HIGH TIME RESOLUTION ANALYSIS OF SOLAR FLARES OBSERVED ON THE ESRO TD-1A SATELLITE

PETER HOYNG, JOHN C. BROWN*, GERARD STEVENS and H. F. VAN BEEK
Space Research Laboratory, University of Utrecht, The Netherlands

Summary

(a) INSTRUMENT AND DATA REDUCTION

The Utrecht Hard Solar X-Ray Spectrometer on board the ESRO TD-1A satellite (launch March 1972) is permanently Sun-pointed and measures the solar radiation between 30 keV and 1000 keV, in 12 logarithmically spaced energy channels, with a continuous fine time resolution, viz. 1.2 s for the four lowest energy channels and 4.8 s for the rest. The detector has a 5 cm^2 Cs I (Na) crystal; counts due to particles are rejected and even during the largest solar flares saturation effects (e.g. pulse pile-up) are absent. For further details see Van Beek (1973), and Van Beek and De Feiter (1973).

The instrument has successfully operated during the two years' lifetime of the satellite and has observed a number of solar flares.

A method was developed that actually reconstructs the photon spectrum from the measured pulse height distribution and yet is much faster than the usual two parameter χ^2-fit (Hoyng and Stevens, 1974). This permitted conversion of large amounts of pulse height distributions into photon spectra and thus full utilization of the 1.2 s time resolution. In addition, a single power law fit to the photon spectrum is routinely computed.

(b) OBSERVATIONAL MATERIAL; THICK TARGET ANALYSIS

A discussion is presented of our analysis of two smaller events, 1972, May 18, UT 1406, class 1B/M4 and 1972, August 7, UT 0252, class SB/M2, and the large event of 1972, August 4, UT 0620, class 2B/X5 (see Hoyng and Stevens, 1973, and Van Beek *et al.*, 1973).

The May 18 event shows a regular single spike structure lasting $\sim 10^2$ s, not unlike the spikes seen by Kane and Anderson (1970); the August 7 event was similar, except for its more detailed time structure. Above 100 keV no flux was detected. The August 4 event is among the largest events ever recorded. The flare still emitted hard X-rays amply when data coverage ended after 21 min from the onset. In addition to rapid time variations the count rates appear to fluctuate periodically, the period increasing from some 20 s through 60 s to 120 s. The photon spectra of the two small events

* On leave from Department of Astronomy, University of Glasgow, Scotland.

Sharad R. Kane (ed.), Solar Gamma-, X-, and EUV Radiation, 233–235. *All Rights Reserved.*

are simple power laws with γ increasing linearly (May 18) or constant (August 7) through the entire event, as also found by McKenzie *et al.* (1973) but contradicting Kane and Anderson's (1970) results. All authors however seem to find that towards the end of *small* events the spectrum softens. This feature, together with the detailed (spiky) structure of the time profile itself, are the main arguments for the existence of continuous electron acceleration.

The spectra of the August 4 event, detectable up to ~400 keV, are not simple power laws. They have a break, not necessarily sharp, around ~60 keV after which the spectrum steepens by $\Delta\gamma \sim 1$. (In the single power law fits, $\gamma(t)$ *decreases* towards the end of the event). This break (cf. also Frost, 1969) is probably too large to be interpreted as an anisotropy effect (cf. Petrosian, 1973) and so should be present in the spectrum of the X-ray emitting electrons. However, as long as no good theoretical explanation for pure power laws exists, observation of a power law with a break must not be considered as more peculiar than a simple power law itself (cf. the cosmic ray spectrum). Using the single power law fits, we determined for all three events with full time resolution the thick target parameters F_{25} and P_{25}, being the total required number flux and energy flux of fast electrons $\geqslant 25$ keV into a target region (Brown, 1971). Table I summarizes typical values.

TABLE I

Total required number and energy flux of electrons $\geqslant 25$ keV in a thick target X-ray source

	Smaller event (lasting 10^2 s)	Large event (lasting 10^3 s)
Mean F_{25} (s^{-1})	$0.5\text{–}1.0 \times 10^{36}$	4×10^{36}
$\int F_{25} dt$	4×10^{37}	5×10^{39}
$\int P_{25} dt$ (erg)	2×10^{30}	2×10^{32}
Mean $n_0 N_{25}$ (cm^{-3})	$3\text{–}8 \times 10^{45}$	3.5×10^{46}

The interpretation of these numbers poses great problems: the energy put into fast electrons about equals the total flare energy spent and the total number of electrons ever accelerated is about equal to the number of electrons in the whole flare, taking some reasonable density (10^{10-11} cm^{-3}). Moreover these numbers are lower limits in the sense that one could well extrapolate below 25 keV and/or the target might be thin!

By using reasonable inflow velocities into some flare region we find that in particular F_{25} is too high. We argue that the only practical way to bring F_{25} down is by accelerating an electron not once but many times. In this case F_{25} has no meaning and from the data one derives the nonthermal emission measure $n_0 N_{25}$ = ambient density × total number of fast electrons $\geqslant 25$ keV at the given time. One could term this a thick target with containment. There is however no way around the large values of $\int P_{25}\, dt$ and we have to face the situation that nearly all flare energy is channeled through fast electrons into other forms. An interesting new feature of the data is the marked correlation of γ and F_{25} in the August 4 event. During the last 7 min (decay phase) the correlation is particularly good and γ and F_{25} decrease monotonically with time. This could indicate the slow collisional decay of a large, low density cloud. From elementary considerations we find a density $n_0 \sim 10^8$ cm^{-3} and a volume $V \sim 10^{33}$ containing $\sim 10^{38}$ fast electrons. These electrons could be due to escape of a small fraction of the total number available, viz. 5×10^{39} (Table I).

(c) FOURIER ANALYSIS

Power spectra have been computed of the raw count rates of channel 2, F_{25} and γ for the three events (the assistance of Drs R. Rutten and G. Geytenbeek is gratefully acknowledged). The results can be summarized as follows:

(i) The power spectrum of the raw count rates of channel 2 of the August 4 event shows *significant* periodicities at 120, 60 and 33 s. The same periodicities are present in the power spectra of F_{25} and, to a lesser degree, of γ. No periodicities were found in the two other events.

(ii) In all three events, the power spectrum of the raw count rates of channel 2 shows an average high frequency power level *significantly* above the level expected from Poisson noise alone. We drew the conclusion that the solar flare must have intrinsic white noise in its emission at all periods from 15 s down to the Nyquist period, 2.4 s.

The periodicities in the August 4 event must correspond to *coherent* changes of the whole flare region. Directly from the time profile we infer physical timescales $\tau = |(1/c)(dc/dt)|^{-1}$, c = count rate, for these changes and find $\tau \gtrsim 10$ s for the large event and $\tau \gtrsim 2$ s (non periodic) for the small events – so that neither case shows changes in the source *as a whole* in times down to 1.2 s.

References

Brown, J. C.: 1971, *Solar Phys.* **18**, 489.
Frost, K.: 1969, *Astrophys. J.* **158**, L159.
Hoyng, P. and Stevens, G. A.: 1973, Proceedings First European Astronomical Meeting, Athens 1972, vol. 1, 97.
Hoyng, P. and Stevens, G. A.: 1974, *Astrophys. Space Sci.* **27**, 307.
Kane, S. R. and Anderson, K. A.: 1970, *Astrophys. J.* **162**, 1003.
McKenzie, D. L., Datlowe, D. W., and Peterson, L. E.: 1973, *Solar Phys.* **28**, 175.
Petrosian, V.: 1973, *Astrophys. J.* **186**, 291.
Van Beek, H. F.: 1973, Ph.D. Thesis, Utrecht.
Van Beek, H. F. and de Feiter, L. D.: 1973, Proceedings First European Astronomical Meeting, Athens 1972, vol. 1, 103.
Van Beek, H. F., Hoyng, P., and Stevens, G. A.: 1973, in H. E. Coffey (ed.), *Collected Data Reports on the August 1972 Solar-Terrestrial Events*, Report UAG-28, part II, 319.