Bull. Spec. Astrophys. Obs., 1998, 46, 130–139

Polarimetric study of the Wolf–Rayet eclipsing binary CQ Cephei

T.A. Kartasheva[a], M.A. Svechnikov[b], I.I. Romanyuk[a], I.D. Najdenov[a]

[a] Special Astrophysical Observatory of the Russian AS, Nizhnij Arkhyz 357147, Russia
[b] Ural State University, Ekaterinburg 620083, Lenina 51

Received November 17, 1998; accepted December 15, 1998.

Abstract. Results of linear polarization measurements of the closest Wolf–Rayet eclipsing binary CQ Cep ($A = 20R_{\odot}$) made in the B band with the telescope Zeiss–1000 of the SAO RAS in 1994 and 1996 are presented. A comparison of two obtained polarization curves with each other and with the results of earlier polarimetric investigations of CQ Cep has shown that the linear polarization of the system is subject to substantial long-term variations. Not only the mean polarization ($\bar{P} = 4.5\,\%$–$6.6\,\%$), but also the amplitude ($A = 0.4\,\%$–$1.6\,\%$) of its variation over the orbital period undergo abrupt changes from one observational run to another. Using the generally accepted method, a Fourier analysis of two new polarization curves of CQ Cep has been made. It has revealed that the most probable value of the inclination of the system's orbit lies around $70° \pm 5°$. The data on the distribution of scattering matter in the system's envelope obtained in the analysis in combination with the fact of sharp envelope electron density variations from run to run point to ejection of great masses of gas to the envelope of the system preceding the 1994 observations and probable expulsion of the outermost layers of the common envelope of CQ Cep before the observations in 1996.

Key words: stars: Wolf–Rayet – stars: polarization – stars: individual: CQ Cep

By the present time a rather large series of observations of polarization variability of WR binaries and suspected binaries have been accumulated. The principal results of these studies are presented in the paper by Schulte-Ladbeck and Van der Hucht (1989) (see Section A of Table 6 therein). It is pointed out in the paper that all double-line spectroscopic WR binaries that have been observed polarimetrically (12 from 23 known) show double-wave phase-dependent linear polarization variations predicted in the model of Thomson scattering of radiation from the companion (or both components) by free electrons of the WR envelope (Brown et al., 1978). The effect revealed has not only made it possible to introduce an additional criterion for establishing duplicity of WR stars, but also opened up a possibility of determining parameters (inclination and orientation) of their orbits and obtaining data on the character of distribution of the scattering matter in the WR envelope by means of harmonic analysis of polarization curves of WR binaries. The orbit inclinations ($i_{pol.}$) of the systems determined by polarimetry permitted accurate measurement of masses of the components of WR spectral binaries irrespective of whether they are eclipsing or not (Rudy and Kemp, 1978; Brown et al., 1978). Besides, the measurement of amplitudes of phase-dependent polarization variations of WR binary stars (lying around $0.2\,\%$–$0.8\,\%$ before our studies of CQ Cep) enabled reliable estimates for the electron density of WR envelopes and mass loss rate in WR stars to be made (St-Luis et al., 1988). Schulte-Ladbeck and Van der Hucht (1989) noted, however, that the observational data summarized in their paper permit the polarization variability analysis on a time scale from several days to a month. There are no data on short-period linear polarization variations in WR stars. Very little is known about the long-term variations of their polarization on scales over several months.

In the present work an attempt is made to investigate the long-term variability of linear polarization of the closest of WR binaries CQ Cep ($P \approx 1^{d}_{.}64$; WN7 + O9.5III). The system is well studied both photometrically and spectroscopically. At the same time it has been debated whether the companion lines are visible in its spectrum. There are great disagreements over the solutions of the light and radial velocity curves of CQ Cep that cause an uncertainty in estimations of geometrical and physical parameters of the components of the system resulting in an uncertainty

Table 1:

N	J.D.⊙ (2400000+)	Phase	q(%)	u(%)	P(%)	$\theta(°)$
1	49547.403	0.301	-2.421	+4.898	5.464	58.2
2	49547.427	0.316	-2.332	+4.876	5.405	57.8
3	49547.433	0.319	-2.408	+4.902	5.462	58.1
4	49548.480	0.957	-4.327	+4.982	6.598	65.5
5	49548.487	0.961	-4.455	+5.099	6.771	65.5
6	49548.492	0.965	-4.215	+5.191	6.686	64.5
7	49549.416	0.528	-3.691	+5.503	6.626	62.0
8	49549.424	0.532	-3.667	+5.611	6.702	61.6
9	49549.432	0.537	-3.290	+5.670	6.555	60.0
10	49551.367	0.716	-3.039	+4.604	5.517	61.7
11	49551.373	0.720	-2.718	+4.912	5.614	59.4
12	50246.430	0.218	-2.853	+3.898	4.831	63.1
13	50246.439	0.223	-2.709	+3.989	4.822	62.1
14	50246.447	0.228	-2.862	+3.917	4.852	63.0
15	50246.456	0.233	-2.597	+4.084	4.840	61.2
16	50246.464	0.238	-2.493	+4.180	4.867	60.4
17	50315.491	0.296	-2.726	+4.212	5.018	61.5
18	50315.500	0.302	-2.820	+4.131	5.001	62.2
19	50315.511	0.309	-2.820	+4.287	5.132	61.6
20	50315.520	0.314	-2.965	+4.114	5.071	62.9
21	50316.303	0.791	-2.574	+4.191	4.918	60.7
22	50316.318	0.800	-2.204	+4.230	4.770	58.7
23	50316.334	0.810	-2.448	+4.301	4.950	59.8
24	50316.351	0.820	-2.392	+4.463	5.064	59.6
25	50316.359	0.825	-2.264	+4.428	4.974	58.5
26	50316.371	0.833	-2.895	+3.948	4.897	63.1
27	50316.380	0.838	-2.642	+4.172	4.938	61.1
28	50331.362	0.967	-2.683	+3.835	4.681	62.5
29	50332.265	0.517	-3.498	+4.699	5.839	63.3
30	50332.273	0.522	-4.010	+4.740	6.208	65.1
31	50332.351	0.569	-3.498	+4.699	5.858	63.3

in its evolutionary status. Our two papers (Kartasheva, Svechnikov, 1996; Kartasheva, 1996) have clarified the points of CQ Cep light curve amplitude instability and of the causes of poor visibility (and at times, probably, full disappearance) of the companion's lines in the spectra of the system which are connected with each other. These lines are simply veiled by the time-variable addition to the continuum radiation caused by the radiation of the gas condensation resulting from collision of the stellar winds of the components. The poorly visible companion's lines can be detected only on high resolution (R$\leq$ 1Å) spectra. In the observations of 1981–1982 performed with the Main Stellar Spectrograph of the 6 m telescope of the SAO RAS CQ Cep spectra with a resolution of 0.3 Å–0.9 Å were obtained. The interpretation of these spectra as well as the refined solution of the radial velocity curves of the components is presented in brief in our paper (Kartasheva, Snezhko, 1985) and their more extended presentation can be found in chapter IV of the Thesis of one of the authors (Kartasheva, 1995). Our spectroscopic investigations supplemented with the results of solution of the most low-amplitude curve of CQ Cep (Kartasheva, Svechnikov, 1996) return the system to ordinary WR binaries with a less massive WR component ($M_{WR} = 18.3 M_\odot$; $M_O = 22 M_\odot$).

The first polarimetric observations of CQ Cep were accomplished by Hiltner in 1948 (Hiltner, 1950). Using the photoelectric technique, he obtained the mean polarization value of the system, $\bar{P} = 4.5\,\%$, and the position angle of the plane of predominant oscillations, $\bar{\Theta} = 62\overset{\circ}{.}5$. The spread in values at the level of observational errors prevented Hiltner from detecting appreciable polarization variations with orbital period phase. As has already been pointed out by Drissen et al. (1986b), the estimate of the degree of polarization of CQ Cep presented by Hiltner (1951) in the catalogue ($P = 5.2\,\%$; $\Theta = 64°$), which was based on later observations, differed essentially from his results of 1948. A little later, in August–September

Table 2:

	1994	1996
q_0	−3.2741	−2.9647
q_1	−0.3936	+0.4104
q_2	+0.3109	−0.0533
q_3	−0.6649	−0.3151
q_4	+0.0320	−0.0919
u_0	+5.1643	+4.2466
u_1	−0.0066	−0.4309
u_2	+0.3432	−0.1971
u_3	+0.3057	−0.0058
u_4	+0.5378	+0.0123

1951, Dombrovsky and Novochadova (1953) investigated the polarization of CQ Cep in two spectral regions by a photographic method. Having concluded that the polarization of radiation from the system is independent of wavelength within the accuracy of observations, they provided the following parameters for it: P = 6.6 %±0.4 %; $\Theta = 87° \pm 1°$.

In late 1961 Shakhovskoj (1964) obtained P = 4.36 %±0.37 % and $\Theta = 67\overset{\circ}{.}8$, using a photoelectric method. He has not detected phase-dependent polarization modulations, since the scatter in estimates does not exceed the measurement errors. Thus, the low accuracy of early polarimetry of CQ Cep could allow only the mean polarization estimates over the period of observations. However, even a comparison of these values permit us to suspect long-term linear polarization variations in the system and argue that in the middle of the century possible polarization variations with orbital period phase did not exceed 0.4 %. The next polarization observations were carried out by Drissen and his colleagues in 1984 (Drissen et al., 1986b), when the advance in polarimetric technology raised the measurement accuracy by an order of magnitude. This research resulted in a clear-cut two-wave polarization curve (0.8 % in amplitude) over the orbital period, which proves definitely that we deal with polarization of radiation in the system itself. The mean value, $\bar{P}$ = 5.2 %, obtained by Drissen and his colleagues was in a good agreement with the results of the repeated polarimetric observations of CQ Cep made by Hiltner (1951). This fact in combination with that that the observations of Shakhovskoj (1964) practically replicated the results of earlier observations of Hiltner (1950) has allowed us to draw a confident conclusion that there exist long-term variability of linear polarization of the system. The results of a number of papers (Gusejnzade, 1967; Kartasheva, 1972; 1976; 1987; Kurochkin, 19797) which point to a strong photometric variability of CQ Cep are not at variance with this conclusion either. The aim of the investigation presented below is to confirm the above inference and to understand nature and scale of the long-term linear polarization variability of the system.

We conducted the polarimetric observations of CQ Cep on the telescope Zeiss–1000 of the SAO RAS in July, 1994 and June–September 1996. A two-channel polarimeter developed by I.D. Najdenov was placed at the Cassegrain focus of the telescope. The quasisimultaneous measurements of the q and u Stokes parameters in B band were made. To obtain the parameters with an accuracy of 0.03 %–0.04 %, 15–20 minutes exposures were required. Zero-polarization standard stars were observed to determine the instrumental polarization. To determine the efficiency of our apparatus and the angular difference between our istrumental system and the equatorial system, standard stars with known polarization of radiation were observed. All observations of CQ Cep were free from systematic errors related to the three effects mentioned above. Table 1 contains final results of our polarimetric observations. In the first column of the table are listed the Julian dates of the observations reduced to the centre of the Sun, in the second column are the phases in fractions of the orbital cycle. The phases were computed by a linear formula $T_{Min} = 2449546\overset{d}{.}909 + 1\overset{d}{.}6412288E$ derived from the more general formula of Kilinc (1994). (The zero phase corresponds to the moment of the main photometric minimum). In columns 3, 4, 5, 6 are tabulated the Stokes parameters (q = Q/I and u = U/I) in the equatorial coordinate system, the degree of linear polarization (P), and the position angle (Θ) of polarization in the equatorial coordinate system, respectively. The results of polarimetry are presented also in Fig. 1. It can be seen from the figure that the observations of 1994 and 1996 designated by different symbols give different curves of variation of polarization parameters (P, q, u, Θ) with orbital cycle phase. In Fig. 2a our results of photometric studies of CQ Cep are compared with the results of earlier investigations. To render the picture complete, not only the results of the detailed polarimetric observations of the system in 1948 (Hiltner, 1950) and 1984 (Drissen et al., 1986b) but also the mean estimates of the degree of CQ Cep polarization (together with their errors) made by Hiltner (1951), Dombrovsky and Novochadova (1953) and Shakhovskoj (1964) are plotted in the figure. It can be seen that the linear polarization shows essential long-term variations (unobservable so far in any other WR binary). Both the mean linear polarization value ($\bar{P}$ = 4.5% − 6.6%) and the amplitude of variation of P over the orbital cycle (A = 0.4 %–1.6 %) undergo abrupt changes from one observing run to another. Besides, Fig. 2b shows the two quantities to have direct linear relationship. As to the angle of polarization, before our observations its mean estimate ($\bar{\Theta}$) suffered minor changes from run to run within 61° − 68° (excluding the ob-

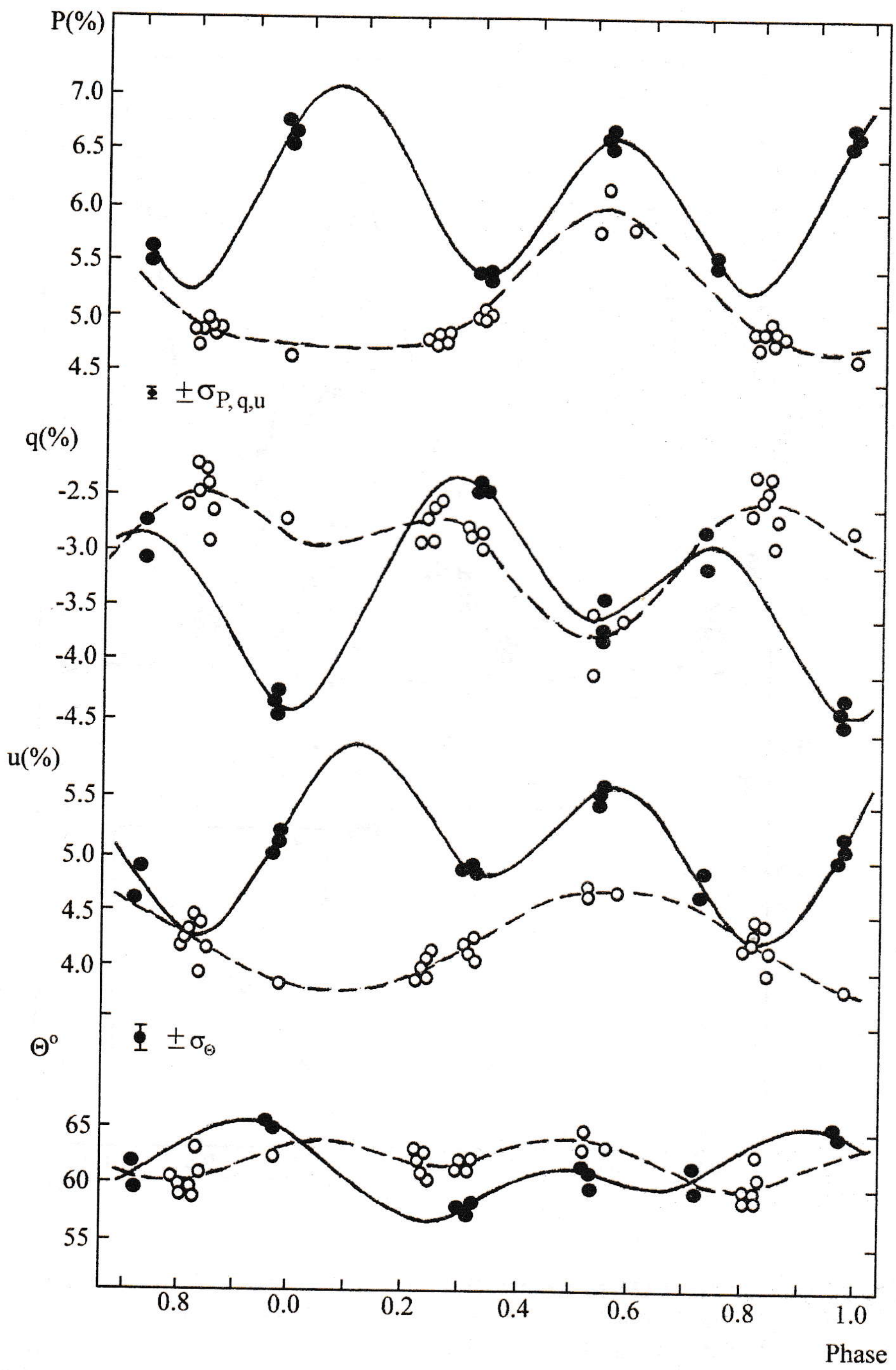

Figure 1: *The curves of variation of linear polarization, q and u Stokes parameters and position angle of polarization with phase of the orbital period derived for CQ Cep from our observational data of 1994 (filled circles) and 1996 (open circles). The solid and dashed lines are the theoretical representation of the linear polarization parameters for the observations of 1994 and 1996, respectively.*

servations of Dombrovsky and Novochadova).

In our measurements of 1994 and 1996 the angle of predominant electric vector oscillations remained within the same limits ($\bar{\Theta} \approx 62°$, see Fig. 1), while the amplitude of its variations over the orbital cycle increased by about a factor of two in 1994 as compared with the polarimetry results of 1984 (Drissen et al., 1986b) ($\Delta\Theta_{1984} \approx 5°$, $\Delta\Theta_{1994} \approx 9°$). In 1996 the amplitude of the polarization position angle variations returned to the value of 1984. When examining

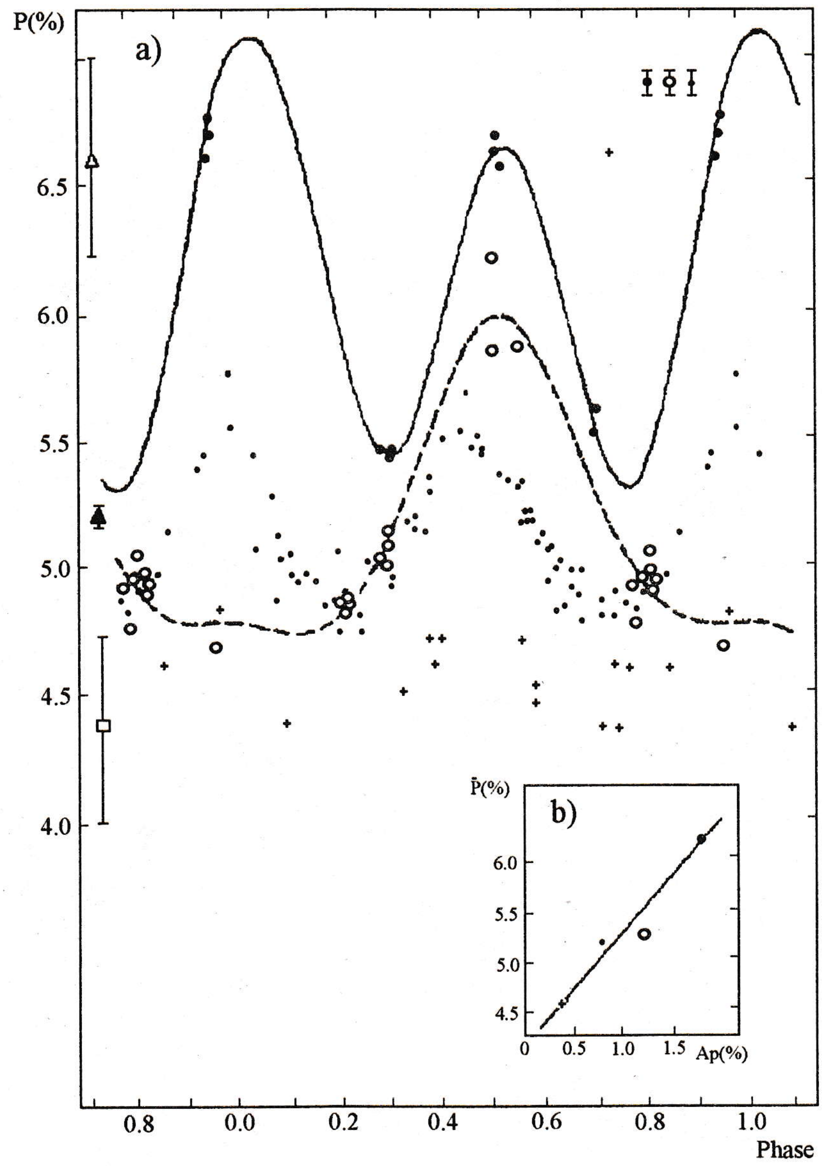

Figure 2: *a) Comparison of our CQ Cep polarization curves from the 1994 observations (filled circles) and 1996 (open circles) with the result of polarimetry of the system done by Hiltner in 1948 (crosses) and Drissen and his colleagues in 1984 (dots). Near the polarization axis are also plotted the mean values of P obtained in early observations of the system by Dombrovsky (open triangle), Hiltner (open square) and Shakhovskoj (filled triangle). b) Relationship between the mean linear polarization value and the amplitude of P variation over the orbital period inferred from polarimetric observations of CQ Cep (designations are the same as in a)).*

Fig. 2, one can see that the shape of the polarization curve derived in 1996 is unusual: the polarization maximum at phases around the main minimum of light is practically lacking. An attempt to account for this anomaly will be made later.

In spite of the fact that the number of measures of the Stokes parameters q and u, covering, however, the whole orbital period, is small, we tried to make a harmonic analysis of their variations with phase of the orbital period (separately for the observations of 1994 and 1996). To this end they were presented in the form of expansion into a Fourier series up to second harmonics, that is:

$$q = q_0 + q_1\cos\lambda + q_2\sin\lambda + q_3\cos 2\lambda + q_4\sin 2\lambda$$

$$u = u_0 + u_1\cos\lambda + u_2\sin\lambda + u_3\cos 2\lambda + u_4\sin 2\lambda,$$

where $\lambda = 2\pi\Phi$, Φ is the orbital period phase. (The great irregularity in the distribution of observations over the orbital cycle made it impossible to involve higher harmonics in the analysis).

The coefficients of the Fourier series found by the least-squares fit are listed in Table 2. The curves approximating the variation of the q and u Stokes parameters are shown in Fig. 1 with the solid line for the observations of 1994 and the dashed line for those of 1996. They are seen to be in good agreement with observations. For the observations of 1994 and 1996, in Fig. 3 are shown the variations of the Stokes parameters in the (q, u) plane and also (q_+u_+) and (q_-u_-) trajectories which represent ellipses described separately by the second and the first harmonics of the series, respectively (see Brown et al., 1978). It is seen from Table 2 and Fig. 3 that the first harmonics play an important part in the expansion, which is unusual for binary systems. In the paper by Brown et al. (1978) the authors performed model calculation for an optically thin envelope with an arbitrary density distribution, which rotates together with a binary system and scatters the radiation of an arbitrary number of point sources. These calculations allow one to relate the results of expansion of the q and u Stokes parameters into the Fourier series to some geometrical and physical characteristics of binary systems (through the parameters of the (q_+u_+) and (q_-u_-) ellipses — the geometrical way and through the expansion coefficients — analytical). Apart from the orbital plane inclination angle (i) and the angle of orbit orientation of a binary in space (Ω), with the aid of the results of expansion we can find numerical values of some spatial integrals which characterize the features of the matter distribution in the envelope ($\tau_0\gamma_1$, $\tau_0\gamma_2$, $\tau_0\gamma_3$, $\tau_0\gamma_4$) (Brown et al., 1978). In addition to the results of model computations of Brown et al. (1978), in our work we employed more convenient formulae of the relationship between the Fourier series coefficients and parameters of the binary deduced by Drissen et al. (1986a) and also the results of model computations of Karitskaya and Bochkarev (1983), which make possible unambiguous determination of angle Ω. The results of harmonic analysis of our polarimetric studies of CQ Cep are collected in Table 3. The first column contains the results of a similar analysis made by Drissen et al. (1986b) for the observations of the system in 1984. The results of the repeated computations that we performed after the reduction of the phase zero point in the observational data of 1984 to the main photometric minimum are given in brackets. In the first four lines are given the orbit inclination angle (i) for CQ Cep and the angle characterizing its orientation in space (Ω). i_1 and Ω_1 were obtained from the examination of the first harmonics, i_2 and Ω_2 from that of the second harmonics. In the next nine lines of Table 3 we give the values of four spatial integrals ($\tau_0\gamma_1$, $\tau_0\gamma_2$, $\tau_0\gamma_3$, $\tau_0\gamma_4$) 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, γ_4/γ_3, γ_2/γ_1), which characterize the distribution of the scattering matter in the envelope of the system. The last but one line presents the differences $\Delta u'$ between u_c' — the coordinate of the second harmonic ellipse centre and u_I' — the parameter of interstellar polarization. In the q′u′ coordinate system referred to the binary, these two quantities must be equal ($u_c' = u_I'$) according to the theory of Brown et al. (1978). We used the measures of interstellar polarization obtained by Drissen et al. (1986b) from stars closest to CQ Cep. In the last line of Table 3 are given the values for the semi-major axis of the (q_+u_+) ellipse, which can be expressed in terms of the spatial integrals $\tau_0\gamma_3$ and $\tau_0\gamma_4$: $A_p = \tau_0(\gamma_3^2 + \gamma_4^2)^{1/2}(I + \cos^2 i)$. Alternatively, A_p can be represented as a function of several physical parameters of the system. According to equations [3]–[5] of the paper by St-Louis et al. (1988), $A_p \sim n_e \sim \dot{M}$ (n_e — electron density, $\dot{M}$ — WR star mass loss rate). From examination of Table 3 a number of conclusions can be drawn.

1. Assigning a small weight to the orbit inclination i_2 inferred from analysis of the 1996 polarimetric observations of CQ Cep (in view of the smallness of coefficients q_4 and u_4), find that the most likely value of $i_{polarim.} = 70° \pm 5°$. This is in fair agreement with the results of Drissen et al. (1986b) as well as with the photometric value of the orbit inclination that we derived from the solution of the most low amplitude light curve of the system of 1937 ($i_{phot.} = 59° \pm 2°$ (Kartasheva, Svechnikov, 1996).

2. The values of quantities Ω_1 and Ω_2 representing the angles of turn of the major axes of the (q_-u_-) and (q_+u_+) ellipses with respect to the q-axis of the equatorial coordinate system were obtained with rather large errors ($\sigma_\Omega = \pm 13°$, results of Wolinski and Dolan (1994) were used). Even this being taken into account, no good agreement between the results following from the analysis of the 1984, 1994 and 1996 observations is attained. As in the analysis of our 1994 observations the condition of orthogonality of the axes of the ellipses of the first and second harmonics was best satisfied, we considered $\Omega = [(\Omega_1 + 90°) + \Omega_2]/2 = 129.°5$ to be a value which is closest to actual.

3. In the analysis of Drissen et al. (1986b) $H \gg G$, which suggests high concentration of the scattering matter at the orbital plane and its symmetric distribution about the plane. The analysis of our observations provided H and G comparable in value. By 1994, as compared with 1984, a rise (two times) in the degree of concentration ($\tau_0 H$) of the scattering matter towards the orbital plane and a very strong rise (an order of magnitude) in the degree of asymmetry in its distribution ($\tau_0 G$) with respect to the same plane occurred. The analysis of the 1996 observations shows that the quantity $\tau_0 H$ returned to the value of 1984,

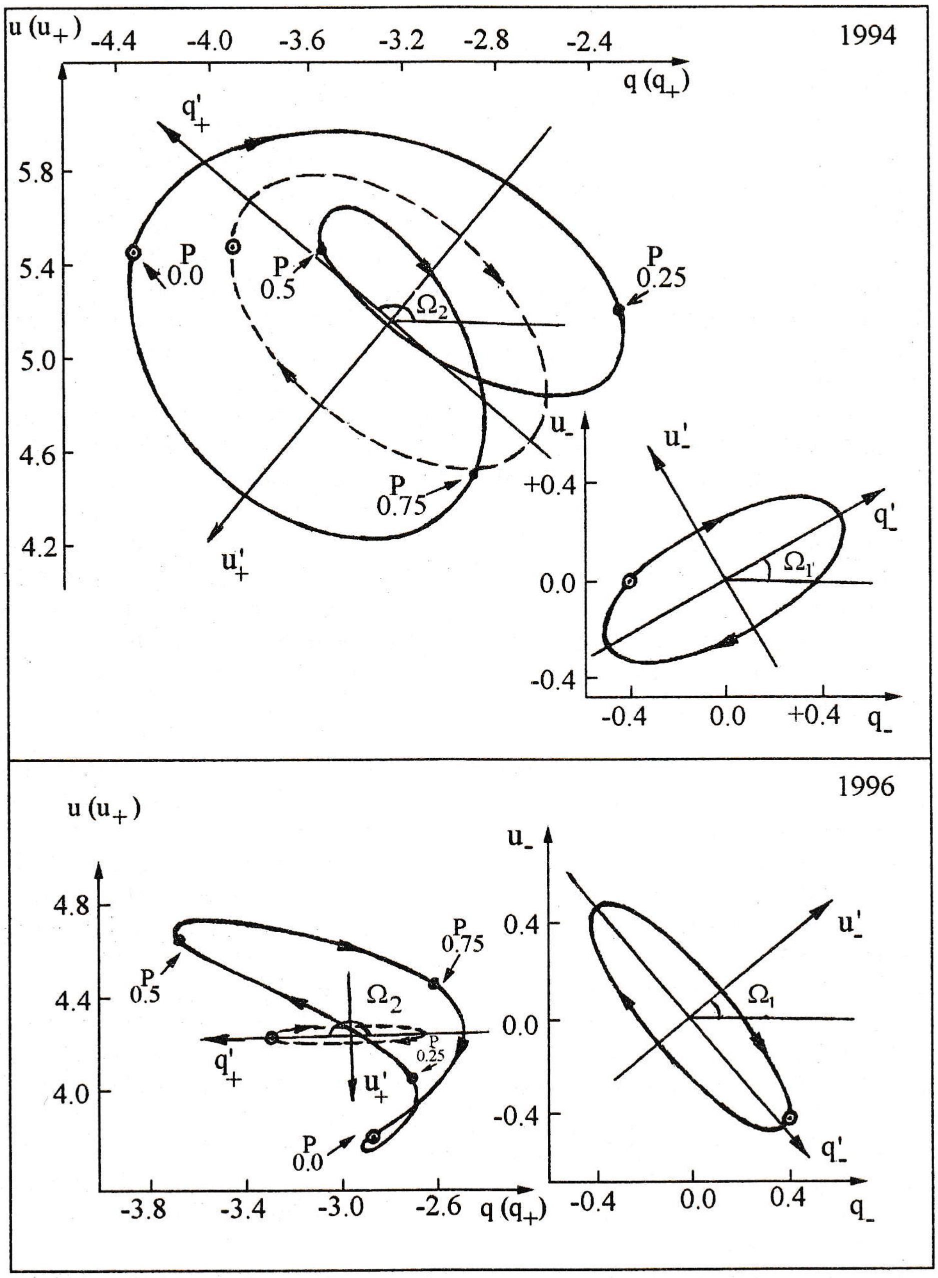

Figure 3: *Variations of Stokes parameters in the (q, u) plane and also* (q_+u_+) *(dashed lines) and* (q_-u_-) *trajectory which we obtained from the harmonic analysis of polarimetric observational data for CQ Cep of 1994 and 1996.*

the high degree of asymmetry in the distribution of matter about the orbital plane being the same.

4. The value of $\Delta u' \approx 0.5\%$ is acceptable and can be accounted for by the accuracy of measurement of interstellar polarization u_I'. The difference $\Delta u' = 1.2\%$, which we derived from the 1996 polarimetry of the system is great and, probably, points to the appearance in the system polarization of a constant component possibly associated with the upset of spherical symmetry of the common envelope.

5. Examination of the last line of Table 3 allows us to conclude that by the time of our observations in 1994 the rate of mass loss by the WR star, and hence the electron density of the CQ Cep envelope, had increased twice as compared with 1984. During two years which followed (from 1994 to 1996) $\dot{M}$ and n_e became as of 1984. This inference together with the above-discussed variations in distribution of the scattering matter in the envelope of the system allows us to assume that a considerable ejection of

Table 3:

	1984	1994	1996
i_1°	+73.1 (67.2)	+65.8	+73.5
i_2°	+77.9 (77.3)	+70.1	+88.8
Ω_1°	+101.4 (−80.8)	+29.3	−49.6
Ω_2°	−16.5 (−24.9)	+139.6	+180.4
$\tau_0\gamma_1$	$+0.30\cdot10^{-3}$ $(-0.26\cdot10^{-3})$	$+2.76\cdot10^{-3}$	$-1.00\cdot10^{-3}$
$\tau_0\gamma_2$	$-0.19\cdot10^{-3}$ $(+0.19\cdot10^{-3})$	$-1.29\cdot10^{-3}$	$-2.16\cdot10^{-3}$
$\tau_0\gamma_3$	$+2.93\cdot10^{-3}$ $(+2.89\cdot10^{-3})$	$-6.31\cdot10^{-3}$	$-3.15\cdot10^{-3}$
$\tau_0\gamma_4$	$+2.05\cdot10^{-3}$ $(+1.80\cdot10^{-3})$	$+2.90\cdot10^{-3}$	$+0.92\cdot10^{-3}$
τ_0G	$+0.36\cdot10^{-3}$ $(+0.31\cdot10^{-3})$	$+3.06\cdot10^{-3}$	$+3.16\cdot10^{-3}$
τ_0H	$+3.58\cdot10^{-3}$ $(+3.40\cdot10^{-3})$	$+6.95\cdot10^{-3}$	$+3.28\cdot10^{-3}$
H/G	+10.2 (+11.0)	+2.23	+1.04
γ_4/γ_3	+0.70 (+0.62)	−0.46	−0.29
γ_2/γ_1	−0.62 (−0.72)	−4.61	+2.16
$\Delta u'$	$+5.2\cdot10^{-3}$ $(+2.9\cdot10^{-3})$	$-4.9\cdot10^{-3}$	$-11.9\cdot10^{-3}$
A_p	$+3.74\cdot10^{-3}$ $(+3.57\cdot10^{-3})$	$+7.75\cdot10^{-3}$	$+3.28\cdot10^{-3}$

matter inside the system preceded our 1994 observations, whereas the 1996 observations were likely to be made after the outermost layers of the envelope had been expelled. This assumption is confirmed by the anomalous shape of the CQ Cep polarization curve of 1996. It is the expulsion of the outermost parts of the envelope that could cause the sudden increase in brightness of the O companion at the main minimum phases (O star is in front of WR), which would abruptly decrease the degree of polarization of the system at these phases and bring about a reduction (and even disappearance) of the polarization maximum at phases close to $0^p.0$.

Our 1996 polarization observations of CQ Cep coincided in time with the latest photometric studies of the system performed by Demircan and his colleagues in April–December, 1995 and June–August, 1996 (Demircan et al., 1997). No sharp amplitude variations or increased scatter of points on the light curve were recorded in the new photometric observations of CQ Cep. An attempt to revise the (O–C) diagram of the system (the diagram of the departures of the moments of primary and secondary minima from the calculated ones) with involvement of the latest photometry data of Kilinc (1994), Demircan et al. (1997), and also Agerer and Huebscher (1998) has revealed that in the interval from 1969 to 1996 the (O–C) departures form a common branch. This suggests that no abrupt changes in the orbital period of the system were observed between 1994 and 1996. The only distinction of the light curves derived by Demircan et al. (1997) is the absorption at the phases after the centre of the secondary minima, which is visible on all three colours (Fig. 4a). Absorption of the same order of magnitude ($\Delta m = 0^m.1$) and at the same phases was noted earlier on the light curves constructed by Kurochkin (1979) from photo-plates of 1937 and 1938 and presented for comparison in Fig. 4b. It will be recalled that the 1937 light curve of CQ Cep has a low amplitude ($\Delta m = 0^m.2$) and a normally-phased primary maximum ($0^p.25$) (see the paper by Kartasheva and Svechnikov (1996), containing a solution of this light curve). The 1938 light curve does not differ in amplitude from ordinary B-curves of the system ($\Delta m \geq 0^m.4$). Since a new branch was noted to form on the (O–C) diagram in 1937 (Kartasheva and Svechnikov, 1989), in examining and solving the 1937 light curve we considered its "anomalous" amplitude as due to loss of enormous masses of gas by the system, which simplified the structure of the common envelope. Similarity of distortions that can be seen on the CQ Cep light curves of 1995–1996 and 1938 may be the only photometric evidence in favour of our conclusion about the expulsion of the outermost CQ Cep envelope layers which probably occurred shortly after our polarimetric observations in 1994.

Inspection of polarization curves of WR spectral binaries reveals that they as a rule are of classical shape (P_{max} approximately in elongations and P_{min} approximately in conjunctions) due to the scatter of radiation from the O-companion by free electrons of the WR envelope. Only three WR spectral binaries (CQ Cep (Drissen et al., 1986b), CX Cep (Schulte-Ladbeck and Van der Hucht, 1989) and HDE 311884

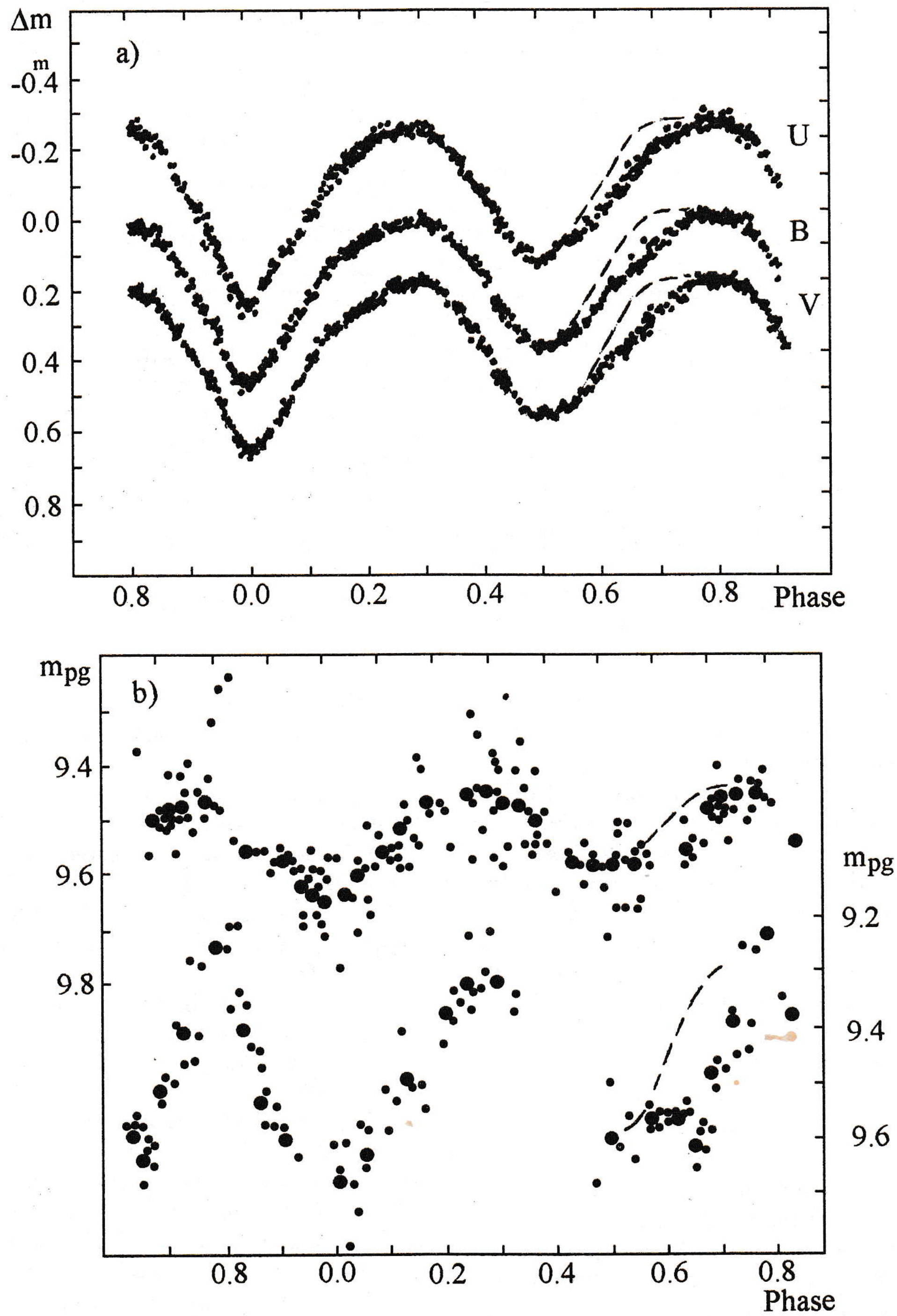

Figure 4: *a) The photoelectric UBV light curves of CQ Cep derived by Demircan et al. (1997) in 1995–1996. b) The 1937 (upper part) and 1938 (lower part) photographic light curves (Kurochkin, 1979). The large filled circles represent the mean light curves. Dashed lines show light curves without an absorption effect.*

(Moffat et al., 1990) exhibit the polarization curves dramatically different from those of the rest of the WR systems. Their polarization curves are "mirror" to their light curves (P_{max} approximately in conjunctions and P_{min} approximately in elongations). CQ Cep and CX Cep are eclipsing systems, but in HDE 311884 only a shallow wind eclipse occurs in conjunctions when the WR star is in front (Moffat et al., 1990). The only explanation of the "mirror" behaviour of polarization of eclipsing binary systems that can be found in the literature is associated with the reduced contribution of non-polarized radiation in the minima of the system's brightness ("effect of contrast"). However, this effect does not account for the shape of the polarization curve of CQ Cep (see Drissen et al., 1986b) and all the more so of non-eclipsing HDE 311884. What the three systems considered above have in common is that all of them are very close, although HDE 311884 is more massive and larger than the former two. The immersion of the O–companion into the WR wind and the formation of the common envelope for the system lead to upset of symmetry of the scattering matter with respect to the WR star, to condensation of parts of the WR wind flowing over the sides of the O–companion, to appearance of a gas condensations between the components, which results from frontal collision of their winds (Kartasheva, Svechnikov, 1996). All these distinguishing characteristics of very close WR binaries are likely to cause the unusual shape of their polarization curves. The non-stationary processes occurring in these systems and connected with the presence of WR stars in them, with filling by the O–companions their critical lobes and also with interaction of stellar winds of the components must cause long-term variability in polarization of their radiation, which has so far been observed only in CQ Cep.

References

Agerer F., Huebscher J., 1998, Inform. Bull. Var. Stars, No **4562**

Aspin C., Simmons J.F.L., Brown J.C., 1981, Mon. Not. R. Astron. Soc., **194**, 283

Brown J.C., Mc.Lean I.S., Emslie A.G., 1978, Astron. Astrophys., **68**, 415

Demircan O., Ak H., Ozdemir S., Tanriver M., Albayrak B., 1997, Astron. Nachr., **318**, 267

Dombrovsky V.A., Novochadova N.V., 1953, Vestnik LSU, No. **2**, 37

Drissen L., Lamontagne R., Moffat A.F.J., Bastien P., Seguin M., 1986a, Astrophys. J., **304**, 188

Drissen L., Moffat A.F.J., Bastien P., Lamontagne R., Tapia S., 1986b, Astrophys. J., **306**, 215

Guseinzade A.A., 1967, Astrofizika, **3**, 359

Hiltner W.A., 1950, Astrophys. J., **112**, 477

Hiltner W.A., 1951, Astrophys. J., **114**, 241

Karitskaya E.A., Bochkarev N.G., 1983, Astron. Zh., **60**, 946

Kartasheva T.A., 1972, Variable stars, **18**, 459

Kartasheva T.A., 1976, Pis'ma Astron. Zh., **2**, 505

Kartasheva T.A., Snezhko L.I., 1985, Bull. Abastum. Astrofiz. Obs., **58**, 25

Kartasheva T.A., 1987, Astrofiz. Issled.(Izv. SAO), **24**, 35

Kartasheva T.A., 1995, Thesis, Nizhnij Arkhyz

Kartasheva T.A., 1996, Bull. Spec. Astrophys. Obs., **39**, 78

Kartasheva T.A., Svechnikov M.A., 1996, Bull. Spec. Astrophys. Obs., **39**, 66

Kilinc B., 1994, Inform. Bull. Var. Stars, No **3998**

Kurochkin N.E., 1979, Astron. Tsirk., No **1063**, 1

Moffat A.F.J., Drissen L., Robert C., Lamontagne R., Coziol R., Mousseau N., Niemela V.S., Cerruti M.A., Seggewiss W., van Weeren N., 1990, Astrophys. J., **350**, 767

Rudy R.J., Kemp J.C., 1978, Astrophys. J., **221**, 200

Schulte-Ladbeck R.E., Van der Hucht K.A., 1989, Astrophys. J., **337**, 872

Shakhovskoi N.M., 1964, Astron. Zh., **41**, 1042

Simmons J.F.L., Aspin C., Brown J.C., 1982, Mon. Not. R. Astron. Soc., **198**, 45

St-Louis N., Moffat A.F.J., Drissen L., Bastien P., Robert C., 1988, Astrophys. J., **330**, 286

Wolinski K.G., Dolan J.F., 1994, Mon. Not. R. Astron. Soc., **267**, 5