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SPECTRAL AND SPATIAL PROPERTIES OF SOLAR MICROFLARES

G.M. Simnett
Department of Space Research
University of Birmingham
England

B.R. Dennis
Goddard Space Flight Center
Code 684, Greenbelt,
MD 20771 USA

ABSTRACT

Solar microflares are studied using both hard (> 28 keV) and soft (3.5-8.0 keV) X-ray observations. The soft X-ray events have durations < 3 m at 0.1x maximum intensity, and typically have similar rise and decay times. The fastest decay observed was < 15 s (1/e). Soft and hard X-ray intensities are uncorrelated. The events are very compact, consistent with a projected area ≲ 8"x8". They are normally not associated with Hα or type III emissions and their time profiles suggest a thermal origin at the top of the chromosphere. If the primary energy release site is in the corona, an energy transfer agent consistent with the observations is a non-thermal proton beam.

1. Introduction Studies of the simplest energetic phenomena which can be identified on the Sun should lead to important boundary conditions on the nature of the primary energy release at the onset of flares, the energy transfer mechanism, and the location of the energy transfer to the X-ray emitting plasma. In simple events the interpretation is not confused by secondary effects which are inevitable in large flares. Short, simple soft X-ray spikes may be close to providing answers to these fundamental points.

2. The Observations

Figure 1 shows three examples of fast, soft X-ray spikes observed by the Hard X-ray Imaging Spectrometer (HXIS) (1) on SMM during 1980. The event on June 27, 19:50 UT was seen only in the HXIS coarse field of view (resolution 32") and during the peak was consistent with a source << 32", but > 8", in dimension. The spectrum was soft, consistent with a two-component thermal source corresponding to 26 x 10^6 K, emission measure 1.7 x 10^{46} cm^{-3}, and 6.6 x 10^6 K, emission measure 5.7 x 10^{48} cm^{-3}. There was no hard X-ray burst observed, no radio emission, and no Hα flare. The rapid decay suggests a chromospheric origin. If we assume a density of 5 x 10^{10} cm^{-3}, consistent with the top of the chromosphere in model F of Vernazza et al. (2), and an area 10^4 x 10^4 km^2, this would correspond to a depth of 230 km below the transition zone.

The event of July 7, 07:08 UT was qualitatively very similar, only slightly weaker. Again, there were no reports of any other coincident activity on the Sun. The event was confined almost totally to two HXIS

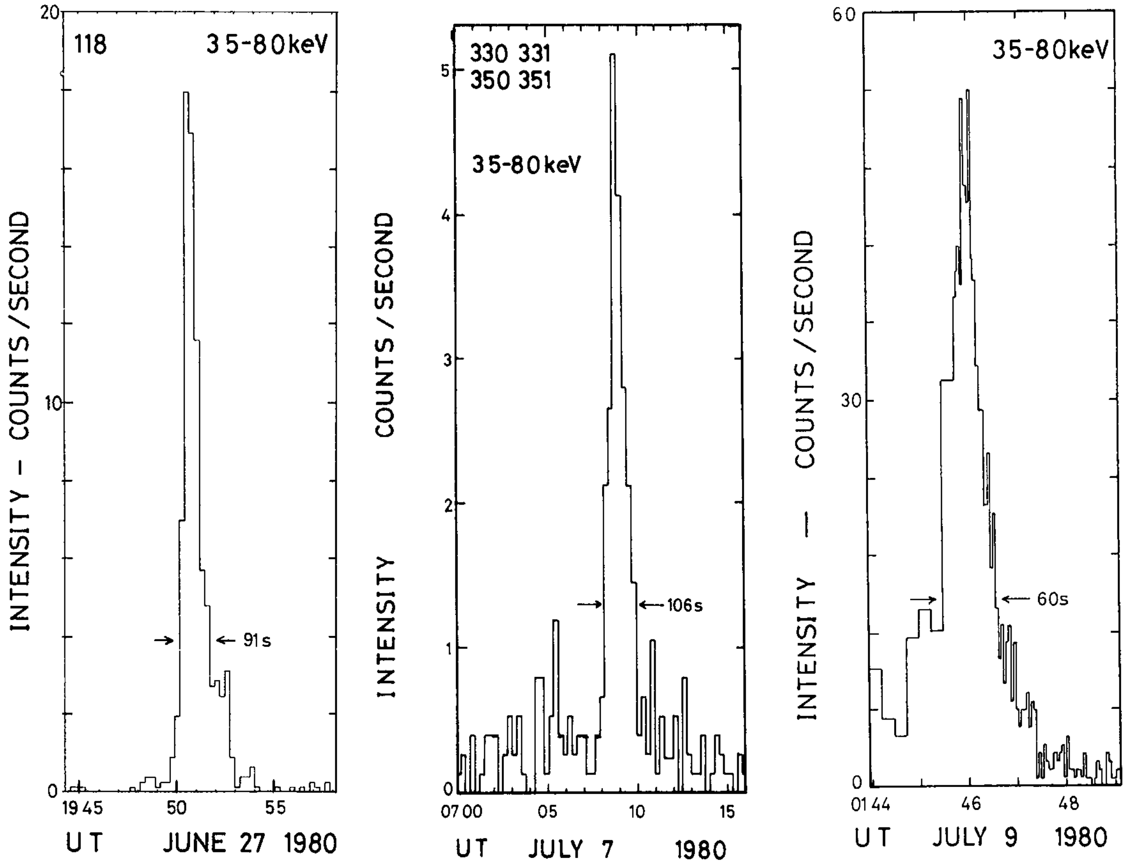

Fig. 1 The 3.5 - 8.0 keV intensity time histories for three events in 1980

fine field of view pixels (resolution 8"), so allowing for the point spread function of the instrument it is deduced that the projected area was < 8" x 8". The spectrum was even softer than the June 27 event, and both events had an e-folding decay time $\sim$ 40 s.

The third event, on July 9, 01:45 UT was much stronger and started from an already enhanced background associated with a SF flare at 01:40 UT, peak 01:42 UT. The Hard X-ray Burst Spectrometer (HXRBS) (3) on SMM observed an X-ray spike starting at 01:45:35 UT, with a width $\sim$ 35 s. This is simultaneous within the resolution of the data, with the soft X-ray and microwave onsets. However, the hard X-ray and microwave events ceased at $\sim$ 01:46 UT, the time of the soft X-ray maximum. If the event has a thermal origin, it would appear that the extremely high temperature required for the hard X-rays cools a factor of 2 or 3 times faster than that required for the soft X-rays. The event is seen close to the solar limb as a compact, < 8" x 8" bright point. The decay time in soft X-rays is $\sim$ 24 s.

If these events are due to energy deposition from the corona, then

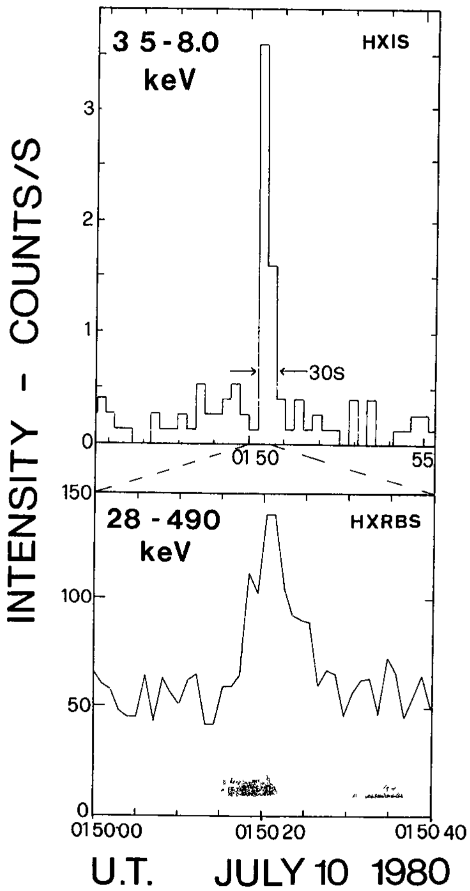

Fig. 2 In the event on July 10,1980 the hard X-ray intensity is shown expanded.

it might be expected that the more energetic events deposit energy at a higher density, and therefore have a faster decay. This is consistent with the observations, but is only one of a number of possible interpretations.

Not all events are as long as that shown in Figure 1. Figure 2 is an example on July 10, 01:50 UT which lasted < 30 s. HXIS data sampling times are shown in black on the hard X-ray enlargement. The data are consistent with a simultaneous start of the hard and soft X-rays, in which case the soft X-ray peak flux would be enhanced; there is a small residual soft X-ray flux from 01:50:30 - 01:50:38 UT. The event was compact and on the limb; there was a type III burst, but no optical or microwave report.

An almost identical soft X-ray event occurred on June 27, 15:24:20 UT, except without any other radiation signatures. Such events occur in isolation, but others are seen on the decay of a normal flare event. Examples are on April 27, 02:23 UT and July 7, 10:17 UT; the latter seen by HXRBS. We suspect that there are many other examples of these events, but a systematic data search has not yet been made.

3. Discussion. From the lack of any consistent correlation with hard X-rays, microwaves, Hα or type III emissions it seems unlikely that the soft X-ray spikes originate in a simple acceleration and impulsive injection of electrons from the corona. The events are all very compact, consistent with a projected dimension $\lesssim 8''$. The rapid decay of the soft X-rays suggests that the emission is from a high density thermal plasma, at least of chromospheric densities. However, it does not produce an Hα response, so this suggests the events are confined to the top of the chromosphere.

The July 10 event showed that a notable hard X-ray burst could be associated with a very weak soft X-ray burst (Figure 2). It is possible that this arises because the hard X-rays come from a simultaneous event beyond the HXIS field of view. However, there was no substantial event seen by the GOES full-Sun soft X-ray instrument at this time, so we believe this interpretation is unlikely. It is then significant that events where the soft X-ray intensity is higher by almost an order of magnitude have no observed hard X-rays. This would reinforce the above conclusion that these events did not originate as non-thermal bremsstrahlung from an electron beam accelerated in the corona for the following reason. If the explanation for the lack of hard X-rays is that the accelerated electron spectrum is very soft, it would also mean that the bulk of the energy would be deposited in the corona. The heated coronal plasma would then be expected to have a much longer decay time than that observed (4). Note that the threshold energy for electrons to reach the chromosphere from the corona (e.g. an altitude of $\sim 10^4$ km) is > 30 keV for any reasonable atmospheric model.

As an electron beam is an unattractive explanation for the spikes, a possible alternative is that the events are multithermal, with the energy transfer by means of a non-thermal proton beam. Such a mechanism has recently been suggested as an important feature of the impulsive phase of flares in general (5). The lack of a long decay for these events indicates that there had been no ablation of hot chromospheric plasma into the corona. This is consistent with a recent theoretical model (6) which argues that for a substantial amount of material to be ablated the deposited energy flux should exceed a threshold value. (6) specifically dealt with electron fluxes, but this conclusion should not be significantly different for protons. If the energy flux is below the threshold, most of the power is radiated away by the dense chromosphere with only a small temperature increase. If the events are due to non-thermal protons, they should be in the energy region 10^2 - 10^3 (5). Such protons will produce none of the radio radiation signatures expected from electrons, and not seen in most of our events, but would produce intense heating at the energy deposition site if it were sufficiently compact. If the heating is sufficiently high and rapid, thermal hard X-rays and microwaves will be observed. The occasional type III burst may arise from run-away electrons from the very hot thermal plasma.

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