THE VARIATION OF FILAMENT DIRECTION IN A FLARING REGION

R. R. RAUSARIA, K. SUNDARA RAMAN, P. S. M. ALEEM
Indian Institute of Astrophysics, Kodaikanal 624 103, India

and

JAGDEV SINGH
Indian Institute of Astrophysics, Bangalore 560 034, India

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Abstract. We have analyzed the variations in shear angle over a time interval of 30 s during a flare on June 11, 1991, using Kodaikanal Observatory spectroheliogram and photoheliogram data, and assuming Hα filaments are a proxy for the neutral lines. The changes in shear angles have been analysed at two points of the filament. The orientation of the Hα filament underwent a considerable change of $\sim$55° from June 10, 1991 to prior to the start of the flare on June 11, 1991. The photoheliogram on June 10, 1991 shows considerable twisting of the umbrae (in one common penumbra) and broke into parts before the onset of the flare on June 11, 1991. The twisting of umbrae on June 10, 1991 shows that sunspot proper motion plays an important role in bringing a non-potential character to the field lines. This in turn develops shear and kink and it is argued that changes in filament orientation over a small interval of a half minute triggers the eruption of the flare.

1. Introduction

Solar flares are explosions in magnetized plasma and a release of up to 10^{32} ergs of energy in a short interval of 10–100 s. Generally the eruption of flares is related to the occurrence of sheared magnetic field structures (Zirin and Tanaka, 1973; Švestka, 1981; Hagyard, Moore, and Emslie, 1984). It is believed that photospheric plasma motion in active regions, such as shear motion of sunspots and rotational motion, can bring in non-potentiality, and can produce shear in the magnetic field. After reaching a critical value, the shear becomes untenable and the flare results.

Flares accelerate particles up to relativistic energies and produce electromagnetic radiation in the range from the radio to γ-ray wavelengths. The important questions related to flares are: (i) cataclysmic release of the non-potential energy of the pre-flare magnetic field configuration and (ii) the acceleration of particles, especially electrons, to energies of at least a few hundred keV or MeV in a time interval of probably 1 s. The release of energy and acceleration of particles are generally attributed to magnetic field reconnection in flares (Syrovatskii, 1978; Priest and Milne, 1980; Leroy, Bommier, and Sahal-Brechot, 1983). The direct evidence of this has been difficult to obtain.

Flares usually occur around the magnetic neutral line (Krüger, 1974, p. 253). The variations in the orientation of field lines in a neutral line may indicate the presence of reconnection. Therefore, in this paper, we have studied the change in the orientation of the neutral line using Hα filaments as proxies. The analyses of

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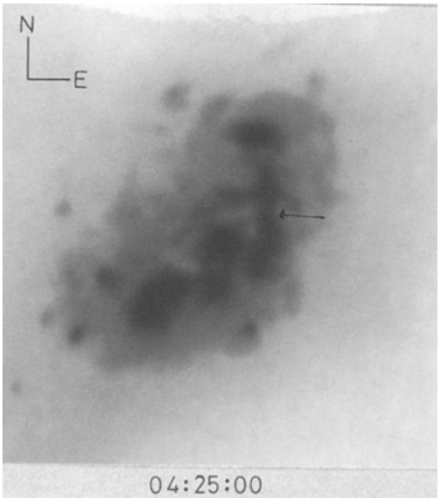


Fig. 1a. Pre-flare white-light photoheliogram on June 10, 1991 at 04:25:00 UT.

the data show a significant change (~5°) in the orientation of the filament over a half minute.

2. Observational Data

A daily, white-light photograph of the Sun of diameter 8″ is taken regularly using a 6″ refractor at Kodaikanal. Hα spectroheliograms are also recorded daily, using a Littrow mount with a solar image diameter of 60 mm. For the present analysis we obtained spectroheliograms every half minute. We had to restrict the observations over 30 s owing to instrumental limitations. The photoheliogram of the flaring region taken at Kodaikanal on June 10, 1991 at 04:25 UT is shown in Figure 1(a). Its location was N31 W07. It is a very complex δ-spot group with 5–6 umbrae in one common penumbra. The umbral positions are quite twisted, indicating the presence of shear and proper motion. The location of the region on June 11, 1991 at 02:25 UT was N31 W19 and on June 12, 1991 was N32 W31 at 03:32 UT. The photoheliograms on June 11 and 12, 1991 are shown in Figures 1(a) and 1(c). At 02:39 UT on June 11, 1991 the flare was already in progress in the region marked 'A'. This flare developed into a 4B flare at 02:52:30 UT and is the biggest flare recorded at Kodaikanal in recent years. The spectroheliograms from June 10 to 12, 1991 and the time sequence of the flare in Hα on June 11, 1991 are given in Figures 2(a) and 2(b).

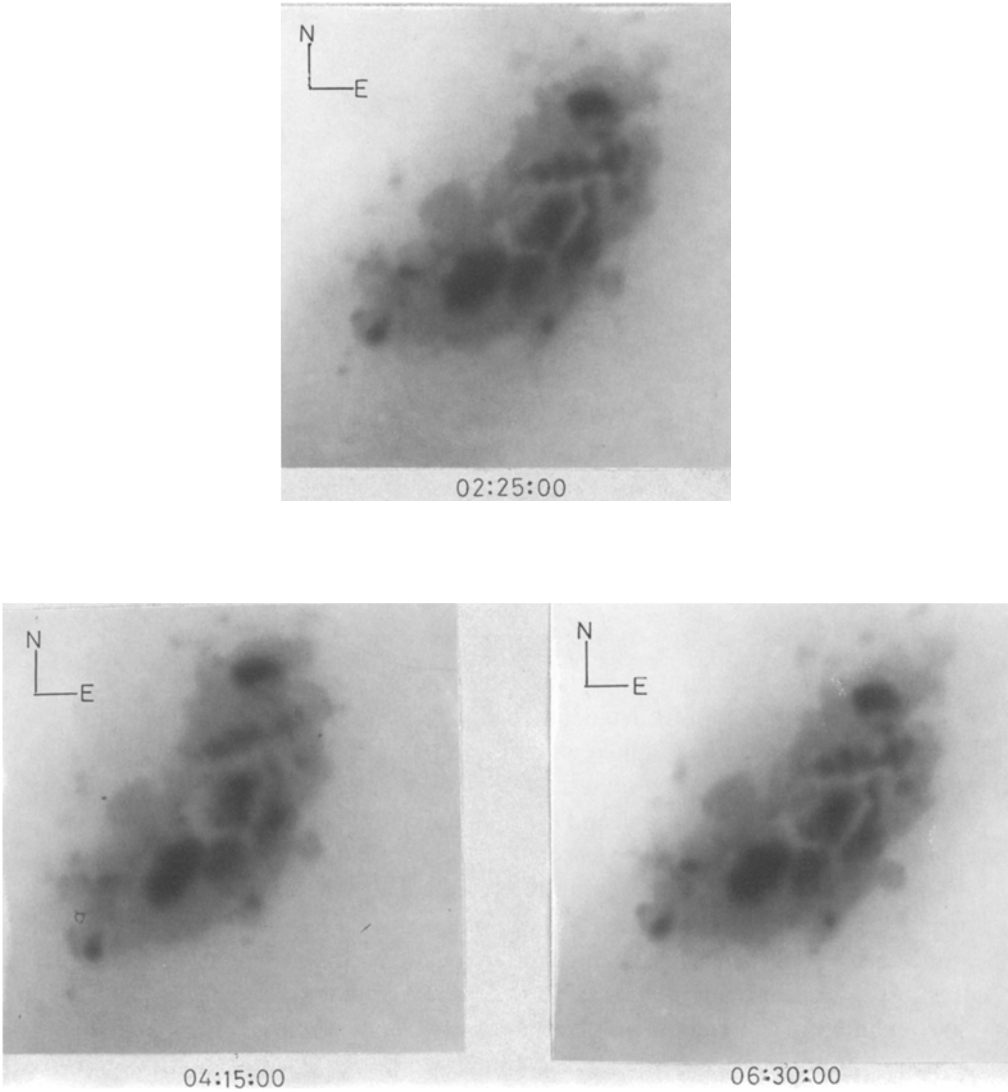


Fig. 1b. White-light photoheliograms on the flare day, June 11, 1991 at 02:25:00, 04:15:00, 06:30:00 UT.

3. Results and Discussions

Vector magnetic field measurements in the photosphere provide direct evidence for the twisted or sheared nature of magnetic loops. In the absence of such measurements, the sheared configuration may be inferred from the Hα fibrils, which align along the neutral line position dictated by the sheared magnetic loops. A

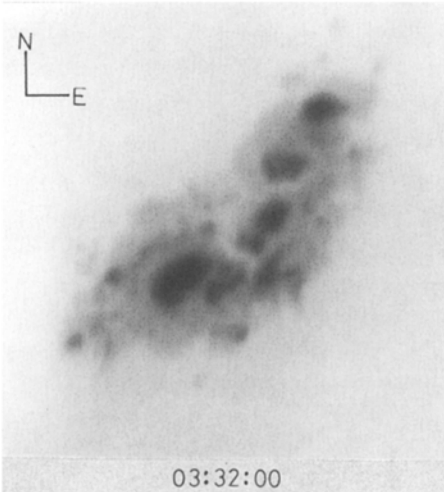


Fig. 1c. Post-flare white-light photoheliogram on June 12, 1991 at 03:32:00 UT.

quantitative measure for the magnetic shear at the photospheric level was proposed by Hagyard *et al.* (1984), from a detailed study of one active region. They defined the degree of shear as the angle in azimuth between the directions of the observed magnetic field and of the potential field.

Comparisons of Hα pictures and the magnetic field measurements of the active regions have shown that the path traced by a filament indicates the magnetic neutral line and lies along the dividing line between the regions of opposite polarity. It appears that position, structure, and orientation of a filament is controlled by magnetic field configuration. Changes in magnetic field structure due to magnetic shear may change the orientation of Hα filament. We have therefore assumed that the orientation of the Hα filament and magnetic shear are closely associated with each other, but without simultaneous data, it is hard to prove it.

Hence, we have used the argument that the value of the shear can be derived from the Hα filaments which assume the azimuth of the neutral line of the non-potential field. We have adopted the following data reduction procedure to derive the angle of shear. We enlarged the spectroheliogram image (60 mm diameter) and projected it (through an enlarger) onto the photographic print of its photoheliogram mate and aligned them for a perfect match using the (N–S) and (E–W) pole markings. We then sketched the position of the Hα filament on the photoheliogram print. To measure the shear angle, we chose the X axis as the line joining the centre of gravity of one sunspot to the centre of gravity of the other spot of the bipolar group. It has been possible to define the centre of gravity of the spots precisely in the case which we have studied. We chose the point of intersection of the neutra line (Hα filament) and the X axis as the origin of the coordinate system and the Y axis to

TABLE I

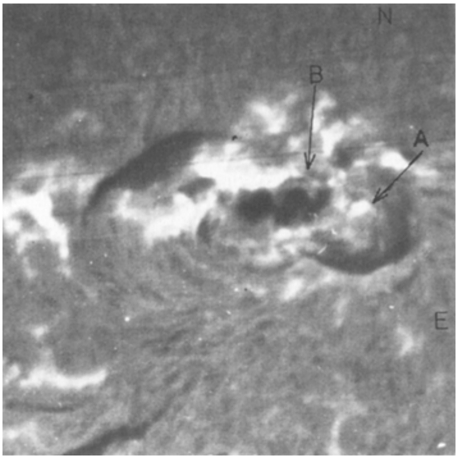
Variations of shear angle as function of time

Date	Time in UT		Spot area in millionth of solar disk	Flare area in millionth of solar disk	Region A
	SHG	PHG			Shear angle
10 June, 1991	04:27:21	04:25:00	2310	–	50
11 June, 1991	02:38:46	02:25:00	2607	3510	10 (opposite direction) Region blown up and filament position undergone considerable change and has shifted downward at the location marked 'C'; measurement in subsequent frames not possible due to blowing up of the reference point.
12 June, 1991	04:29:08	03:32:00			30

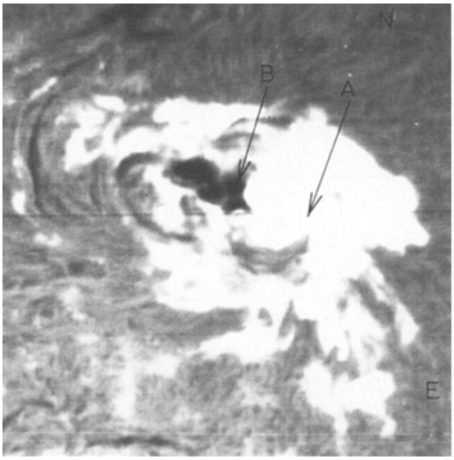
TABLE II

Variations of shear angle as function of time

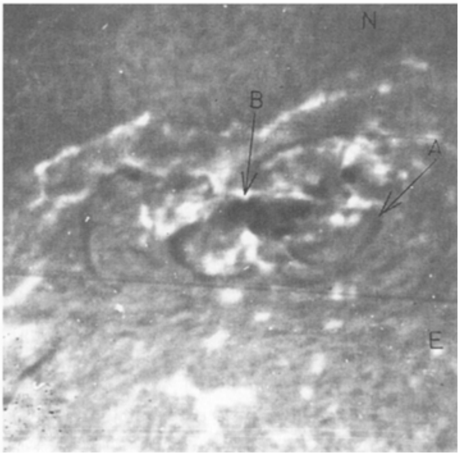
Date	Time in UT		Region B
	SHG	PHG	Shear angle
10 June, 1991	04:27:21	04:25:00	60
11 June, 1991	02:38:46	02:25:00	5 flare already in progress
	02:52:30		10
	02:53:05		20 increase in flare area
	02:53:35		25 and intensity
	02:54:14		30
	02:54:45		25 slight decrease in flare
	02:57:15		20 area and intensity
	02:57:42		15
	02:58:10		
	02:58:35		30 increase in area and
			35 intensity of flare
12 June, 1991	04:29:08	03:32:00	50



04:27:21 (10 June)



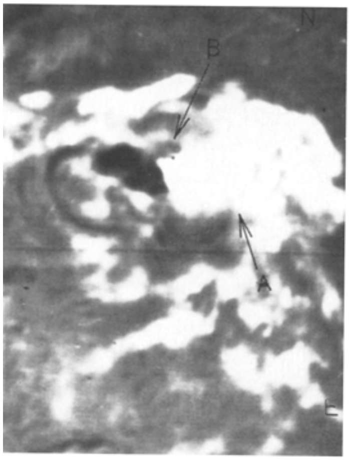
02:38:46 (11 June)



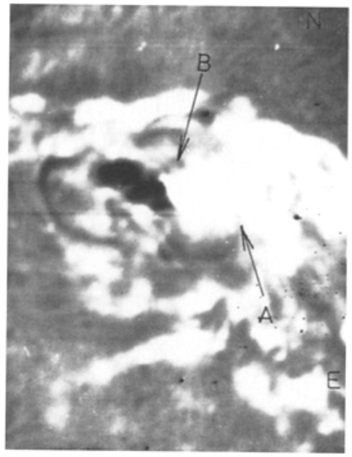
04:29:08 (12 June)

Fig. 2a. Hα spectroheliograms for June 10 to 12, 1991 showing the evolution of the filament and its subsequent eruptions as a flare on June 11, 1991. The time of observation is indicated on each frame.

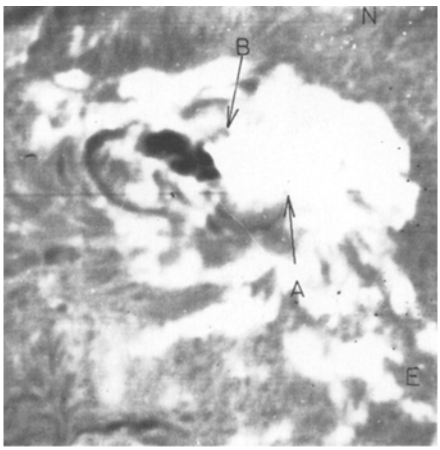
be orthogonal to the X axis. Now, the shear angle 'γ' is the angle between the Y axis and the neutral line (i.e., the Hα filament). Using this procedure we have studied the evolution of shear over a 24-hour period in an earlier paper (Sivaraman, Rausaria, and Aleem, 1992) and have shown that a change in the shear, not the large value of the shear, is the forerunner criterion for the onset of flares. However, the shear and flow velocities may change significantly over a short period before the onset of a flare. Therefore, in this paper we have carried out a detailed study of shear change with very high time resolution. The variation of the shear angle 'γ' in the regions marked 'A' and 'B' are given in Tables I and II, respectively, on various days and times.



02:52:30 (i)



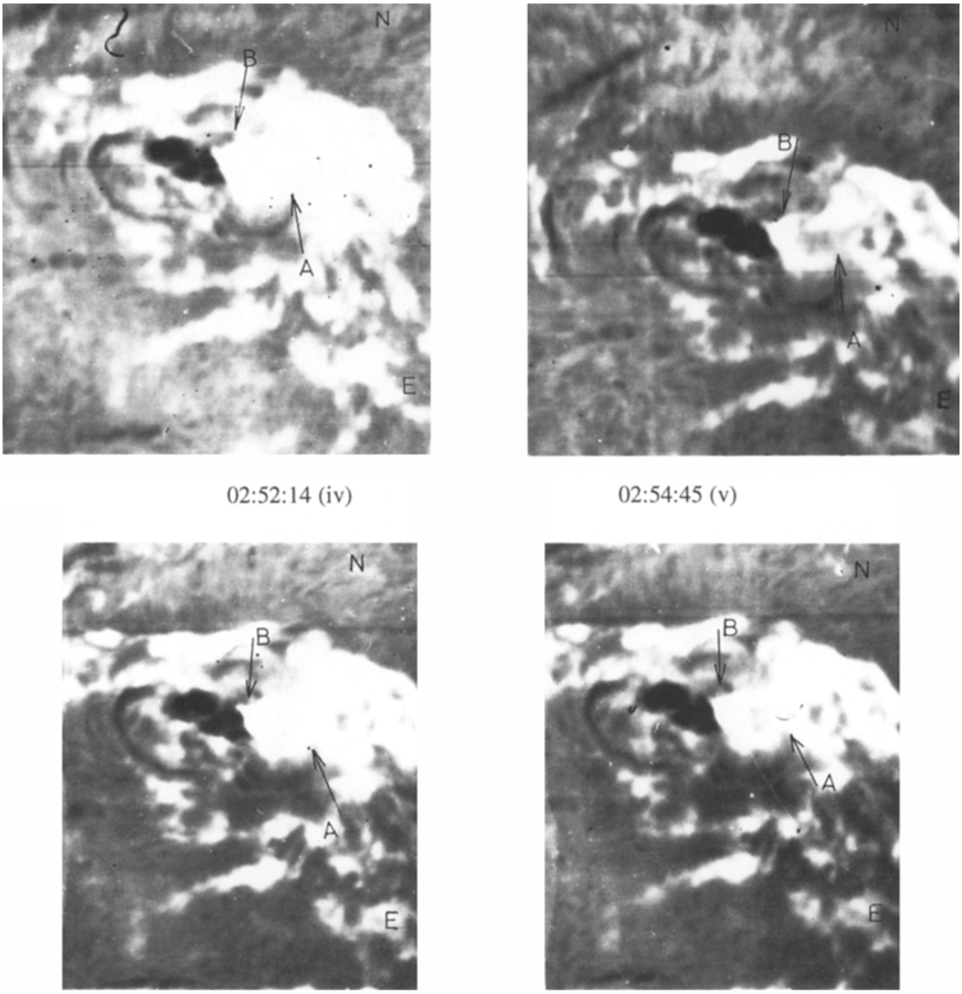
02:53:05 (ii)



02:53:35 (iii)

Fig. 2b. The time sequence Hα spectroheliograms on the flare day June 11, 1991.

The shear angle 'γ' for both the regions 'A' and 'B' have very large variations from June 10 to 11, 1991. On June 11, 1991, when the flare is already in progress, the filament orientation of the region 'B' shows considerable change at a half-minute interval. The region 'A' is blown up and the reference point lost due to film saturation. As a result, a measurement of the shear angle is not possible. On June 12, 1991 the filament orientations of both regions have returned to almost the normal position of June 10, 1991. Based on the analysis of the variation of shear angle 'γ' on different days and times for this region, the following conclusion may be drawn. "The umbral positions on June 10, 1991 look to be quite twisted, the region

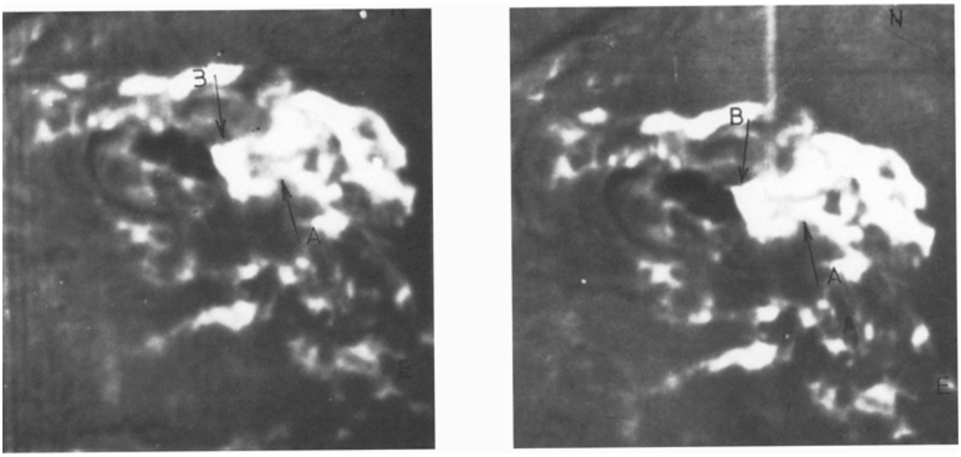


02:52:14 (iv) 02:54:45 (v)

02:57:15 (vi) 02:57:42 (vii)

Fig. 2b (continued).

indicated by the arrow mark on Figure 1(a) and broke into parts on June 11, 1991. The changes in the structure of the umbrae are quite clearly visible in Figure 1 of June 10 to 12, 1991. This results in an increase of shear angle of both the regions ‘A’ and ‘B’. The shear undergoes almost a 60° change from June 10 to 11, 1991, which introduces a non-potential character in the field lines and after reaching a critical value this becomes untenable and results in the flare onset. Thus, we feel that the observations presented in this paper are representative of the onset of a flare due to variations in the filament orientation at high time resolution, and after the flare is over, the field lines regain their original position.”



02:58:10 (viii) 02:58:35 (ix)

Fig. 2b (continued).

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