THE CATACLYSMIC BINARY KR AURIGA IN FEBRUARY 2002: FLICKERING AND OSCILLATIONS

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КАТАКЛИЗМИЧЕСКАЯ ДВОЙНАЯ KR AURIGA В ФЕВРАЛЕ 2000 г.: МЕРЦАНИЕ И КОЛЕБАНИЯ, Верлюк И., Жиляев Б. – KR Aur известна как антикарликовая новая в тесной двойной системе, состоящей из белого карлика и красного карлика с орбитальным периодом 3.91 часа. Мы представляем первые результаты высокоскоростного мониторинга KR Aur в течение трех ночей в феврале 2002 г., полученные на 2-м телескопе обсерватории Терскол в полосе U с временным разрешением 0.1 с. Наши наблюдения показали, что KR Aur была в ярком состоянии. Были обнаружены быстрые мерцания (фликеринг) и колебания с амплитудами от нескольких сотых до нескольких десятых звездной величины на временном масштабе от нескольких секунд до нескольких минут. Полная мощность быстрых вариаций составляет приблизительно 1.2 % в полосе U. Обнаружено колебание в окрестности 0.04 Гц со временем когерентности не меньше чем 7000 циклов. Амплитуда колебания около 0.6 % в полосе U.

KR Aur is known as an anti-dwarf novae in a close binary system consisting of a white dwarf and a red dwarf with orbital period of 3.91 hours. We present first results of the high-speed monitoring of KR Aur during three nights in February 2002 with the 2-m RCC telescope at Terskol Peak in the U band with a time resolution of 0.1 s. Our observations revealed that KR Aur was in its bright state. Rapid flickering and coherent oscillations were observed with amplitudes of some hundredths to some tenths and on time scales of some seconds to some minutes. The total power of short-term variations amounts to about 1.2 % of stellar luminosity in the U band. A coherent oscillation around 0.04 Hz is seen during several nights. Its coherence time is of no less than 7000 cycles. The pulsed fraction is 0.6 % in the U band.

INTRODUCTION

KR Aur is classified as an anti-dwarf novae. From time to time it exhibits brightness drops by a considerable amount, the flickering activity with amplitudes to some tenth of a magnitude on wide time-scales, monochromatic and quasi-periodic oscillations with periods of seconds to minutes in the optical and in the X-rays range. KR Aur has been observed photometrically during the high state in the U band with the 2-m telescope at Terskol Peak equipped with a high-speed two-channel photometer in the period of February 8–10, 2002. The sampling time of 0.1 s and the exposure time up to one hour were used. The light curve were found highly variable on time scales from seconds to minutes. Simultaneous light curves of a reference star during the observing runs show brightness fluctuations, which did not exceed photon noise.

FLICKERING

A phenomenon called flickering is present in all dwarf novae in all stages of activity [1]. This is the random brightness variations with a continuous distribution in frequency. Flickering activity has been claimed to arise from the hot disk close to the white dwarf. The frequency distribution gives some indication about the geometrical extent of the flickering source, namely there is either a point-like source or an extended optically thick one. Our observational data permit to trace the flickering properties up to 5 Hz. As it can be seen below the KR Aur flickering drops practically to zero on time-scales as short as 5 s.

In view of random nature of flickering, there is some difficulties to detect intrinsic small fluctuations hidden by noises. A new promising tool for solving the problem concerns the theory of count statistics. The intrinsic activity can be detected using the the factorial moments [3]

$$\left\langle \frac{n!}{(n-k)!} \right\rangle = \langle n(n-1)...(n-k+1) \rangle = n_{[k]}, \tag{1}$$

where the angle brackets denote time average. It is convenient to use the normalized factorial moments

$$h_{[k]} = \frac{n_{[k]}}{\langle n \rangle^k}.$$

In the case of the Poisson statistics it may be shown that all the moments $h_{[k]} \equiv 1$ identically for any k. Hence, if any $h_{[k]}$ differs from one significantly, we may affirm that variability is detected.

To detect activity of KR Aur on the shortest time-scales the above mentioned relation was applied. The expression for the factorial moment of second order

$$\varepsilon = \frac{\sigma^2 - \langle n \rangle}{\langle n \rangle^2} = h_{[2]} - 1$$

specifies the relative power of fluctuations ε in the frequency domain $\Delta f = \left(\frac{1}{2\Delta t} - \frac{1}{N\Delta t}\right)$, where Δt is the sampling time, N is the length of the data segment, $\langle n \rangle$ and σ^2 are the sample mean count rate and the variance, respectively. Choosing the appropriate values of N and Δt one can calculate the power spectrum of fluctuations by averaging of ε over time. The standard deviation for $h_{[2]}$, as shown by Zhilyaev *et al.* [5], is defined by the relation

$$std(h_{[2]}) \simeq \frac{1}{\langle n \rangle}\sqrt{\frac{1}{N}}.$$

The actual value of ε caused by atmospheric scintillation can be determined from the measurements of a reference star. The difference in ε between the observed relative power of the star and that of the atmospheric scintillation is taken to be the intrinsic ε – spectrum of star.

Fig. 1 shows portions of the light curves of KR Aur and its reference star. Raw U data indicate obvious variability on KR Aur with amplitude about of 0.15 mag. At the same time, a reference star shows brightness variations, which did not exceed photon noise. A demonstration of the ε-technique is shown in Fig. 2. The ε-spectrum of a reference star does not overflow the 95 % confidence barrier.

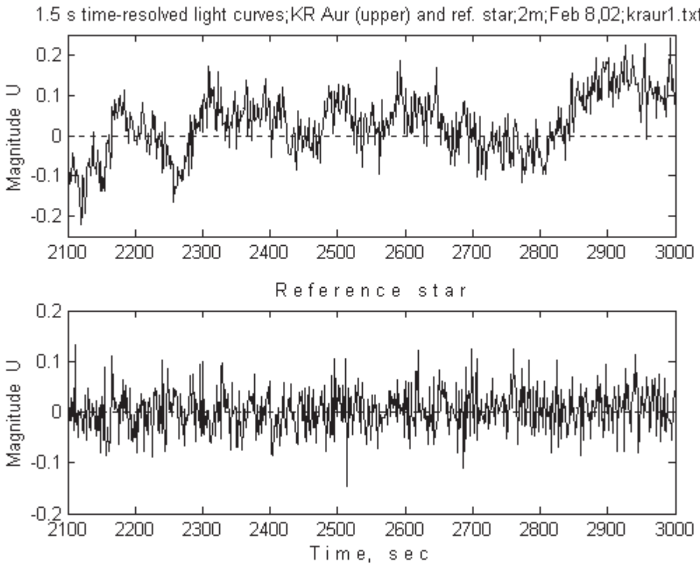

Figure 1. The time-resolved (1.5 s) light curves of KR Aur (top) and of a reference star (bottom) on February 08, 2002. Terskol Peak, the 2-m telescope, the U band

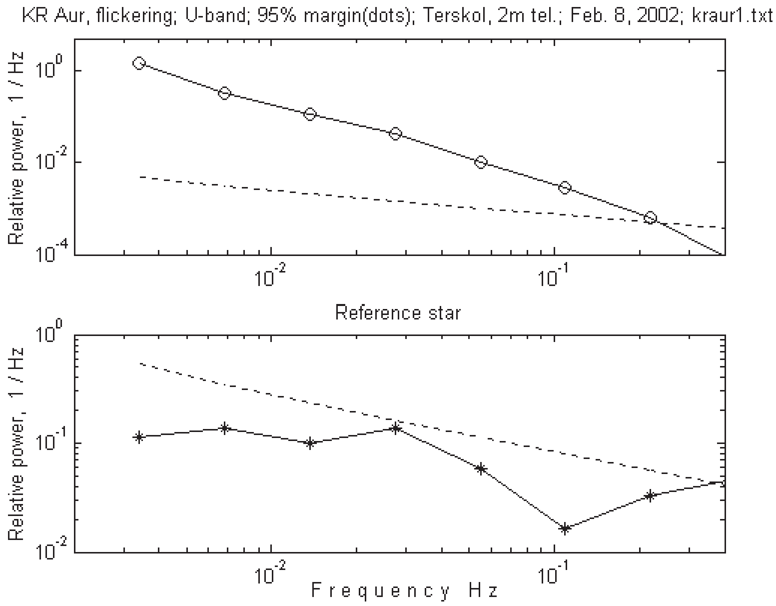

Figure 2. The relative power spectra of KR Aur (top) and of a reference star (bottom). The upper 95 % confidence level is shown as the dashed line

The distinctly different situation occurs in the case of KR Aur. The ε-spectrum indicates clearly the presence of activity in the range 0.003–0.2 Hz. Relative power of short-term variations on KR Aur is found to be about 1.2 % of the total luminosity in the U band. For frequencies higher 0.2 Hz flickering lies under the threshold level.

If the fluctuations are due to randomly occurring light pulses (shot noise), than the shape of the power spectrum, according to the Carson theorem, is the same that for any individual pulse [4]. In the case of shot noise the rate of the pulses, their effective length can be established from the continuous power spectrum for low frequencies. A competing mechanism producing the variability in optical luminosity can be accounted for by more or less periodic light source. Observations give evidence for the presence of such periodicities.

OSCILLATIONS

Besides of flickering, the coherent oscillations are seen to occur in dwarf-novae in their bright state on time-scales of typically 10 to 30 s, amplitudes of 0.0005 to 0.005 mag [1].

To investigate the oscillation frequency spectra the light curves in the U band were subjected to the standard power spectrum analysis. To detect small oscillations, large intensity variations were first removed. We apply the high-pass digital filtering, the cutoff frequency value of 0.02 Hz was employed. The Tukey spectral window was used in this analysis [2]. The normalized power spectra of KR Aur on Feb. 8, 2002, 17:28 UT; Feb. 10, 2002, 17:00 UT; Feb. 10, 2002, 17:53 UT are shown in Fig. 3. The normalized power evaluates a contribution of the harmonic to the total variance. The frequency resolution in all the spectra is 0.0009 Hz. The 99 % confidence level for the white noise data is shown as the dashed horizontal line. Inspection of the power spectra reveals that all the significant harmonics (0.023, 0.029, 0.039, 0.059 Hz) appear being similar to coherent oscillations. The harmonic at 0.039 Hz is very stable and is present for two days, other harmonics are present at any rate for two sets of observations lasted about 2 hours. They showed the coherence time of no less than 7000 and 150 cycles, respectively. The pulsed fraction of the U radiation is of typical value of 0.006 mag at all events.

As mentioned above, high-pass digital filtering of the light curves was applied to study short-term variations. The well-defined long-period oscillations are clearly seen in Fig. 1 as well. The power spectrum analysis had shown the low-coherent oscillations with the periods of 125, 69, 61, 56 and 51 s. These harmonics were, however, eliminated from consideration as being less trustworthy.

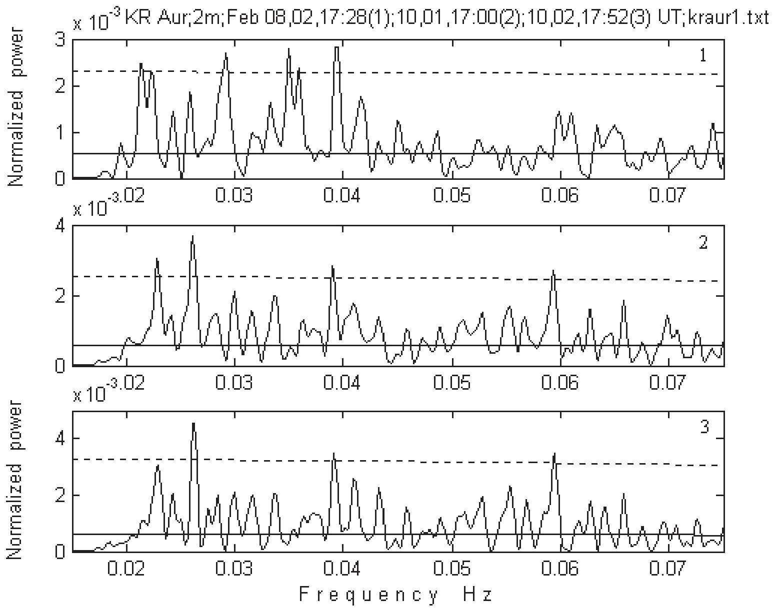

Figure 3. The power spectra of KR Aur on Feb. 08, 2002, 17:28 (1); Feb. 10, 17:00 (2); Feb. 10, 17:52 (3) UT. The 95 % confidence level for noise peaks is shown as the dashed line

FLICKERING OR OSCILLATIONS ?

What really results in variability: flickering or oscillations? A typical power spectrum of flickering shows a continuous density distribution. The power spectra of KR Aur showing multi-peak structure, point rather to oscillations as the most favored mechanism. One can assume that the oscillation frequency may be identified with the Keplerian frequency in the hot disk around the white dwarf. The Keplerian frequency for a $0.5M_{\odot}$ white dwarf nearly its surface is ~ 0.070 Hz. Some orbits by the inner edge of the disk may be disrupted leading to random light pulses formation on the surface of the white dwarf. The maximum oscillation frequency of 0.059 Hz corresponds to the Keplerian orbit at a distance of the 1.12 white dwarf radius.

CONCLUSION

The high-speed monitoring of the anti-dwarf novae KR Aur in its bright state was performed during three nights in February 2002. The total power of short-term variations, rapid flickering and oscillations was evaluated to amount to about of 1.2 per cent of that the star radiates in the U band. A coherent oscillation around 0.04 Hz with coherence time of no less than 7000 cycles is seen. The pulsed fraction is 0.6 % in the U band. It was found that the flickering drops practically to zero for frequencies higher 0.2 Hz. The power spectra of KR Aur point to oscillations as the mechanism most favored to its variability in bright state.

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