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CQ Cep – a close Wolf-Rayet binary system + a third body?

T.A. Kartasheva, M.A. Svechnikov

[a] Special Astrophysical Observatory of the Russian AS, Nizhnij Arkhyz 369167, Russia
[b] Ural State University, Ekaterinburg 620083, Lenina 51

Abstract.
One more variant of interpretation of the (O – C_1) and (O – C_2) diagrams of the Wolf-Rayet eclipsing binary CQ Cep is suggested. The deviations of the observed moments of the primary and secondary minima from the computed ones are represented by the sum of three components: 1) cyclic oscillation caused by the apsidal motion in the close orbit; 2) cyclic oscillation related to the rotation of the binary around the centre of gravity of the triple system; 3) effects due to the distortion of the moments of the minima by the circumstellar gas medium. Assuming that the long-period orbit is circular and its inclination is coincident with the orbital inclination of the binary system, estimates of the period of rotation on the long-period orbit (P'=134.9 years), the radius of the long-period orbit ($R = 6.5 \cdot 10^3 R_\odot$) and the mass of a third body ($M_3 = 17.2\, M_\odot$) were obtained. The last estimate is in good agreement with the results of our photometric studies of CQ Cep, indicating that the unobstructed light $L_3 = 0.27$ (when $L_{WR} + L_O + L_3 = 1$) may belong to a star of spectral type O8–B1(V–III). The γ-velocity variations of CQ Cep confirm the possibility that the binary system rotated on a long-period orbit.

Key words: stars: Wolf-Rayet – stars: kinematics and dynamics – stars: individual: CQ Cep

The interpretation of the (O–C) diagrams of eclipsing binaries with a Wolf-Rayet component has so far been lacking full clarity. Nor, therefore, is there certainty in the behaviour of the orbital period of these systems. For two sufficiently bright and thus well-studied WR binaries — V444 Cyg (Semeniuk, 1968; Khaliullin, 1974; Kornilov & Cherepashchuk, 1979; Khaliullin et al., 1984; Underhill et al., 1990a) and CQ Cep (Gaposhkin, 1944; Svechnikov, 1954; Semeniuk, 1968; Kurochkin, 1979; Antokhina et al., 1982, 1987; Walker et al., 1983; Krainer & Tremko, 1983, 1985; Kartasheva & Svechnikov, 1989, 1991; Kartasheva, 1995; Kilinc, 1994) — the (O–C) diagrams are parabolas (concave for the former and convex for the latter). This would seem to be evidence of secular variation of the orbital periods of the systems. However, an interpretation of their (O–C) diagrams as fragments of long-period harmonic variations caused by the presence of a third star in the systems is not improbable. For CX Cep — a fainter ($m_v = 12\overset{m}{.}6$) and therefore worse-understood WR system — the (O–C) diagram is a straight line parallel to the time axis (Kurochkin, 1985), which suggests that its orbital period is constant.

The possibility of rotating of the WR binaries V444 Cyg and CQ Cep around the centres of gravity of the triple systems has been discussed by Khaliullin (1974), Kornilov and Cherepashchuk (1979), and Kartasheva (1995), however the existence of the long-period harmonic variation on the (O–C) diagrams of these system is not obvious yet. In consequence of this, most researchers interprete the shape of the (O–C) diagrams of V444 Cyg and CQ Cep as an indication of secular increase of the orbital period in the former system ($\dot{P} > 0$) and its secular decrease in the latter ($\dot{P} < 0$). Khaliullin (1974) explained this orbital period behaviour in V444 Cyg as due to mass loss of the WR component caused by radially symmetric outflow of matter or by its flowing towards the O component through the inner Lagrangian point. The wind from the O component was fully disregarded as being insignificant. In later papers (Kornilov & Cherepashchuk, 1979; Khaliullin et al., 1984; Underhill et al., 1990a) only the radially symmetric outflow of matter from the WR component of V444 Cyg was considered. The determination of the rate of mass loss by the WR star from the secular variation of the orbital period of the WR binary provided a purely dynamic method of $\dot{M}_{WR}$ estimation.

When this manner was adopted to interprete the behaviour of the orbital period of CQ Cep (Antokhina et al., 1982, 1987; Kartasheva & Svechnikov, 1989, 1991), it did not succeed without considering the flow of matter from the O component towards the WR star ($\dot{M}_O^{(2)}$). The introduction of $\dot{M}_O^{(2)}$ along with the flow of matter from the WR component to the O star ($\dot{M}_{WR}^{(2)}$) and the radially symmetric flow of matter from the WR star ($\dot{M}_{WR}^{(1)}$) with $\dot{P} < 0$ and $M_{WR}/M_O = 0.83$ (Kartasheva & Snezhko, 1985) resulted in a relation $\dot{M}_O^{(2)} > \dot{M}_{WR}^{(2)} + 1.77\,\dot{M}_{WR}^{(1)}$. The latter suggested that the rate of mass flow from the O-star to the WR component was very high ($\dot{M}_O^{(2)} = (0.6 - 3.4) \cdot 10^{-4} M_\odot$ per year), which seems to be unlikely. It is possible that for such a close system not all mechanisms of loss of mass and angular moment were taken into account. It is also possible that the very interpretation of the CQ Cep (O–C) diagram was wrong. Our doubts concerning the correctness of the interpretation enhanced after obtaining of the solution of the most low-amplitude and, in our opinion, least distorted by the circumstellar gas medium light curve of CQ Cep of July-August, 1937 (Kurochkin, 1979; Kartasheva & Svechnikov, 1996). The solution of this curve gave a very high estimate of the third body luminosity (L_3): 27 % of the total light of the system. We ascribed traditionally this additional unobscured light to the luminosity of the WR envelope, realizing, however, that it is too high for the latter. At last, the fact that CX Cep keeps constant the orbital period, according to Kurochkin (1985), also renders questionable the secular variation of the orbital period in other WR binaries.

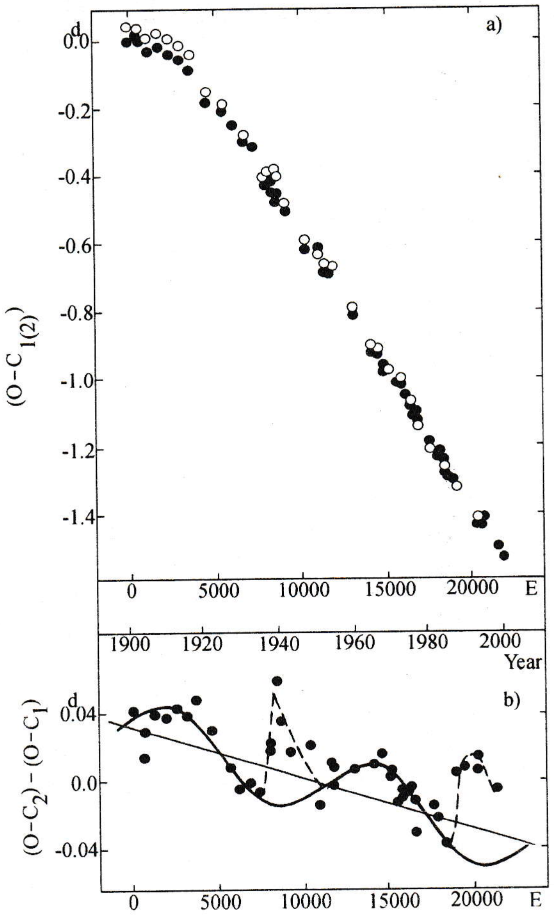

Figure 1: *a)* $\mathrm{O} - \mathrm{C}_{1(2)}$ *diagram of CQ Cep. The departures of the moments of the main minimum from the computed (filled circles), those of the secondary minimum (open circles). b) Differential* $[(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1)]$ *diagram of the system. The thin line shows the linear run of the moments of the secondary minimum with respect to the moments of the main minimum. The bold line is the theoretical representation of the differential diagram by a sloping cosinusoid:* $[(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1)] = 0\overset{d}{.}034 - 0\overset{d}{.}0000029\,\mathrm{E} + 0\overset{d}{.}020\cos(0\overset{\circ}{.}030\,\mathrm{E} + 295^\circ)$. *The dashed line is the approximate run of the* $[(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1)]$ *differences inside the two anomalous regions.*

It was Gaposhkin (1944) who first assumed CQ Cep to be a triple system. In our work we have attempted twice to roughly estimate the parameters of the possible long-period orbit and the mass of the third star (M_3) (Kartasheva, 1995). In connection with doubt about the correctness of interpreting the (O–C) diagram of the system, we have decided to perform more precise calculations within the frame of the "third body" hypothesis.

The history of investigation of the CQ Cep (O–C) diagram is reported in the paper by Kartasheva and Svechnikov (1989). Therein is presented a list of the observed moments of minimum light of the system, which is extended in our next paper (Kartasheva & Svechnikov, 1991). The list is complemented by fourteen new estimates of $T_{MinI(II)}$ collected in Table 1 of the present paper. As in our earlier investigations, we have applied the linear formula

$$T_{MinI(II)}(J.D.) = 2415500\overset{d}{.}780 + 1\overset{d}{.}641323\,E$$

to obtain deviations of the moments of the primary and secondary minima from the calculated. Apart from references, the last column of Table 1 presents information about the method of investigation (phe — photoelectric).

The (O–C) diagram supplemented by observations of the last few years is displayed in Fig. 1a. The differential $(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1)$ diagram of the system is shown in Fig. 1b

$$(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1) = (T_{MinII} - T_{MinI}) - P/2.$$

With the general uncertainty (multivariant character) of interpretation of the (O–C) diagram of CQ Cep, the two results of our previous examination of it re-

Table 1:

No.	Number of cycles (E)	Year	$T_{MinI(II)}$ (J.D.⊙)	Error	$\mathrm{O} - \mathrm{C}_{1(2)}$	$(\mathrm{O} - \mathrm{C}_2) - -(\mathrm{O} - \mathrm{C}_1)$	References
1	2	3	4	5	6	7	8
		1900+	2400000+				
105	20068.0	91.49	$48437\overset{\mathrm{d}}{.}435$		$-1\overset{\mathrm{d}}{.}415$		Kilinc, 1994, phe
106	20110.0	91.68	48506.367		-1.419		"-"
107	20115.5	91.71	48515.405		-1.408	$+0\overset{\mathrm{d}}{.}011$	"-"
108	20121.0	91.73	48524.419		-1.421		"-"
109	20305.0	92.56	48826.407		-1.437		"-"
110	20316.0	92.61	48844.465		-1.433		"-"
111	20319.0	92.62	48849.394		-1.428		"-"
112	20333.0	92.68	48872.363		-1.437		"-"
113	20335.5	92.70	48876.487		-1.417	+0.020	"-"
114	20338.5	92.71	48881.411		-1.417	+0.020	"-"
115	21183.0	96.60	50267.432	± 0.003	-1.494		Demircan et al.,1997, phe
116	21183.5	96.60	50268.252	± 0.005	-1.494	0.000	"-"
117	21230.0	96.80	50344.571	± 0.001	-1.496		Agerer and Huebscher, 1998, phe
118	21598.0	98.38	50948.542	± 0.001	-1.532		Barkovits and Biro, 1998, phe

main unchanged. The question is that of confirming the existence of the motion of the line of apsides in the system and subsequent revealing of the branchy character of the (O–C) diagram.

It is not simple to detect the apsidal motion in CQ Cep either because the amplitude of this effect is small or because in such a close system all the effects are distorted by the influence of the circumstellar gas environment. We have "seen" the cyclic variations attributed to the apsidal motion on the differential $[(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1)]$ diagram (Fig. 1b) as superimposed on the linear run of the differences:

$$(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1) = 0\overset{\mathrm{d}}{.}034 - 0\overset{\mathrm{d}}{.}0000029\,E+ \\ +0\overset{\mathrm{d}}{.}020\cos(0\overset{\circ}{.}030\,E + 295^\circ).$$

(The apsidal motion period U=54 years, the orbit eccentricity e=0.02). As can be seen from Fig. 1b, this linear run was violated twice during the century: in the interval between the years 1936 and 1949 (anomalous region I) and 1986–1999 (anomalous region II). The two anomalous regions are spaced by a time interval close to the apsidal motion period, which allows one to suppose that these two phenomena are related. The deviations associated with direct variation of the orbital period and with the possible rotation of the system on the long-period orbit are kept out of the differential $[(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1)]$ diagram (see formulae (2)–(4) in the paper by Kartasheva & Svechnikov, 1989). Proceeding from this, we have attributed the linear run of the difference $(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1)$ and its behaviour within the two anomalous regions wholly to the additional distortion of the moments of the secondary minima by the circumstellar gas surrounding (additional to the distortion of the moment of the main minimum). We cannot so far prove directly the correctness of our interpretation of the differential $(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1)$ diagram of CQ Cep. However, we are capable to check the reality of the apsidal motion parameters we have obtained by using them to determine the constants (k_2) of the internal structure of the system's components, which characterize the degree of concentration of matter towards the centres of the stars. We have accomplished this work (Kartasheva & Svechnikov, 1998). In the computation we used the estimates of masses and relative radii of the system's components which we had obtained (Kartasheva & Snezhko, 1985; Kartasheva & Svechnikov, 1996). The results of investigation show that for CQ Cep $k_{2WR} \approx k_{2O} = 0.0003$, which is an order of magnitude less than the value of the constants of the internal structure of main sequence stars. A comparison has been made of this estimate with the evaluations of k_2 derived for close binary systems showing the apsidal motions and containing a far-evolved component (α Vir, V380 Cyg, δ Ori(A), V1765 Cyg and β Per). The comparison has shown that the value of the constants of the internal structure of the CQ Cep components is close to the value of k_2 for the most evolutionary advanced components δ Ori(A) (O9.5 II) and V1765 Cyg (B0.5 Ib). Indeed in a number of papers (Marchenko et al., 1995; Kartasheva & Svechnikov, 1996; Kartasheva, 1996) it is shown that not only the WR but also the O component of CQ Cep are far-evolved stars. Thus the above result indicates that the parameters of the apsidal motion of CQ Cep we have derived are real, confirming indirectly that our interpretation of its $[(\mathrm{O}-\mathrm{C}_2)-(\mathrm{O}-\mathrm{C}_1)]$ diagram is correct.

For further inspection the $(\mathrm{O}-\mathrm{C}_1)$ and $(\mathrm{O}-\mathrm{C}_2)$ diagrams of the system were liberated from the effects associated with the apsidal motion, the $(\mathrm{O}-\mathrm{C}_2)$ diagram was cleared also from the additional distortions of the moments of the secondary minimum by the circumstellar gas medium. These procedures coordinated well the $(\mathrm{O}-\mathrm{C}_1)$ and $(\mathrm{O}-\mathrm{C}_2)$ differences with each other and reduced them to a common $(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}$ diagram. It can be seen well from Fig. 2a that the latter has disintegrated into six separate branches keeping on the whole the previous shape.

In our two studies (Kartasheva & Svechnikov, 1989, 1991) and in the Ph.D. thesis of one of the authors (Kartasheva, 1995) several variants of interpreting the run of the $(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}$ diagram of CQ Cep, as the secular decrease of its orbital period ($\dot{P}<0$), were considered. The branchy character of the corrected diagram ($\dot{P}\neq\mathrm{const}$) was taken into account. In the present paper we have deviated from the conventional interpretation and represented the $(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}$ diagram as a fragment of the long-period harmonic variation caused by the rotation of the WR binary around the centre of gravity of the triple system, assuming the orbit to be circular, that is:

$$(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}=\Delta T_0+\Delta P\,E+a\cos(\dot{\omega}_1\,E+\omega_{01}),$$

where

ΔT_0 is the correction to the origin of phase reckoning in a short-period orbit;

ΔP is the correction to the adopted value of the binary system orbital period;

a is the half-amplitude of the harmonic variation of the $(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}$ differences caused by the WR binary long-period orbiting: $a=a'\mathrm{sin}i'/c$ (a' is the radius of the long-period orbit, i' is the long-period orbit inclination);

$\dot{\omega}_1$ is the angular velocity of the motion of the binary system's centre of gravity on the long-period orbit: $\dot{\omega}_1=2\pi P/P'$ (P is the orbital period of the binary system, P' is the period of rotation of the binary's centre of gravity along the long-period orbit);

ω_{01} is the longitude of the centre of gravity of the binary system in the long-period orbit at the moment T_0.

The values of ΔT_0, ΔP, a, $\dot{\omega}_1$ and ω_{01} can roughly be estimated from the shape of the $(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}$ diagram. An attempt to calculate corrections to these preliminary values by the least squares method led us to "refined" values that gave a sloping straight line but not a sloping cosinusoid. This could be due to the great number of unknowns which distort one another when applying the least squares method. In our particular case the failure was most likely caused by the branchy character of the diagram. Indeed, the relative displacement of the $(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}$ diagram branches, which are probably caused by occasional bounces of the origin of phase reckoning (T_0), favoured scattering on the $(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}$ diagram and fuzzing up harmonic oscillation. For this reason specification of the above five parameters was performed by two steps in a manner similar to that done in the paper by Tchudowitchev (1939). The corrections to ΔT_0 and ΔP were specified first. By selecting different values of a, $\dot{\omega}_1$ and ω_{01}, we attained the difference

$$[(\mathrm{O}-\mathrm{C}_{1(2)})_{corr}-a\mathrm{cos}(\dot{\omega}_1\,E+\omega_{01})]=\Delta T_0+\\+\Delta P\,E \qquad (1)$$

to be linearly variable with time. Really, with $a=0\overset{\mathrm{d}}{.}15$, $\dot{\omega}_1=0\overset{\circ}{.}012$ and $\omega_{01}=275^\circ$ we managed to convert all branches of difference (1) to straight lines parallel to each other (Fig. 2b). The slope of the straight lines gives $\Delta P=-0\overset{\mathrm{d}}{.}000065$ which resulted in an orbital period value of the binary system $P=1\overset{\mathrm{d}}{.}641258$. As the correction to the origin of phase reckoning in the short-period orbit ΔT_0 was fixed to be $+0\overset{\mathrm{d}}{.}030\pm0\overset{\mathrm{d}}{.}030$, which yielded the original epoch value $T_0=2415500\overset{\mathrm{d}}{.}810$. The displacements of the branches with respect to the fixed ΔT_0 value turned out to be: $\Delta_1=-0\overset{\mathrm{d}}{.}020$, $\Delta_2=+0\overset{\mathrm{d}}{.}020$, $\Delta_3=-0\overset{\mathrm{d}}{.}037$, $\Delta_4=-0\overset{\mathrm{d}}{.}100$, $\Delta_5=-0\overset{\mathrm{d}}{.}035$, $\Delta_6=+0\overset{\mathrm{d}}{.}007$, $\Delta_7=-0\overset{\mathrm{d}}{.}010$. The number of branches had to be increased to seven, since the first branch of the $(\mathrm{O}-\mathrm{C}_{1(2)})_{corr}$ diagram broke down into two on the diagram $[(\mathrm{O}-\mathrm{C}_{1(2)})_{corr}-0.15\cos(0\overset{\circ}{.}012\,E+275^\circ)]$. Next, having pulled the branches to the level $\Delta T_0=+0\overset{\mathrm{d}}{.}030$ and introduced the corrections for ΔT_0 and ΔP, that is, having computed the expressions

$A=(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}-\Delta_i-(\Delta T_0+\Delta P\,E)=a\mathrm{cos}(\dot{\omega}_1\,E+\omega_{01})$ (i=1–7),

we got a chance to specify the parameters of the long-period harmonic variation associated with the movement of the binary around the centre of gravity of the triple system.

The following designations were introduced:

$$a=a_0+x,$$

$$\dot{\omega}_1=(\dot{\omega}_1)_0+y,$$

$$\omega_{01}=(\omega_{01})_0+z,$$

where

a, $\dot{\omega}_1$ and ω_{01} are the unknown quantities; a_0, $(\dot{\omega}_1)_0$ and $(\omega_{01})_0$ are the approximate values derived above ($a_0=0.15$, $(\dot{\omega}_1)_0=0\overset{\circ}{.}012$ and $(\omega_{01})=275^\circ$),

x, y, z are the corrections to the approximate values of the parameters.

By applying expansion of $A=a\mathrm{cos}(\dot{\omega}_1\,E+\omega_{01})$ into a Taylor series, we derived a set of linear conditional equations:

$$a_kx+b_ky+c_kz+l_k=0,$$

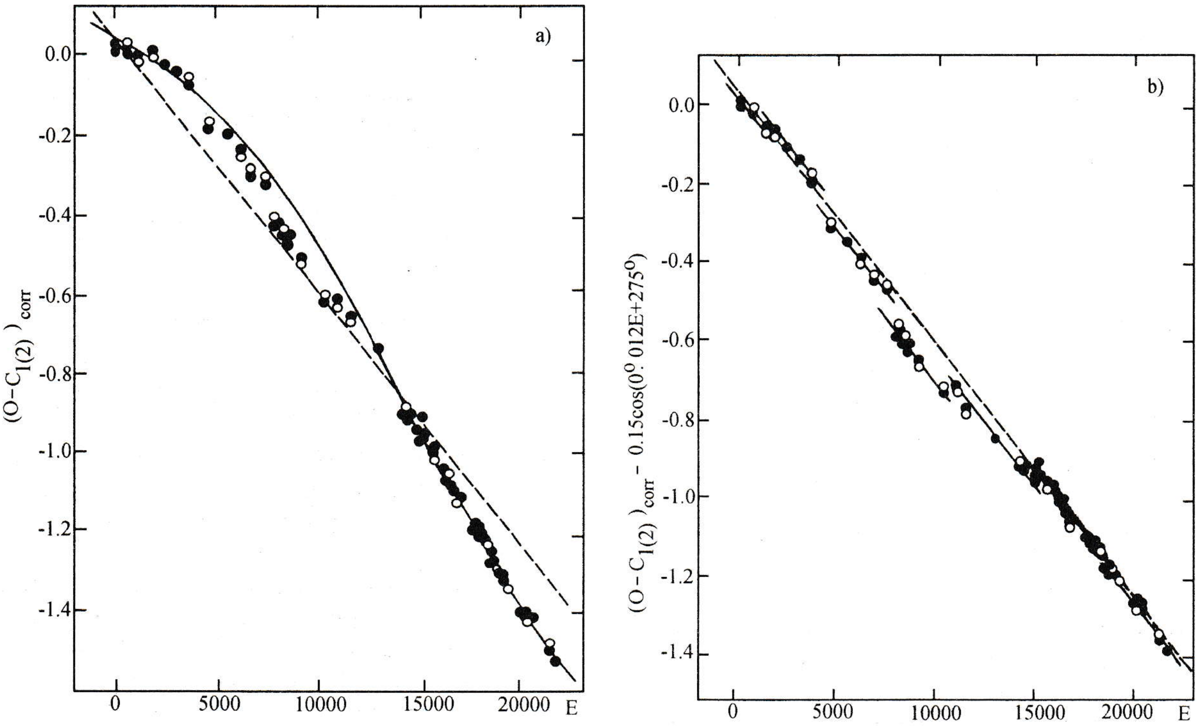

Figure 2: *a)* $(O-C_{1(2)})_{corr}$ *diagram of CQ Cep for the moments of the main (filled circles) and secondary (open circles) minima corrected for the apsidal motion and additional distortions of the moments of the secondary mimimum by the circumstellar gas medium. The solid line is the theoretical representation of the* $(O-C_{1(2)})_{corr}$ *diagram by a sloping cosinusoid:* $(O-C_{1(2)})_{corr} = +0^{d}.030 - 0^{d}.000065\,E + 0^{d}.15\cos(0^{\circ}.012\,E + 275^{\circ})$. *The dashed line shows the linear run of the* $(O-C_{1(2)})_{corr}$ *differences caused by inaccuracies of the adopted values of the origin of phase reckoning* (T_0) *and of the orbital period (P).*
b) $[(O-C_{1(2)})_{corr} - 0^{d}.15\cos(0^{\circ}012\,E+275^{\circ})]$ *diagram for the moments of the main (filled circles) and secondary (open circles) minima of the system. The solid line shows the theoretical representation of the branches of this diagram by parallel straight lines. The sense of the dashed line is the same as in Fig. 2a.*

where $a_k = [\cos(\dot{\omega}_1\,E + \omega_{01})]_0$,
$b_k = [-a\,E\sin(\dot{\omega}_1\,E + \omega_{01})]_0$,
$c_k = [-a\sin(\dot{\omega}_1\,E + \omega_{01}]_0$,
$l_k = [a\,cos(\dot{\omega}_1\,E + \omega_{01})]_0 - [(O - C_{1(2)})_{corr} - \Delta_i - (\Delta T_0 + \Delta P\,E)]$.

The null index by the square brackets indicates that the values of derivatives and the values of the function A should be computed with approximate a_0, $(\dot{\omega}_1)_0$ and $(\omega_{01})_0$ given above.

As a result of the calculations performed, we have derived the following expression for the long-period harmonic variation:

$$A = 0^{d}.1517\cos(0^{\circ}.01200\,E + 271^{\circ}.83).$$
$$\pm 0.0005 \qquad \pm\, 0.00003 \qquad \pm\, 0.40.$$

We restricted ourselves to a first approximation since the x_1 and z_1 corrections turned out to be small, and the values of $(\dot{\omega}_1)_0$ and $(\dot{\omega}_1)_1$ coincided altogether. An attempt to specify ΔT_0 and ΔP using the new parameters of the long-period harmonic variation has not affected them.

The $(O - C_1)$ and $(O - C_2)$ diagrams of CQ Cep recalculated with involvement of the refined values of the original epoch ($T_0 = 24151500^{d}.810$) and the orbital period ($P = 1^{d}.641258$) of the binary are displayed in Figs. 3 and 4a. The bold solid lines are the theoretical representation of the diagrams as the sum of harmonic fluctuation of the (O–C) differences associated with the apsidal motion in a binary system, harmonic variation due to rotation of the binary around the centre of gravity of the triple system, and deviations caused by distortion of the moments of the minima by the circumstellar gas medium. In Fig. 4b are presented the residual deviations of the (O–C) differences from the computed.

Our parameters of the long-period orbit and the third body mass (M_3) of CQ Cep are collected in Table 2. When computing, we made use of an expression

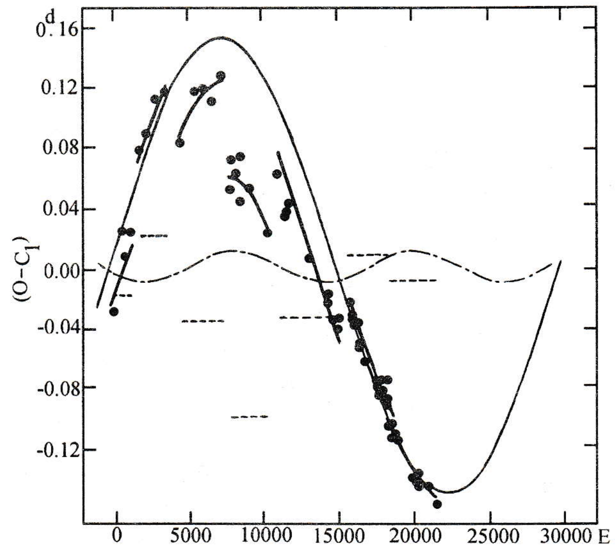

Figure 3: (O – C$_1$) *diagram recomputed with specified values of* T_0 *and* P. *The thick lines are a theoretical representation of the diagram as the sum of three components: cyclic variation caused by the apsidal motion in the binary system (dash-and-dot line); cyclic variation associated with the motion of the binary around the centre of gravity of the triple system (thin solid line), and effects due to the distortion of the moments of the minima by the circumstellar gas medium (dashed line).*

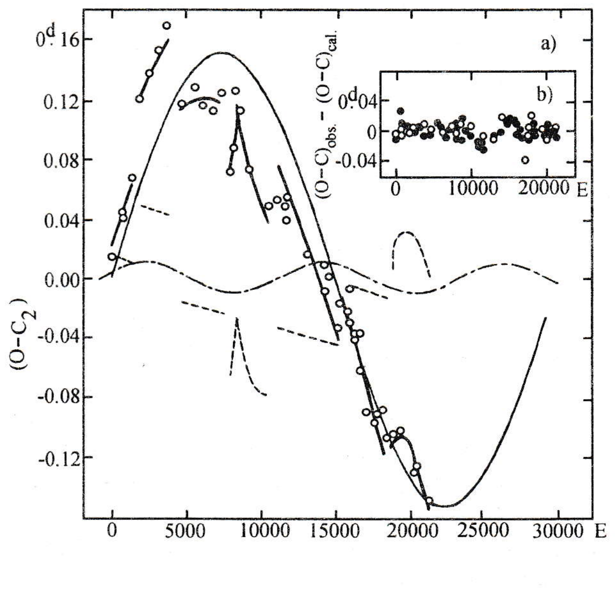

Figure 4: *a)* (O – C$_2$) *diagram of CQ Cep recalculated with refined values of* T_0 *and* P. *The sense of the lines is the same as in Fig. 3.*
b) Diagram of residual deviations of the (O – C) *differences from the computed for the moments of the main (filled circles) and secondary (open circles) minima.*

Table 2:

P'(years)	134.9
a'(km)	$4.56 \cdot 10^9$ (30.4 a.u.)
$\beta('')$	0.008
$M_3(M_\odot)$	17.2
Sp M_3	B0 V – B1 IV–III

for the “mass function” of the triple system:

$$f(M_3) = \frac{(M_3 \sin i')^3}{(M_{WR} + M_O + M_3)^2} = \frac{(a' \sin i')^3}{(P')^2},$$

(see Zverev et al., 1947), where the long-period orbit radius (a') is measured in astronomical units, the period of rotation on the long-period orbit (P') in years, the masses of the components (M_{WR}, M_O and M_3) are expressed in solar masses. The orbits of the binary and triple systems were assumed to have the same inclinations ($i' = i = 59\overset{\circ}{.}5$) (Kartasheva and Svechnikov, 1996). M_{WR} and M_O were taken from the paper by Kartasheva and Znezhko (1985). β — the angular separation of the third body and the eclipsing pair ($\beta'' \approx a' \sin i'/r$) — was estimated with the distance to CQ Cep r = 3.5 kpc (Van der Hucht et al., 1988). The spectral class of the third star was determined from a refined relation Sp–M of Straizys and Kuriliene (1981).

In accordance with the results of solution of the lowest-amplitude light curve of CQ Cep of July-August 1937 (Kurochkin, 1979; Kartasheva and Svechnikov, 1996) the relative luminosities of the system's stars (with $L_{WR} + L_O + L_3 = I$) are: $L_{WR} = 0.375$, $L_O = 0.355$ and $L_3 = 0.270$. From this it follows that $L_O/L_3 = 1.32$ and $\Delta m = m_3 - m_O = 0\overset{m}{.}3$. Knowing the absolute visual magnitude for the O-companion ($M_{vO} = 5\overset{m}{.}14$, Kartasheva & Svechnikov, 1996), we succeeded in finding M_v of the third star: $M_{v3} = -4\overset{m}{.}84$. Next, from the relation $Sp - M_v$ of Straizys and Kuriliene (1981) its spectral class was estimated, O8–B1(V–III). That is the results of photometric studies are fairly consistent with those following from the examination of the CQ Cep (O–C) diagram. Since there are no lines of the third star in the spectrum of the system, and absorption lines of the O companion of the eclipsing binary (O9.5 III) are at the limit of detection (Kartasheva, 1996), the spectrum of the third star is then most likely to be B0–B1(V–III).

A convincing reason “for” and “against” triplicity of CQ Cep is the behaviour of γ-velocity with time in the binary system. In Table 3 are collected all γ-velocity estimates of CQ Cep, which are derived from measuring the narrowest emission line in the spectrum NIV 4058 Å (the emission line that represents well the motion of the WR component). The data of

Table 3:

Date	γ-velocity (km/s) (NIV 4058Å)	References
November, December 1943	-75 (-75± 5)	Hiltner, 1944
	-53.4 ± 2.3 (-65 ± 5)	Stickland et al., 1984
1951–1952	-61.6	Bappu and Visvanadham, 1977
	-60.8 ± 3.7	Shylaja, 1986
September 1978	-60 ± 5	Leung et al., 1983
?	-85	Niemela, 1981
1981–1982	-55.4 ± 7.7	Kartasheva and Snezhko, 1985
1988—1994	no (-65 ± 5)	Marchenko et al., 1995
August 1995	-72 ± 1 (-66 ± 5)	Harries and Hilditch, 1997

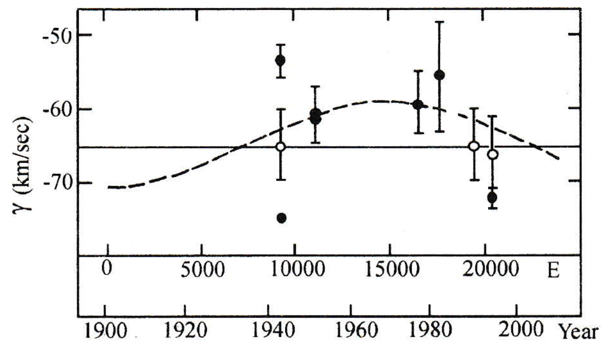

Figure 5: *Time dependence of the observed γ-velocity values of CQ Cep which follow from measurements of the emission line NIV 4058 Å in its spectra (filled circles). Our repeated measurements of γ-velocity for a series of observations are designated by open circles. The dashed line is a representation of the computed curve of the γ-velocity variations of CQ Cep caused by the long-period orbiting of the binary system on the assumption that the γ-velocity of the binary system $\gamma_0 = -65$ km/s.*

Table 3 are presented in Fig.5. For the earliest two collections of spectra of CQ Cep (Hiltner, 1944; Bappu & Visvanadham, 1977) Table 3 gives two estimates of the γ-velocity for either collection, for in the 1980s they were remeasured using updated devices (Stickland et al., 1984; Shylaja, 1986). After examining Table 3 and the papers in which γ-velocities had been obtained we thought it necessary to introduce some corrections into estimates of the latter (our results are presented in brackets). Firstly, we determined the γ-velocity of the system from the measures of the emission line NIV 4058 Å in the spectra taken by Marchenko in 1988–1994 without involving the results of the earlier spectral studies. Secondly, we revised the γ-velocity value given in the paper by Harries and Hilditch (1997), taking account of the highest estimates of V_r ignored by their fitting curve (see Fig. 1 in Harries & Hilditch, 1997). At last, we reevaluated the γ-velocities from two series of measurements of the emission line NIV 4058 Å in the spectra observed by Hiltner in 1943. The results of Niemela (1981) are not presented in Fig. 5 because we have no information about the time she obtained the spectra of CQ Cep.

As is seen from Fig. 5, with allowance made for our specifications, the γ-velocity is apparently time dependent. The half-amplitude of the additional radial velocity variation related to rotation of the binary on the long-period orbit can readily be computed:

$$K = 1.99 \times 10^{-7} \frac{a' \sin i'}{P'} = 5.8\,\mathrm{km/s},$$

where a' is measured in kilometres, P' in years, K in km/s. If the γ-velocity of the binary system be taken as $\gamma_0 = -65$ km/s, the sinusoid

$$B = 5.8 \sin\,(0^{\circ}\!.012\,E + 271^{\circ}\!.83)\ \mathrm{km/s}$$

described by the γ-velocity due to rotation of the binary around the centre of gravity of the triple system is in good agreement with observations (Fig. 5).

The studies performed show that to a high degree of probability CQ Cep is a triple star. Besides, the computations made on the assumption that the period of the binary system is constant suggest that the distortions of the moments of the minima (especially the secondary) by the circumstellar gas environment make a great contribution to the behaviour of the $(\mathrm{O} - \mathrm{C}_1)$ and $(\mathrm{O} - \mathrm{C}_2)$ diagrams of CQ Cep. The medium manifests itself in two ways: through distortion of the differential $[(\mathrm{O} - \mathrm{C}_2) - (\mathrm{O} - \mathrm{C}_1)]$ diagram and through displacement of the origin of phase reckoning (T_0) on the $(\mathrm{O}-\mathrm{C}_{1(2)})_{\mathrm{corr}}$ diagram. The jumps of T_0 are probably associated with abrupt changes in the spatial distribution of circumstellar matter caused by episodic expulsion of the outer parts of the common envelope of the system. That such processes occur in the system is evidenced by recent polarimetric observations of CQ Cep (Kartasheva et al., 1999). The difference in the distortion of the moments of the primary and secondary minima are natural. The size of the O-star is essentially larger than that of the WR core (Kartasheva and Svechnikov, 1996), and at the phases of the secondary minima not only the WR core is projected onto the O-star, but also an unstable gas condensation which forms between the components as a consequence of collision of their stellar winds. The run of this difference is, apparenty, complex, but it basically preserves its linearity throughout the 100-year interval of observations. Violation of this linearity and the appearance on the $[(\mathrm{O}-\mathrm{C}_2)-(\mathrm{O}-\mathrm{C}_1)]$ diagram of two anomalous regions similar in shape and amplitude and spaced by a time approximately equal to the apsidal motion period does not seen to us accidental and serves as indirect confirmation of the motion of the line of apsidal motion in the close orbit. Indeed, in every orbital cycle of the eclipsing pair additional ejection of matter from the O-component, filling its Roche lobe, is likely to occur at the moment of the closest approach of the components in the eccentric orbit. Additional distortion of the secondary minimum moment, which accompanies this phenomenon, will occur, however, but in a particular combination of phases of the orbital and apsidal cycles. At the moments of the two anomalous regions on the differential $[(\mathrm{O}-\mathrm{C}_2)-(\mathrm{O}-\mathrm{C}_1)]$ diagram of CQ Cep the closest approach of the components fell on the elongation preceding the secondary minima. For a quarter of the orbital period additional matter ejected at the time the components approach most closely one another and having a velocity ($\Delta V \approx 100\,\mathrm{km/s}$) sufficing to defeat the WR wind could really shift and introduce additional distortion of the secondary minimum moment. In this case, this distortion must preserve, gradually reducing, for a quarter of the apsidal period and disappear when the closest approach of the components of the eclipsing binary falls at the moment of the secondary minimum. At this moment additional matter, being projected onto the disk of the O-star, will be located symmetrically about the disk centre, producing no distortions of the moment of the minimum. No additional distortions of the moments of the secondary minimum are to be observed for the remaining three quarters of the apsidal period. This is confirmed by the shape of the differential $[(\mathrm{O}-\mathrm{C}_2)-(\mathrm{O}-\mathrm{C}_1)]$ diagram.

The results obtained in the paper are in good agreemem with the results of photomeric and spectral studies of the system. However, one can state conclusively that CQ Cep is a triple system, that the orbital period of the eclipsing binary keeps constant, and it is the circumstellar gas medium that is responsible for all non-cyclic variations of the (O–C) differences no sooner than in a few decades, after the whole cycle of the suspected long-period motion of the binary have been observed. Thus the importance of further photometric and spectral studies of CQ Cep is obvious.

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