ON THE LOCALIZATION, SIZE AND STRUCTURE OF THE REGIONS OF THE X-RAY FLARES ON THE SUN

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Abstract. With the use of X-ray heliographs carried by the satellites 'Cosmos-166' and 'Cosmos-230' the height of an X-ray flare was found to be about 20–25 000 km. The regions of the X-ray flares possess a filamentary structure which, during the development of the flares, shows spatial changings with speeds up to 10^7 cm/sec.

1. Introduction

In recent years an essential advance in the study of solar X-ray flares has been achieved (De Jager, 1965; Culhane *et al.*, 1968; Neupert *et al.*, 1967; Meekins *et al.*, 1968). The flux and the spectral composition of radiation were measured. For the interpretation of the mechanism of the flare generation it is essential to know where in the solar atmosphere the X-ray flares arise, and the sizes and structures of the flare regions.

The first set of X-ray photographs of the sun during an X-ray flare was obtained on October 1, 1965, during the flight of a geophysical rocket (Žitnik *et al.*, 1967). The angular size of the flare was found to be about 1 arc min, but the spatial resolution was insufficient to reveal the structure of this region. Recently a set of X-ray photographs of a flare was obtained with a resolution of 2 arc sec at the centre of the field of view (Vaiana *et al.*, 1968). These photographs show an *S*-like structure, a few arc minutes long and about 20 arc sec broad and two filaments 2 arc sec in diameter at a separation of 5 arc sec.

2. Satellite X-Ray Heliograph

The observation of X-ray flares by means of rocket-borne instruments requires a synchronization of the launching with the flare. Evidently it cannot provide systematic data on the localization and the development of flares. We have used the satellites 'Cosmos-166' and 'Cosmos-230' for monitoring X-ray active regions and flares in the periods June 16 to September 11, 1967, and July 5 to November 1, 1968. Both satellites carried X-ray heliographs, giving two orthogonal one-dimensional scans of the sun (Vasiljev *et al.*, 1968). The X-ray heliograph consists of two orthogonal Soller type collimators with photon counters, placed behind the collimators. The projections of the collimators form a cross on the Sun. The satellite axis was pointed to the Sun and automatically performed three scans during each revolution or independently at ground command. The photon-counters pulses rate meter output was stored in the memory-system and then telemetered to the ground stations and independently transmitted by real-time telemetry.

The 'Cosmos-166' carried two heliographs – for the spectral bands, 2–8 Å and 8–14 Å, with an angular resolution approximately 3′ on both axes. The 'Cosmos-230' carried also two heliographs: the first was for the 2–8 Å band with an angular resolution of 20″ at the X-axis and 2′ at the Y-axis, the second heliograph had at the X-axis, for the 2–8 Å band, a 20″ resolution, and at the Y-axis, for the 8–14 Å band, a resolution of 15″. The reduction of the data is not finished yet and in this paper we summarize the preliminary results.

3. Limb Observations

The observation of a limb occultation of a flare permitted us to measure its altitude (Žitnik, 1969). For this measurement we used the active region M8836 which was the centre of regular optical flares until its disappearance behind the limb on June 16. The last optical flare was recorded at 08^h07^m. The active region was on the limb at 02^h and was invisible at 13^h40^m. It was observed, however, at least at 20^h21^m by its radio emission at 9.1 cm. In Figure 1 the variation is shown of the X-ray fluxes

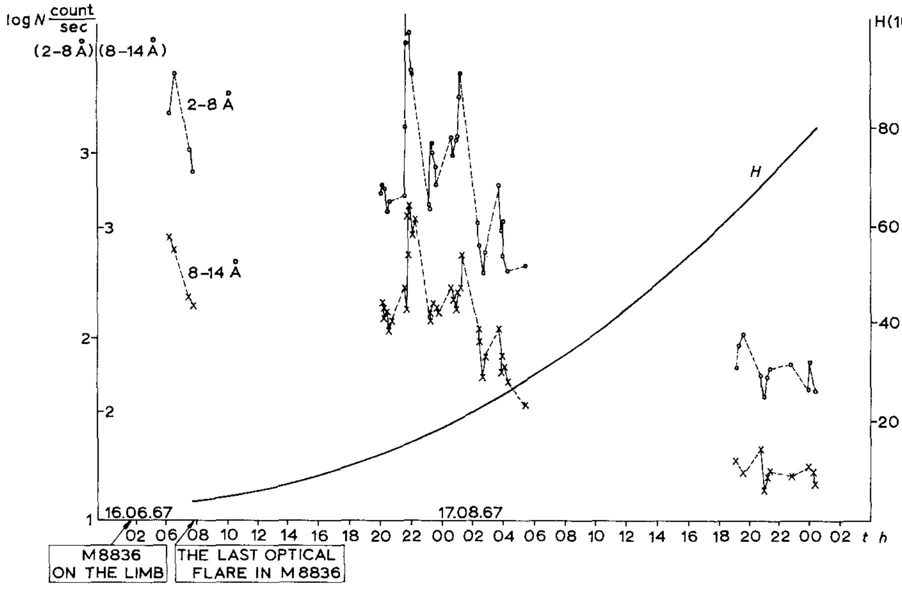

Fig. 1. X-ray flux from the western limb on June 16–18, 1967, during the disappearance of the active region M8836.

in the 2–8 Å and 8–14 Å bands from the vicinity of the western edge of the limb. We can assume that the X-ray flares observed during June 16 and 17 are connected with the region M8836 which was behind the limb. The last X-ray flare was recorded at 04^h00^m on June 17.

The solid curve in the figure represents the height H of the point above the active region M8836 that was screened by the limb at the time t. It can be seen that the last

X-ray flare at 04^h on June 17 corresponds to $H \approx 20\,000$–$25\,000$ km. The steady decrease of the X-ray flux of successive flares, allows us to assume that the absence of later recordings of flares is connected not with a ceasing of the flare activity in this region but with its increased screening by the limb. So $H \approx 20\,000$–$25\,000$ km is believed to be the top height of the X-ray flare region. This agrees well with the observation by Sawyer-Warwick (1955), that only optical flares with the heights $H \gtrsim 15\,000$ km give SID's; these are known to be produced by X-rays. On the other hand the mean height of the optical flares is $H \approx 20\,000$ km (Warwick, 1955). So it seems that the X-ray flares are generated in the region of the optical flares or slightly over this region.

From Figure 1 we can also see that the X-ray emission of the active region in the absence of flares was recorded up to 01^h on June 18. This means that the X-ray active region extends up to $H \approx 80\,000$ km. The electron density of the X-ray active regions determined by the measurements of the X-ray flux is always about 10 times the density of the undisturbed regions of the corona (Mandel'stam, 1965). The figures – $H \approx 80\,000$ km and $N_e \approx 10^9$ cm^{-3} agree well with the values of the mean height and density of permanent coronal condensations determined from optical observations (Newkirk, 1967).

4. Flares on the Disk

Next we shall consider the results on the existence of a distinct structure of the X-ray flare regions. Figure 2 shows three successive scans of the region of a X-ray

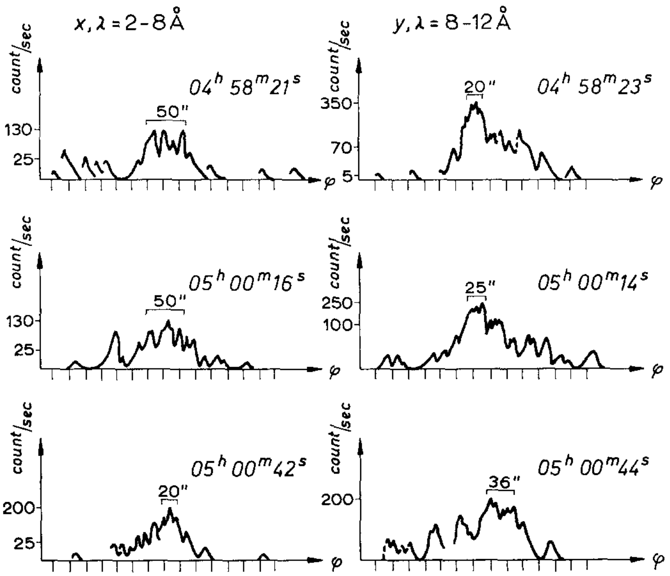

Fig. 2. One-dimensional orthogonal scans (X and Y) of the region of the X-ray flare on August 29, 1968.

flare, occurring on August 29, 1968; the records of two orthogonal components X and Y are shown. The direction of the scans was approximately S→N for the collimator X, and W→E for the collimator Y. The moment of start of the X-ray flare was not determined, because the instruments were switched on 10 sec before the first scan. Optical ground patrol at this time shows a break (*Solar Geophys. Data*, 1968). The last recorded optical flare was a subflare which started at 04^h24^m with coordinates N14° and E67°. The comparison of each two orthogonal components X and Y, shows that the flare region consists of a stretched 'envelope' about 1.3′ long and a bright 'filament', about 20″ wide and 50″ long. There is very likely an additional structure, which is masked by signal fluctuations. The successive scans at $05^h00^m14–16^s$ and $05^h00^m42–44^s$ shows fast spatial alterations of the flare region structure.

Figure 3 shows two successive scans of another X-ray flare region. The optical flare

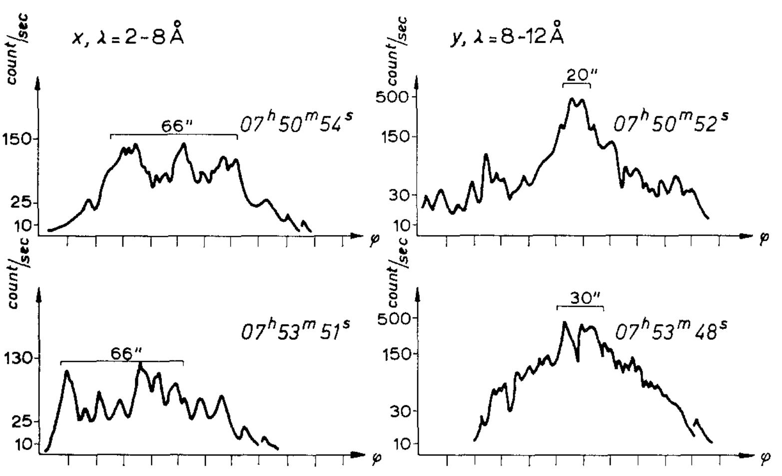

Fig. 3. One-dimensional orthogonal scans (X and Y) of the region of the X-ray flare on October 22, 1968.

Cl.1 started at 07^h30^m on October 22, 1968 in the region with coordinates N17° and E18°. A comparison of the X and Y components of the first scan at $07^h50^m52–54^s$ shows, that the flare region again has an extended "envelope" about 3′ long and 1′ wide. Inside this region were two brighter 'filaments' about 1′ long, separated by less than 20″; each filament consisted of three "knots". The second scan at $07^h53^m48–51^s$, also shows a variation of the structure of this region. The distance between the filaments increased to 20″–30″ and the 'knots' are smoothed. The structural changes, – the 'filament' displacements for example, correspond to velocities of the order of 10^7 cm/sec in good agreement with the rates of structural changes in optical flare regions.

Similar structures and velocities were observed on recordings of about ten flare regions analyzed by us so far.

Let us next assume that the X-ray emission of the flares has a thermal origin. This

TABLE I

Temperature, angular dimensions and emission measures of the region of the X-ray flare of August 29, 1968

Time (UT)	'filament'			'envelope'		
	T (K)	S	$Y = \int N_e^2\, dh$ cm^{-5}	T (K)	S	$Y = \int N_e^2\, dh$ cm^{-5}
$04^h58^m23^s$	8×10^6	$0'.3 \times 0',8$	1.7×10^{29}	7×10^6	$1'.3 \times 0',8$	0.3×10^{29}
$05^h00^m16^s$	8×10^6	$0'.4 \times 0',8$	1.1×10^{29}	$4,5 \times 10^6$	$1'.5 \times 0',8$	1.1×10^{29}
$05^h00^m42^s$	8×10^6	$0'.6 \times 0',4$	1.7×10^{29}	3×10^6	$1'.5 \times 0,8$	1.4×10^{29}

is supported by the estimation of the thermalization time for 10–100 keV electrons at $N_e \approx 10^{10}$ cm^{-3} which is about 1–10 sec. From the ratio of fluxes in the 2–8 Å and 8–14 Å bands and the absolute values of the fluxes we found the temperature and the linear emission measure of the flare region. The results of calculations for the flare of August 29 are given in Table I. In the calculations of the fluxes we included the radiation from free-free and free-bound transitions and from lines (for details see Beigman and Vainstein, 1969). The relatively low values of the flare temperature may perhaps be explained by taking into account the fact that the recordings belong to the late phase of the flare. Taking for the thickness of the 'filament' and the 'envelope' in the line of sight $h \approx 10^4$ km, we obtain for the electron density $N_e \approx 10^{10}$ cm^{-3}. This is one or two orders of magnitude smaller than the usually assumed electron density in optical flares. It is possible, however, that the thickness of the X-ray emitting region is much smaller than 10^4 km.

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References

Beigman, I. L. and Vainstein, L. A.: 1969, *Astron. J. USSR* (in press).
Culhane, I. L., Sanford, P. U., Shaw, M. L., Pounds, K. A., and Smith, D. A.: 1967, Preprint.
De Jager, C.: 1965, *Ann. Astrophys.* **28**, 125.
Mandel'stam, S.: 1965, *Space Sci. Rev.* **4**, 587.
Meeking, G., Kreplin, R., Shubb, T., and Friedman, H.: 1968, Preprint.
Neupert, W. M., Gates, W., Swartz, M., and Young, R.: 1967, *Astrophys J.* **149**, 279, part 2.
Newkirk, G.: 1967, *Ann. Rev. Astron. Astrophys.* **5** (ed. by L. Goldberg).
Sawyer-Warwick, C.: 1955, *Astrophys. J.* **121**, 385.
Solar Geophys. Data 1968, September.
Vaiana, G. S., Reidy, W. P., Zehnpfenning, T., Van Speybroeck, L., and Giacconi, R.: 1968, *Science* **161**, 564.
Vasiljev, B. N., Žitnik, I. A., Korneev, V. V., Krutov, V. V., Mandel'stam, S. L., Tindo, I. P., Čeremuhin, G. S., and Šurigin, A. I.: 1968, *Kosmičeskie Issledovanija* **6**, 420.
Warwick, J.: 1955, *Astrophys. J.* **121**, 376.
Žitnik, I. A., Krutov, V. V., Maljavkin, L. P., Mandel'stam, S. L., and Čeremuhin, G. S.: 1967, *Space Research* **7**, 2, 1263.
Žitnik, I. A., Krutov, V. V., Maljavkin, L. P., Mandel'stam, S. L., and Čeremuhin, G. S.: 1967, *Kosmičeskie Issledovanija* **5**, 274.
Žitnik, L. A.: 1969, *Kosmičeskie Issledovanija* (in press).