PROCEEDINGS OF SCIENCE

Optical flickering of KR Aurigae in different states

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We present observations of the cataclysmic variable KR Aurigae. The observations cover different conditions – at normal state prior 2008 and during the last 12 years long deep minimum. We investigate how the rapid variability of the system changes depending on the state.

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1. Introduction

KR Aur is a cataclysmic variable discovered in 1960 by M. Popova. It is one of the only two variables from VY Scl type which low states can have a duration of the order of 10 years. Three such deep states of KR Aur were observed – in the 30s and 40s of 20th century (Liller, 1980), in 1994 – 2001 and the last 12 years long minimum started in 2008 (the longest observed low state).

Such deep low states are rare and there is no enough data collected with a good photometric accuracy. We studied a rapid variability (flickering) during the recent minimum and we compared it with normal state variability.

2. The system

KR Aur is a member of VY Scl subclass nova-like variables. They are non-magnetic systems (~ 10^5 G) with a predominantly high accretion rate ~ 10^{-9} $M_{\odot}$/ yr and bright stable accretion disks (about 6 mag for KR Aur). They rarely present low states with drops of a few magnitudes lasting typically months or years.

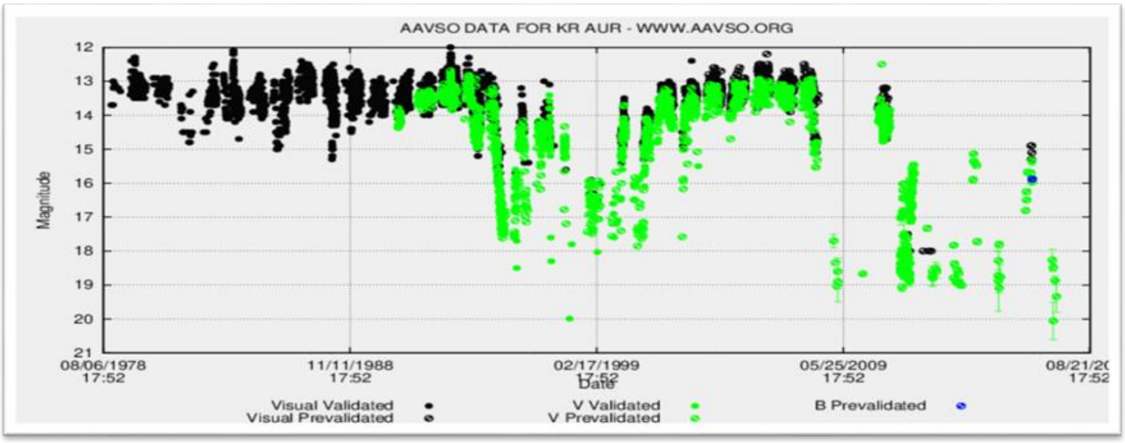

Fig.1 Long term light curve of KR Aur (1978 –2019) from AAVSO.

Usually KR Aur is in high state with V~13.5 mag and rarely fades to 18-19 mag. The light curves commonly present flickering with amplitude of few tenths of magnitude. The spectroscopic period is typical for VY Scl type - 3.907 h (Shafter, 1983). The mass of the components are 0.7 or 0.59 $M_\odot$ for the white dwarf and 0.48 or 0.35 $M_\odot$ for the red dwarf according to Shafter (1983) and Ritter and Kolb (2003).

On Fig.1 are shown several short minima in 1980s with drops of about 2 magnitudes and next two deep minima. In the low state the brightness is not constant – there are some rises to intermediate state and subsequent decreases to very low magnitudes.

3. Energy distribution

Following the decrease of brightness the energy distribution of the system changed. While in a high state the energy distribution is close to power low distribution ($F_\lambda \sim \lambda^{-\alpha}$) of an accretion disk, in low state it could be detected a contribution of radiation from the white or the red dwarf. On Fig.2 are shown fluxes in UBVRI bands for 2 nights in high and low state.

It seems that in the case of KR Aur even being in deep state, the weak (up to 1 – 2 mag) accretion disk exists (Boeva et al., 2010) because the flickering activity never stops completely.

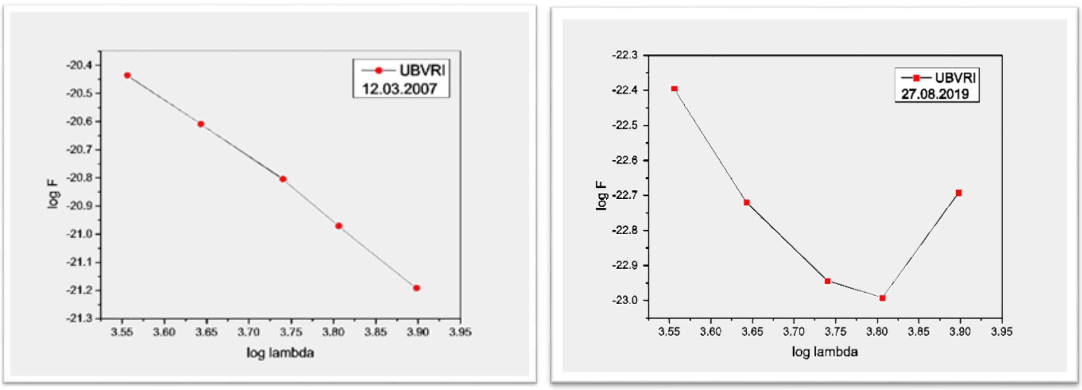

Fig.2 Energy distribution (UBVRI) on 12.03.2007 (high state) and 27.08.2019 (low state) corrected for interstellar reddening.

4. Fast brightness variations

Rapid brightness variations with an amplitude of few hundredths or tenths of a magnitude (flickering) are a common property of the cataclysmic variables. In the light curves are often seen different periodic or quasiperiodic oscillations with periods of range of seconds or minutes.

4.1 Flickering in high state

At normal brightness KR Aur always has fast variations with amplitude 0.2 – 0.5 mag which are seen even on time scales of minutes. In the blue bands (U, B) the amplitude is larger than in V and in the red ones (R, I) as it is shown on Fig.3a, but the shapes of the light curves are similar. Often in the light curves are visible quasiperiodic oscillations (QPOs). The periods of QPOs are about 5-10-15 min, but sometimes were detected longer periods - about 20 min or even 40 min (Georgiev et al., 2012). These periods change from night to night (Singh et al., 1993). Probably on short scales (5-10 min) the variations are stochastic, but on larger scales they have another nature (Bachev et al., 2011). We also found no time lags of the flickering in different bands longer than 30 s.

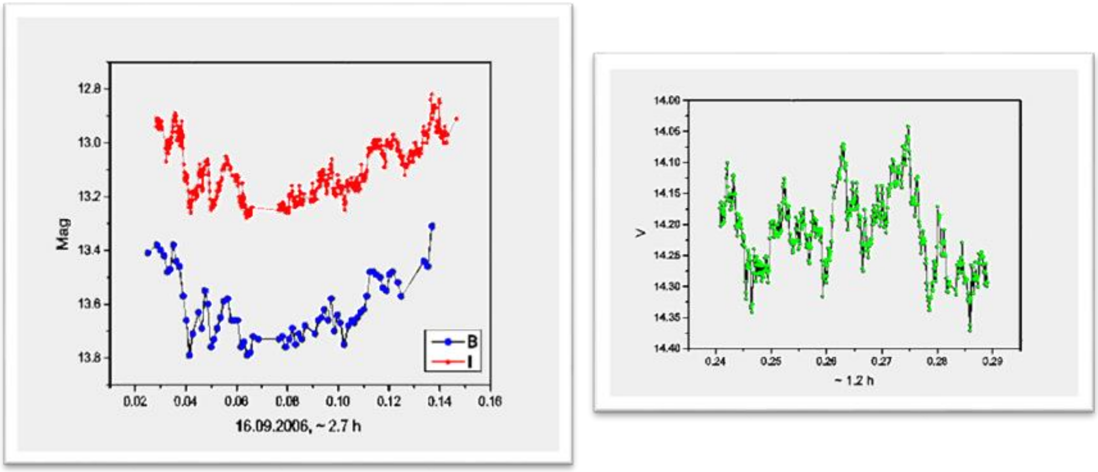

Fig.3 a) Simultaneous BI light curve on 16.09.2006; b) QPOs (~ 16 min) on 08.02.2011 in V band.

4.2 Flickering in low state

In low state we observed also fast brightness variability however it appears quite different. In the light curves with duration of several hours we detected single increases of the brightness with large amplitude reaching even more than 1 mag as well as states with no variations. Such structures are shown in Fig.4. These “flares” could be interpreted as accretion of single blobs onto the white dwarf and they have a typical duration about 1 h. On 20.01.2009 we observed series blobs, while on 17.02.2018 there was only one and for 2 hours flickering did not exist.

On 23.02.2017 we observed extremely large amplitude of brightness variation – more than 2 mag with a duration of single “flare” more than 2 hours (Fig.5a). Probably in the system KR Aur at minimum exists almost permanent but unstable mass transfer.

In the low state flickering amplitude also grows in the blue filters but we have examples when this does not occur. Fig. 5b shows 8 hours light curve with R amplitude ~ 0.2 mag and B amplitude ~ 0.1 mag. It is possible that in this case we observed ellipsoidal variations of the red dwarf because the two minima in R band are approximately one orbital period apart.

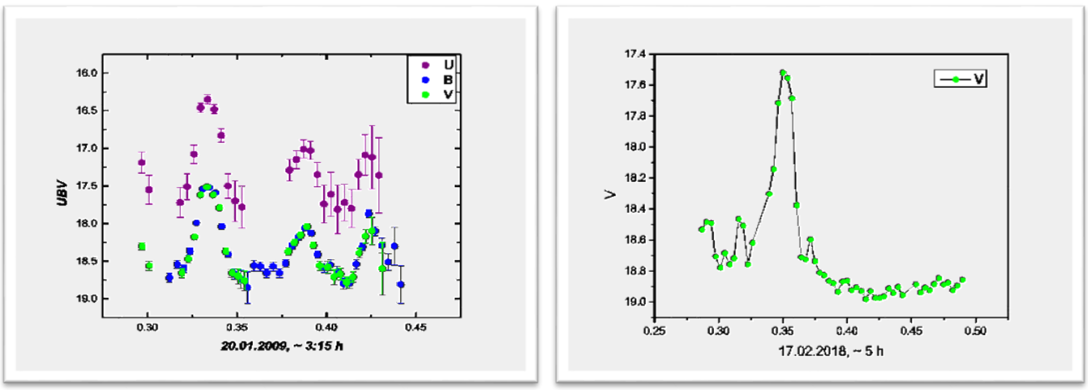

Fig.4 a) Simultaneous UBV light curve on 20.01.2009 (from Boeva et al., 2012); b) V light curve on 17.02.2018.

In low state QPOs are not seen and light curves are more "smooth" but it can be a result of the low time resolution of the observations. Usual exposures at minimum light are 5 min while in high state we use exposures of a few seconds. Then 5-10 min QPO will be described only with 1-2 points and will not be visible.

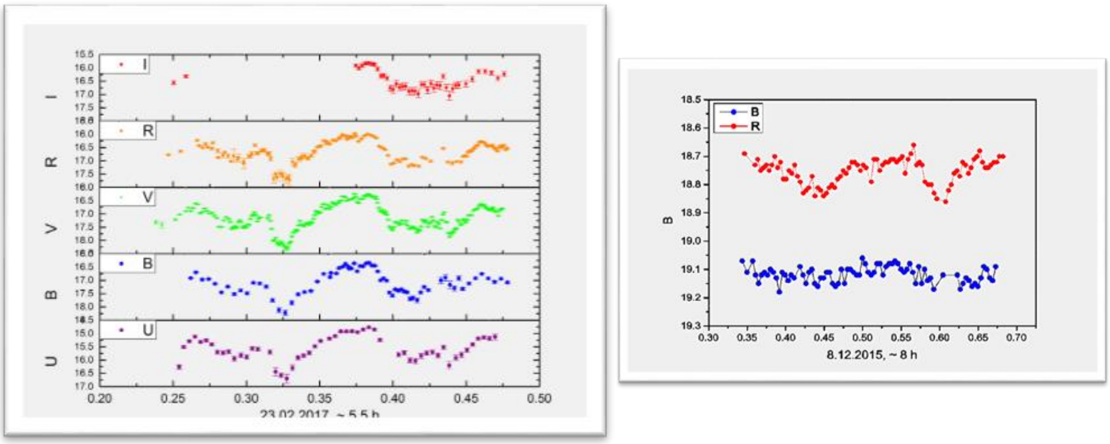

Fig.5 a) Simultaneous UBVRI light curve obtained on 23.02.2017 with 4 telescopes and 5 CCD cameras in Bulgaria and Serbia; b) BR light curve obtained on 8.12.2015 with 2 m telescope of NAO Rozhen and 2 channel focal reducer FoReRo2.

5. Parameters of flickering light source

Using method described by A. Bruch (1992) we calculated colors, temperature and radius of the flickering light source in high and low state. We use black body approximation for determination of its temperature.

At minimum flickering source become bluer: $(B-V)_0$ is changing from 0.00 in high state to -0.09 in the low one, but $(U-B)_0$ is undergoing much significant variation from -0.61 to -1.55. The temperature of the flickering source increases from 9 500 *K* to 41 000 *K*. It is the highest temperature which we calculated so far for several cataclysmic or symbiotic stars.

Unlike the values of a few $R_\odot$ obtained for the radius of the flickering light source for the recurrent symbiotic nova RS Oph, we calculated for KR Aur 0.28 $R_\odot$ in bright state and 0.03 $R_\odot$ in deep state. Such values are probably due to the less optical thickness of the radiating area, especially in the deep state when the accretion disk is much weaker.

6. Conclusions

The fast variations of the brightness of KR Aurigae are changing in different states. At the minimum could are observed very small (less than 0.05 mag) as well as very high (up to 2 mag) flickering amplitudes. QPOs do not exist or they are not visible in the faint state due to the low time resolution of the observations.

We estimate the flickering source parameters as T = 41 000 *K*, R = 0.03 $R_\odot$ in low state and respectively as T = 9 500 *K*, R = 0.28 $R_\odot$ in high state. The higher temperature and the lower size of the flickering light source at minimum can be due to that the source is directly visible.

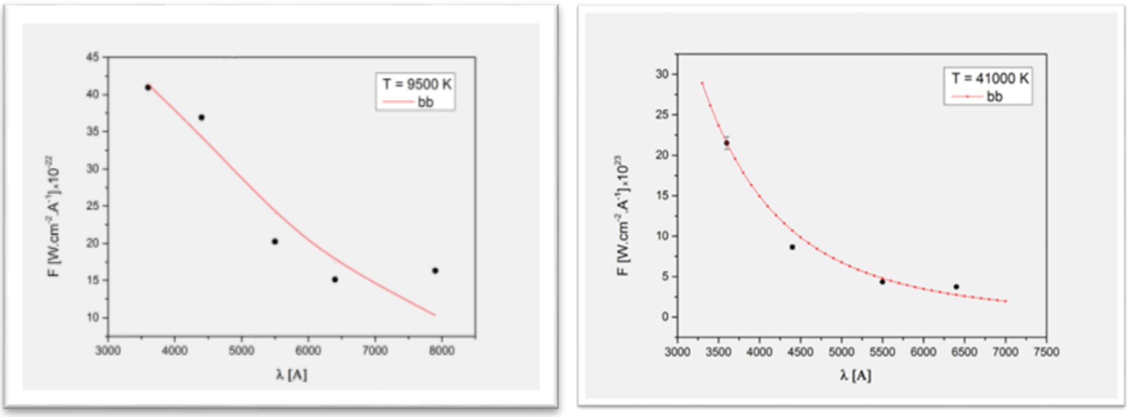

Fig.6 Black body approximation for the flickering light source derredened fluxes in high and low state.

Acknowledgements

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DISCUSSION

KENJI TANABE: Please tell me the diameter of the telescopes for your photometric observations. (The reason for this is that whether the variations you detected are real or noise.)

SVETLANA BOEVA: We used different telescopes – with diameter from 60 cm to 2 m. For example in Fig.4 we used data from 2 telescopes: 2m for U and V bands and 50/70 cm Schmidt telescope for B band. Fig.5 was obtained with data from 4 telescopes. In low state the brightness of KR Aur is close to the limit of the small telescopes. Usually the photometric errors are several hundredths of magnitude but sometimes they could be several tenths of magnitude. Despite of this the shapes and amplitudes of the light curves in all filters are similar.