RECENT OBSERVATIONS OF ENERGETIC ELECTRONS IN SOLAR FLARES

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SUMMARY

It has been apparent for the last few years that a large fraction of the total energy released during a solar flare appears initially in the form of energetic electrons accelerated during the impulsive phase. An estimate of the energy of these electrons is based on the observed hard x-ray spectra as well as the assumed form (thermal or non-thermal) of the electron distribution. Even after the basic form of the electron distribution is assumed, additional assumptions, such as the low energy cut-off in the case of the power law energy spectrum or existence of a multi-thermal source in the case of the thermal spectrum, are usually required. In order to test these assumptions, measurements of the hard x-ray spectrum with spatial resolution and covering a wide range of x-ray energy are essential. In absence of good spatial resolution, as is the case with most of the presently available hard x-ray observations, the impulsive x-ray emission at energies $h\nu \lesssim 10$ keV is often unobservable because of the presence of a large background of relatively intense gradual emission associated with most flares. Observations made in the past suffered either because of the lack of a clearly identifiable impulsive x-ray emission at low energies (Peterson et al, 1973) or an adequate spectral resolution (Kahler, 1973). Thus so far it has not been possible to measure unambiguously the spectrum of impulsive x-rays $\lesssim 10$ keV and hence to deduce a possible low energy cut-off in the energetic electron spectrum. Here we report briefly such an observation made with the ISEE-3 x-ray spectrometer experiment and its implications with regard to the characteristics of energetic electrons in solar flares.

The x-ray spectrometer experiment aboard the International Sun-Earth Explorer-3 (ISEE-3) spacecraft has been described in detail elsewhere (Anderson et al, 1978; Kane et al, 1979). It consists of two detectors: a xenon-filled proportional counter covering the energy range 4.8-14 keV and a NaI (Tl) scintillator covering the energy range 12-1264 keV.

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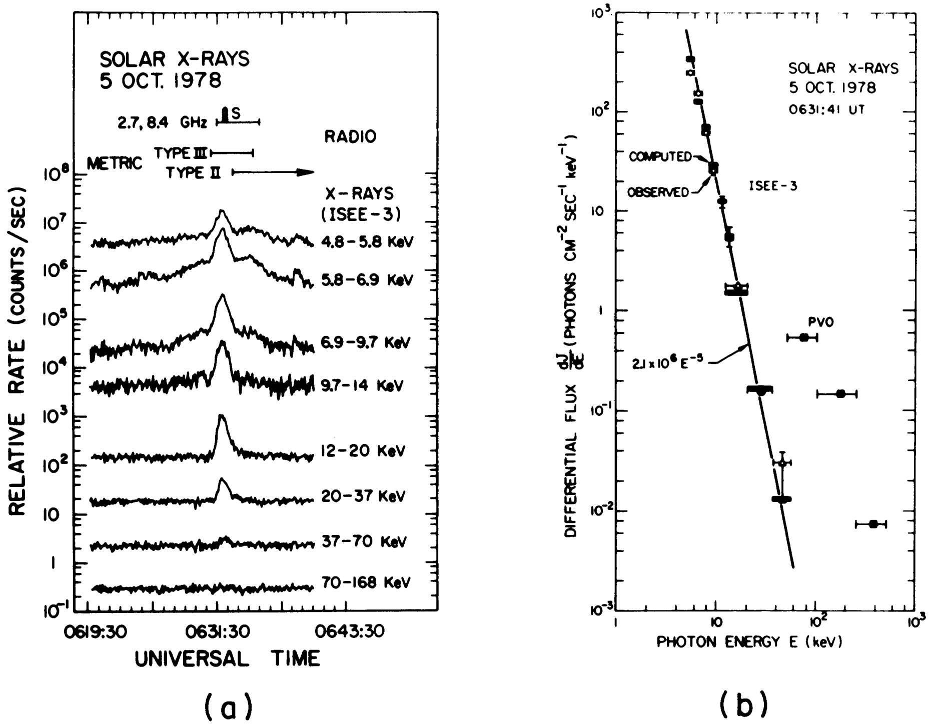

Fig. 1. Observations of an impulsive x-ray burst on 5 October 1978 attributed to a relatively large solar flare located $\sim$ 15° behind the east limb of the Sun. (a) Time intensity profile: the impulsive emission can be clearly identified down to the lowest x-ray energy ($\sim$ 5 keV) observable with the ISEE-3 spectrometer. (b) Spectral plot at the time of maximum: note that the x-ray flux observed by ISEE-3 is much smaller than that observed by the PVO detectors. Also note that the impulsive x-ray spectrum observed by ISEE-3 is consistent with a power law down to $\sim$ 5 keV energy (Kane et al, 1979).

Fig. 1 shows an impulsive solar x-ray burst observed by the ISEE-3 experiment on 5 Oct. 1978. This x-ray burst was also observed by a detector aboard the Pioneer Venus Orbiter (PVO) and it has been estimated that the associated solar flare was located $\sim$ 15° behind the east limb of the Sun (Kane et al, 1979). Thus only the part of the x-ray source located at a height $\gtrsim$ 25,000 km above the photosphere was visible to the ISEE-3 detector, the lower part of the source being occulted by the photosphere from the ISEE-3 field of view. From Fig. 1(a) it can be seen that the impulsive emission from the coronal source can be identified down to x-ray energies $\sim$ 5 keV. This has been possible because most of the gradual emission, presumably emitted at much lower altitudes, was occulted, making the impulsive emission dominant even at x-ray energies ∿ 5 keV. The x-ray spectrum, shown in Fig. 1(b), is consistent with a power law electron spectrum with no apparent low energy cut-off up to energies ∿ 5 keV. Although an explanation of the observed x-ray spectrum in terms of the emission from a multi-thermal electron spectrum cannot be ruled out, we believe that the present observation lends new support to the existence of non-thermal electron spectra during the impulsive phase of solar flares.

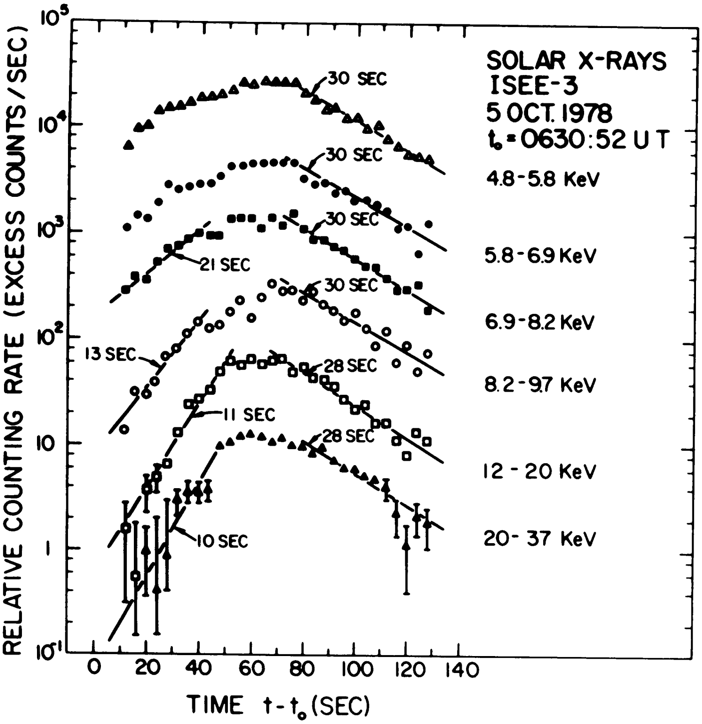

Fig. 2. Rise and decay characteristics of the impulsive x-ray burst shown in Fig. 1(a). Note that the decay time is essentially independent of energy for 5-35 keV x-rays.

Details of the rise and decay of the x-ray burst are shown in Fig. 2. Both the rise and decay times are larger than those in the case of on-the-disk flares. Further, whereas the rise time does decrease with increase in x-ray energy, the decay time is relatively constant for x-rays in 5-35 keV range. This suggests that the coronal part of the impulsive x-ray source probably consists of a relatively large region in which energetic electrons are injected more or less continuously during the impulsive phase. Because of the relatively low ambient density at coronal altitudes, the collisional losses are expected to be negligible for these electrons. If electrons are injected uniformly into the impulsive x-ray source, which extends from the upper chronosphere/transition region to the corona, the low-altitude part will be an intense thick-target x-ray source and the coronal part will be a relatively weak thin-target x-ray source. If the injected electron spectrum is a power law in energy, comparison of the ISEE-3 measurements of the coronal source with the PVO measurements of the total source shows the following: (1) $n_i\tau = 2 \times 10^8$ sec cm^{-3} where n_i is the average ion density inside the coronal source and τ is the lifetime of energetic electrons in that source; (2) the lifetime τ is not determined by coulomb collisions but by escape of the electrons from the coronal source into outer corona (Kane et al, 1979).

Thus there is evidence that the energy spectrum of the electrons accelerated during the impulsive phase of a flare extends down to ∿ 5 keV energy. Further, a substantial fraction of the accelerated electrons is present in the corona during the impulsive phase thus indicating only a partial precipitation of the accelerated electrons in the upper chronosphere/transition region.

ACKNOWLEDGEMENTS

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