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Analysis of solar flare in CaII K on 1989 March 13

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Abstract. We report here the CaII K observations of a major umbral solar flare of optical class 3B which occurred on 1989 March 13. Correlated optical, microwave, soft X-ray (SXR), sudden ionospheric disturbance (SID) observations and the resulting proton enhancements have also been analysed. The values of magnetic field perpendicular to electron velocity $H_{\perp}$ electron energy E and angular size ϕ of great microwave burst (GB) source are estimated as 897 gauss, 1.4 MeV and 7 arcsec respectively. Due to the production of long duration hard X-ray burst (HXRB) and GB, we conclude that the observed flare is very energetic.

Key words : umbral flare—curvature of ribbons—flash phase—explosive phase

1. Introduction

During the ascending phase of the 22nd cycle of solar activity, the most active sunspot group in active region NOAA 5395 appeared at a high latitude in the northern hemisphere. The active region was extraordinary for both its flare production during its complete disk transit and also for generating one of the largest geomagnetic storms on record. When the active region crossed the sun's meridian, the emission from the series of flares resulted in additional dramatic terrestrial effects. On March 13, 1989 a geomagnetic storm, which disrupted radio communications and triggered power surges, left people in Quebec without power for over ten hours. Geomagnetic storms also resulted in brilliant giant auroral displays on nights of March 12/13 and 13/14, 1989 (Sky and Telescope 1989, Astronomy 1989).

We have observed this giant active region during its complete disk tranist, and we were able to observe one major flare on 1989 March 13 in CaII K. Electromagnetic radiations in a very broad wavelength range were emitted by this flare from different heights above the solar photosphere and thus from different parts of the flare. Our observations show chromospheric activity, the low temperature part of the flare (Svestka 1976).

2. Observations and analysis

The observations comprised on time lapse photographs (at about 1 minute time intervals) recorded on Kodak Technical Pan 2415 film, using an Olympus camera body which is placed at the focal plane of a f/15 coudè refractor of 15 cm. While monitoring the sun through the CaII K filter with full width at half maximum 1.2 Å, we noticed a flare at the heliographic location N31 W04 around 025949 UT. The maximum phase of the flare occurred approximately at 032341 UT and a noticeable decay started at around 043006 UT. The flare associated radiations in Hα, microwave, SXR and SID events are given in table 1 for comparison along with our observational results in CaII K. Above data were taken from the Solar Geophysical Data (SGD), 1989. Correlation study of all umbral flares of class B, GBs and HXRBs for the period 1980 to 1985 (*cf.* table 2) shows that the observed flare could also have produced HXRB. This is confirmed by recently published HXRB data of Dennis *et al.* (1991). Data of umbral flares of class B, GBs and HXRBs for correlation study of the aforesaid period were taken from SGD (1980-1986) and Dennis *et al.* (1985).

Table 1. Observations in different wavelengths along with our observations in CaII K

Flare related phenomena	Start (UT)	Max (UT)	End (UT)	Importance
CaII K flare	025949 E	032341	043006 D	–
Hα flare	0257 E	0321	0419	3B
Microwave Burst	0259 E	0317	0332 D	GB
SXR	0259 E	0320	0417 D	X 1.2
SID	0250 E	0328	0447 D	SPA 3+

E means event began before the time listed and D means event lasted longer than indicatd time.

Table 2. Correlated B class umbral flares, GBs and HXRBs

Flare class	Total no. of flares	GBs Total (%)	HXRBs with GBs Total (%)
SB	32	3 (9)	1 (33)
1B	77	13 (16)	6 (46)
2B	53	21 (39)	12 (57)
3B	17	11 (64)	7 (64)

The flare occurred in the south-east side of the sunspot group is of delta type magnetic configuration (*cf.* figure 1). Umbrae, penumbrae and ribbons of flare are shown by filled, crossed and blank areas respectively. Solid line drawings between the ribbons, marked as c_1, c_2 and c_3, show curvatures of the ribbons. The sunspot group shows umbrae of north (N) and south (S) polarities (Solar Data in Russian 1989) in a common penumbra, which signifies that the active region under reference possesses a mixed polarity. Footpoints of ribbon nos. 1 and 2 are anchored in major south and north polarity umbrae respectively. On this basis it seems that these ribbons have S and N polarity respectively. Ribbon no. 3 is relatively far away and manifests a strong interaction with ribbon no. 1. This interaction implies S polarity for ribbon no. 3, which may also be inferred from magnetogram of this region (SGD 1989).

For the study of evolution of the flare from our observations, we have selected eight filtergrams in CaII K shown in figures 2a to 2h. All these filtergrams show considerable changes in shape and brightening with time. Figure 2a shows the pre-flare stage (44^m16^s before the flare start) in which the relevant sunspot group is surrounded by bright plages. At 030005 UT (see figure 2b) flare started brightening existing plages in the south-east

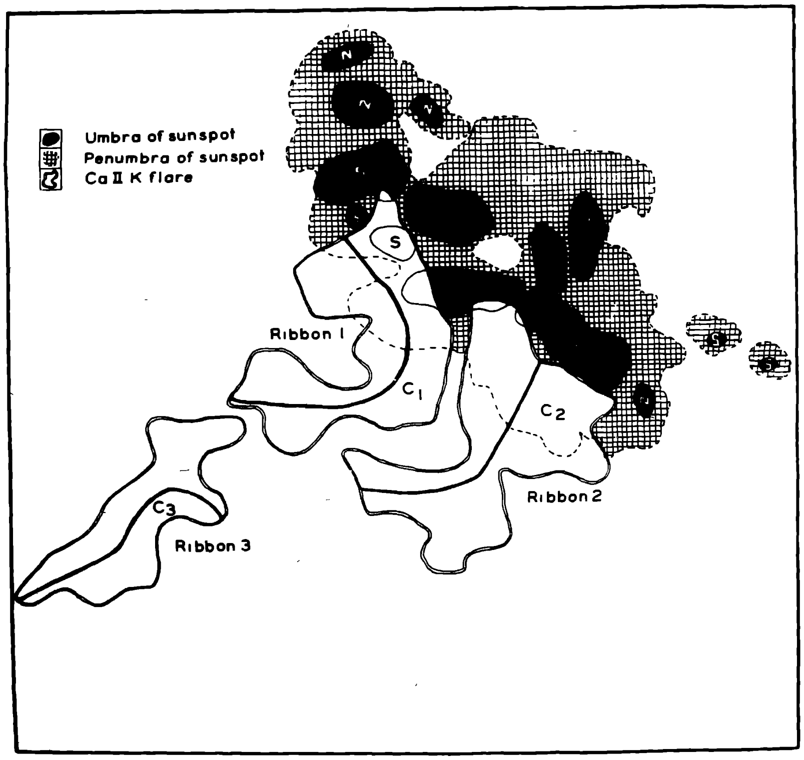

Figure 1. Composite diagram of white light photograph and CaII K filtergram at the maximum phase of the flare.

side of the sunspot group, in other words, at this time we have noticed the flare in the form of several bright-knots/footpoints. These bright-knots appear to make loop like structures (ribbon nos. 1, 2 and 3) in helical shape at three places at 031250 UT (*cf.* figure 2c). These ribbons seem to evolve appreciably from stage in figure 2b to stage in figure 2c, and maximum increase in brightness and area of ribbons occurred at 032341 UT (*cf.* figure 2d). From about 032433 UT (*cf.* figure 2e) the decay phase of the flare ribbons began. For studying the evolution of the flare, we have also compared line drawings of CaII K and Hα photographs of pre-maximum and post-decay of the flare (*cf.* figure 3). Figures 3a and 3b show the brightening in the footpoints (cross-hatched areas) of the flare and it seems that these bright footpoints produce loop like structure in the three places at the pre-maximum in CaII K and Hα. Similarly comparing figures 3c and 3d after the decay of the flare, similar plage structures have been noticed both in CaII K and Hα.

From the filtergrams it is obvious that increase is intensity and area of the three flare ribbons occurred slowly in the beginning but at the maximum phase we noticed maximum increase in intensity and area. This incidence supports the occurrence of the flash-phase and explosive-phase simultaneously. To confirm this incidence quantitatively, we determined intensities with the help of microdensitometer and areas of three main ribbons. The results are shown in figure 4 which clearly confirms simultaneous occurrence of flash and explosive phases.

Zirin & Tanaka (1973) observed untwisting change of magnetic field during post maximum phase of a flare. Field configurations were inferred from flare loops. Further,

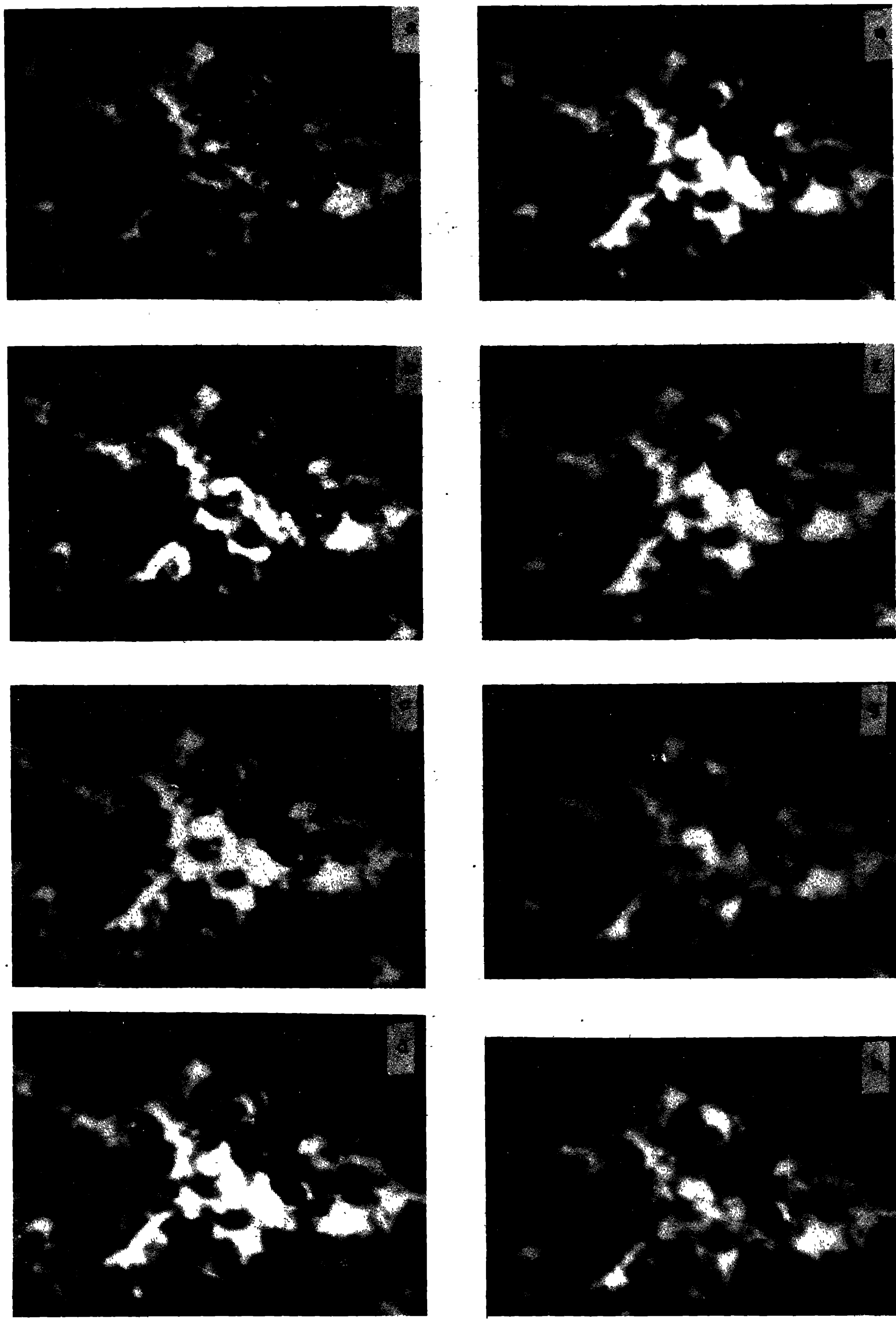

Figure 2a to 2h. Selected filtergrams in CaII K show the evolution of the flare of 1989 March 13.

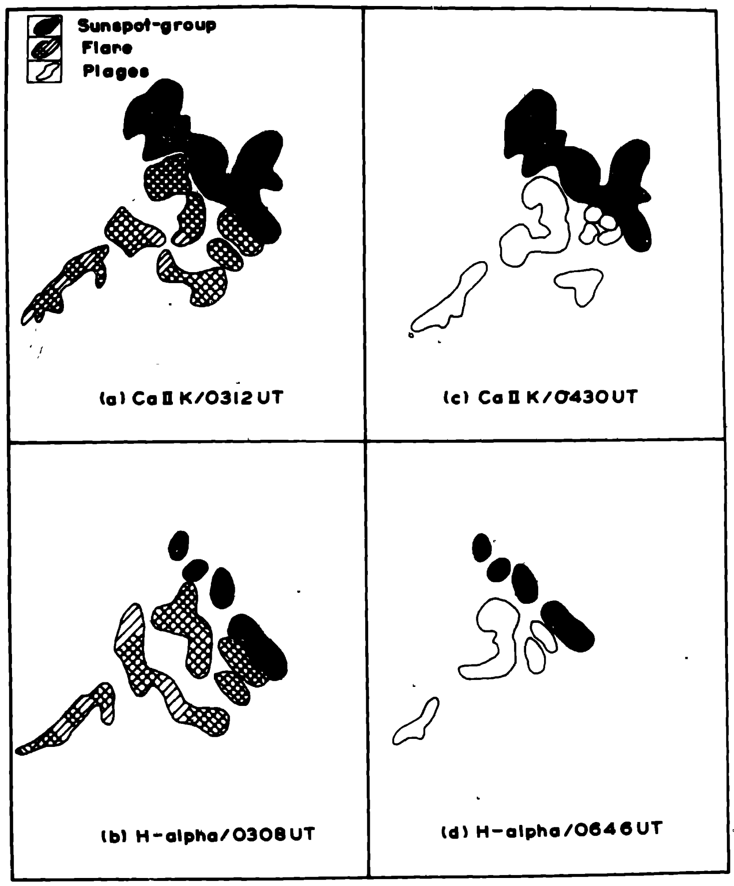

Figure 3. Line drawings of the flare obtained from CaII K and Hα photographs, respectively at the pre-maximum (a and b) and past-decay (c and d) of the flare.

untwisting changes of flare loops are accompanied by increasing separation between the footpoints. Our observations show that curves of different curvatures can be fitted into three observed ribbons and their radii of curvature change during the course of flare evolution. In figure 5, changes in curvatures of the ribbon nos. 1, 2 and 3 are plotted. As per our measurements the flare ribbon nos. 1 and 2 separated from each other with velocity of about 27 km s^{-1} at the maximum phase. For this velocity measurement figures 2c and 2d were used. The velocity could have been measured more accurately if one had photographs with higher temporal resolution.

3. Results and discussions

The observed flare is an umbral-flare (*cf.* figure 1) of 3B importance in Hα. Generally flares avoid to cover magnetic hills, that is, the sunspot umbrae. Only very energetic flares have a tendency to cover magnetic hills during their evolution. Our observations clearly show that ribbon nos. 1 and 2 cover the umbrae during flare evolution (*cf.* figures 2b, 2d and 2g). Ribbon no. 3 stays away from the umbra. The maximum coverage by ribbon nos. 1 and 2 corresponds to the maximum phase. From the observed filtergrams in CaII K we measured emission movement above sunspot umbrae of these ribbons. The

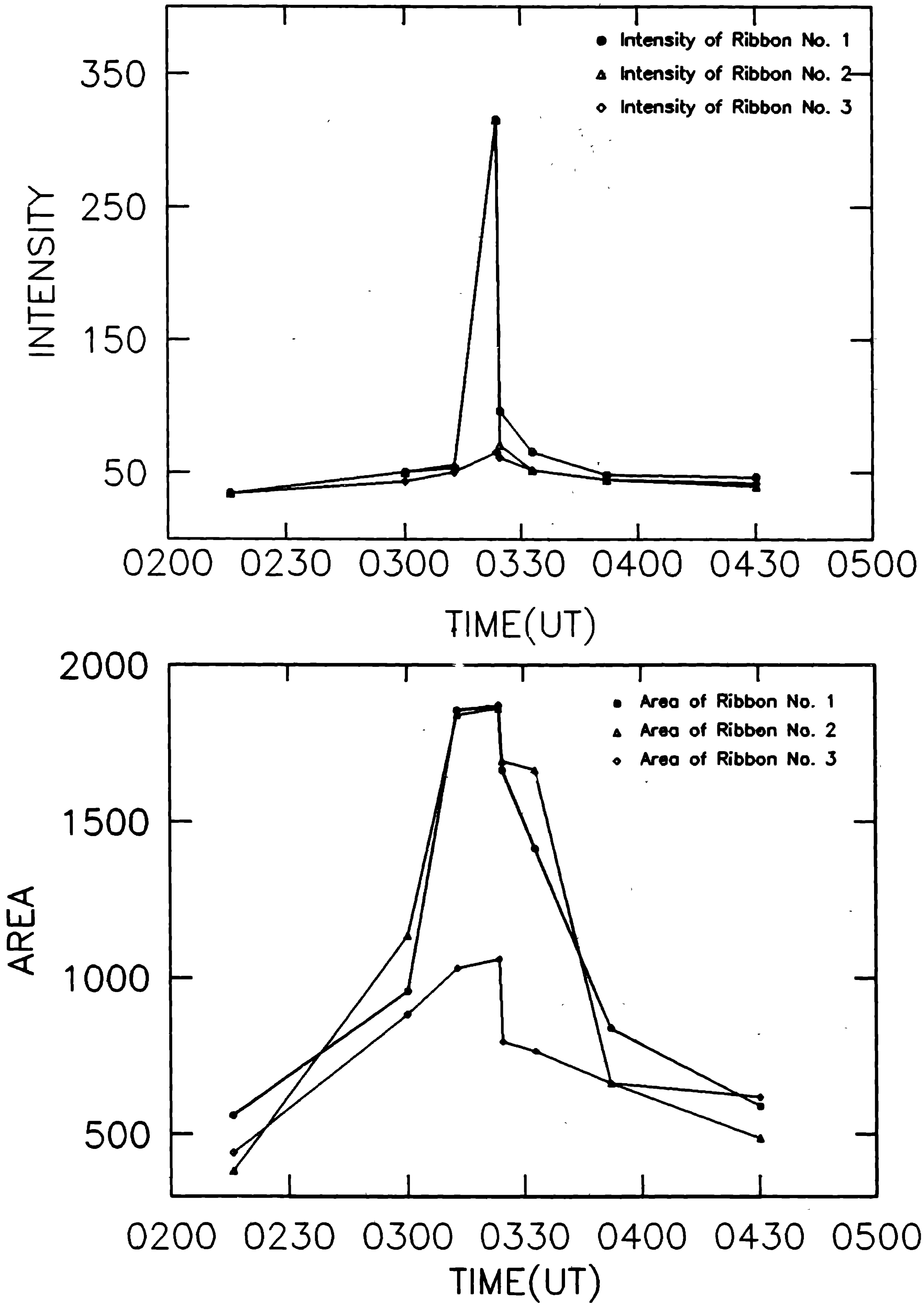

Figure 4. Temporal behaviours of CaII K three flare ribbons in (a) intensity (arbitrary units) and in (b) area (millionths of visible disk).

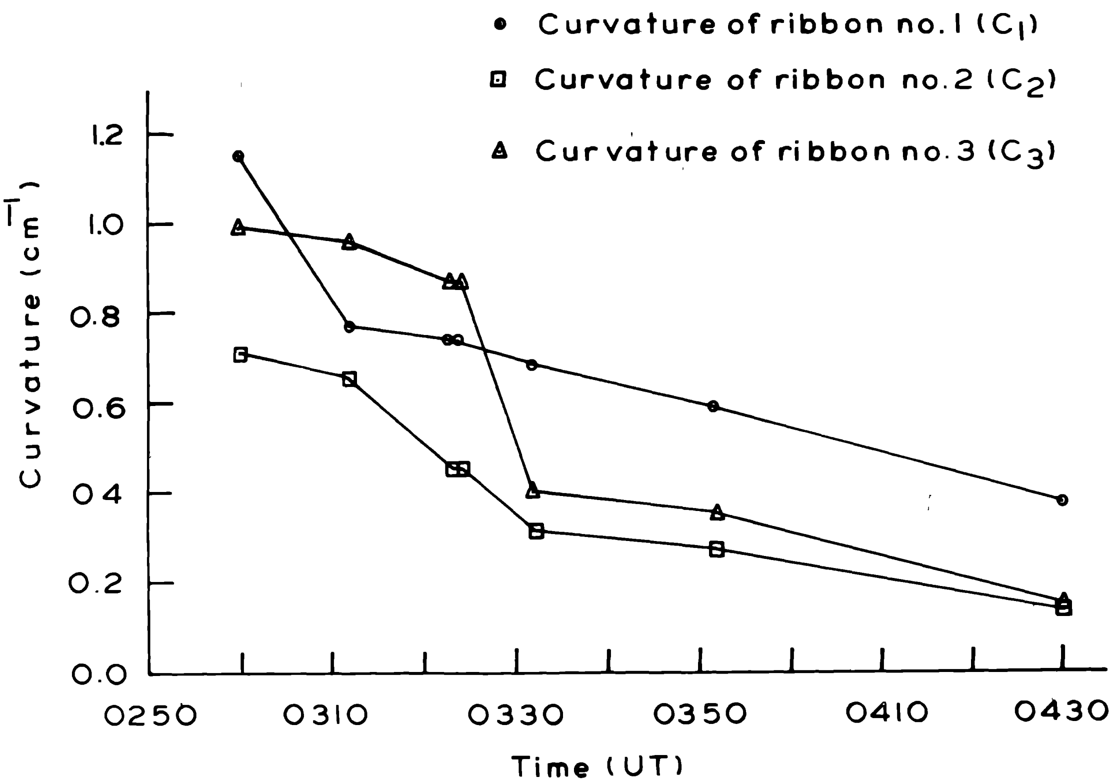

Figure 5. Plots of curvature vs time for three flare ribbons

average velocity of umbrae coverage by these ribbons is about 4.2 km s^{-1}. The average velocity with which the ribbons are moving away from the sunspot umbrae during decay phase is measured as about 1.3 km s^{-1}. Similar measurements of umbrae coverage velocity of flare of 1982 September 9 by Khusainov (1989) was reported to be 2.4 km s^{-1}.

When flare occurs over a spot some new signatures appear as the flare plasma becomes the generator of radio microwave radiation and X-rays (Dodson-Prince & Hedeman 1960; Ellison *et al.*, 1961; Martres & Pick 1962). These observations tell us about the hot high energy part of the flares. During the time of our observations, microwave burst of importance GB and SXR flare of importance X1.2 were recorded. These observations along with ours are given in table 1. As is obvious from table 1, the maximum phase of the observed flare shows a reasonable agreement with the maximum phase of the associated Hα, GB, SXR and resulting SID event. The GB having the maximum flux density at 8800 MHz occurred prior to the maximum phase of the CaII K flare. Following the procedure by Degaonkar *et al.* (1981), we found the value for magnetic field perpendicular to electron velocity $H_{\perp} \sim 897$ gauss, electron energy $E \sim 1.4$ MeV and angular size $\phi \sim 7$ arcsec for the GB source. Takakura (1967) showed that the mechanism for the centimetric radiation of solar burst is considered to be gyrosynchrotron radiation from non-relativistic or barely relativistic electrons in strong magnetic field ($\sim$ 1000 gauss). Ionospheric disturbances of 02 hours 37 minutes duration occurred during the flare which disrupted radio communications. SIDs also give good information on the SXR flux emitted during solar flares (Svestka 1976). SXR observations (*cf.* figure 6) in wavelength regions 1-8 Å and 0.5-4 Å show maximum flux

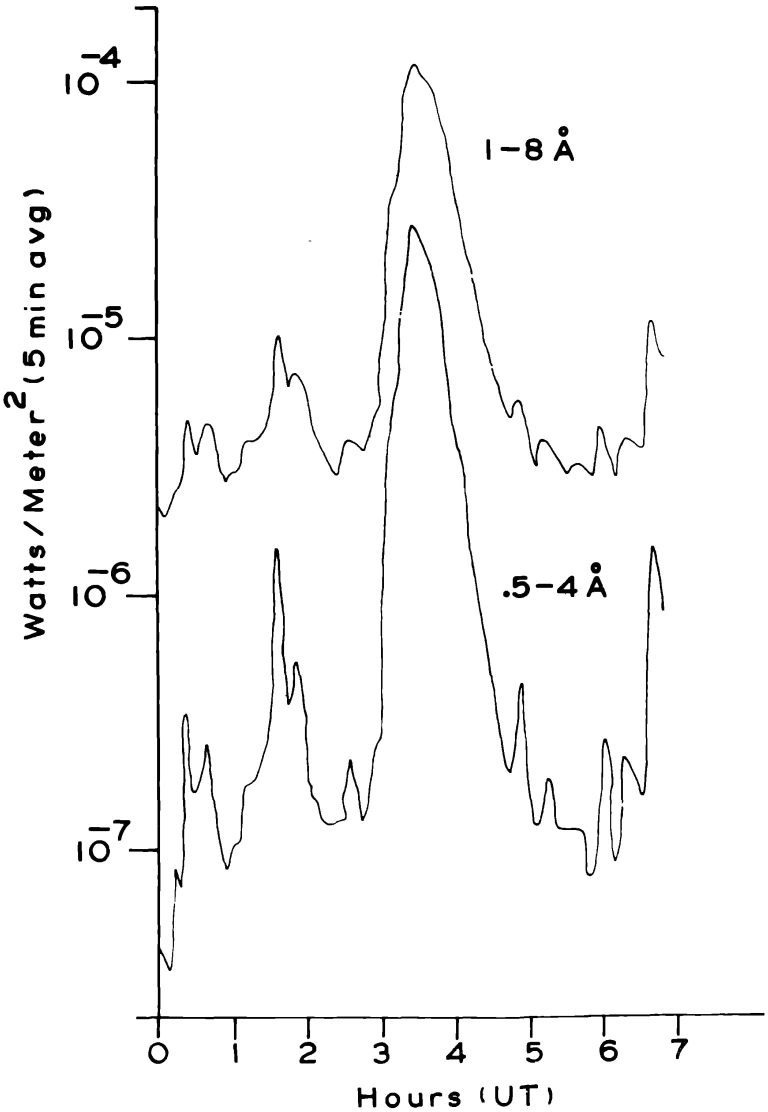

Figure 6. GOES-7, 1-8 Å and 0.5-4 Å, time profiles of solar X-ray flux.

at the time of flare maxima. Proton flux in the energy range of 4.2-8.7 MeV ejected during the flare observed by GOES-7 satellite is shown in figure 7. The figure shows that the enhancement in proton flux starts at about 032100 UT. Flux value at 062000 UT shows a maximum of 10^3 counts $cm^{-2}s^{-1}sr^{-1}MeV^{-1}$ which is the measuring limit of the detector seen from the reported data. Table 2 shows that the correlation between umbral flares of class B and GBs increases with importance class *i.e.* 3B class flares have more chance of producing GBs, the same is true for HXRBs. Thus umbral flares of class 3B may also produce GBs and HXRBs. Dennis *et al.* (1991) reported long duration (3514 sec) HXRB which is associated with our observed flare. The HXRB started at 030337 UT about six minutes after the onset of optical flare and reached at its maximum at 031651 UT.

The observed CaII K filtergrams of the flare show simultaneous occurrence of the flash-phase and the explosive-phase (*cf.* figure 4) which is a rare phenomenon in the flare

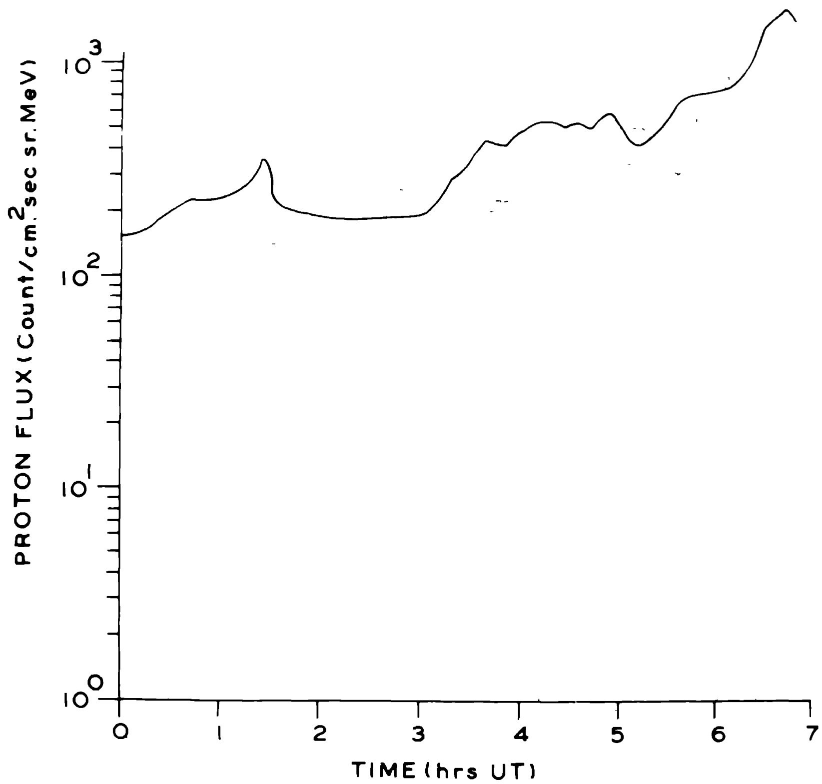

Figure 7. GOES-7, 4.2-8.7 MeV protron fluxes.

morphology. Unfortunately, we do not have full sequence of Hα observations of this event. Therefore, we are unable to see whether flash and explosive phases for this flare also coincide in the case of Hα. This is important as physics of line excitation is different for CaII K line from that for Hα. But through private communications (Sakurai & Singh 1992) we are able to find two Hα photographs corresponding to pre-maximum and post-decay of the flare. These photographs show that the observed flare could also have produced similar evolution in Hα. The CaII K filtergrams show a very rapid increase in brightness of all the ribbons and significant increase in the area of ribbons during the maximum phase. In other words they show maximum brightness of most intense parts (ribbon nos. 1 and 2) of the flare and maximum increase in flare area (total area of ribbon nos. 1, 2 and 3) at the maximum phase. An interesting feature that we have observed is a perceptible helical structure in the flare ribbons. The possible cause for the helical structure may be upward transfer of large amount of helical twist in ribbons probably due to the rotation of footpoints of the ribbons (Piddington 1979). The helical structure reveals itself more conspicuously at the maximum phase of the flare (*cf.* figure 2d). For the production of major flares a large amount of energy $\sim 10^{33}$ ergs is required. This energy is stored in highly sheared magnetic field and released during the evolution of flare (Hagyard *et al.* 1982; Krall *et al.* 1982). Zirin & Tanaka (1973) also reported the existence of great shear in the magnetic field of the active region that produced the big 1972 August flare. The shear was large at the beginning of the flare and relaxed during the flare development. Like these relaxation characteristics we find that the curvature of the flare ribbons decreases with the time (*cf.* figure 5).

4. Conclusions

The great umbral-flare of 13 March 1989 was recorded in CaII K for about 02 hours 14 minutes 17 seconds covering pre-flare phase, pre-maximum phase, maximum phase and decay phase. The occurrence of long duration HXRB and GB suggests the most energetic nature of the flare. Evolutionary trend of the flare could also be similar in Hα. The important finding of this work is the simultaneous occurrence of the flash-phase and explosive-phase at the maximum phase (032341 UT). The active region 5395 began as a magnetically sheared complex region which relaxed with time. The relaxation in the complexity of magnetic field and decrease in the curvature of flare ribbons show similar behaviour, though connection between them and physical significance of ribbon curvature relaxation are presently not clear to us.

Zirin & Liggett (1987) have given a list of circumstances leading to a great flare event in Hα. The circumstances for great flare event in Hα are as follows :

1. δ Spots.
2. Umbrae obscured by Hα emission.
3. Bright Hα emission, which marks flux emergence and reconnection.
4. New flux erupting on the leading side of the penumbra of dominant p spot.
5. A filament crossing δ spots.
6. All these effects are associated with greatly sheared magnetic configurations.

Hα filtergrams and magnetograms of this active region given in SGD, 1989 and our observations in CaII K and white light seem to satisfy aforesaid circumstances except point no. 5.

In our reckoning simultaneous occurrence of flash and explosive phases, relaxation in the flare ribbons curvatures and circumstances for a great flare event in CaII K were carried out for the first time. The observations in CaII K line of this flare are not sufficient to locate the exact maximum and development of each bright-knot of the flare as white light photographs and CN filtergrams are also interspersed in between. Multispectral simultaneous observations of such flares would greatly facilitate our understanding of flare mechanisms.

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