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A STUDY OF STARTING TIME IN GREAT HARD X-RAY FLARES

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Abstract

An analysis of the starting time in ten great hard x-ray bursts observed with HXRBS is presented. It is shown that the impulsive phase of nine of them is composed of a pre-flash phase, during which the burst is observed up to an energy limit ranging from some tens of keV to 200 keV, followed ten to some tens of seconds afterwards by a flash phase, where the count rate rises simultaneously in all detector channels. For two events strong gamma-ray line emission is observed and is shown to start close to the onset of the flash phase.

1. Introduction

Hard x-ray and gamma-ray observations from SMM have shown that energetic electrons and ions are accelerated since the early stage of solar flares. There is nevertheless still controversy as to whether high energy electrons and ions are accelerated simultaneously with electrons of lower energy or whether a second, distinct step of acceleration is necessary to account for high particle energies. This controversy arose mainly from analyses of the temporal evolution of hard x-ray bursts, where in a minority of cases high energy peaks were observed to lag those at lower energies. This was ascribed to the acceleration process itself by several authors (e.g. Bai and Ramaty, 1979; Bai and Dennis, 1985), whereas others showed that the interaction of energetic electrons with the background plasma can account for such delays (Vilmer et al., 1982). In fact the interaction effects make the peak time analyses yield ambiguous results. On the other hand, as hard x-ray emission is the immediate response of a plasma to the injection of energetic electrons, the starting time of the burst is not affected by the above-mentioned ambiguities. It is clear, however, that this parameter is influenced by the energy-dependent detector threshold.

Studies of the onset phase of the radiation from energetic electrons in solar flares are still rare. Forrest and Chupp (1983) concluded for two events that the hard x-ray and gamma-ray observations were compatible, within the limits of detector sensitivity, with a simultaneous start of photon emission from 40 keV to 8 MeV. Benz et al. (1983) considered hard x-rays and radio waves at the very beginning of the impulsive phase. They found in some events evidence for two components of the impulsive phase: a weak hard x-ray emission lasting up to one minute, followed by a steep rise within some seconds to the peak count rate. They termed these phases respectively pre-flash and flash phase. Subsequently Raoult et al. (1985) showed for a series of energetic hard x-ray bursts a systematic evolution from the pre-flash phase, associated with metric type III bursts, to the more energetic flash phase with associated continua in the decimetre to metre waveband (type V burst).

In this contribution we present an analysis of the onset phase of hard x-ray bursts aiming at the precise definition of the starting time of the burst in each detector channel. The paper focusses on the observational results. Section 2 introduces the method of analysis and the selection criteria for the studied events. The results are presented in section 3 and discussed in section 4 with respect to relevant observations in other ranges of the electromagnetic spectrum.

2. Method

We have analyzed the starting time of ten hard x-ray bursts observed with the Hard X-ray Burst Spectrometer (HXRBS; Orwig et al., 1980) on the Solar Maximum Mission. These events had peak count rates above 7000 s^{-1} integrated over all detector channels (HXRBS event listing; Dennis et al., 1982). Six of them exhibit significant emission in the 4 to 8 MeV band of the Gamma-Ray Spectrometer (Chupp, pers. comm.). For some of the events ISEE 3 data were also available (courtesy S.R. Kane).

In order to define a starting time of the burst, we computed in each channel the background count rate (mean value) and the noise (standard deviation σ) in the minutes before burst onset. The starting time was defined by the instant after which for the first time three successive count rate values exceeded the background + $n\sigma$ - level. We considered separately the cases $n=3$ and $n=5$ in order to have an approximate measure of the uncertainty of our results. In all channels count rates integrated during 1.024 s were used.

3. Results

Fig. 1 shows the results for the strongest event of our sample, the neutron flare of 1982 June 3. Crosses give the photon energy where the count rate exceeds the threshold value, as a function of time: horizontal error bars delimit the time interval between the 3 σ and 5 σ levels' being exceeded (if no error bars are plotted, these levels are exceeded simultaneously), vertical error bars represent

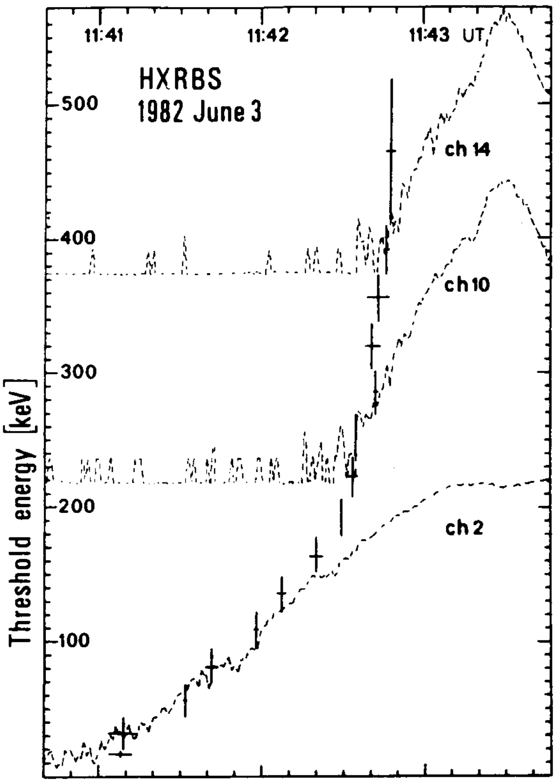

Fig. 1

the width of the detector channels. For the purpose of illustration we have also plotted - on a logarithmic scale - the count rate time histories in three HXRBS channels. At low photon energies the burst starts with apparent delays of several seconds between successive detector channels. After some tens of seconds the delays shorten and at high photon energies the emission starts nearly simultaneously in all channels. This rapid rise of the count rate, which is the first feature of the burst detected at high energies, is also discerned at lower energies, but there its start is masked by the preceding emission. The delays between successive channels, which are particularly important at low energies, are seen to be at least partly an artefact due to the energy-dependent detector threshold.

Figs. 2.a, b compare the results obtained with HXRBS and with ISEE 3 for the 1980 June 7 event and the one of fig. 1.Despite of differences introduced by the detector characteristics, the global pictures converge: Low-energy emission is detected first, with an apparent delay between adjacent channels. Some tens of

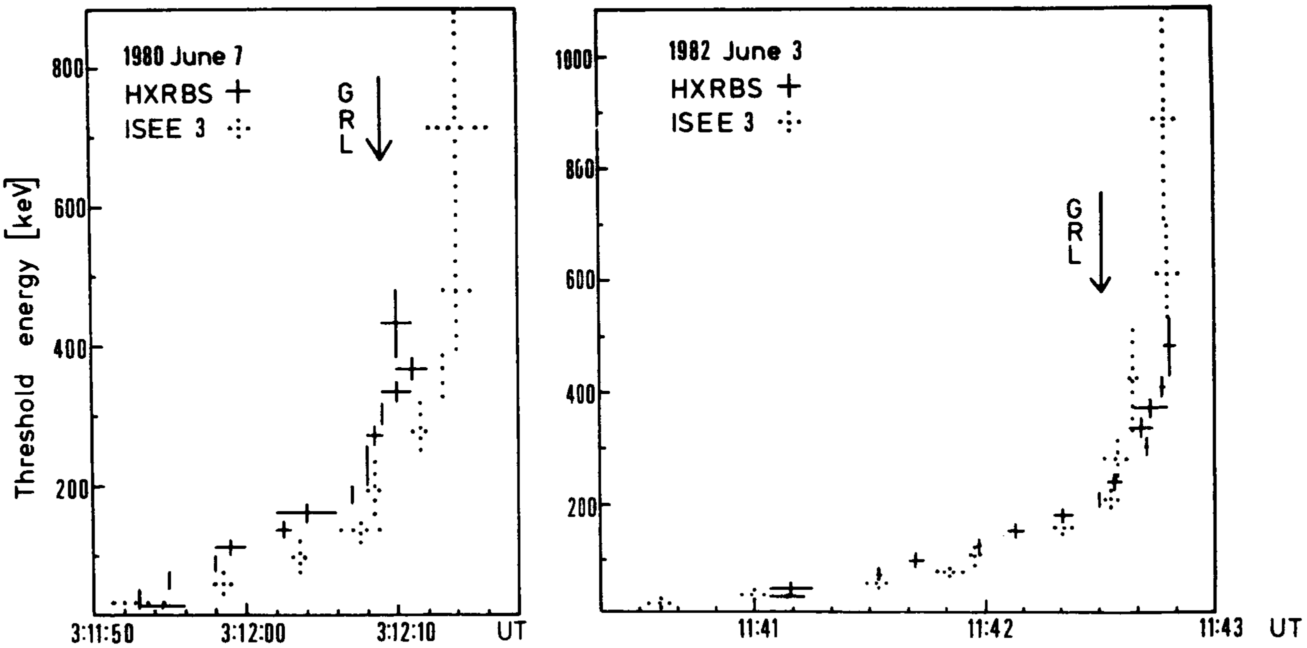

Fig. 2

seconds after the first signature at low energies a rapid rise occurs as a distinctive feature in all channels, and during which the detection threshold is exceeded in the high energy channels nearly simultaneously. In accordance with the terminology of Benz et al. (1983), we refer to these two phases as pre-flash and flash phase, respectively. The onset times of the flash phase observed with HXRBS and ISEE 3 are seen to coincide within some seconds. Both events exhibit strong excess emission in the 4-8 MeV photon energy range. This emission (Forrest and Chupp, 1983; Chupp, pers. comm.) starts, as indicated by the arrows in figs. 2.a, b, close to the onset of the flash phase of hard x-rays.

As at low energies the start of the flash phase is masked by the pre-flash emission, it cannot be analyzed by the method of section 2. We attempted to get an indication of the starting time by extrapolating the observed rise back to zero through a straight line. This was possible for four events of our sample. The starting time of the flash phase found this way in the low energy channels agreed with that in the high energy channels obtained with the method of section 2 within an uncertainty of ±3 s, which cannot be considered as a significant difference in the frame of the method used here.

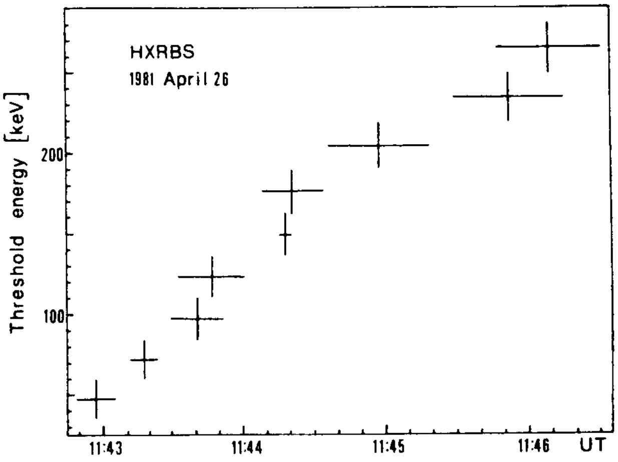

Fig. 3

The two phases have been found in nine of the ten events studied. The upper energy limit where pre-flash emission could be detected ranges between some tens of keV to 200 keV. The duration is some seconds to 80 s. No flash phase signature has been observed in the "gradual" flare of 1981 April 26 at 11:40 UT (Bai and Dennis, 1985). Fig. 3 shows the temporal evolution of its threshold energy. The emission exhibits a slow rise in all detector channels up to 250 keV. In the two highest channels there seems to be some fine structure disturbing the slow rise, but the count rate statistics is too poor to yield clear evidence for flash-phase like features.

4. Discussion

We have shown that nine out of our sample of ten hard x-ray bursts with peak count rates above 7000 s^{-1} exhibit two components of the impulsive phase:

- a pre-flash phase restricted to lower energies up to 200 keV and lasting some seconds to 80 s,
- a flash phase during which the emission in all detector channels rises simultaneously within an uncertainty of some seconds.

In their study of 45 events with HXRBS count rates above 1000 s^{-1} Benz et al. (1983) found evidence for these two phases in seven cases from visual inspection

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of the count rate time histories integrated from 26 keV to 461 keV. Two of these events (on 1980 March 29, cf. fig. 1 of Benz et al.) belong to the sample discussed in this contribution and confirm the identification of pre-flash and flash phase with the features found in our analysis. The presence of these two phases seems to be a much more frequent phenomenon in the great hard x-ray bursts discussed here than in the smaller events of Benz et al. (1983), probably because the pre-flash emission is too weak to be detected in events with low peak count rate.

In the two events where we dispose of precise onset times measured with the gamma-ray spectrometer, the rise of emission in the 4 to 8 MeV band occurs close to the onset of the flash phase of energetic electrons. Forrest and Chupp (1983), comparing starting times of the 40 keV to 8 MeV emission in the 1980 June 7 and June 21 events, concluded on their simultaneous rise in all channels of the gama-ray spectrometer. This is, however, only valid for the flash phase, in agreement with our results. The pre-flash emission was not detected in their study. For the 1982 June 3 flare detailed observations of low-energy photons are also available. Centimetric radio observations at Bern University show a spectrum peaking at low frequencies during the pre-flash phase. With the rise of the flash phase the spectral maximum starts a rapid drift to high frequencies. In the metre waveband the pre-flash hard x-rays are accompanied by fast-drift bursts. Near the onset of the flash phase the starting frequency increases rapidly - in accordance with the observations reported by Benz et al. (1983) - and a continuum emission extending over all the band 150 MHz to 470 MHz covered by the Nançay radio spectrograph is established some seconds after the start of the flash phase in hard x-rays. Raoult et al. (1985) have shown that this is a typical evolution of radio emission associated with impulsive hard x-ray bursts.

These independent observations suggest that the pre-flash and flash phase as defined by the method of section 2 are physically significant phenomena occurring during the early stage of a flare, despite the problems introduced by the detector properties into an analysis based on low count rates. These problems affect the question of time delays between different photon energies. The reality and physical meaning of these - evolution of a single mechanism of acceleration/injection or action of different processes - can only be investigated through a thorough simulation of the detector response to model spectra.

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