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TIME - EVOLUTION OF COLOURS OF TWO EV Lac FLARES

Time - evolution of colours of pure flare radiation has been a subject of many studies with controversial conclusions. Earlier studies by Chugainov (1961, 1965) and Kunkel (1967) revealed reddening of the $(B-V)_f$ and $(U-B)_f$ colours of pure flare radiation during the decay of stellar flares. Kunkel (1967) assumed a two-component model consisting of hot plasma and photospheric bright spot, the cooling of the later being responsible for the observed reddening of flare colours. Kodaira et al. (1976), Cristaldi and Longhitano (1970) and Pettersen (1983) found no time changes of flare colours and suggested that flare colours remain essentially constant during flares. The general consensus on this point at the Catania meeting in 1982 (IAU Coll. No 71) seemed to be that flare colours remain constant with perhaps a little reddening in the last stages of flares (Byrne, 1983). This controversy is probably due to the difficulties in measuring colours of pure flare radiation and the common large observational errors.

In August and September 1985, in the framework of cooperation between Bulgarian Academy of Sciences and the Academy of Finland, joint monitoring observations of the flare star EV Lac were carried out with the Finnish 5 - channel UBVRI photometer-polarimeter attached to the 2 m telescope of the Bulgarian National Astronomical Observatory - Rozhen. The Finnish photometer-polarimeter is of the same type described by Piirola (1975). The photometer design makes it possible to obtain strictly simultaneous observations in all UBVRI colours, which is especially suitable for studies of stellar flares. On Sept. 11, 1985, two flares were observed, No 21 and No 22 of our sample. The amplitudes at maximum (in mag) for Flare 21C (21A and 21B are only small precursors) are: $\Delta U=1.23$, $\Delta B=0.23$, $\Delta V=0.08$, $\Delta R=0.02$ and $\Delta I=0.01$. The amplitudes for Flare 22 are: $\Delta U=2.36$, $\Delta B=0.70$, $\Delta V=0.27$, $\Delta R=0.09$ and $\Delta I=0.02$. Flare 22 is the largest in our sample with a total duration of more than 2.5 hours and time of rise $\sim$ 24 minutes. Pure flare colours $(U-B)_f$ and $(B-V)_f$ were determined for these flares. $(U-B)_f$ versus $(B-V)_f$ are plotted in Fig. 1.

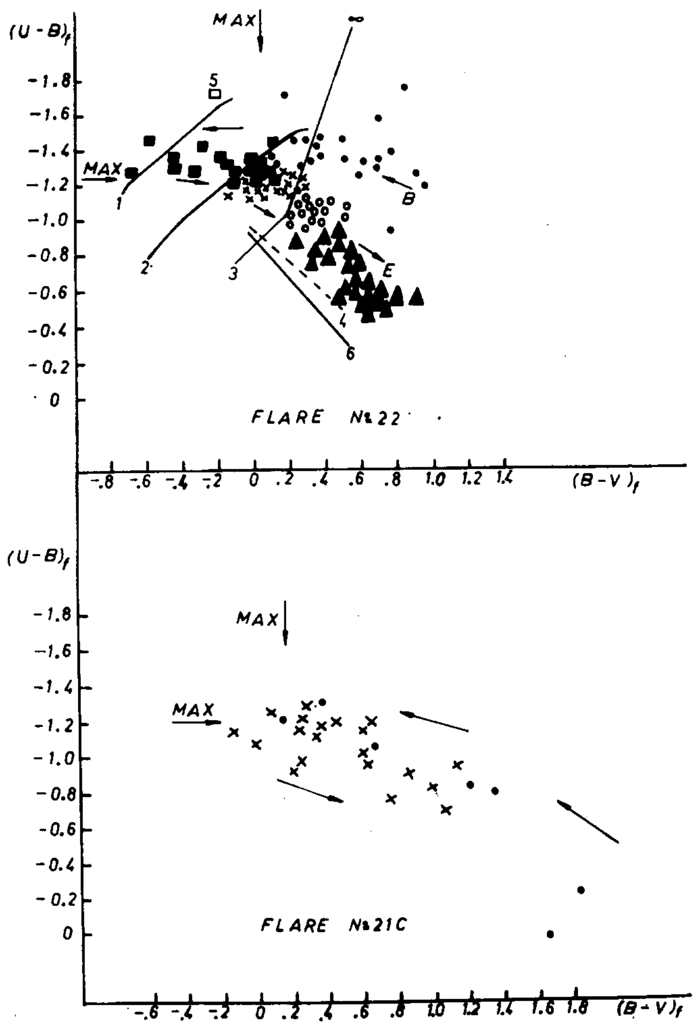

Figure 1

Upper pannel: Two colour diagram of Flare 22. Different symbols stand for different phases of the flare (see text). Arrows show direction of time-evolution. Letters "B" and "E" denote begin and end, respectively. Two arrows show the position of maximum brightness. Lines with numbers represent models: 1 and 2 , nebular models by Kunkel (1970) for T; 14000 K and 25000 K , respectively; 3, model of Gershberg (1967) for T= 80000 K and "border line"; 4, synchrotron ; 5, model of Gursadian (1985) for n = 1 and γ^2= 10; 6, black body. Lower pannel: Two colour diagram of Flare 21C. Points represent observations from flare begin to flare maximum.Crosses are observations after flare maximum.

Different symbols stand for the different phases of the flares. Lines represent different models.

Conclusions:

1. There is strong evidence in support of time-evolution of flare colours.
2. On the ground of Flare 22 diagram time-evolution of colours of pure flare includes four stages:

i/ The initial flare colours are: $(U-B)_f \sim -1.2$ and $(B-V)_f \sim 0.6$.
During the first phase there is a transition to the left upper corner of the diagram (point symbols) - to a region with colours $(U-B)_f \sim -1.4$ and $(B-V)_f \sim -0.5$.

ii/ Transition to a region with $(U-B)_f = -1.2$ and $(B-V)_f = 0$ (squares). This is the position of maximum brightness.

iii/ The third phase begins with the maximum brightness. During this phase there are little changes of both $(U-B)_f$ and $(B-V)_f$.
For Flare 22 this phase lasts about 40 minutes and flare colours remain approximately constant. Though there might be a small decrease of both colours near the end of this phase (crosses).

iv/ Final or "reddening" phase. From the region with $(U-B)_f = -1.2$ and $(B-V)=$ 0 transition takes place to the right lower corner of the diagram (circles and triangles). By the end of the observations flare position was: $(U-B)_f \sim -0.5$ and $(B-V)_f \sim 0.8$. Observations were stopped before the end of the flare.

The two colour diagram of Flare 21C shows similar transitions,except that the second phase cannot be distinguished. For this flare the initial flare colours are redder: $(U-B)_f \sim -0.8$ and $(B-V)_f \sim 1.3$, or even redder:

Our observations show that time-evolution of flare colours is quite complicated. The existence of four phases in the development of Flare 22 is supported also by the study of its U,B,V amplitudes. None of the existing theories of flares provides an adequate description of time-evolution of flare colours, shown in Fig. 1, and the matter is still far from clear.Nebular theories of Gersberg (1967) and Kunkel (1970) seem to fit observations of colours around maximum (i.e. phases 2 and 3 from the previous discussion). During the final (reddening) phase flare radiation might be dominated by emission of a gradually cooling bright spot. The most difficult part of the present picture seems to be the initial flare phase, for which no theoretical account exists. Observationally, this is the most difficult part of flares too and further observations are needed.

In the theory of Gursadian (1985) evolution of colours of pure flare radiation is only possible, if changing flare-geometry is assumed. For each of the two flares discussed above we would have to admit the same sequence of flare geometrical positions, which is unlikely.

A detailed account of the present work will be submitted to the Astronomy and Astrophysics.

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