Period study of the contact system VW Cep

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Abstract. New photoelectric U,B and V observations of the eclipsing contact system VW Cep were taken in 1998 - 2000 and 23 new minima times were determined. The (O-C) diagram constructed using photographic and photoelectric minima times can be explained by the light-time effect caused by the presence of a third and fourth body in the system and the long-term period decrease interpreted by the mass transfer from the more to the less massive component or/and the magnetic-braking process. The sudden period increase detected in 1999 is probably a consequence of the episodic mass transfer from the less to the more massive component. Enhanced surface activity causes short-term apparent variations of the orbital period. The differences of times of the subsequent primary and secondary minima show two significant periodicities $P_1 = 2.94 \pm 0.07$ years and $P_2 = 2.36 \pm 0.05$ years. The latter periodicity is probably the beat period of the orbital and rotational period at the latitudes of most frequent occurrence of the spots.

Key words: binaries - photometry - orbital period - multiple systems

1. Introduction

VW Cep (BD +75°752, HD 197433, SAO 9828) is a W-type W UMa system with a chromospherically-active components of G5V and G8V spectral types. The apparent brightness $V_{max} \approx 7.3$ mag, the short period (P $\approx$ 0.27832 days), the pronounced variations of its light curve and the presence of a third component have caused VW Cep to be one of the most observed variable stars. In spite of a huge amount of photometric data the overall picture of the system is still unclear and the absolute parameters rather unreliable.

The light variation of VW Cep was discovered by Schilt (1926). The first photoelectric observations of the object were performed by Huffer (1946) in 1932. He showed that the observed minima times did not fit the ephemeris given by

Table 1. Spectroscopic elements of VW Cep

	Popper (1948)	Binnendijk (1967)	Hill (1989)	Kaszás et al. (1998)
Observatory	McDonald	Victoria	Dominion	D. Dunlap
Date(s)	Jun 13, 1946	Aug 2 - Sep 22, 1947	Sep 28-30, 1987	Sep 19, 1995
Disp. [Å/mm]	26	50.8	20	10
No. of spectra	19	16	31	40
V_0 [km.s^{-1}]	-35.4±4.5	+9.8±2.6	-8.0±1.0	-16.4±1
K_1 [km.s^{-1}]	81.6±5.6	90.4±3.3	67.8±1.7	85.5*
K_2 [km.s^{-1}]	233.8±4.9	222.7±3.3	245.1±1.5	244.3*
$m_1 \sin^3 i$ [$M_\odot$]	0.67±0.04	0.63±0.02	0.693±0.011	0.7665*
$m_2 \sin^3 i$ [$M_\odot$]	0.24±0.02	0.26±0.01	0.192±0.005	0.2683*
q	0.35	0.41	0.28	0.35

* - determined from published $m_1 + m_2 = 1.37$ $M_\odot$, $i = 65.6°$ and $q = 0.35$

Dugan (1933) and proposed a cosine term to represent the variations of the period. In further photoelectric studies performed by Moncibowycz & Walter (1952), Schmidt & Schrick (1955), Rakosh (1960) and Walter (1961) many peculiarities of the light curve were detected. The first multi-site international photometric campaign organized by Kwee (1966c) was devoted to the study of light-curve variations of VW Cep.

Many alternative models were proposed to explain the disturbances of the light curve including: a circumstellar ring (Kwee, 1966a), a precession of rotational axes of the components (Walter, 1983), a hot spot due to a gas stream (van't Veer, 1973; Pustylnik & Sorgsepp, 1976), dark starspots (Yamasaki, 1982; Linnel, 1986, 1991; Hendry et al., 1992). The starspot model is supported by an enhanced surface activity indicated by increased H_α emission (Barden, 1985), a fast rotational velocity (Rucinski, 1993), flare events (Egge & Pettersen, 1983) and a cyclic change of the frequency and strength of the light-curve disturbances (Bradstreet & Guinan, 1988).

The observed times of minima were first suspected of exhibiting a light-time effect (LITE) by Payne-Gaposhkin (1941). The (O-C) residuals were interpreted solely as a light-time effect by Archer (1948), Schmidt & Schrick (1955) and Herczeg & Schmidt (1960). The last authors determined the period of the third body $P_3 = 28.75$ years and proposed the mass of the third body ranging from 0.54 to 1.37 $M_\odot$ at separations 0.5" and 1.2". The presence of the third body was conclusively confirmed astrometrically by Hershey (1975) and directly by visual detection (Heintz, 1974). The former author determined reliable orbital elements of the 30.45±1.17 years third-body orbit and masses of all three components: $m_{1+2} = 1.5±0.4$ $M_\odot$ and $m_3 = 0.58±0.14$ $M_\odot$. A review of the published elements of the third-body orbit is given in Table 5.

The spectroscopic observations of VW Cep are rather inconsistent (see Table 1). The first spectroscopic elements were determined by Popper (1948), who also found a combined spectral type of G8 - K0 and concluded that the more

Table 2. Journal of photometric observations. Dates, intervals of phases , observatory, number of observations in one filter (N) and estimated standard deviation of an individual observation in V/B filter (σ)

Date	HJD_{mean} 2 400 000+	Phases	Filters	Obs.	N	σ
Sep 10, 1968	40110.583	0.460 – 0.577	B	SP	31	0.010
Oct 26, 1968	40156.556	0.632 – 0.771	V	SP	36	0.006
Oct 27, 1968	40157.426	0.600 – 1.032	V	SP	77	0.006
Oct 28, 1968	40158.367	0.075 – 0.352	V	SP	77	0.007
Nov 26, 1968	40187.664	0.357 – 0.593	V	SP	52	0.009
Nov 30, 1968	40191.639	0.521 – 0.976	V	SP	91	0.006
Dec 8, 1968	40199.374	0.438 – 0.657	V	SP	61	0.005
Dec 13, 1968	40204.262	0.005 – 0.221	B	SP	50	0.004
Mar 3, 1969	40287.326	0.528 – 0.609	V	SP	17	0.008
Oct 27, 1976	43079.530	0.569 – 1.599	V	SP	280	0.013
Dec 21, 1976	43134.341	0.774 – 1.252	V	SP	105	0.010
Sep 10, 1998	51067.462	0.189 – 1.118	UBV	SL	150	0.006
Dec 2, 1998	51150.367	0.461 – 0.598	UBV	SL	30	0.010
Dec 3, 1998	51151.311	0.642 – 1.214	UBV	SL	106	0.010
Jul 18, 1999	51378.464	0.826 – 1.347	UBV	SL	95	0.007
Aug 8, 1999	51399.423	0.037 – 0.768	UBV	SL	129	0.005
Aug 28, 1999	51419.321	0.843 – 1.984	UBV	SL	22	0.010
Sep 3, 1999	51425.363	0.358 – 0.864	UBV	SL	90	0.004
Sep 14, 1999	51436.514	0.250 – 0.986	UBV	SL	190	0.006
Nov 29, 1999	51512.422	0.156 – 0.727	BV	SL	163	0.009
Dec 6, 1999	51519.272	0.774 – 1.292	BV	SL	159	0.005
Jan 12, 2000	51556.269	0.687 – 1.114	BVR	SP	100	0.005
May 11, 2000	51676.476	0.369 – 1.032	BV	SL	137	0.008
May 12, 2000	51677.434	0.863 – 1.666	BV	SL	246	0.008
Jun 5, 2000	51701.402	0.199 – 0.572	BV	SL	110	0.008

massive primary component is a cooler one. Binnendijk (1967) derived rather different spectroscopic elements from the spectra taken by M. Petrie at the Victoria observatory. Both sets of spectra were of low quality and affected by rather long exposure times. Anderson et al. (1980) extracted broadening functions (BF) from 2 photographic high-resolution spectra taken at the quadratures. Their best fit of BFs gave $q = 0.4 \pm 0.05$ and only marginal contact. A third component is clearly visible in the BFs. An advanced cross-correlation analysis (CCF) of new spectra obtained by Hill (1989) yielded spectroscopic elements (Table 1) as well as rotational velocities of the components $v_1 . \sin i = 163$ km.s^{-1} and $v_2 . \sin i =$ 95 km.s^{-1}.

Frasca et al. (1996) performed medium-dispersion spectroscopy and found an additional H_α emission connected with the primary component as well as P Cygni profiles at the phases 0.500 and 0.537 interpreted by the mass transfer from the secondary component through the inner Lagrangian point.

Kaszás et al. (1998) published a study based on BV photometry (1987 - 1995) and new high-resolution spectroscopy. The radial velocities of both components

Table 3. Unpublished times of primary (I) and secondary (II) minima of VW Cep

JD_{hel} 2400000+	σ	Type	Filter	JD_{hel} 2400000+	σ	Type	Filter
40110.5754	0.0004	II	B	51676.3722	0.0001	II	B
40187.6726	0.0001	II	V	51676.5076	0.0001	I	B
40199.35949	0.00006	II	V	51676.5078	0.0001	I	V
43079.5037	0.0001	I	V	51677.3425	0.0004	I	V
43079.6388	0.0005	II	V	51677.3433	0.0002	I	B
43134.3280	0.0002	I	V	51701.4185	0.0001	II	B
				51701.4193	0.0002	II	V

were determined by the CCF method after removing the third component and telluric lines. Simultaneous fitting of an undisturbed light curve and radial velocity curve yielded new physical parameters of the system. Subtraction of the observed and synthetised spectra showed an additional H_α emission connected with the primary component. The positions of the emissions and spots were found to be in anticorrelation.

Hendry & Mochnacki (2000) performed an detailed analysis of the simultaneous UBVRI photometry and high-resolution spectroscopy centred on the Na I D and H_α lines. Maximum entropy images of the ecplising pair show rather high spot coverage and the presence of polar spots on both components. The authors detected three flares in H_α and found that the distribution of chromospheric emission at H_α vary from epoch to epoch.

2. New photoelectric observations

New U,B,V and R photoelectric photometry was performed during 14 nights from September 1998 to June 2000 (Table 2) at the Stará Lesná (SL) and Skalnaté Pleso observatories of the Astronomical Institute of the Slovak Academy of Sciences. 0.6 m Cassegrain telescopes equipped with single-channel pulse-counting photoelectric photometers were used. For all observations a 10 second integration was chosen. HD 197665 (SAO 9836) served as the comparison star. All observations were corrected for the differential extinction. The airmass for VW Cep changes only a little because it is close to the north pole. Therefore we have used mean seasonal extinction coefficients. Further data reduction and transformation to the standard international system were carried out in the usual way.

We present also unpublished B and V photometry obtained on 13 nights from September 1968 to April 1977 at the SP Observatory (see Table 2). For these observations a 40 second integration was used. HD 198547 (SAO 9870) served as a comparison star. Due to the fact that the data in B and V passbands were not obtained simultaneously, they are given in the instrumental system.

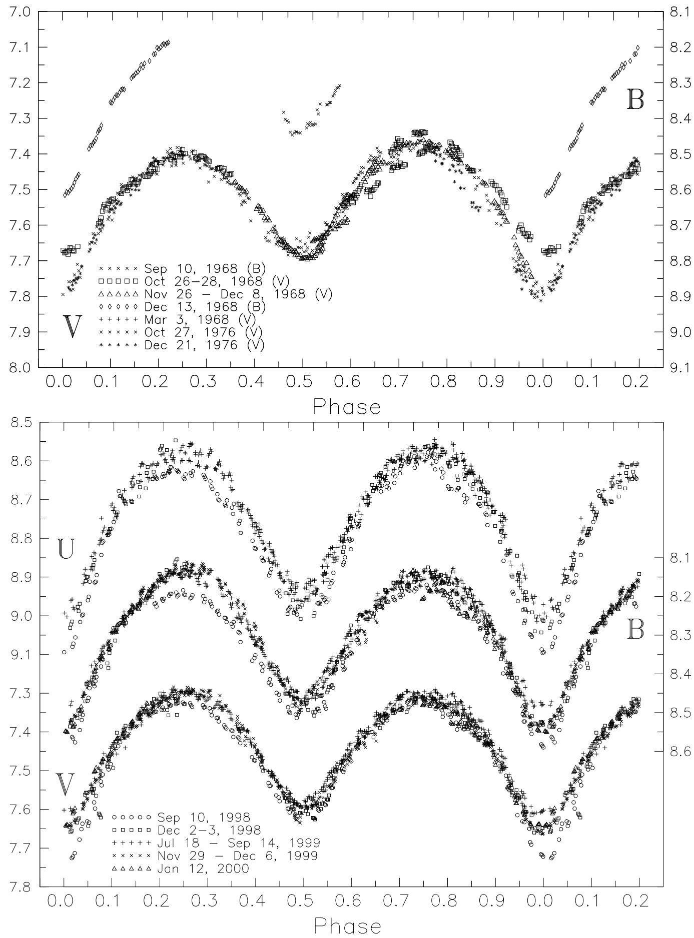

Figure 1. U,B and V light curves of VW Cep obtained at the Stará Lesná and Skalnaté Pleso Observatories from 1968 to 1976 (top) and from 1998 to 2000 (bottom)

All individual U,B and V observations of VW Cep can be obtained from one of the authors (TP) upon request. Selected light curves are shown in Fig. 1.

Our observations led to the determination of 13 primary and 10 secondary new minima times. We have calculated the times of minima separately for all three filters using the Kwee and Van Woerden (K&W), the parabola fit, sliding integration, the tracing paper and the "centre of mass" method which were described in detail by Ghedini (1982). The computer code was kindly provided by Dr. R. Komžík (1999). The resulting averages are less affected by the light-curve asymmetries than times determined solely by symmetric methods (K&W, parabola fitting). We have used only a ± 0.07 phase interval for the minima determination to decrease the influence of the asymmetries as suggested by van't

Table 4. U,B,V magnitudes of all comparison stars used in the previous studies.

Star	SAO	HD	BD	V	B-V	U-B	Sp.	Note
S1	9836	197665	76°809	7.07	0.38	0.11	F2	
S2	9841	197750	75°753	8.11	1.19	1.21	K0	susp. var.
CH	9824	197306	75°750	8.67	1.04	0.63	K0	susp. var.
S5	9899	199476	74°889	7.81	0.69	0.16	G5	
S6	9917	200251	75°765	6.76	1.10	1.07	K2	susp. var.
S7	9870	198547	75°755	8.89	0.48	0.01	G0	
S8	9945	201356	74°902	8.18	0.50	0.05	F8	
S9	9911	200039	75°764	5.98	0.94	0.67	G5	
S10	9669	192889	75°726	8.09	0.76	0.37	G5	
S11	9659	192635	73°900	8.85	0.41	0.05	F5	
S12	9825	–	75°751	10.27	0.65	0.36	G0	
S13	9802	196502	74°872	5.24	0.07	0.11	A0p	AF Dra
S14	9829	–	74°876	10.27	0.74	0.35	G5	
S15	9837	197617	74°877	8.68	0.14	0.28	A2	susp.var.

Veer (1973). The minima times from the 1998 - 2000 data have been already published (Pribulla et al., 1999, 2000a). The average times of minima from the 1968 - 1977 photometry and recent observations are given in Table 3.

On September 14, 1999 we observed all the comparison stars of VW Cep used in the previous studies of VW Cep. Their UBV magnitudes were determined using SAO 9899 (S5) as a principal comparison star. Due to the large angular distance of the comparison stars S10 and S11 from S5, we have used S1 for the measurement of their brightness. The brightness of S1 with respect to S5 was found to be stable within 0.01 on two nights (September 10, 1998 and September 14, 1999). Since we have made the observations on only one night, the variability of four stars given in the New Catalog of the Suspected variable stars (Kukarkin et al., 1982) cannot be ruled out (see Table 4).

The international U,B,V magnitudes of all measured comparison stars calculated using the average of the published magnitudes of S5[1], are given in Table 4. Their mean errors are lower than 0.008 mag.

3. Long-term period changes

The (O-C) diagram of VW Cep is quite complicated and has not been satisfactory explained since the minima times of VW Cep are influenced by several processes acting simultaneously. Long-term variations in the (O-C) diagram were explained by an intrinsic period decrease probably caused by a mass transfer from the more to the less massive component combined with the light-time effect due to the presence of the third body (Hershey, 1975; Kaszás et al., 1998). Short-term variations as well as seasonal differences in (O-C) times for the primary and secondary minima (see Kwee, 1966a) are probably the result of the

[1] see `http://obswww.unige.ch/gcpd/gcpd.html`

Table 5. Light-time and astrometric orbit of the eclipsing pair around the common center of gravity of the triple system VW Cep. The argument of the periastron passage (ω) is given for the primary component

Parameter	Hershey (1975)	Heintz (1993)	Kaszás et al. (1998)	Söderhjelm (1999)
P [years]	30.45±1.17	29	30.89±0.02	32
i [°]	29.2	21±5	–	27
a_{12} [AU]	3.170±0.046	3.822	–	–
$a_{12} \sin i$ [AU]	1.547±0.024	1.370	1.852±0.007	–
e	0.595±0.028	0.65	0.431±0.003	0.58
ω [°]	255.5	267	221.4±0.4	226
Ω [°]	0.9	340.5	–	202
T_0 [JD]	2439301±73	2439126	2438651±12	2439100
K [km s^{-1}]	1.88±0.15	1.85	1.98±0.01	–
$f(m_3)$ [$10^{-3} M_\odot$]	4±1	3	6.7±0.1	–
d [pc]	24.4±1.2	26.2±1.3	–	27.0±0.4

Table 6. The light-time effect solutions and corresponding ephemerides of the binary system. T_{super} and T_{infer} are the times of the superior and inferior conjunction of the third (fourth) body, respectively.

Element		3^{rd} body		4^{th} body	
			σ		σ
P	[years]	31.4	0.2	18.6	0.2
e		0.771	0.019	0.499	0.056
ω	[°]	183	1	143	6
T_0	[JD]	2 448 930	40	2 445 530	170
a sin i	[AU]	3.26	0.13	1.00	0.05
$f(m_3)$	[$M_\odot$]	0.035	0.0024	0.0029	0.0003
T_{super}	[JD]	2 449 270	50	2 426 510	280
T_{infer}	[JD]	2 448 547	60	2 424 874	190

Quadratic ephemeris			σ
JD_0	[JD]	2 433 898.4353	0.0016
P_{binary}	[days]	0.27831804	0.00000001
Q	[days]	$8.06 \ 10^{-11}$	$0.22 \ 10^{-11}$
$\sum$(O-C)^2	[days^2]	0.024317	

surface activity of the primary component. These differences also depend on the method of the minimum time determination (van't Veer, 1973) and contribute to the rather high scatter of data in the (O-C) diagram.

To analyze the period changes of VW Cep we have collected all available photoelectric and photographic times of minima from the literature. The main source of the minima was the paper of Karimie (1983) and *IBVS*, *BAAVSS* and *BBSAG* bulletins. Seven photoelectric minima were determined from the unpublished multi-colour photometry of Eaton (1976). Since the last compre-

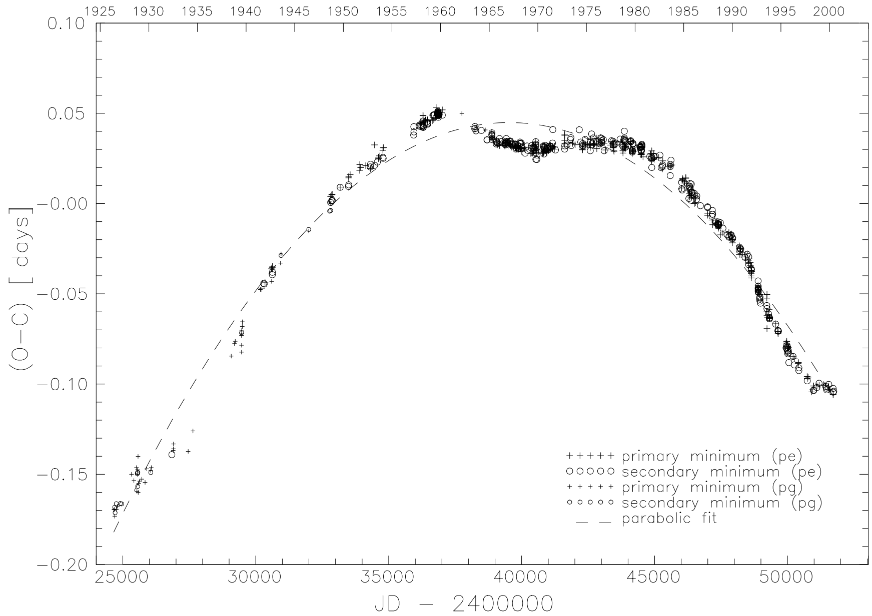

Figure 2. (O-C) diagram from the mean linear ephemeris Min I = 2 433 898.4226 + 0.27831477$\times E$

hensive list of the photographic and photoelectric minima appeared 17 year ago (Karimie, 1983), we have decided to publish all photographic and photoelectric minima with complete references. To reduce the huge amount of data, for the photoelectric minima we give only averages from different passbands (Table 7).

A preliminary (O-C) diagram of all data from the mean linear ephemeris showed many scattered points. These were either corrected (typing errors) or neglected in our study (typed in italic in Table 7) when the deviation exceeded 3σ. The higher accuracy of the photoelectric minima times in comparison with the photographic ones was evaluated using a five times larger weighting in calculations.

A weighted regression was applied to all usable minima times and the resulting (O-C) residuals from this ephemeris are plotted in Fig. 2. The (O-C) diagram clearly shows a light-time effect caused by the third body superimposed on the long-term period decrease.

The determination of the orbital parameters of the third body is rather complicated and unreliable and the resulting parameters differ from paper to paper (see Table 5). Kaszás et al. (1998) assumed a continuous period decrease and showed that the amplitude of the observed light-time effect is higher than expected from the astrometric orbit (Hershey, 1975).

To analyze the period behaviour of VW Cep properly we have concentrated on subtracting the LITE caused by the presence of the third body. We have used

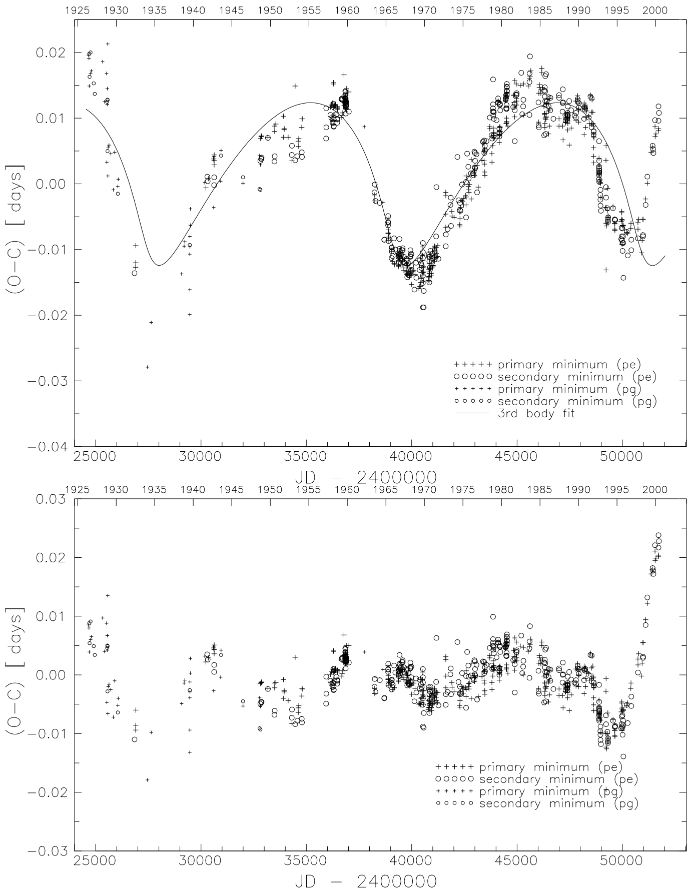

Figure 3. The 3rd body fit (top) and resulting residuals (bottom)

the orbital parameters determined from the combination of the ground-based and Hipparcos astrometry by Söderhjelm (1999). Unfortunately the semi-major axis of the eclipsing pair around the common centre of the gravity was not published. Hence we have tried to fit $a_{12} \sin i$ to the data. In our approach we have assumed that the times of the primary minima follow a quadratic ephemeris and are deviated by the LITE, so the minima times can be computed as follows:

$$\begin{aligned} \text{Min I } &= JD_0 + PE + QE^2 + \\ &+ \tfrac{a_{12}.\sin i}{c}\left[\tfrac{1-e^2}{1+e\cos\nu}\sin(\nu+\omega) + e\sin\omega\right], \end{aligned} \tag{1}$$

where $a_{12} \sin\ i$, e, ω are orbital elements, ν is the true anomaly of the binary orbit around the centre of the mass of the triple system, $JD_0 + PE + QE^2$ is the quadratic ephemeris of the minima in an eclipsing binary and c is the velocity of the light. To obtain the optimal fit and corresponding elements of the light-time orbit including errors, we have used the damped differential corrections method. We have fitted only $a_{12}\sin i, JD_0, P$ and Q. This resulted in $a_{12}\sin i$ = 2.43±0.05 AU and optimal quadratic ephemeris:

$$\begin{array}{llll} \text{Min I } = 2\,433\,898.4350 & +\ 0.27831808 & \times\ E & -\ 8.24\ \ 10^{-11} \times E^2 \\ \qquad\qquad\qquad\ \pm 4 & \qquad\ \pm 2 & & \quad \pm 4 \end{array} \tag{2}$$

The mass ratio $m_3/m_{1+2} = 0.39$ was determined by Heintz (1974). Using the whole semi-major axis $a = 12.53$ AU and the inclination of the orbit $i = 27°$ (Söderhjelm, 1999) we get $a_{12}\sin i = 1.596$ AU. Therefore the semi-amplitude of the orbit of the ecplising pair around the common centre of gravity does not correspond to that obtained from the ground-based astrometry. For $a_{12}\sin i =$ 2.43±0.05 AU and $a\sin i = 5.688$ AU (from Söderhjelm, 1999) we get m_3/m_{1+2} = 0.745. Using m_{1+2} = 1.37 $M_\odot$ (Kaszás et al., 1998), this leads to m_3 = 1.02 $M_\odot$ in odds with the third-light contribution detected both from the light-curve solutions and the intensity of third-component lines. Hence, there must be a further effect contributing to the observed period changes. The optimal fit is shown in Fig. 3.

From the (O-C) diagram one can see that the data are not fully explained by the fit. This is clearly visible during 1928 - 1934 and since 1999. The last minima determined from our observations do not obey the general course of the (O-C) diagram and show a major period increase.

For recent times of minima we have got an approximate linear ephemeris:

$$\begin{array}{lll} \text{Min I } = 2\,433\,898.403 & +\ 0.2783134 & \times\ E. \\ \qquad\qquad\qquad\ \pm 2 & \qquad \pm 3 & \end{array} \tag{3}$$

Apart from these two deviations there is also a wave-like variation seen after 1935. Fourier period analysis of the residuals from the third body fit in the interval of 1 - 75 years revealed the best period 19.7±2.0 years, caused either by the Applegate mechanism or by the presence of the fourth body in the system. We have tested the latter possibility. In spite of using the residuals for the determination of the fourth body orbit parameters, we have tried to obtain a simultaneous fit for both bodies with no parameters fixed. In our approach we have assumed that the observed times of the minimum light are deviated by the LITE caused by two bodies revolving the ecplising pair and the period of the eclipsing pair is changing continuously.

The resulting orbital elements of the eclipsing pair around the common center of gravity of the quadruple system are given in Table 6. The best fit is shown in Fig. 4. It is clear that the fit represents data very well up to 1998. Since then a major period increase has been observed. We have tried to force the fitting procedure to fit the recent minima by giving them five times larger weightings.

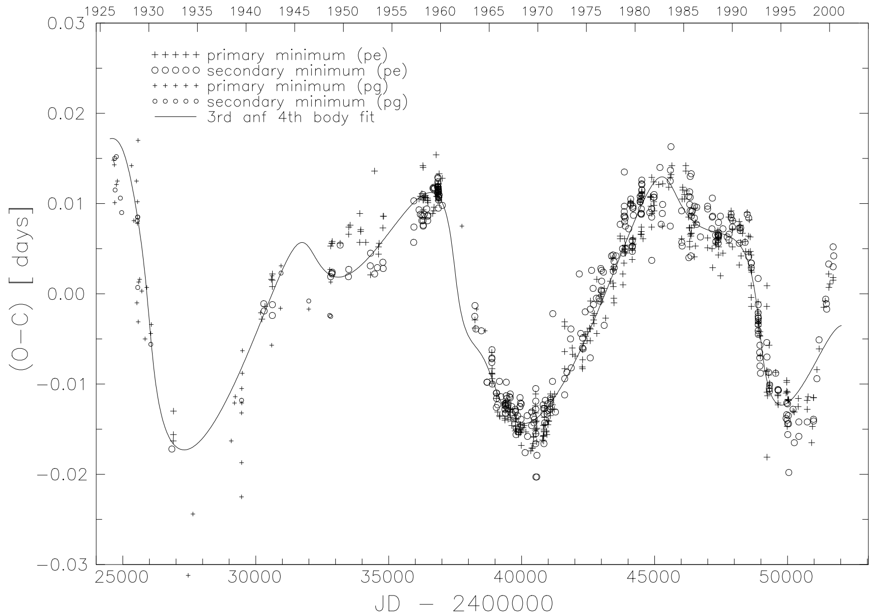

Figure 4. The 3rd and 4th body fit

The differential corrections did not converged. Hence it is probable that the period increase is a result of some episodic physical process connected with mass transfer or some structural change in the interior of one of the components.

The overall continuous period decrease is rather fast. Using the quadratic term Q from Table 6 for the rate of the period decrease we get:

$$\Delta P/P = \frac{2Q\ 365.25}{P^2} = (7.60 \pm 0.07)\ 10^{-7}\ \mathrm{year}^{-1} \tag{4}$$

The total shortening of the orbital period adds up to only 1.35 seconds. The observed period decrease cannot be caused by the mass outflow from the system through the outer Lagrangian point L_2 since the binary just fills its inner critical surface. Mass transfer from the more to less massive component seems to be more probable. If we assume $m_1 + m_2 = 1.37\ \mathrm{M}_\odot$, $q = 0.35$ (Kaszás et al., 1998) and neglect the spin angular moments of the components we get the mass transfer rate $\Delta m = (1.38{\pm}0.01)\ 10^{-7}\ \mathrm{M}_\odot\ \mathrm{year}^{-1}$. Another possible process is angular momentum loss caused by magnetic braking. Bradstreet & Guinan (1994) derived an approximate formula for the period decrease rate for tidally-coupled binaries with Sun-type components

$$\frac{dP}{dt} \approx 1.1\ 10^{-8} k^2 \frac{(1+q)^2}{qP^{\frac{7}{3}}} \frac{(m_1 R_1^4 - m_2 R_2^4)}{(m_1 + m_2)^{\frac{5}{3}}}, \tag{5}$$

where m_1, m_2 a R_1, R_2 are masses and radii of the components in solar units, q is the mass ratio, k is the gyration constant, P is the orbital period in days and dP/dt is expressed in days per year. If we use the masses given above, $k^2 = 0.1$ typical for the main sequence stars, radii determined from the semi-major axis and fill-out = 0 from Kaszás et al. (1998): $R_1 = 0.94$ $\mathrm{R}_\odot$, $R_2 = 0.58$ $\mathrm{R}_\odot$, we get the theoretical rate of the AML as $\Delta P/P = 1.81\ 10^{-7}$ year^{-1}. The observed period decrease is four times faster. Therefore magnetic braking alone is unable to explain observed period decrease. Mass transfer from the more to less massive component is necessary. It is also possible that the magnetic activity and stellar wind of the contact pair is stronger than in usual Sun-like systems making the magnetic braking more efficient.

4. Short-term variations

The scatter of the (O-C) residuals is much higher than the standard errors of the individual minima. The most probable explanation of these variations is the existence of dark photospheric spots present on the surface of the primary component. A spot positioned on either of the components affects the observed times of the primary and secondary minima in the opposite way (see e.g., Pribulla et al., 2000b). On the other hand such a spot causes the maxima to be of unequal height. The observed time of the minimum light depends strongly on the time interval used for the determination of the minimum (van't Veer, 1973).

Leung (1993) found that the 33 LCs of Kwee (1966a) taken in 1957-59 can be fitted by the superposition of the binary LC and modulating LC with the amplitude 0.04 mag and a slightly longer period (about 0.0001 day). This close periodicity produces a beat period of 718 days. This modulation does not seem to be cyclic and coherent in recent years. Hence the time scale of the variations in the positions of the spots is virtually unknown. Therefore for our analysis we have taken only time differences between the successive primary and secondary minima:

$$\Delta T = Min\ II - Min\ I - \frac{1}{2}P. \tag{6}$$

We had at our disposal 184 differences. Their Fourier period analysis has shown two significant periods $P_1 = 2.94 \pm 0.07$ years and $P_2 = 2.36 \pm 0.05$ years. The amplitude of the former period is $A = 0.0009$ days. These periodicities do not explain the short-term variations well. This indicates a short time scale of the surface activity. The periodicities detected by previous investigators in rather short time intervals are probably related to some more-persistent surface structures. The 862 days (and previously found 718 days) periodicities are the beat periodicities of the orbital and rotational periods. The length of the beat period depends on the latitude of a spot during the time of observation. If there are several spot-formation regions the variations in the times of minima cancel out.

Table 7. Primary (I) and secondary (II) minima of VW Cep. Photographic minima are given at the beginning above the line

JD$_{hel}$ 2 400 000+	type	Ref.	JD$_{hel}$ 2 400 000+	type	Ref.	JD$_{hel}$ 2 400 000+	type	Ref.
24658.759	I	1	25572.496	I	3	29465.6313	I	8
24680.746	I	1	25578.599	I	3	29486.787	I	7
24695.493	I	1	25593.9112	I	4	29490.686	I	7
24696.472	II	1	25632.320	I	1	30166.4521	I	9
24711.498	II	1	25713.589	I	2	30590.330	I	9
24757.425	II	1	25835.489	I	2	30605.367	I	9
24758.396	I	1	25898.674	I	3	30921.813	I	7
24798.475	I	1	26050.633	I	3	30943.665	II	7
24907.715	II	1	26051.606	II	3	30943.805	I	7
24955.585	II	2	26069.560	I	3	31984.715	I	10
25328.404	I	2	27454.185	I	5	31984.855	II	10
25416.348	I	2	27633.431	I	6	32770.692	I	7
25514.322	I	3	29070.690	I	7	32770.826	II	7
25527.668	I	3	29193.712	I	7	32807.564	II	7
25545.629	II	3	29223.493	I	7	32807.707	I	7
25548.551	I	3	29456.724	I	7	37734.485	I	11
25551.615	I	3	29457.828	I	8	38288.324	I	12
25555.649	II	3	29460.615	I	8	38613.394	I	12
25560.651	II	3	29460.761	II	7			
25562.607	II	3	29464.798	I	7			
26841.7515	II	13	33900.3924	I	20	36269.5710	II	27
26894.7728	I	13	33932.3970	I	19	36277.3610	II	27
26899.7833	I	13	33936.2936	I	19	36277.3615	II	26
26901.7342	I	13	34122.4870	I	21	36277.5060	I	27
30224.3420	I	14	34294.3456	II	18	36280.4218	II	26
30292.6713	II	13	34303.3900	I	18	36280.5639	I	26
30311.5963	II	13	34303.5315	II	18	36282.5110	I	27
30339.5679	I	13	34454.5280	I	21	36285.4316	II	26
30579.2045	I	15	34457.4390	II	21	36285.5736	I	26
30613.4370	I	15	34458.2609	II	21	36308.3960	I	26
30614.4080	II	15	34558.4690	II	21	36324.3972	II	26
30614.5510	I	15	34603.4196	I	19	36324.5381	I	26
30616.5000	I	15	34604.5320	I	22	36365.4508	I	26
30618.5840	II	15	34628.4686	I	22	36368.5125	I	26
32804.3711	I	16	34768.3210	II	23	36373.5220	I	26
32804.5069	II	16	34768.4640	I	24	36415.4073	II	26
32845.2843	I	16	34780.2880	II	23	36443.3793	I	26
32845.4201	II	16	34780.4330	I	24	36448.3887	I	26
32856.1387	I	16	34797.4103	I	21	36448.5257	II	26
32856.2745	II	16	35925.5662	II	25	36449.5021	I	26
32864.2101	I	16	35930.5805	II	25	36452.4226	II	26
32864.3459	II	16	35932.5258	II	25	36454.3709	II	26
33163.8197	II	17	36124.4283	I	26	36459.5212	I	26
33163.9590	I	17	36124.5663	II	26	36637.3642	I	26
33474.4195	II	18	36173.4124	I	26	36647.5256	II	26
33483.4695	I	18	36173.5495	II	26	36676.4704	II	26
33485.4185	I	18	36228.3772	II	26	36679.3903	I	26
33485.5530	II	18	36232.4158	I	26	36679.5321	II	26
33539.4125	I	18	36232.5526	II	26	36687.4619	I	26
33898.4410	I	19	36269.4350	I	27	36701.5190	II	26

Table 7. (continued)

JD$_{hel}$ 2 400 000+	type	Ref.	JD$_{hel}$ 2 400 000+	type	Ref.	JD$_{hel}$ 2 400 000+	type	Ref.
36768.4578	I	28	37001.5421	II	26	39426.4840	II	29
36778.4725	I	18	38219.4401	II	29	39467.2548	I	29
36803.5210	I	18	38225.4235	I	29	39467.3958	II	29
36820.6379	II	26	38226.3992	II	29	39467.5344	I	29
36826.3437	I	26	38227.3708	I	29	39467.6739	II	29
36826.4832	II	26	38263.4126	II	29	39521.2487	I	29
36826.7614	II	26	38468.5308	II	29	39521.3895	II	29
36827.3181	II	26	38677.5400	II	29	39553.5336	I	31
36827.4572	I	26	38686.4461	II	29	39553.6743	II	31
36827.7348	I	26	38859.4223	I	29	39554.5089	II	31
36828.4319	II	26	38860.3953	II	29	39554.6464	I	31
36829.4053	I	26	38860.5332	I	29	39561.6037	I	31
36829.5457	II	26	38862.3440	II	29	39562.4393	I	31
36830.5180	I	26	38862.4814	I	29	39567.4492	I	29
36830.5191	I	26	38863.4571	II	29	39567.4492	I	29
36831.4921	II	26	38866.3767	I	29	39607.3877	II	29
36839.7016	I	26	38866.5196	II	29	39607.5252	I	29
36840.3999	II	26	38869.4398	I	29	39608.3597	I	29
36840.5374	I	26	38871.3874	I	29	39608.5002	II	29
36840.6772	II	26	38873.3351	I	29	39734.4356	I	29
36841.3725	I	26	38880.4316	II	29	39739.4470	I	29
36841.5126	II	26	39028.3544	I	29	39740.4218	II	29
36841.6508	I	26	39028.4926	II	29	39747.3794	II	29
36842.3469	II	26	39028.4942	II	29	39747.5169	I	29
36842.4857	I	26	39035.4515	II	29	39748.3524	I	29
36843.3208	I	26	39035.4521	II	29	39748.4927	II	29
36843.4594	II	26	39044.4972	I	29	39765.6083	I	32
36843.4602	II	26	39079.4245	II	29	39766.4420	I	32
36843.5988	I	26	39079.5629	I	29	39766.5806	II	32
36850.6943	II	26	39146.5011	II	29	39776.3223	II	32
36853.6187	I	26	39147.4714	I	29	39780.3589	I	32
36854.4536	I	26	39159.4388	I	29	39786.4805	I	32
36855.2885	I	26	39200.4925	II	29	39829.2035	II	29
36855.4266	II	26	39348.4145	I	30	39838.2475	I	29
36855.7060	II	26	39348.5546	II	30	39848.4054	II	29
36856.4025	I	26	39350.3625	I	30	39852.3018	II	29
36857.3751	II	26	39350.5032	II	30	39865.2431	I	29
36857.5153	I	26	39351.3384	II	30	39873.3144	I	29
36857.6534	II	26	39364.5575	I	30	39914.7837	I	33
36858.3504	I	26	39370.4031	I	30	39917.4302	II	29
36858.4890	II	26	39372.3513	I	30	39918.2661	II	29
36859.3240	II	26	39372.4904	II	30	39918.4023	I	29
36859.4636	I	26	39373.3242	II	30	39918.5435	II	29
36867.3945	II	26	39375.4126	I	30	39935.3795	I	29
36875.4659	II	26	39375.5507	II	30	39935.5210	II	29
36875.6045	I	26	39390.5806	II	29	39936.7702	I	33
36877.2744	I	26	39398.3745	II	29	39949.8510	I	33
36879.3624	II	26	39400.4605	I	29	39955.5579	II	29
36880.3388	I	26	39400.6025	II	29	39976.4308	II	29
37001.4059	I	26	39409.5063	II	29	39966.4139	II	31

Table 7. (continued)

JD_{hel} 2 400 000+	type	Ref.	JD_{hel} 2 400 000+	type	Ref.	JD_{hel} 2 400 000+	type	Ref.
39967.3834	I	31	40823.7579	I	40	42146.4610	II	46
39987.4237	I	34	40829.3250	I	39	42198.7773	II	45
40034.4592	I	31	40833.5005	I	37	42256.8019	I	45
40078.4330	I	34	40839.3464	I	37	42261.3962	II	46
40110.5754	II	35	40839.4852	II	37	42261.5351	I	46
40137.4350	I	34	40846.4415	II	37	42263.4812	I	46
40187.6726	II	35	40870.3790	II	39	42268.7702	I	45
40199.3595	II	35	40876.3600	I	39	42269.7467	II	45
40322.5120	I	31	40903.3557	I	41	42290.7587	I	45
40352.4336	II	31	40903.3558	I	37	42290.8973	II	45
40354.3833	II	31	40927.2904	I	31	*42336.3769*	?	47
40358.4148	I	34	40930.4936	II	31	42353.3802	I	47
40388.4770	I	34	40932.3016	I	31	42364.3760	II	46
40389.8643	I	36	40932.4415	II	31	42385.3860	I	46
40411.8517	I	36	40960.2740	II	31	42434.3686	I	48
40420.8999	II	36	40964.3073	I	31	42449.3985	I	48
40426.8813	I	36	40989.3559	I	31	42530.3880	I	48
40430.4995	I	31	40989.4963	II	31	42556.4070	II	48
40441.7727	II	36	40992.4174	I	31	42556.5480	I	48
40456.8021	II	36	40996.5921	I	31	42557.8039	II	45
40490.3378	I	34	41056.4302	I	31	42562.3970	I	48
40494.5152	I	37	41056.5700	II	31	42563.7854	I	45
40506.3393	II	37	41059.4940	I	42	42606.5130	II	48
40506.4840	I	37	41060.4776	II	42	42662.4519	II	49
40508.2922	II	37	41060.6056	I	42	42666.4844	I	49
40510.2418	II	37	41070.4867	II	42	42679.4272	II	50
40510.3783	I	37	41071.4609	I	42	42680.3996	I	50
40510.5151	II	37	41071.5997	II	42	42693.4799	I	50
40511.3453	II	38	41139.7890	II	40	42716.3027	I	51
40512.3255	I	38	41139.9250	I	40	42787.4133	II	52
40512.3242	I	37	41140.4822	I	41	42799.5220	I	53
40512.4660	II	37	41149.3891	I	37	42800.3510	I	53
40530.4151	I	37	41149.5375	II	37	42888.4409	II	52
40532.3642	I	37	41207.2770	I	41	42913.4887	II	52
40544.3294	I	38	41217.2980	I	41	42950.6440	I	35
40547.2478	II	38	41248.3280	II	41	42950.7862	II	35
40553.5153	I	31	41595.2560	I	43	42958.7145	I	35
40554.2081	II	31	41595.3870	II	43	42960.6637	I	35
40765.3110	I	39	41595.5310	I	43	42961.7767	I	35
40787.4409	II	31	41596.3640	I	44	42964.6995	II	35
40788.4115	I	31	41597.3370	II	43	42977.7824	II	45
40793.4224	I	39	41597.4820	I	43	42984.7390	II	35
40799.8225	I	40	41678.3270	II	44	42989.4692	II	50
40802.7478	II	40	*41698.4190*	?	44	43050.4218	II	52
40806.7797	I	40	41814.4260	II	44	43079.5037	I	35
40811.7900	I	40	41829.4560	II	44	43079.6388	II	35
40817.3570	I	37	41842.8107	II	40	43134.3280	I	35
40817.4945	II	37	41880.8027	I	40	43312.4522	I	54
40817.7761	II	40	41895.8309	I	45	43354.3410	II	55
40817.9134	I	40	41989.3440	I	44	43378.4148	I	54

Table 7. (continued)

JD_{hel} 2 400 000+	type	Ref.	JD_{hel} 2 400 000+	type	Ref.	JD_{hel} 2 400 000+	type	Ref.
43395.4722	?	56	44135.5648	II	64	44834.8279	I	68
43399.2870	I	56	44138.3480	II	64	44859.3171	I	75
43410.4180	I	57	44138.4866	I	64	44862.5187	II	75
43411.3952	II	57	44157.4131	I	65	44864.4621	II	75
43417.3786	I	56	44157.5557	II	65	44865.4454	I	75
43421.2737	I	56	44158.3907	II	65	44865.5811	II	75
43421.4126	II	56	44158.5264	I	65	44869.3378	I	75
43424.3332	I	56	44159.3614	I	65	44941.1435	I	76
43436.3029	I	56	44159.5041	II	65	44941.9806	I	76
43441.3090	I	56	44176.6161	I	66	44942.1181	II	76
43447.5751	II	58	44176.7584	II	66	44954.9207	II	76
43448.2663	I	56	44428.4934	I	67	44955.0581	I	76
43459.2635	II	56	44429.3281	I	67	44955.8936	I	76
43524.3900	II	59	44429.4673	II	67	44956.0337	II	76
43678.5786	II	60	44430.4412	I	67	45125.3877	I	77
43679.5510	I	60	44430.5805	II	67	45171.4501	II	77
43680.6646	I	60	44431.4160	II	67	45219.3134	II	78
43766.5226	II	61	44431.5553	I	67	45263.2878	II	78
43782.2444	I	61	44455.7641	I	68	45264.2605	I	78
43785.3046	I	61	44455.9072	II	68	45275.2562	II	78
43796.3015	II	61	44457.8538	II	68	45276.2326	I	78
43822.3226	I	61	44470.7930	I	69	45507.7873	I	68
43822.4669	II	23	44472.7412	I	69	45560.5229	II	79
43832.4867	II	23	44472.8825	II	69	45562.7544	II	68
43835.2704	II	61	44476.7795	II	69	45562.8940	I	68
43837.2224	II	61	44476.9166	I	69	45566.3737	II	80
43844.3108	I	62	44477.7511	I	69	45586.4147	II	75
43844.4530	II	62	44477.8922	II	69	45590.4471	I	75
43844.5891	I	62	44488.4702	II	70	45623.2888	I	80
43848.4866	I	23	44489.3063	II	70	*45946.3996*	?	73
43849.4632	II	23	44489.4439	I	70	*45948.3428*	?	73
43849.5984	I	23	44490.4189	II	70	*45948.4762*	?	73
43870.3355	II	62	44490.5577	I	70	45988.2889	II	81
43870.4726	I	62	44491.3926	I	70	45988.4250	I	81
43870.6148	II	62	44492.3681	II	70	45994.4082	II	81
43870.7508	I	62	44492.5060	I	70	46004.2931	I	82
43880.3523	II	23	44493.3409	I	70	46008.3234	II	81
43880.4909	I	23	44493.4803	II	70	46029.3424	I	82
44001.4203	II	59	44494.3158	II	70	46030.4553	I	82
44075.3151	I	63	44494.4537	I	70	46094.4664	I	83
44075.4541	II	63	44538.4223	I	71	46101.4236	I	83
44076.4284	I	63	44788.7666	II	68	46143.4517	I	83
44076.5673	II	63	44812.8423	I	68	46145.4005	I	83
44077.4028	II	63	*44821.4850*	?	73	46180.4648	I	83
44077.5415	I	63	*44822.4588*	?	73	46249.4830	I	84
44130.4162	I	64	44822.8616	I	68	46257.4104	II	85
44130.5558	II	64	*44823.4325*	?	73	46257.4172	II	84
44131.5278	I	64	*44824.4066*	?	74	46276.4780	I	84
44135.2859	II	64	44824.8097	I	68	46277.5912	I	86
44135.4254	I	64	*44826.4941*	?	74	46287.6104	I	86

Table 7. (continued)

JD_{hel} 2 400 000+	type	Ref.	JD_{hel} 2 400 000+	type	Ref.	JD_{hel} 2 400 000+	type	Ref.
46288.4439	I	86	47350.7552	I	95	48449.5261	I	101
46288.5885	II	86	47350.8946	II	95	48500.4541	I	104
46289.4221	II	86	47352.4255	I	93	48506.4398	II	105
46289.5565	I	86	47353.3999	II	93	48506.5751	I	105
46308.6248	II	86	47362.8616	II	96	48508.3836	II	104
46309.4612	II	86	47367.4544	I	97	48531.3483	I	101
46309.5963	I	86	47368.4290	II	97	48566.4134	I	105
46310.5768	II	86	47368.5656	I	97	48570.5864	I	105
46333.4046	?	73	47374.4119	I	97	48576.56860	II	123
46333.4139	?	87	47374.5513	II	97	48597.3037	I	105
46333.5527	?	73	47375.3878	II	97	48600.0834	I	100
46334.3658	I	85	47379.5610	II	97	48600.5034	II	105
46334.5027	II	85	47380.3960	II	97	48602.0303	I	100
46336.3354	?	73	47380.5339	I	97	48603.0077	II	100
46350.5087	I	86	47442.4613	II	94	48603.9815	I	100
46351.4841	II	83	47445.3769	I	94	48604.2601	I	105
46351.4888	II	86	47539.5901	II	98	48606.9045	II	100
46351.6213	I	86	47539.7266	I	98	48607.0389	I	100
46352.4563	I	86	47698.5043	II	98	48619.2883	I	105
46373.3316	I	88	47763.3502	II	99	48800.74249	I	123
46373.4712	II	88	47763.4919	I	99	48859.4661	I	106
46378.4807	II	88	47767.3853	I	99	48860.4389	II	106
46466.2828	I	88	47767.5255	II	99	48860.4376	II	107
46466.4262	II	88	47847.2639	I	98	48860.5770	I	106
46467.2625	II	88	47847.4022	II	98	48861.4118	I	106
46467.3995	I	88	47847.5418	I	98	48861.5560	II	106
46506.6432	I	88	47847.6809	II	98	48862.3851	II	106
46508.3089	I	88	47892.0698	I	100	48862.3867	II	107
46509.4247	I	88	47895.9641	I	100	48862.5255	I	107
46550.4754	II	88	47896.9404	II	100	48862.5264	I	106
46555.4869	II	88	47899.0274	I	100	48863.3600	I	106
46694.3606	II	89	47905.0121	II	100	48863.5012	II	106
46962.6554	II	90	47912.9439	I	100	48865.72588	II	123
46962.7899	I	90	48150.3421	I	101	48866.4216	I	106
46963.7683	II	90	48152.1487	II	101	48866.5608	II	106
46964.7392	I	90	48152.2855	I	101	48867.3943	II	106
47127.2713	I	91	48155.0729	I	100	48867.5338	I	106
47127.4126	II	91	48160.7781	II	96	48868.3693	I	106
47138.2680	II	91	48185.9649	I	100	48868.5093	II	106
47142.4448	II	92	48191.9484	II	100	48869.3442	II	106
47153.2969	II	93	48200.9941	I	100	48869.4829	I	106
47153.4303	I	93	48206.0018	I	100	48920.9687	I	100
47272.4109	II	94	48206.1425	II	100	48921.1060	II	100
47272.5497	I	94	48219.9158	I	100	48923.0535	II	100
47263.3656	I	93	48276.4151	I	102	48927.9264	I	100
47263.5057	II	93	48337.36397	I	123	48928.0645	II	100
47293.4235	I	93	48372.4311	I	103	48929.0401	I	100
47348.8075	I	95	48372.5701	II	103	48929.1754	II	100
47348.9470	II	95	48395.8080	I	96	48949.21693	II	123
47349.9215	I	95	48449.3867	II	101	48949.9106	I	100

Table 7. (continued)

JD_{hel} 2 400 000+	type	Ref.	JD_{hel} 2 400 000+	type	Ref.	JD_{hel} 2 400 000+	type	Ref.
48950.0478	II	100	49609.4978	I	111	50390.5693	II	117
49046.76378	I	123	49624.3890	II	112	50703.5295	I	101
49118.14823	II	123	49907.426	II	106	50707.2843	II	118
49185.6369	I	108	49908.4028	I	106	50707.4248	I	118
49186.4790	I	109	49933.4518	I	106	50738.3185	I	101
49186.6141	II	108	49933.452	I	106	50871.6230	I	119
49186.7501	I	108	49933.5887	II	106	50900.5689	I	119
49191.4790	I	109	49934.4223	II	106	50941.3418	II	119
49192.4570	II	109	49934.5641	I	106	50941.4834	I	119
49192.6040	I	109	49953.3467	II	113	50942.4549	II	119
49193.4200	I	109	49953.4852	I	113	50942.5966	I	119
49213.4650	I	110	49967.4044	I	106	51067.4199	II	120
49252.4306	I	110	49967.5422	II	106	51067.5600	I	120
49253.4050	II	110	49968.3750	II	106	51150.3600	II	120
49276.3685	I	101	49971.5782	I	106	51151.3331	I	120
49278.3116	I	101	49975.3315	II	113	51327.2283	I	121
49278.4510	II	101	49994.2586	II	113	51378.4377	I	120
49284.0169	II	100	49996.3476	I	113	51399.4501	II	122
49284.1568	I	100	50003.3053	I	113	51425.3323	II	122
49284.9913	I	100	50004.2768	II	113	51436.4640	II	122
49292.9235	II	100	50006.3668	I	114	51512.3068	I	122
49293.0629	I	100	50012.3424	II	114	51512.4470	II	122
49521.4165	II	101	50171.4026	I	115	51519.26295	I	122
49523.5040	I	101	50171.5419	II	115	51556.2783	I	122
49603.3761	I	111	50218.4366	I	116	51676.3722	II	35
49604.3508	II	101	50218.5724	II	116	51676.5077	I	35
49604.4893	I	101	50363.7143	I	117	51677.3431	I	35
49608.3848	I	111	50372.6210	I	117	51677.4833	II	35
49609.3603	II	111	50388.6196	II	117	51701.4187	II	35

References: 1 - van Gent (1929), 2 - Kukarkin (1931), 3 - Dugan (1933), 4 - Walter (1934), 5 - Gaposchkin (1953), 6 - Walter (1936), 7 - Woodward (1951), 8 - Woodward (1942), 9 - Todoran (1963), 10 - Popper (1948), 11 - Karetnikov a Komarov (1965), 12 - Obůrka (1965), 13 - Huffer (1946), 14 - Walter (1961), 15 - Moncibowycz & Walter (1952), 16 - Kostylev (1950) , 17 - McNamara & Stern (1950), 18 - Balasz & Detre (1961), 19 - Kwee (1958), 20 - Piotrowski (1952), 21 - Szczepanowska (1959), 22 - Szafraniec (1962), 23 - Karimie (1983) 24 - Schmidt & Schrick (1955), 25 - Szafraniec (1960), 26 - Kwee (1966a), 27 - Archer (1958), 28 - Kalchaev & Truttse (1960), 29 - Kotarska & Glownia (1983), 30 - Cester (1967), 31 - Tempesti & De Carlo (1972), 32 - Rossati (1970), 33 - Brown & Pinnington (1969), 34 - Pohl & Kizilirmak (1970), 35 - this paper, 36 - Scarfe & Birmacombe (1971), 37 - Todoran (1972), 38 - Muthsam (1972), 39 - Kizilirmak & Pohl (1971), 40 - Scarfe et al. (1973), 41 - Pohl & Kizilirmak (1972), 42 - Breinhorst et al. (1973), 43 - Braune et al. (1977), 44 - Kizilirmak & Pohl (1974) 45 - Scarfe & Barlow (1978), 46 - Pohl & Kizilirmak (1975), 47 - Baldinelli & Ghedini (1976), 48 - Pohl & Kizilirmak (1976), 49 - Patkos (1975), 50 - Patkos (1976), 51 - Brancewicz & Kreiner (1976), 52 - Pohl & Kizilirmak (1977), 53 - Lunel et al. (1979), 54 - Ebersberger et al. (1978), 55 - Guinan et al. (1980), 56 - Cristescu (1978), 57 - Hopp et al. (1979), 58 - Skillman (1978), 59 - Pohl & Gülmen (1981), 60 - Niarchos (1979), 61 - Cristescu et al. (1979), 62 - Egge (1983), 63 - Niarchos (1980), 64 - Rovithis et al. (1980), 65 - Kreiner & Winiarski (1981), 66 - Guinan & Weisenberger (1980), 67 - Niarchos (1981), 68 - Scarfe et al. (1984), 69 - Linnel (1981), 70 - Niarchos (1983), 71 - Lunel et al. (1982), 73 - Rovithis &

Rovithis-Livaniou (1986), 74 - Mahdy & Soliman (1982), 75 - Rovithis & Rovithis-Livaniou (1984), 76 - Abe (1982), 77 - BAV-M 36, 78 - Cristescu & Oprescu (1984), 79 - BAA VSS 60, 80 - BAV-M 38, 81 - BAA VSS 61, 82 - BAA VSS 66, 83 - BAA VSS 63, 84 - Pohl et al. (1987), 85 - Rovithis & Rovithis-Livaniou (1986), 86 - Santiago et al. (1986), 87 - Jabir et al. (1989), 88 - Lapeta & Pajdosz (1988), 89 - BAV-M 46, 90 - Hendry et al. (1992), 91 - BAA VSS 70, 92 - Hegedüs (1987), 93 - Hegedüs et al. (1996), 94 - BAA VSS 72, 95 - Glownia (1988), 96 - Nelson (1998), 97 - Vinkó (1989), 98 - BAA VSS 73, 99 - Wunder et al., (1992), 100 - Arai (1994), 101 - Niarchos (1998), 102 - Hanžl (1994), 103 - BAV-M 59, 104 - BBSAG 109, 105 - Lloyd et al. (1992), 106 - Szatmáry (2000), 107 - Navrátil (1994), 108 - Abbot & Rumignani (1994), 109 - Aluigi & Galli (1994), 110 - Vinkó et al. (1993), 111 - Kiss et al. (1995), 112 - BAAVSS 84, 113 - Oprescu et al. (1996), 114 - BAAVSS 90, 115 - Bíró et al. (1998), 116 - BAAVSS 92, 117 - Jay & Guinan (1997), 118 - Kiss et al. (1999), 119 - Borkovits & Bíró (1998), 120 - Pribulla et al. (1999), 121 - Kang & Lee (1999), 122 - Pribulla et al. (2000a), 123 - Hendry & Mochnacki (2000)

5. Discussion and conclusion

A detailed analysis of the (O-C) diagram of the system revealed that VW Cep is probably a quadruple system. The observed times of minimum light as well as positions of the eclipsing pair obtained from ground-based as well as Hipparcos astrometry cannot be explained by the presence of the known third component solely. This is indicated by a very large error of the astrometric solution (Söderhjelm, 1999).

The detailed analysis of the (O-C) diagram of the system revealed the continuous period decrease explained by the mass transfer from the more to less massive component and/or the magnetic braking process. A mass transfer rate of (1.38±0.01) 10^{-7} $M_\odot$ y^{-1} fully explains the period decrease. (O-C) residuals from the parabolic fit show the light-time effect due to the third body on the 30-years orbit and 19-years wave-like variation caused either by the fourth body orbit or by the Applegate mechanism. The latter possibility should be tested, however, by the analysis of the long-term changes of the brightness and colour of the eclipsing pair. If VW Cep is a quadruple system the minimum masses of the components are $m_3 = 0.49$ $M_\odot$ ($P = 31.3$ years) and $m_4 = 0.19$ $M_\odot$ ($P =$ 18.6 years). The mass of the third body is still incompatible with the observed third light and intensity of the third-component lines in the spectrum. Hence, it is possible that the observed period changes are partly caused by the intrinsic processes in the system.

Although our analysis of the (O-C) diagram are not conclusive, its probable that VW Cep is a multiple system. For the reliable detection of all components more extensive and precise observations are needed. The orbital elements of the component should be determined by simultaneous fitting of the astrometric data and observed times of the minimum light.

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References

Abe, T.: 1982, *Inf. Bull. Variable Stars* , 2108
Abbot, B.P., Rumignani, D.J.: 1994, *Inf. Bull. Variable Stars* , 4041
Aluigi, M., Galli, G.: 1994, *Inf. Bull. Variable Stars* , 4117
Anderson, L., Raff, M., Shu, F.H.: 1980, in *Close Binary Stars: Observations and Interpretation*, eds.: M.J. Plavec , D.M. Popper and R.K. Ulrich, D. Reidel, Dordrecht, 485
Arai, K.: 1994, *Inf. Bull. Variable Stars* , 4086
Archer, S.: 1948, *J. British Astron. Assoc.* **58**, 269
Balázs, J., Detre, L.: 1961, *Mitt. Budapest* **50**, 1
Baldinelli, L., Ghedini, S.: 1976, *Inf. Bull. Variable Stars* , 1143
Barden, S.C.: 1985, *Astrophys. J.* **295**, 162
Binnendijk, L.: 1967, *Publ. Dominion Astron. Obs.* **13**, 27
Bíró, I.B., Borkovits, T., Hegedüs, T., Paragi, Z.: 1998, *Inf. Bull. Variable Stars* , 4555
Borkovits, T., Bíró, I.B.: 1998, *Inf. Bull. Variable Stars* , 4633
Bradstreet, D.H., Guinan, E.F.: 1988, *A Decade of UV Astronomy with IUE, ESA SP-281* **1**, 303
Bradstreet, D.H., Guinan, E.F.: 1994, in *Interacting Binary Stars*, ed.: A.W. Shafter, ASP Conf. Series 56, 228,
Brancewicz, H., Kreiner, J.M.: 1976, *Inf. Bull. Variable Stars* , 1119
Braune, W., Hübscher, J., Mundry, E: 1977, *Astr. Nacht.* **298**, 121
Breinhorst, R.A., Pfleiderer, J., Reihardt, M.: 1973, *Astron. Astrophys.* **22**, 239
Brown, B.M.K., Pinnington, E.H.: 1969, *Astron. J.* **74**, 538
Cester, B.: 1967, *Inf. Bull. Variable Stars* , 201
Cristescu, C.: 1978, *Inf. Bull. Variable Stars* , 1383
Cristescu, C., Oprescu, G., Suran, M.D.: 1979, *Inf. Bull. Variable Stars* , 1589
Cristescu, C., Oprescu, G.: 1984, *Inf. Bull. Variable Stars* , 2516
Dugan, R.S.: 1933, *Contrib. Princeton Univ.* **13**, 13
Eaton, J.A.: 1976, *unpublished* ,
Ebersberger, J., Pohl, E., Kizilirmak, A.: 1978, *Inf. Bull. Variable Stars* , 1449
Egge, K.E., Pettersen, B.R.: 1983, in *Activity in Red-Dwarf Stars*, eds.: P.B. Byrne and M. Rodonò, D. Reidel, Dordrecht, 481
Egge, K.E.: 1983, *Diploma thesis* , University of Tromso
Frasca, A., Sanfilippo, D., Catalano, S.: 1996, *Astron. Astrophys.* **313**, 532
Gaposchkin, S.: 1953, *Harv. Ann.* **113**, 73
Ghedini, S.: 1982, *Software for Photometric Astronomy* , Willmann-Bell Publ. Comp., Richmond
Glownia, Z.: 1988, *Inf. Bull. Variable Stars* , 3258
Guinan, E.F., Najafi, S.I., Zamani-Noor, F.: 1980, *Inf. Bull. Variable Stars* , 1850
Guinan, E.F., Weisengerger, A.G.: 1980, *Inf. Bull. Variable Stars* , 1856
Hanžl, D.: 1994, *Inf. Bull. Variable Stars* , 4097
Hegedüs, T.: 1987, *Inf. Bull. Variable Stars* , 3125
Hegedüs, T., Bíró, I.B., Paragi, Z.: 1996, *Inf. Bull. Variable Stars* , 4340
Heintz, W.D.: 1974, *IAU Circ.* , 2698
Heintz, W.D.: 1993, *Publ. Astron. Soc. Pac.* **105**, 586
Hendry, P.D., Mochnacki, S.W., Collier Cameron, A.: 1992, *Astrophys. J.* **399**, 246
Hendry, P.D., Mochnacki, S.W.: 2000, *Astrophys. J.* **531**, 467

Herbst, W., Bishel, L.E.: 1987, *Astron. J.* **94**, 1051
Herczeg, T., Schmidt, H.: 1960, *Veröff. Univ. Stern. Bonn* **No. 57**, 1
Hershey, J.L.: 1975, *Astron. J.* **80**, 662
Hill, G.: 1989, *Astron. Astrophys.* **218**, 141
Hopp, U., Witzigmann, S., Kiehl, M.: 1978, *Inf. Bull. Variable Stars* , 1599
Huffer, C.M.: 1946, *Astrophys. J.* **103**, 1
Jabir, N.L., Lafta, S.J, Jabbar, S.R., Fleyeh, H.A.: 1989, *Inf. Bull. Variable Stars* , 3363
Jay, J.E., Guinan, E.F.: 1997, *Inf. Bull. Variable Stars* , 4511
Kalchaev, K., Truttse, Yu.: 1960, *Astron. Circ. USSR* **210**, 19
Kang, B.S., Lee, Y.S.: 1999, *unpublished* ,
Karetnikov, V.G., Komarov, N.S.: 1965, *Perem. Zvezdy* **15**, 511
Karimie, M.T.: 1983, *Astrophys. Space Sci.* **92**, 53
Kaszás, G., Vinkó, J., Szatmáry, K., Hegedüs, T., Gál, J., Kiss, L. L., Borkovits, T.: 1998, *Astron. Astrophys.* **331**, 231
Kiss, L.L., Gál, J., Kaszás, G.: 1995, *Inf. Bull. Variable Stars* , 4181
Kiss, L.L., Kaszás, G., Fürész, G., Vinkó, J.: 1999, *Inf. Bull. Variable Stars* , 4681
Kizilirmak, A., Pohl, E.: 1971, *Inf. Bull. Variable Stars* , 530
Kizilirmak, A., Pohl, E.: 1974, *Inf. Bull. Variable Stars* , 937
Komžík, R.: 1999, *private communication* ,
Kostylev, K.W.: 1950, *Astron. Circ. USSR* **96**, 4
Kotarska, I., Glownia Z.: 1983, *Astr. Nacht.* **304**, 181
Kreiner, J.M., Winiarski, M.: 1981, *Acta Astron.* **31**, 351
Kukarkin, B.: 1931, *Niznij Novgorod V.S.* **3**, 96
Kukarkin, B., Kholopov, P.N., Artiukhina, N.M., Fedorovich, V.P., Frolov, M.S., Goranskij, N.A., Gorynya, N.A., Karitskaya, E.A., Kireeva, N.N., Kukarkina, N.P., Kurochkin, N.E., Medvedeva, G.I., Perova, N.B., Ponomareva, G.A., Samus, N.N., Shugarov, S.Yu.: 1982, *New Catalog of Suspected Variable Stars* , Nauka, Moscow
Kwee, K.K.: 1958, *Bull. Astron. Inst. Nether.* **14**, 131
Kwee, K.K.: 1966a, *Bull. Astron. Inst. Nether.* **18**, 448
Kwee, K.K.: 1966b, *Bull. Astron. Inst. Nether. Suppl. Ser.* **1**, 245
Kwee, K.K.: 1966c, *Bull. Astron. Inst. Nether. Suppl. Ser.* **1**, 265
Lapeta, A., Pajdosz, G.: 1988, *Inf. Bull. Variable Stars* , 3207
Leung, K.C.: 1993, in *New Frontiers in Binary Star Research,* eds.: J.C. Leung and I.-S. Nha, ASP Conf. Series 38, 154,
Linnell, A.P.: 1981, *Inf. Bull. Variable Stars* , 1967
Linnell, A.P.: 1986, *Astrophys. J.* **300**, 304
Linnell, A.P.: 1991, *Astrophys. J.* **383**, 330
Lloyd, C., Watson, J., Pickard, R.D.: 1992, *Inf. Bull. Variable Stars* , 3704
Lunel, M., Roux, S., Bergeat, J.: 1979, *Inf. Bull. Variable Stars* , 1670
Lunel, M., Garnier, R., Bergeat, J., van't Veer, F.: 1982, *Inf. Bull. Variable Stars* , 2176
Mahdy, H.A., Soliman, M.A.: 1982, *Inf. Bull. Variable Stars* , 2153
McNamara, H., Stern, A.V.: 1950, *Publ. Astron. Soc. Pac.* **62**, 112
Moncibowycz, A., Walter, K.: 1952, *Z. Astrophys.* **31**, 223
Muthsam, H.: 1972, *Inf. Bull. Variable Stars* , 631
Navrátil, M.: 1994, *Inf. Bull. Variable Stars* , 3997

Nelson, R.H.: 1998, *Inf. Bull. Variable Stars* , 4621
Niarchos, P.G.: 1979, *Inf. Bull. Variable Stars* , 1576
Niarchos, P.G.: 1980, *Inf. Bull. Variable Stars* , 1729
Niarchos, P.G.: 1981, *Inf. Bull. Variable Stars* , 1962
Niarchos, P.G.: 1983, *Inf. Bull. Variable Stars* , 2375
Niarchos, P.G., Hric, L., Manimanis, V., Theodossiou, E.: 1998, in *Proc. of the 20th Stellar Conference*, eds.: J. Dušek and Zejda, M., Nicholas Copernicus Observatory and Planetarium, Brno, 89,
Obůrka, O.: 1965, *Bull. Astron. Inst. Czechosl.* **16**, 212
Oprescu, G., Dumitrescu, A., Rovithis, P., Rovithis-Livaniou, H.: 1996, *Inf. Bull. Variable Stars* , 4307
Patkos, L.: 1975, *Inf. Bull. Variable Stars* , 1065
Patkos, L.: 1976, *Inf. Bull. Variable Stars* , 1200
Payne-Gaposchkin, C.: 1941, *Publ. Am. Astron. Soc.* **10**, 127
Piotrowski, S.: 1952, *SAC* **23**, 84
Pohl, E., Akan, M.C., Ibanoglu, C., Sezer, C., Güdur, N.: 1987, *Inf. Bull. Variable Stars* , 3078
Pohl, E., Gülmen, Ö.: 1981, *Inf. Bull. Variable Stars* , 1924
Pohl, E., Kizilirmak, A.: 1970, *Inf. Bull. Variable Stars* , 456
Pohl, E., Kizilirmak, A.: 1972, *Inf. Bull. Variable Stars* , 647
Pohl, E., Kizilirmak, A.: 1975, *Inf. Bull. Variable Stars* , 1053
Pohl, E., Kizilirmak, A.: 1976, *Inf. Bull. Variable Stars* , 1163
Pohl, E., Kizilirmak, A.: 1977, *Inf. Bull. Variable Stars* , 1358
Popper, D.M.: 1948, *Astrophys. J.* **108**, 490
Pribulla, T., Chochol, D., Parimucha, Š.: 1999, *Inf. Bull. Variable Stars* , 4751
Pribulla, T., Parimucha, Š, Vaňko, M.: 2000a, *Inf. Bull. Variable Stars* , 4847
Pribulla, T., Chochol, D., Milano, L., Errico, L., Vittone, A.A., Barone, F., Parimucha, Š.: 2000b, *Astron. Astrophys., in press* ,
Pustylnik, I., Sorgsepp, L.: 1976, *Acta Astron.* **26**, 319
Rakosh, K.: 1960, *Z. Astrophys.* **50**, 178
Rossati, F.: 1970, *Mem. Soc. Astron. Ital.* **61**, 395
Rovithis, P., Rovithis-Livaniou, H.: 1980, *Inf. Bull. Variable Stars* , 1736
Rovithis, P., Rovithis-Livaniou, H.: 1984, *Inf. Bull. Variable Stars* , 2457
Rovithis, P., Rovithis-Livaniou, H.: 1986, *Inf. Bull. Variable Stars* , 2916
Rucinski, S.M.: 1993, in *The Realm of the Interacting Binaries*, ed.: J. Sahade, G. McCluskey, Y. Kondo, Kluwer Acad. Publishers, 111,
Santiago, F., Quesada, J.A., Palacios, F., Sanchez, J.A., Cobo, M.: 1986, *Inf. Bull. Variable Stars* , 2907
Scarfe, C.D., Niehaus, R.J., Barlow, D.J., Baldwin, B.W.: 1973, *Inf. Bull. Variable Stars* , 844
Scarfe, C.D., Barlow, D.J.: 1978, *Inf. Bull. Variable Stars* , 1379
Scarfe, C.D., Birmacombe, J.: 1971, *Astron. J.* **76**, 50
Scarfe, C.D., Forbes, D.W., Delaney, P.A., Gagne, J.: 1984, *Inf. Bull. Variable Stars* , 2545
Schilt, J.: 1926, *Astrophys. J.* **64**, 215

Schmidt, H., Schrick, K.W.: 1955, *Z. Astrophys.* **37**, 73
Skillman, D.R.: 1978, *J. AAVSO* **7**, 23
Söderhjelm, S.: 1999, *Astron. Astrophys.* **341**, 121
Szafraniec, R.: 1960, *Acta Astron.* **10**, 109
Szafraniec, R.: 1962, *Acta Astron.* **12**, 181
Szatmáry, K.: 2000, *private communication* ,
Szczepanowska, A.: 1959, *Acta Astron.* **9**, 38
Tempesti, P., De Carlo, R.: 1972, *Mem. Soc. Astron. Ital.* **43**, 1
Todoran, I.: 1963, *Studii si Cercetari de Astronomie* **8**, 27
Todoran, I., Pop, V.: 1972, *Acta Astron.* **22**, 267
van Gent, H.: 1929, *Bull. Astron. Inst. Nether.* **5**, 89
van't Veer, F.: 1973, *Astron. Astrophys.* **26**, 357
Vinkó, J.: 1989, *Inf. Bull. Variable Stars* , 3291
Vinkó, J., Gál, J., Szatmáry, K., Kiss, L.: 1993, *Inf. Bull. Variable Stars* , 3965
Walter, K.: 1934, *Astr. Nach.* **253**, 9
Walter, K.: 1936, *Veröff. Königsberg* **7**,
Walter, K.: 1961, *Astr. Nacht.* **286**, 186
Walter, K.: 1983, *Astron. Astrophys.* **128**, 391
Woodward, E.J.: 1942, *Harv. Circ. 446* **19**,
Woodward, E.J.: 1951, *Astron. J.* **56**, 77
Wunder, E., Wieck, M., Kilinc, B., Gulmen, O., Tunca, Z., Evren, S.: 1992, *Inf. Bull. Variable Stars* , 3760
Yamasaki, A.: 1982, *Astrophys. Space Sci.* **85**, 43