
Figure 4



1549:07 UT

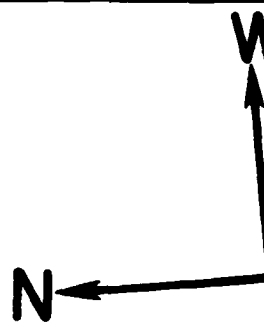


1550:37 UT



1551:12 - 1550:12
UT

4.35×10^4 km



JUNE 25, 1980
BBSO H α

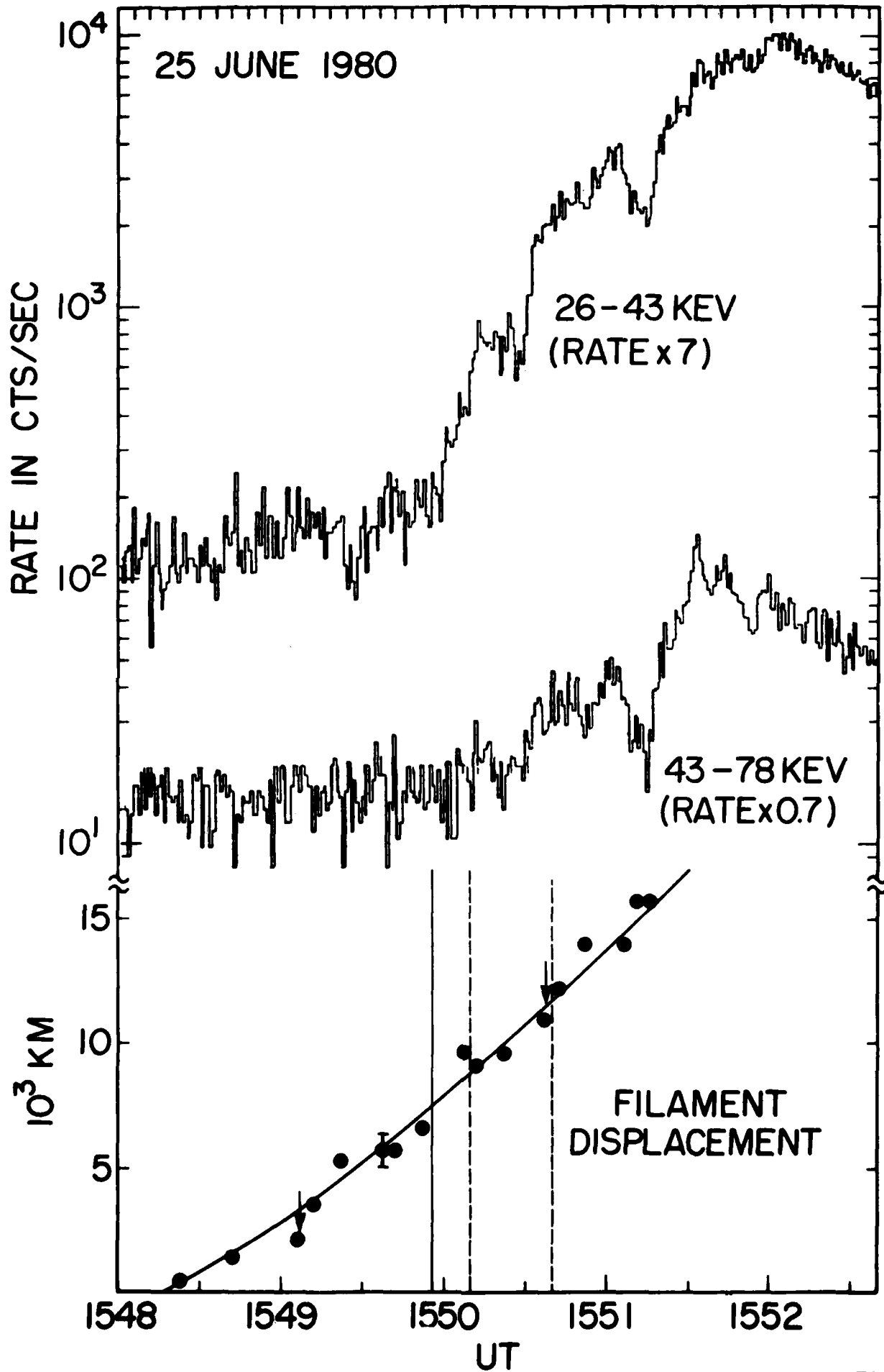
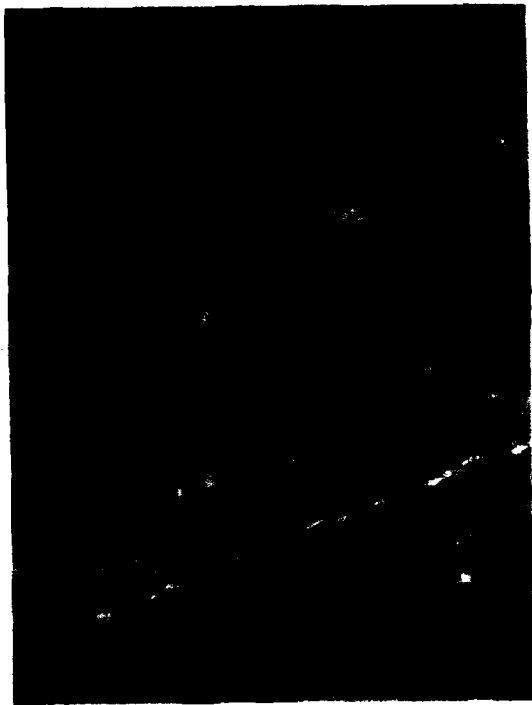


Figure 6

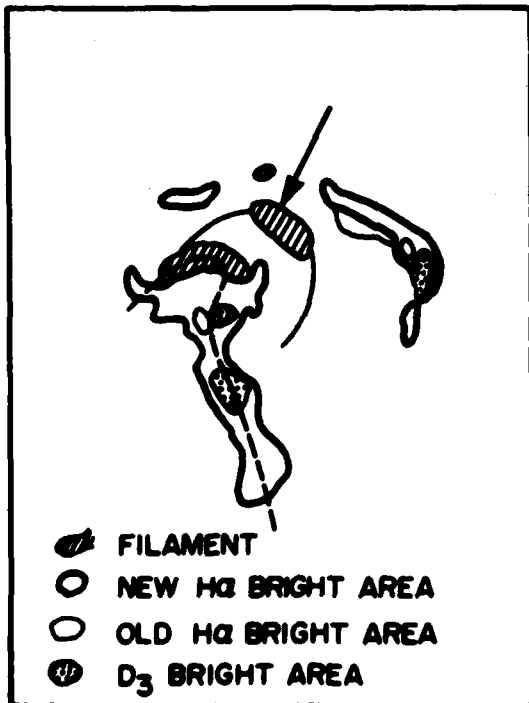
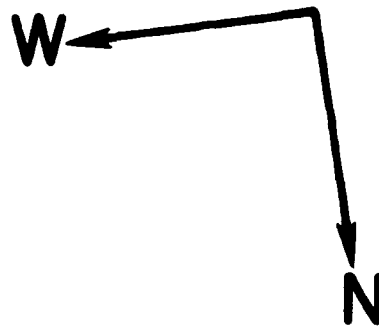


1722:57 UT



1724:27 UT

$4.35 \times 10^4 \text{ km}$



1724:27-1723:12
UT

JULY 27, 1981
BBSO H α

