vARIATION OF THE SOLAR FLARE ENERGY SPECTRUM OVER THE 11-YEAR ACTIVITY CYCLE

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ABSTRACT. Based on X-ray (1-8 Å) flux data for 1977-1987, the integral spectra of solar flare energy were computed. The energy spectra were approximated by a power law $N(E) \propto E^{-\beta}$, with N being the number of flares with energy in excess of E. It is shown that the spectral index (β) varies systematically with the 11-year cycle phase.

Research done on UV Cet type stars during the 70-ies made it possible to suggest the similarity of flare activity mechanism on red dwarf stars (RDS) and on the Sun [1]. Statistical studies of RDS have shown, that the distribution of total flare energies for these stars may be represented in the optical band, by a power-law [2]. Flare energies as high as 10^{36} ergs impose stringent constraints on theoretical models of stellar and solar flares [3]. According to estimates made in [3] for an equilibrium plasma, the magnetic energy in a current sheet of volume V may not exceed (a viral theorem) the potential energy of the coronal mass contained in the volume of the same sheet: $W_H = M g_\odot H$, which, for $H = 5\times10^{9}$ cm, yields $M = 3\times10^{10}$ g and $W_H = 4\times10^{17}$ J, but this is in contrast with the observed total energy of 10^{25} J for the most powerful flares.

Peak energies of stellar flares may be derived from their energy spectrum distribution. According to Hudson [4], the energy spectrum of solar flares in the soft X-ray range shows a power spectrum with spectral index β = 0.8 - 0.85, which virtually agrees with optical data. Changes in the energy spectrum of solar flares with the 11-year cycle phase are very useful to study solar flare activity in connection with activity on red dwarfs to investigate possible cyclic behaviour.

Using data on the X-ray emission energy flux within the range 1-8 Å (Solar-Geophys. Data, PRF) the accumulated number of flares

$$N(E) = \int_E^\infty E\, N(E)\, dE$$

was plotted versus E. The distribution may be represented as a power law $N(E) \propto E^{-\beta}$, where E is a given threshold energy and β is the spectral index. To obtain the flare energy, the flux F was integrated over the duration of the individual flare (τ) and over the solid angle of 2π radians:

$$E = \pi R^2_{AE} \int_0^T F(1-8\ \text{Å})\, dt \qquad (\text{ergs})$$

where R_{AE} is the distance from the Sun to the Earth.

The advantage of studying the solar flare energy spectrum is twofold, namely, (1) the energy spectrum of the smallest flares ($\approx 10^{24}$ ergs) may be investigated, and (2) the variations of energy spectrum parameters (1977-1987) may be traced against the solar activity phase. The relevant energy spectrum parameters for cycle No. 21 are given in Table 1.

Table 1

Year	Number of flares	FLARE ENERGY (ergs) Min	Max	Mean	Spectral index β	Wolf No.
1977	238	4×10^{25}	8×10^{27}	2.3×10^{27}	0.65	15
1978	1215	8×10^{25}	1×10^{31}	3.0×10^{27}	0.70	40
1979	1291	1×10^{26}	1×10^{31}	3.0×10^{27}	0.83	115
1980	2161	1×10^{26}	4×10^{30}	3.0×10^{27}	0.92	160
1981	3544	9×10^{25}	3×10^{30}	2.0×10^{27}	0.95	145
1982	3693	4×10^{25}	8×10^{30}	1.0×10^{27}	0.83	140
1983	2453	2×10^{25}	3×10^{30}	4.0×10^{26}	0.89	100
1984	1991	1×10^{24}	2×10^{30}	6.0×10^{25}	0.81	60
1985	1026	1×10^{25}	3×10^{30}	2.0×10^{27}	0.76	40
1986	853	9×10^{24}	7×10^{27}	8.0×10^{26}	0.66	16
1987	1259	9×10^{24}	1×10^{27}	8.0×10^{26}	0.72	32

The Table columns present, respectively: the year (21st cycle), the number of flares, the minimum, maximum and mean flare energy (ergs), the spectral index β, and the Wolf number.

The mean energy was determined in the power-law spectrum approximation [2]. It is interesting to note that the spectral index varies with the 11-year cycle phase, increasing at maxima to 0.95 (1981) and decreasing at the two minima (1977 and 1987) to 0.65-0.72. This means that, at cycle maximum, the relative number of low-energy flares exceeds that of high-energy flares. Accordingly, the minimum, maximum and mean flare energies correlate with the 11-year cycle phase. An approximation made using a power-law energy spectrum gives the following linear dependence between lg E and lg N (for all flares in the cycle):

$$\lg E = 31.2 - 1.17 \lg N(E), \qquad \beta = 0.85$$

Figure 1 presents typical power spectra for X-ray flares' energy during the fourth period of the 21st cycle: $\beta = 0.71$, during the

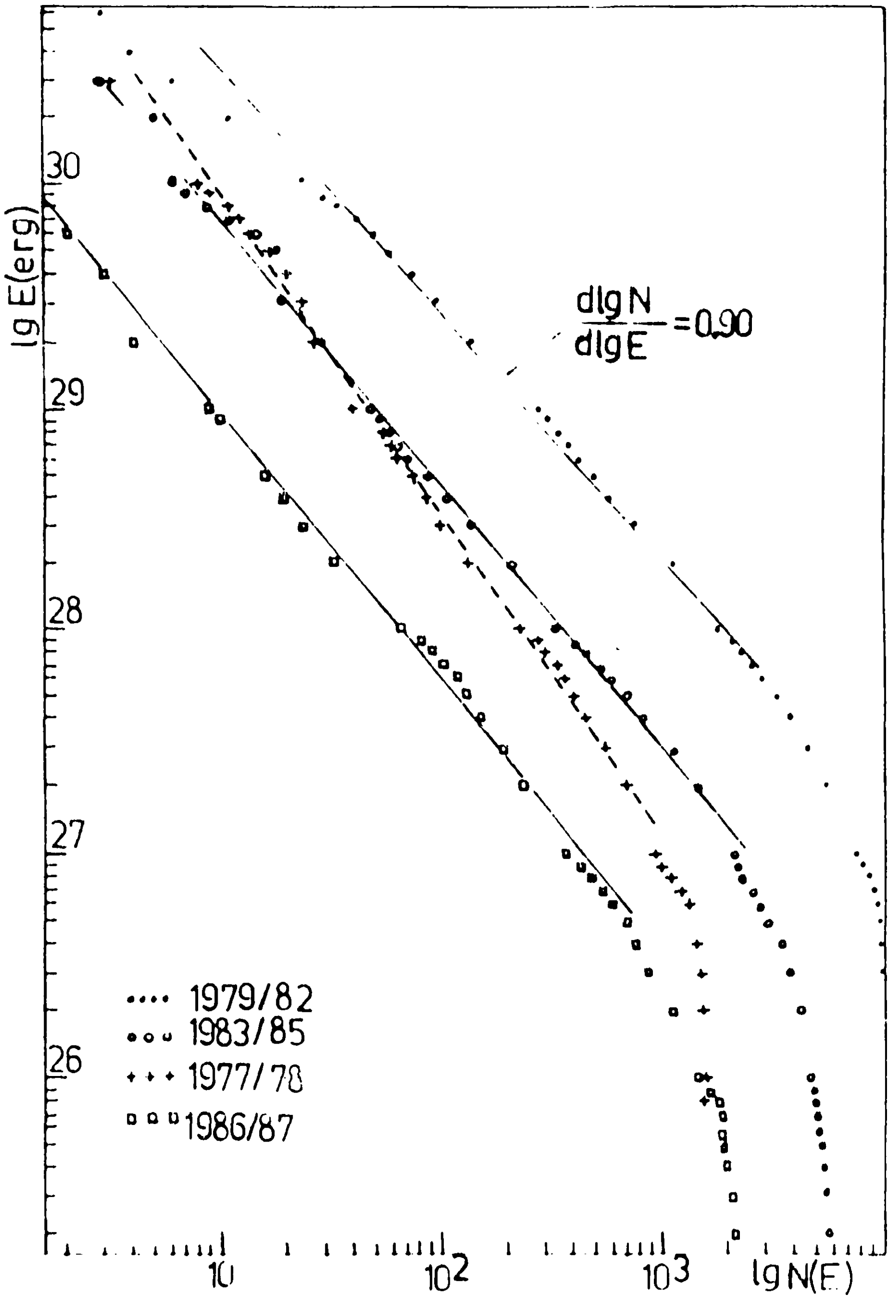

Figure 1. Power law distributions of X-ray (1-8 Å) flare energies for different phases of the 21st solar activity cycle.

ascending phase (1977-1978); β = 0.91, close to maximum (1979-1982); β = 0.84, during the descending phase (1983-1985); β = 0.78 at minimum phase (1986-1987). The variation of the spectral index is evident.

The results obtained in this study are certainly useful for modelling stellar flares. The variation of the spectral index with the solar activity phase (β larger at maximum) may be used to identify cyclic activity on RDS. The universal character of the flare energy spectra for the Sun and stars [1, 2, 3] provides evidence in favour of a common energy mechanism for flares.

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