TWO TYPES OF ELECTRON EVENTS IN SOLAR FLARES

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Abstract. The fluxes and spectra of the flare electrons measured on board Venera-I3 and I4 space probes are compared with the parameters of the hard ($E_x \geqslant 55$ keV) and thermal X-ray bursts. The electron flux amplitude has been found to correlate with flare importance in the thermal X-ray range ($r \sim 0.8$). The following two types of flare events have been found in the electron component of SCR. (I) The electron flux increase is accompanied by a hard X-ray burst and the electron spectrum index in the ~ 25-200 keV energy range is $\gamma \sim 2$-3. (2) The electron flux increase is not accompanied by a hard X-ray burst and the electron spectrum is softer ($\Delta\gamma \sim 0.7$-I.0).

I. Method and statistics.

The fluxes and spectra of the 25-I500 keV electrons and 55-I00 keV hard (Xh-) X-rays were systematically measured in I98I-I983 on board Venera-I3 and I4 /I-3/. 300 SCR events were selected which could be considered as flare-induced. Only the SCR events which could be identified, using H_α and thermal X-rays, with the flares in the Sun's Western hemisphere were selected in order to study the relationships between the flare electron fluxes injected to interplanetary space and the X-rays. The events were only analysed where the > 70 keV electrons were observed, for it is obvious that the > 55 keV X -rays are produced by the electrons with $E_e > E_x$. Such events amount to I30; out of them only 67 were accompanied by the Xh-bursts; in 63 cases such an accompaniment was not detected. These sets of events will be henceforth designated eXtXh and $eXt\overline{X}h$.

2. Distribution functions.

We constructed the size distributions of the number of events with given parameter Y: $f(Y) = (I/N)(dN/dY)$, where N is the number of events in a given set. The highest electron fluxes (J_e) and the amplitudes J_{Xt} and J_{Xh} of, respectively, the Xt- and Xh-bursts are used as Y . The functions $f(J_e)$, $f(J_{Xt})$, and $f(J_{Xh})$ are shown in Fig.Ia,b,c where the crosses and the dashed lines relate to the eXtXh set. From Fig. I it is seen that, throughout the major part of the interval of the amplitudes J_e , J_{Xt} , and J_{Xh} the distribution functions may be approximated by a power low with index α . It is seen that (I) the distribution functions of various parameters within the same set are alike and have similar indices and (2) the distribution functions of the same parameters within different sets are characterized by different α . We have $\alpha \sim$ I.2-I.4 for eXtXh and $\alpha \sim$ I.7-I.8 for $eXt\overline{X}h$. Thus, by using the additional indication (the accompanying Xh-burst), we have obtained two sets of events in which the intensity distributions differ in slopes. This means that two types of electron events are realized in SCR which correspond to different conditions for particles acceleration and leakage in solar flares. We think that the conventional approach (see, for example, /4/) makes it difficult to discriminate the types of flare events in SCR because in this case the distribution function of the events of given parameter is usually constructed, irrespectively of the relationships of these events to other parameters of flare activity.

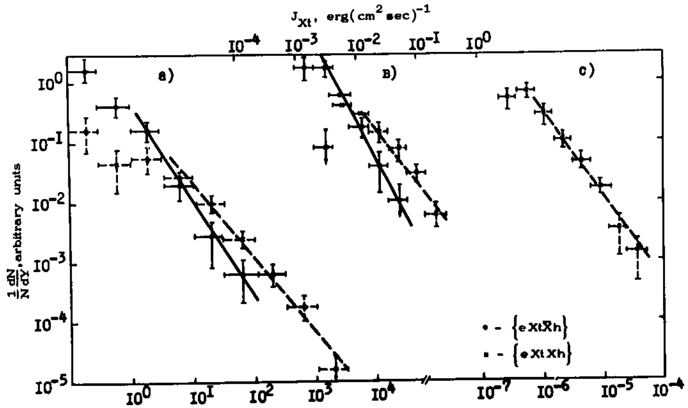

Fig. I

From Fig. I it is seen that the eXtXh to-$eXt\bar{X}h$ events number ratio increases with amplitudes J_e and J_{Xt} and that, starting from certain values of the amplitudes, only the eXtXh events occur. This is understandable in terms of the big flare syndrome /5/ according to which, as the power of a flare rises, the probability for the flare to be accompanied by the entire spectrum of flare events rises also. However, two types of the SCR events can hardly be accounted for only by the difference in the power of parent flares. From Fig. I it is seen that there exists the interval of the J_e and J_{Xt} amplitudes where the SCR events of both types are realized.

The electron spectra

Fig. 2 shows the results of comparing between the differential electron energy spectra in the eXtXh and $eXt\bar{X}h$ events. In the energy range $E_e \sim$ 25-2I0 keV the electron spectra were approximated by a power law with exponent γ_e. The values of γ_e presented in Fig.2 have been obtained by averaging over the number of the events of given type in the intensity interval $[J_e, J_e + \Delta J_e]$. The dots relate to the $eXt\bar{X}h$ events, and the crosses to the eXtXh events. According to Fig.2, the eXtXh events differ from the $eXt\bar{X}h$ events in the electron spectrum slope ($\Delta\gamma_e \sim$ 0.7-I.0) and in the dependence of γ_e on J_e. Nevertheless, the differences in the spec-

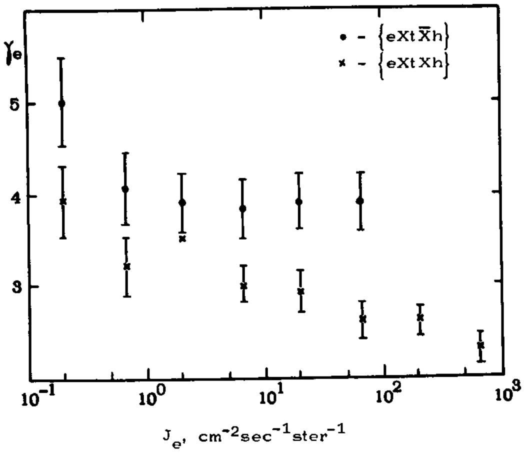

Fig. 2

tral characteristics of electron fluxes cannot account in all cases for the Xh-burst accompaniment of the SCR events. It is easy to verify that the identical electron fluxes at $\Delta\gamma_e \simeq 2$ produce the quantum fluxes differing by a factor of less than 3. In some cases, therefore, we must have seen both an Xh-burst and a SCR electron event.

The most probable condition for the $eXt\bar{X}h$ events to be realized consists in that the plasma density n in the acceleration region is low and all the accelerated electrons or the majority of them, are ejected to interplanetary medium within a period smaller than the Coulomb loss time. The values of J_e and γ_e from Figs. I and 2 were used to estimate the upper limit of the density for the $eXt\bar{X}h$ events: $< 5xI09-I0^{10}$ cm^{-3}.

Correlations

The coincidence of the slopes of the distribution functions of events for the amplitudes of various parameters (see Fig. I) ensues from the correlation between the electron events and X-ray bursts:This is confirmed by direct calculations of the correlation coefficients between the intensities of X-ray bursts and electron fluxes from the central and western flares. $r(\lg J_e, \lg J_{Xt}) \sim 0.8 \pm 0.02$ for I47 events with the > 25 keV electrons and I30 events with the > 70 keV electrons. Such value of r_{eXt} means that (I) the energy lost for SCR electron acceleration is approximately proportional to the flare energy because the energy release in the Xt-range is proportional to the energy realized in the flare /4/ and (2) the Xt-flux may be also a measure of the power of a SCR event. We have also obtained that $r(\lg J_e, \lg J_{Xh}) \sim 0.69$. Partly, this may be relevant to the fact that the electron flux must be compared with the total number of quanta or with energy release in a burst $\varepsilon = \int J_{Xh}\,dt$ rather than with the J_{Xh}-burst amplitude, because it is ε that is proportional to the particle number in the generation region of the Xh-rays in terms of the nonthermal model. Fig. 3 shows the correlation between ε and J_e. It is seen that the relationship between J_e and ε is nearly linear and that the calculated $r_{eXh} \sim 0.79 \pm 0.03$. From this it follows that the effectiveness of electron leakage to interplanetary medium is approximately constant irreespectively of flare intensity.

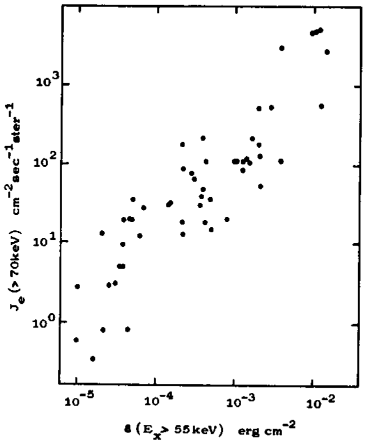

Fig. 3

Considering the index of the Xh-ray quantum spectrum δ is ~ 4 and varies little with flare intensity, we obtain for the energy release ε and the particle number at the Xh-ray source n_s: $n_s = k(\delta)\varepsilon$, where $k(\delta) \simeq I.3 \times I0^{4I}$ at the threshold values $E_x = 70$ keV and $E_e = 55$ keV in case of thick target or trap model /6/. Considering that $\varepsilon = bJ_e$ (see Fig. 3) and turning to the number of particles injected from the source, n_{inj} , we obtain the following relation between n_s and n_{inj} in terms of the diffusion model: $n_s = A n_{inj}$ and $A \simeq 10^3$.

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