HIGH TIME RESOLUTION PHOTOMETRY OF RED DWARF FLARE STARS II. THE SHORTEST FLARE RISE TIME

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ABSTRACT. We have studied the initial phases of 65 optical flares on UV Cet type stars with a time resolution of 3×10^{-7} s. Ninety per cent of these flares have rapid brightenings shorter than 10 s and several are shorter than 1 s. We detected on UV Cet the shortest flare observed to date with a total duration of 1.7 s and a rise time of 0.3 s. The shortest flare rise times on the observed stars fit the predictions of the gas-dynamic flare model by Katsova et al. (1981) and Katsova and Livshits 1986).

We selected 65 flares with well observed initial phases from a set of 73 flares on CN Leo, UV Cet, Wolf 424 and V 577 Mon. The observations were obtained with 3×10^{-7} s time resolution during the course of our flare star monitoring program at the 6-m telescope of the Special Astrophysical Observatory using the MANIA system (Neizvestnyj and Pimonov, 1978; Pimonov, 1979). During the rising phase of a stellar flare the continuum radiation dominates in the optical wavelength range (Bopp and Moffett, 1973) and just at this phase one may expect to find some effects of non-thermal processes.

For each of the 65 selected flares we measured the duration of the "leading front", i.e., the duration of the phase when the flare intensity increases with the steepest and nearly constant rate. We excluded the slow brightness increases sometimes observed at flare beginning, which are due to emission line radiation (Bopp and Moffett, 1973).

The distributions of leading front durations are given in Figure 1. These plots show that for the overwhelming majority of flares these durations do not exceed 10 s. There may be a maximum near 2-3 s that is more clearly exhibited in the total distribution, which includes all four observed stars. On each of these stars we detected flares with leading front durations shorter than 1 s. The light curves of these flares are shown in Figure 2. The UV Cet flare on 18 December 1984, at 18h 09m UT, was the most rapid event ever detected: the flaring up time and total duration were 0.3 s and 1.7 s, respectively.

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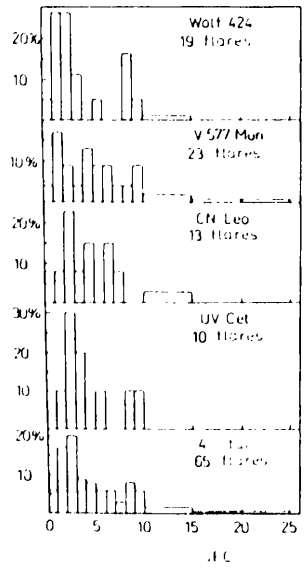

Figure 1. Distributions of leading front durations for stellar flares.

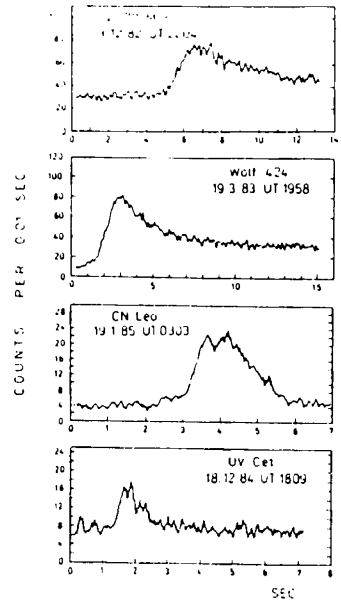

Figure 2. Light curves of stellar flares with fast initial phases.

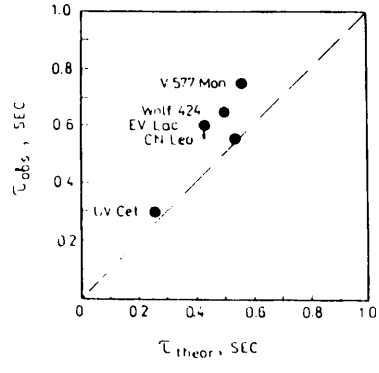

Figure 3. Comparison between the shortest flare leading fronts from observations and theoretical estimates (τ_{min}) from the gas-dynamical stellar flare model.

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One can show that if the optical flare radiation is due to non-thermal mechanisms, flares may have fine structures on time scales in the range 10^{-6} – 10^{-1} s, while for thermal mechanisms significant details on flare light curves must exceed 0.1 – 1 s. Therefore, the fact that the rise times for all of the observed events exceed 0.2–0.3 s implies that there is no evidence that the optical flare radiation is excited by a non-thermal mechanism, even at the very beginning of flares.

Within the framework of the thermal gas-dynamic model of flares on UV Cet type stars (Katsova et al., 1981; Katsova and Livshits, 1986), the lifetime of the rising phase is ultimately determined by the time interval to shift the front of a shock wave that propagates along a magnetic flux tube, toward the stellar photosphere, i.e., to a distance of about one scale height of the stellar atmosphere. According to this model, $\tau_{min} = v_s / M g$, where v_s is the sound velocity in the low quiet chromosphere, M is the Mach number for the downward shock wave and g is the gravity acceleration at the stellar surface. We have used Rodonò's (1987) g data for flare stars and the estimate of $M < 30$ by Katsova and Livshits (1986) to calculate τ_{min} for the flare stars in Fig. 2 and for EV Lac, a very rapid flare of which was detected with a temporal resolution 0.61 s with the space astrophysical station ASTRON (Gershberg and Petrov, 1986). In Fig. 3 the computed τ_{min} are compared with the observed durations of the leading fronts. For EV Lac we can estimate only the upper limit of such duration. Fig. 3 shows that the observed times are rather close, but never shorter than the theoretical limits. This fact is an argument in favour of the validity of the thermal gas-dynamic model for stellar flares on UV Cet type stars.

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