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# Polarimetric study of the very close eclipsing binary system of the Wolf-Rayet type CX Cep

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**Abstract.** The results of polarization observations of CX Cep carried out at SAO RAS in August, 1998 were compared with the results of its earlier investigations by Schult-Ladbec and Van der Hucht (1989). The mean level of linear polarization of the system is noted to sharply increase (from $\approx 6.1\,\%$, in observations of the first researchers, to $\approx 7\,\%$, in ours) which was accompanied by a rise in the amplitude of polarization variations over the orbital period (from $\approx 0.3\,\%$ to $\approx 1\,\%$, respectively).

A Fourier analysis of the new polarization curve of CX Cep was made by the universally accepted method. The results of the analysis were compared with the analogous results of our repeat analysis of the observations made by Schult-Ladbec and Van der Hucht (Kartasheva, 2002a). The comparison showed that by 1998 an abrupt increase ($\approx$ 3 times) occurred in the degree of asymmetry of scattering matter relative to the orbital plane of the system. This increase was accompanied by a sharp rise ($\approx$ 5 times) of the degree of matter concentration towards this plane and by a growth of more than 3 times of the electron density of the WR envelope. All this suggests that CX Cep was in the state of excitation in 1998 August. This is also evidenced by the revealed in the analysis of our observations rough violation of orthogonality of the axes of ellipses described by the first and second harmonics of expansion, which does not allow the estimate of the orbit inclination of the system obtained in this analysis to be trusted.

An identity is noted of the state of CX Cep in the observations of August, 1998 with the state of the closest of the WR binaries CQ Cep in 1994 July.

**Key words:** stars: Wolf-Rayet — stars: polarization — stars: individual: CX Cep

## 1. Introduction

CX Cep (WN5 + 08V, $V = 12\overset{m}{.}5$, $P = 2\overset{d}{.}126897$) is a second, as to the degree of closeness, after CQ Cep, pair with a Wolf-Rayet component. The previous study of the system is described in detail in our recent paper (Kartasheva, 2002a) where it is noted, in particular, that the polarization observations of CX Cep conducted in 1987 by Schmidt-Ladbec and Van der Hucht (1989) are sole so far. The same paper (Kartasheva, 2002a) contains the results of our repeat analysis of these observations made with the use of a refined value of the orbital period of CX Cep ($P = 2\overset{d}{.}126897$). The new value of the orbit inclination of the system ($i_{polar} = 53\overset{\circ}{.}9$) and the use of more reliable spectroscopic elements, obtained for CX Cep by Massey and Conti (1981), allow us to obtain more accurate mass estimates of the system components and the distance between them: $M_{WR} = 10.0\,M_\odot$, $M_O = 23.1\,M_\odot$ and $A = 22.4\,R_\odot$.

## 2. The results of polarization observations of CX Cep of 1998 August

New polarization observations of CX Cep were conducted with the "Zeiss-1000" telescope of SAO RAS in 1998 August. The two-channel polarimeter "MINIPOL" of the University of Arizona (Frecker and Serkovski, 1976) installed at the Cassegrain focus of the telescope was employed. A quasisimultaneous measurements of the $q$ and $u$ Stokes parameters were made in the V band. To obtain the parameters with an acuracy 0.11 %–0.15 % ten-twenty minute exposures were required. To define the instrumental polarization a standard star with a zero polarization (HD 212311) was observed. To estimate the zero-point shift of our system of counting of position angles, standard stars with the known polarization (HD 204827 and HD 218342) were observed. Before and after the observations of each of stars, the polarization of the sky background was measured.

First of all the observations were corrected for the contribution of the sky background polarization. Next

Table 1: *The log of our polarization observations of CX Cep carried out in August 1998*

| $J.D.\odot$ (2451000+ ) | $\Phi$ in frac. of P | $q(\%)$ | $u(\%)$ | $P(\%)$ | $\Theta°$ |
|---|---|---|---|---|---|
| 41.3038 | 0.3545 | -0.066 | 6.680 | 6.681 | 45.3 |
| 41.3286 | 0.3661 | -0.096 | 6.592 | 6.593 | 45.4 |
| 41.3952 | 0.3974 | -0.102 | 6.515 | 6.516 | 45.5 |
| 41.4268 | 0.4123 | +0.131 | 6.840 | 6.841 | 44.5 |
| 41.4550 | 0.4255 | +0.067 | 6.983 | 6.983 | 44.7 |
| 41.5105 | 0.4516 | -0.428 | 7.011 | 7.024 | 46.8 |
| 43.3412 | 0.3124 | +0.277 | 6.653 | 6.659 | 43.8 |
| 43.4064 | 0.3430 | -0.128 | 6.664 | 6.665 | 45.6 |
| 43.4808 | 0.3780 | +0.062 | 6.646 | 6.646 | 44.7 |
| 43.5061 | 0.3899 | -0.150 | 6.791 | 6.793 | 45.6 |
| 44.3860 | 0.8036 | +0.064 | 6.901 | 6.901 | 44.7 |
| 44.4477 | 0.8326 | -0.005 | 6.653 | 6.653 | 45.0 |
| 44.4993 | 0.8569 | +0.191 | 6.848 | 6.851 | 44.2 |
| 44.5217 | 0.8674 | +0.480 | 6.833 | 6.849 | 43.0 |
| 44.5472 | 0.8794 | +0.392 | 6.975 | 6.986 | 43.4 |
| 45.2916 | 0.2294 | +0.227 | 6.678 | 6.682 | 44.0 |
| 45.3257 | 0.2454 | +0.258 | 6.809 | 6.814 | 43.9 |
| 45.3821 | 0.2719 | +0.207 | 7.033 | 7.036 | 44.2 |
| 45.4054 | 0.2829 | +0.511 | 6.698 | 6.717 | 42.8 |
| 45.4596 | 0.3084 | +0.407 | 6.661 | 6.674 | 43.3 |
| 45.5077 | 0.3310 | +0.049 | 6.722 | 6.722 | 44.8 |
| 45.5280 | 0.3405 | +0.154 | 6.460 | 6.462 | 44.3 |
| 55.4275 | 0.9950 | -0.281 | 6.892 | 6.898 | 45.8 |
| 55.4498 | 0.0055 | -0.230 | 6.867 | 6.870 | 45.4 |
| 55.4728 | 0.0163 | -0.257 | 6.910 | 6.915 | 45.7 |
| 55.4978 | 0.0280 | -0.197 | 7.291 | 7.294 | 45.4 |
| 55.5409 | 0.0483 | -0.410 | 7.114 | 7.126 | 46.3 |
| 56.3675 | 0.4369 | -0.282 | 6.630 | 6.636 | 45.8 |
| 56.4198 | 0.4615 | -0.117 | 7.197 | 7.198 | 45.5 |

Table 2: *A comparison of the averaged estimates of P obtained for the polarization standards in observations of 1998 August with their catalogue values*

| Standarts of polarisation | HD 204827 | HD 218342 |
|---|---|---|
| $\bar{P}_{V,1998}$ | $5.38\% \pm 0.05\%$ | $2.17\% \pm 0.04\%$ |
| $P_{V,catalog.}$ | 5.35% (Serkowski et al.,1969) | 2.20% (Coyne and Gehrels, 1966) |

the observations of CX Cep and standard stars were cleaned from the instrumental polarization. After that using the stars–standards of polarization the zero-point shift of our system of countings of position angles was determined, and $q$ and $u$ Stokes parameters were converted into the equatorial coordinate system. Table 1 contains the final results of our polarization observations of CX Cep. In the first column of Table 1 are listed the Julian dates of observations reduced to the centre of the Sun, the second column gives the phases expressed in the fractions of the orbital period. The phases were computed by the formula: $T_{min1} = 2444451^{d}.423 + 2^{d}.126897 \times E$ taken from Kurochkin (1985). The third-sixth columns of

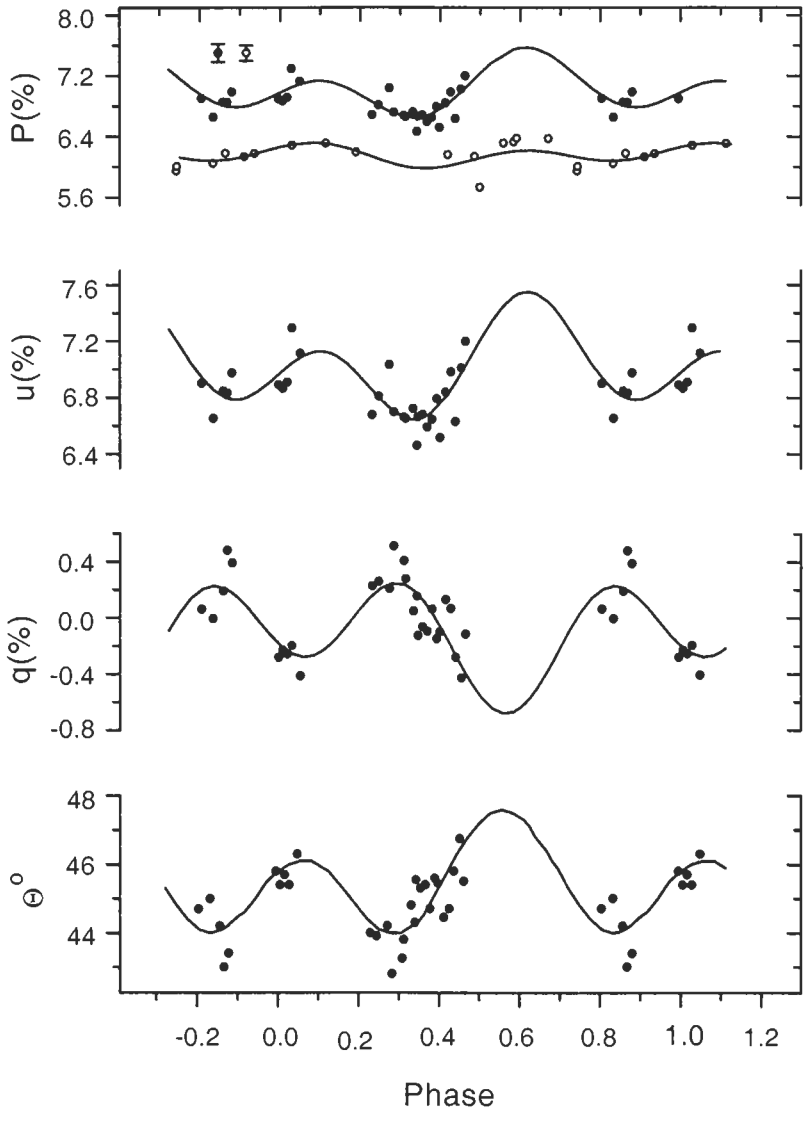


Figure 1: *The curves of linear polarization variations (P), q and u Stokes parameters and position angle of polarization plane (Θ) with the phase of the orbital period. The filled circles are the results of our 1998 August observations, the open circles are the results of observations of Schult-Ladbec and Van der Hucht of 1987. The solid lines show theoretical curves.*

Table 1 present normalized Stokes parameters ($q = Q/I$ and $u = U/I$) in the equatorial coordinate system, the degree of linear polarization of radiation of the system $P = (q^2 + u^2)^{1/2}$ and the position angle of the polarization plane $\Theta (tg\, 2\Theta = u/q)$, respectively. To illustrate the accuracy and stability of observations, a comparison of the averaged over the observational period estimates of $P$ standards of polarization with their catalogue values is given in Table 2. The results of our polarization observations are also presented in Fig. 1 by filled circles. The data of observations of Schult-Ladbec and Van der Hucht (1989) are shown in this figure with open circles. It can be seen from the figure that in our observations of 1998 the mean level of linear polarization of the system sharply increased (from $\approx 6.1\,\%$ in Schult-Ladbec and Van der Hucht to $\approx 7\,\%$ in our observations), which was accompanied by rising amplitude of $P$ variation along the orbital period (from $\approx 0.3\,\%$ in observations of the former researchers to $\approx 1\,\%$ in ours).

## 3. Analysis of the results of polarimetric studies of CX Cep

As usual $q$ and $u$ Stokes parameters were represented in the Fourier series up to the second harmonics inclusive, that is:

$$q = q_0 + q_1 cos\lambda + q_2 sin\,\lambda + q_3 cos2\,\lambda + q_4 sin2\,\lambda,$$

$$u = u_0 + u_1 cos\lambda + u_2 sin\,\lambda + u_3 cos2\,\lambda + u_4 sin2\,\lambda,$$

where $\lambda = 2\pi\Phi$, $\Phi$ is the phase of the orbital period. The expansion coefficients determined by the least squares method are given in Table 3.

The curves approximating the variations of the $q$ and $u$ Stokes parameters are shown in Fig. 1 by the solid lines. For observations of 1998 Fig. 2 displays the variations of the Stokes parameters in the $(q,u)$- plane and also the $(q_+u_+)$ trajectory which represent an ellipse described by the second expansion harmonics (see the paper by Brown et al., 1978). It is seen from Table 3 that the role of the first harmonics in the expansion is significant, which suggests that the degree of symmetry of the scattering matter with respect to the orbital plane of the system is not high (Brown et al., 1978). To connect the obtained expansion coefficients with the geometric and physical parameters of the system, a model of Brown et al. (1978) was used. A comparison of the results of our analysis of the polarization observations of Schult-Ladbec and Van der Hucht (1989) (Kartasheva, 2002a) and of our observations of the system in 1998 is shown in Table 4. The first line of Table 4 gives the value of the orbit inclination of CX Cep following from the analysis of the second harmonics of expansion. The second and third lines show the values of the angle $\Omega$ which characterizes the orbit orientation of the system in space. The values were obtained from the analysis of the first ($\Omega_1$) and the second ($\Omega_2$) harmonics. The fourth line presents the absolute value of the difference of these values ($\Delta\Omega$). In the next six lines are collected the values of some spatial integrals ($\tau_0\gamma_3, \tau_0\gamma_4$) and their combinations ($\tau_0 G = \tau_0(\gamma_1^2+\gamma_2^2)^{1/2}$, $\tau_0 H = \tau_0(\gamma_3^2+\gamma_4^2)^{1/2}$, $H/G$, $\gamma_4/\gamma_3$), which characterize the features of the matter distribution in the light-scattering WR envelope. Five of them were computed in an analytical manner (see Drissen et al., 1986), the value $\tau_0 G$ was determined graphically (Brown et al., 1978).

The difference $\Delta u'$ between $u'_c$ ($u$ coordinate of the centre of the ellipse described by the second harmonics) and $u'_I$ ($u$ parameter of interstellar polarization) is shown in the last but one line of Table 4. In the $q'u'$ system of coordinates related with the binary system these two values, according to the theory of Brown et al. (1978), must be equal ($u'_c = u'_I$). The fulfillment (or non-fulfillment) of the latter allows one to judge of the absence (or the presence) of a constant component in the linear polarization, which is connected with the system itself. An estimate of interstellar polarization obtained by Kartasheva (2002a) $q_I = -0.27\% \pm 0.30\%$; $u_I = 4.05\% \pm 0.53\%$ was used. In the system of $q'u'$ coordinates related with the star, these parameters get the values: $q'_I = 2.80\%, u'_I = -2.94\%$. In the same coordinate system $q'u'$ the coordinates of the centre of the ellipse described by the second expansion harmonics are: $q'_c = 4.60\%, u'_c = -5.32\%$.

Table 3: *Coefficients of expansion of q and u Stokes parameters into Fourier series (our observations of CX Cep in August 1998)*

| $q_0$ | $q_1$ | $q_2$ | $q_3$ | $q_4$ |
|---|---|---|---|---|
| -0.1285 | 0.1821 | 0.0845 | -0.2524 | -0.2446 |
| $u_0$ | $u_1$ | $u_2$ | $u_3$ | $u_4$ |
| 7.0357 | -0.1186 | -0.1884 | 0.0617 | 0.2953 |

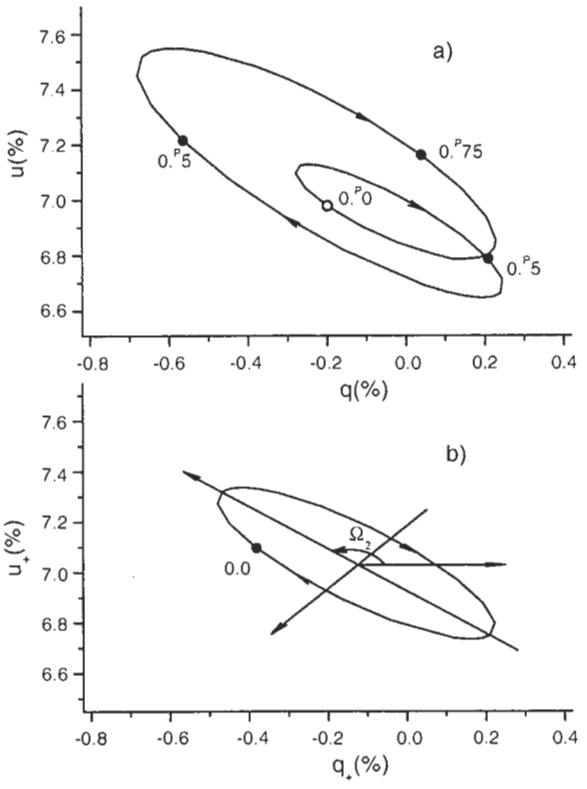


Figure 2: *Stokes parameter variations in the $(q,u)$ plane (a), and the $(q_+u_+)$ trajectory (b) obtained from the harmonic analysis of the results of our polarization observations of CX Cep in 1998 August.*

The value of the semi-major axis of the ellipse which is described by the second harmonics of expansion and which can be expressed through spatial integrals $\tau_0\gamma_3$ and $\tau_0\gamma_4$ : $A_p = \tau_0(\gamma_3^2+\gamma_4^2)^{1/2}(I+cos^2 i)$ is given in the last line of Table 4. The same value ($A_p$) can be represented by a function of a few physical parameters of the system, where $A_p \sim n_e \sim \dot{M}_{WR}$ ($n_e$ is the electron density of the envelope, $\dot{M}_{WR}$ is the mass loss rate by the WR star) (St.-Louis et al., 1988).

A comparison of the data of Table 4 showed that by 1998 a sharp rise ($\approx$ 3 times) occurred in the de-

Table 4: *A comparison of the geometrical and physical parameters obtained from the analysis of our results of CX Cep observations in August 1998 and those of Schult-Ladbec and Van der Hucht (1989) made in 1987*

| | Kartasheva (observ.1998) | Kartasheva (observ.1987, Schult-Ladbec and Van der Hucht (1989)) |
|---|---|---|
| $i°_2$ | 81.1 | 53.9 |
| $\Omega°_1$ | 311.5 | -44.2 |
| $\Omega°_2$ | 140.2 | 57.7 |
| $\Delta\Omega° = \lvert\Omega_1 - \Omega_2\rvert$ | 171.3 | 101.9 |
| $\tau_0\gamma_3$ | $-2.28 \times 10^{-3}$ | $0.12 \times 10^{-3}$ |
| $\tau_0\gamma_4$ | $3.67 \times 10^{-3}$ | $0.90 \times 10^{-3}$ |
| $\tau_0 G$ | $1.51 \times 10^{-3}$ | $0.51 \times 10^{-3}$ |
| $\tau_0 H$ | $4.33 \times 10^{-3}$ | $0.90 \times 10^{-3}$ |
| $H/G$ | 2.87 | 1.76 |
| $\gamma_4/\gamma_3$ | -1.613 | 7.5 |
| $\Delta u'$ | $-23.8 \times 10^{-3}$ | $9 \times 10^{-3}$ |
| $A_P$ | $4.43 \times 10^{-3}$ | $1.2 \times 10^{-3}$ |

gree of asymmetry of the scattering matter relative to the orbital plane of the system ($\tau_0 G$). At the same time a sharp ($\approx$ 5 times) increase of the degree of concentration of the scattering matter towards this plane ($\tau_0 H$) and an increase of more than 3 times of the electron density of the envelope ($n_e \sim Ap$) were observed. All this points to the fact that CX Cep was in an excited state in 1998 August. The same is suggested by a rough violation of orthogonality of the axes of the ellipses described by the first and the second harmonics ($\Delta\Omega = 171°.3$), which does not allow us to trust the estimate of the orbit inclination of the system derived from the analysis of the 1998 observations. Finally, the analysis of our observations has shown a considerable increase in absolute value of the difference $\Delta u'$. This indicates that the contribution into the linear polarization of the system of the constant component related to the system itself grows.

## 4. Conclusions

CX Cep is a third system, after CQ Cep (Kartasheva et al., 1998, 2000) and HD 211853 (Kartasheva, 2002b), in which we have found considerable long-term (on scales of years) linear polarization variations. These variations are similar to those noted in the polarization observations of CQ Cep in 1994 (Kartasheva et al., 1998): an abrupt increase ($\approx$ 1 %) of the amplitude of polarization variations along the orbital period accompanied by an approximately analogous increase of the mean level of linear polarization of the system. As analysis shows, in both cases (CQ Cep in 1994, CX Cep in 1998) a phase of enhanced activity of the WR component characterized by a growth (several times) of the degree of concentration and asymmetry of the scattering matter with respect to the orbital plane of the sytem, and also by an increase (2–3 times) of the electron density of the envelope was observed. Unfortunately we did not succeed in observing the expulsion of the uppermost parts of the WR envelope of CX Cep following this phase, which we noted in 1996 in CQ Cep (Kartasheva et al., 1998) and in 1999 in HD 211853 (Kartasheva, 2002b). In 1999 and in the years that followed, the observations of CX Cep were not conducted for technical reasons.

The observations of Schult-Ladbec and Van der Hucht (1989) made in 1987 when CX Cep was in a quiet state still remain the only polarization observations of the system analysis of which makes it possible to estimate the inclination of its orbit and refine the physical characteristics of the stars of the system (Kartasheva, 2002a).

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