HIGH TIME RESOLUTION PHOTOMETRY OF RED DWARF FLARE STARS III. THE MOST RAPID AND FAINTEST OBSERVED STELLAR FLARES: THEIR PHYSICS AND STATISTICS

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ABSTRACT. High time resolution monitoring of the UV Cet type flare stars has enabled us to detect flares with total duration of a few seconds and with energy output comparable to solar subflares. We find that the time scales of decay for such flares correspond to recombination times of optically thin gas or to cooling times of optically thick gas heated in flares. Therefore, faster flares cannot be detected individually but their accumulated effect may be one source of brightness fluctuations of the "quiet" star. The upper limit for the total power of such microflares does not exceed the time-averaged power of individually detected flares.

While monitoring red dwarf flare stars, many observers have detected very fast bursts with total durations of about 2-3 s. However, since the typical time resolutions of common photoelectric photometers were compatible with the intrinsic time scale of such bursts, they could not be studied in detail and sometimes even their reality was open to question. Our observations at the 6-m telescope with a time resolution of 3×10^{-7} s using the MANIA system (Neizvestnyj and Pimonov, 1978; Pimonov, 1979), confirm the reality of such fast flares and has allowed us to detect very small energy flares on the faintest flare stars.

The energy spectra of flares for 4 red dwarfs, which were monitored with the 6-m telescope of the Special Astrophysical Observatory, are given in Fig 1. Dots indicate flares that were detected during our observations, and straight lines correspond to energy spectra of flares that were based on previous traditional observations (Gershberg and Shakhovskaya, 1983). The two sets of data show a rather good agreement, especially if one takes into account possible seasonal variations of the mean frequency of flares and the fact that the previous energy spectrum of flares on Wolf 424 was based on a 4 times smaller

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amount of data than ours. Figure 1 also shows that during the course of our observations we detected stellar flares with energy emissions comparable with those of solar subflares. This implies that stellar flares on red dwarfs not only extend solar flare data to larger energies but also cover the whole energy range of solar flares.

The rapid flares of UV Cet on 18 December 1984 at 18h 09m UT and of CN Leo on 19 January 1985 at 03h 03m UT, whose light curves are presented in the second paper of this series, had decay times of 1.5s and 2-3 s, respectively. The decay time of the EV Lac on 24 February 1984 at 17h 03m UT, which was detected with the Space Astrophysical Station ASTRON (Gershberg and Petrov, 1986), did not exceed 2.4 s. If these short decay times are due to recombination in an optically thin plasma, then one can estimate $n_e > 2\times10^{12}$ cm^{-3}. However, according to the gas-dynamic model of stellar flares (Katsova et al., 1981), in the quoted time scales a downward propagating shock wave crosses a distance of more than ten times its thickness. Therefore, a flare density $n_e > 6\times10^{13}$ cm^{-3} results. This estimate is in agreement with the results of spectroscopic analysis of flares (Gershberg, 1974) and the mathematical simulation of such events (Katsova et al., 1981). Even if such faint and fast stellar flares are optically thick in the continuum at flare maximum, their decay should be related to blackbody radiation of stored thermal energy. If deviations from isothermality within the radiating and moving gas are neglected, such process may be described as follows:

$$d(n\ k\ T\ l)\ /\ dt = -\ \sigma\ T^4$$

whence,

$$n\ l = 3\ \sigma t(T_o^{-3} - T^{-3})^{-1}\ /\ k$$

Let T_o = 8500 K (Mochnacki and Zirin, 1980), T = 5000 K and t=1 s; then, we obtain a column density $nl \leqslant 2\times10^{23}$ cm, in agreement with Grinin's and Sobolev's (1977) results for stellar flares that are not transparent in the Balmer continuum.

Thus, it is very likely that the lifetimes of the fastest observed stellar flares are determined by thermal relaxation processes within the flare heated gas. If such processes last several seconds we cannot expect to detect significantly faster flares than events with characteristic times of, say, 0.1 - 1 s. All such faster events must be smoothed out by relaxation processes and give a contribution to the "quiet" level luminosity.

Using the statistical d^2-function method described in the first paper of this series, we have analyzed the light curves of the "quiet" stars on time intervals that are apparently free from individual flares and we have estimated an upper limit of a variable component contribution to the "quiet" level of the stellar luminosity. In time scales interval 1-10 s, the relative power S of such component is less than 0.02-0.03. On the other

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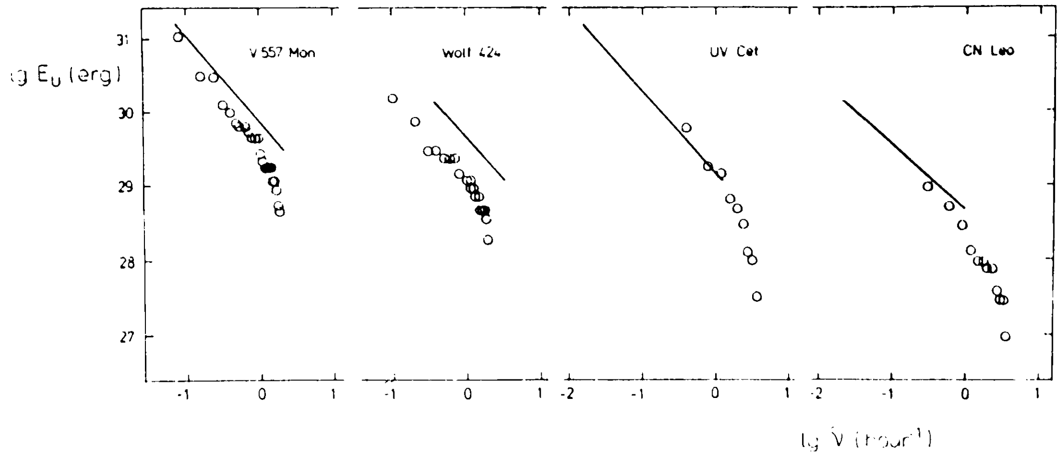

Figure 1. Energy spectra of flares for red-dwarf stars observed with the 6-m telescope of the Special Astrophysical Observatory at Nizhnij Arkhyz.

hand, the total optical radiation energy of individually detected flares divided by the quiescent stellar luminosity and by the monitoring time (ΣP/t) is in the range from 0.03 to 0.06 for the 4 flare stars we studied. Hence, ΣP/t > S. This means that the total energy of microflares in the optical region does not exceed the total energy of individually detected flares. This fact may be important for the hotly debated question on the heating of stellar coronae by microflares.

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