1992A&A...253..178P

Astron. Astrophys. 253, 178–184 (1992)

ASTRONOMY
AND
ASTROPHYSICS

The orbit of β Cephei derived from the light-time effect

A. Pigulski and D. A. Boratyn

Wrocław University Observatory, Kopernika 11, PL-51-622 Wrocław, Poland

Received June 11, accepted July 24, 1991

Abstract. An inspection of the O – C diagram of β Cep suggests that the star's pulsation period underwent an abrupt increase of unknown origin around 1915. After this date, a slow increase of the pulsation period with a rate of more than 1 s century^{-1} was found by some authors, while others proposed that the period remained constant. In the present paper a natural explanation of the variations seen in the O – C diagram of β Cep is offered. It is shown that the apparent changes of the period can be understood in terms of orbital motion of the variable in a binary system, in which the secondary is the less massive companion resolved by speckle interferometry. The spectroscopic orbital elements are derived from the O – C diagram, and the visual ones from the speckle interferometric data. The orbital elements fit very well the observed changes of the period and are consistent with the non-pulsational component of the radial velocity variation. Other properties of the system are also discussed.

Key words: β Cep stars – spectroscopic binary stars – visual binary stars – individual stars: β Cep

1. Introduction

In 1902 Edwin B. Frost discovered changes of the radial velocity of the bright star β Cephei (HR 8238, HD 205021, $V = 3.23$, B1 IV). He subsequently established that the period of these changes amounted to about 4.5 h (Frost 1906). Some years later, Guthnick & Prager (1914) detected a light variation of β Cep with the same period. In the following years, more stars of similar type of variability were discovered. Much later it became clear that these stars form a class of short-period pulsating variables, of which β Cep became the prototype. Some of these stars are multiperiodic. β Cep itself is monoperiodic with a period of $0\overset{d}{.}19048$; semi-amplitudes of light and radial-velocity variations are equal to 0.015 mag in V and 8–20 km s^{-1}, respectively.

The variable is the brighter member of the visual pair ADS 15032 (separation $13\overset{''}{.}4$, $\Delta m = 4.6$ mag). Fitch (1969) analyzed a set of 713 spectrograms of the star, collected by Struve and co-workers in the years 1950–52. He concluded that the changes of radial velocity of the variable's centre of mass are caused by a close companion orbiting the variable primary with a period of $10\overset{d}{.}893$. Later, still another component in the system of β Cep was found by Gezari et al. (1972) by means of speckle interferometry; the separation was about $0\overset{''}{.}25$ in 1971. Gezari et al. (1972) suggested that the orbital period of the speckle companion is of the order of 100 yr.

In studies of the O – C diagram for the moments of maxima of the radial velocity it was suggested (Smith 1943; Struve et al. 1953; Chapellier 1985) that an abrupt increase of the pulsation period took place around 1915. Smith (1943) and Struve et al. (1953), respectively, found that after this date the period was slightly increasing with a rate of 1.7 and 1.2 s century^{-1}. On the other hand, Chapellier (1985) maintains that the pulsation period remained constant after 1925, but that the phase difference between light and radial velocity curves was changing (Chapellier 1986).

In an attempt to resolve this controversy, we obtained photometric observations of the star on two nights in October 1990. Using these observations, we found a $0\overset{d}{.}05$ discrepancy between the observed times of maximum light and the ephemeris of Chapellier (1985). We then decided to reinvestigate all available observations of the star in order to clarify the character of the period changes.

In the present paper we show that the apparent changes of the pulsation period of β Cep can be explained by the light-time effect, induced by the orbital motion of the variable around the barycentre of the variable–speckle companion system. All the available spectrographic and photometric observations, including the new ones, are used to construct an O – C diagram, from which the spectroscopic orbital elements of the system are then derived. The speckle interferometric observations, compiled from the literature, allow determination of additional orbital elements of the system.

2. The data

During the first half of the century numerous spectrograms of β Cep were secured from the above-mentioned Frost's observations to those of Struve et al. (1953). Later, unfortunately, spectrographic observations became sporadic. In our analysis we used all published radial velocity data, namely those of Crump (1916, 1934), Henroteau (1922, 1925), van Arnam (1929), Mendenhall (1930), Duncan & Mitchell (1929), Kohl (1933), Smith (1943), Roman (1947), Rudkjöbing (1949), Struve et al. (1953), Goldberg et al. (1974), Lane & Percy (1979), Hutchings & Hill (1977), Campos & Smith (1980), and Mathias et al. (1991). In some cases, when the data were not given in tabular form, numbers were read from the figures.

Photometry of β Cep is much less extensive than are the spectrographic data, mainly because of the brightness of the star

---

Send offprint requests to: A. Pigulski

1992A&A...253..178P

and lack of suitable comparison stars. As in the case of the spectrographic observations, we used all available data from Guthnick & Prager (1914, 1918), Cummings (1922), Henroteau (1925), Güssow (1926), Stebbins & Kron (1954), Gray (1970), Beeckmans & Burger (1977), Hutchings & Hill (1977), and the moments of maximum light reported in Chapellier (1985) and Valtier et al. (1985). Since the Julian day for the observations listed by Hutchings & Hill (1977) is 1 day greater than the one, found from the published day of year, we corrected those dates accordingly. The photometric observations made at Białków during two nights in October 1990 are described in Appendix A.

3. The O – C diagram

Changes of period can be studied on the O – C diagram, that is, a diagram of the differences between observed times of maximum radial-velocity or light and the time predicted from an ephemeris, plotted as a function of the number of elapsed cycles. In the present case, the O – C diagram will be used for deriving spectroscopic orbital elements. Radial velocities of the variable's centre of mass, which could also be used for this purpose, are much less suitable because they show a large amount of scatter (see Sect. 5 and Fig. 4).

For the O – C diagram, the times of maximum radial-velocity and light are needed. Following Fitch (1969), we derived them by fitting a single sinusoid with assumed pulsation period to the observations on a given night. The values of radial velocity of the variable's centre of mass, obtained at this time, will be discussed in Sect. 5. The pulsational period was assumed to be equal to $0\overset{\mathrm{d}}{.}19048$.

The O – C values for maximum radial-velocity were calculated using the ephemeris:

$$\text{max. radial-velocity} = \text{JDH}\,2\,413\,499.5407 + 0\overset{\mathrm{d}}{.}1904852\,\text{E}\,, \tag{1}$$

where E is the number of cycles.

The photometric observations were used for supplementing the O – C diagram obtained from the spectrographic data. The O – C values for the photometric maxima were derived assuming the same ephemeris (1). The pioneer photoelectric photometry of Guthnick & Prager (1914, 1918) and that of Cummings (1922) and Güssow (1926) has been made with a slightly variable α Cep as the comparison star; the O – C values derived from these data show large scatter. Therefore, the average O – C value for each of these sets of data was used in the analysis. The O – C values for the first five filters of the six-colour photometry of Stebbins & Kron (1954) were also averaged. The I observations were omitted due to very small amplitude of the variation in this filter.

4. Orbital elements of the binary system

4.1. Spectroscopic orbit

We derived the system's spectroscopic orbital elements from the O – C diagram, assuming that the orbital motion is the only cause of the observed variation of the pulsation period. Both the photometric and radial velocity times of maximum were used to construct a single O – C diagram. Therefore, the average phase difference, $\Delta\phi$, between the radial-velocity curve and light curve had to be established.

For β Cep stars the value of $\Delta\phi$ amounts to about 1/4 of the pulsation period. As a first approximation of $\Delta\phi$ we adopted the value of $0\overset{\mathrm{d}}{.}0476 = 0\overset{\mathrm{d}}{.}19048/4$. This value of the phase difference was subtracted from the photometric O – C values.

The observed pulsation period, $P_{\rm puls}$, is a function of radial velocity of variable's centre of mass, $V_{\rm rad}$, and the true (i.e., in the variable's frame) pulsation period P_0: $P_{\rm puls} = P_0(1 + V_{\rm rad}/c)$, where c is the velocity of light. $V_{\rm rad}$ is fully described by six elements of the spectroscopic orbit, namely: radial velocity of the system's barycentre γ, orbital period $P_{\rm orb}$, semi-amplitude K_1 of the radial-velocity curve, due to orbital motion of the variable star, eccentricity of the orbit e, longitude of periastron ω, and the time of periastron passage T_0. The O – C diagram depends also on the choice of the period and initial epoch in the ephemeris, according to which the O – C values are calculated. Since P_0 and γ are not known beforehand, and the values of initial epoch and period in (1) were chosen arbitrarily, we calculated the synthetic O – C curve, assuming the values of 5 orbital parameters, $P_{\rm orb}$, K_1, e, ω, and T_0 (without γ) and allowing the presence of a linear trend of the form $a + b\text{E}$ in the O – C diagram. Thus, we considered the O – C as a function of 7 parameters: $\text{O} - \text{C} = \text{O} - \text{C}(P_{\rm orb}, K_1, e, \omega, T_0, a, b)$.

In calculations, we applied the method of differential corrections, where the parameters are improved during consecutive iterations. Having fixed the approximate values of all seven parameters, the corrections were obtained by the method of least squares. The iterations were performed until all corrections become negligible. Then, the synthetic O – C curve was fitted separately to the spectrographic and photometric O – C values in order to improve the value of the phase difference $\Delta\phi$. Next, the new value of $\Delta\phi$ was subtracted from the photometric O – C values and the procedure of determining the orbital elements was repeated. Finally, we obtained the values of the orbital elements and the average value of $\Delta\phi$, listed in Table 1. The final O – C diagram, with the ultimately adopted synthetic curve is shown in Fig. 1.

4.2. Visual orbit

As is well known, the orbit of a visual binary is fully determined by seven orbital elements, of which four, $P_{\rm orb}$, T_0, e, and ω, are common to the spectroscopic orbit. The three remaining ones are:

– the inclination, i, the angle between the true orbital plane and plane perpendicular to the line of sight,

Table 1. The elements of the binary system of β Cep

Orbital elements

$P_{\rm orb} = 91.6 \pm 3.7\,\text{yr}$

$K_1 = 8.0 \pm 0.5\,\text{km}\,\text{s}^{-1}$

$e = 0.65 \pm 0.03$

$\omega = 194^\circ \pm 4^\circ$ (from spectroscopic orbit)

$ = 34\overset{\circ}{.}9 \pm 1\overset{\circ}{.}1$ (from visual orbit)

$T_0 = 1914.6 \pm 0.4$

$\Omega = 223\overset{\circ}{.}7 \pm 1\overset{\circ}{.}1$

$i = 86\overset{\circ}{.}7 \pm 1\overset{\circ}{.}2$

$a'' = 0\overset{\prime\prime}{.}25 \pm 0\overset{\prime\prime}{.}07$

$\gamma = -6.6 \pm 0.4\,\text{km}\,\text{s}^{-1}$

Other parameters

$\Delta\phi = 0.0508 \pm 0.0015\,\text{d} = 0.267 \pm 0.008\,P_{\rm puls}$

$a_1 = (2.8 \pm 0.3)\,10^9\,\text{km} = 18.6 \pm 1.8\,\text{AU}$

$f(\mathcal{M}) = 0.77 \pm 0.16\,\mathcal{M}_\odot$

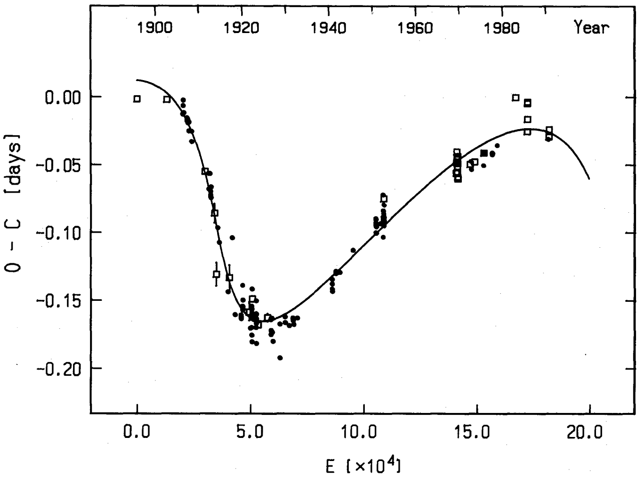

Fig. 1. The O – C diagram for the radial-velocity (filled circles) and photometric (open squares) times of maxima. Mean photometric O – C values are shown with their error bars. Predicted times of maximum were calculated from Eq. (1). An average phase difference $\Delta\phi = 0\overset{\rm d}{.}0508$ was subtracted from all photometric O – C values. Continuous line represents the O – C curve, derived from orbital elements listed in Table 1

– position angle of the line of nodes Ω,
– major semi-axis of the true orbit in arc sec a''.

The longitude of periastron, ω, differs by 180° for the spectroscopic and visual orbits, as the first one refers to the orbit of the primary, while the second, to that of the secondary.

The speckle interferometric observations of β Cep are compiled in Table 2. They cover an interval of 17 yr, that is about 1/5 of the orbital period. We cannot thus derive the orbital elements from the speckle interferometric data alone. However, after fixing three elements, namely $P_{\rm orb}$, T_0, and e, we can easily obtain the four remaining ones, that is, ω, Ω, i, and a''.

Elements of the visual orbit were derived following Heintz (1978), with $P_{\rm orb}$, T_0, and e taken from the spectroscopic solution. The elements are listed in Table 1. The relative orbit of the secondary with respect to the primary is shown in Fig. 2. The longitude of periastron, ω, obtained from the visual orbit is 21° greater than the value which would be in agreement with ω obtained from the spectroscopic orbit. We believe, however, that it is too early to try to derive consistent orbital elements from a combination of the O – C and speckle data. It will be much safer to do so in about 20 yr from now, when the observations will have covered the next periastron passage.

4.3. Properties of the system

The time of periastron passage which we derived (see Table 1) coincides with the time of abrupt change of period found by Struve et al. (1953) and Chapellier (1985). This is understandable because the orbit is highly eccentric and the major semi-axis is almost perpendicular to the line of sight. Therefore, near the time of periastron passage the changes of radial velocity and, in consequence, of the period are very fast, leading to an almost abrupt change in the O – C diagram.

If the distance of the system were known, the masses of the components could be determined. Jenkins (1952) and Hoffleit (1982) give the star's parallax equal to $0\overset{\prime\prime}{.}005$ and $0\overset{\prime\prime}{.}014$, respectively. These values show that the parallax of β Cep is too small to be measured with satisfactory accuracy. The only way to obtain the distance is the use of photometric calibrations of the absolute magnitudes. From the photometric indices, $\beta = 2.601$, $c_0 = -0.020$ and $V = 3.19$, given by Shobbrook (1978) for β Cep, we derived $M_V = -3.67$, using the recent calibration of Balona & Shobbrook (1984) for evolved stars. Thus, the distance of β Cep is 235 pc. However, the accuracy of photometric calibration for early B stars is of the order of 0.5 mag, leading to a 25% uncertainty in the distance. Moreover, the errors of a'' and the mass function $f(\mathscr{M})$ are also large (see Table 1). Consequently, formally obtained masses of the system's components amounting to 17 and 8 $\mathscr{M}_\odot$ are very uncertain.

5. Apparent changes of the pulsation period and the radial velocity of the variable's centre of mass

From the orbital elements we can calculate the observed value of the pulsation period and the radial velocity of the variable's centre of mass, V_0, as a function of time. The results, synthetic changes of $P_{\rm app}$ and V_0, are shown as continuous lines in Figs. 3 and 4, respectively.

The average values of the observed pulsation period, plotted in Fig. 3 as closed circles with error bars, were obtained in the following way. To begin with, we selected such sets of observations which relatively well covered time intervals of 2 to 4 yr. Next, a Fourier transform of each of these data sets was computed in order to derive the period for which the spectral power has a maximum. This value was used as a first approximation, and was iteratively improved by fitting a sine curve to the data.

Additional average values of the period were obtained assuming that in between two selected maxima, derived from good quality data, a constant number of cycles has elapsed. The number of elapsed cycles, N, was chosen so that the resulting period was close to the values obtained in the analysis of selected sets of data. In no case there was any doubt about the value of N to be chosen.

The periods derived using both these methods, together with their errors, are shown in Fig. 3. The agreement between the average values of the period and their computed changes is excellent.

The observed radial velocities of the variable's centre of mass were derived by fitting the sinusoid to the spectrographic observations on individual nights. They are plotted as filled circles in Fig. 4. The value of γ cannot be derived from the O – C diagram (see Sect. 4.1). It can be obtained, however, by fitting the synthetic radial-velocity curve to the observations of the nightly radial velocities of the variable's centre of mass by the method of least squares. The value of γ is listed in Table 1 and the computed changes of radial-velocity of variable's centre of mass are shown as continuous line in Fig. 4.

As can be seen from Fig. 4, the scatter of the radial velocities around the synthetic curve is substantial. The question, whether it is due to systematic errors or to some physical phenomenon is beyond the scope of this paper. As we mentioned in the Introduction, from the analysis of Struve et al. (1953) data, Fitch (1969) tried to explain this scatter, assuming the existence of a close companion, orbiting the variable with a period of $10\overset{\rm d}{.}893$. We carried out a similar analysis of the Struve et al. (1953) data and found that in the Fourier spectrum the peak at $10\overset{\rm d}{.}893$ is not clearly distinguishable from the noise. In addition, in the Fourier spectra of other data sets we did not find any significant peaks,

Table 2. A compilation of the speckle interferometric observations of β Cep

Date (yr)	Binary separation (″)	Position angle (°)	Ref.
1971	0.255±0.010	–	Gezari et al. (1972)
1971.48	0.255	47	Labeyrie et al. (1974)
1971.48	0.256	48	Labeyrie et al. (1974)
1971.78	0.264	48	Labeyrie et al. (1974)
1972.27	0.258	47	Labeyrie et al. (1974)
1972.27	0.262	47	Labeyrie et al. (1974)
1972.46	0.252	47	Labeyrie et al. (1974)
1972.46	0.258	47	Labeyrie et al. (1974)
1973.45	0.244	49	Labeyrie et al. (1974)
1975.545	0.225±0.009	37.2±1.5	Morgan et al. (1978)
1975.6305	0.242±0.024	47 ±1	Blazit et al. (1977)
1975.7152	0.234±0.002	47.8±0.5	McAlister (1977)
1975.7728	0.247±0.025	48 ±1	Blazit et al. (1977)
1975.956	0.210±0.004	47.3±1.0	Morgan et al. (1978)
1976.3019	0.224±0.001	49.9±0.3	McAlister (1978)
1976.4007	0.242±0.030	54 ±1	Blazit et al. (1977)
1976.4497	0.219±0.001	49.3±0.5	McAlister (1978)
1976.6165	0.221	53.2	McAlister & Hendry (1982a)
1976.6192	0.234	50.1	McAlister & Hendry (1982a)
1976.6220	0.226	49.9	McAlister & Hendry (1982a)
1976.8594	0.222±0.002	49.2±0.4	McAlister (1978)
1977.4818	0.217±0.001	48.8±0.2	McAlister (1979)
1977.4874	0.218±0.001	48.7±0.4	McAlister (1979)
1977.6348	0.214	48.5	McAlister & Hendry (1982a)
1977.8811	0.204±0.008	47.2±1.9	Morgan et al. (1980)
1977.9134	0.205	47.5	McAlister & Hendry (1982a)
1977.9189	0.226	45.8	McAlister & Hendry (1982a)
1978.3947	0.233±0.008	51 ±2	Bonneau & Foy (1980)
1978.5413	0.206±0.001	49.6±0.4	McAlister & Fekel (1980)
1978.6097	0.204±0.001	49.6±0.4	McAlister & Fekel (1980)
1978.6150	0.203±0.001	49.2±0.4	McAlister & Fekel (1980)
1979.4685	0.204±0.010	51.0±1.5	Bonneau et al. (1980)
1979.5297	0.201	48.5	McAlister & Hendry (1982b)
1979.7700	0.194	49.2	McAlister & Hendry (1982b)
1980.4185	0.184±0.003	49.2±0.3	Dudinov et al. (1987)
1980.4743	0.180±0.005	52 ±1	Balega et al. (1984)
1980.4798	0.188	49.4	McAlister et al. (1983)
1980.4852	0.191	49.6	McAlister et al. (1983)
1980.7202	0.184	49.4	McAlister et al. (1983)
1980.7953	0.182±0.002	48.9±0.3	Dudinov et al. (1987)
1981.4655	0.172	50.6	McAlister et al. (1984)
1981.4711	0.175	48.4	McAlister et al. (1984)
1982.5031	0.156	49.6	McAlister et al. (1987)
1982.5057	0.151	50.8	McAlister et al. (1987)
1982.7599	0.159	51.5	McAlister et al. (1987)
1983.4259	0.151	51.4	McAlister et al. (1987)
1983.4341	0.144	50.9	McAlister et al. (1987)
1983.7100	0.146	52.1	McAlister et al. (1987)
1984.7013	0.129	51.5	McAlister et al. (1987)
1985.4849	0.121	51.8	McAlister et al. (1987)
1986.4452	0.11	–	Lortet et al. (1987)
1986.8910	0.100	52.5	McAlister et al. (1989)
1987.7593	0.090	55.1	McAlister et al. (1989)
1988.6632	0.068	51.0	McAlister et al. (1990)

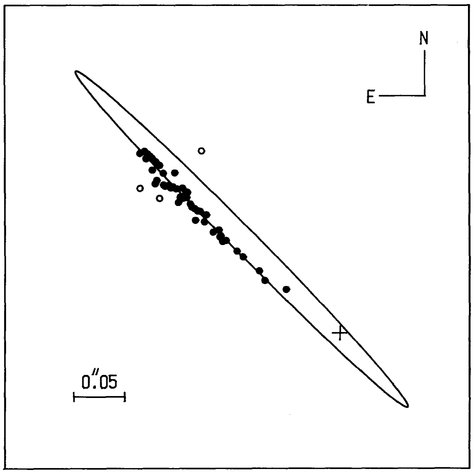

Fig. 2. Relative orbit of the secondary in the β Cep system. Position of the primary is marked by plus sign. The speckle interferometric observations are shown as filled circles. Observations omitted in analysis are plotted as open circles

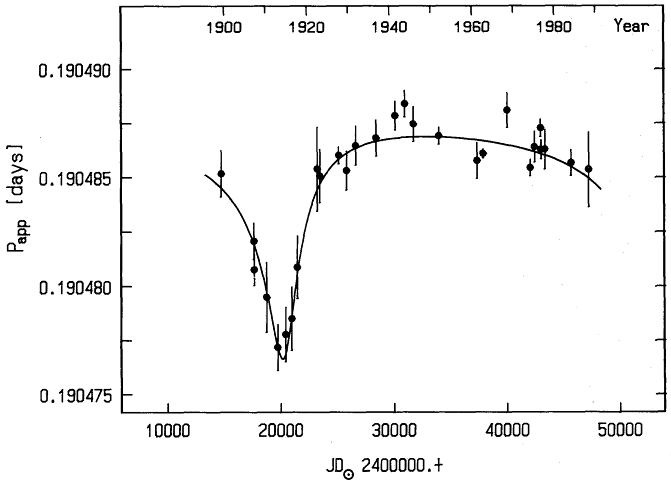

Fig. 3. Apparent pulsation periods of β Cep, obtained as described in the text. Continuous line represents the period changes predicted from the orbital elements

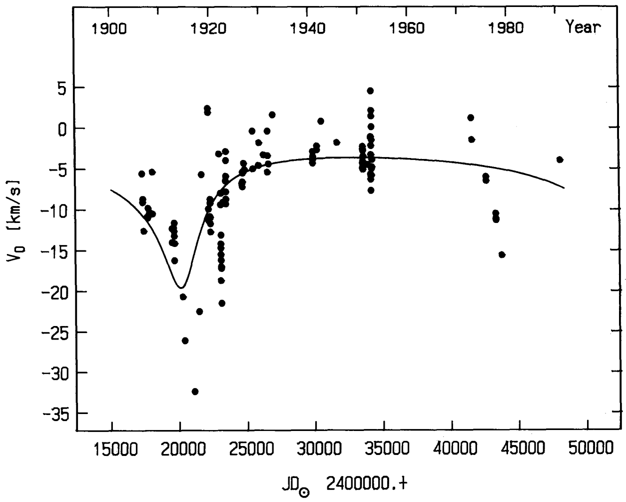

Fig. 4. Nightly values of the radial velocity of the variable's centre of mass, V_0, plotted as a function of heliocentric Julian day. Continuous line represents radial velocities computed from the orbital elements

except the ones corresponding to the pulsation period. Thus, the closest companion of β Cep, which presence was postulated by Fitch (1969), probably does not exist.

6. Summary and conclusions

Our analysis of the spectrographic and photometric observations of β Cep shows that the apparent changes of the pulsation period of β Cep are due to orbital motion in a binary system. The secondary is the companion resolved by speckle interferometry. The orbital elements of the system, derived from the O−C diagram and speckle observations, are consistent with the observed variations of the period and the radial velocity of the variable's centre of mass.

Since the spectrographic and photometric observations of β Cep cover only one orbital period, and the speckle observations only 1/5 of the orbital period, further observations are needed to improve the orbital elements. A significant improvement can be expected even from the observations obtained in the nearest 15 to 20 yr, when the observations cover the periastron passage.

The analysis of the radial velocity data led us to the conclusion that the close component, proposed by Fitch (1969), does not exist. Therefore, the β Cep system consists of only three stars: the variable primary, secondary resolved by the speckle interferometry and the distant visual tertiary.

The significant changes of the phase difference $\Delta\phi$ for β Cep, found by Chapellier (1986), are undoubtedly the result of an incorrect assumption of the constancy of the observed pulsation period after 1925.

Acknowledgements. We are indebted to Prof. M. Jerzykiewicz and Dr. C. Sterken for valuable comments upon reading the manuscript and to Dr. M. Muciek for help in collecting of the speckle interferometric data.

Appendix A

The observations were carried out on two nights in October 1990 at the Białków station of the Wrocław University Observatory. We used a conventional one-channel photoelectric photometer with

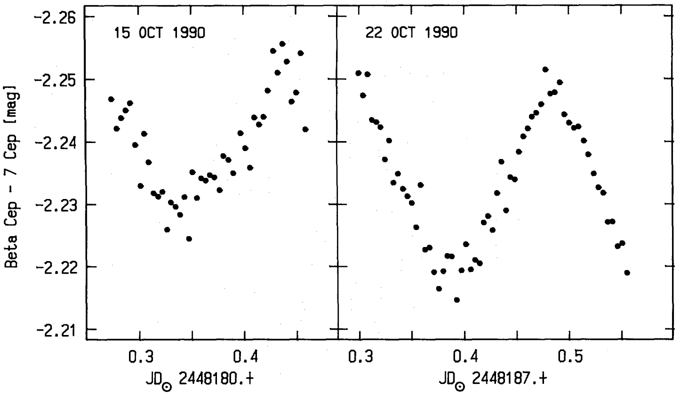

Fig. 1 A. The Strömgren y magnitude differences "β Cep minus 7 Cep", obtained on two nights in 1990, plotted as a function of heliocentric Julian day

Table A1. The Strömgren y filter differential photometry of β Cep. Δm means "β Cep − 7 Cep"

JDH 2448180.+	Δm	JDH 2448180.+	Δm
0.2740	−2.247	7.3432	−2.234
0.2788	−2.242	7.3474	−2.235
0.2835	−2.244	7.3519	−2.232
0.2877	−2.245	7.3562	−2.231
0.2919	−2.246	7.3605	−2.230
0.2965	−2.240	7.3647	−2.226
0.3011	−2.233	7.3689	−2.233
0.3052	−2.241	7.3730	−2.223
0.3092	−2.237	7.3773	−2.223
0.3134	−2.232	7.3814	−2.219
0.3178	−2.231	7.3859	−2.216
0.3219	−2.232	7.3902	−2.219
0.3260	−2.226	7.3942	−2.222
0.3301	−2.230	7.3983	−2.222
0.3346	−2.230	7.4031	−2.215
0.3388	−2.228	7.4073	−2.219
0.3429	−2.231	7.4117	−2.224
0.3469	−2.225	7.4161	−2.220
0.3510	−2.235	7.4203	−2.221
0.3551	−2.231	7.4245	−2.221
0.3593	−2.234	7.4288	−2.227
0.3634	−2.234	7.4328	−2.228
0.3677	−2.235	7.4370	−2.226
0.3720	−2.234	7.4413	−2.232
0.3766	−2.232	7.4457	−2.234
0.3809	−2.238	7.4499	−2.229
0.3857	−2.237	7.4540	−2.234
0.3900	−2.235	7.4581	−2.234
0.3974	−2.241	7.4622	−2.238
0.4019	−2.239	7.4665	−2.241
0.4061	−2.236	7.4707	−2.242
0.4107	−2.244	7.4748	−2.244
0.4151	−2.243	7.4790	−2.245
0.4194	−2.244	7.4836	−2.246
0.4235	−2.248	7.4880	−2.251
0.4286	−2.255	7.4923	−2.248
0.4330	−2.251	7.4966	−2.248
0.4373	−2.256	7.5015	−2.249
0.4417	−2.253	7.5058	−2.244
0.4462	−2.246	7.5102	−2.243
0.4506	−2.248	7.5147	−2.242
0.4548	−2.254	7.5189	−2.242
0.4592	−2.242	7.5241	−2.240
		7.5285	−2.238
7.3101	−2.251	7.5334	−2.235
7.3143	−2.247	7.5377	−2.233
7.3186	−2.251	7.5424	−2.232
7.3228	−2.244	7.5467	−2.227
7.3269	−2.243	7.5513	−2.227
7.3308	−2.242	7.5561	−2.223
7.3351	−2.237	7.5605	−2.224
7.3391	−2.240	7.5649	−2.219

an EMI 6256S photomultiplier tube mounted at the Cassegrain focus of a 60-cm reflecting telescope. HR 8227 = 7 Cep (V = 5.44 mag, B 7V) and HR 8342 (V = 6.29 mag, A 0V) were used as the comparison and check star, respectively. The 4.6 mag fainter visual companion of β Cep was always included in the photometer's diaphragm. All observations were obtained with the Strömgren y filter. The observations were corrected for the differential atmospheric extinction, but no attempt was made to transform them to the standard system. The differential magnitudes in the sense of "β Cep minus 7 Cep" are plotted in Fig. A1 and listed in Table A1.

References

Balega Y., Bonneau D., Foy R., 1984, A&AS 57, 31

Balona L. A., Shobbrook R. R., 1984, MNRAS 211, 375

Beeckmans F., Burger M., 1977, A&A 61, 815

Blazit A., Bonneau D., Koechlin L., Labeyrie A., 1977, ApJ 214, L 79

Bonneau D., Blazit A., Foy R., Labeyrie A., 1980, A&AS 42, 185

Bonneau D., Foy R., 1980, A&A 86, 295

Campos A. J., Smith M. A., 1980, ApJ 238, 250

Chapellier E., 1985, A&A 147, 135

Chapellier E., 1986, A&A 163, 329

Crump C. C., 1916, Publ. Detroit Obs., Univ. of Michigan 2, 144

Crump C. C., 1934, ApJ 79, 246

Cummings E., 1922, Lick Obs. Bull. 11, 99

Dudinov V. N., Kuz'menkov S. G., Konichek V. V., Tsvetkova V. S., Rylov V. S., Erokhin V. N., 1987, SvA 30, 359

Duncan J. C., Mitchell H. M., 1929, ApJ 70, 127

Fitch W. S., 1969, ApJ 158, 269

Frost E. B., 1906, ApJ 24, 259

Gezari D. Y., Labeyrie A., Stachnik R. V., 1972, ApJ 173, L 1

Goldberg B. A., Walker G. A. H., Odgers G. J., 1974, A&A 32, 35

Gray D. F., 1970, AJ 75, 958

Güssow M., 1926, Astron. Nachr. 229, 197

Guthnick P., Prager R., 1914, Veröff. der Königlichen Sternwarte zu Berlin-Babelsberg 1, Heft 1, 23

Guthnick P., Prager R., 1918, Veröff. Königlichen Sternwarte Berlin-Babelsberg 2, Heft 3, 78

Heintz W. D., 1978, Double stars. Reidel, Dordrecht

Henroteau F., 1922, Publ. Dominion Obs., Ottawa 5, 77

Henroteau F., 1925, Publ. Dominion Obs., Ottawa 9, 36

Hoffleit D., 1982, The Bright Star Catalogue. Yale Univ. Obs., New Haven

Hutchings J. B., Hill G., 1977, ApJ 213, 111

Jenkings L. F., 1952, General catalogue of trigonometric stellar parallaxes. Yale Univ. Obs., New Haven

Kohl O., 1933, Astron. Nachr. 248, 397

Labeyrie A., Bonneau D., Stachnik R. V., Gezari D. Y., 1974, ApJ 194, L 147

Lane M. C., Percy J. R., 1979, AJ 84, 831

Lortet M. C., Blazit A., Bonneau D., Foy R., 1987, A&A 180, 111

Mathias P., Gillet D., Kaper L., 1991, Proceedings of the ESO workshop on Rapid variability of B-stars: nature and diagnostic value. Baade D. (ed.) ESO Conference and Workshop Proceedings No. 36, Garching bei München, p. 193

McAlister H. A., 1977, ApJ 215, 159

McAlister H. A., 1978, ApJ 225, 932

McAlister H. A., 1979, ApJ 230, 497

McAlister H. A., Fekel F. C., 1980, ApJS 43, 327

McAlister H. A., Hartkopf W. I., Franz O. G., 1990, AJ 99, 965

McAlister H. A., Hartkopf W. I., Gaston B. J., Hendry E. M., Fekel F. C., 1984, ApJS 54, 251

McAlister H. A., Hartkopf W. I., Hutter D. J., Franz O. G., 1987, AJ 93, 688

McAlister H. A., Hartkopf W. I., Sowell J. R., Dombrowski E. G., Franz O. G., 1989, AJ 97, 510

McAlister H. A., Hendry E. M., 1982a, ApJS 48, 273

McAlister H. A., Hendry E. M., 1982b, ApJS 49, 267

McAlister H. A., Hendry E. M., Hartkopf W. I., Campbell B. G., Fekel F. C., 1983, ApJS 51, 309

Mendenhall H. S., 1930, Lick Obs. Bull. 14, 133

Morgan B. L., Beckmann G. K., Scaddan R. J., 1980, MNRAS 192, 143

Morgan B. L., Beddoes D. R., Scaddan R. J., Dainty J. C., 1978, MNRAS 183, 701

Roman N. G., 1947, ApJ 106, 311

Rudkjöbing M., 1949, ApJ 109, 331

Shobbrook R. R., 1978, MNRAS 184, 43

Smith B., 1943, ApJ 98, 82

Stebbins J., Kron G. E., 1954, ApJ 120, 189

Struve O., McNamara D. H., Kung S. M., Beymer C., 1953, ApJ 118, 39

Valtier J. C., Chapellier E., Morel P. J., le Contel J. M., 1985, IBVS No. 2843

van Arnam R. N., 1929, Publ. Dominion Astron. Obs., Victoria 4, 171