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Flares in Low State in KR Aurigae

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Abstract

We present examples of light curves observed during the last low state of the cataclysmic variable KR Aur, containing flares with amplitudes up to 2 magnitudes. We calculate the energy of these flares and compare with the energies of similar events in the Sun, single eruptive stars and cataclysmic variables.

The relatively high energy of the flares (10^{33} – 10^{35} erg) in *UBV* bands can be interpreted as evidence of their accretion origin.

Introduction

KR Aur is a novalike cataclysmic variable (CV). It is member of VY Scl class and occasionally drops to low state with 6 mag down from its normal brightness. Long-term light curve from 1980 to 2021 is presented on Fig.1.

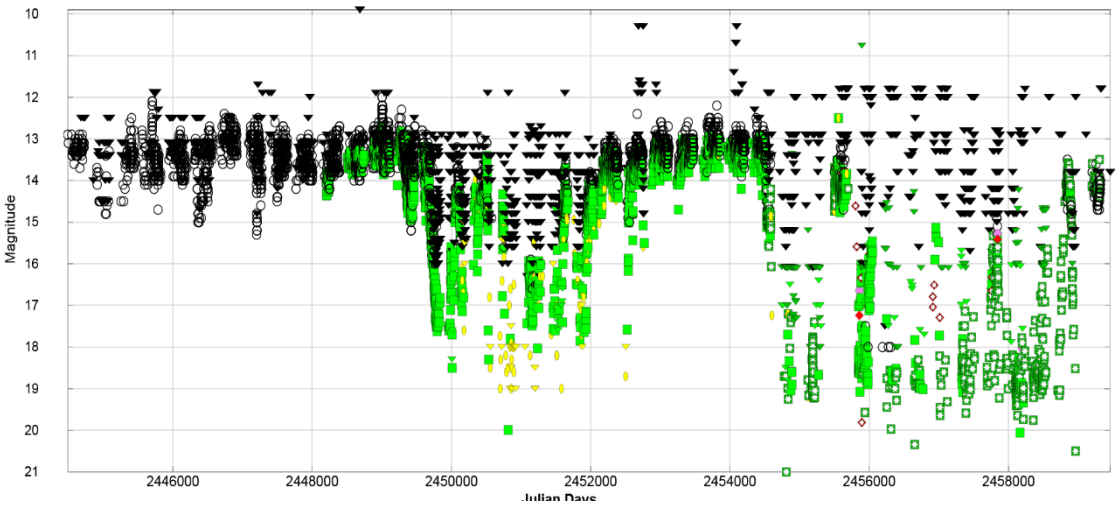

Fig.1. Long-term light curve from 1980 to 2021 from AAVSO data. The two low states of KR Aur in 1994-2001 and 2008-2020 are clearly visible.

The system consists of a white dwarf with mass 0.94 $M_\odot$ and a red dwarf with mass 0.37 $M_\odot$ [Rodríguez-Gil et al. 2020]. In high photometric state the brightness of system is dominated by the accretion disk. In low state the disk is weak or lacking due to reduced mass transfer rate from the secondary component. The solar type magnetic cycles of the secondary can be the reason for such a behavior [Bianchini 1990]. It is possible, the system to be detached for some time. Nevertheless, we rarely observe flares with high amplitude during the low state 2008-2020. Flaring activity in the light curve and in the spectra due to episodic accretion was reported by Rodríguez-Gil et al. (2020).

The spectral type of the secondary is M4-5V. Such low mass stars have relatively strong magnetic fields and can produce flares with energy 10^3 – 10^4 times greater than observed on the Sun (10^{28} – 10^{32} erg) [Paudel et al. 2021]. Flares emit significant energy from X-ray, UV, optical, infrared to radio wavelengths.

Results and discussion

We use observations, obtained with the 2 m and the 50/70 cm Schmidt telescopes at NAO Rozhen and 1.4 m telescope at AS Vidojevica during the latest minimum of KR Aur [Boeva et al. 2012, 2021]. Only a part of the low-state observations contain flare activity in KR Aur. Light curves with duration 3-6 hours in one (17.02.2018) and 3 bands (20.01.2009; 26.02.2009; 23.02.2017) are selected and plotted on Fig. 2.

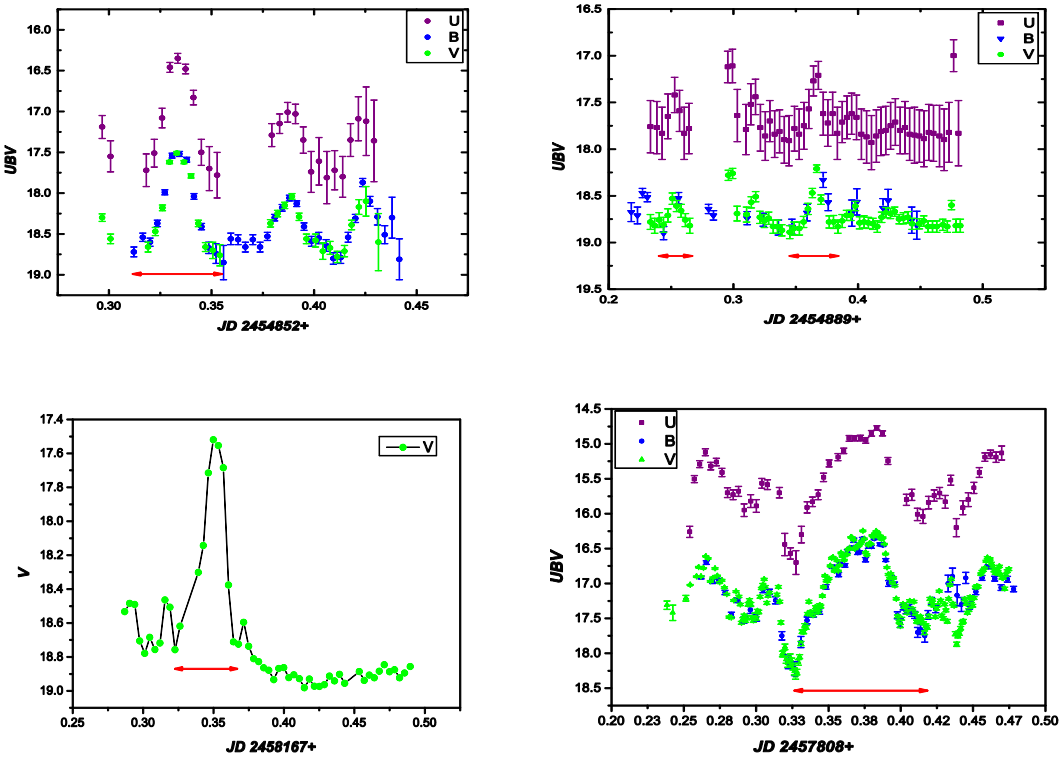

Fig.2 Light curves of KR Aur in low state. Flares used for calculation are marked with red arrows. The arrow's length correspond to the flare duration.

In low states for some CVs flares were reported: with durations 15 – 90 min with amplitudes up to 0.6 mag for AM Her [Kafka et al. 2005], with durations ~ 30 min and amplitudes up to 2 mag for MV Lyr [Scaringi et al. 2017]. Our observations show even larger amplitudes. The brightest flare observed on 23.02.2017 in *UBV* bands has amplitude ~2 magnitudes (2.08 mag in *V*) and duration more than 2 hours. Similar flare was reported by Shakhovskoy et al. (1993) in low state of AM Her (duration ~ 20 min, ΔV = 2.14 mag).

We calculate the energy of the flares for different filters using the relation:

$$E = 4\pi d^2 F_\lambda \Delta\lambda \Delta t$$

where d is the distance (we used d=500 pc), F_λ is the flux, $\Delta\lambda$ is filter's equivalent width and Δt is duration on the flare.

In Table 1 we present our results. The values of ***E*** are larger for blue and UV bands in comparison to the visible band (V band). The weaker flares with amplitude ~ 0.3 mag show energy ~ 10^{33} erg and the strongest flare reaches 10^{35} erg.

Date	A [mag]	Δt [min]	E_U [x 10^{33} erg]	E_B [x 10^{33}erg]	E_V [x 10^{33}erg]	E_U/E_B	E_U/E_V
20.1.2009	1.25-1.50	70	38.67	25.35	12.45	1.53	3.11
26.2.2009	0.30-0.40	30	3.08	2.17	0.98	1.42	3.15
26.2.2009	0.60	45	5.10	4.61	2.26	1.11	2.25
23.2.2017	1.50-2.00	120	482.79	466.70	135.22	1.03	3.57
17.2.2018	1.30	65			10.64		

Tabl.1 Date of observations, amplitude, duration and calculated absolutely and relative energy of the flares in UBV bands.

The total energy of the flare is few times more than the energy in *U* or *B* band. For single M dwarfs (flare stars) observed simultaneously in different bands Gershberg & Shakhovskaya (1983) derived relation:

$$E_U = 1.2\ E_B = 1.8\ E_V.$$

For the total optical radiation they give:

$$E_{opt} = 3.5\ E_U = 4.2\ E_B.$$

In the case of KR Aur average values are:

$$E_U = 1.3\ E_B = 3.0\ E_V.$$

The coefficients are larger and depend on the flare. Probably it is due to the different temperatures of the flares.

Woods et al. (2004) obtained that only ~ 20 % of the flare's energy was emitted at UV and X-ray bands and assumed that the main part of the energy was emitted at optical wavelengths. If we use the approximation for the total energy:

$$E \approx 5\ E_U,$$

the energy of the flares is from 10^{34} erg for weak to 10^{36} erg for the strongest flare. These values are close to the energy of the most powerful flares in other systems (~ 10^{36} – 10^{37} erg) [Schmitt et al. 2019].

Contrary to the normal flares in active single stars, the shape of the flares in KR Aur is almost symmetrical or with slower rising than declining. Relatively high energy even for weak flares can be explaine with accretion of blobs on the white dwarf. Therefore our data support the claim of an accretion origin of the flare events proposed by Rodríguez-Gil et al. (2020).

Coronal mass ejections (CME's) in the Sun contribute 15-20 % of the mass loss rate. CME's in secondaries in CVs can provide blobs and episodic mass transfer, which can produce such flares.

Conclusions

Our observations in low state show flares in KR Aur with duration 30-120 min and amplitudes 0.3 – 2.0 mag in *UBV* bands.

The calculated energy of the flares is 10^{33} - 10^{35} erg. The energy in U is on average 1.3 times more than E_B and 3.0 times more than E_V. The total energy of the largest flare is estimated to be close to the strongest flares in other systems.

The shapes and energies of the flares support the claim of an accretion origin of the observed flare events. Coronal mass ejections from secondary star can be the reason for these events.

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