BRIGHTNESS AND SPECTRUM VARIATIONS OF THE CATACLYSMIC BINARY STAR KR AURIGAE

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The purpose of this work is to study the brightness and spectrum variations of the cataclysmic binary star KR Aur using observational data for the last 30 years.

The star is included in our programme for investigations of close binaries of VY Scl type and since 1980 it has been actively observed at the NAO Rozhen. A characteristic feature of its photometric behaviour are the cyclic deep minima which took place every 8 - 9 years, when the star dropped from 13.5-th to approximately 18-th magnitude. Papers of Popova (1975) and Liller (1980) followed the brightness variations of the star for a time interval of about 100 years, but most informations comprise the last 20 years. In this time interval the number of photometric observations have greatly increased and they have studied the light curve in minima quite well. In 1967 Popova (1970) photographed first spectrum of the star, but up to now there is no organized spectral patrol of the object. Except for some high-dispersion spectra of Shafter (1983) and Hutchings et al. (1983) used for study of radial velocities, there are few sporadic spectral observations with low and medium dispersion which can give only a limited number of spectral characteristics.

In view of the expected drop in the brightness of the object after 1990 it is worthwile, on the basis of the observations available for the last 3 cycles since 1957, to:

1. Analyse the long-term behaviour of the star
2. Follow the changes of the spectrum in quiet state and look for possible spectral changes during the drop in brightness.

I. LONG-TERM BRIGHTNESS VARIATIONS OF KR AUR DURING THE PERIOD 1957 - 1990

Fig. 1 presents mean semiannual photographic magnitudes during this period. Exept for mean magnitudes, the range of magnitude variations is also plotted. Arrows at the abscissa point to the moments when spectroscopic observations were obtained. Fig. 1 is based upon 720 photographic estimates of the brightness known since 1957. About 600 of these estimates are published in the papers of Popova (1975), Liller (1980), Popov (1982), Bortle (1983), Liller and Popova (1984), Popova et al. (1984), Popov et al. (1986), Götz (1983, 1984, 1985, 1986, 1987, 1988) and there are 110 not yet published estimates from NAO Rozhen (1985-1990).

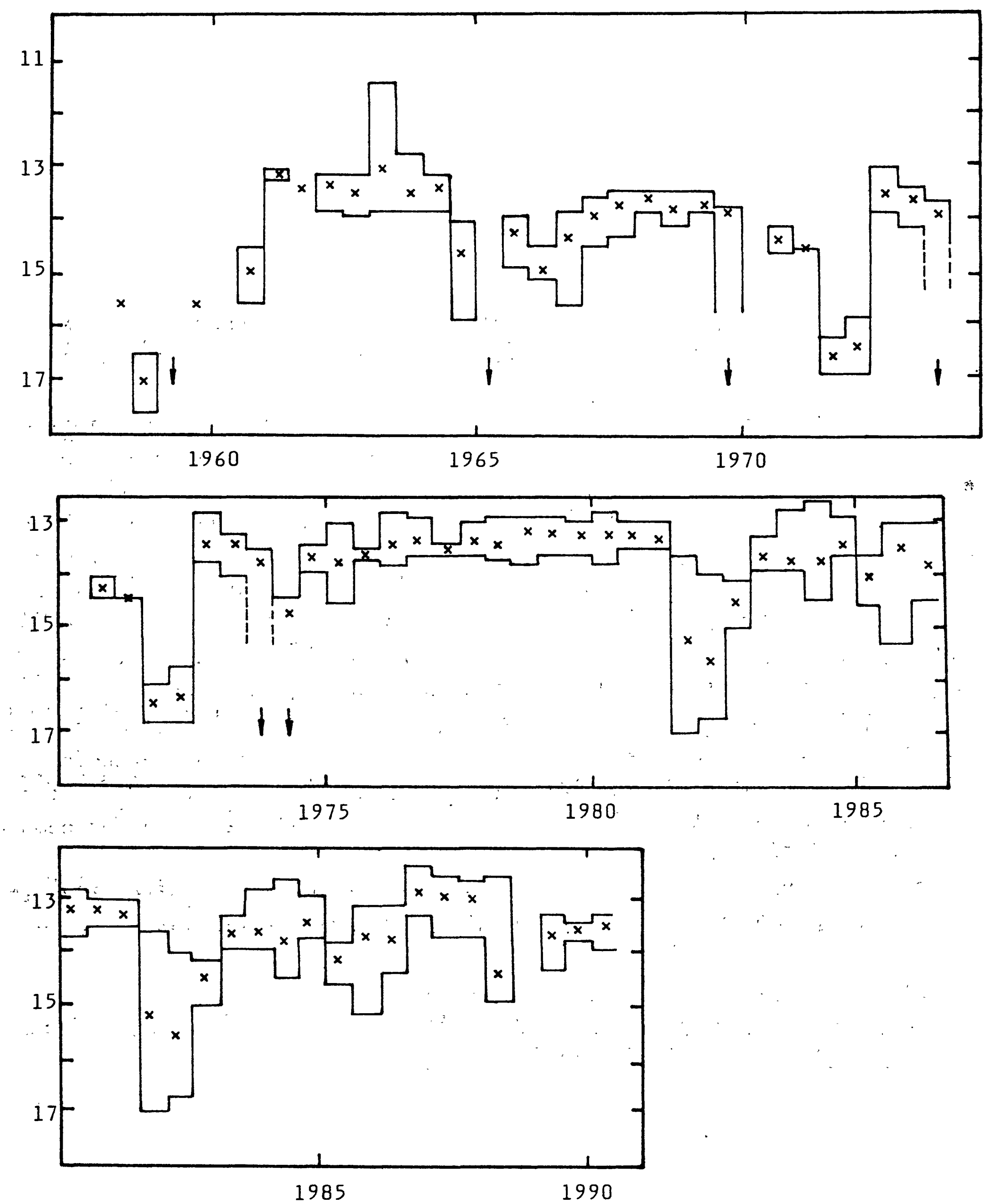

Fig. 1

Observations in 1957-70 were not so frequent and they were especially scarce around the minima. This is a reason for which it is difficult to determine with sure if in 1965 there was end-of-a-cycle deep minimum or if whether there was a big variation in the maximum since such were sometimes observed up to 15 - 15.5 magnitude. It has to be noted that the 1972 - 1982 cycle is characterized with a greater stability in the maximum. This cycle is quite similar to that in 1958 - 1972 and a new deep minimum can be expected in 1992-94.

II. SPECTRAL VARIATIONS OF KR AURIGAE IN 1967 - 1990

Basic results from spectral observations up to now giving a possibility for quantitative estimates are summarized in Table 1.

Table 1

SOURCE	$H\alpha$			$H\beta$			$H\gamma$			$H\delta$		
	W_λ [nm]	FWHM [km/s]	I_ε/I_c	W_λ [nm]	FWHM [km/s]	I_ε/I_c	W_λ [nm]	FWHM [km/s]	I_ε/I_c	W_λ [nm]	FWHM [km/s]	I_ε/I_c
Popova, Vitrichenko (1978), $13^m_.5$ Feb. 1976				0.68	750	0.4						
Hutchings et al. (1983), $13^m_.5$, Nov. 1979 Feb., Sep., Oct. 1980				0.55	710	0.45	0.34	810	0.33	0.2	750	0.22
Shafter (1983), $15^m_.5$ Jan. 1982	8.5	750	2.8	7.0	750	2.2	5.5	750	1.8	4.0	750	1.5
Popov, Kraicheva $13^m_.5$ Feb. 1990				1.15	1000	0.7	0.5	800	0.3	0.4	1000	0.35
Vitrichenko (1981), $13^m_.5$ Jan., Feb. 1978	0.6-1.0	550-1100	0.34 0.70									

All spectra exept those of Shafter (1983) and Wisniewski and Ferguson (1982) are in maximum. In this Table besides the moments of observation and brightness estimates, also equivalent widths, central intensities in continuum units and full widths at half maximum of emission lines are cited. Values presented in the Table are either given in the respective publications or are measured on the registrograms presented there.

In the fourth line in the preliminary results from our observations with the scanner of the 6-m telescope BTA of the USSR Special Astrophysical Observatory are presented. Its characteristics are given by Somova et al. (1982). In

Fig. 2 a record of the spectrum of a 20 minute exposure is plotted. The resolution is approximatelly 0.5 nm of FWHM of a narrow line. Simultaneously a photometric patrol was carried out with the same telescope with a 12" diapragm. There is a change in the brightness of about a half of magnitude during the exposure. Such changes are characteristic for the light curve of KR Aur. The mean magnitude in the color B is about 13.5. There is a strong Balmer line emission in the spectrum. In all four lines in the observed spectral region (390 - 500 nm) a three-component structure is clearly visible. There is a well-recognizable blue component at 900 km/s to the blue in the velocity scale with 1/3 central intensity of that of main line. But the central maximum is also splitted in two with a velocity difference of about 300 km/s. Possible three-component structure of H_α line was suspected by Vitrichenko (1981) who has observed an asymmetry of the contour. But the observations of Popova and Vitrichenko (1978) show symmetric contour of hydrogen lines. Almost symmetric contours of those lines were also observed by Shafter (1983) in 1982 when the star was nearly in minimum. The observations which are available up to now are not sufficient to find a time-scale and physical mechanism for the changes in the shape of the emission lines. However they are not directly related with the high and low state of the object.

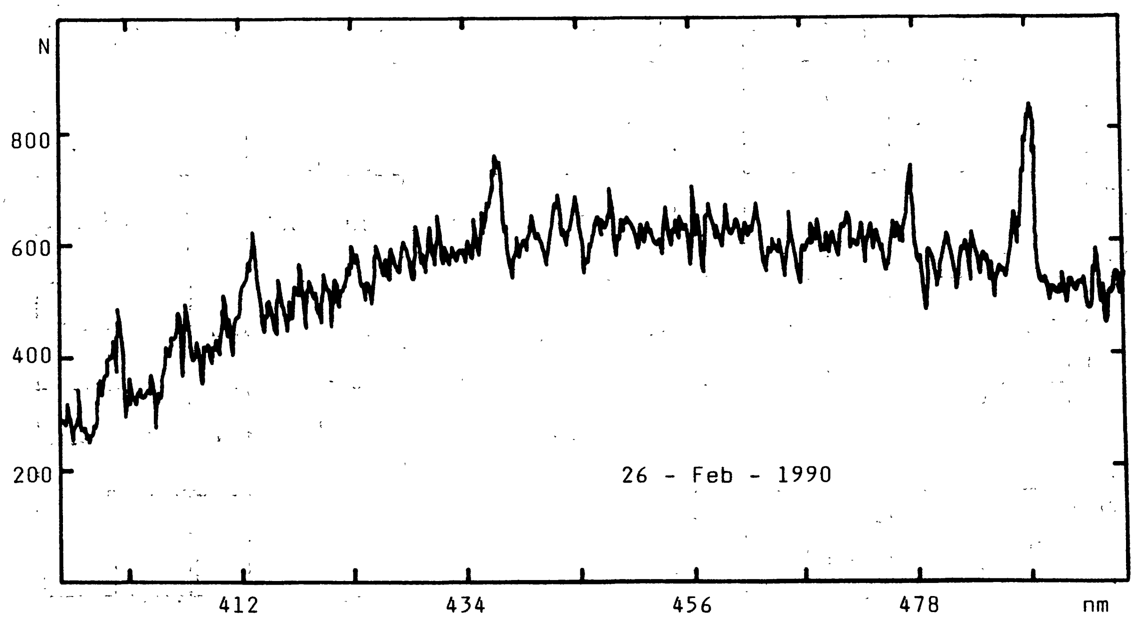

Fig. 2

Review of the spectrograms makes clear that the line spectrum of the object shows considerable differences in time. On the spectrum of Popova (1975) photographed in 1967 there is a strong emission in He II 4686 and weak absorptions in the hydrogen lines. In 1976 He II 4686 disappears and H_β and H_γ appear in emission. During 1982, when the star is in minimum, Balmer lines are seen in emission up to H_8, and there is strong emission in He II 4686. There is also emission in

He I. Closest to that date spectrograms - those of Hutchings et al. in 1979 and 1980 and Popov (1988), as well as our spectrum in 1990 show that qualitatively the spectrum in maximum is not very different from that in minimum. There are, however, considerable quantitative differences between the spectral lines in different states. The central intensities of H I lines in maximum are less than 1 in continuum units. In minimum they are 6-7 times greater. There is also a considerable growth of the equivalent widths of the H I lines in minimum. At the same time FWHM of these lines does not change significantly. This increase in the emission with respect to the continuum is consistent with the continuum drop in minimum. The fact that differences between spectra in maximum can be very considerable (hydrogen emission is changed into absorption) and differences in the minimum are only qualitative proves, that great changes in brightness are not directly related with the line spectrum and are mainly associated with changes in continuum.

Fig. 3 presents the results of the determination of the Balmer decrement in the cases where nesessary data are available. The spectrum in minimum, as well as that of Hutchings et al. (1983) and our spectrum of 1990 have a shallow Balmer decrement as it is usually observed in the cataclysmic variables. Only in 1976, at maximum brightness, a very steep Balmer decrement was observed, which is close to the theoretical one for collisional excitation (Sobolev, 1975). It is obvious, that changes in the Balmer decrement are not correlated with the photometric behaviour of the object.

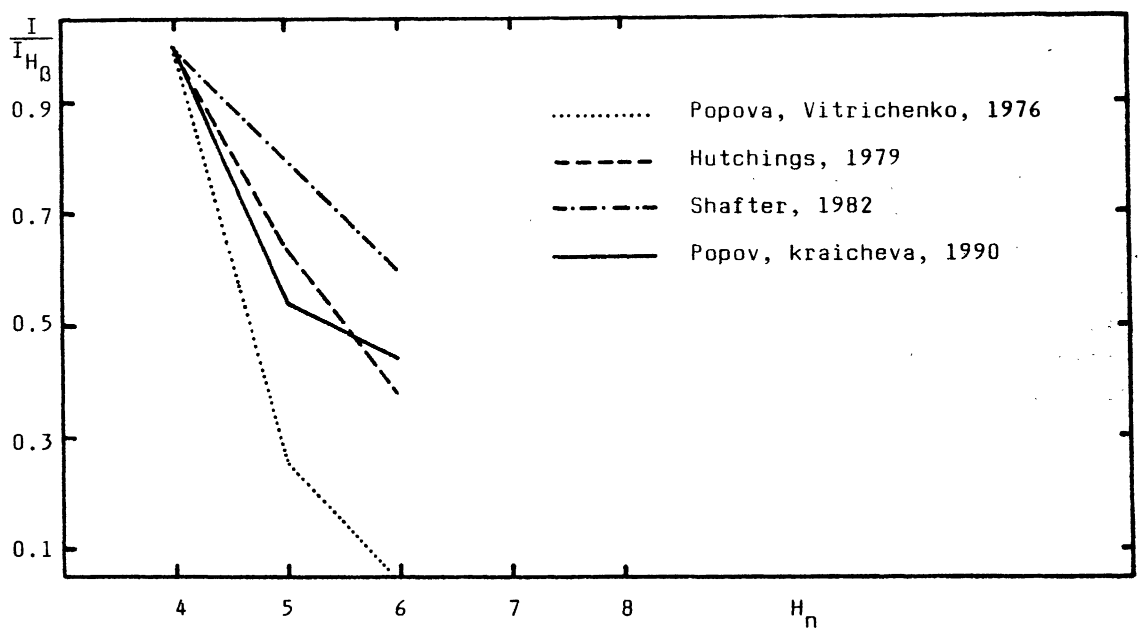

Fig. 3

In the papers of Popova and Vitrichenko (1978), Doroshenko et al. (1977) and Shafter (1983) the energy distribution in the spectrum is found to be consistent with a power law $F_{\lambda} \sim \lambda^{-\alpha}$, characteristic for non-thermal emission. Shafter (1983) found a change of α from 2 in maximum (Popova and Vitrichenko, 1978) to 1.4 at the moment of his observations and considers this change to be connected with changes in mass transfer rate. At the moment of our observation the energy distribution in the continuum deviates from power law even in the spectral range 390 - 500 nm.

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