ON THE PRE-MAXIMUM PHASE OF THE SOLAR EVENT OF AUGUST 7, 1972

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Abstract: Drawing on a detailed discussion of H-alpha filtergrams, an attempt has been made at a complex study of the initial phase of the big flare event of August 7, 1972. A strong parallelism has been established between the derived speeds of the splitting of the H-alpha ribbons, both growing fast in close relation to the observed intensities of the radio, hard X-ray and gamma-ray emissions during the pre-maximum stage of the flare development. This pre-maximum phase has also been found to be characteristic of remarkable polarization properties in both X-ray and microwave regions. In this way the interrelation of the 'hard', 'impulsive', 'flash', and 'explosive' phases has been analyzed with respect to their information content on requirements on the acting effective acceleration processes.

Analysis of Typical Proton Flare on August 7, 1972

During the transit of the active region associated with the McMath plage region No. 11976 where a series of large and remarkable flares occurred (Křivský and Pintér, 1973). The present report deals with an analysis of the pre-maximum phase of the event of August 7, 1972 (13°N, 39°W) which exhibited an interesting and peculiar time structure and was very well displayed by quite different methods of observations (Křivský et al., 1973).

The maximum phase of the H-alpha flare exhibited a typical double-ribbon structure which is very characteristic of large solar events (Fig. 1). The visible flare started with the appearance of bright patches, immediately followed by the flash-like extension of the flare brightness. This process of pre-flare was already fully developed at 15.13 UT and apparently coincided with the stage of increase of the radio microwave and 5—20 keV X-ray emissions which started at about 15.08 UT. There followed the phase of splitting and successive separation into the two main flare ribbons (the Y-phase) from 15.13 until about 15.26 UT. Obviously this phase is associated with the ejection of energetic particles (cf. Křivský, 1963, 1975) for this case the time of ejection was determined at 15.13—15,23 (for particles — 8 min).

The rapid separation of the flare ribbons ended at about 15.27 UT simultaneously with the decrease of the hard X-ray and microwave emissions (Figs 2, 3). In contrast to this the H-alpha brightness and soft X-ray fluxes culminated delayed at about 15.27—15.30 UT.

It should be noted that the initial splitting velocity of about 50 km s^{-1} is rather exceptional; such velocities can only be expected in cases of big proton flares (cf. Valníček, 1967). The maximum width of the flare channel reached a value of 56,000 km which is quite usual for proton flares. Furthermore, the sharp decrease of the splitting velocity down to values of about 1 km s^{-1} at the end of the explosive phase is a well marked phenomenon.

It is evident that the stage of great splitting velocities corresponds to the impulsive phase of the hard (40—100 keV) X-ray emission (Fárník et al., 1973; van Beek et al., 1973) and microwave emission (Castelli et al., 1973; Cromm and Harris, 1973; Fürst et al., 1973; Mathews and Lanzerotti, 1973; Böhme and Krüger, 1973). This indicates that the process of rapid extension of the flare channel is in physical connection with the emission of hard X-rays and microwaves, on the one hand, and with the ejection of energetic particles during middle part of the whole explosive phase, on the other.

Radio Event

A spectral diagram providing an outline of the whole radio event is shown in Figure 4. Additionally, due to sufficient frequency coverage, it was

Fig. 1. H-alpha photograph of the proton flare of August 7, 1972, 15.59.45 UT exihibiting the full development of the flare channel.

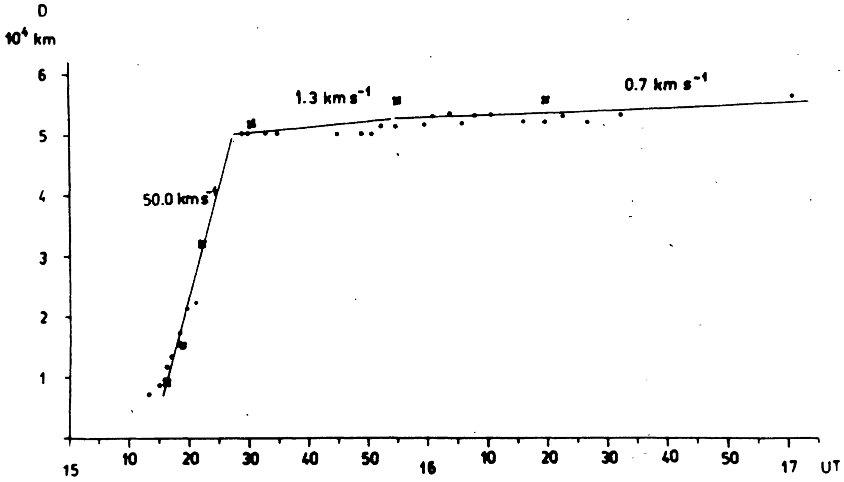


Fig. 3. Temporal change of the width of the flare channel along section 'a' of Figure 2. Dots and crosses refer to observations of the Úpice Observatory (ČSSR) and Big Bear Observatory (USA), respectively.

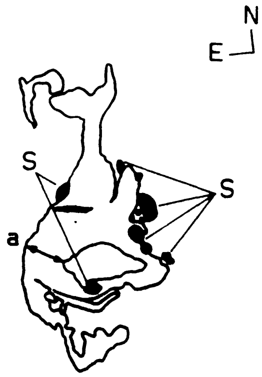


Fig. 2. Schematic picture of the H-alpha structure of the flare of August 7, 1972, referring to the development at 15.22.30 UT. Sunspots not covered by the flare are denoted by S.

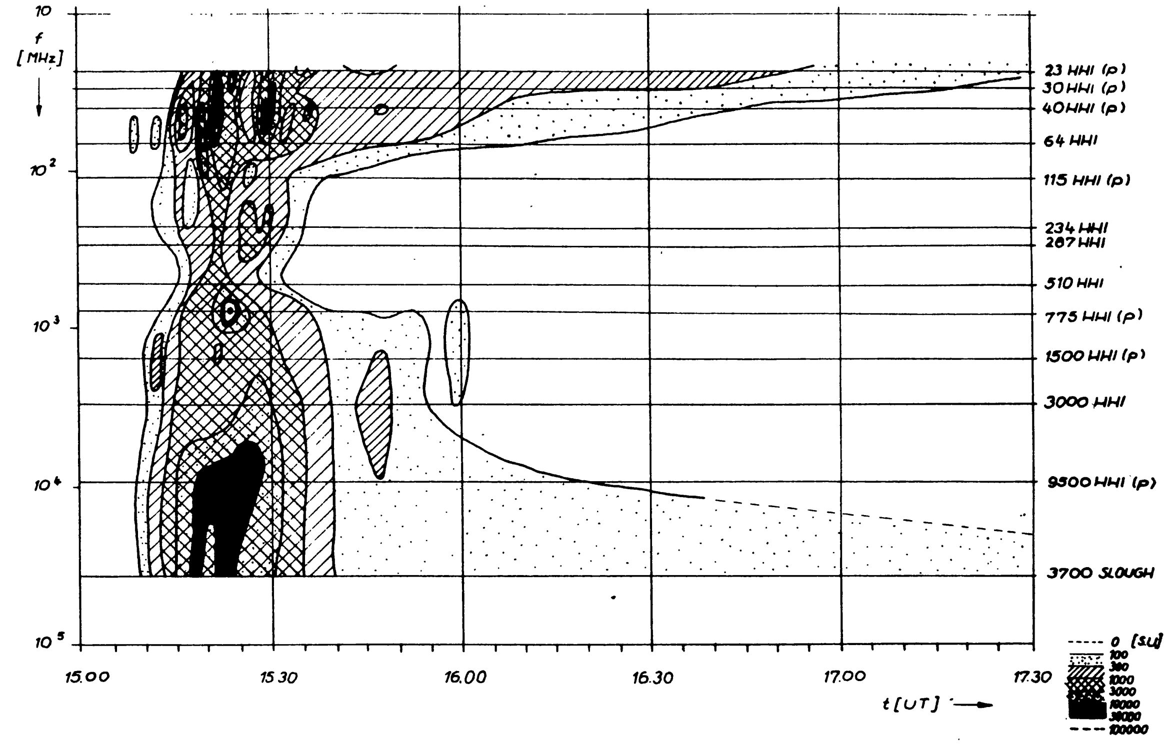


Fig. 4. Spectral diagram of the radio event of August 7, 1972.

possible to derive a polarization diagram which is presented in Figure 5.

Studying the early phase, the type IV μ component is of greatest interest. Similarly as the soft X-ray emission, the radio event already started with the pre-flare with a gradual onset at about 14.58 UT, i. e. about 14 minutes before the sudden increase of the microwave emission and about 18 minutes before the great 'explosive' flux increase of the type IV μ component. This step-like development at the time of the pre-flare and subsequent main flare is also typical for the X-ray emission and appears characteristic for the action of the big-flare mechanism (Bumba and Křivský, 1959).

The spectrum of the microwave emission as given in Figure 6 seems to indicate variations of the position of the spectral maximum for different peaks of the emission corresponding to pulses of different energies of the radiating particles apparently changing the energy spectrum in a time scale of about one minute. Likewise changes of the sense of circular polarization make probable an influence of temporally variable contributions of different regions inside the whole flare area. However, a preliminary inspection of the H-alpha photographs fails to show an unique relation between single flare centres and single flux maxima of the radio or X-emission.

Another peculiar feature of the spectra shown in Figure 6 is the appearance of very narrow bands at

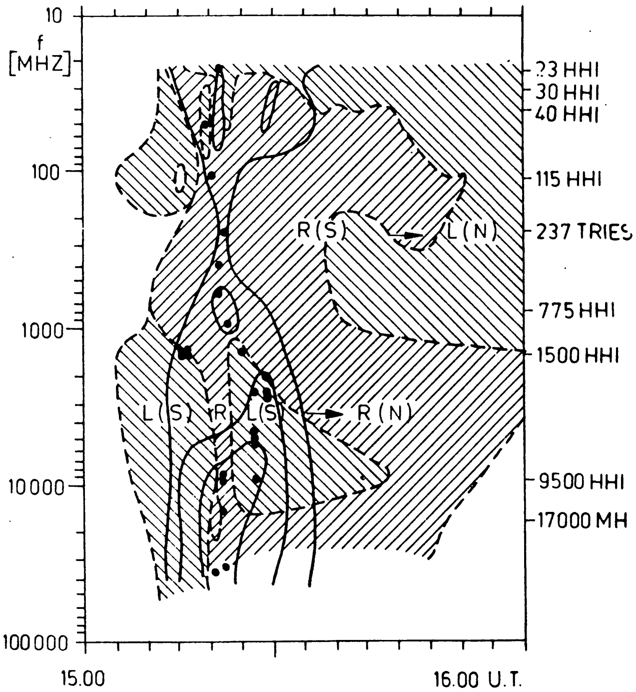


Fig. 5. Polarization diagram of the radio event of August 7, 1972 (R — right handed, L — left handed circular polarization).

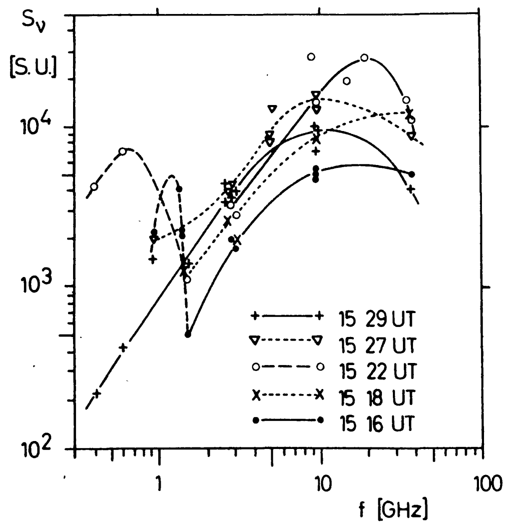


Fig. 6. Microwave flux spectra of the event of August 7, 1972.

1500 MHz. If the measurements are reliable, we have evidence of a steep increase of the high frequency wing of a decimetric component amounting to more than 3500 s. u. from 1490 to 1415 MHz.

Concerning the other components of the radio event displayed in Figures 4 and 5, the occurrence of a type II burst (15.13 UT) is of special interest. The generation of a shock wave is indicated during the impulsive or flash phase of the event, but not during the subsequent explosive phase which coincides better with the appearance of a IVmA type component.

Comparison with the X-ray Emission and Related Events

In Figure 7 the time profiles of the X-ray emission obtained at five energetic levels are shown in relation to the increasing distance between the main H-alpha flare ribbons. The onset of channels X1 and X2 referring to the lowest energies clearly display the pre-flare and initial phase. Also the coincidence of the subsequent temporal development of the impulsive hard X-radiation with fast motions of the width of flare channel is very clearly demonstrated. The fast motion of both flare ribbons indicating the expansion of the flare channel (loop system) coincides with the impulsive occurrence of hard X-ray emissions especially in the energy channels x4 and x5. The stage of the flare development is characterized by a maximum energy output corresponding to an occurrence of the most violent energy transformation processes. Suggesting a sudden release of accelerated particles from the Sun during the same time, which is supported by space particle observations (Kohl et al., 1973) this stage with two parts mentioned above is called the explosive flare phase (Křivský, 1974).

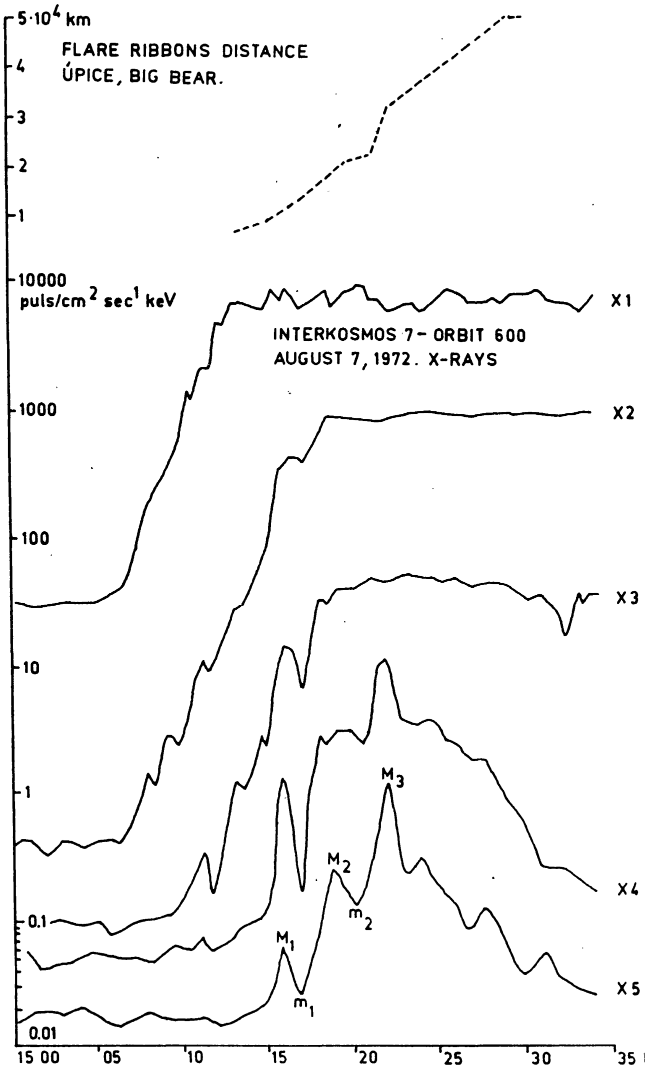


Fig. 7. X-ray records of the IK7 satellite for the event of August 7, 1972, representing five energetic levels x1: 5—10 keV, x2: 10—20 keV, x3: 20—40 keV, x4: 40—60 keV, x5: 60—100 keV. For comparison the temporal change of the width of the flare channel as derived from the H-alpha photographs has been included.

The complex character of the impulsive phase is demonstrated by Figure 8 showing X-ray spectra obtained for the five various time intervals. The small inclination of curves by high energies is clearly indicated by these spectra which have been derived for the two main emission peaks (M2, M3) and the greater inclination by high energies is related to minima (m1, m2) which occurred during

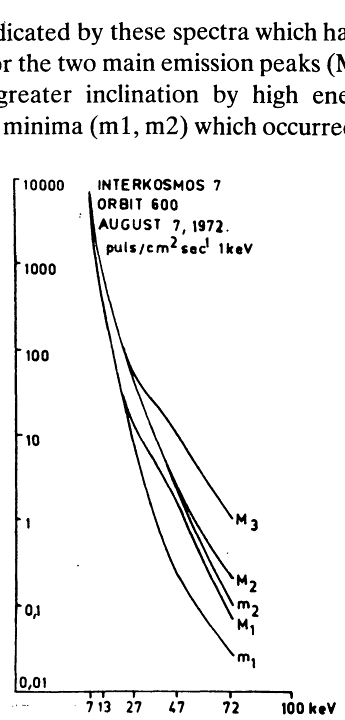


Fig. 8. X-ray spectra derived from measurements of IK7 satellite referring to five important phases of the event of August 7, 1972, marked by M1, M2, M3, m1, and m2 (see Fig. 7).

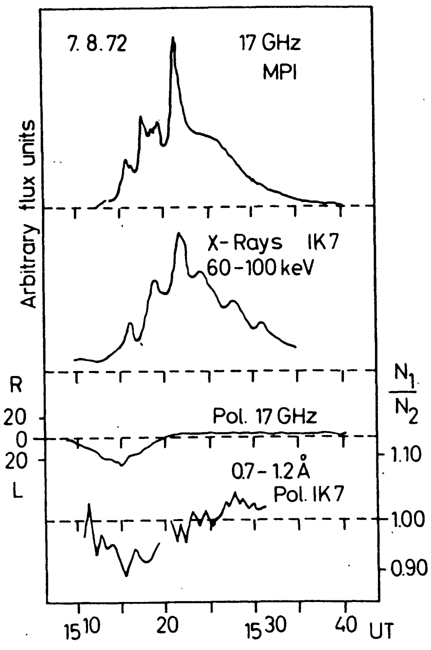


Fig. 9. Time profiles of 17 GHz flux and polarization measurements obtained by Fürst et al. (1973), channel x5 of hard X-rays and linear polarization obtained in the 0.7—1.2 Å band by Tindo et al. (1973) for the August 7, 1972 event.

the same impulsive phase. The form of the spectra gives important information about the thermal or non-thermal character of the emission, yielding a predominance of non-thermal processes during the flux maxima (M2, M3), but a prevailing quasi-thermal character during the moments ml, m2 and M1 of the X-ray emission. It should be mentioned that the non-thermal parts of the hard X-ray spectrum extended up to the gamma region was detected by Chupp et al. (1973).

The subdivision of the whole explosive phase into initial (triggering) phase and into impulsive phase is also well established by polarization measurements, available in both the soft X-ray and short microwave region. Figure 9 shows a comparison between 17 GHz flux and circular polarization measurements obtained by Fürst et al. (1973) with the hard X-ray channel x5 and linear polarization of X-rays in the 0.7—1.2 Å band obtained by Tindo et al. (1973). Two features draw our attention:

— The good correspondence of the time profiles of the short microwave and hard X-ray emissions even in small details (see also Arnoldy et al., 1968), suggesting roughly overlapping emission volumes of both components.

— The qualitative similarity of the polarization properties of the X-ray and short microwave emission indicating a directed acceleration process acting during the initial phase apparently inside a restricted volume being masked by the expansion of the flare volume during the second part of explosive phase.

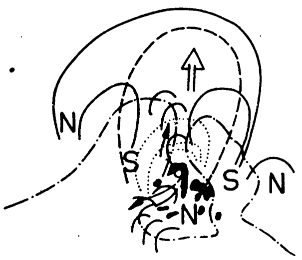
Main Tentative Results on the Pre-maximum Phase

Table 1 summarizes the main evolutional stages of the flare event development in different spectral regions. The suggested spatial configuration of the flare volume is shown in Figures 10 and 11.

As indicated by the gradual microwave and soft X-ray emissions, the event started with an obviously quasi-thermal instability at the time of the pre-flare which, after a period of about ten minutes, was followed by a second main instability, expressed by the onset of the initial triggering or flash phase connected with the main flare. Radio emission spectra and H-alpha photographs suggest an origin located near the top of the subsequently developing flare loop system in the centre of the flare channel within a restricted volume.

Table 1. Characteristic stages of the development of the big proton flare of August 07, 1972

Components	Stages				
		Main flare:			
H-alpha	pre-flare	bright spots, onset of initial flash phase	——— Y-phase 15 13—15 23	rapid expanding of flare channel 15 13—15 27	H-alpha maximum and decrease
radio cm μ	gradual onset	onset of circ. polarized emission max. 15 15		impulsive bursts with complex structure max. 15 22	decline
Soft X	gradual onset	onset of lin. polarized emission max. 15 16		delayed maximum prolonged decline	
Hard X	—	slow onset		steep onset, impulsive complex structure (3 maxima, main at 15 22)	decline
radio m		type III type II (onset 15 13)		IVmA	(IVmB)
Time	< 15 00 15 08 15—12	~ 15 16		~ 15 27	UT
phases	I preparative phase	A initial phase		B impulsive phase	III decay phase
		II explosive (expanding) phase			



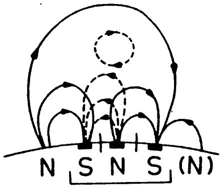


Fig. 11. Tentative magnetic field configuration on August 7, 1972

Fig. 10. Neutral line and flare position on August 7, 1972.

The flare volume expanded drastically during the following impulsive part of explosive phase which was clearly separated from the initial triggering phase.

Tentative physical interpretation of both parts of explosive phase is following: It seems be confirmed on this case that the triggering of the explosive phase is characterized with the rise of anisotropic beams of the electrons (it shows the linear polarization of the X-emission, Tindo et al., 1973), a part of electrons thermalizes the ambient plasma, originates the softer and the hard X-emission of the thermal origin (Petersen et al., 1973) and a part of the released electrons of the same population is captured in the close vicinity by magnetic fields of the intensity ~ 10^3 gauss and in this manner occurs the enhancement of synchrotron radio emissions in the mm and cm range. The saturation of the magnetic field with the electrons occurs practically in the same wide space and with the same variations as the repeating accelerations of anisotropical beams of electrons occurs within this space as well the production of the bursts of the X-emissions of the nonthermal and thermal origin (Hudson, 1973; Takakura, 1973).

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