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Statisticial Distribution of Solar Soft X-Ray Bursts

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We analysed statistically nearly 1000 solar events with fluxes measured in 0.5-3Å, 1-8Å and 8-20Å bands by Explorer 37 (S NRL Solrad) satellite. The differential distribution of peak fluxes can be represented by power laws with exponents - 1.4, -2.2, -2.9 respectively, which are compared to 2-12Å results obtained by Drake[1] At the 0.5-3Å band there is a suggested peak in the distribution. Autocorrelation analysis of the distribution have shown that in the harder band (0.5-3Å) there is a concentration of events at preferred values multiplied of about 10×10^{-5} erg $cm^{-2}s^{-1}$, of unknown origin.

Analisamos cerca de 100 eventos solares com fluxos medidos pelo satélite Explorer 37 US NRL Solrad) nas bandas 0.5-38, 1-8Å e 8-20Å. As distribuições diferenciais dos fluxos máximos nas três bandas podem ser representadas por leis de potência cujos expoentes são -1.4, -2.2, e 2.9 respectivamente, os quais são comparados com resultados obtidos por Drake[1] na banda 2-12Å. Para os dados na banda de 0.5-3Å sugere-se a existência de um pico na distribuição. A partir de uma análise por autocorrelação da distribuição encontrou-se na banda mais dura (0.5-3Å) uma tendência de concentração de eventos em valores múltiplos de cerca de 10×10^{-5} erg cm^{-2} s^{-1}, cuja origem é desconhecida.

A complete study on statistical properties of soft X-ray solar bursts was performed by Drake[1], using nearly 4000 events measured in the 2-12Å range by Explorer 33 and 35 satellite (University of Iowa experiment). For comparison purposes we analysed 1000 events in the 0.5-3Å and 8-20Å bends and 900 events in the 1-8Å band, which peak fluxes were reported by NOAA's *Solar Geophysical Data* bulletins, as frommeasurements USNRL Solrad experiment using Explorer 37 satellite. We used all data available for events with defined start and end times in the period 1970 to 1975.

The criteria used for burst identification and data reduction were described in a number of paper by Kreplin and co-workers[2,3,4], and in *Solar Geophysical Data* bulletin's Descriptive Text[5].

The flux data derived by the Solrad experiment have a severe selective effect produced by the fixed amount of flux required to change the digital count output by a single count. This correspond, in units of erg cm^{-2} s^{-1}, to i.1 x 10^{-5} (0.5-3Å, single range), 8.6 × 10^{-5} and 4.5 × x 10^{-3} (1-8Å high and low sensitivity ranges, respectively) and 2.4×10^{-4} and 1.3 x 10^{-2} (8-20Å high and low sensitivity ranges, respectively) .

In order to obtain broad differential distribution diagrams, we must take into account these seletive effects. In figure 1 (a) we have a differential distribution for 1000 events in the 0.53Å band. The ordinates are $\Delta N/\Delta T$ where ΔN is the number of events in the peak flux interval ΔI. In this diagram ΔI is always equal or larger than the digital count interval. For fluxes larger thanabout 9×10^{-5} erg cm^{-2} s^{-1}, the distribution has a least squares best fit to a straight line of the form

$$\Delta N/\Delta I = AI^{\alpha} \tag{1}$$

where A is a constant and a = -1.4 for the 0.5-3Å band.

In figure 1 (b), for the 1-8Å band (900 events), ΔI is always larger than the high sensitivity digital count interval. For fluxes larger than 100 x 10^{-4} erg cm^{-2} s^{-1}, ΔI is equal or larger than the lowsensitivity digital count interval. The excess concentration of events at 40-50 × 10^{-4} and 80-90 × 10^{-4}, in units of erg cm^{-2} s^{-1}, are produced by the low sensitivity digital count selection effect, and were neglectedin the derivation of the best fit straight line. For the 1-8Å band we obtained a = -2.2.

The data in the 8-20Å band (1000 events) has the worst selection effect produced by the low sensitivity digital count interval. The

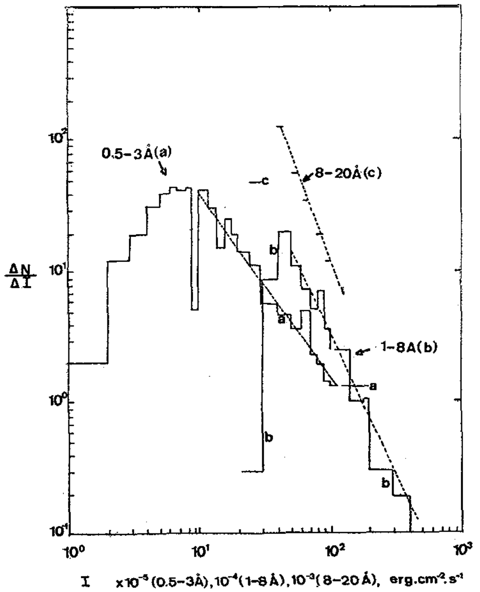

Fig.1 - Differentiai distribution plots for solar flare peak fluxes in the three soft X-ray bands measured by Explorar 37 satellite. $\Delta N/\Delta I$ is the nucber of events in the interval ΔI centered at a peak flux value I.

data are clearly concentrated in discrete intervals, indicated in figure 1 (c), outside of whose $\Delta N/\Delta I$ falls to nearly zero. The power law function was derived for these intervals, and produced a = -2.9.

The differential distributions appear to become steeper for softer wavelength bands. At 0.5-3Å band the diagram coversnearly two orders of magnitude of peak fluxes, while at 8-20Å band the diagram covers nearly less than one order of magnitude. At 2-12Å band Drake[1] has found a = -1.75, which correspond to a spectral information situated somewhere between the bands 0.5-3Å and 1-8Å from the Solrad experiment.

Peaks in the distributions are suggested for the three bands. These may be attributed to selection criteria at lower sensitivity limits, where background flux corrections are relatively more important, and should not be claimed as real[1]. Nevertheless, for the 0.5-3Å band, the peak at about $8,5 \times 10^{-5}$ erg cm^{-2} s^{-1} is preceded by six statistically significartt intervals with increasing $\Delta N/\Delta I$, not influenced bethe digital count selection effect. A truncation of the 0.5-3Å band distribution is more clearly noticeable at about 9.5 $\times 10^{-5}$ erg $cm^{-2} s^{-1}$, and is of unknown origin.

We also notice that in figure 1, curves (b) and (c) that the cutoff towards lower flux values in rather sharp (i.e., for the 1-8Å and 8-20Å bands). This can be attributed to the selection criteria, as described in NOAA[5]. Analog plots on Solrad X-ray measurements are sometimes available in NOAA's data bulletins, and they include plots on background, or charged particles interferences. But the data processing computer exclude events contaminated by interferences, especially at the 0.5-3Å and 1-8Å bands. The plot also indicate gaps in flux measurements, due to background interferences, or to the satellite s nights. The nature and the effects of background interferences on Solrad experiment were also discussed in a number of previous studies[2,6,7], and it does appear that the reported solar flare flux data are rather free from particle interference effects, and might provide meaningful statistical treatment.

Still referring to the experiment description we note that the flux value at the peak of the distribution of the 0.5-3Å band events in figure 1 is nearly one order of magnitude larger than the lower limit of the dynamic range, but the events' selection for listing is regulared by the 1-8Å band event selection criteria. An event is only listed when the 1-8Å band flux remains above 3×10^{-3} erg $cm^{-2} s^{-1}$ for more than 3 minutes. This level is more than one order of magnitude larger than the lower limit from the dynamic range of measurement at that band. It does not correspond to the cutoff et the 1-8Å band, nor to the lowest detectable limit at the 0.5-3Å band. Weaker events are in fact not listed, and were not used in the statistics. All the 0.5-3Å band events have their correspondent identified events at the 1-8Å band (used as a reference for data selection). But, in spite of this correspondence, the distributions at the two harder bands look quite different in relation to the cutoff toward lower flux values, which is not sharp for the 0.5-3Å band. On the other hand, the reported time durations are also referred to the 1-8Å band, and they are set rather arbitrarily. But we know from other works, at 2-12Å band[1] and at 1.2-3Å band[8] that the great majority of events have durations situated between 10-60 minutes, and 3-30 minutes, respectively. In the harder 0.5-3Å band the durations are known to be smaller but, doe to the selection criteria, they always correspond to 1-8Å band events with durations equal or larger than 3 minutes, and one would not expect any serious selection effect due to desconsideration of events with smaller durations. Alternatively, if the peak in the 0.5-3Å band events' distribution is not of real nature, one should find a considerably larger number of weaker events in that band which does not produce correspondent 1-88 band events. But this does not seem evident when inspecting analog displays of 24 hours .Solrad reduced measurements, which are sometimes published in NOAA's *Solar Geophysical Data* Comprehensive reports. The plots still show the existence of a number of smaller events, at both bands, but not listed due to the selection criteria. In view of these comments, it does seem that the maximum in the 0.5-3Å distribution might be of different nature from the peaks at the other two bands. The shape of the distribution for lower flux values might be still contaminated by selection effects but selection effects but the cutoff towards lower flux values seems to be a likely real effect.

The data used in the present analysis was reorganized in the form of histograms for discrete autocorrelation analysis of the form

$$R(k) = \frac{1}{m} \sum_{1}^{m} n(I) \times n(I + k\delta I), \qquad k = 1,2,3... \tag{2}$$

where $n(I)$ is the discrete function corresponding to the number of events in the interval δI centered at the peak flux value ■ $n(I + k\delta I)$ is the histograrn displaced by k times δI, m is the number of successive intervals and $R(k)$ is the autocorrelation function.

The digital count effects for the 0.5-3Å band and high sensitivity ranges for the 1-8Å and 8-20Å bandç are nearly smoothed out by data reduction at integers from 10^{-5}, 10^{-4} and 10^{-3} units of erg $cm^{-2}s^{-1}$, respectively. Important experimentally produced quantisation effects of instrumentiil origin can be evidenced at 1-88 and 8-20Å bands, selecting δI smaller than the reported low sensitivity digital count effect. We found data selection with magnitudes comparable to the reported information on the experirnent[5].

Finally, in order to eliminate these undesirable effects, we autocorrelated the histograms in the three bands with 61 equal to the digital sensitivity, i.e., 10^{-5}, 45×10^{-4} and 13×10^{-3} units of erg

cm^{-2} s^{-1}, for 0.5 -38, 1-8Å and 8-20Å bands, respectively. The results are shown in figure 2, and were obtained for bursts with peak fluxes smaller than about 200×10^{-5}, 800×10^{-4} and 500×10^{-3} units of erg cm^{-2} s^{-1}, in the three bands, respectively. Referring to equation (2), the values of m are 200, 14 and 38 for the three bands, respectively, and the autocorrelation function is much better defined for the 0.5-3Å band data.

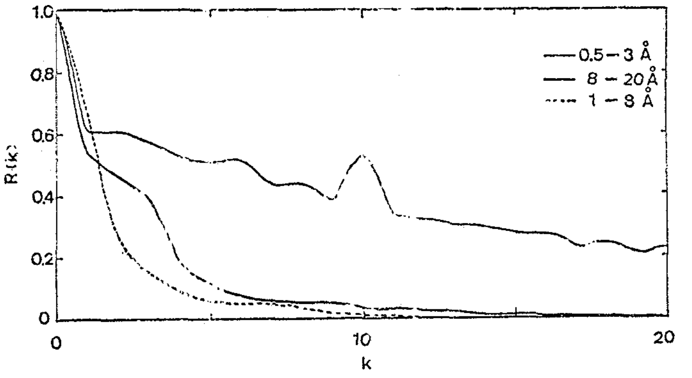

Fig.2 - Autocorrelation functions with the searching intervals equal to the experimentally produced selection effects, $\delta I = 10^{-5}$, 45×10^{-4} and 13×10^{-3} in units of erg cm^{-2} s^{-1} for the 0.5-3Å, 1-8Å, and 8-20Å bands, respectively. The 0.5-3Å band flux data tendency for concentration at 10×10^{-5} erg cm^{-2} s^{-1} is of unknown origin.

The functions for the 1-8Å and 8-20Å band data are smooth, corresponding to randomly distributed histograms. The 0.5-3Å band function display a tendency for concentration of peak flux values at about 10×10^{-5} erg cm^{-2} s^{-1} superimposed to a random distribution. This "period" is nearly ten times larger than the predicted digital counteffect for this band, and it can be related to the truncations observed in the distribution diagram of figure 1(a). This unexpected selection effect in the 0.5-3Å band might also be due to some unknown experimental cause that requires an explanation.

The confirmation of the existence of a lower finite limit for solar bursts fluxes might constitute an important boundary condition connected to the flare production processes. Further works in this respect are desirable but they are dependent on the availability of a statistically meaningful amount of data obtained with higher sensitivity, at various energy levels, in order to have a clearer picture of the effects which were discussed in this paper.

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