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VARIATIONS OF THE SOLAR FLARE ENERGY SPECTRUM OVER TWO ACTIVITY CYCLES (1972 - 1995)

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ABSTRACT

Based on X-ray (1-8 Å) flux data for 1972-1995 the integral spectra of solar flare energy were computed. It has been shown that the spectral index β of the integral energy spectrum (IES) varies systematically with the 11-year cycle phase. The interval of β-variations ($0.47 < \beta < 1$) is characteristic of UV-Cet stars. The maximum energy of the X-ray flares does not exceed 10^{32} erg.

Solar flares are the process of rapid release of significant energy.In recent years similar flare processes were observed for red dwarfs (UV-Cet stars) (Krasnobabtsev and Gershberg, 1976). The investigations carried out for the UV Cet type stars during the 70-ies made it possible to suggest the similarity of the flare activity mechanisms for the red dwarf stars (RDS) and for the Sun. As shown (Hudson ,1991), solar flares have the exponential energy spectrum with $\beta \sim 0.80$. The investigation of the changes in the energy spectrum of the X-ray solar flares (Kasinsky and Sotnikova, 1989) with the 11-year cycle phase is very useful for understanding the mechanisms of the flare activity of the Sun and the red dwarfs. The energy spectrum of solar flares may be calculated for a short time interval, namely, a year. For this purpose, the data on the X-ray emission energy flux within the range 1-8 Å (Solar Geophys.Data, PRF) were used to calculate the number of accumulated flares that is approximated by the exponential function:

$$N(E_m) = \int_{E_m}^{\infty} n(E)dE \sim E_m^{-\beta} \qquad (1)$$

where E_m is the predetermined threshold energy and β is the spectral index. In coordinates $\log E - \log N$ of the linear part of IES β was determined to be equal to the angular coefficient of a straight line: $\beta = -d \lg N / d \lg E$. Table 1 presents parameters of integral energy spectrum of flares for 22 years (two solar cycles).

It follows from the Table 1 that β varies with cycle phase, that is, it obviously varies with Wolf numbers W; in this case β shows the minimum values 0.47 - 0.61 at cycle minimum. Therefore, at cycle minimum, rare but powerful flares contribute to the average emission power of flares. Further, β has a consistent tendency for an increase to a maximum, being kept during 1-2 years following the maximum. The interval of β-variations ($0.47 < \beta < 1$) is characteristic of UV-Cet stars.

The estimates of the largest energy that can be released in a single flare, are of principal interest. Taking logs of (1) we have the regression equations for the years listed in Table 1:

$$\lg E = \lg E_m - (1/\beta) \lg N \qquad (2)$$

Table 1. Energy Spectrum of X-ray Solar Flares

Year	lg E	β	W	N
1972	31.1 - 1.375 lg N	0.727	69	2923
1973	29.4 - 1.254 lg N	0.797	38	318
1974	31.9 - 2.111 lg N	0.474	34	339
1977	30.4 - 1.608 lg N	0.622	27	238
1978	31.4 - 1.525 lg N	0.656	92	1215
1979	31.5 - 1.472 lg N	0.679	155	1291
1980	30.9 - 1.148 lg N	0.871	155	2161
1981	31.1 - 1.169 lg N	0.855	140	3544
1982	31.4 - 1.302 lg N	0.768	116	3693
1983	30.6 - 1.211 lg N	0.826	67	2453
1984	31.3 - 1.243 lg N	0.804	46	1191
1985	29.8 - 1.372 lg N	0.729	18	1026
1986	30.4 - 1.630 lg N	0.613	13	856
1987	30.1 - 1.345 lg N	0.744	29	1259
1988	30.8 - 1.316 lg N	0.760	100	1654
1989	31.7 - 1.299 lg N	0.800	158	2513
1990	31.0 - 1.111 lg N	0.900	142	2551
1991	31.7 - 1.250 lg N	0.800	145	3229
1992	30.7 - 1.075 lg N	1.000	90	2552
1993	30.3 - 1.333 lg N	0.750	56	2161
1994	30.1 - 1.075 lg N	0.700	30	582
1995	30.4 - 1.620 lg N	0.670	18	989

Thus, the free term in (2) can be considered as the estimate of maximum energy in a single flare event for a given year. The largest time-integrated energy of optical and UV emission during flare events is 10^{32} erg multiple of several units (Gershberg et al.,1987; Hudson, 1991; Kurochka, 1987; Somov, 1981). As follows from the Table 1, the estimates of maximum flare energy in the X-ray range do not exceed 10^{32} erg.

According to Kurochka (1987), β for the optical flares is 0.8. It should be noted that the variations of β for the optical flares over 11-year cycle were not studied. We tried to do this by means of specific method using the data on flares in H_α, of importance 1, 2, 3, during 1936-1960 (Smith, 1966). Summary tables usu-

Table 2. Energy spectrum of optical solar flares

Year	β	W	Flares	Year	β	W	Flares
1936	0.66	80	1568	1948	1.02	136	2044
1937	0.74	114	2159	1949	1.04	135	2160
1938	0.91	110	2464	1950	1.07	84	1066
1939	0.94	89	2417	1951	1.04	69	864
1940	0.90	68	1263	1952	0.88	32	428
1941	0.74	48	1574	1953	0.92	14	242
1942	0.74	31	650	1955	1.00	38	544
1943	0.73	16	652	1956	1.04	142	3003
1944	0.73	10	322	1957	1.04	190	4226
1945	0.80	33	554	1958	1.11	183	3536
1946	0.68	96	1215	1959	1.15	159	3924
1947	1.02	152	3339	1960	1.04	112	2386

ally give distributions of flares in importances M in percentage: $\Delta N(M)/N, (\%)$, where N is a total number of flares of every importance. With a knowledge of the distribution in importances, it may be possible to obtain the accumulated distribution and to determine its logarithm:

$$\lg [\, \Sigma N(M > M_i)/N \,]\,. \qquad (3)$$

Next, it is assumed that the flares of importance $1, 2, 3$ correspond to the linear part of the IES and the importance is the logarithmic measure of energy, i.e. the relationship $M \sim \lg E$ is reasonably well satisfied. In such an approximation the logarithms of importances $1, 2, 3$ flare energy are in the ratio of 29:30:31 in accordance with the above statement. Thus, $\Delta(\lg E) = \Delta M$ and β can be calculated:

$$\beta = -\frac{\Delta(\lg \Sigma N/N)}{\Delta(\lg E)} \qquad (4)$$

The calculated values of β are presented in Table 2.

As follows from the comparison of Table 1 with Table 2, the behaviour of β in the optical range is similar to that in X-rays: β for optical flares has a stable tendency for an increase to a maximum, being kept during 1-2 years after the maximum. On the whole, $\beta_{opt}/\beta_x > 1$. It may imply that the flare occurrence rate in the optical range is higher compared with that for the X-ray flares, especially at cycle maximum. An investigation of solar flares IES during 2 cycles reveals the following:

1. The integral energy spectrum of the solar flares has the power law form. The β undergoes the variations associated with the cycle phase, correlating with the Wolf numbers.

2. The spectral index β increases from the epoch of minimum to the epoch of maximum of solar activity, that means an increase in flare occurrence rate.

3. Cycle-like variations of β with the phase of an 11-year solar cycle can be a base for identifying the similar cyclic variability for red dwarf stars.

The results obtained in this study are certainly useful for modelling the stellar flares. The universal character of the flare energy spectra for the Sun and stars provides the evidence in favour of the common energy mechanism for the flares.

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