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NORTHERN CEPHEIDS:
PERIOD UPDATE AND DUPLICITY EFFECTS

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ABSTRACT

O-C diagrams have been continued for 64 northern Cepheids with the primary aim of studying the effects of duplicity on the pulsation period. Because the light-time effect in the O-C diagrams of binary Cepheids has to be accompanied with properly phased variations in the γ-velocity, the radial velocity of the programme stars has been studied, as well. Light-time effect is suspected in the O-C diagram of FM Aql, RW Cam, Y Lac, and RS Ori, and confirmed for AW Per. One or more phase jumps are present or suspected in the O-C diagram of 19 northern Cepheids (FF Aql, BY Cas, DD Cas, DL Cas, X Cyg, SU Cyg, SZ Cyg, DT Cyg, V532 Cyg, V924 Cyg, TX Del, DX Gem, X Lac, CV Mon, RS Ori, SV Per, SZ Tau, T Vul, X Vul). In addition to the Cepheids with known spectroscopic orbit, the spectroscopic binary nature based on the variability of the γ-velocity has been confirmed, revealed or suspected for the majority of the programme stars. The most probable new spectroscopic binary Cepheids are: KL Aql, η Aql, SU Cas, V636 Cas, BZ Cyg, MW Cyg, V386 Cyg, W Gem, RZ Gem, AD Gem, RS Ori, SV Per, SW Tau, T Vul, and U Vul. A preliminary value of the orbital period is suggested for η Aql, SU Cas, RZ Gem, T Vul, and U Vul.

INTRODUCTION

Period changes of more than a hundred northern Cepheids were studied in a series of papers (*Szabados*, 1977, 1980 and 1981, hereinafter referred to as Papers I, II and III, respectively). As a result, the observed period changes were compared with the theoretical ones, predicted by the stellar evolutionary calculations (*Szabados*, 1983). In addition to the evolutionary changes (manifested in parabolic O-C graphs), two special kinds of period variations were also revealed in several cases, both of them being characteristic of binary Cepheids:

1. light-time effect due to the orbital motion,
2. phase jump, i.e. a stepwise O-C graph.

The origin of this latter type of the period change has not been clarified yet, but the phase jumps always occur in Cepheids having a companion star.

Later on, it became obvious that the extension of that study to southern Cepheids was of importance because the period variation of most Cepheids with negative declination had not been followed closely. The investigation of 44 bright southern Cepheid variables was published recently (*Szabados*, 1989 = Paper IV). Because the programme stars were selected arbitrarily, the primary goal of Paper IV was the study of duplicity effects in the O-C diagram, and no special attention was paid to follow the evolutionary period changes.

A companion star can also alter the observable γ-velocity of the given variable, if the orbital inclination significantly differs from zero. A light-time effect in the O-C diagram has to be accompanied with properly phased γ-velocity variations of the same period, and the amplitude of the oscillation in the O-C diagram is not independent from that deduced from the diagram γ-velocity vs. time. For this reason the study of period changes was supplemented with a comprehensive study of γ-velocity variations of the programme stars.

By the end of the eighties it became obvious that the frequency of the Cepheid binaries is much higher than thought before (*Szabados*, 1990b). The increase of the known spectroscopic binaries among Cepheids is mostly a result of the ultraviolet spectroscopy made with the IUE-satellite, and the thorough radial velocity studies performed in the last decade. In some cases, however, the available, sometimes sporadic, radial velocity measurements were even sufficient for revealing the orbital effect, or determining the orbital period (see e.g. *Szabados*, 1990a).

The aim of the present paper is to analyse the period changes of the known binary Cepheids of the northern sky, in order to study the effects of duplicity, and to search for γ-velocity variations in the case of suspected binary Cepheids with a declination larger than zero. Therefore the sample of stars studied here is selected arbitrarily: it contains 64 stars of various brightness (including four Population II Cepheids). Even some of the brightest Cepheids have been omitted (e.g. δ Cephei itself), being very probably single stars. Their period changes have to be also studied, but this paper is the last one in the extensive series on this topic, and the similar studies in the future will concentrate on individual Cepheids. Unfortunately the variable star astronomers have lost their interest in the regular photometry of the Cepheid variables, and it is to be afraid that the subtle but important period changes in these stars will pass unnoticed.

The programme stars are arranged in alphabetical order of constellations. The list of the Cepheids involved in this study is as follows (the ordinal number following the name of the Cepheid gives the page number where the discussion on the given star begins):

In addition to the binary Cepheids, some other Cepheid variables not having a companion were also studied, provided that the construction of a new O–C diagram contains relevant new information as compared with the original O–C plot published in Papers I–III. The new piece of information can be a recent period change, or larger accuracy due the new photoelectric O–C residuals overwhelming in the present O–C diagrams. Similarly, the shape of the O–C diagram is differently interpreted in the case of several binary Cepheids, as compared with the previous one. Besides the reasons listed above, the main cause of the modified shape of the O–C graphs is a recently discovered phase jump.

Since the duplicity effects in the O–C diagram (light-time effect and phase jump) are usually very subtle, only the photoelectric observations have been taken into account whenever possible. In a number of cases, however, photographic observations were also used when constructing the new O–C diagram, and for seven Cepheids (SU Cyg, VZ Cyg, W Gem, RZ Gem, ζ Gem, X Lac, SV Per) the early visual observations were also analysed. These latter exceptional cases are examples for either a parabolic O–C graph or an early phase jump, therefore the visual observations even from the last century are of primary importance.

The O-C residuals taken from Papers I-III have the same weight as that assigned to them originally. As far as the visual and the photographic observations are concerned, the O-C residuals based on such observations with a weight less than unity have not been used here.

The recently published photoelectric light curves are often superior to the previous ones. The new normal light curve determined for more than twenty programme stars showed a marked difference as compared with the previously used normal curve. In these cases the O-C residuals taken from Papers I-III were corrected accordingly. It has to be noted that, although solely photoelectric data have been used from among the recently published observations, several photoelectric observational series have been omitted, i.e. those obtained in the IR-region (e.g. *Schmidt*, 1976; *Welch* et al., 1984) because of the uncertain phase shift between the moments of maxima in the blue and infrared bands.

In the following discussion there are usually two tables and one figure for each Cepheid. The successive columns of the tables containing information on the O-C residuals give the following data:

1. Moment of normal maximum (an asterisk indicates that the given moment is a new one, not appearing in Papers I-III),
2. The corresponding epoch,
3. O-C residual (in days),
4. The weight assigned to the residual (a blank character means that the given residual has not been used in the curve-fitting procedure),
5. Source of the observational data.

The epoch and the O-C residual have been obtained using the linear ephemeris given in the discussion on each Cepheid.

The determination of the γ-velocities was performed in a similar manner as described in Paper IV. The successive columns in the Tables of the γ-velocities contain the following data:

1.-2. Mean date of the observations and its formal standard deviation,

3.-4. γ-velocity and its formal standard deviation,

5. Number of radial velocity observations used,

6. Source of the observational data.

Note that the uncertainty in the zero-point of the individual radial velocity measurement series tends to increase the standard deviation given in the tables, but no allowance was made for the zero-point differences.

The γ-velocity of a programme star is considered to be variable if its variation is larger than five km/s. The uncertainty of the zero-point hardly exceeds one km/s in the case of the modern radial velocity observations. The γ-velocity of the Cepheid-binaries with known orbit is not analysed here.

The figures visualizing the tabular data are usually divided into two parts. The upper panel shows the O-C diagram of the given variable. Filled circles denote the O-C residuals based on photoelectric observations, while open circles are those of photographic (or visual, in the case of the seven Cepheids listed above) origin. The size of the circles refers to the weight assigned to the O-C residual. The least squares fit (usually linear or parabolic) is also shown. It has to be noted, however, that the O-C residuals earlier than J.D. 2420000 are not plotted, even if they are listed in the corresponding table because those particular residuals were used during the curve-fitting procedure. In several cases sections of the O-C graph not studied here are also drawn for convenience (without listing the corresponding visual or low quality photographic O-C residuals). The ephemeris used for obtaining the O-C residuals is indicated at the top of the figure.

The lower panel of the figures shows the individual γ-velocities as a function of the Julian Date. The reliability of the data points can be estimated from the error bars (if the standard deviation exceeds the size of the dot). Again, the figure does not show the tabular values before J.D. 2420000.

REMARKS ON THE INDIVIDUAL VARIABLES

SZ Aquilae

The three more recent photoelectric observational series confirm the previous conclusion (Paper III) about the continuous period increase. The new O-C diagram has been constructed using the elements:

$$C = \underset{\pm .032}{2443807.165} + \underset{\pm .000233}{17\overset{d}{.}140554} \cdot E \qquad (1)$$

The momentary value of the period is as follows:

$$P = \underset{\pm .000233}{17\overset{d}{.}140554} + \underset{\pm .64}{3\overset{d}{.}29} \cdot 10^{-6} \cdot E \qquad (2)$$

Table 1. O-C residuals for SZ Aql

Norm.max. JD2400000+	E	O-C	W	Reference
29513.184	-834	1.487		Ahnert (1951)
29838.681	-815	1.308		Erleksova (1960)
31638.130	-710	0.758		Erleksova (1960)
32460.734	-662	0.616		Erleksova (1960)
33112.198	-624	0.739	3	Eggen (1951)
33454.820	-604	0.550		Erleksova (1960)
34414.613	-548	0.472		Erleksova (1960)
35494.235	-485	0.239		Erleksova (1960)
35580.096	-480	0.397	1	Walraven et al. (1958)
36231.149	-442	0.109		Erleksova (1960)
37156.786	-388	0.156	2	Mitchell et al. (1964)
37945.611	-342	0.515	1	Williams (1966)
40910.526	-169	0.115	3	Pel (1976)
41338.940*	-144	0.015	3	Feltz & McNamara (1980)
42898.836	-53	0.120	2	Dean (1977)
43807.095	0	-0.070	3	Szabados (1981)
44441.228*	37	-0.137	2	Eggen (1983b)
44612.842*	47	0.071	3	Moffett & Barnes (1984)

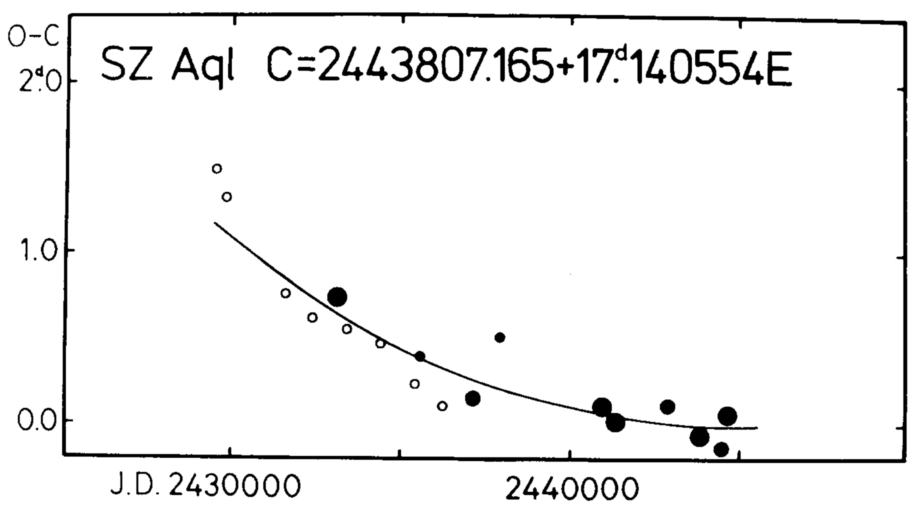

Figure 1. O-C diagram of SZ Aql

The O-C residuals are listed in Table 1 and shown plotted in Figure 1. The small number of radial velocity data (*Joy*, 1937; *Barnes* et al., 1988) does not allow the determination of accurate γ-velocities.

TT Aquilae

This bright Cepheid was frequently observed photometrically in the last two decades, thus making possible the reliable period determination based on photoelectric observations alone (see Table 2 and Figure 2). The current ephemeris is as follows:

$$C = 2443810.958 + 13\overset{d}{.}754954 \cdot E \qquad (3)$$
$$\pm.014 \qquad \pm.000043$$

Although the O-C residuals based on the photographic and the early photoelectric observations suggest a wave-like pattern, this tendency disappears after J.D. 2440000, as if a sudden change in the pulsation period occurred.

It is worth mentioning that the Julian Dates in *Connolly* et al.'s (1982) paper need a correction of -1 day. The revised pulsation period in their paper is also an artifact of this mistake.

The γ-velocities of TT Aql are collected in Table 3, and are shown plotted in the lower panel of Figure 2. A slight variation in the average radial velocity cannot be excluded but further high quality observations

Table 2. O-C residuals for TT Aql

Norm.max. JD2400000+	E	O-C	W	Reference
29385.963	-1016	0.038		Erleksova (1960)
30564.956	-963	0.019		Erleksova (1960)
31527.765	-893	-0.019		Erleksova (1960)
32449.337	-826	-0.029		Erleksova (1960)
33109.654	-778	0.050	3	Eggen (1951)
33494.741	-750	-0.002		Erleksova (1960)
34416.368	-683	0.044		Erleksova (1960)
35282.936	-620	0.049	2	Irwin (1961)
35502.954	-604	-0.012		Erleksova (1960)
35558.014	-600	0.028	2	Walraven et al. (1958)
36218.152	-552	-0.071		Erleksova (1960)
37208.525	-480	-0.055	3	Mitchell et al. (1964)
37937.601	-427	0.008	1	Williams (1966)
40413.494*	-247	0.010	2	Feltz & McNamara (1980)
40867.193	-214	-0.205	1	Evans (1976)
40867.331	-214	-0.067	3	Pel (1976)
41266.313*	-185	0.021	2	Feltz & McNamara (1980)
41912.777	-138	0.003	3	Landis (1976)
42916.670	-65	-0.216	2	Dean (1977)
43343.343*	-34	0.053	3	Moffett & Barnes (1984)
43810.884	0	-0.074	3	Szabados (1981)
43865.980*	4	0.002	3	Moffett & Barnes (1984)
44443.719*	46	0.033	3	Connolly et al. (1982)
44443.719*	46	0.033	3	Coulson et al. (1985)
44512.589*	51	0.128	3	Eggen (1983b)
44691.332*	64	0.057	2	Connolly et al. (1982)
44828.824*	74	-0.001	2	Coulson et al. (1985)

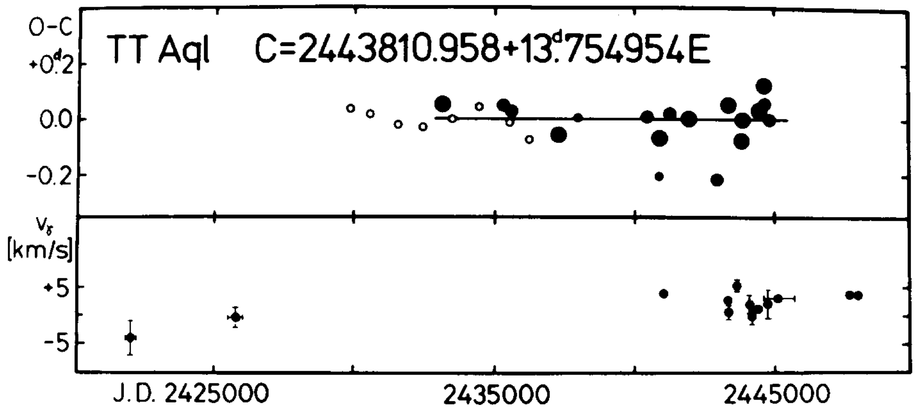

Figure 2. Upper panel: O-C diagram of TT Aql
Lower panel: γ-velocities for the same Cepheid

Table 3. γ-velocities of TT Aql

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
22002	152	-4.1	3.2	3	Joy (1937)
25809	260	-0.4	1.8	7	Joy (1937)
41031	146	4.0	0.2	7	Evans & Lyons (1986)
43317	31	3.0	0.4	3	Evans & Lyons (1986)
43369	36	0.8	1.2	12	Wilson et al. (1989)
43688	75	5.5	1.0	16	Barnes et al. (1987)
44036	47	2.1	1.8	6	Barnes et al. (1987)
44180	3	0.1	1.4	4	Coulson et al. (1985)
44427	10	1.3	0.5	27	Coulson et al. (1985)
44778	1	2.2	2.5	2	Coulson et al. (1985)
45133	521	3.3	0.2	7	Evans & Lyons (1986)
47745	34	3.9	0.4	15	Samus (1990)
48044	42	3.8	0.4	18	Samus (1990)

are necessary to make a firm statement. *Leonard* and *Turner* (1986) summarized the available information on duplicity of TT Aql. Although the photometric test by *Madore* and *Fernie* (1980) suggests the presence of a bright blue companion, no other positive evidence is available (see *Evans*, 1985; *Coulson* et al., 1986).

FF Aquilae

This variable is one of the most popular Cepheids among the observers, therefore a number of new results has been achieved. As to its photometry, the new O-C diagram (see Figure 3 and Table 4) clearly shows the existence

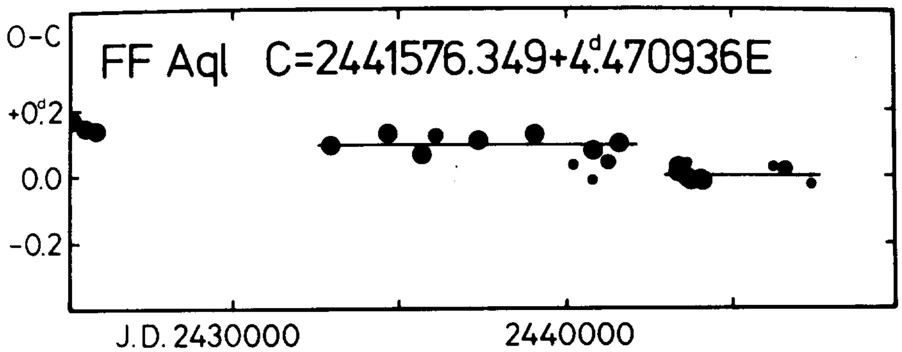

Figure 3. O-C diagram of FF Aql

Table 4. O-C residuals for FF Aql

Norm.max. JD2400000+	E	O-C	W	Reference
25096.650	-3686	0.171	3	Huffer (1931)
25490.067	-3598	0.146	3	Huffer (1931)
25811.968	-3526	0.139	3	Huffer (1931)
32960.946	-1927	0.091	3	Eggen (1951)
34628.641	-1554	0.127	3	Szabados (1977)
35625.598	-1331	0.065	3	Walraven et al. (1958)
36099.567	-1225	0.115	2	Svolopoulos (1960)
37320.127	-952	0.109	3	Mitchell et al. (1964)
39019.100	-572	0.126	3	Wisniewski & Johnson (1968)
40266.395*	-293	0.030	1	Feltz & McNamara (1980)
40789.448*	-176	-0.016	1	Feltz & McNamara (1980)
40811.901	-171	0.082	3	Pel (1976)
41245.539*	-74	0.039	2	Feltz & McNamara (1980)
41576.448	0	0.099	3	Szabados (1977)
43342.376*	395	0.007	3	Moffett & Barnes (1984)
43369.211*	401	0.017	3	present paper
43615.129*	456	0.033	1	Henden (1979)
43673.206*	469	-0.012	3	Moffett & Barnes (1984)
43731.324*	482	-0.016	3	present paper
44035.355*	550	-0.009	2	Moffett & Barnes (1984)
44853.537*	733	-0.008	3	Arellano Ferro (1984)
46284.270*	1053	0.025	1	"Carlsberg" (1989)
46624.056*	1129	0.020	2	present paper
47455.601*	1315	-0.029	1	Usenko (1990a)

of a phase jump, a phenomenon that has already been suspected by *Evans* et al. (1990b) on the basis of the new radial velocity data. The O-C residuals in Table 4 have been computed using the ephemeris:

$$C = \underset{\pm .009}{2441576.349} + \underset{\pm .000014}{4^{d}\!.470936}\cdot E \qquad (4)$$

and this ephemeris is valid for predicting the maxima after J.D. 2443000. Between J.D. 2433000 and 2442000 the following formula gives the best fit to the O-C residuals:

$$C = 2441576.423 + 4\overset{d}{.}470918 \cdot E \qquad (5)$$
$$\pm.011 \quad \pm.000010$$

Therefore the pulsation period remained constant during the two sections of the O-C graph, while the amount of the phase shift is about 0.08 day (or 0.02 phase). The phase jump occurred between J.D. 2442000 and 2443000. The different values of the pulsation period as determined from the O-C diagrams for the maximum and median brightness (see Paper I, page 92) can now be interpreted as a minor change in the light curve shape similarly to the other known case of SU Cyg (see Paper I and this paper, p. 159).

The radial velocity measurements of FF Aql are not analysed here because the study of *Evans* et al. (1990b) is so thorough and complete. Their paper includes a new determination of the orbit, and also contains all the available information concerning the companions to FF Aql. The only contribution here to the spectroscopic study is a single radial velocity measurement listed in Table 109.

FM Aquilae

The new O-C diagram based on only photoelectric observations (see Table 5 and Figure 4) gives a slightly longer period than that determined in Paper II. The new ephemeris is as follows:

$$C = 2442678.253 + 6\overset{d}{.}114265 \cdot E \qquad (6)$$
$$\pm.006 \quad \pm.000008$$

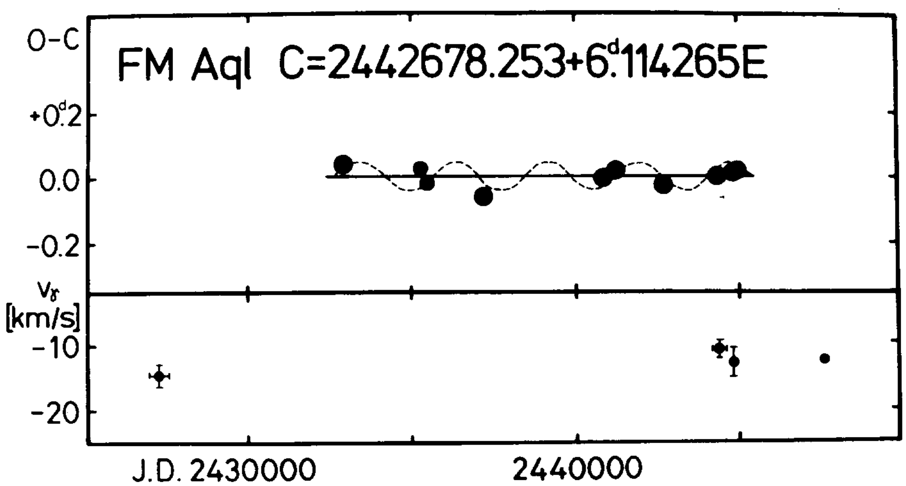

Figure 4. Upper panel: O-C diagram of FM Aql
Lower panel: γ-velocities for the same Cepheid

Table 5. O-C residuals for FM Aql

Norm.max. JD2400000+	E	O-C	W	Reference
32962.724	-1589	0.038	3	Eggen (1951)
35292.245	-1208	0.024	2	Irwin (1961)
35500.086	-1174	-0.020	2	Walraven et al. (1958)
37187.583	-898	-0.060	3	Mitchell et al. (1964)
40819.509	-304	-0.007	3	Pel (1976)
41223.078*	-238	0.020	3	Feltz & McNamara (1980)
42678.229	0	-0.024	3	Szabados (1980)
44335.221*	271	0.002	3	Moffett & Barnes (1984)
44830.486*	352	0.012	3	Eggen (1985)
44983.348*	377	0.017	3	Moffett & Barnes (1984)

Table 6. γ-velocities of FM Aql

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
27219	278	-14.5	1.7	8	Joy (1937)
44391	192	-10.8	1.4	9	Barnes et al. (1988)
44821	45	-12.8	2.3	4	Barnes et al. (1988)
47648	4	-12.4	0.2	6	Samus (1990)

Moreover, an apparent period variation caused by the light-time effect may be superimposed on the O-C graph (see Figure 4). The estimated period (about 2800 days) and the amplitude of the sinusoidal variation implies an orbital radial velocity variation that might be easily detected.

The available radial velocity measurements (see Table 6), however, do not support the variable γ-velocity hypothesis. Nevertheless, there have been evidence in favour of a blue companion. *Madore* (1977) derived a B9V type photometric companion, while *Pel* (1978) concluded that FM Aql had a peculiar colour - colour loop. The ultraviolet spectrum of this Cepheid, however, does not indicate the presence of a companion earlier than A0V (*Evans* et al. 1990a). Further spectroscopic observations are desirable to settle this problem.

KL Aquilae

There are no newly published photometric observations on this neglected Cepheid, thus the previous O-C diagram (Paper II, p. 53) cannot be replaced with a recent one. The existing radial velocity measurements, however, have not been analysed before. As one can see in Table 7, the γ-velocities show a strong variation on a time-scale of several hundred days. KL Aql seems to be a new spectroscopic binary Cepheid, worthy of immediate observation.

Table 7. γ-velocities of KL Aql

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
27543	124	-1.5	2.0	6	Joy (1937)
28097	1	-6.8	4.5	1	Joy (1937)
28396	21	-45.5	1.4	3	Abt (1973)
44735	129	-0.5	1.2	12	Harris & Wallerstein (1984)
45167	48	1.0	2.0	5	Harris & Wallerstein (1984)

V572 Aquilae

All the previous photoelectric observations have been analysed again, because *Henden*'s (1979) data form a better normal light curve than that used in Paper I. Therefore the moments of the normal maxima listed in Table 8 are different from the corresponding values listed in Paper I (p. 70). In spite of the reliable new normal light curve, the O-C residuals widely scatter around the best fitting line (see Figure 5) described with the formula:

$$C = 2441921.693 + 3\overset{d}{.}768001 \cdot E \qquad (7)$$
$$\pm.088 \quad \pm.000080$$

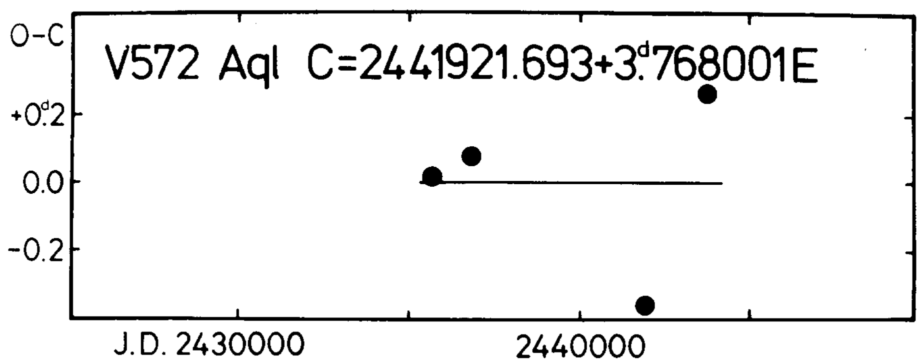

Figure 5. O-C diagram of V572 Aql

Table 8. O-C residuals for V572 Aql

Norm.max. JD2400000+	E	O-C	W	Reference
35666.826	-1660	0.015	3	Walraven et al. (1958)
36789.753	-1362	0.077	3	Oosterhoff (1960)
41921.334	0	-0.359	3	Szabados (1977)
43734.368*	481	0.267	3	Henden (1979)

These deviations are possibly caused by period changes (a previous change in the pulsation period was suspected in Paper I). Therefore the elements given here and in Table 110 are only tentative.

No radial velocity measurements have been published about this star.

V1344 Aquilae

Arellano Ferro's (1984) recent photoelectric observations form a new normal light curve superior to the previous one (*Kovács* and *Szabados*, 1979), therefore these earlier published observations were re-analysed when constructing the O-C diagram. The O-C residuals plotted in Figure 6 and listed in Table 9 have been calculated with the ephemeris:

$$C = 2443398.184 + 7^{d}.476787 \cdot E \qquad (8)$$
$$\pm.015 \qquad \pm.000104$$

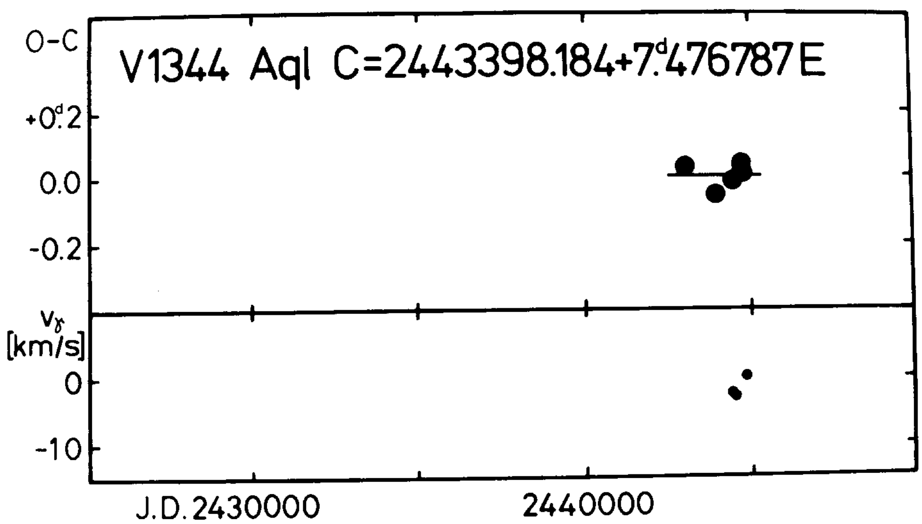

Figure 6. Upper panel: O-C diagram of V1344 Aql
Lower panel: γ-velocities for the same Cepheid

Table 9. O-C residuals for V1344 Aql

Norm.max. JD2400000+	E	O-C	W	Reference
43016.896	-51	0.028	3	Kovács & Szabados (1979)
43958.889	75	-0.054	3	Kovács & Szabados (1979)
44482.301*	145	-0.017	3	Fernie & Garrison (1981)
44781.430*	185	0.040	3	Arellano Ferro (1984)
44788.871*	186	0.005	3	Eggen (1985)

Table 10. γ -velocities of V1344 Aql

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
44424	27	-2.3	0.1	16	Balona (1981)
44528	15	-2.7	0.2	8	Balona (1981)
44832	6	0.2	0.6	8	Arellano Ferro (1984)

The available radial velocity data, although being very accurate, are not sufficient to draw a firm conclusion on the variability of the γ -velocity (see Table 10). If V1344 Aql is really a spectroscopic binary, then the orbital period has to be relatively short (several hundred days). An extension of the observations to a longer time-base both in photometry and spectroscopy would be necessary.

η Aquilae

Because the photoelectric observations obtained by *Moffett* and *Barnes* (1984) offered a better normal ligth curve than that used previously, this new normal curve has been used for determining the moments of normal maxima for the photoelectric observations published in the eighties. In order to eliminate the systematic difference in the phase of the maximum light between the recent and the previous normal curve, a correction of -0.029 day has been applied to the photoelectric O-C residuals published in Paper II. Both the corrected and the recently determined O-C residuals are listed in Table 11. A parabolic fit, i.e. a continuously increasing pulsation period is still the most appropriate interpretation of the O-C graph (see Figure 7). The O-C residuals have been calculated using the

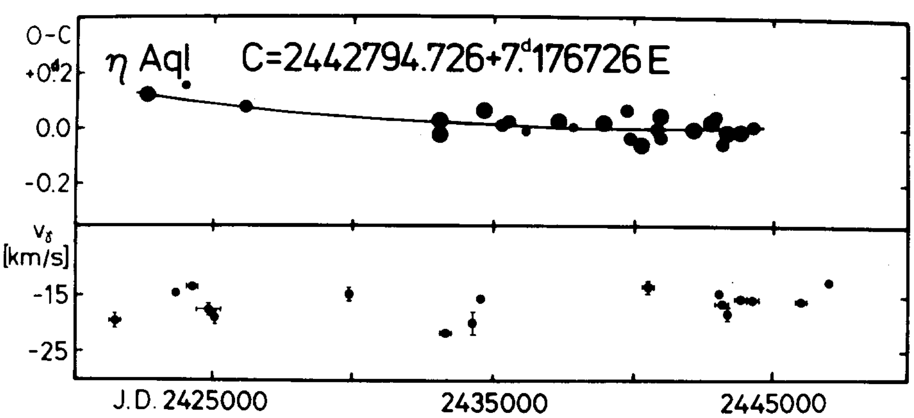

Figure 7. Upper panel: O-C diagram of η Aql
Lower panel: γ -velocities for the same Cepheid

ephemeris:

$$C = 2442794.726 + 7\overset{d}{.}176726 \cdot E \qquad (9)$$
$$\pm.006 \quad \pm.000014$$

The instantaneous value of the period can be predicted as follows:

$$P = 7\overset{d}{.}176726 + 3\overset{d}{.}16 \cdot 10^{-8} \cdot E \qquad (10)$$
$$\pm.000014 \quad \pm 1.13$$

There is no significant difference between this value and that determined in Paper II.

Table 11. O-C residuals for η Aql

Norm.max. JD2400000+	E	O-C	W	Reference
22585.188	-2816	0.122	3	Wylie (1922)
23991.859	-2620	0.155	1	Pettit & Nicholson (1933)
26144.796	-2320	0.074	2	Bernheimer (1931)
33041.532	-1359	-0.023	3	Eggen (1951)
33070.289	-1355	0.027	3	Stebbins et al. (1952)
34613.324	-1140	0.066	3	Szabados (1980)
35295.055	-1045	0.008	2	Irwin (1961)
35574.965	-1006	0.025	2	Walraven et al. (1958)
36141.892	-927	-0.009	1	Oke (1961)
37283.027	-768	0.027	3	Mitchell et al. (1964)
37857.144	-688	0.005	1	Williams (1966)
38926.492	-539	0.021	3	Wisniewski & Johnson (1968)
39751.864	-424	0.070	2	Sudzius (1969)
39888.119	-405	-0.033	2	Schmidt (1971)
40239.753*	-356	-0.058	3	Feltz & McNamara (1980)
40857.010*	-270	0.000	2	Feltz & McNamara (1980)
40928.825	-260	0.048	3	Pel (1976)
40957.453	-256	-0.031	2	Evans (1976)
42127.285*	-93	-0.005	3	Depenchuk (1980)
42794.752	0	0.026	3	Szabados (1980)
42945.483	21	0.046	2	Dean (1977)
43203.745*	57	-0.054	2	Depenchuk (1980)
43311.439*	72	-0.011	2	Dean (1981)
43340.153*	76	-0.004	3	Moffett & Barnes (1984)
43864.047*	149	-0.011	3	Moffett & Barnes (1984)
44373.617*	220	0.011	2	Schmidt & Parsons (1982)

The study of the radial velocity observations, however, gives more novelty. It is a well-known fact that η Aql belongs to a binary system (*Mariska* et al., 1980). Based on the IUE spectra, *Böhm-Vitense* and *Proffitt* (1985) derived an AlV companion of ΔV = 4.6 mag. *Jacobsen* and *Wallerstein* (1981) suspected long period changes in the systemic radial velocity. As a matter of fact, the analysis of the radial velocity data collected from the literature (see Table 12 and Figure 7) strengthens their conclusion on the variability of the γ-velocity. It is not clear, however, what period can be assigned to the γ-velocity changes. The formal period search resulted in a value as short as 926 days. The deviations of the O-C residuals from the fitted parabola clearly show a

Table 12. γ-velocities of η Aql

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
14129	10	-16.7	0.9	13	Belopolski (1897)
14517	32	-15.0	0.6	28	Wright (1899)
19277	366	-13.7	2.1	3	Spencer Jones (1928)
21429	233	-19.6	1.2	4	Abt (1973)
23653	43	-14.4	0.6	28	Jacobsen (1926)
24226	173	-13.4	0.4	57	Henroteau (1928)
24869	461	-17.6	0.9	6	Abt (1973)
25084	23	-18.9	0.8	17	Henroteau & Vibert (1929)
29873	12	-14.6	1.2	4	Jacobsen (1961)
33292	190	-21.6	0.4	22	Jacobsen (1954)
34258	15	-19.8	2.0	2	Jacobsen (1954)
34548	32	-15.3	0.6	14	Jacobsen (1961)
40502	139	-13.3	1.0	5	Lloyd Evans (1980)
43049	33	-14.3	0.7	3	Jacobsen & Wallerstein (1981)
43141	206	-16.3	0.3	7	Beavers & Eitter (1986)
43384	4	-17.9	1.3	11	Wilson et al. (1989)
43828	206	-15.2	0.7	29	Barnes et al. (1987)
44290	143	-15.4	0.2	18	Jacobsen & Wallerstein (1981)
46033	157	-16.0	0.2	18	Jacobsen & Wallerstein (1987)
47027	1	-12.5	0.7	1	Samus (1990)

sinusoidal pattern at this period, as if it were a light-time effect, but this is too subtle to detect with an eye inspection in Figure 7. Further extensive radial velocity measurements are necessary to find the correct value of the spectroscopic orbital period.

RT Aurigae

Table 13. O-C residuals for RT Aur

Norm.max. JD2400000+	E	O-C	W	Reference
29603.272	-3251	-0.035	3	Bennett (1941)
33141.392	-2302	0.025	3	Eggen et al. (1957)
35799.601	-1589	0.029	3	Prokof'yeva (1961)
35881.611*	-1567	0.018	3	Bahner & Mavridis (1977)
36202.239*	-1481	0.021	3	Bahner & Mavridis (1977)
36616.072*	-1370	0.024	2	Bahner & Mavridis (1977)
37339.350	-1176	0.032	3	Mitchell et al. (1964)
37995.423	-1000	-0.058	2	Williams (1966)
38920.047	-752	-0.027	3	Wisniewski & Johnson (1968)
39359.960	-634	-0.041	3	Takase (1969)
40843.831*	-236	0.007	2	Feltz & McNamara (1980)
40996.642*	-195	-0.038	2	Evans (1976)
41429.115	-79	-0.036	3	Winzer (1973)
41723.711	0	0.032	3	Szabados (1977)
43539.286*	487	-0.025	2	Moffett & Barnes (1984)
44106.001*	639	0.003	3	Moffett & Barnes (1984)
44534.795*	754	0.055	2	Eggen (1985)

The eight new O-C residuals supplemented with the earlier photoelectric O-C values (see Table 13) confirm the value of the pulsation period as determined in Paper I. The O-C diagram has been calculated using the formula:

$$C = 2441723.679 + 3\overset{d}{.}728198 \cdot E \qquad (11)$$
$$\pm.006 \quad \pm.000005$$

Although a very long (10000 - 15000 days) wave may be superimposed on the straight line in Figure 8, no spectroscopic confirmation of the light-time effect can be deduced from the available radial velocity data (Table 14). *Leonard* and *Turner* (1986) summarized the various arguments for and against duplicity of RT Aur and concluded that this Cepheid probably does not have a bright blue companion.

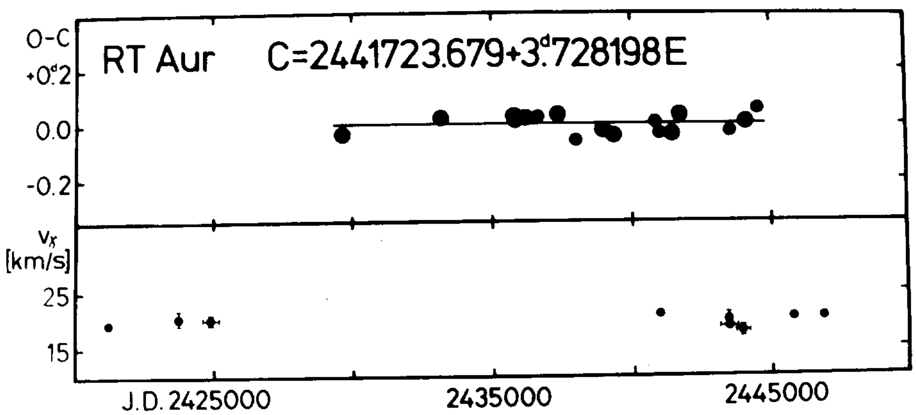

Figure 8. Upper panel: O-C diagram of RT Aur
Lower panel: γ-velocities for the same Cepheid

Table 14. γ-velocities of RT Aur

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
18230	18	21.5	0.6	24	Petrie (1932)
21210	65	19.5	0.6	30	Kiess (1917)
23723	30	20.6	1.3	6	Petrie (1932)
24955	253	20.1	0.7	19	Petrie (1932)
40979	9	21.0	0.3	4	Evans (1976)
43449	59	20.0	1.4	9	Wilson et al. (1989)
43457	275	18.7	0.4	5	Beavers & Eitter (1986)
43963	245	18.0	0.8	25	Barnes et al. (1987)
45717	9	20.4	0.1	45	Gieren (1985)
46866	1	20.4	0.5	2	Samus (1990)

AN Aurigae

Berdnikov's (1987) recent photometry confirms the period change suspected in Paper III but the phase jump interpretation does not seem to be correct. The O-C residuals listed in Table 15 have been obtained by the formula:

$$C = 2443799.022 + 10\overset{d}{.}289563 \cdot E \qquad (12)$$
$$\pm.017 \qquad \pm.000036$$

The photoelectric O-C residuals are plotted in Figure 9. It should be noted that *Berdnikov*'s (1987) photoelectric observations do not support the change in the light curve shape suspected in Paper III.

Nevertheless, AN Aur is a binary Cepheid, since the radial velocity observations show a variation in the γ-velocity. In Figure 10 the open circles denote *Joy*'s (1937) radial velocity data, while *Samus*' (1990) observations are plotted as filled circles. Zero phase is chosen arbitrarily, the pulsation period is according to Eq.(12). The deviation in the average radial velocity is even more obvious if the phase shift due to the period change occurred after the epoch of *Joy*'s observations is also taken into account. *Madore* (1977) estimates a B5 photometric companion. Further spectroscopic observations of this Cepheid would be of primary importance.

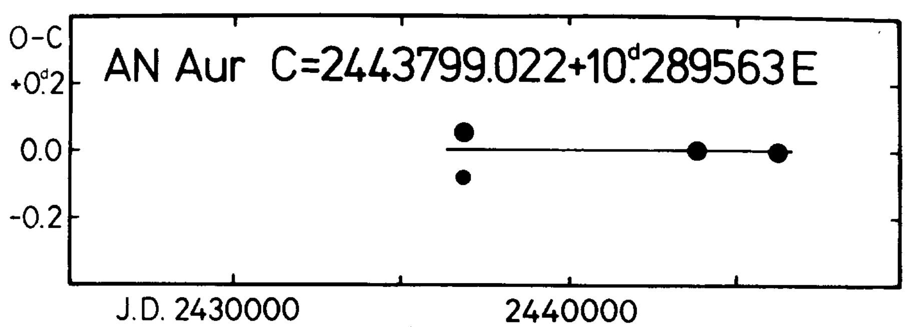

Figure 9. O-C diagram of AN Aur

Table 15. O-C residuals for AN Aur

Norm.max. JD2400000+	E	O-C	W	Reference
36832.907	-677	-0.081	2	Oosterhoff (1960)
36833.041	-677	0.053	3	Weaver et al. (1960)
43799.026	0	0.004	3	Szabados (1981)
46299.383*	243	-0.003	3	Berdnikov (1987)

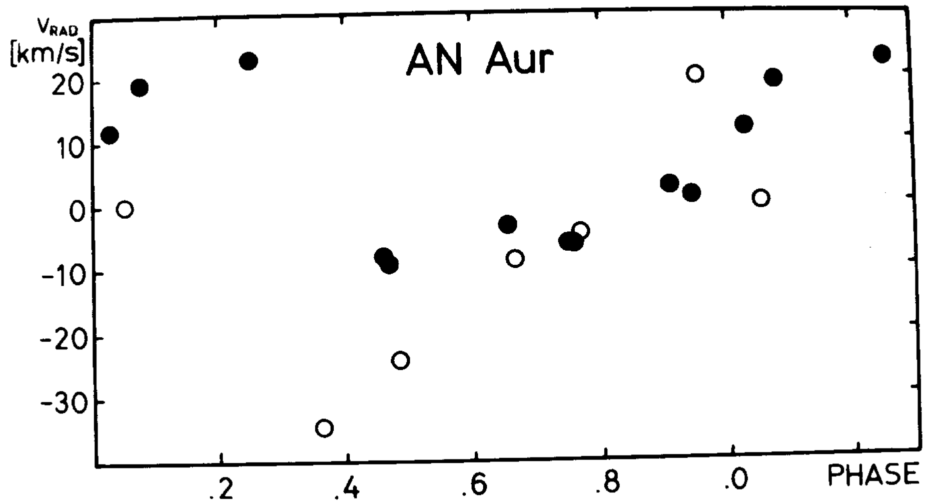

Figure 10. Radial velocity observations of AN Aur folded with the period 10.289563 days. Zero phase is chosen arbitrarily. Open circles: *Joy*'s (1937) data, filled circles: *Samus*' (1990) observations

RW Camelopardalis

The O-C diagram of this binary Cepheid supplemented with the recent O-C residuals (see Table 16) is plotted in Figure 11. The O-C residuals have been calculated using the ephemeris:

$$C = 2443840.694 + 16\overset{d}{.}415015 \cdot E \qquad (13)$$
$$\pm.020 \qquad \pm.000067$$

If the wave-like pattern is interpreted in terms of the light-time effect, an orbital period of about 7000 days characterizes the system. In

Table 16. O-C residuals for RW Cam

Norm.max. JD2400000+	E	O-C	W	Reference
36174.873	-467	-0.009	3	Bahner & Mavridis (1977)
36831.480	-427	-0.003	3	Oosterhoff (1960)
36831.546	-427	0.063	3	Weaver et al. (1960)
36880.608	-424	-0.120	3	Bahner et al. (1962)
39113.340	-288	0.170	3	Wamsteker (1972)
39786.182	-247	-0.003	2	Szabados (1981)
43840.515	0	-0.179	3	Szabados (1981)
44382.394*	33	0.005	2	Moffett & Barnes (1984)
45038.953*	73	-0.037	3	Moffett & Barnes (1984)
45695.611*	113	0.020	3	Berdnikov (1986)
46483.539*	161	0.028	2	present paper
47304.378*	211	0.116	2	present paper

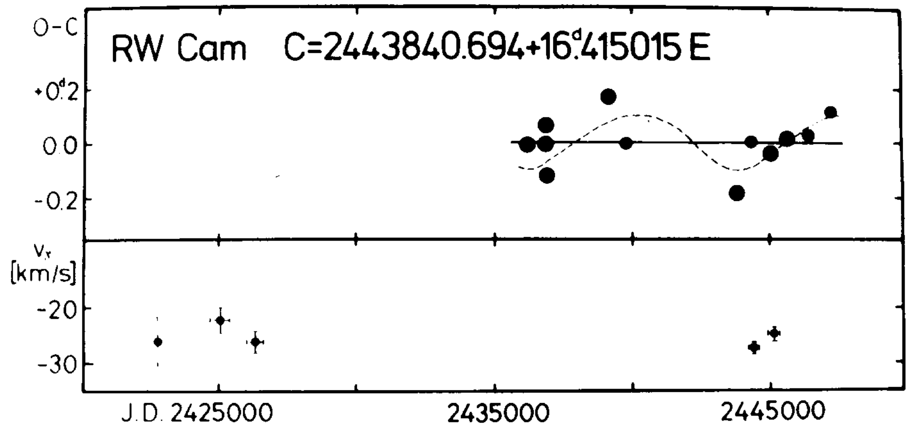

Figure 11. Upper panel: O-C diagram of RW Cam
Lower panel: γ-velocities for the same Cepheid

Table 17. γ-velocities of RW Cam

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
22740	1	-26.1	4.5	1	Joy (1937)
25050	340	-22.1	2.3	5	Joy (1937)
26364	288	-26.1	2.0	6	Joy (1937)
44456	160	-27.1	1.0	18	Barnes et al. (1988)
45168	223	-24.8	1.2	12	Barnes et al. (1988)

Paper III a somewhat shorter orbital period was suggested but *Joy*'s (1937) radial velocity measurements (see Table 17) prefer this longer value. The amplitude of the sinusoidal O-C variation is rather large, giving rise to considerable γ-velocity changes. Therefore the variation in the γ-velocity has to be larger than it has been observed till now. The phasing of the radial velocity data with the suspected orbital period, however, shows that RW Cam has never been observed spectroscopically during the phases when the Cepheid is approaching the observer. According to Figure 11, this orbital phase occurs just in the nineties, so any radial velocity study to be performed in the near future would answer the question whether the light-time effect interpretation is correct. If this is not the case, the other plausible interpretation of the O-C graph would be the occurrence of a phase jump. In any case, a regular coverage of the light variation is also desirable.

In addition to the previously published photometric evidence, the blue companion of RW Cam has been pointed out in the IUE spectra (*Böhm-Vitense* and *Proffitt*, 1985).

SU Cassiopeiae

The O-C diagram of this bright Cepheid based on only photoelectric observations is shown in Figure 12 (see also Table 18). The pulsation period has been constant since the discovery of the light variation of SU Cas. The current ephemeris

$$C = 2441645.913 + 1\overset{d}{.}949325 \cdot E \qquad (14)$$
$$\pm.003 \quad \pm.000003$$

is practically the same as derived in Paper I. The same conclusion has been drawn by *Rhode* (1990a).

On the contrary, the study of the available radial velocity observations gives more interesting results. SU Cas also belongs to a binary system (*Evans*, 1985). This finding has been confirmed photometrically (*Usenko*, 1990b): the position of SU Cas on the two-colour diagram can be explained by assuming an A0 companion. In the light of these facts it is worth looking for any change in the γ-velocity of this Cepheid (see Table 19). There are four possible values of the orbital period: 462.5 , 928, 1375 and 1682 days. Although any data set can be folded with a "best fitting" sinusoid, and the periodicity does not necessarily bear physical significance, the 462.5 day period seems to be not simply an artifact of the data distribution. Of course, the "orbital velocity curve" plotted in Figure 13 has to be confirmed by additional radial velocity measurements.

Table 18. O-C residuals for SU Cas

Norm.max. JD2400000+	E	O-C	W	Reference
30404.167	-5767	0.011	3	Walter (1943)
30905.119	-5510	-0.013	3	Groeneveld (1944)
35755.041	-3022	-0.012	3	Prokof'yeva (1961)
36121.522*	-2834	-0.004	3	Bahner & Mavridis (1977)
36199.516	-2794	0.017	2	Svolopoulos (1960)
36836.942	-2467	0.014	2	Bahner et al. (1962)
37439.297	-2158	0.027	3	Mitchell et al. (1964)
38384.671	-1673	-0.021	3	Wisniewski & Johnson (1968)
39055.269	-1329	0.009	3	Milone (1970)
39361.299	-1172	-0.005	3	Takase (1969)
39447.074	-1128	0.000	3	Wamsteker (1972)
39751.198	-972	0.029	2	Sudzius (1969)
39864.198	-914	-0.032	3	Reed (1968)
40180.041*	-752	0.020	2	Feltz & McNamara (1980)
40963.647*	-350	-0.002	3	Feltz & McNamara (1980)
41645.925	0	0.012	3	Szabados (1977)
41930.480	146	-0.034	3	Gieren (1976)
43347.688*	873	0.014	3	Niva & Schmidt (1979)
43690.749*	1049	-0.006	3	Moffett & Barnes (1984)
44178.083*	1299	-0.003	3	Moffett & Barnes (1984)
47149.804*	2962	-0.010	3	Rhode (1990a)

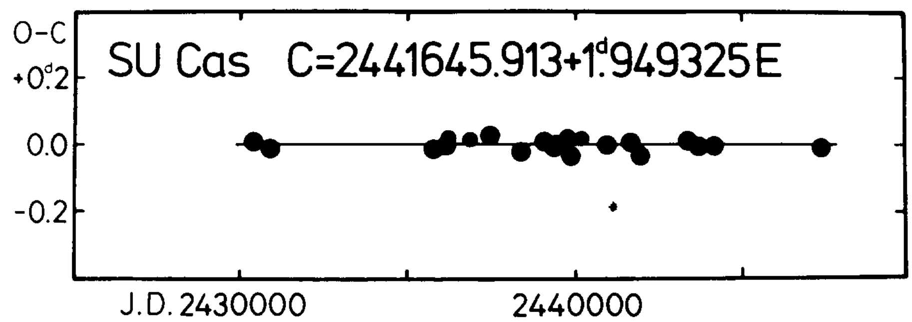

Figure 12. O-C diagram of SU Cas

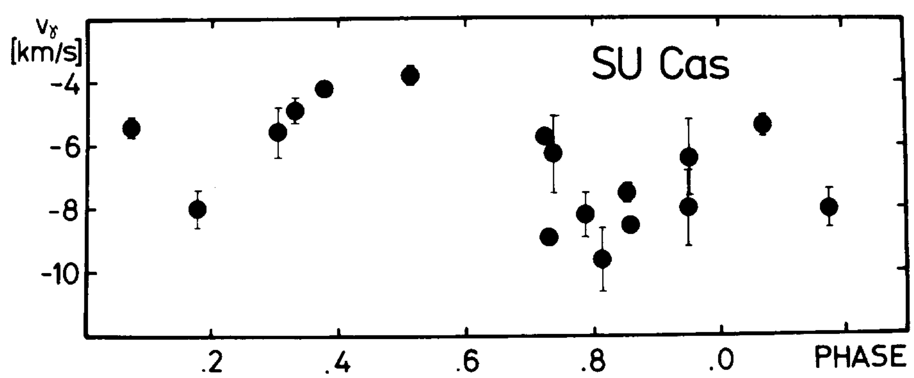

Figure 13. γ-velocity values of SU Cas folded with the 462.5 day period

Table 19. γ-velocities of SU Cas

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
20229	162	-6.3	1.2	4	Adams & Shapley (1918)
21252	153	-8.0	1.2	4	Adams & Shapley (1918)
34307	17	-8.0	0.6	4	Abt (1959)
34621	23	-8.5	0.3	14	Abt (1959)
35051	1	-8.2	0.7	3	Abt (1959)
36451	1	-9.6	1.0	1	Abt (1959)
40943	47	-3.8	0.3	7	Niva & Schmidt (1979)
41962	29	-8.9	0.1	63	Gieren (1976)
43406	3	-7.5	0.1	27	Niva & Schmidt (1979)
43453	59	-6.4	1.2	12	Wilson et al. (1989)
43810	28	-5.7	0.1	51	Beavers & Eitter (1986)
44079	264	-5.6	0.8	23	Barnes et al. (1987)
44574	46	-4.2	0.2	14	Häupl (1988)
44895	54	-5.4	0.3	11	Häupl (1988)
46866	1	-4.9	0.4	2	Samus (1990)

SZ Cassiopeiae

The very rapid increase in the pulsation period of SZ Cas has been continuing (see Figure 14). The O-C diagram based on the photoelectric O-C residuals, however, results in an ephemeris slightly different from that determined in Paper III. The O-C residuals listed in Table 20 have been obtained using the new elements:

$$C = 2443817.978 + 13\overset{d}{.}636857 \cdot E \qquad (15)$$
$$\pm.029 \qquad \pm.000305$$

The value of the period as a function of the epoch elapsed can be given as follows:

$$P = 13\overset{d}{.}636857 + 18\overset{d}{.}72 \cdot 10^{-6} \cdot E \qquad (16)$$
$$\pm.000305 \qquad \pm 1.37$$

Coker et al. (1989) obtained very accurate radial velocity measurements on SZ Cas, resulting in one of the best radial velocity

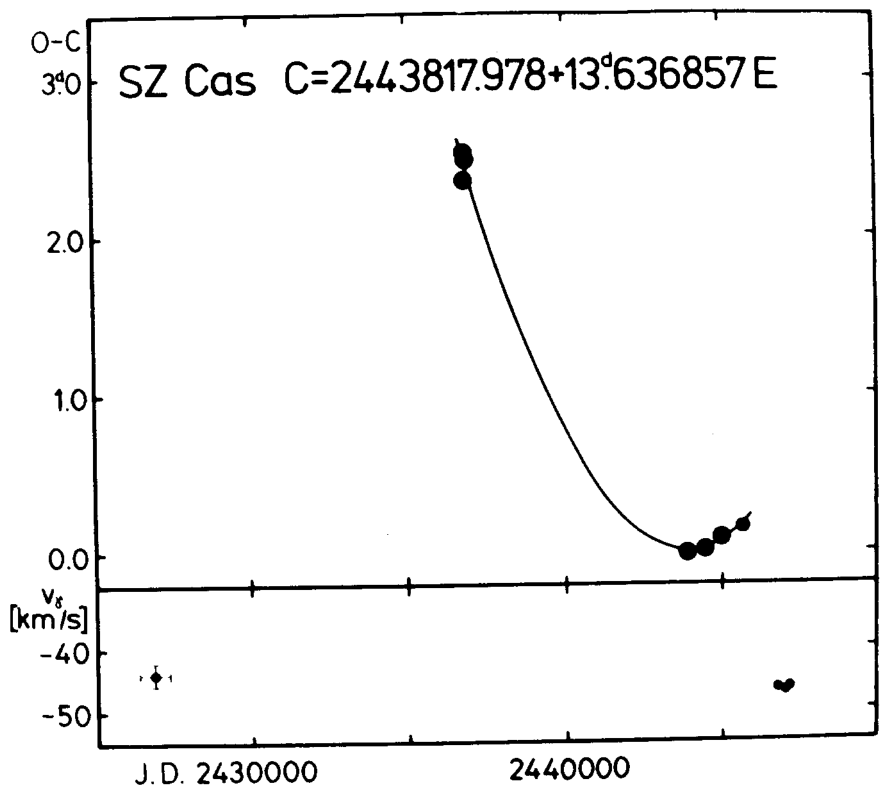

Figure 14. Upper panel: O-C diagram of SZ Cas
Lower panel: γ-velocities for the same Cepheid

Table 20. O-C residuals for SZ Cas

Norm.max. JD2400000+	E	O-C	W	Reference
36824.793	-513	2.523	3	Oosterhoff (1960)
36838.243	-512	2.336	3	Weaver et al. (1960)
36892.930	-508	2.475	3	Bahner et al. (1962)
43817.966	0	-0.012	3	Szabados (1981)
44404.379*	43	0.016	3	Moffett & Barnes (1984)
44963.567*	84	0.093	3	Moffett & Barnes (1984)
45672.744*	136	0.153	2	Berdnikov (1986)

Table 21. γ-velocities of SZ Cas

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
26892	488	-43.8	1.8	7	Joy (1937)
46794	91	-46.5	0.1	24	Coker et al. (1989)
47024	47	-46.9	0.1	26	Coker et al. (1989)
47194	94	-46.3	0.1	20	Coker et al. (1989)

curves ever observed for a Cepheid. There is a hint that the γ-velocity slightly varies from year to year (see Table 21), but further accurate measurements are necessary to confirm this suspicion. The recent study about the the position of SZ Cas on the two-colour diagram (*Usenko*, 1990b) assumes a B3 - B4 companion to this Cepheid.

BY Cassiopeiae

The new version of the O-C diagram suggests an early phase jump in addition to the recent period change (see Table 22 and Figure 15). The pulsation of BY Cas can be characterized with the following periods during the various time intervals:

between J.D. 2428500 and 2432000 P = 3.221315 ±.000112 days,
between J.D. 2432000 and 2434500 P = 3.221557 ±.000104 days,
between J.D. 2435500 and 2440000 P = 3.222618 ±.000037 days,
after J.D. 2443000 P = 3.222199 ±.000031 days.

The O-C residuals have been calculated with this latter period:

$$C = \underset{\pm .019}{2441774.634} + \underset{\pm .000031}{3\overset{d}{.}222199} \cdot E \qquad (17)$$

The phase jump occurring at J.D. 2432000 was as large as 0.2 day. The type of the most recent period change is not clear yet. Further photometric observations are necessary.

The available sporadic radial velocity observations (*Joy*, 1937; *Samus*, 1990) are not enough for the determination of the radial velocity curve itself. Nevertheless, BY Cas is a promising candidate for binarity: *Usenko*

Table 22. O-C residuals for BY Cas

Norm.max. JD2400000+	E	O-C	W	Reference
28563.344	-4100	-0.274	1	Parenago (1940)
29223.824	-3895	-0.345	1	Kukarkina (1954)
30480.163	-3505	-0.664	1	Satyvaldiev (1970)
30650.693	-3452	-0.910	1	Dirks & Vaucouleurs (1949)
31014.735	-3339	-0.977	1	Satyvaldiev (1970)
31781.530	-3101	-1.065	1	Ashbrook (1954)
32048.696	-3018	-1.341	1	Dirks & Vaucouleurs (1949)
32132.390	-2992	-1.425	1	Satyvaldiev (1970)
33524.240	-2560	-1.565	1	Satyvaldiev (1970)
33736.708	-2494	-1.761	1	Kukarkina (1954)
33878.460	-2450	-1.786	1	Ashbrook (1954)
34361.768	-2300	-1.808	1	Kheilo (1962)
35557.258	-1929	-1.754	1	Kheilo (1962)
35615.515	-1911	-1.497	1	Satyvaldiev (1970)
36143.784	-1747	-1.668	1	Kheilo (1962)
36820.545	-1537	-1.569	3	Oosterhoff (1960)
36827.004	-1535	-1.555	3	Weaver et al. (1960)
36843.175	-1530	-1.495	1	Kheilo (1962)
36910.801	-1509	-1.535	3	Bahner et al. (1962)
38248.220	-1094	-1.328	1	Satyvaldiev (1970)
38409.256	-1044	-1.402	3	Malik (1965)
38660.818	-966	-1.172	1	Satyvaldiev (1970)
39785.406	-617	-1.131	3	Szabados (1977)
41774.189	0	-0.445	3	Szabados (1977)
43079.635	405	0.010	2	Szabados (1977)
43456.607*	522	-0.015	2	present paper
44168.732*	743	0.004	3	present paper

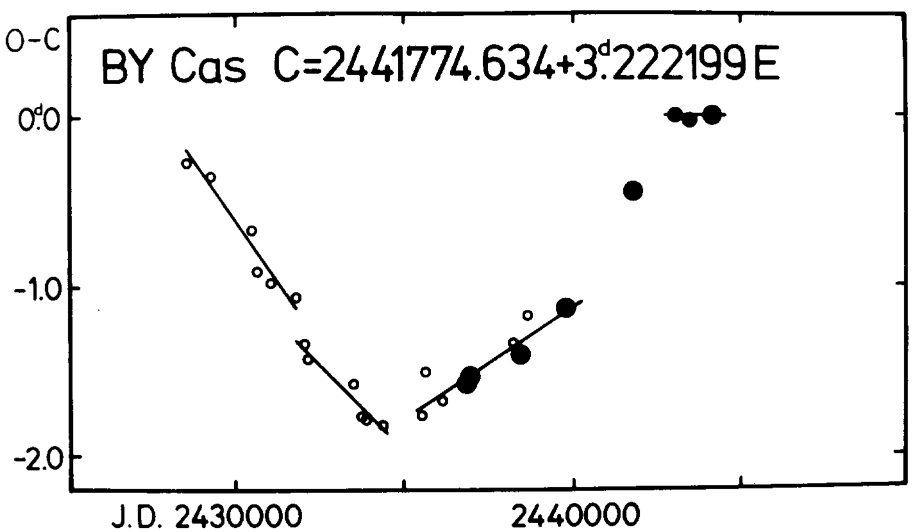

Figure 15. O-C diagram of BY Cas

(1990b) assumes a B5 photometric companion, thus supporting the earlier suspicion published by *Kurochkin* (1966) and *Madore* and *Fernie* (1980). The phase jump in the pulsation is a further evidence for duplicity.

DD Cassiopeiae

The normal light curve formed on the basis of the observations obtained by *Moffett* and *Barnes* (1984) made the re-discussion of the previous O-C diagram possible. According to the recent photoelectric observations (see Table 23 and Figure 16) a period change occurred between J.D. 2438000 and 2442500. The O-C residuals have been calculated with the ephemeris:

$$C = \underset{\pm.009}{2442780.426} + \underset{\pm.000060}{9^{d}.811656}\cdot E \qquad (18)$$

The O-C residuals based on earlier photographic observations are compatible with the phase jump interpretation, because DD Cas was pulsating with practically the same period between J.D. 2430000 and 2438000, the phase jump being about 0.2 day. The light-time effect

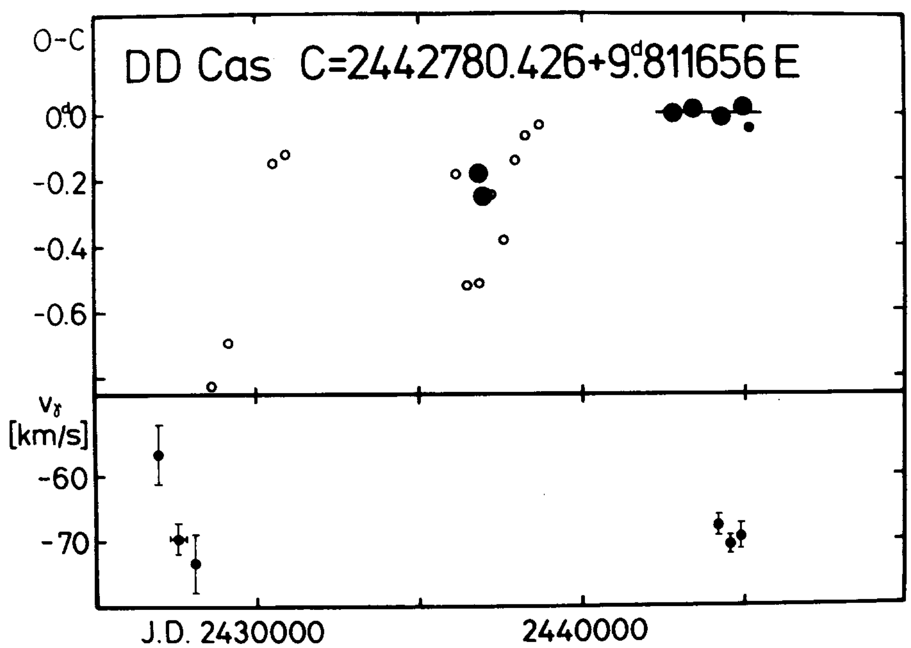

Figure 16. Upper panel: O-C diagram of DD Cas
Lower panel: γ-velocities for the same Cepheid

Table 23. O-C residuals for DD Cas

Norm.max. JD2400000+	E	O-C	W	Reference
17063.619	-2621	-0.457		Parenago (1940)
28601.761	-1445	-0.822		Parenago (1940)
29170.967	-1387	-0.692		Parenago (1940)
30584.392	-1243	-0.146		Solov'yov (1958)
30976.882	-1203	-0.122		Solov'yov (1958)
36137.753	-677	-0.182		Makarenko (1969)
36490.636	-641	-0.519		Makarenko (1969)
36804.942	-609	-0.185	3	Oosterhoff (1960)
36843.862	-605	-0.512		Makarenko (1969)
36932.426	-596	-0.253	3	Bahner et al. (1962)
37197.343	-569	-0.251		Makarenko (1969)
37579.865	-530	-0.383		Makarenko (1969)
37923.516	-495	-0.140		Makarenko (1969)
38296.432	-457	-0.067		Makarenko (1969)
38688.932	-417	-0.033		Makarenko (1969)
42780.422	0	-0.004	3	Szabados (1980)
43388.760*	62	0.011	3	Chekhanikhina (1982)
44252.160*	150	-0.014	3	Moffett & Barnes (1984)
44958.635*	222	0.021	3	Moffett & Barnes (1984)
45125.371*	239	-0.041	1	present paper

Table 24. γ-velocities of DD Cas

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
26983	15	-56.5	4.5	2	Joy (1937)
27565	178	-69.5	2.3	5	Joy (1937)
28097	1	-73.3	4.5	1	Joy (1937)
44184	57	-67.5	1.6	7	Barnes et al. (1988)
44508	49	-70.6	1.3	10	Barnes et al. (1988)
44877	76	-69.1	2.0	5	Barnes et al. (1988)

suggested in Paper II cannot be responsible for the shape of the O-C graph, since the amplitude of the wave would correspond to an enormously massive companion.

Duplicity of DD Cas suggested by *Madore* (1977) and *Madore* and *Fernie* (1980) has been checked by the radial velocity measurements, too. As Table 24 and the lower panel of Figure 16 shows, the variation in the γ-velocity is very probable, but further observations have to confirm the orbital motion.

DL Cassiopeiae

The new normal light curve based on the observations obtained by *Moffett* and *Barnes* (1984) defines the moment of light maxima more clearly than the previously used one. Owing to the new normal curve, a systematic correction of -0.192 day has been applied to the photoelectric O-C residuals published in Paper II. These corrected values, together with the more recent O-C residuals are listed in Table 25 and shown plotted in Figure 17. The new ephemeris for calculating the moments of maxima is as follows:

$$C = 2442780.172 + 8^{d}\!.000598 \cdot E \qquad (19)$$
$$\pm.011 \qquad \pm.000022$$

The pulsation period of DL Cas has remained constant for the last decades, although *Meyers* (1988) determined a continuously increasing period. This latter study was based on photographic observations and, in my opinion, *Meyers*' (1988) O-C diagram can be better represented with two linear sections and a phase jump in between. The phase jump might occur at about J.D. 2429000, therefore unnoticeable in the O-C diagrams both in Paper II and here, in Figure 17.

Table 25. O-C residuals for DL Cas

Norm.max. JD2400000+	E	O-C	W	Reference
36163.576	-827	-0.101	3	Arp et al. (1959)
36803.750	-747	0.025	3	Oosterhoff (1960)
37219.860	-695	0.104	2	Mitchell et al. (1964)
37947.796	-604	-0.015	2	Williams (1966)
38707.934	-509	0.066	2	Haug (1970)
42692.156*	-11	-0.009	3	Szabados (1980)
43468.311*	86	0.088	1	Szabados (1980)
44292.283*	189	-0.002	3	Moffett & Barnes (1984)
44532.191*	219	-0.112	2	Eggen (1983a)
44972.332*	274	-0.004	3	Moffett & Barnes (1984)
45684.408*	363	0.019	3	Berdnikov (1986)
46284.450*	438	0.016	3	Berdnikov (1987)

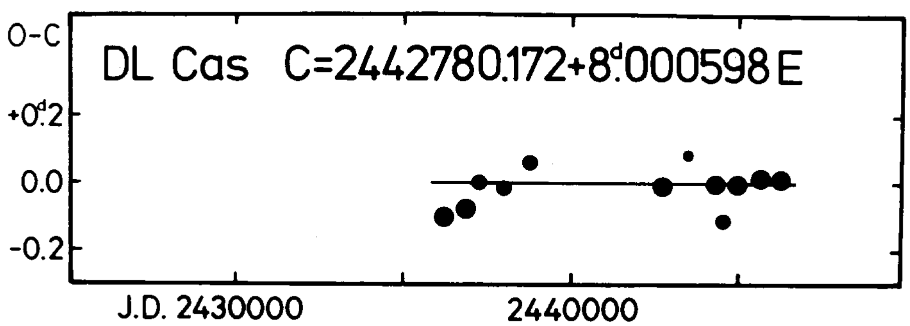

Figure 17. O-C diagram of DL Cas

The spectroscopic binary nature of DL Cas was discovered quite recently, independently by two groups (*Harris* et al., 1987; *Mermilliod* et al., 1987). The orbital period is rather short, at least among the Cepheid binaries: 688.0 days (*Harris* et al., 1987). The orbital radial velocity curve gives an approximate value for the amplitude of the light-time effect in the O-C diagram. The full amplitude of this wave is about 0.02 day, therefore it can hardly be pointed out from the available photometric data.

It is worth mentioning that DL Cas is one of the calibrating Cepheids for the period - luminosity relationship, because this Cepheid belongs to the open cluster NGC 129 (see *Walker*, 1987 and the references therein).

IX Cassiopeiae

Being a newly discovered spectroscopic binary (*Harris* and *Welch*, 1989), this Population II Cepheid would deserve more attention. The part of the O-C diagram based on photoelectric observations is shown in Figure 18 (see also Table 26). The frequent variations in the pulsation period are intrinsic to this star, and the straight line fit to the recent O-C residuals:

$$C = \underset{\pm .030}{2442780.264} + \underset{\pm .000104}{9\overset{d}{.}154549} \cdot E \qquad (20)$$

does not necessarily mean constancy of the period. When determining the O-C residuals, a new normal curve based on the photometric observations made by *Harris* and *Welch* (1989) was used. The earlier O-C residuals have also been altered according to the new normal curve.

The radial velocity measurements of IX Cas were published by *Harris* and *Wallerstein* (1984) and *Harris* and *Welch* (1989). Moreover, this latter paper also deals with the determination of the orbital parameters: the orbital period of IX Cas is 110.29 days.

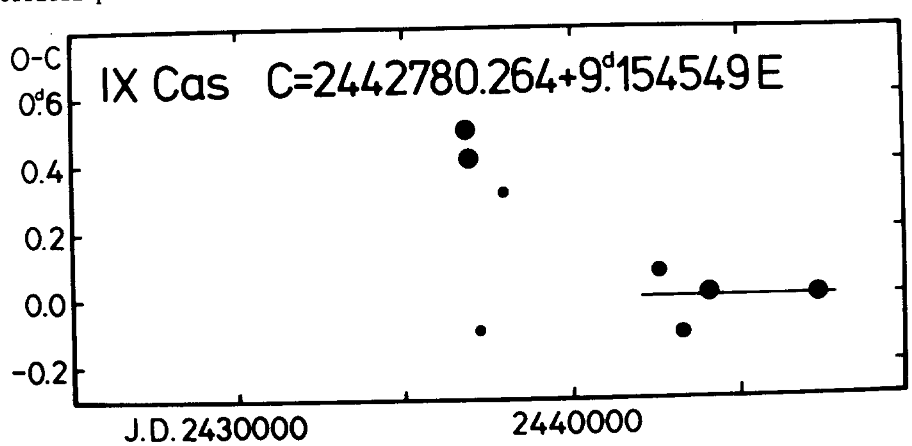

Figure 18. O-C diagram of IX Cas

Table 26. O-C residuals for IX Cas

Norm.max. JD2400000+	E	O-C	W	Reference
36802.848	-653	0.504	3	Oosterhoff (1960)
36903.457	-642	0.413	3	Bahner et al. (1962)
37205.051	-609	-0.093	1	Mitchell et al. (1964)
37974.445	-525	0.319	1	Williams (1966)
42560.633*	-24	0.078	2	Szabados (1980)
43247.037*	51	-0.109	2	Szabados (1980)
44034.452*	137	0.015	3	Harris & Welch (1989)
47348.390*	499	0.006	3	Harris & Welch (1989)

V636 Cassiopeiae

V636 Cas is one of the recently discovered Cepheid variables (*Burki* and *Benz*, 1982), therefore it does not have a long history of observations. The new photometric observations of this Cepheid listed in Table 108 are differential magnitudes with respect to BD+62°259. The O-C residuals in Table 27 and in Figure 19 (upper panel) have been calculated using the formula:

$$C = 2444519.260 + 8^{d}.375735 \cdot E \qquad (21)$$
$$\pm.009 \quad \pm.000039$$

The number of the existing radial velocity observational series is also small but it can be stated with certainty that the γ-velocity of V636 Cas is varying. In addition to the γ-velocity values listed in Table 28, there are two more series of observations with no information about the moment or epoch of the measurements. *Redman* (1930) published a single radial velocity value of -19 km/s, being more positive than any other velocity value published for this star. *Boulon* et al. (1958) gave -31 km/s as the average of seven measurements. This latter value is even more negative than the extreme γ-velocity obtained from *Samus*' (1990) radial velocity data. Note that the value published by *Boulon* et al. is probably close to the γ-velocity because of the short pulsation period and very low amplitude variation. However, the companion is not bright and blue enough to appear in the IUE spectrum of the Cepheid (*Arellano Ferro* and *Madore*, 1986).

Table 27. O-C residuals for V636 Cas

Norm.max. JD2400000+	E	O-C	W	Reference
41964.655*	-305	-0.006	3	Burki & Benz (1982)
44519.250*	0	-0.010	3	Burki & Benz (1982)
45231.237*	85	0.040	2	present paper
47794.140*	391	-0.032	1	present paper

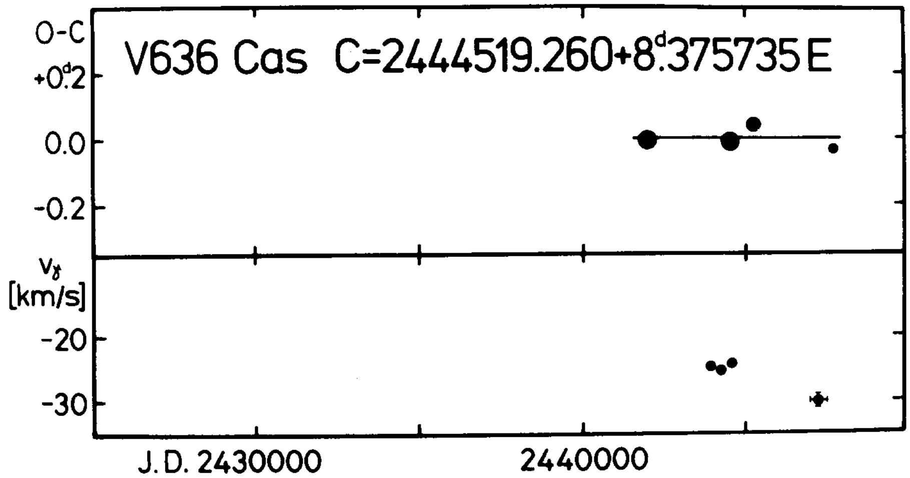

Figure 19. Upper panel: O-C diagram of V636 Cas
Lower panel: γ-velocities for the same Cepheid

Table 28. γ-velocities of V636 Cas

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
43855	42	-24.5	0.1	12	Burki & Benz (1982)
44201	26	-25.2	0.1	20	Burki & Benz (1982)
44558	57	-24.3	0.1	20	Burki & Benz (1982)
47282	266	-30.0	0.8	2	Samus (1990)

IR Cephei

The new photoelectric observations published here (see Table 108) confirm the value of the pulsation period determined in Paper I. This means that no new change has occurred in addition to that noted in Paper I (p. 43). The O-C residuals in Table 29 and in Figure 20 have been calculated using the equation:

$$C = \underset{\pm.005}{2441696.581} + \underset{\pm.000004}{2^{d}.114088} \cdot E \qquad (22)$$

Table 29. O-C residuals for IR Cep

Norm.max. JD2400000+	E	O-C	W	Reference
40965.096	-346	-0.011	3	Wachmann (1976)
41696.580	0	-0.001	3	Szabados (1977)
43045.394	638	0.025	2	Szabados (1977)
47413.066*	2704	-0.009	2	present paper

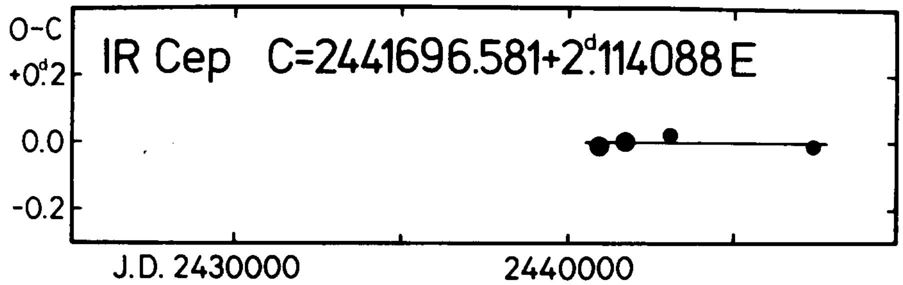

Figure 20. O-C diagram of IR Cep

There is only one radial velocity measurement series on IR Cep (*Samus*, 1990), giving -4.9 km/s for the γ-velocity. Although the membership of IR Cep in Cep OB2 association has been doubted on account of the age difference between the Cepheid and the association (*Kun* and *Szabados*, 1988), it should be noted that the γ-velocity of IR Cephei derived here is in a good agreement with the radial velocity of some bona fide members of Cep OB2. For example, the bright O-star, HD 206267, the most massive member of the IC 1396 + Tr 37 complex, forming one part of Cep OB2 (*Kun*, 1986), has an average radial velocity of -8 km/s (*Hoffleit* and *Jaschek*, 1982).

V351 Cephei

This relatively new Cepheid variable has been observed frequently since the discovery of its light variability (see Table 30 and Figure 21). The pulsation period is considered to be constant during the interval of the photoelectric observations, although *Erleksova* (1978) was able to point out two major period changes on the basis of archival photographic observations. The O-C residuals have been calculated here using a new

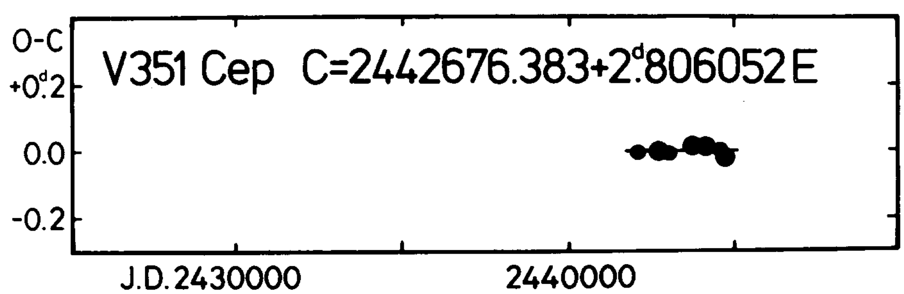

Figure 21. O-C diagram of V351 Cep

Table 30. O-C residuals for V351 Cep

Norm.max. JD2400000+	E	O-C	W	Reference
42030.985	-230	-0.006	2	Percy (1975)
42676.380	0	-0.003	3	Szabados (1977)
42993.459*	113	-0.008	2	Szabados (1977)
43700.608*	365	0.016	3	Henden (1979)
44071.005*	497	0.014	3	Diethelm & Tammann (1982)
44528.380*	660	0.003	2	Eggen (1985)
44696.720*	720	-0.020	3	Arellano Ferro (1984)

normal light curve based on *Arellano Ferro*'s (1984) observations and the following ephemeris:

$$C = 2442676.383 + 2^{d}.806052 \cdot E \qquad (23)$$
$$\pm.005 \qquad \pm.000010$$

Unfortunately no radial velocity measurements have been made on this Cepheid so far.

X Cygni

Although X Cygni belongs to the most frequently observed Cepheids, its O-C diagram has not yet been interpreted concordantly. The most comprehensive analysis has been performed by *Evans* (1984). In the present paper, however, I propose a new interpretation, viz. a phase jump in the O-C diagram, that has not been mentioned in the literature on X Cygni so

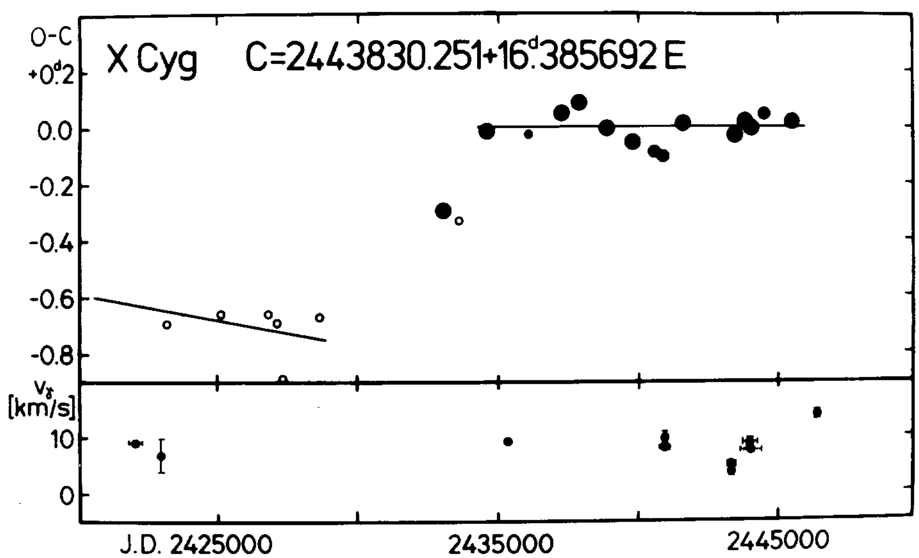

Figure 22. Upper panel: O-C diagram of X Cyg
Lower panel: γ-velocities for the same Cepheid

Table 31. O-C residuals for X Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
17055.372	-1634	-0.658	1	Wilkens (1906)
17694.729	-1595	-0.343	1	Jordan (1919)
23183.584	-1260	-0.695	1	Henroteau (1924)
25117.137	-1142	-0.654	1	Hellerich (1935)
26804.859	-1039	-0.658	1	Kox (1935)
27148.928	-1018	-0.689	1	Dziewulski (1948)
27328.968	-1007	-0.891	1	Liau (1935)
28672.816	-925	-0.670	1	Dziewulski (1948)
33031.783	-659	-0.297	3	Eggen (1951)
33605.249	-624	-0.330	1	Romano (1951)
34605.093	-563	-0.013	3	Szabados (1981)
36096.180	-472	-0.024	1	Svolopoulos (1960)
37226.867	-403	0.050	3	Mitchell et al. (1964)
37898.718	-362	0.088	3	Williams (1966)
38881.767	-302	-0.005	3	Wisniewski & Johnson (1968)
39782.931	-247	-0.054	3	Szabados (1981)
40585.795*	-198	-0.089	2	Feltz & McNamara (1980)
40929.879	-177	-0.105	2	Evans (1976)
41618.198	-135	0.015	3	Landis (1973)
43486.127*	-21	-0.024	3	Moffett & Barnes (1984)
43830.274	0	0.023	3	Szabados (1981)
44092.421*	16	-0.001	3	Moffett & Barnes (1984)
44534.885*	43	0.049	2	Eggen (1983b)
45534.385*	104	0.022	3	Berdnikov (1986)

Table 32. γ-velocities of X Cyg

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
22094	191	9.3	0.5	23	Duncan (1921)
22973	1	7.0	3.0	1	Harper (1934)
35332	21	9.5	0.2	17	Abt (1978)
40945	36	10.1	1.1	3	Schmidt (1974)
40952	169	8.2	0.3	5	Evans (1976)
43329	150	5.6	0.3	8	Beavers & Eitter (1986)
43393	49	4.2	1.1	15	Wilson et al. (1989)
44013	271	9.2	0.7	27	Barnes et al. (1987)
44055	382	7.9	0.5	18	Wallerstein (1983)
47473	1	13.9	0.7	1	Samus (1990)

far. The photoelectric O-C residuals supplemented with the early photographic ones are listed in Table 31. After J.D. 2434000 the photoelectric O-C residuals can be best represented by a straight line as follows:

$$C = 2443830.251 + 16\overset{d}{.}385692 \cdot E \qquad (24)$$
$$\pm.011 \qquad \pm.000041$$

As one can see in Figure 22 (the two residuals from the epoch earlier than J.D. 2420000 have not been plotted here), the O-C residuals before J.D. 2429000 define a slightly shorter, though constant period: P = 16.385356 ± 0.000176 days. According to this interpretation the phase jump with an amplitude of 0.8 day occurred between J.D. 2429000 and 2434000.

The γ-velocity values of X Cyg are listed in Table 32 and shown plotted in the lower panel of Figure 22. The variation in the γ-velocity seems to be larger than determined by *Evans* (1984) but its physical reality cannot be supported with definitive evidence for duplicity. The phase jump interpretation of the O-C diagram, however, implies the duplicity of X Cyg because such phenomena only occur in binary Cepheids.

SU Cygni

The phase jump reported in Paper I is confirmed here. Because the phase jump in the pulsation period of SU Cyg seems to be the best documented example for this phenomenon, the whole O-C diagram has been studied again (including the O-C diagram for the median brightness), only omitting the very uncertain visual observations before the jump and all visual data after the phase jump. The O-C residuals corresponding to the maximum light, listed in Table 33, have been calculated with the current ephemeris:

$$C_{max} = \underset{\pm .004}{2441778.977} + \underset{\pm .000004}{3\overset{d}{.}845512} \cdot E \qquad (25)$$

while those for the median brightness (see Table 34) have been computed as follows:

$$C_{med} = \underset{\pm .005}{2441778.616} + \underset{\pm .000010}{3\overset{d}{.}845500} \cdot E \qquad (26)$$

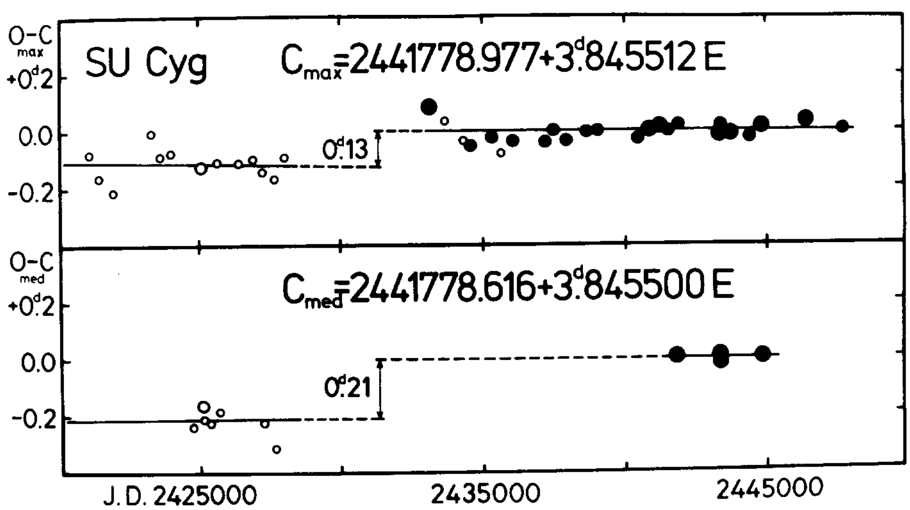

Figure 23. Upper panel: O-C diagram of SU Cyg (maximum brightness)
Lower panel: the same for the median brightness

Table 33. O-C residuals for SU Cyg (maximum brightness)

Norm.max. JD2400000+	E	O-C	W	Reference
14256.621	-7157	-0.027	1	Müller & Kempf (1897)
14491.161	-7096	-0.063	1	Zinner (1932)
14564.221	-7077	-0.067	1	Luizet (1899)
14591.118	-7070	-0.089	1	Wendell (1913)
17052.191	-6430	-0.144	2	Wilkens (1906)
17829.048	-6228	-0.080	1	Zeipel (1908)
17882.822	-6214	-0.143	1	van der Bilt (1925)
18175.117	-6138	-0.107	1	van der Bilt (1925)
18528.908	-6046	-0.103	1	van der Bilt (1925)
19271.104	-5853	-0.091	1	van der Bilt (1925)
21086.203	-5381	-0.074	1	Luyten (1922)
21443.751	-5288	-0.159	1	Luyten (1922)
21943.616	-5158	-0.210	1	Luyten (1922)
23320.515	-4800	-0.004	1	Hellerich (1925)
23662.684	-4711	-0.086	1	Hellerich (1925)
24028.020	-4616	-0.074	1	Hellerich (1925)
25100.868	-4337	-0.123	2	Hellerich (1935)
25696.940	-4182	-0.106	1	Zverev (1936)
26423.739	-3993	-0.109	1	Zverev (1936)
26923.669	-3863	-0.095	1	Florya & Kukarkina (1953)
27277.410	-3771	-0.141	1	Florya & Kukarkina (1953)
27677.322	-3667	-0.162	1	Krebs (1935)
28050.410	-3570	-0.089	1	Krebs (1936)
33126.659	-2250	0.084	3	Eggen (1951)
33680.364	-2106	0.035	1	Chuprina (1952)
34368.640	-1927	-0.035	1	Shteiman (1958)
34591.666	-1869	-0.049	2	Szabados (1977)
35356.949	-1670	-0.023	2	Walraven et al. (1958)
35645.305	-1595	-0.080	1	Shteiman (1958)
36099.119	-1477	-0.037	2	Svolopoulos (1960)
37172.013*	-1198	-0.041	2	Mitchell et al. (1964)
37498.922*	-1113	0.000	2	Mitchell et al. (1964)
37941.117	-998	-0.039	2	Williams (1966)
38664.105*	-810	-0.007	2	Wisniewski & Johnson (1968)
39029.433*	-715	-0.003	2	Wisniewski & Johnson (1968)
40452.240*	-345	-0.035	2	Feltz & McNamara (1980)
40867.591*	-237	0.000	3	Evans (1976)
41225.237*	-144	0.014	3	Feltz & McNamara (1980)
41540.552*	-62	-0.003	2	Szabados (1977)
41932.815*	40	0.018	2	Szabados (1977)
43344.084*	407	-0.016	3	Moffett & Barnes (1984)
43367.170*	413	-0.003	3	Fernie (1979b)
43378.722*	416	0.012	2	present paper
43786.320*	522	-0.014	3	Moffett & Barnes (1984)
44474.659*	701	-0.022	2	Berdnikov & Bogdanov (1987)
44866.935*	803	0.012	3	present paper
46412.858*	1205	0.039	3	present paper
47793.366*	1564	0.008	2	present paper

The difference between the periods as determined from the various parts of the O-C diagram (see Figure 23) is insignificant:

for the maximum brightness:

before the phase jump $P = 3.845502 \pm 0.000007$ days

after the phase jump $P = 3.845512 \pm 0.000004$ days ,

Table 34. O-C residuals for SU Cyg (median brightness)

Norm.max. JD2400000+	E	O-C	W	Reference
14590.722	-7070	-0.209	1	Wendell (1913)
17051.794	-6430	-0.257	2	Wilkens (1906)
17828.641	-6228	-0.201	1	Zeipel (1908)
24738.969	-4431	-0.237	1	Moncibowitz (1938)
25100.518	-4337	-0.165	2	Hellerich (1935)
25131.234	-4329	-0.213	1	Moncibowitz (1938)
25323.499	-4279	-0.223	1	Moncibowitz (1938)
25696.552	-4182	-0.183	1	Zverev (1936)
27277.010	-3771	-0.226	1	Florya & Kukarkina (1953)
27676.857	-3667	-0.311	1	Krebs (1935)
41778.619	0	0.003	3	Szabados (1977)
43343.719*	407	-0.016	3	Moffett & Barnes (1984)
43366.817*	413	0.010	3	Fernie (1979b)
44866.555*	803	0.003	3	present paper

for the median brightness:

before the phase jump P = 3.845502 ± 0.000011 days

after the phase jump P = 3.845500 ± 0.000010 days.

(Note that the O-C residuals before J.D. 2420000 listed in the respective tables do not appear in Figure 23.) The amount of the phase jump, however, clearly differs if the two O-C diagrams are compared. The phase jump is 0.13 day for the maximum brightness, while the value of 0.21 day can be determined from the moments of the median brightness. This difference is a manifestation of a noticeable change in the shape of the light curve, in the sense that the ascending branch has become steeper since the phase jump. The moment of the phase jump is not known yet: it might occur between J.D. 2428000 and 2433000.

SU Cyg belongs to the most thoroughly studied Cepheids from the spectroscopic point of view, as well. The spectroscopic orbit was recently published by *Evans* (1988), while the detailed study of the companion (a spectroscopic binary itself) was performed by *Evans* and *Bolton* (1990). The orbital period is too short (549.16 days) to cause noticeable light-time effect in the O-C diagram.

<u>SZ Cygni</u>

The new version of the O-C diagram (see Table 35 and Figure 24) is interpreted as one more case for a phase jump. The earlier suggestion on the light-time effect (see Paper III) is not tenable any more because the amplitude of the O-C wave would involve much too large orbital velocity variations that are not observed (see below). The O-C residuals have been calculated using the ephemeris:

$$C = 2443760.344 + 15\overset{d}{.}110228 \cdot E \qquad (27)$$
$$\pm.033 \qquad \pm.000078$$

This period describes well the behaviour of the pulsation after J.D. 2430000 , while before that epoch the period was 15.110536 ± 0.000161

Table 35. O-C residuals for SZ Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
14991.044	-1904	0.574	1	Williams (1900)
15973.353	-1839	0.718	1	Florya & Parenago (1933)
17499.452	-1738	0.684	1	Florya & Parenago (1933)
22667.246	-1396	0.780	1	Henroteau (1924)
30659.819	-867	0.043	1	Filin (1951)
31702.567	-798	0.185	1	Filin (1951)
32201.239	-765	0.219	1	Kulikov (1957)
32820.760	-724	0.221	1	Filin (1951)
34588.194	-607	-0.241	1	Kulikov (1957)
35389.154	-554	-0.124	1	Kulikov (1957)
36779.369	-462	-0.050	3	Oosterhoff (1960)
36794.540	-461	0.011	3	Weaver et al. (1960)
37217.632	-433	0.017	2	Mitchell et al. (1964)
37942.574	-385	-0.332	1	Girnyak (1971)
38229.979	-366	-0.022	3	Kwee & Braun (1967)
39302.479	-295	-0.348	1	Girnyak (1971)
43760.486	0	0.142	3	Szabados (1981)
44349.673*	39	0.030	3	Moffett & Barnes (1984)
44999.388*	82	0.005	3	Moffett & Barnes (1984)
45603.789*	122	-0.003	3	Berdnikov (1986)

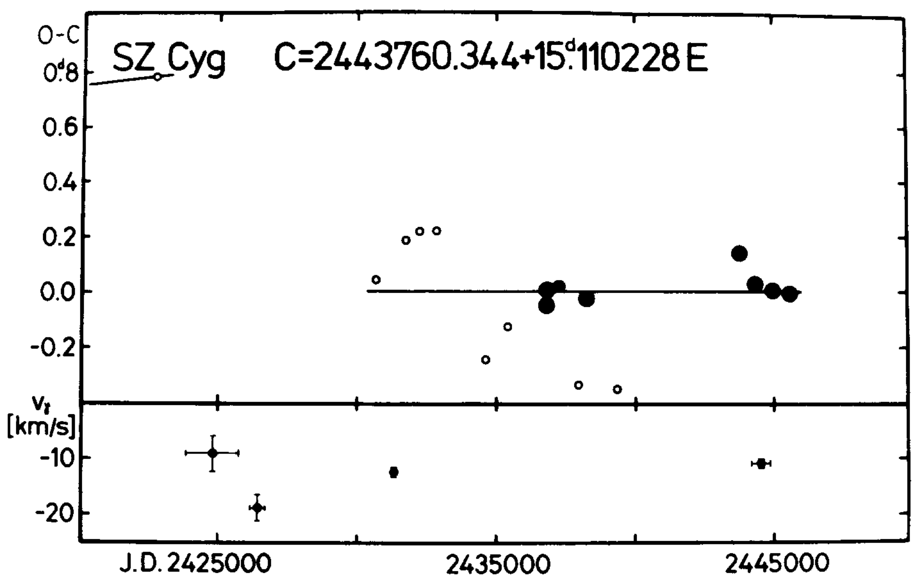

Figure 24. Upper panel: O-C diagram of SZ Cyg
Lower panel: γ-velocities for the same Cepheid

Table 36. γ-velocities of SZ Cyg

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
24819	962	-8.9	3.2	3	Joy (1937)
26435	231	-18.7	2.3	5	Joy (1937)
31304	7	-12.2	0.8	17	Struve (1945)
44529	309	-10.7	0.9	21	Barnes et al. (1988)

days. The phase jump was as large as 0.8 day (or about 0.05 pulsation period). The visual observations also support the occurrence of a phase jump at about J.D. 2430000. Nevertheless, these low quality observations have not been taken into account in the line fitting procedure.

The analysis of the available radial velocity data leads to the conclusion that the γ-velocity of SZ Cyg is variable (see Table 36) but further spectroscopic observations are desirable in order to point out definitely the effect of the hypothetical B4 photometric companion (*Madore*, 1977).

TX Cygni

The recent photoelectric observations clearly show the major period change suspected in Paper III. Both the recent value of the pulsation period and the moment of the sudden increase can be determined from the available data. The O-C residuals listed in Table 37 (see also Figure 25) can be represented with the elements:

$$C = 2443795.007 + 14^{d}.711635 \cdot E \qquad (28)$$
$$\pm .019 \qquad \pm .000272$$

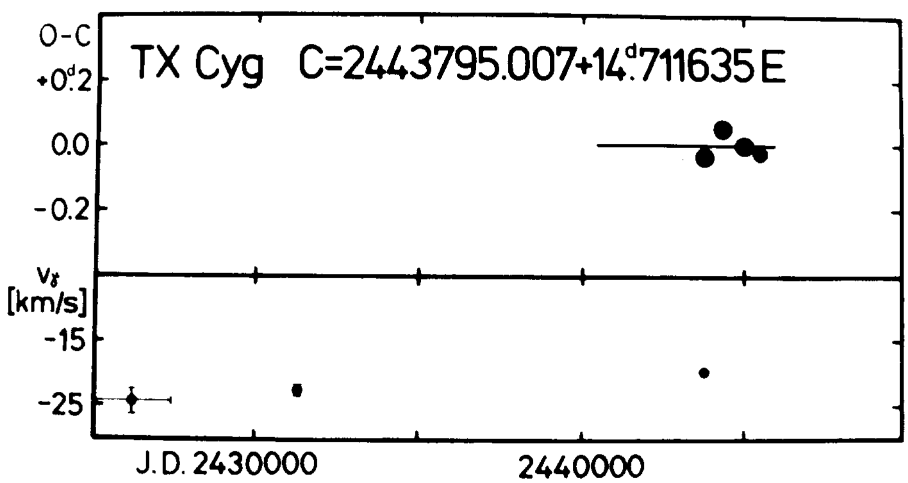

Figure 25. Upper panel: O-C diagram of TX Cyg
Lower panel: γ-velocities for the same Cepheid

Table 37. O-C residuals for TX Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
43794.971	0	-0.036	3	Szabados (1981)
44339.391*	37	0.054	3	Moffett & Barnes (1984)
45001.361*	82	0.000	3	Moffett & Barnes (1984)
45545.668*	119	-0.024	2	Berdnikov (1986)

Table 38. γ-velocities of TX Cyg

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
26188	1256	-24.4	1.8	7	Joy (1937)
31306	6	-22.5	0.8	14	Struve (1945)
43741	1	-19.6	0.3	1	Harris et al. (1979)

Combining the above elements with those published in Paper III, the change in the period occurred at about J.D. 2440500. Since the period valid previously was 14.708157 days, the difference (0.024 per cent) is unusually large for a classical Cepheid. It is interesting to note that *Kovács* et al. (1990) determined a value of 14.1369 days for the period on the basis of the available radial velocity data. None of the recent photoelectric observational series, however, supports a period as short as this.

The γ-velocity of TX Cyg may be variable (see Table 38) but further observations are necessary to confirm this suspicion.

VZ Cygni

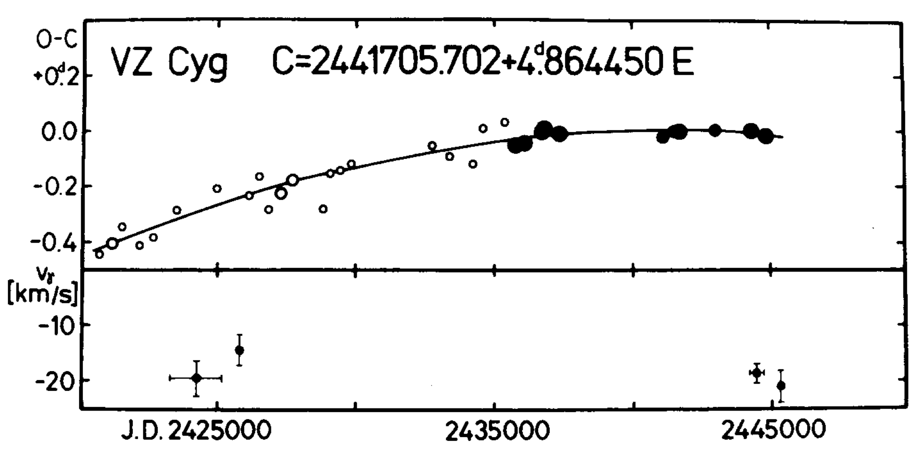

Figure 26. Upper panel: O-C diagram of VZ Cyg
Lower panel: γ-velocities for the same Cepheid

The plot of O-C residuals supplemented with the data derived from the recently published photoelectric observations (see Table 39 and Figure 26) can best be represented with a parabola, indicating a continuous period decrease. The O-C residuals have been calculated as follows:

$$C = \underset{\pm.007}{2441705.702} + \underset{\pm.000008}{4^{d}.864450}\cdot E \qquad (29)$$

The value of the pulsation period can be calculated using the formula:

$$P = \underset{\pm.000008}{4^{d}.864450} - \underset{\pm.44}{4^{d}.55}\cdot 10^{-8}\cdot E \qquad (30)$$

Table 39. O-C residuals for VZ Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
20627.598	-4333	-0.442	1	Doberck (1920)
21114.079	-4233	-0.406	2	Jordan (1929)
21498.432	-4154	-0.345	1	Doberck (1920)
22179.388	-4014	-0.412	1	Doberck (1920)
22656.134	-3916	-0.382	1	Jordan (1929)
23507.509	-3741	-0.286	1	Nielsen (1954)
24996.109	-3435	-0.207	1	Wachmann (1935)
26163.550	-3195	-0.234	1	Wachmann (1935)
26513.862	-3123	-0.163	1	Wachmann (1935)
26898.035	-3044	-0.281	1	Wachmann (1935)
27321.296	-2957	-0.227	2	Gesundheit (1938)
27739.687	-2871	-0.179	2	Gesundheit (1938)
28848.680	-2643	-0.281	1	Abidov (1963)
29096.894	-2592	-0.154	1	Abidov (1963)
29452.007	-2519	-0.145	1	Abidov (1963)
29812.004	-2445	-0.118	1	Abidov (1963)
32755.060	-1840	-0.054	1	Novikov (1951)
33387.402	-1710	-0.091	1	Abidov (1963)
34219.193	-1539	-0.120	1	Abidov (1963)
34589.022	-1463	0.010	1	Abidov (1963)
35362.501	-1304	0.042	1	Vyskupaitis (1961)
35732.104*	-1228	-0.053	3	Bahner & Mavridis (1977)
36106.672*	-1151	-0.048	3	Bahner & Mavridis (1977)
36773.146	-1014	-0.004	3	Weaver et al. (1960)
36802.348	-1008	0.012	3	Oosterhoff (1960)
37352.009	-895	-0.010	3	Mitchell et al. (1964)
41160.858*	-112	-0.026	2	Feltz & McNamara (1980)
41525.716*	-37	-0.001	2	Feltz & McNamara (1980)
41705.698	0	-0.004	3	Szabados (1977)
43062.886	279	0.002	2	Szabados (1977)
44366.557*	547	0.001	3	Moffett & Barnes (1984)
44911.356*	659	-0.019	3	Moffett & Barnes (1984)

Table 40. γ-velocities of VZ Cyg

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
24235	949	-19.4	3.2	3	Joy (1937)
25819	37	-14.4	2.6	4	Joy (1937)
44489	241	-18.5	1.8	6	Barnes et al. (1988)
45342	1	-21.0	2.8	3	Barnes et al. (1988)

Variations in the γ-velocity of VZ Cyg cannot be excluded (see Table 40) but further radial velocity measurements are necessary to make a firm statement on this matter.

BZ Cygni

The pulsation period keeps on being constant, but its value is slightly modified with respect to that published in Paper III. The O-C residuals listed in Table 41 and plotted in Figure 27 can be approximated with a line:

$$C = 2443774.199 + 10\overset{d}{.}142222 \cdot E \qquad (31)$$
$$\pm.032 \qquad \pm.000065$$

As to the radial velocity measurements of BZ Cyg, a difference as large as 20 km/s can be seen between the γ-velocity of the available radial velocity measurement series (see Table 42 and the lower panel of

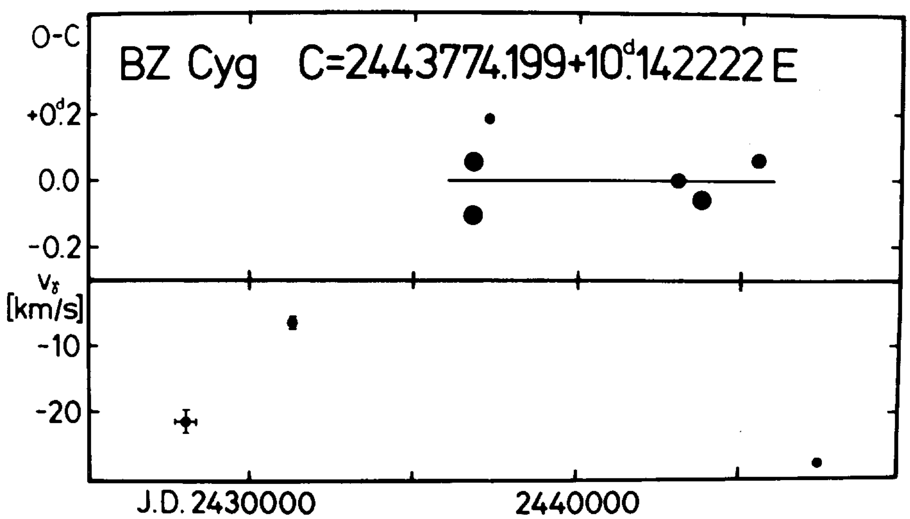

Figure 27. Upper panel: O-C diagram of BZ Cyg
Lower panel: γ-velocities for the same Cepheid

Table 41. O-C residuals for BZ Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
36786.104	-689	-0.104	3	Weaver et al. (1960)
36796.408	-688	0.058	3	Oosterhoff (1960)
37273.217	-641	0.182	1	Mitchell et al. (1964)
43013.533*	-75	0.001	2	Chekhanikhina (1982)
43774.144	0	-0.055	3	Szabados (1981)
45539.006*	174	0.060	2	Berdnikov (1986)

Table 42. γ-velocities of BZ Cyg

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
28000	312	-21.4	1.8	7	Joy (1937)
31306	6	-6.4	0.8	14	Struve (1945)
47473	1	-27.0	0.6	1	Samus (1990)

Figure 27). Since BZ Cyg is a new spectroscopic binary beyond doubt, this Cepheid deserves immediate attention of the spectroscopists.

DT Cygni

This bright Cepheid was frequently observed photoelectrically during the last two decades, therefore the most recent part of the O-C diagram (see Table 43 and Figure 28) is of exceptionally good quality. Due to the new normal light curve based on the observations obtained by *Moffett* and *Barnes* (1984), a correction of -0.080 day has been applied to the previously determined O-C residuals (taken from Paper I). The section of the O-C diagram between J.D. 2440000 and 2447000 can be approximated with the line:

$$C = \underset{\pm .005}{2441737.702} + \underset{\pm .000005}{2^{d}.499086} \cdot E \quad (32)$$

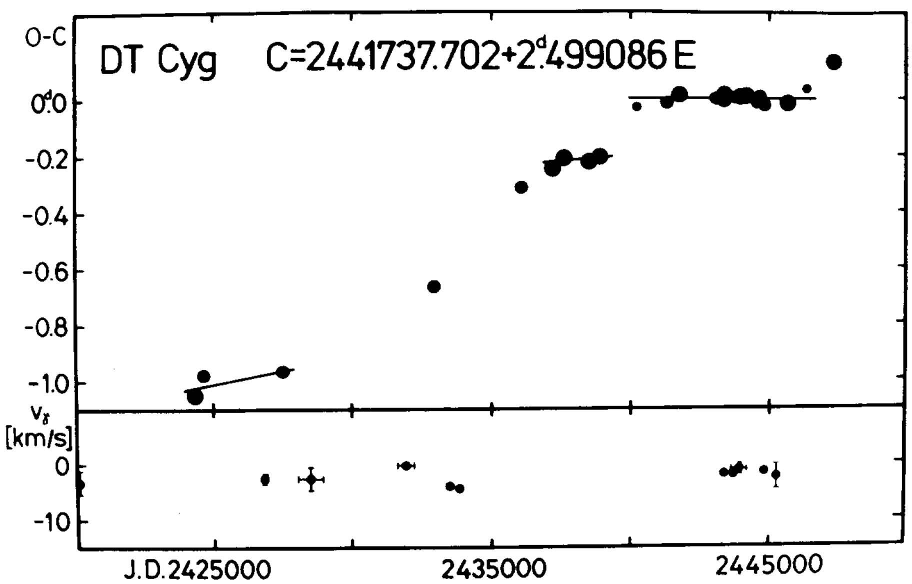

Figure 28. Upper panel: O-C diagram of DT Cyg
Lower panel: γ-velocities for the same Cepheid

Table 43. O-C residuals for DT Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
24375.503	-6947	-1.049	3	Huffer (1928b)
24695.458	-6819	-0.977	2	Huffer (1928b)
27546.928	-5678	-0.964	2	Schneller (1936)
32975.235	-3506	-0.667	2	Eggen (1951)
36099.447	-2256	-0.317	2	Svolopoulos (1960)
37176.620	-1825	-0.250	3	Mitchell et al. (1964)
37579.011	-1664	-0.212	3	Johansen (1971)
38496.161	-1297	-0.226	3	Johansen (1971)
38871.042	-1147	-0.208	3	Wisniewski & Johnson (1968)
40185.742*	-621	-0.028	1	Feltz & McNamara (1980)
41297.846*	-176	-0.017	2	Feltz & McNamara (1980)
41737.718	0	0.016	3	Szabados (1977)
43044.725	523	0.001	2	Szabados (1977)
43379.606*	657	0.004	3	Moffett & Barnes (1984)
43399.611*	665	0.017	3	present paper
43754.468*	807	0.004	2	present paper
43871.925*	854	0.004	3	Moffett & Barnes (1984)
44149.328*	965	0.008	3	present paper
44534.159*	1119	-0.020	1	Eggen (1985)
44684.129*	1179	0.005	2	present paper
44869.031*	1253	-0.026	2	Arellano Ferro (1984)
45646.256*	1564	-0.017	3	Guetter & Hewitt (1984)
46341.053*	1842	0.035	1	"Carlsberg" (1989)
47343.284*	2243	0.132	3	Rhode (1990b)

Two other linear sections are also marked in the O-C graph in Figure 28, viz.:

between J.D. 2424000 and 2428000 P = 2.499137 ± 0.000022 days, and

between J.D. 2437000 and 2439000 P = 2.499101 ± 0.000023 days.

Between the intervals of pulsating with the periods listed above, phase jumps caused some shifts in the O-C diagram. Since the visual and the photographic observations have not been taken into account in this study, only the last phase jump is seen well, the amount of the jump being about 0.2 day. The suggestion put forward in Paper I (p. 49) concerning the regular phase shift (about 0.22 day or its multiple) cannot be confirmed here, its verification should wait until the next occurrence of the phase jump. A new period change event can be suspected at the most recent O-C residual in Figure 28. Further observations will clarify whether this change will turn out to be a new phase shift. In any case, the prediction for the moment of the light maximum near J.D. 2450000 in Table 110 may not be accurate.

The phase jump is a characteristic feature of the binary Cepheids. There are a few pieces of evidence concerning the duplicity of DT Cygni. Most of them are summarized by *Leonard* and *Turner* (1986), concluding that the existence of an early type companion is uncertain. However, according

Table 44. γ-velocities of DT Cyg

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
20080	29	-3.3	2.1	3	Sanford (1930)
26865	93	-2.5	0.9	12	Sanford (1930)
28519	446	-2.5	2.1	3	Young (1939)
31905	284	0.0	0.4	7	Sanford (1951)
33486	25	-3.8	0.3	11	Grassberger & Herbig (1952)
33843	24	-4.1	0.4	9	Grassberger & Herbig (1952)
43392	43	-1.7	0.6	46	Wilson et al. (1989)
43711	206	-1.7	0.2	15	Beavers & Eitter (1986)
43946	218	-0.9	0.8	23	Barnes et al. (1987)
44832	2	-1.3	0.7	6	Arellano Ferro (1984)
45270	1	-2.4	2.3	1	present paper

to a very recent paper by *Usenko* (1990b), DT Cyg has an A2-A3 type photometric companion. An early evidence for the changes in the γ-velocity was published by *Lloyd Evans* (1968). His conclusion is confirmed here (see Table 44 and Figure 28). The extreme values of the γ-velocity differ from each other by more than four km/s, and this difference exceeds the observational uncertainty. New high quality radial velocity measurements will hopefully solve the problem of duplicity of DT Cygni because the amplitude of the expected γ-velocity changes is rather low.

MW Cygni

The two recent O-C residuals (see Table 45 and Figure 29) indicate that the pulsation period is slightly longer than determined in Paper II. The O-C graph can be approximated with a line as follows:

$$C = 2442923.907 + 5\overset{d}{.}954666 \cdot E \qquad (33)$$
$$\pm.007 \quad \pm.000007$$

There is an obvious variation in the γ-velocity of MW Cyg. According to the data listed in Table 46, *Moffett* and *Barnes* (1987) underestimated

Table 45. O-C residuals for MW Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
30532.222	-2081	-0.025	1	Solov'yov (1946)
31038.435	-1996	0.041	1	Solov'yov (1946)
33884.781	-1518	0.057	1	Shteiman (1958)
34539.757	-1408	0.020	1	Shteiman (1958)
35677.074	-1217	-0.004	1	Shteiman (1958)
36802.499	-1028	-0.011	3	Oosterhoff (1960)
36820.339	-1025	-0.035	3	Weaver et al. (1960)
42923.911	0	0.004	3	Szabados (1980)
44364.932*	242	-0.004	3	Moffett & Barnes (1984)
44877.050*	328	0.013	3	Moffett & Barnes (1984)

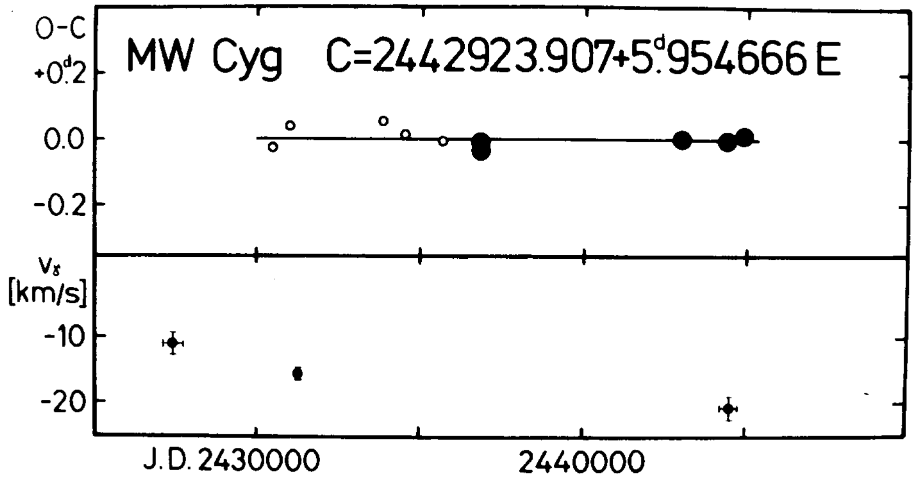

Figure 29. Upper panel: O-C diagram of MW Cyg
Lower panel: γ-velocities for the same Cepheid

Table 46. γ-velocities of MW Cyg

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
27487	311	-11.0	1.7	8	Joy (1937)
31304	7	-15.5	0.8	15	Struve (1945)
44514	282	-20.6	1.8	6	Barnes et al. (1988)

the difference between the γ-velocities determined from *Joy*'s (1937) and their own data. While *Moffett* and *Barnes* derived -2.8 km/s, now the difference is -9.4 km/s. The deviating result is probably caused by the different methods in determining the γ-velocities. In the present study the normal radial velocity curve has been based on *Struve*'s (1945) measurements, and the other radial velocity measurements have been fitted to this normal curve. MW Cyg is therefore a new spectroscopic binary Cepheid candidate.

V386 Cygni

The O-C diagram (see Table 47 and Figure 30) confirms the earlier conclusion (in Paper II) about the constancy of the pulsation period of V386 Cygni. The new, slightly modified ephemeris for the moments of maxima is as follows:

$$C = 2442777.141 + 5^{d}.257635 \cdot E \qquad (34)$$
$$\pm.003 \qquad \pm.000004$$

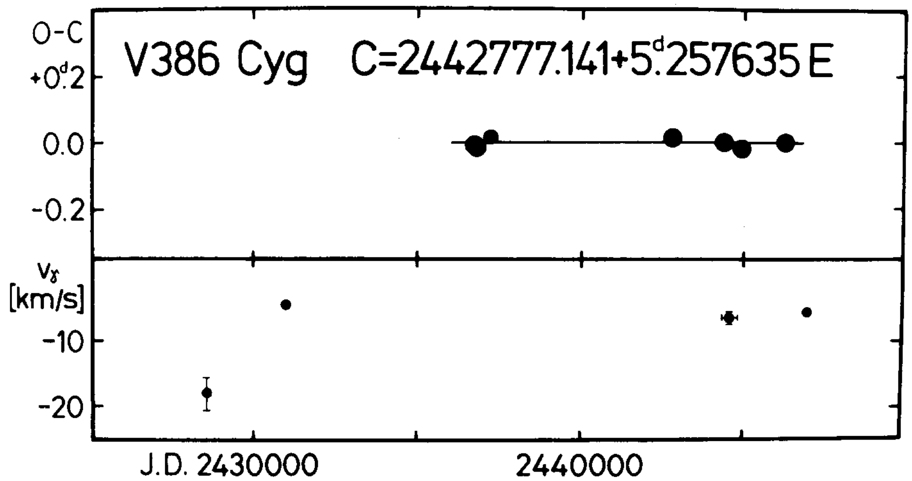

Figure 30. Upper panel: O-C diagram of V386 Cyg
Lower panel: γ-velocities for the same Cepheid

Table 47. O-C residuals for V386 Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
36762.403	-1144	-0.004	3	Weaver et al. (1960)
36804.456	-1136	-0.012	3	Oosterhoff (1960)
37251.385	-1051	0.018	2	Mitchell et al. (1964)
42777.160	0	0.019	3	Szabados (1980)
44359.691*	301	0.002	3	Moffett & Barnes (1984)
44927.497*	409	-0.017	3	Moffett & Barnes (1984)
46289.243*	668	0.002	3	Berdnikov (1987)

Table 48. γ-velocities of V386 Cyg

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
28571	90	-17.9	2.6	4	Joy (1937)
31006	7	-4.2	0.8	16	Struve (1945)
44581	257	-6.5	0.9	19	Barnes et al. (1988)
47010	15	-5.6	0.3	8	Metzger et al. (1990)

The study of the γ-velocity gives a new piece of evidence for the binary nature of V386 Cyg. It is noteworthy that there is a difference as large as 13.7 km/s between the γ-velocities on a time-base of about 2500 days (see Table 48 and Figure 30, lower panel). Although *Moffett* and *Barnes* (1987) gave a smaller value for the discrepancy between the individual γ-velocity values, the other pieces of evidence (*Kurochkin*, 1966; *Madore*, 1977; *Madore* and *Fernie*, 1980) make the spectroscopic binary interpretation very reasonable.

V532 Cygni

The new photoelectric observations confirm the occurrence of the phase jump first suggested in Paper I. Because a new normal light curve was used here, the previously determined normal maxima have been corrected by 0.102 day accordingly (see Table 49 and Figure 31). The O-C residuals have been calculated with the elements:

$$C = 2441706.686 + 3\overset{d}{.}283494 \cdot E \qquad (35)$$
$$\pm.007 \quad \pm.000007$$

Table 49. O-C residuals for V532 Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
33889.249	-2381	0.562	1	Shteiman (1958)
34434.386	-2215	0.639	1	Shteiman (1958)
35642.593	-1847	0.520	1	Shteiman (1958)
36817.805	-1489	0.242	3	Oosterhoff (1960)
37684.512*	-1225	0.106	1	Girnyak (1971)
38229.434	-1059	-0.032	3	Kwee & Braun (1967)
38439.599*	-995	-0.010	1	Girnyak (1971)
39024.197*	-817	0.126	1	Girnyak (1971)
39411.594*	-699	0.070	1	Girnyak (1971)
41338.896*	-112	-0.039	2	Feltz & McNamara (1980)
41706.661	0	-0.025	3	Szabados (1977)
43026.673	402	0.022	2	Szabados (1977)
43420.683*	522	0.013	3	present paper
44149.609*	744	0.003	2	present paper
44438.557*	832	0.004	3	Moffett & Barnes (1984)
44911.371*	976	-0.005	3	Moffett & Barnes (1984)
45009.840*	1006	-0.041	2	present paper
46490.739*	1457	0.002	2	present paper
47534.898*	1775	0.010	3	present paper

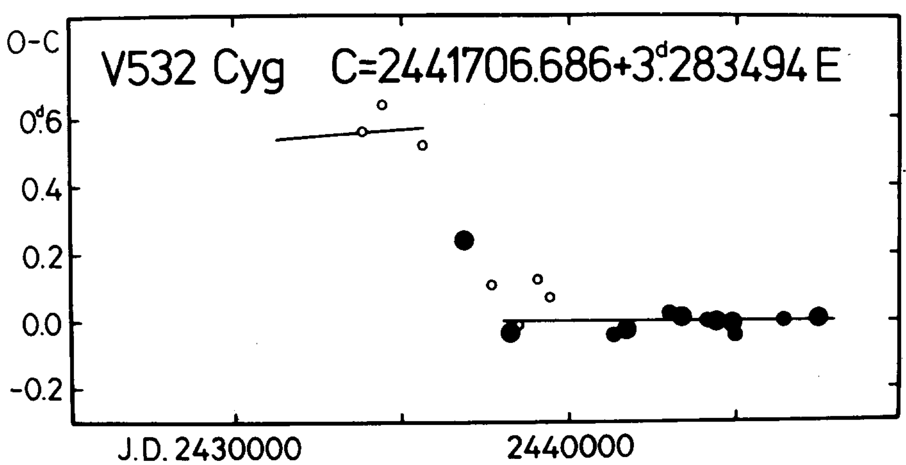

Figure 31. O-C diagram of V532 Cyg

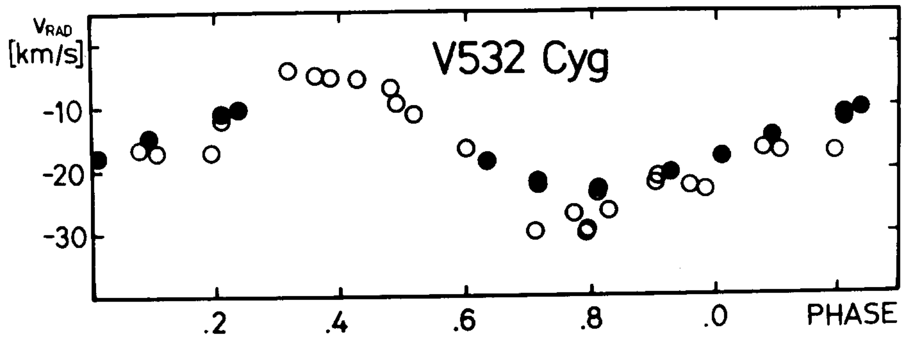

Figure 32. Radial velocity observations of V532 Cygni folded with the 3.283494 day pulsation period. Zero phase is chosen arbitrarily at J.D. 2440000. Open circles: *Barnes* et al.'s (1988) data, filled circles: *Metzger* et al.'s (1990) observations

This formula can be used for predicting the maxima after J.D. 2438000. Before that epoch a phase shift occurred: between J.D. 2431200 and 2435700 the pulsation period was 3.283514 ± 0.000056 days. This latter period was determined on the basis of the three O-C residuals listed in Table 49 supplemented with four other, less reliable O-C residuals taken from Paper I. These low quality residuals have not been listed nor plotted here. The phase difference, that can be seen between J.D. 2435700 and 2438000 is about 0.58 day (= 0.18 pulsation period).

Because the phase jump is a characteristic feature of the binary Cepheids, one expects that V532 Cygni also belongs to a binary system. In addition to the previous photometric evidence for a B8 companion (*Madore*, 1977), in a more recent paper *Usenko* (1990b) also assumes a B7 – B8 photometric companion. The available radial velocity measurements are not enough for the numerical determination of the γ-velocity itself, but the composite phase diagram of the two available radial velocity series indicates that a shift in the γ-velocity might occur between the epochs of observation of the respective series. In Figure 32 open circles denote the data obtained by *Barnes* et al. (1988), while *Metzger* et al.'s (1990) velocity measurements are plotted as filled circles. Zero phase is arbitrarily chosen at J.D. 2440000, and the data are folded with the period given in Eq.(35). It is very unfortunate that *Metzger* et al. could not cover the phases of least negative velocities, because the systematic difference between the most negative values of the two radial velocity series is clearly seen. Further photometry and spectroscopy of V532 Cygni is extremely important.

V924 Cygni

This very low amplitude Cepheid continues to be a rather neglected variable. The O-C residuals based on the photoelectric observations published in the literature are listed in Table 50. These residuals have been calculated using the elements:

$$C = 2443065.993 + 5\overset{d}{.}571305 \cdot E \qquad (36)$$
$$\pm.017 \quad \pm.000044$$

In addition to the photoelectric O-C residuals, and the line fitted to these residuals, Figure 33 also shows another section of line corresponding to the O-C residuals from earlier epochs. Those rather inaccurate photographic O-C residuals are listed in Paper II, where the deviating part was explained as a systematic difference caused by the fact that the two sections had been obtained by different methods (because the early photographic observations have been unpublished, and the originally published normal maxima were used in Paper II). There is, however, another possibility, viz. the phase jump interpretation of the O-C diagram. The former pulsation period was 5.571106 ± 0.000029 days.

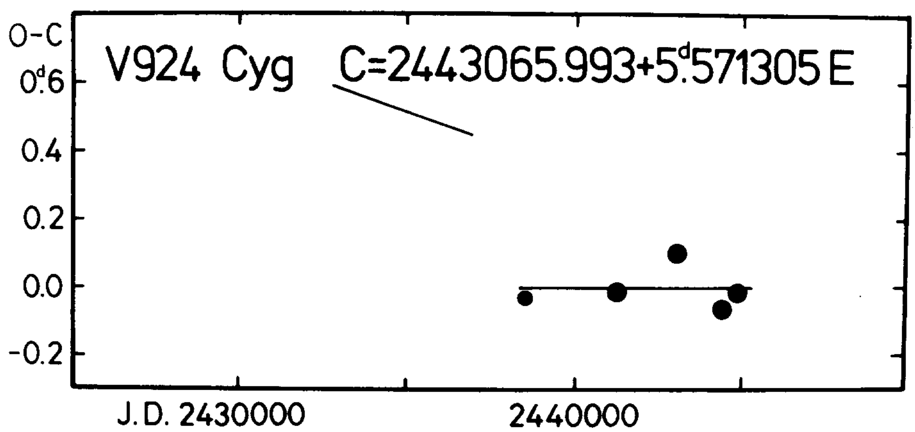

Figure 33. O-C diagram of V924 Cyg

Table 50. O-C residuals for V924 Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
38558.778	-809	-0.029	2	Eggen (1969)
41260.881	-324	-0.009	3	Wachmann (1976)
43066.098	0	0.105	3	Szabados (1980)
44391.902*	238	-0.062	3	Moffett & Barnes (1984)
44893.368*	328	-0.013	3	Moffett & Barnes (1984)

Again, the phase jump implies the existence of a companion. As to duplicity of V924 Cygni, the only evidence is the assumption of a B8 - B9 photometric companion by *Usenko* (1990b). It is worth mentioning, however, that V924 Cyg is one of the lowest amplitude Cepheids, and the extremely low amplitude light variability can well be explained with the photometric effect caused by the extra (and constant) light of a secondary star. Unfortunately, no radial velocity measurements of this interesting Cepheid have been performed yet.

V1334 Cygni

Arellano Ferro's (1984) photoelectric light curve served as the new normal curve for determining the moments of the normal maxima. The O-C residuals listed in Table 51 and plotted in Figure 34 have been calculated with the elements:

$$C = 2441760.896 + 3\overset{d}{.}332804 \cdot E \qquad (37)$$
$$\pm.018 \qquad \pm.000024$$

V1334 Cygni has long been known as a visual binary (ADS 14859). Now there is growing evidence, including this paper, that the Cepheid component of the visual pair is itself a spectroscopic binary. As to the visual binary, *Abt* and *Levy* (1970) determined an orbital period of about 30 years from position angle measurements, while *Henriksson* (1982) derived an 80 year orbital period in the same manner. The γ-velocity data of V1334 Cyg listed in Table 52, shown plotted in the lower panel of Figure

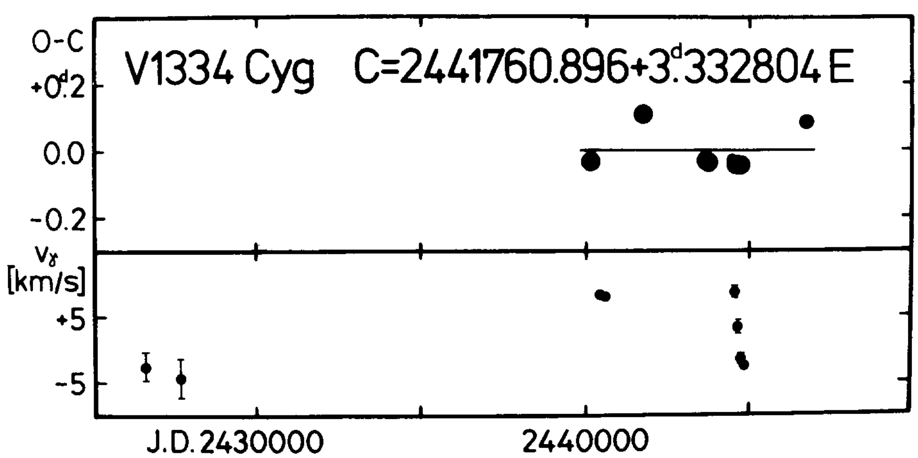

Figure 34. Upper panel: O-C diagram of V1334 Cyg
Lower panel: γ-velocities for the same Cepheid

Table 51. O-C residuals for V1334 Cyg

Norm.max. JD2400000+	E	O–C	W	Reference
40117.791	-493	-0.033	3	Millis (1969)
41761.010	0	0.114	3	Szabados (1977)
43657.233*	569	-0.028	3	Henden (1979)
43720.554*	588	-0.031	3	Percy et al. (1979)
44480.439*	816	-0.025	1	Parsons & Montemayor (1982)
44530.424*	831	-0.032	3	Bartolini et al. (1981)
44743.717*	895	-0.039	3	Arellano Ferro (1984)
46726.861*	1490	0.087	2	Arellano Ferro et al. (1987)

Table 52. γ-velocities of V1334 Cyg

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
26580	5	-2.4	2.1	3	Harper (1934)
27666	7	-4.2	3.0	2	Harper (1937)
40449	35	8.4	0.2	10	Abt & Levy (1970)
40551	23	8.3	0.2	10	Abt & Levy (1970)
44536	23	8.7	0.8	5	Arellano Ferro (1984)
44672	108	3.5	1.0	2	Parsons (1983)
44747	17	-1.5	0.8	5	Arellano Ferro (1984)
44831	6	-2.5	0.5	9	Arellano Ferro (1984)

34 clearly demonstrate that the γ-velocity varies on a much shorter time-scale. This variation was already reported by *Abt* and *Levy* (1970) and *Henriksson* (1982), but now an upper limit can be deduced for the spectroscopic orbital period. A formal period search routine applied to the data set resulted in 1240 days as the most reliable value of the orbital period, but a number of other values between 500 and 1150 days would also give a resonable preliminary orbit. The 4.5 year long orbital period determined by *Henriksson* seems to be too long but the orbital velocity amplitude derived by him (23 km/s) is confirmed here, based on the data listed in Table 52, and one more value of the γ-velocity, not reported in that table, because *Shajn* and *Albitzky* (1932) published -15.2 km/s as the average radial velocity of V1334 Cyg without reporting the epoch of the observation. The close companion to V1334 Cyg is an early type star: *Henriksson* derived a spectral type of B8III from the ultraviolet spectrum, while *Usenko* (1990b) assumes a B4 photometric companion. In the latest edition of the catalog of interferometric measurements of binary stars *McAlister* and *Hartkopf* (1988) reported that *Yu. Balega* had been able to separate the two components of the close pair at an angular distance of 0.035 arcsecond (epoch 1986.66).

The shorter orbital period is expected to cause a light-time effect that cannot be pointed out in the O–C diagram, but the same statement is not valid a priori for the orbital motion of the visual pair. Therefore regular photometric and spectroscopic observations are recommended.

V1726 Cygni

There are only two series of photoelectric observations on this Cepheid, variability of which was only discovered in 1979. The two O-C residuals are listed in Table 53. The moments of light maxima can be predicted by using the following elements:

$$C = 2444105.697 + 4^{d}.236978 \cdot E \qquad (38)$$

A very recently obtained radial velocity measurement series (*Metzger* et al., 1990) gives -15.3 ± 0.3 km/s for the γ-velocity at an epoch of J.D. 2447002. Further observations, both photometric and spectroscopic, are desirable.

Table 53. O-C residuals for V1726 Cyg

Norm.max. JD2400000+	E	O-C	W	Reference
44105.697*	0	0.000	3	Platais & Shugarov (1981)
45622.535*	358	0.000	3	Berdnikov (1986)

TX Delphini

This star is one of the Population II Cepheids in this sample. Because of its belonging to a spectroscopic binary system (*Harris* and *Welch*, 1989), TX Del deserves a special attention. The photoelectric observations have been analysed using a new normal light curve, based on *Moffett* and *Barnes*' (1984) observations. The O-C graph (see Table 54 and Figure 35) has been approximated with a straight line as follows:

$$C = \underset{\pm .012}{2442947.138} + \underset{\pm .000023}{6^{d}.165904} \cdot E \qquad (39)$$

The deviations from this straight line are in some cases much larger than expected due to the observational errors. The dashed lines in Figure 35 suggest a plausible solution to this anomaly: several successive phase jumps might occur, similarly to the case of Y Oph (Paper IV, p. 42). The pulsation period corresponding to the dashed lines is about 6.1664 days, being in excellent agreement with the period valid before J.D. 2436600: P = 6.166585 days (see Paper II, p. 58). Reality of the phase jump approximation, however, has to be proven by future observations.

Table 54. O-C residuals for TX Del

Norm.max. JD2400000+	E	O-C	W	Reference
35665.108	-1181	-0.097	3	Walraven et al. (1958)
37293.130	-917	0.126	3	Mitchell et al. (1964)
39099.574	-624	-0.040	3	Takase (1969)
40819.978	-345	0.077	3	Pel (1976)
41929.732*	-165	-0.032	3	Dean et al. (1977)
42293.514*	-106	-0.038	3	Dean et al. (1977)
42361.345*	-95	-0.032	3	Harris & Welch (1989)
42947.169	0	0.031	3	Szabados (1980)
43816.622*	141	0.092	3	Harris & Welch (1989)
44359.105*	229	-0.025	3	Moffett & Barnes (1984)
44457.760*	245	-0.024	2	present paper
44926.369*	321	-0.024	3	Moffett & Barnes (1984)
45549.100*	422	-0.049	1	Diethelm (1986)

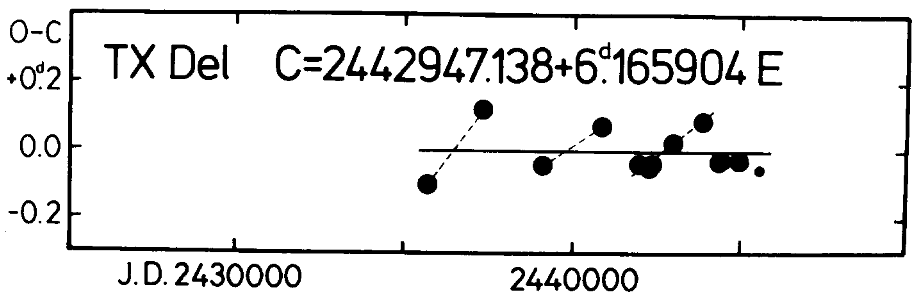

Figure 35. O-C diagram of TX Del

Because the orbital period is as short as 133.15 days (*Harris* and *Welch*, 1989), the orbital light-time effect cannot cause an observable wave in the O-C diagram.

The radial velocity observations of TX Del are not discussed here, because a detailed analysis was performed recently (*Harris* and *Welch*, 1989).

W Geminorum

The reliable O-C residuals from Paper II supplemented with those obtained from the more recent photoelectric observations can be better approximated with a parabola instead of a single sudden period decrease suggested in Paper II. The residuals in Table 55 (see also Figure 36) have been obtained using the equation:

$$C = \underset{\pm.024}{2442755.176} + \underset{\pm.000047}{7.^{d}913624} \cdot E \qquad (40)$$

Table 55. O-C residuals for W Gem

Norm.max. JD2400000+	E	O-C	W	Reference
14136.862	-3616	-2.650	1	Pickering (1904)
17318.675	-3214	-2.113	1	Wendell (1913)
17659.022	-3171	-2.052	1	Zeipel (1908)
17944.327	-3135	-1.638	1	van der Bilt (1926b)
18324.126	-3087	-1.693	1	van der Bilt (1926b)
18807.014	-3026	-1.536	1	van der Bilt (1926b)
19748.851	-2907	-1.420	1	van der Bilt (1926b)
24980.146	-2246	-1.030	1	Carrasco (1932)
25296.648	-2206	-1.073	2	Hellerich (1935)
25716.263	-2153	-0.881	1	Zverev (1936)
26578.991	-2044	-0.738	1	Zverev (1936)
26666.149	-2033	-0.629	1	Kukarkin (1940)
26895.429	-2004	-0.845	1	Kox (1935)
27030.096	-1987	-0.709	1	Florya & Kukarkina (1953)
29364.701	-1692	-0.623	1	Koshkina (1963)
35165.909	-959	-0.102	1	Irwin (1961)
35561.781	-909	-0.089	1	Nikulina (1959)
35569.363	-908	-0.242	2	Walraven et al. (1958)
36186.729	-830	-0.139	1	Latyshev (1969)
37270.925	-693	-0.110	3	Mitchell et al. (1964)
37927.814	-610	-0.051	1	Fridel' (1971)
39043.666	-469	-0.020	3	Wisniewski & Johnson (1968)
39083.150	-464	-0.104	3	Takase (1969)
39502.615	-411	-0.062	3	Wamsteker (1972)
39787.563	-375	-0.004	3	Szabados (1980)
40903.421*	-234	0.033	2	Feltz & McNamara (1980)
40927.150	-231	0.021	3	Pel (1976)
41006.204	-221	-0.061	2	Evans (1976)
42755.172	0	-0.004	3	Szabados (1980)
43878.923*	142	0.012	3	Moffett & Barnes (1984)

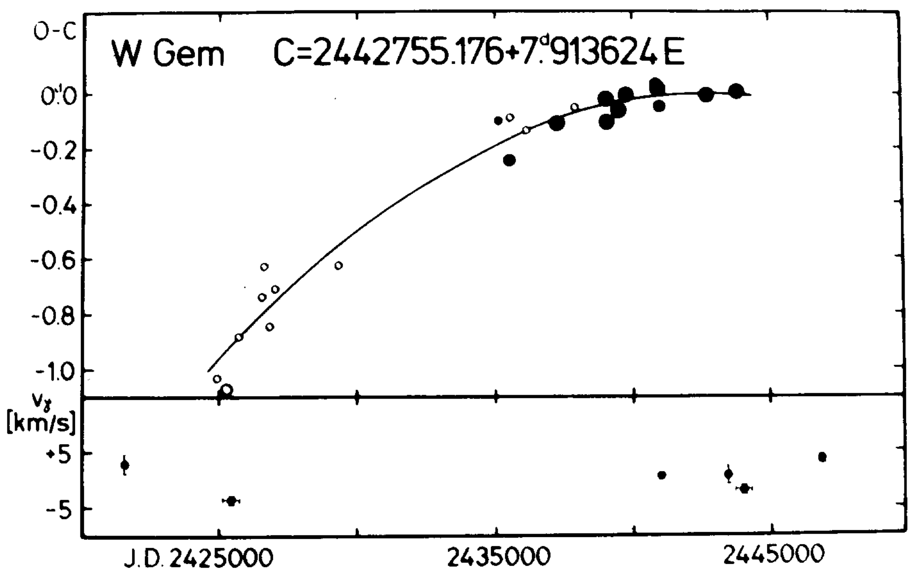

Figure 36. Upper panel: O-C diagram of W Gem
Lower panel: γ-velocities for the same Cepheid

Table 56. γ-velocities of W Gem

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
21600	30	3.0	1.7	4	Sanford (1930)
25468	305	-3.5	0.7	19	Sanford (1930)
41011	29	0.7	0.3	4	Evans (1976)
43445	63	0.9	1.5	8	Wilson et al. (1989)
44015	318	-1.8	0.8	24	Barnes et al. (1987)
46866	1	3.7	0.7	2	Samus (1990)

The continuous period decrease is represented with the formula:

$$P = 7\overset{d}{.}913624 - 3\overset{d}{.}79\cdot10^{-7}\cdot E \qquad (41)$$
$$\pm.000047 \quad \pm.29$$

The γ-velocities determined for W Gem listed in Table 56 are shown plotted in the lower panel of Figure 36. The total variation of the γ-velocity is larger than 7 km/s, a value far exceeding the uncertainty due to the observational errors. Thus W Gem is a spectroscopic binary Cepheid candidate. The information on the duplicity of W Gem is summarized by *Leonard* and *Turner* (1986). They conclude that W Gem does not have an early type companion. The amplitude ratios determined from the BVRI photometry obtained by *Moffett* and *Barnes* (1984) imply a late type companion. In any case, W Gem is a promising target for further spectroscopic observations.

RZ Geminorum

Similarly to W Gem, the new O-C diagram of this Cepheid is also approximated with a parabola, instead of two linear sections (see Table 57 and the upper panel of Figure 37). The O-C residuals have been obtained using the elements:

$$C = 2442714.955 + 5\overset{d}{.}529166\cdot E \qquad (42)$$
$$\pm.012 \quad \pm.000015$$

The value of the continuously decreasing period can be calculated as follows:

$$P = 5\overset{d}{.}529166 - 1\overset{d}{.}70\cdot10^{-7}\cdot E \qquad (43)$$
$$\pm.000015 \quad \pm.08$$

The γ-velocity of RZ Gem shows an obvious variation (see Table 58 and the lower panel of Figure 37). Because this variation seems to be very rapid (i.e. the orbital period is rather short, at least for a Cepheid), a separate γ-velocity has been determined for each season whenever the radial velocity of RZ Gem was measured. The formal period search routine resulted in the value of 886 days, and this value is considered as the

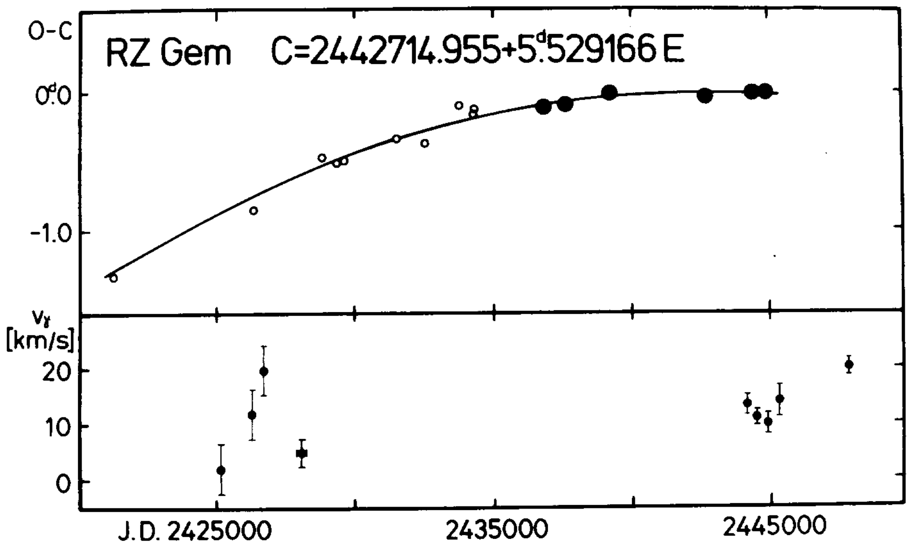

Figure 37. Upper panel: O-C diagram of RZ Gem
Lower panel: γ-velocities for the same Cepheid

Table 57. O-C residuals for RZ Gem

Norm.max. JD2400000+	E	O-C	W	Reference
18324.181	-4411	-1.623	1	Enebo (1909)
18832.935	-4319	-1.552	1	Enebo (1911)
21277.055	-3877	-1.323	1	Jordan (1929)
26375.422	-2955	-0.847	1	Kukarkin (1940)
28869.451	-2504	-0.472	1	Koshkina (1963)
29383.624	-2411	-0.512	1	Koshkina (1963)
29632.453	-2366	-0.495	1	Chudovicheva (1952)
31556.759	-2018	-0.339	1	Chudovicheva (1952)
32557.503	-1837	-0.374	1	Chudovicheva (1952)
33801.844	-1612	-0.095	1	Koshkina (1963)
34304.930	-1521	-0.164	1	Koshkina (1963)
34327.082	-1517	-0.128	1	Rosino & Nobili (1955)
36831.810	-1064	-0.112	3	Weaver et al. (1960)
37633.563	-919	-0.088	3	Mitchell et al. (1964)
39248.161	-627	-0.007	3	Takase (1969)
42714.927	0	-0.028	3	Szabados (1980)
44440.044*	312	-0.011	3	Moffett & Barnes (1984)
44976.380*	409	-0.004	3	Moffett & Barnes (1984)

tentative orbital period. The γ-velocities folded with this period are plotted in Figure 38. Zero phase is arbitrarily chosen at J.D. 2400000. This orbital radial velocity curve is very promising, but another value for the orbital period cannot be excluded (e.g. 930 days). Duplicity of RZ Gem is supported by other facts, as well. *Madore* (1977) assumes a B5 photometric companion, and the phase-test by *Madore* and *Fernie* (1980) is

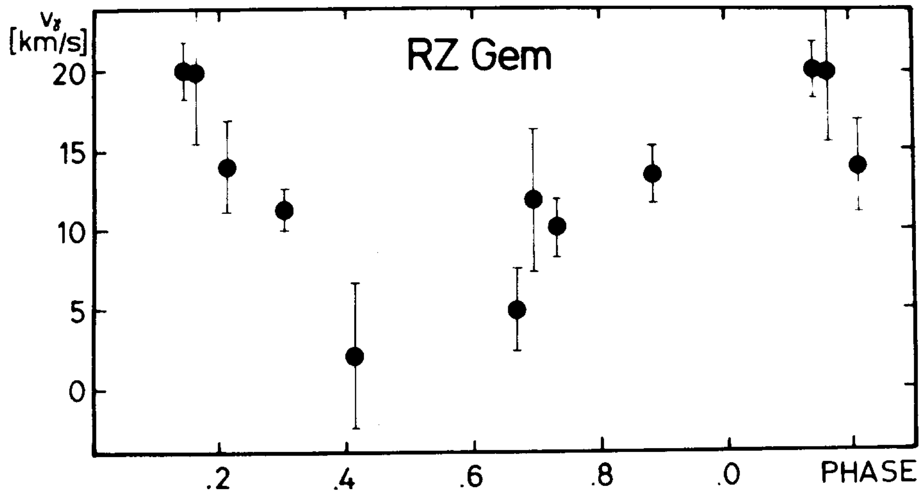

Figure 38. γ-velocity values of RZ Gem folded with the 886 day period

Table 58. γ-velocities of RZ Gem

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25175	18	2.1	4.5	2	Joy (1937)
26311	1	11.9	4.5	1	Joy (1937)
26724	1	20.0	4.5	1	Joy (1937)
28058	146	5.0	2.6	4	Joy (1937)
44196	20	13.5	1.8	6	Barnes et al. (1988)
44568	43	11.3	1.3	11	Barnes et al. (1988)
44948	51	10.1	1.8	6	Barnes et al. (1988)
45373	26	14.0	2.9	3	Barnes et al. (1988)
47970	9	20.1	1.8	3	Samus (1990)

another piece of evidence for an early type companion. The discrepancy in the γ-velocity was already apparent in the compilation of *Moffett* and *Barnes* (1987). New radial velocity observations would be extremely valuable, especially because the whole orbit can be covered within three years.

AD Geminorum

The photoelectric O-C residuals including those published in Paper I (and modified according to the new normal light curve) have been approximated with a constant period (see Table 59 and Figure 39):

$$C = \underset{\pm.004}{2441694.999} + \underset{\pm.000005}{3^{d}.787990} \cdot E \qquad (44)$$

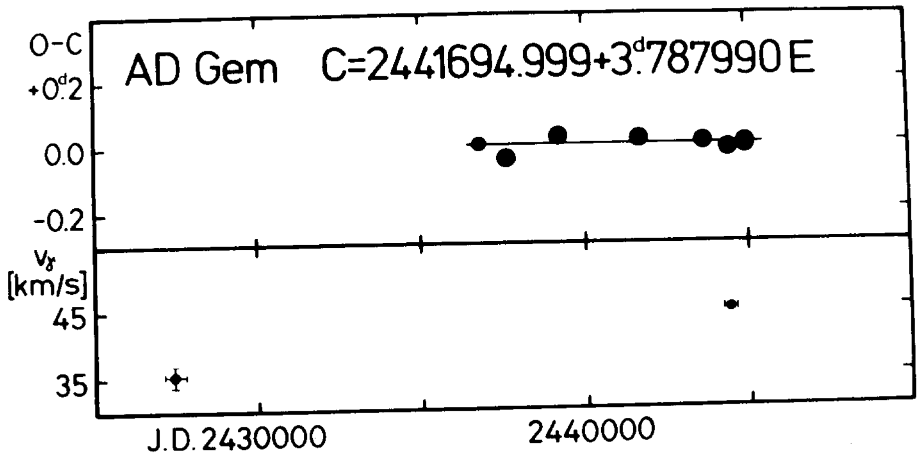

Figure 39. Upper panel: O-C diagram of AD Gem
Lower panel: γ-velocities for the same Cepheid

Table 59. O-C residuals for AD Gem

Norm.max. JD2400000+	E	O-C	W	Reference
36835.010	-1283	0.002	2	Weaver et al. (1960)
37630.445	-1073	-0.041	3	Mitchell et al. (1964)
39202.527	-658	0.025	3	Takase (1969)
41695.016	0	0.017	3	Szabados (1977)
43649.613*	516	0.011	3	Henden (1979)
44407.186*	716	-0.014	3	Moffett & Barnes (1984)
44960.239*	862	-0.007	3	Moffett & Barnes (1984)
44964.034*	863	0.000	3	Connolly et al. (1983)

Table 60. γ-velocities of AD Gem

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
27438	329	35.4	1.7	8	Joy (1937)
44406	195	45.0	0.1	38	Imbert (1983)

The γ-velocity of AD Gem may be variable (see Table 60 and the lower panel of Figure 39). This suspicion can be supported by the facts that *Joy*'s (1937) radial velocity data give a deviating value from the γ-velocity determined from *Imbert*'s (1983) observations, and *Imbert*'s radial velocity measurements themselves seem to show a systematic trend in the sense that the more recent observations imply a more positive γ-velocity. Further spectroscopic study of AD Gem would be desirable.

DX Geminorum

The photographic and photoelectric O-C residuals obtained by fitting the new normal light curve based on *Moffett* and *Barnes*' (1984)

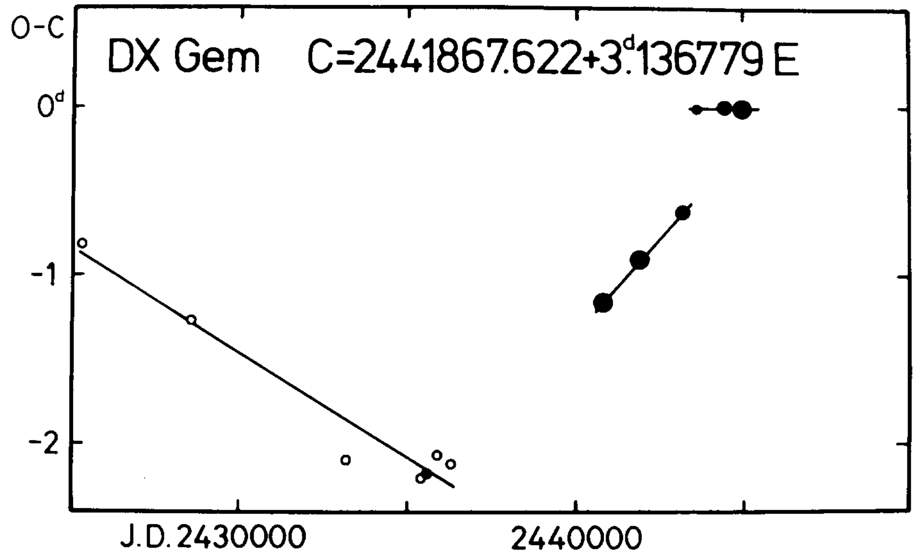

Figure 40. O-C diagram of DX Gem

Table 61. O-C residuals for DX Gem

Norm.max. JD2400000+	E	O-C	W	Reference
25295.211	-5283	-0.808	1	Bartkus & Puchinskas (1961)
28594.649	-4231	-1.261	1	Meshkova (1940)'
33182.929	-2768	-2.089	1	Satyvaldiev (1970)
35413.074	-2057	-2.194	1	Satyvaldiev (1970)
35554.252	-2012	-2.171	1	Walraven et al. (1958)
35896.275	-1903	-2.057	1	Bartkus & Puchinskas (1961)
36275.769	-1782	-2.113	1	Bartkus & Puchinskas (1961)
40793.694	-342	-1.150	3	Pel (1976)
41866.721	0	-0.901	3	Szabados (1977)
43165.632	414	-0.617	2	Szabados (1977)
43614.804*	557	-0.004	1	Henden (1979)
44439.787*	820	0.006	2	Moffett & Barnes (1984)
44954.210*	984	-0.003	3	Moffett & Barnes (1984)

observations are listed in Table 61 (see also Figure 40). The following ephemeris was used when computing the O-C residuals:

$$C = 2441867.622 + 3^{d}.136779 \cdot E \qquad (45)$$
$$\pm.012 \quad \pm.000013$$

The photoelectric data clearly show a recent phase jump with an amplitude of 0.2 period. This phase jump can also be suspected in the O-C diagram based on the Sonneberg photographic observations (*Hacke*, 1989). Although its scatter is very wide, *Hacke*'s O-C diagram also shows a further period change (after J.D. 2445000) that cannot be seen here, because no such recent photoelectric observations are available. Consequently the ephemeris given in Eq. (45) might not be correct for predicting the maxima occurring even in the near future (the true period is expected to be shorter: 3.13669 days according to *Hacke*). Another phase jump might occur just before J.D. 2440500, but this phase shift cannot be traced with the photoelectric observation. The following values of the pulsation period can be derived from the existing data:

before J.D. 2436500	P = 3.136387 ± 0.000041 days
between J.D. 2440700 and 2443200	P = 3.137486 ± 0.000005 days
after J.D. 2443600	P = 3.136779 ± 0.000013 days.

The occurrence of the phase jump(s) in the O-C diagram of DX Gem is in accordance with the suspected spectroscopic binary nature of this Cepheid (*Burki*, 1985). Unfortunately the radial velocity data have not been published yet.

ζ Geminorum

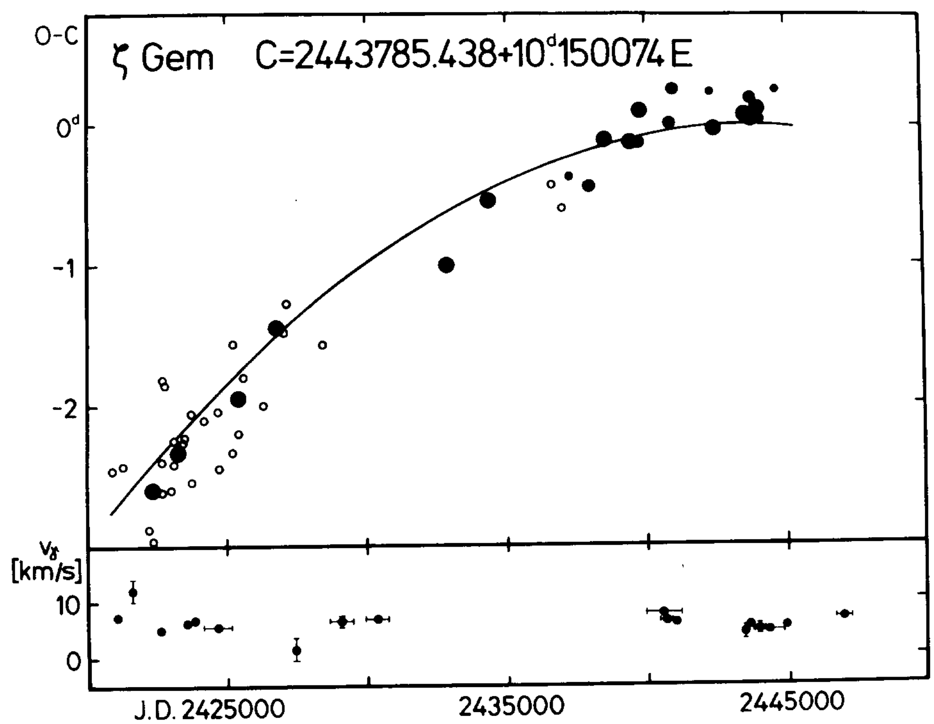

Figure 41. Upper panel: O-C diagram of ζ Gem
Lower panel: γ -velocities for the same Cepheid

Table 62. O-C residuals for ζ Gem

Norm.max. JD2300000+	E	O-C	W	Reference
96027.855	-4704	-11.635	1	Hagen (1903)
96088.465	-4698	-11.925	1	Argelander (1869)
96474.176	-4660	-11.917	1	Argelander (1869)
96565.026	-4651	-12.418	1	Hagen (1903)
97154.525	-4593	-11.623	1	Argelander (1869)
97459.537	-4563	-11.113	1	Hagen (1903)
97519.975	-4557	-11.576	1	Argelander (1869)
97875.456	-4522	-11.347	1	Argelander (1869)
98241.363	-4486	-10.843	1	Argelander (1869)
98536.305	-4457	-10.253	1	Hagen (1903)
98586.501	-4452	-10.807	1	Argelander (1869)
98982.738	-4413	-10.423	1	Argelander (1869)
99317.451	-4380	-10.663	1	Argelander (1869)
99632.685	-4349	-10.081	1	Zinner & Wachmann (1931)
99723.768	-4340	-10.349	1	Argelander (1869)
2400000+				
00099.937	-4303	-9.733	1	Argelander (1869)
01927.501	-4123	-9.182	1	Argelander (1869)
02313.385	-4085	-9.001	1	Valentiner (1900)
02648.656	-4052	-8.682	1	Valentiner (1900)
02993.591	-4018	-8.850	1	Valentiner (1900)
03785.426	-3940	-8.720	1	Valentiner (1900)
03786.543	-3940	-7.603	1	Zinner & Wachmann (1931)
04090.631	-3910	-8.018	1	Valentiner (1900)
04466.252	-3873	-7.949	1	Valentiner (1900)
04608.424	-3859	-7.878	1	Zinner & Wachmann (1931)
04831.417	-3837	-8.187	1	Valentiner (1900)
05166.882	-3804	-7.674	1	Valentiner (1900)
05552.714	-3766	-7.545	1	Valentiner (1900)
05928.082	-3729	-7.730	1	Valentiner (1900)
10009.990	-3327	-6.152	1	Hagen (1891)
13564.137	-2977	-4.531	1	Plassmann (1900)
13950.417	-2939	-3.954	1	Plassmann (1900)
13979.885	-2936	-4.936	1	Pickering (1904)
14335.691	-2901	-4.382	1	Pickering (1904)
14478.219	-2887	-3.955	1	Plassmann (1900)
14487.821	-2886	-4.503	1	Wirtz (1901)
15320.879	-2804	-3.752	1	Plassmann (1900, 1901, 1908)
15605.224	-2776	-3.609	1	Tass (1925)
15787.268	-2758	-4.266	1	Plassmann (1908)
15787.949	-2758	-3.585	1	Nijland (1923)
15797.704	-2757	-3.980	1	Kopff (1902)
15970.085	-2740	-4.150	1	van der Bilt (1926a)
16143.288	-2723	-3.498	1	Plassmann (1908)
16172.918	-2720	-4.319	1	Lau (1904)
16406.864	-2697	-3.824	1	Götz (1906)
16508.718	-2687	-3.471	1	Plassmann (1908)
16711.866	-2667	-3.325	1	Olivier (1952)
16721.611	-2666	-3.730	1	van der Bilt (1926a)
16874.025	-2651	-3.567	1	Tass (1925)
16874.320	-2651	-3.272	1	Tass (1925)
16883.963	-2650	-3.779	1	Plassmann (1908)
16894.896	-2649	-2.996	1	Schiller (1906)
17228.908	-2616	-3.936	1	van der Bilt (1926a)
17238.785	-2615	-4.209	1	Plassmann (1908)

Table 62. (cont.)

Norm.max. JD2400000+	E	O-C	W	Reference
17310.450	-2608	-3.595	1	Lohnert (1909)
17594.592	-2580	-3.655	1	Olivier (1952)
17604.986	-2579	-3.411	1	Nijland (1923)
17614.853	-2578	-3.694	1	van der Bilt (1926a)
17777.885	-2562	-3.063	1	Plassmann (1908)
17939.841	-2546	-3.509	1	Nijland (1923)
17950.165	-2545	-3.335	1	van der Bilt (1926a)
18315.716	-2509	-3.186	1	Nijland (1923)
18417.041	-2499	-3.362	1	Mündler (1911)
18559.427	-2485	-3.077	1	Olivier (1952)
18640.796	-2477	-2.909	1	Nijland (1923)
19899.406	-2353	-2.908	1	Kaiser (1915)
20904.713	-2254	-2.458	1	Luyten (1922)
21320.897	-2213	-2.427	1	Luyten (1922)
22244.104	-2122	-2.877	1	Rabe (1923)
22366.187	-2110	-2.595	3	Guthnick (1921)
22375.973	-2109	-2.959	1	Bellemin (1922)
22721.639	-2075	-2.395	1	Leiner (1922)
22731.566	-2074	-2.619	1	Rabe (1923)
22732.368	-2074	-1.817	1	Gallisot (1923)
22803.383	-2067	-1.852	1	Bellemin (1922)
23056.382	-2042	-2.605	1	Rabe (1923)
23137.772	-2034	-2.415	1	Nielsen (1927a)
23168.397	-2031	-2.241	1	Zverev (1936)
23269.793	-2021	-2.345	3	Bottlinger (1928)
23442.428	-2004	-2.262	1	Leiner (1928)
23543.967	-1994	-2.223	1	Parenago (1938)
23736.995	-1975	-2.047	1	Hopmann (1926)
23797.392	-1969	-2.550	1	Leiner (1928)
24203.841	-1929	-2.104	1	Leiner (1928)
24711.413	-1879	-2.036	1	Leiner (1928)
24761.751	-1874	-2.448	1	Kukarkin (1940)
25228.769	-1828	-2.334	1	Hellerich (1935)
25280.295	-1823	-1.558	1	Leiner (1928)
25310.362	-1820	-1.941	1	Collmann (1930)
25340.804	-1817	-1.950	3	Güssow (1930)
25462.360	-1805	-2.194	1	Kukarkin (1940)
25625.169	-1789	-1.787	1	Zverev (1936)
26325.312	-1720	-1.999	1	Zverev (1936)
26802.918	-1673	-1.446	3	Hall (1934)
27056.638	-1648	-1.478	1	Florya & Kukarkina (1953)
27198.938	-1634	-1.279	1	Nielsen (1941)
28436.956	-1512	-1.570	1	Günther (1939)
32883.249	-1074	-1.010	3	Eggen (1951)
34416.368	-923	-0.552	3	Harris (1953)
36639.347	-704	-0.439	1	Azarnova (1960a)
37004.583	-668	-0.606	1	Mayall (1964)
37258.567	-643	-0.373	1	Mitchell et al. (1964)
37979.154	-572	-0.442	2	Williams (1966)
38527.582	-518	-0.118	3	Wisniewski & Johnson (1968)
39420.773	-430	-0.133	3	Takase (1969)
39765.870	-396	-0.139	2	Sudzius (1969)
39796.556	-393	0.097	3	Szabados (1981)
40892.664*	-285	-0.003	2	Feltz & McNamara (1980)

Table 62. (cont.)

Norm.max. JD2400000+	E	O-C	W	Reference
41004.565	-274	0.247	2	Evans (1976)
42354.510	-141	0.232	1	Scarfe (1976)
42465.897	-130	-0.031	3	Depenchuk (1980)
43552.060*	-23	0.074	3	Moffett & Barnes (1984)
43785.473	0	0.035	3	Szabados (1981)
43805.927	2	0.189	2	Depenchuk (1980)
44039.297*	25	0.107	3	Moffett & Barnes (1984)
44140.727*	35	0.036	1	Schmidt & Parsons (1982)
44709.348*	91	0.253	1	Ridgway et al. (1982)

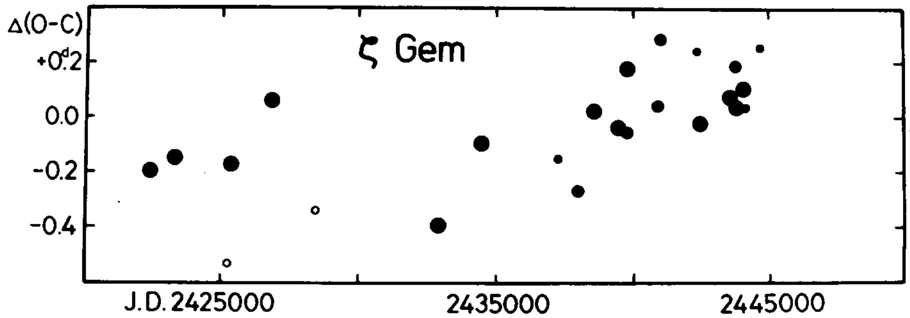

Figure 42. Δ(O-C) diagram of ζ Gem

The old visual observations have also been taken into account during the re-discussion of the O-C diagram, because the previous study (see Paper III) revealed some shorter time-scale deviations superimposed on the general parabolic trend of the O-C diagram. In order to obtain the value of the period decrease as accurately as possible, a long time-base data set is necessary. The currently used ephemeris is deduced from the best parabolic fit (see Table 62 and Figure 41):

$$C = 2443785.438 + 10\overset{d}{.}150074 \cdot E \qquad (46)$$
$$\pm.053 \qquad \pm.000053$$

while the continuous period decrease is as follows:

$$P = 10\overset{d}{.}150074 - 10\overset{d}{.}76 \cdot 10^{-7} \cdot E \qquad (47)$$
$$\pm.000053 \qquad \pm.23$$

The deviations from the least squares fitted parabola are shown on the Δ (O-C) diagram in Figure 42. Here only the photoelectric and the photographic O-C residuals have been taken into account. The trend of the deviations resembles the phase jump appearing in the O-C diagram of a number of Cepheids. In most cases, however, the O-C diagrams are linear, and ζ Gem would be the first case when a phase jump occurs on a parabolic O-C diagram. It cannot be excluded that this phase shift is not the commonly appearing one in binary Cepheids, but its origin can be explained

Table 63. γ-velocities of ζ Gem

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
14419	170	13.5	0.8	15	Henroteau (1925)
14650	39	6.0	2.1	3	Campbell (1899)
14851	158	7.1	0.5	44	Henroteau (1925)
19799	1312	11.3	2.1	3	Spencer Jones (1928)
21014	417	7.4	0.5	42	Hase (1929)
21592	1	12.2	2.0	1	Abt (1970)
22606	188	5.1	0.6	23	Hase (1929)
23541	80	6.3	0.7	22	Jacobsen (1926)
23837	21	6.9	0.5	43	Henroteau (1925)
24664	496	5.6	0.6	25	Hase (1929)
27413	86	1.6	2.0	2	Abt (1970)
29028	393	6.5	0.9	6	Abt (1970)
30368	408	7.1	0.1	13	Scarfe (1976)
40506	636	7.8	0.1	15	Abt & Levy (1974)
40625	224	6.5	0.1	12	Scarfe (1976)
40990	21	6.2	0.3	6	Evans (1976)
43463	57	4.4	1.2	12	Wilson et al. (1989)
43619	135	5.7	0.5	4	Beavers & Eitter (1986)
43934	218	5.0	0.8	21	Barnes et al. (1987)
44313	540	4.8	0.4	19	Jacobsen & Wallerstein (1982)
44916	8	5.4	0.3	7	Beavers & Eitter (1986)
46951	296	6.7	0.4	10	Samus (1990)

in terms of the stellar activity (see *Hall*, 1990, and the general remarks in this paper, on page 233).

The γ-velocities determined from the available radial velocity data (see Table 63 and the lower panel of Figure 41) do not show a clear variation but changes up to 4-5 km/s cannot be excluded. Even in this latter case, no observable light-time effect is expected in the O-C diagram. A long series of homogeneous radial velocity observations will hopefully solve the problem of duplicity of ζ Gem.

V Lacertae

The photographic and photoelectric O-C residuals listed in Paper I have been supplemented with the more recent photoelectric data. The O-C diagram continues to be parabolic (see Figure 43). During the present analysis the O-C residuals (listed in Table 64) have been calculated using the elements:

$$C = 2441907.706 + 4\overset{d}{.}983179 \cdot E \qquad (48)$$
$$\pm.006 \qquad \pm.000003$$

The continuous decrease in the period can be characterized as follows:

$$P = 4\overset{d}{.}983179 - 1\overset{d}{.}09 \cdot 10^{-7} \cdot E \qquad (49)$$
$$\pm.000003 \qquad \pm.02$$

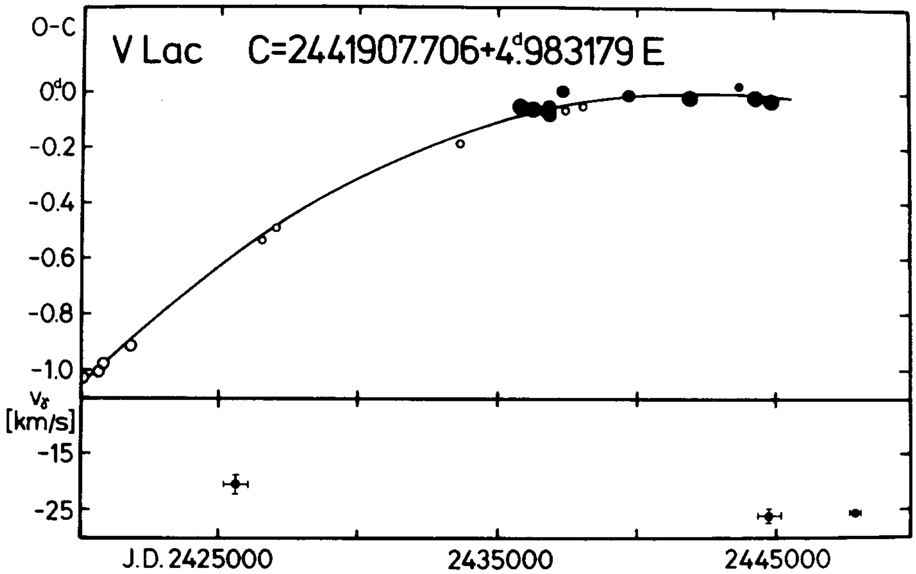

Figure 43. Upper panel: O-C diagram of V Lac
Lower panel: γ-velocities for the same Cepheid

Table 64. O-C residuals for V Lac

Norm.max. JD2400000+	E	O-C	W	Reference
19716.574	-4453	-1.036	1	Martin & Plummer (1916)
20070.390	-4382	-1.026	2	Martin & Plummer (1916)
20633.512	-4269	-1.003	2	Martin & Plummer (1916)
20817.920	-4232	-0.972	2	Hertzsprung (1922)
21844.515	-4026	-0.912	2	Jordan (1929)
26558.980	-3080	-0.535	1	Zonn (1933)
27092.226	-2973	-0.489	1	Zonn (1933)
33635.445	-1660	-0.184	1	Solov'yov (1952)
35788.311*	-1228	-0.051	3	Bahner & Mavridis (1977)
36266.691*	-1132	-0.056	3	Bahner & Mavridis (1977)
36794.894	-1026	-0.070	3	Weaver et al. (1960)
36809.829	-1023	-0.085	2	Oosterhoff (1960)
36834.777	-1018	-0.053	2	Bahner et al. (1962)
37348.104	-915	0.007	2	Mitchell et al. (1964)
37422.781	-900	-0.064	1	Golovatyj (1964)
38070.607	-770	-0.051	1	Golovatyj (1964)
39754.969	-432	-0.004	2	Szabados (1977)
41907.688	0	-0.018	3	Szabados (1977)
43711.644*	362	0.027	1	Henden (1979)
44329.517*	486	-0.014	3	Moffett & Barnes (1984)
44957.385*	612	-0.027	3	Moffett & Barnes (1984)

Because traces of a wave-like distorsion are apparently superimposed on the fitted parabola, light-time effect was also searched for. Two possible periods could be deduced in this way: 4020 and 8040 days. It is, however, improbable that either of these values corresponds to the orbital period

Table 65. γ-velocities of V Lac

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25632	440	-20.4	1.6	9	Joy (1937)
44771	427	-26.0	1.3	11	Barnes et al. (1987)
47970	164	-25.7	0.7	8	Samus (1990)

because the waves caused by these periods are not compatible with the γ-velocity changes to be discussed below.

The γ-velocities derived from the available radial velocity data are listed in Table 65 (see also the lower panel of Figure 43). The discrepancy noted by *Moffett* and *Barnes* (1987) is clearly seen between *Joy*'s (1937) and the more recent data. Nevertheless, additional radial velocity measurements are needed to confirm the spectroscopic binary nature of V Lac. As a matter of fact, *Oosterhoff* (1960) assumed a blue photometric companion, but the spectrophotometric study performed by *Miller* and *Preston* (1964a) does not support the existence of a blue secondary star.

X Lacertae

The recent photoelectric data imply that the O-C diagram of X Lac can be properly interpreted in terms of phase jumps (see Figure 44). A new

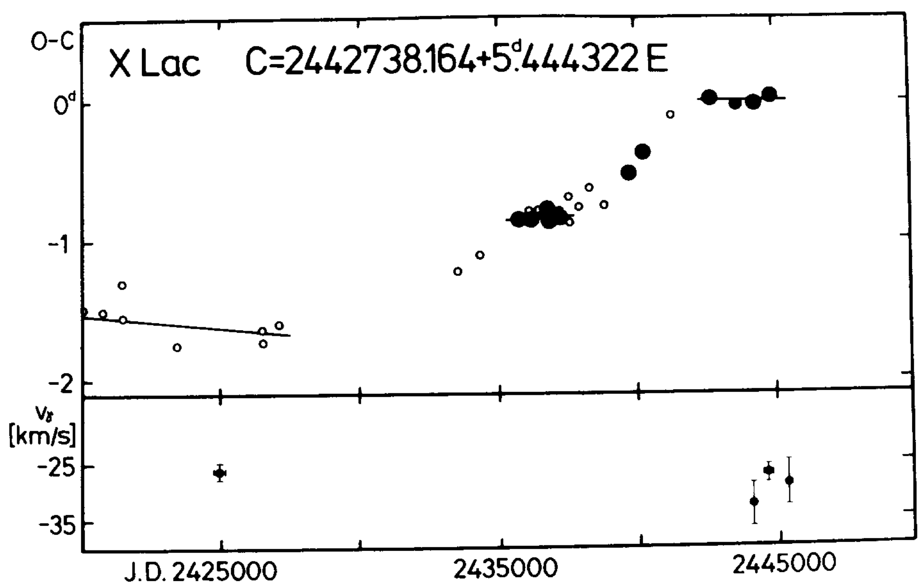

Figure 44. Upper panel: O-C diagram of X Lac
Lower panel: γ-velocities for the same Cepheid

Table 66. O-C residuals for X Lac

Norm.max. JD2400000+	E	O-C	W	Reference
17551.212	-4626	-1.518	1	Seares (1906, 1907)
19870.408	-4200	-1.604	1	Martin & Plummer (1916)
20012.081	-4174	-1.483	1	Hertzsprung (1922)
20741.601	-4040	-1.502	1	Martin & Plummer (1916)
21460.459	-3908	-1.295	1	Hertzsprung (1922)
21487.423	-3903	-1.552	1	Jordan (1929)
23458.068	-3541	-1.752	1	Doberck (1924)
26539.666	-2975	-1.640	1	Kukarkin (1940)
26550.469	-2973	-1.726	1	Zonn (1933)
27105.928	-2871	-1.598	1	Zonn (1933)
33536.037	-1690	-1.223	1	Solov'yov (1952)
34358.247	-1539	-1.105	1	Romano (1955)
35757.696	-1282	-0.847	3	Bahner & Mavridis (1971)
36122.521	-1215	-0.792	1	Makarenko (1969)
36193.241	-1202	-0.848	3	Bahner & Mavridis (1971)
36487.298	-1148	-0.784	1	Makarenko (1969)
36786.745	-1093	-0.775	3	Weaver et al. (1960)
36797.603	-1091	-0.806	3	Oosterhoff (1960)
36835.657	-1084	-0.862	3	Bahner et al. (1962)
36841.091	-1083	-0.872	1	Makarenko (1969)
37200.493	-1017	-0.796	1	Makarenko (1969)
37216.790	-1014	-0.831	3	Mitchell et al. (1964)
37576.258	-948	-0.689	1	Makarenko (1969)
37635.956	-937	-0.878	1	Golovatyj (1964)
37946.397	-880	-0.764	1	Makarenko (1969)
38305.854	-814	-0.632	1	Makarenko (1969)
38866.704	-711	-0.754	1	Makarenko (1969)
39743.265	-550	-0.522	3	Szabados (1980)
40195.303	-467	-0.363	3	Asteriadis et al. (1977)
41333.418*	-258	-0.111	1	Feltz & McNamara (1980)
42738.184	0	0.020	3	Szabados (1980)
43696.330	176	-0.034	2	Henden (1979)
44327.880*	292	-0.026	3	Moffett & Barnes (1984)
44948.587*	406	0.028	3	Moffett & Barnes (1984)

normal light curve was used during this study, and the O-C residuals listed in Table 66 have been calculated according to the ephemeris:

$$C = \underset{\pm .015}{2442738.164} + \underset{\pm .000057}{5\overset{d}{.}444322} \cdot E \qquad (50)$$

The three intervals during which the pulsation period was nearly the same are listed below:

between J.D. 2417550 and 2427100 P = 5.444212 ± 0.000066 days

between J.D. 2435750 and 2437200 P = 5.444403 ± 0.000080 days

after J.D. 2442700 P = 5.444322 ± 0.000057 days.

The pulsation period valid during the intermediate intervals cannot be determined reliably. The value of the phase jump was about 0.18 day (≈0.15 cycle) in both cases.

The variation in the γ-velocity can be suspected on the basis of the radial velocity data (see Table 67 and the lower panel of Figure 44).

Table 67. γ-velocities of X Lac

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
24959	201	-26.2	1.5	10	Joy (1937)
44061	1	-32.6	4.0	1	Barnes et al. (1988)
44608	175	-27.1	1.5	8	Barnes et al. (1988)
45340	2	-28.9	4.0	2	Barnes et al. (1988)

Moffett and *Barnes* (1987) also mentioned this discrepancy. There are, however, other pieces of evidence for the binary nature of X Lac: the method of *Madore* and *Fernie* (1980) indicated a blue photometric companion, while *Usenko* (1990b) assumes a B7 companion from the two-colour diagram. In addition, the phase jumps seen in the O-C diagram give an independent evidence for duplicity of X Lacertae.

Y Lacertae

The new photoelectric O-C residuals confirm the earlier conclusion about the constancy of the pulsation period of Y Lac. The new ephemeris used for computing the O-C residuals listed in Table 68 is as follows:

$$C = 2441746.722 + 4^{d}.323769 \cdot E \qquad (51)$$
$$\pm.004 \quad \pm.000003$$

The plot of the residuals in Figure 45, however, shows hints of a wave-like pattern with a cycle-length of more than ten thousand days. Obviously, more observations are needed to decide whether these deviations from the straight line can be attributed to the light-time effect or not.

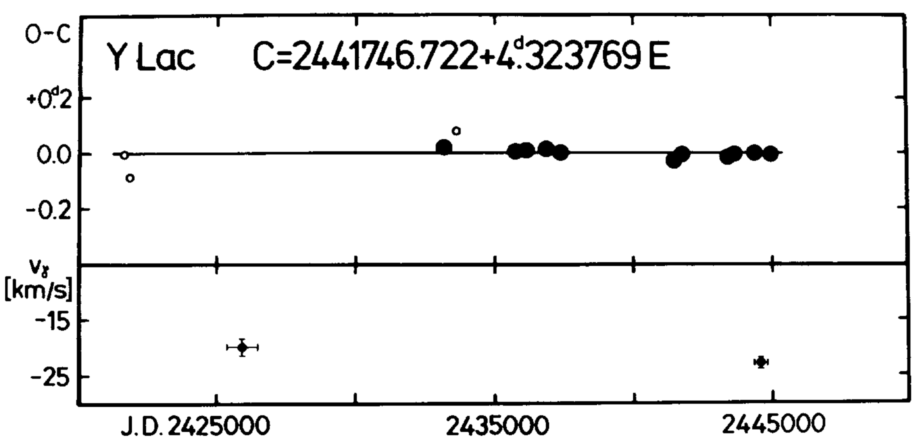

Figure 45. Upper panel: O-C diagram of Y Lac
Lower panel: γ-velocities for the same Cepheid

Table 68. O-C residuals for Y Lac

Norm.max. JD2400000+	E	O-C	W	Reference
21658.488	-4646	-0.003	1	Jordan (1929)
21818.386	-4609	-0.085	1	Martin & Plummer (1919)
33125.147	-1994	0.020	3	Eggen (1951)
33609.468	-1882	0.079	1	Solov'yov (1952)
35710.744*	-1396	0.004	3	Bahner & Mavridis (1977)
36112.859*	-1303	0.008	3	Bahner & Mavridis (1977)
36834.936	-1136	0.016	3	Bahner et al. (1962)
37366.745	-1013	0.001	3	Mitchell et al. (1964)
41431.062*	-73	-0.025	3	Feltz & McNamara (1980)
41746.720	0	-0.002	3	Szabados (1977)
43039.515*	299	-0.014	3	Chekhanikhina (1982)
43683.766*	448	-0.005	3	Henden (1979)
44349.632*	602	0.001	3	Moffett & Barnes (1984)
44457.722*	627	-0.003	1	present paper
44924.690*	735	-0.002	3	Moffett & Barnes (1984)

Table 69. γ-velocities of Y Lac

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25943	564	-19.8	1.5	10	Joy (1937)
44576	225	-22.7	0.9	21	Barnes et al. (1988)

The two γ-velocities determined from the available radial velocity data (see Table 69) deviate from each other. This discrepancy has been already noted by *Moffett* and *Barnes* (1987). An A0V companion has been discovered in an IUE spectrum (*Evans* et al., 1990a), thus confirming *Madore*'s (1977) earlier suggestion concerning the existence of a blue companion to Y Lac. The spectroscopic binary nature of this Cepheid, however, has to be studied further.

Z Lacertae

The recent O-C residuals confirm the parabolic shape of the O-C diagram (see Table 70 and Figure 46). The ephemeris is slightly modified as compared with that determined in Paper III. When constructing the present O-C diagram, the following ephemeris was used:

$$C = 2442827.136 + 10\overset{d}{.}885642 \cdot E \qquad (52)$$
$$\pm.007 \qquad \pm.000021$$

The decrease of the pulsation period is as follows:

$$P = 10\overset{d}{.}885642 - 6\overset{d}{.}4 \cdot 10^{-8} \cdot E \qquad (53)$$
$$\pm.000021 \quad \pm 2.8$$

Because Z Lac is a member in a newly discovered spectroscopic binary (*Moffett* and *Barnes*, 1987; *Gieren*, 1989a) an attempt was made to search for a light-time effect in the O-C diagram. The only reasonable fit

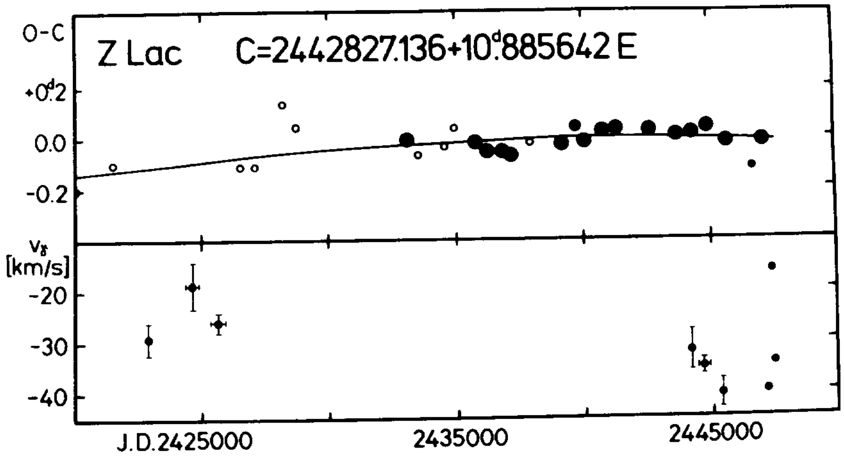

Figure 46. Upper panel: O-C diagram of Z Lac
Lower panel: γ-velocities for the same Cepheid

Table 70. O-C residuals for Z Lac

Norm.max. JD2400000+	E	O-C	W	Reference
20108.601	-2087	-0.200	1	Hertzsprung (1922)
21534.721	-1956	-0.099	1	Hertzsprung (1922)
26542.105	-1496	-0.111	1	Zonn (1933)
27108.157	-1444	-0.112	1	Zonn (1933)
28229.624	-1341	0.134	1	Gur'yev (1937)
28741.160	-1294	0.045	1	Gur'yev (1938)
33084.478	-895	-0.008	3	Eggen (1951)
33519.846	-855	-0.066	1	Solov'yov (1952)
34575.782	-758	-0.037	1	Chuprina (1954a)
34967.738	-722	0.036	1	Chuprina (1956)
35751.452	-650	-0.017	3	Bahner & Mavridis (1971)
36230.385	-606	-0.052	3	Bahner & Mavridis (1971)
36829.095	-551	-0.052	3	Bahner et al. (1962)
37199.191	-517	-0.068	3	Mitchell et al. (1964)
37928.575	-450	-0.022	1	Girnyak (1964)
39180.423	-335	-0.023	3	Takase (1969)
39768.312	-281	0.041	2	Szabados (1981)
40083.936	-252	-0.018	3	Asteriadis et al. (1977)
40791.548	-187	0.027	3	Asteriadis et al. (1977)
41324.953*	-138	0.036	3	Feltz & McNamara (1980)
42674.769*	-14	0.032	3	Szabados (1977)
43708.881*	81	0.008	3	Szabados (1977)
44318.486*	137	0.017	3	Moffett & Barnes (1984)
44938.988*	194	0.037	3	Moffett & Barnes (1984)
45679.155*	262	-0.019	3	Berdnikov (1986)
46702.305*	356	-0.120	1	"Carlsberg" (1989)
47126.952*	395	-0.013	3	Gieren (1989a)

results in a period of about, 8700 days but a period as long as this can hardly correspond to the orbital period of the system because the variation in the γ-velocity suggests a much shorter value.

Table 71. γ-velocities of Z Lac

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
22936	15	-29.1	3.2	3	Joy (1937)
24613	277	-18.7	4.5	2	Joy (1937)
25665	282	-26.0	2.0	6	Joy (1937)
44131	95	-31.7	4.0	2	Barnes et al. (1988)
44613	188	-35.0	1.6	7	Barnes et al. (1988)
45343	1	-40.4	2.8	3	Barnes et al. (1988)
47134	7	-39.9	0.3	7	Gieren (1989a)
47373	1	-16.4	0.5	1	Samus (1990)
47472	1	-34.5	0.7	1	Samus (1990)

The γ-velocities of Z Lac are listed in Table 71. As is clearly seen from the lower panel of Figure 46, the orbital period is much shorter than 8700 days, perhaps it can be as short as one year. Further speculation on the value of the orbital period is untimely yet.

RR Lacertae

A new normal light curve based on *Moffett* and *Barnes'* (1984) observations was used when studying the period changes of RR Lac. As a consequence, a systematic correction of -0.026 day has been applied to the normal maxima taken from Paper II. The new values of the O-C residuals (see Table 72) have been computed with the formula:

$$C = \underset{\pm.006}{2442776.681} + \underset{\pm.000011}{6\overset{d}{.}416289}\cdot E \tag{54}$$

The best representation of the O-C plot is the approximation with a

Table 72. O-C residuals for RR Lac

Norm.max. JD2400000+	E	O-C	W	Reference
20005.526	-3549	0.255	2	Hertzsprung (1922)
21429.895	-3327	0.208	2	Hertzsprung (1922)
21667.339	-3290	0.249	1	Jordan (1929)
26537.195	-2531	0.141	1	Zonn (1933)
27095.442	-2444	0.171	1	Zonn (1933)
32998.324	-1524	0.067	3	Eggen (1951)
33537.290	-1440	0.065	1	Solov'yov (1952)
34968.107	-1217	0.050	1	Azarnova (1957)
36033.188	-1051	0.027	3	Bahner & Mavridis (1971)
36835.212	-926	0.015	3	Bahner et al. (1962)
37213.735	-867	-0.023	3	Mitchell et al. (1964)
37579.554	-810	0.067	1	Girnyak (1964)
38240.312	-707	-0.053	1	Girnyak (1964)
40582.324	-342	0.014	3	Asteriadis et al. (1977)
42776.694	0	0.013	3	Szabados (1980)
44335.840*	243	0.001	3	Moffett & Barnes (1984)
44932.557*	336	0.003	3	Moffett & Barnes (1984)

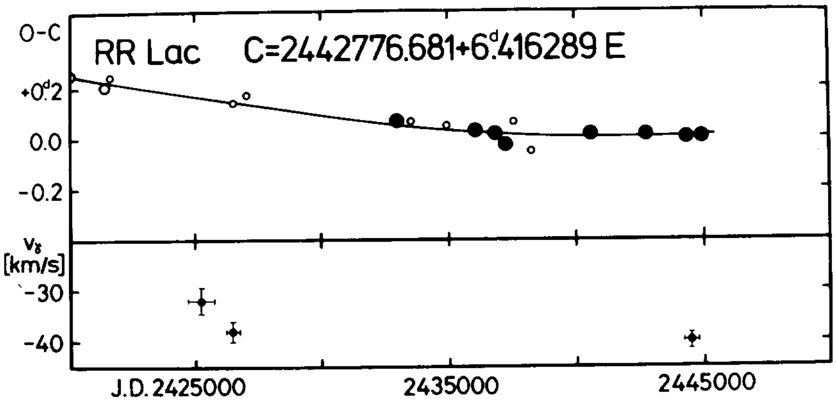

Figure 47. Upper panel: O-C diagram of RR Lac
Lower panel: γ-velocities for the same Cepheid

Table 73. γ-velocities of RR Lac

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25244	526	-31.9	2.6	4	Joy (1937)
26502	255	-37.9	2.0	6	Joy (1937)
44510	288	-39.8	1.5	8	Barnes et al. (1987)

parabola (see Figure 47) indicating a continuously increasing pulsation period:

$$P = 6^{d}_{.}416289 + 4^{d}_{.}1 \cdot 10^{-8} \cdot E \quad (55)$$
$$\pm.000011 \quad \pm 0.6$$

There are three values of the γ-velocity that can be deduced from the published radial velocity measurements (see Table 73). These data indicate that the γ-velocity of RR Lac possibly varies, in accordance with the study performed by *Moffett* and *Barnes* (1987) who also noticed the discordant γ-velocities. Further radial velocity observations would be very important.

BG Lacertae

BG Lac keeps its constant pulsation period. The new value based on solely photoelectric data (see Table 74) only slightly differs from that determined in Paper II. The O-C residuals plotted in Figure 48 have been approximated with the line:

$$C = 2442673.187 + 5^{d}_{.}331902 \cdot E \quad (56)$$
$$\pm.009 \quad \pm.000010$$

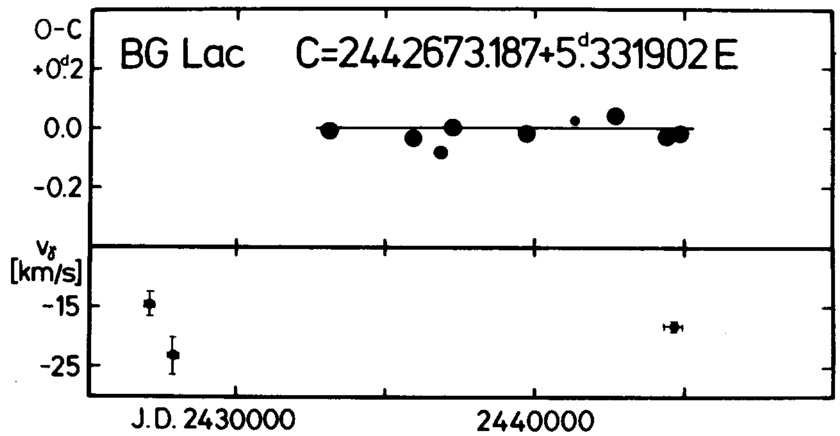

Figure 48. Upper panel: O-C diagram of BG Lac
Lower panel: γ-velocities for the same Cepheid

Table 74. O-C residuals for BG Lac

Norm.max. JD2400000+	E	O-C	W	Reference
33129.068	-1790	-0.014	3	Eggen (1951)
35938.962	-1263	-0.033	3	Bahner & Mavridis (1977)
36834.834	-1095	-0.080	2	Bahner et al. (1962)
37261.307	-1015	0.001	3	Mitchell et al. (1964)
39772.614	-544	-0.018	3	Szabados (1980)
41361.567*	-246	0.028	1	Feltz & McNamara (1980)
42673.231	0	0.044	3	Szabados (1980)
44400.699*	324	-0.024	3	Moffett & Barnes (1984)
44896.574*	417	-0.016	3	Moffett & Barnes (1984)

Table 75. γ-velocities of BG Lac

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
27048	180	-14.5	2.0	6	Joy (1937)
27868	195	-23.1	3.2	3	Joy (1937)
44640	309	-18.0	0.9	23	Barnes et al. (1988)

As to the duplicity of BG Lac, *Madore* (1977) assumed a B8 type photometric companion. No blue companion star was, however, found during the IUE-study of this Cepheid (*Böhm-Vitense* and *Proffitt*, 1985). Nevertheless, the γ-velocity seems to be variable judging from the data listed in Table 75. Further radial velocity measurements are necessary to point out the possible orbital effect more clearly.

T Monocerotis

The O-C diagram of T Mon published in Paper III clearly showed a continuous period increase during an interval of more than one century. A

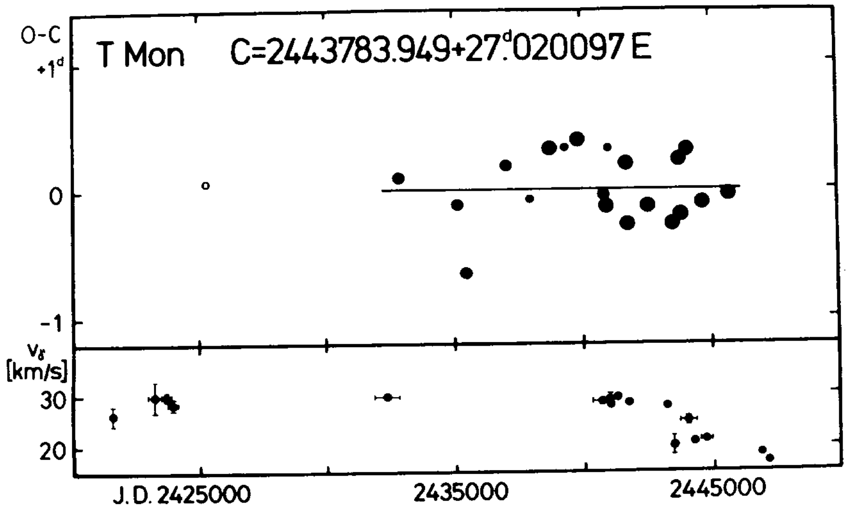

Figure 49. Upper panel: O-C diagram of T Mon
Lower panel: γ-velocities for the same Cepheid

Table 76. O-C residuals for T Mon

Norm.max. JD2400000+	E	O-C	W	Reference
25302.270	-684	0.067		Hellerich (1935)
32840.908	-405	0.098	2	Eggen (1951)
35191.449	-318	-0.109	2	Irwin (1961)
35488.134	-307	-0.645	2	Walraven et al. (1958)
37056.133	-249	0.188	2	Mitchell et al. (1964)
37974.560	-215	-0.068	1	Williams (1966)
38758.533	-186	0.322	3	Wisniewski & Johnson (1968)
39352.984	-164	0.331	1	Takase (1969)
39812.386	-147	0.391	3	Szabados (1981)
40892.759*	-107	-0.040	2	Feltz & McNamara (1980)
40919.687	-106	-0.132	3	Pel (1976)
41001.207	-103	0.328	1	Evans (1976)
41730.626	-76	0.204	3	Landis (1976)
41757.170*	-75	-0.272	3	Dean et al. (1977)
42567.909*	-45	-0.136	3	Dean et al. (1977)
43513.475*	-10	-0.273	3	Dean (1981)
43784.184	0	0.235	3	Szabados (1981)
43810.773*	1	-0.196	3	Moffett & Barnes (1984)
44081.479*	11	0.309	3	Eggen (1983b)
44702.532*	34	-0.100	3	Coulson & Caldwell (1985)
45702.336*	71	-0.040	3	Berdnikov (1986)

closer look at the O-C residuals revealed deviations from the uniform period decrease (see Figure 53 in Paper III). These deviations are much too large to be explained by the light-time effect. Because the photoelectric O-C residuals fall on a branch of such systematic deviation,

Table 77. γ-velocities of T Mon

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
17174	21	22.1	2.1	3	Frost (1906)
21580	30	26.2	2.0	5	Sanford (1927)
23262	268	30.0	3.0	2	Harper (1934)
23698	181	30.1	0.8	27	Sanford (1927)
23934	195	28.4	1.1	15	Sanford (1927)
32327	575	29.8	0.5	20	Sanford (1956)
40682	364	28.7	0.3	25	Wallerstein (1972)
40984	11	29.2	1.1	3	Schmidt (1974)
41006	15	28.1	0.3	4	Evans (1976)
41285	8	29.6	0.2	8	Coulson (1983)
41713	52	28.6	0.2	14	Coulson (1983)
43204	1	28.0	0.6	1	Coulson (1983)
43435	60	20.2	1.6	7	Wilson et al. (1989)
44023	314	25.0	0.8	25	Barnes et al. (1987)
44266	61	21.0	0.6	27	Coulson (1983)
44723	150	21.4	0.5	31	Coulson (1983)
46862	7	18.7	0.6	3	Samus (1990)
47134	7	17.0	0.2	13	Gieren (1989b)

the O-C diagram covering the last forty years cannot be approximated with a parabola. Instead, a constant period has been assumed here, when constructing the O-C diagram from the data points listed in Table 76 (and shown plotted in Figure 49):

$$C = 2443783.949 + 27\overset{d}{.}020097 \cdot E \qquad (57)$$
$$\pm.048 \qquad \pm.000305$$

Note that this ephemeris is not valid before J.D. 2425000, and the reality of predicting future maxima using Eq. (57) may be doubted.

The duplicity of T Mon was frequently discussed in the last decade. In the most recent detailed study *Gieren* (1989b) concludes that the orbital period is about 175 years. The γ-velocities have been redetermined in the present study, supplemented with the results obtained from the recently published radial velocity measurements (see Table 77 and the lower panel of Figure 49). The new values of the γ-velocity also confirm *Gieren*'s conclusion concerning the long orbital period. Although the orbital motion of this Cepheid causes a light-time effect with a full amplitude exceeding 0.1 day, the effect cannot be pointed out in the O-C diagram because of the wide scatter due to the long pulsation period of T Mon.

Being a possible member in the Mon OB2 association (*Gieren*, 1988), T Mon can be an important calibrating Cepheid.

SV Monocerotis

The new value of the pulsation period determined only from photoelectric data (see Table 78 and Figure 50) is somewhat shorter than that determined in Paper III. The O-C residuals have been calculated using the elements:

$$C = 2443794.249 + 15\overset{d}{.}232582 \cdot E \quad (58)$$
$$\pm.019 \qquad \pm.000073$$

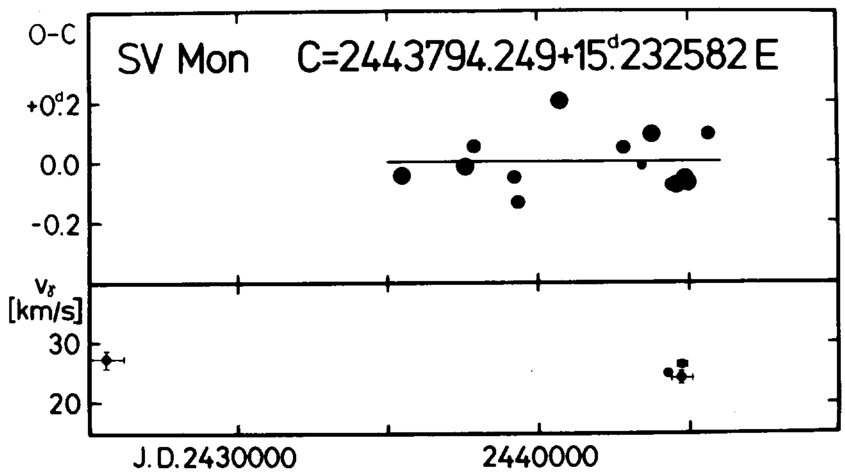

Figure 50. Upper panel: O-C diagram of SV Mon
Lower panel: γ-velocities for the same Cepheid

Table 78. O-C residuals for SV Mon

Norm.max. JD2400000+	E	O-C	W	Reference
35477.219	-546	-0.040	3	Walraven et al. (1958)
37564.109	-409	-0.014	3	Mitchell et al. (1964)
37899.291	-387	0.051	2	Eggen (1969)
39209.191	-301	-0.051	2	Wamsteker (1972)
39346.203	-292	-0.132	2	Takase (1969)
40732.705	-201	0.205	3	Pel (1976)
42865.108	-61	0.047	2	Dean (1977)
43489.586*	-20	-0.011	1	Dean (1981)
43794.342	0	0.093	3	Szabados (1981)
44449.175*	43	-0.075	2	Eggen (1983b)
44525.339*	48	-0.074	3	Coulson & Caldwell (1985)
44890.941*	72	-0.054	3	Moffett & Barnes (1984)
44967.090*	77	-0.068	3	Coulson & Caldwell (1985)
45683.183*	124	0.094	2	Berdnikov (1986)

Table 79. γ-velocities of SV Mon

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25581	625	27.3	1.5	10	Joy (1937)
44264	64	24.9	0.2	26	Coulson & Caldwell (1985)
44705	370	24.2	0.9	19	Barnes et al. (1988)
44723	150	26.5	0.2	31	Coulson & Caldwell (1985)

There is no evidence for duplicity of SV Mon published in the literature, and correspondingly, the γ-velocities listed in Table 79 show no sign of variability.

CV Monocerotis

Considerable attention has been paid to this not very bright Cepheid, because it is a suspected member of an anonymous open cluster (see *Walker*, 1987 and the references therein). *Turner*'s (1978) photometric data were used for determining a new normal light curve. The earlier (partly photographic) observations have been analysed again because of the existence of the phase jump pointed out in Paper II. The O-C residuals listed in Table 80 have been obtained using the ephemeris:

$$C = \underset{\pm .013}{2442773.064} + \underset{\pm .000026}{5\overset{d}{.}378804}\cdot E \qquad (59)$$

The O-C diagram in Figure 51 confirms the occurrence of the phase jump at about J.D. 2436000. The shift between the two almost parallel sections is about -0.34 day. Before J.D. 2436000 the pulsation period was 5.378757 ± 0.000011 days, i.e. practically the same value as given in the current ephemeris (Eq. 59).

Unfortunately the observational efforts have not been extended towards the spectroscopy of CV Mon. Only one set of radial velocity data is available in the literature (*Barnes* et al., 1988). A second epoch radial velocity observation would be extremely valuable for pointing out the spectroscopic binary nature of this Cepheid. The companion is expected to be a B7 star (*Madore*, 1977), or at least a blue one (*Pel*, 1978).

Table 80. O-C residuals for CV Mon

Norm.max. JD2400000+	E	O-C	W	Reference
29805.169	-2411	0.401	1	Teplitskaya (1951)
30778.710	-2230	0.379	1	Teplitskaya (1951)
31908.250	-2020	0.371	1	Filatov (1961)
35447.480	-1362	0.347	1	Filatov (1961)
36571.216	-1153	-0.087	2	Arp (1960)
41035.782	-323	0.072	3	Pel (1976)
42773.133	0	0.069	3	Szabados (1980)
42842.984	13	-0.004	3	Turner (1978)
43886.453*	207	-0.023	2	Dean (1981)
44499.642*	321	-0.018	2	Moffett & Barnes (1984)
44951.475*	405	-0.005	3	Moffett & Barnes (1984)
45962.734*	593	0.039	1	Visvanathan (1989)
46468.211*	687	-0.091	2	present paper

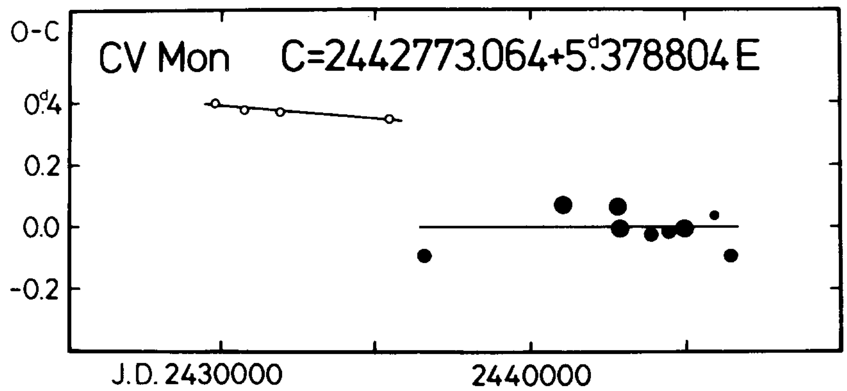

Figure 51. O-C diagram of CV Mon

V465 Monocerotis

There are only four photoelectric maxima determined for V465 Mon (see Table 81 and Figure 52). The weighted least squares fit resulted in the ephemeris:

$$C = 2441698.707 + 2^{d}.713006 \cdot E \quad (60)$$
$$\pm.028 \quad \pm.000048$$

The behaviour of the pulsation period prior to J.D. 2441000 is poorly known. As is seen in the previous O-C diagram (in Paper I), the period has not been constant since the discovery of light variability. V465 Mon deserves more attention. Further photometric data will hopefully explain and remove the zero point difference between the magnitude scales used by the three observers involved in Table 81.

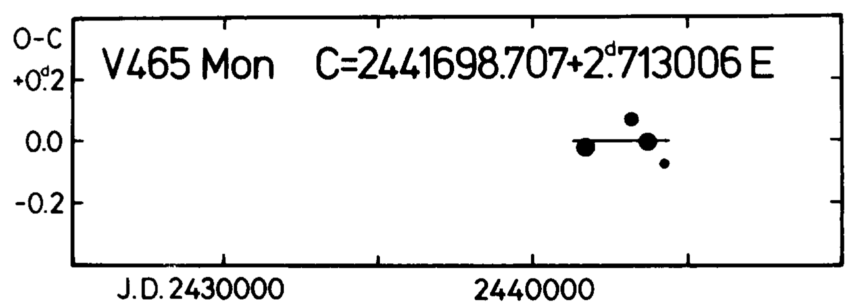

Figure 52. O-C diagram of V465 Mon

Table 81. O-C residuals for V465 Mon

Norm.max. JD2400000+	E	O-C	W	Reference
41698.687	0	-0.020	3	Szabados (1977)
43166.515	541	0.072	2	Szabados (1977)
43676.484*	729	-0.004	3	Henden (1979)
44235.292*	935	-0.076	1	Diethelm & Tammann (1982)

According to *Burki* (1985) V465 Mon is a component in a spectroscopic binary system. Unfortunately the radial velocity data have not been published yet.

RS Orionis

The O-C diagram of RS Ori is very interesting: possibly shows both a light-time effect and a phase jump. The photoelectric and the reliable earlier photographic observations have been converted into O-C residuals (see Table 82) using the ephemeris:

$$C = 2442820.769 + 7\overset{d}{.}566841 \cdot E \qquad (61)$$
$$\pm.009 \qquad \pm.000014$$

Table 82. O-C residuals for RS Ori

Norm.max. JD2400000+	E	O-C	W	Reference
16533.795	-3474	0.232	1	Kukarkina (1955)
21936.353	-2760	0.145	1	Jordan (1929)
25326.322	-2312	0.089	1	Puchinskas (1962)
26393.242	-2171	0.085	1	Martynov (1951)
27233.264	-2060	0.187	1	Martynov (1951)
27581.209	-2014	0.058	1	Puchinskas (1962)
27982.333	-1961	0.139	1	Martynov (1951)
28565.060	-1884	0.219	1	Martynov (1951)
29064.379	-1818	0.127	1	Martynov (1951)
29306.578	-1786	0.187	1	Koshkina (1963)
29798.322	-1721	0.086	1	Martynov (1951)
30751.793	-1595	0.135	1	Martynov (1951)
31039.385	-1557	0.187	1	Kukarkina (1955)
33892.019	-1180	0.122	1	Koshkina (1963)
33960.037	-1171	0.039	1	Solov'yov (1956)
35178.286	-1010	0.026	2	Irwin (1961)
35208.500	-1006	-0.027	2	Walraven et al. (1958)
36192.193	-876	-0.023	3	Bahner et al. (1977)
36282.987	-864	-0.031	1	Puchinskas (1962)
36835.395	-791	-0.003	3	Weaver et al. (1960)
37047.280	-763	0.011	3	Mitchell et al. (1964)
38076.401	-627	0.041	1	Fridel' (1971)
40777.748	-270	0.026	3	Pel (1976)
42820.794	0	0.025	3	Szabados (1980)
44440.057*	214	-0.016	3	Moffett & Barnes (1984)
44644.241*	241	-0.137	1	present paper
44795.791*	261	0.076	1	Eggen (1985)
44969.752*	284	0.000	3	Moffett & Barnes (1984)

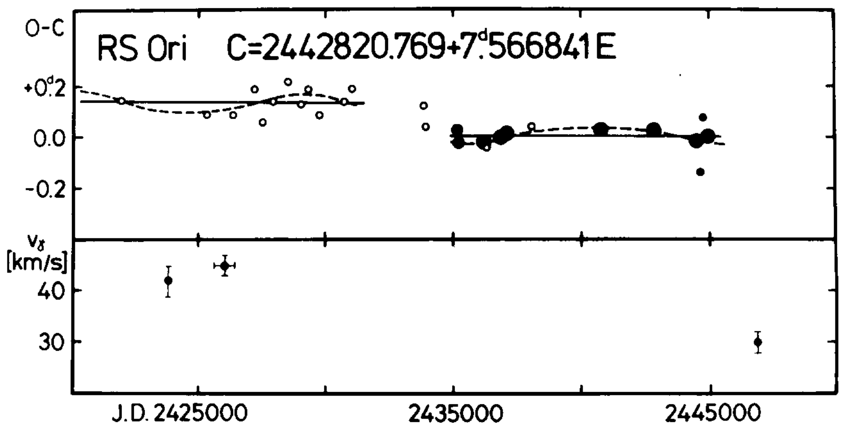

Figure 53. Upper panel: O-C diagram of RS Ori
Lower panel: γ-velocities for the same Cepheid

Table 83. γ-velocities of RS Ori

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
23814	66	42	3	5	Joy (1937)
26029	400	45	2	8	Joy (1937)
46866	1	30	2	2	Samus (1990)

The O-C graph in Figure 53 shows a phase jump between J.D. 2431000 and 2435000 (as already noted in Paper II). In addition to this phase shift (of -0.13 day) a long-term sinusoidal pattern of the O-C residuals is also suspected (see the free-hand dashed lines in Figure 53). If these waves are attributed to the orbital motion of the Cepheid component, the phasing of the γ-velocity variations (see Table 83 and the lower panel of Figure 53) is in accord with the expected tendency. The wave and the rejump to the earlier pulsation period has to be confirmed. Before J.D. 2431000 the period was 7.566830 ± 0.000034 days. An attempt was made to approximate the whole interval of observations with a single line. In that case, however, the amplitude of the sinusoidal term would be too large, therefore incompatible with the light-time interpretation.

The γ-velocities determined for RS Ori are not accurate enough, because no well covered pulsational radial velocity curve has been obtained yet. Nevertheless, the variability of the γ-velocity cannot be doubted. Duplicity of RS Ori has been confirmed by recent IUE observations (*Evans* et al., 1990a), the spectral type of the companion being B8V - B9V. RS Orionis is a very promising target for the observers.

GQ Orionis

Using the photoelectric observations published in the last decade, the pulsation period of GQ Ori can be refined. The O-C residuals listed in Table 84 (see also Figure 54) have been obtained with the help of the following ephemeris:

$$C = 2442798.377 + 8\overset{d}{.}616283 \cdot E \qquad (62)$$
$$\pm.011 \quad \pm.000058$$

The only available series of radial velocity observations (*Barnes* et al., 1988) is not enough for studying the duplicity of GQ Ori.

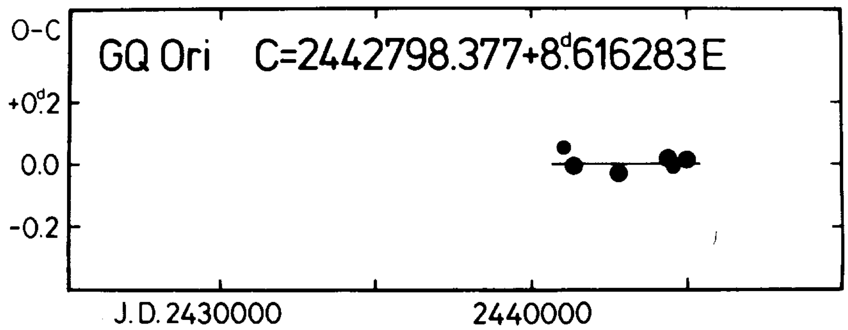

Figure 54. O-C diagram of GQ Ori

Table 84. O-C residuals for GQ Ori

Norm.max. JD2400000+	E	O-C	W	Reference
41066.557	-201	0.053	2	Pel (1976)
41368.070	-166	-0.004	3	Wachmann (1976)
42798.348	0	-0.029	3	Szabados (1980)
44392.411*	185	0.022	3	Moffett & Barnes (1984)
44599.171*	209	-0.009	2	Eggen (1985)
44986.928*	254	0.015	3	Moffett & Barnes (1984)

SV Persei

The O-C residuals listed in Table 85 have been computed with the elements:

$$C = 2443839.303 + 11\overset{d}{.}129319 \cdot E \qquad (63)$$
$$\pm.008 \quad \pm.000019$$

The plot of the O-C residuals in Figure 55 shows that a phase shift might have occurred. This has been already pointed out in Paper III. The pulsation period was 11.129027 ± 0.000183 days before J.D. 2426000, and a

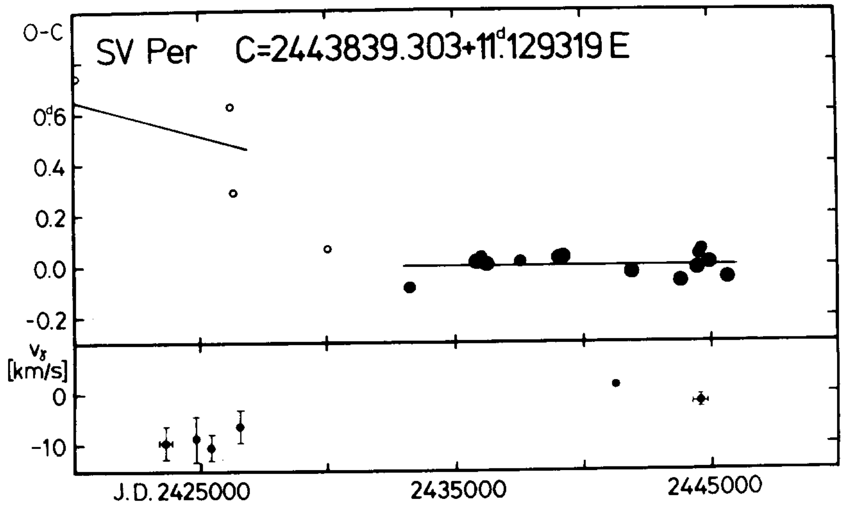

Figure 55. Upper panel: O-C diagram of SV Per
Lower panel: γ-velocities for the same Cepheid

Table 85. O-C residuals for SV Per

Norm.max. JD2400000+	E	O-C	W	Reference
17930.893	-2328	0.645	1	Enebo (1908)
18298.108	-2295	0.592	1	Enebo (1909)
18977.140	-2234	0.736	1	Enebo (1914)
20112.339	-2132	0.744	1	Enebo (1914)
26288.996	-1577	0.629	1	Kukarkin (1940)
26377.692	-1569	0.291	1	Rügemer (1932)
30027.889	-1241	0.071		Mergentaler (1948)
33232.980	-953	-0.082	2	Eggen et al. (1957)
35848.470	-718	0.018	3	Bahner & Mavridis (1977)
36260.245	-681	0.008	3	Bahner & Mavridis (1977)
37595.773	-561	0.018	2	Mitchell et al. (1964)
39075.985	-428	0.030	3	Takase (1969)
39209.541	-416	0.035	3	Wamsteker (1972)
41913.906	-173	-0.025	3	Vasil'yanovskaya (1977)
43839.246	0	-0.057	3	Szabados (1981)
44473.663*	57	-0.011	3	Moffett & Barnes (1984)
44529.365*	62	0.044	2	Eggen (1983b)
44651.810*	73	0.067	2	present paper
44963.375*	101	0.011	3	Moffett & Barnes (1984)
45686.725*	166	-0.045	3	Berdnikov (1986)

phase shift of about -0.3 day might occur between J.D. 2426000 and 2430000. Since most of the early O-C residuals are based on visual observations, the phase jump cannot be determined as clearly as in the cases when more accurate observations are also available.

Table 86. γ-velocities of SV Per

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
23635	264	-9.4	3.2	3	Joy (1937)
24822	18	-8.6	4.5	2	Joy (1937)
25413	157	-10.3	2.6	4	Joy (1937)
26572	30	-6.3	3.2	3	Joy (1937)
41252	1	1.8	0.1	3	Lloyd Evans (1984)
44586	290	-1.7	0.9	20	Barnes et al. (1988)

The γ-velocities listed in Table 86 confirm the previous conclusion drawn by *Lloyd Evans* (1984) about the spectroscopic binary nature of SV Per. The blue companion suspected from photometry (*Madore*, 1977) has been discovered in the ultraviolet spectrum of this Cepheid (*Böhm-Vitense* and *Proffitt*, 1985). The orbital period might not be very short, because *Gieren* and *Brieva* (1990) found no evidence for variable γ-velocity between 1971 and 1987.

VX Persei

The old O-C residuals corrected according to the new normal curve, supplemented with the more recent residuals (see Table 87) indicate a changing period (see Figure 56). The new ephemeris used in the present study is as follows:

$$C = 2443759.184 + 10^{d}.886972 \cdot E \qquad (64)$$
$$\pm.017 \qquad \pm.000142$$

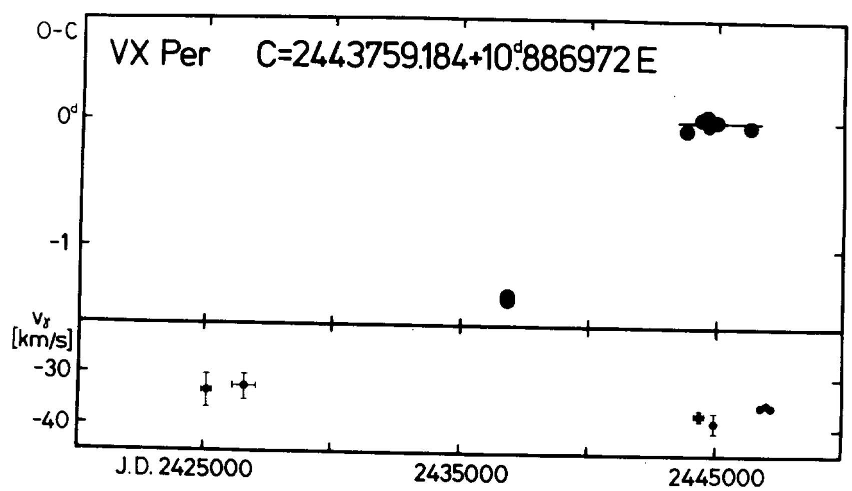

Figure 56. Upper panel: O-C diagram of VX Per
Lower panel: γ-velocities for the same Cepheid

Table 87. O-C residuals for VX Per

Norm.max. JD2400000+	E	O-C	W	Reference
36811.935	-638	-1.361	3	Oosterhoff (1960)
36822.785	-637	-1.398	3	Weaver et al. (1960)
43759.125	0	-0.059	3	Szabados (1981)
44358.001*	55	0.034	3	Moffett & Barnes (1984)
44532.214*	71	0.055	3	Eggen (1983b)
44651.885*	82	-0.031	2	present paper
44956.767*	110	0.016	3	Moffett & Barnes (1984)
46284.936*	232	-0.026	3	Berdnikov (1987)

Table 88. γ-velocities of VX Per

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25113	193	-33.3	3.2	3	Joy (1937)
26626	477	-32.4	2.6	4	Joy (1937)
44386	178	-37.0	1.0	18	Barnes et al. (1988)
44948	57	-38.4	2.0	5	Barnes et al. (1988)
46767	64	-35.3	0.1	56	Coker et al. (1989)
47004	15	-34.8	0.3	7	Metzger et al. (1990)
47124	63	-35.4	0.2	6	Coker et al. (1989)

Before J.D. 2443000 the pulsation period was longer, but an accurate value of the period for the previous epochs cannot be determined due to the paucity of data. A parabolic O-C graph, i.e. a continuously decreasing period is also possible, and photometric observations to be obtained in the near future will give a definitive answer for this problem.

The γ-velocity of VX Per can be considered as stable (see the values listed in Table 88). No other evidence exists for the duplicity of this Cepheid.

AS Persei

The recent high quality photoelectric observations (especially those obtained by *Moffett* and *Barnes*, 1984) do not support the hypothesis raised in Paper I concerning the changing pulsational amplitude of AS Per. The O-C residuals listed in Table 89 (see also Figure 57) have been obtained using the elements:

$$C = \underset{\pm.004}{2441723.941} + \underset{\pm.000007}{4^{d}.972540}\cdot E \qquad (65)$$

The pulsation period of AS Per has remained constant since the beginning of the photoelectric observations.

The available radial velocity observations (*Joy*, 1937) are not sufficient for the reliable determination of the γ-velocity, therefore new radial velocity observations would be valuable.

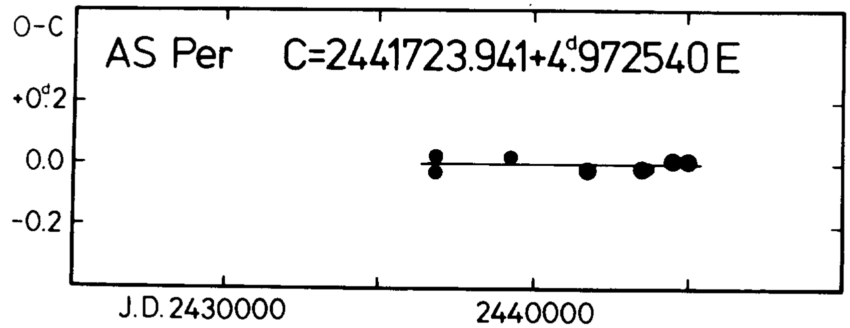

Figure 57. O-C diagram of AS Per

Table 89. O-C residuals for AS Per

Norm.max. JD2400000+	E	O-C	W	Reference
36816.019	-987	-0.025	2	Weaver et al. (1960)
36821.041	-986	0.024	2	Oosterhoff (1960)
39252.614	-497	0.025	2	Takase (1969)
41723.922	0	-0.019	3	Szabados (1977)
43484.207*	354	-0.013	3	present paper
43688.080*	395	-0.014	2	Henden (1979)
44473.768*	553	0.012	3	Moffett & Barnes (1984)
44971.024*	653	0.014	3	Moffett & Barnes (1984)

AW Persei

This Cepheid, belonging to a wide binary system, has become a popular object among the observers. The behaviour of AW Per is best described by

Table 90. O-C residuals for AW Per

Norm.max. JD2400000+	E	O-C	W	Reference
29070.812	-2110	-0.021	1	Opolski (1948)
32865.073	-1523	0.094	1	Erleksova (1961)
35463.438	-1121	0.083	1	Erleksova (1961)
36109.735	-1021	0.018	3	Bahner & Mavridis (1977)
36426.431	-972	-0.003	1	Erleksova (1961)
36820.711	-911	-0.004	3	Oosterhoff (1960)
36827.181	-910	0.002	3	Weaver et al. (1960)
39503.063	-496	-0.055	3	Wamsteker (1972)
40155.863*	-395	-0.081	1	Feltz & McNamara (1980)
40996.175*	-265	-0.040	2	Feltz & McNamara (1980)
40996.204	-265	-0.011	2	Evans (1976)
42709.062	0	-0.013	3	Szabados (1980)
43704.490*	154	0.017	3	Moffett & Barnes (1984)
44079.371*	212	0.008	3	Moffett & Barnes (1984)
44641.665*	299	-0.033	1	present paper
46477.402*	583	0.035	2	present paper
47311.211*	712	0.037	2	present paper

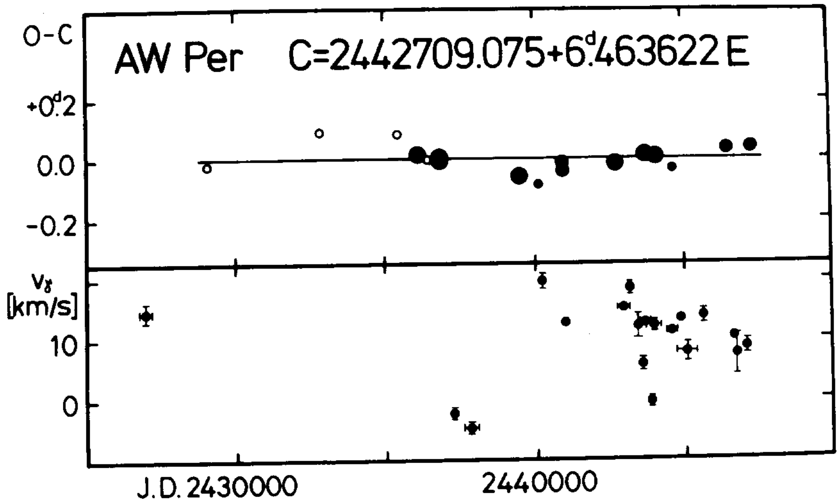

Figure 58. Upper panel: O-C diagram of AW Per
Lower panel: γ-velocities for the same Cepheid

Table 91. γ-velocities of AW Per

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
26981	188	14.8	1.6	9	Joy (1937)
37247	33	-2.1	0.9	8	Miller & Preston (1964b)
37798	223	-4.5	0.9	9	Miller & Preston (1964b)
40214	43	19.7	1.2	2	Welch & Evans (1989)
40971	4	12.9	0.4	3	Evans (1976)
42989	188	15.3	0.2	7	Griffin (1982) *
43155	2	18.5	1.0	2	McNamara & Chapman (1977)
43408	49	12.3	2.0	5	Wilson et al. (1989)
43559	15	6.0	1.0	2	Evans (1983)
43639	179	12.9	0.2	11	Griffin (1982) *
43821	1	-0.3	0.8	1	Beavers & Eitter (1986)
43962	220	12.3	0.8	25	Barnes et al. (1987)
44549	169	11.5	0.2	14	Griffin (1982) *
44836	159	13.4	0.4	5	Evans (1983)
45036	373	8.0	1.6	6	Barnes et al. (1987)
45610	1	13.9	1.2	1	Welch & Evans (1989)
46639	118	10.5	0.4	12	Welch & Evans (1989)
46727	1	7.5	3.4	2	present paper
47091	4	8.8	1.2	2	Welch & Evans (1989)

* Observer: T. Lloyd Evans

Welch and *Evans* (1989), and the additional photometric and spectroscopic data analysed here confirm their results. The O-C residuals listed in Table 90 have been calculated with the formula:

$$C = 2442709.075 + 6\overset{d}{.}463622 \cdot E \qquad (66)$$
$$\pm.007 \quad \pm.000009$$

The plot of the O-C residuals in Figure 58 clearly shows the wave-like pattern due to the orbital motion. The light-time effect keeps on being consistent with the phase of the γ-velocity variation.

In addition to the radial velocity data analysed by *Welch* and *Evans* (1989), Table 91 also lists some other γ-velocity values that have not been used for deriving the orbit of AW Persei, including that obtained from *Lloyd Evans'* radial velocity measurements (*Griffin*, 1982), and from the two spectra taken by the author at Rozhen Observatory (see Table 109). The γ-velocity values plotted in the lower panel of Figure 58 well demonstrate the long orbital period: 13100 $\pm$ 100 days, as determined by *Welch* and *Evans* (1989).

In view of its importance, regular photometric observations of AW Per will continue at Konkoly.

V440 Persei

Due to the short time-base of the available photometric observations, the shape of the O-C graph cannot be determined reliably. The O-C residuals listed in Table 92 have been obtained using the linear ephemeris:

$$C = \underset{\pm.014}{2444551.137} + \underset{\pm.000074}{7^{d}_{\cdot}572498} \cdot E \qquad (67)$$

Further observations are necessary to decide whether an additional parabolic term would give a better fit when predicting the forthcoming light maxima (cf. Figure 59).

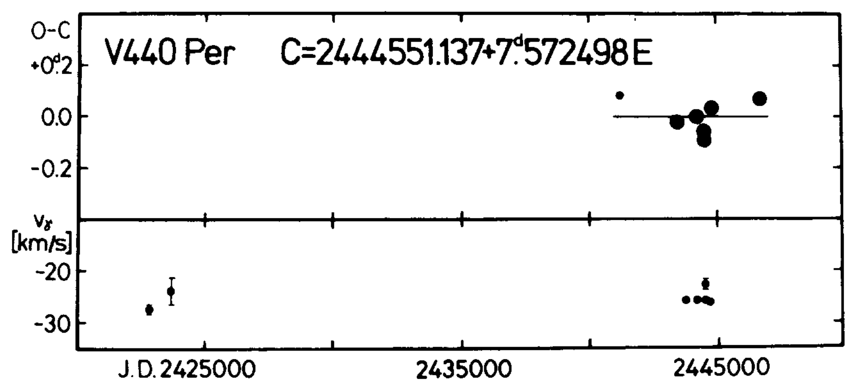

Figure 59. Upper panel: O-C diagram of V440 Per
Lower panel: γ-velocities for the same Cepheid

Table 92. O-C residuals for V440 Per

Norm.max. JD2400000+	E	O-C	W	Reference
41219.322*	-440	0.084	2	Burki & Benz (1982)
43483.394	-141	-0.021	3	Szabados (1980)
44240.668*	-41	0.003	3	Burki & Benz (1982)
44528.363*	-3	-0.057	3	Eggen (1985)
44551.047*	0	-0.090	3	Burki & Benz (1982)
44869.217*	42	0.035	3	Arellano Ferro (1984)
46724.514*	287	0.070	3	Arellano Ferro et al. (1987)

Table 93. γ-velocities of V440 Per

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
22863	107	-27.4	0.9	6	Abt (1970)
23699	28	-23.7	2.5	2	Plaskett (1934)
43796	126	-25.6	0.1	18	Burki & Benz (1982)
44202	24	-25.6	0.1	23	Burki & Benz (1982)
44525	1	-22.4	0.8	2	Beavers & Eitter (1986)
44559	67	-25.6	0.1	19	Burki & Benz (1982)
44712	136	-25.8	0.4	15	Arellano Ferro (1984)

The γ-velocities of V440 Per are listed in Table 93. Although the γ-velocity seems to be constant, the variable star may have a companion, but the inclination of the orbit is unfavourable for detecting the orbital motion. In addition to the fact that *Usenko* (1990b) assumes a B8 type photometric companion, the suspicion supporting the existence of the companion is based on the relatively large radial velocity amplitude, as compared with the amplitude of the light variation. It is obvious that a companion star tends to diminish the photometric amplitude of the variable, and does not influence the pulsational radial velocity amplitude (i.e. having removed the orbital effect). The binary Cepheids usually have a larger ratio of radial velocity amplitude per light variation amplitude (*Szabados*, unpublished). A detailed analysis of this effect is in progress.

S Sagittae

The reliable earlier O-C residuals taken from Paper II have been supplemented with the O-C values derived from the more recently published photoelectric observations (see Table 94). The O-C residuals (partly plotted in Figure 60) have been approximated with a parabola instead of two intersecting straight lines, as suggested in Paper II. The O-C residuals in Table 94 have been computed with the formula:

$$C = 2442678.821 + 8^{d}.382146 \cdot E \qquad (68)$$
$$\pm.021 \quad \pm.000029$$

Table 94. O-C residuals for S Sge

Norm.max. JD2400000+	E	O-C	W	Reference
09829.793	-3919	0.602	1	Gore (1886)
09888.258	-3912	0.392	1	Gore (1886)
10164.999	-3879	0.522	1	Gore (1887)
10567.248	-3831	0.428	1	Gore (1888)
11263.052	-3748	0.514	1	Gore (1890)
11615.078	-3706	0.490	1	Gore (1891)
11975.160	-3663	0.140	1	Markwick (1892)
14196.461	-3398	0.172	1	Pickering (1904)
14934.134	-3310	0.216	1	Prittwitz (1901)
16082.542	-3173	0.270	1	Tass (1925)
16761.439	-3092	0.213	1	Lau (1907)
16803.375	-3087	0.239	1	Tass (1925)
17062.887	-3056	-0.096	1	Wilkens (1906)
17632.674	-2988	-0.295	1	Jordan (1919)
17850.862	-2962	-0.043	1	Hertzsprung (1909)
17851.029	-2962	0.124	1	Nijland (1923)
17851.054	-2962	0.149	1	Zeipel (1908)
18035.437	-2940	0.125	1	Tass (1925)
18152.813	-2926	0.151	1	Nijland (1923)
18521.561	-2882	0.085	1	Nijland (1923)
18806.555	-2848	0.086	1	Nijland (1923)
18957.443	-2830	0.095	2	Hertzsprung (1917)
19317.859	-2787	0.079	2	Hertzsprung (1917)
21061.385	-2579	0.119	1	Luyten (1922)
21488.867	-2528	0.111	1	Lacchini (1921)
21748.891	-2497	0.289	1	Luyten (1922)
22192.987	-2444	0.131	1	Leiner (1926)
22897.156	-2360	0.200	1	Eaton (1920, 1921, 1922) & Walker (1921, 1922)
23316.013	-2310	-0.051	1	Nielsen (1927c)
23333.038	-2308	0.210	1	AFOEV (1922, 1923)
24213.006	-2203	0.053	1	Parenago (1938)
24690.941	-2146	0.205	1	Leiner (1938)
24774.587	-2136	0.030	1	Kukarkin (1940)
25134.962	-2093	-0.027	1	Hellerich (1935)
25386.645	-2063	0.191	1	Leiner (1938)
25445.085	-2056	-0.044	1	Zverev (1936)
25453.702	-2055	0.191	1	Kukarkin (1940)
25797.187	-2014	0.008	1	Zverev (1936)
25847.689	-2008	0.217	1	Leiner (1938)
26182.943	-1968	0.185	1	Leiner (1938)
26384.157	-1944	0.228	1	Parenago (1938)
26451.214	-1936	0.228	1	Kukarkin (1940)
26476.126	-1933	-0.007	1	Zverev (1936)
26794.741	-1895	0.087	1	Kox (1935)
26920.633	-1880	0.246	1	Florya & Kukarkina (1953)
27591.056	-1800	0.010	1	Krebs (1935)
28001.975	-1751	0.292	1	Krebs (1936)
29091.599	-1621	0.237	1	Leiner (1938)
29141.833	-1615	0.178	3	Bennett (1939)
33131.605	-1139	0.048	3	Eggen (1951)
33198.520	-1131	-0.094	1	Solov'yov (1959)
34036.880	-1031	0.052	1	Solov'yov (1959)
34598.351	-964	-0.081	1	Solov'yov (1959)

Table 94. (cont.)

Norm.max. JD2400000+	E	O-C	W	Reference
34615.241	-962	0.044	3	Szabados (1980)
35285.815	-882	0.047	2	Irwin (1961)
35403.191	-868	0.073	1	Solov'yov (1959)
35730.121	-829	0.099	3	Prokof'yeva (1961)
35730.154	-829	0.132	1	Solov'yov (1959)
36048.551	-791	0.007	1	Solov'yov (1959)
36190.964	-774	-0.076	1	Latyshev (1969)
36207.768	-772	-0.036	1	Svolopoulos (1960)
36450.962	-743	0.075	1	Solov'yov (1959)
36459.445	-742	0.176	1	Solov'yov (1959)
36509.621	-736	0.059	3	Walraven et al. (1958)
36718.940	-711	-0.175	1	Azarnova (1960b)
37213.656	-652	-0.006	3	Mitchell et al. (1964)
37917.700	-568	-0.062	3	Walraven et al. (1964)
39040.928	-434	-0.042	3	Wisniewski & Johnson (1968)
40440.802*	-267	0.014	3	Feltz & McNamara (1980)
40834.696	-220	-0.053	2	Evans (1976)
41220.269*	-174	-0.059	2	Feltz & McNamara (1980)
42595.144	-10	0.144	1	Berdnikov (1977)
42678.783	0	-0.038	3	Szabados (1980)
43340.987*	79	-0.024	3	Moffett & Barnes (1984)
43835.505*	138	-0.052	3	Moffett & Barnes (1984)
44808.023*	254	0.137	1	present paper
46643.574*	473	-0.002	2	present paper

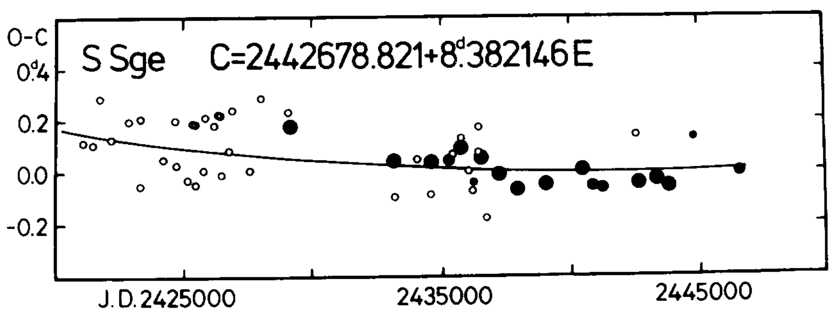

Figure 60. O-C diagram of S Sge

The continuous period increase is given by the equation:

$$P = 8\overset{d}{.}382146 + 4\overset{d}{.}4\cdot10^{-8}\cdot E \quad (69)$$
$$\pm.000029 \quad \pm1.6$$

Future photoelectric observations are needed to decide whether the deviations from the parabola are systematic or random. It is clear, however, that the light-time effect expected from the orbital motion is much less than the detection limit.

S Sge is one of the best studied binary Cepheids, therefore no attempt was made here for determining the orbital elements. A single new radial velocity value obtained with the 2m telescope in Rozhen is, however, listed in Table 109. The most recent results concerning the duplicity of S Sge are published by *Slovak* and *Barnes* (1987) (P_{orb} = 676.2 days), *Evans* et al. (1989), and *Slovak* et al. (1989). The two latter papers put forward evidence for a third component in the system, what makes S Sge an even more interesting object for future observations.

SW Tauri

The previously determined O-C residuals (see Paper I) have been corrected according to the new normal light curve based on the superior observations made by *Moffett* and *Barnes* (1984). The corrected and the newly determined O-C residuals are all listed in Table 95. The plot of these residuals in Figure 61 shows a parabolic shape instead of the occurrence of a single period change suggested in Paper I. The new ephemeris used when determining the O-C values is as follows:

$$C = 2441687.762 + 1^{d}.583577 \cdot E \qquad (70)$$
$$\pm.003 \qquad \pm.000001$$

The continuous period decrease can be computed from the formula:

$$P = 1^{d}.583577 - 7^{d}.13 \cdot 10^{-9} \cdot E \qquad (71)$$
$$\pm.000001 \qquad \pm.54$$

This slight and smooth period change is atypical of the short period Population II Cepheids.

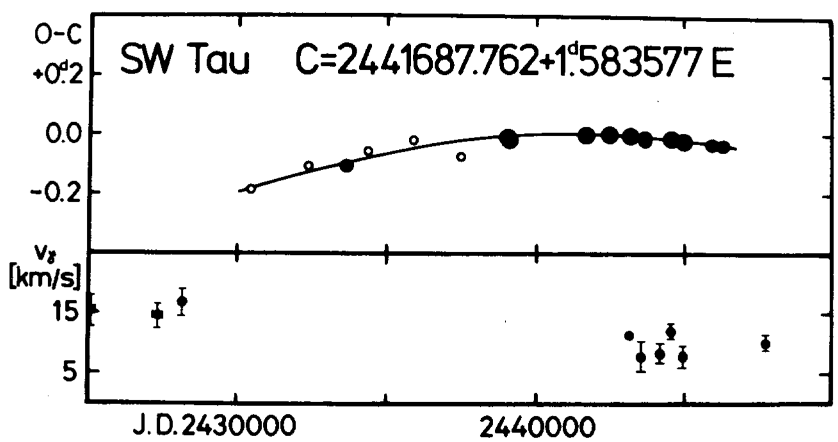

Figure 61. Upper panel: O-C diagram of SW Tau
Lower panel: γ-velocities for the same Cepheid

Table 95. O-C residuals for SW Tau

Norm.max. JD2400000+	E	O-C	W	Reference
30434.681	-7106	-0.183	1	Solov'yov (1957)
32354.052	-5894	-0.107	1	Borzdyko (1965)
33638.337	-5083	-0.103	2	Eggen et al. (1957)
34377.911	-4616	-0.059	1	Borzdyko (1965)
35879.185	-3668	-0.017	1	Borzdyko (1965)
37465.873	-2666	-0.073	1	Mandel' (1970)
39059.018	-1660	-0.006	3	Milone (1970)
39078.014	-1648	-0.013	3	Wamsteker (1972)
41687.762	0	0.000	3	Szabados (1977)
42455.800*	485	0.003	3	Dean et al. (1977)
43166.821*	934	-0.002	3	Stobie & Balona (1979)
43176.324	940	0.000	2	Szabados (1977)
43630.795*	1227	-0.016	2	Henden (1979)
43675.141*	1255	-0.010	2	Diethelm & Tammann (1982)
44519.188*	1788	-0.010	3	Moffett & Barnes (1984)
44994.253*	2088	-0.018	3	Moffett & Barnes (1984)
45966.558*	2702	-0.029	2	Diethelm (1986)
46337.110*	2936	-0.034	2	Wallerstein (1987)

Table 96. γ-velocities of SW Tau

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
24993	176	15.3	2.6	4	Joy (1937)
27343	174	14.6	2.0	6	Joy (1937)
28175	59	16.8	2.3	5	Joy (1937)
43139	26	11.5	0.6	17	Stobie & Balona (1979)
43526	1	8.0	2.5	1	Stobie & Balona (1979)
44187	29	8.6	1.6	7	Barnes et al. (1988)
44555	49	12.2	1.3	10	Barnes et al. (1988)
44948	51	8.0	1.8	6	Barnes et al. (1988)
47793	1	10.4	1.2	1	Samus (1990)

The γ-velocity of SW Tau seems to be variable (see Table 96 and the lower panel of Figure 61). Nevertheless, further radial velocity observations are necessary to confirm the duplicity of this variable star.

SZ Tauri

A rejump to an earlier pulsation period was reported in Paper I. Since then a new period change has occurred (*Trammell*, 1987), and interestingly enough, the new period is almost identical with that valid during the interval 1920 - 1960. The photoelectric O-C residuals listed in Table 97 confirm the new phase jump, though this event took place so slowly that the intermediate period can well be determined (see Figure 62). The current ephemeris used for calculating the O-C residuals is as follows:

$$C = 2441659.262 + 3^{d}.149138 \cdot E \qquad (72)$$
$$\pm.032 \quad \pm.000043$$

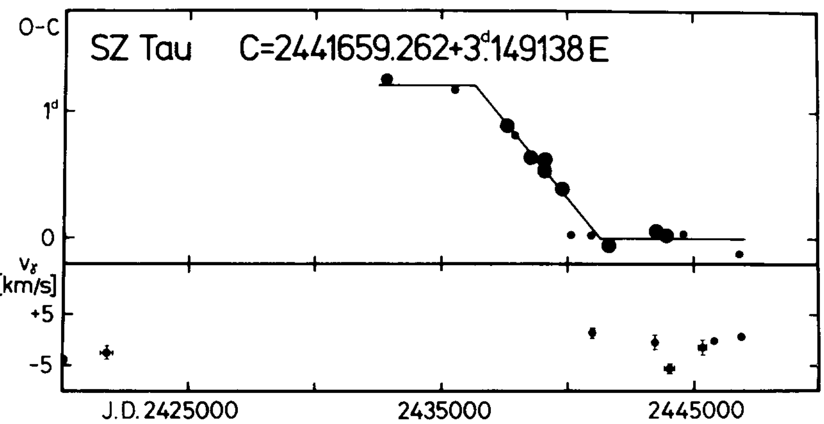

Figure 62. Upper panel: O-C diagram of SZ Tau
Lower panel: γ-velocities for the same Cepheid

Table 97. O-C residuals for SZ Tau

Norm.max. JD2400000+	E	O-C	W	Reference
32852.379	-2797	1.256	2	Eggen (1951)
35541.659	-1943	1.172	1	Walraven et al. (1958)
37619.809	-1283	0.891	3	Mitchell et al. (1964)
37962.988	-1174	0.814	1	Williams (1966)
38529.659	-994	0.640	3	Wisniewski & Johnson (1968)
39055.461	-827	0.536	3	Milone (1970)
39077.600	-820	0.631	3	Wamsteker (1972)
39807.965	-588	0.396	3	Szabados (1977)
40147.996*	-480	0.032	1	Feltz & McNamara (1980)
40991.677*	-212	0.032	1	Feltz & McNamara (1980)
41659.204	0	-0.058	3	Szabados (1977)
43520.462*	591	0.059	3	Moffett & Barnes (1984)
43926.666*	720	0.025	3	Moffett & Barnes (1984)
44647.837*	949	0.043	1	present paper
46845.772*	1647	-0.120	1	Trammell (1987)

The earlier values of the pulsation period have not been determined again, these values are taken from Paper I:

before J.D. 2418500	P = 3.14839 days,
between J.D. 2425500 and 2436300	P = 3.149057 days,
between J.D. 2436300 and 2441300	P = 3.148380 days,
after J.D. 2441300	P = 3.149138 days.

Because of the stepwise O-C graph, i.e. the phenomenon of the phase jump, SZ Tau probably belongs to a binary system, as well. The existence of a bright blue companion is, however, doubtful (see *Leonard* and *Turner*, 1986, and the references therein). As can be seen in the lower panel of

Table 98. γ-velocities of SZ Tau

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
20095	49	-3.7	0.6	30	Haynes (1914)
21784	236	-2.5	1.2	4	Abt (1970)
40972	10	1.4	0.8	5	Schmidt (1974)
43449	59	-0.3	1.4	9	Wilson et al. (1989)
44011	220	-5.5	0.8	25	Barnes et al. (1987)
45311	147	-1.3	1.5	8	Barnes et al. (1987)
45721	8	-0.1	0.1	36	Gieren (1985)
46866	1	0.9	0.5	2	Samus (1990)

Figure 62, and in the data listed in Table 98, the γ-velocity of SZ Tau might be variable. The spectroscopic binary nature of SZ Tau, however, needs confirmation.

SZ Tau is an important object because of one more reason, viz. its possible membership in the open cluster NGC 1647 (*Walker*, 1987; *Gieren*, 1988).

S Vulpeculae

S Vul is one of the longest period Cepheids in our Galaxy. Its pulsation period has been strongly varying (*Mahmoud* and *Szabados*, 1980), and the latest period change just noticeable in 1980 now can be traced. The O-C residuals listed in Table 99, and shown plotted in Figure 63 have been obtained with the elements:

$$C = 2444147.692 + 68^d.500 \cdot E \qquad (73)$$
$$\pm.518 \quad \pm.027$$

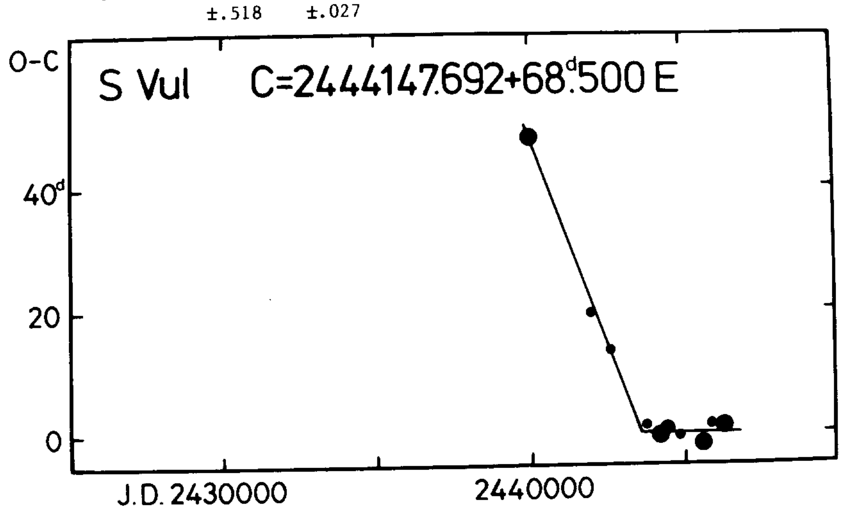

Figure 63. O-C diagram of S Vul

Table 99. O-C residuals for S Vul

Norm.max. JD2400000+	E	O-C	W	Reference
40017.349	-61	48.157	3	Fernie (1970)
41975.061*	-32	19.369	1	Schmidt (1976)
42585.601*	-23	13.409	1	Dawson (1979)
43738.161	-6	1.469	1	Turner (1980)
44147.253	0	-0.439	3	Mahmoud & Szabados (1980)
44422.573	4	0.881	2	Mahmoud & Szabados (1980)
44832.141*	10	-0.551	1	present paper
45584.257*	21	-1.935	3	Berdnikov & Ivanov (1986)
45861.682*	25	1.490	1	Berdnikov & Ivanov (1986)
46272.203*	31	1.011	3	Berdnikov & Ivanov (1986)

The available radial velocity data do not permit even the reliable determination of the γ-velocity, but as a matter of fact, no evidence can be found in the literature regarding the duplicity of S Vul.

T Vulpeculae

A new normal light curve has been determined on the basis of the photoelectric observations made by *Moffett* and *Barnes* (1984). The new O-C residuals (listed in Table 100) have been determined with the help of this normal curve, and the O-C residuals published earlier in Paper I have been corrected accordingly. The best linear fit to the data points after J.D. 2434500 is as follows:

$$C = 2441705.127 + 4\overset{d}{.}435453 \cdot E \qquad (74)$$
$$\pm.007 \qquad \pm.000009$$

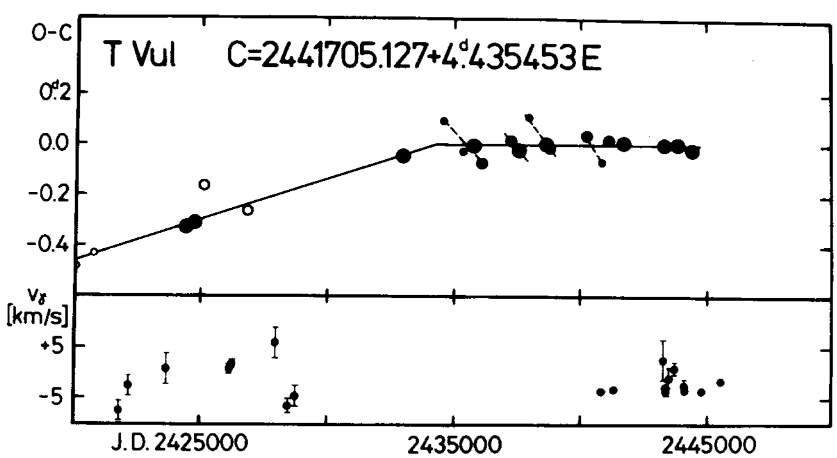

Figure 64. Upper panel: O-C diagram of T Vul
Lower panel: γ-velocities for the same Cepheid

Table 100. O-C residuals for T Vul

Norm.max. JD2400000+	E	O-C	W	Reference
20001.972	-4893	-0.483		Hertzsprung (1919)
20747.181	-4725	-0.431		Hertzsprung (1919)
24375.483	-3907	-0.329		Huffer (1928a)
24721.463	-3829	-0.314		Huffer (1928a)
25116.367	-3740	-0.166		Hellerich (1935)
26859.398	-3347	-0.268		Kox (1935)
32967.242	-1970	-0.043		Eggen (1951)
34595.189	-1603	0.093	1	Szabados (1977)
35362.401	-1430	-0.028	1	Walraven et al. (1958)
35757.181	-1341	-0.004	3	Prokof'yeva (1961)
36098.640	-1264	-0.074	2	Svolopoulos (1960)
37212.028	-1013	0.015	2	Mitchell et al. (1964)
37562.390	-934	-0.024	3	Johansen (1971)
37939.534	-849	0.107	1	Williams (1966)
38649.098	-689	-0.002	3	Johansen (1971)
38733.365	-670	-0.008	2	Wisniewski & Johnson (1968)
40254.769*	-327	0.035	2	Feltz & McNamara (1980)
40853.449*	-192	-0.071	1	Evans (1976)
41128.537*	-130	0.019	2	Feltz & McNamara (1980)
41705.136	0	0.009	3	Szabados (1977)
43359.552*	373	0.001	3	Moffett & Barnes (1984)
43874.070*	489	0.006	3	Moffett & Barnes (1984)
44472.831*	624	-0.019	3	Berdnikov & Bogdanov (1987)

Table 101. γ-velocities of T Vul

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
16683	2	9.0	3.0	2	Frost (1904)
16699	19	-1.5	1.5	5	Albrecht (1907)
16765	11	-3.8	3.0	2	Albrecht (1907)
17093	18	1.0	1.5	5	Albrecht (1907)
17151	19	-1.4	0.6	24	Albrecht (1907)
17214	3	-3.5	3.0	2	Albrecht (1907)
17438	7	-0.8	0.8	14	Albrecht (1907)
21796	2	-7.5	2.0	2	Abt (1973)
22166	68	-2.5	2.0	2	Abt (1973)
23622	11	0.8	3.0	2	Harper (1934)
26179	10	0.9	0.9	12	Lüst-Kulka (1954)
26220	14	1.8	0.8	16	Lüst-Kulka (1954)
27995	1	5.8	3.0	1	Young (1939)
28450	1	-6.4	1.4	3	Abt (1973)
28760	32	-4.5	2.1	3	Young (1939)
40825	24	-3.2	0.3	4	Evans (1976)
41336	11	-2.8	0.4	3	Evans (1976)
43293	1	2.8	4.0	2	Wilson et al. (1989)
43327	33	-2.4	0.3	3	Evans & Lyons (1986)
43377	46	-3.2	0.4	5	Beavers & Eitter (1986)
43382	4	-3.2	0.9	21	Wilson et al. (1989)
43500	5	-0.7	2.0	5	Wilson et al. (1989)
43735	69	1.1	1.2	11	Barnes et al. (1987)
44134	81	-2.2	1.1	12	Barnes et al. (1987)
44136	36	-2.8	0.2	4	Evans & Lyons (1986)
44811	1	-3.2	0.4	1	Evans & Lyons (1986)
45539	24	-1.6	0.2	4	Evans & Lyons (1986)

Before J.D. 2434500 the pulsation period was somewhat longer (see Figure 64): P = 4.435589 days, as determined in Paper I. Moreover, it cannot be excluded that the period of pulsation before J.D. 2419000 practically coincided with the recent value, i.e. a phase slide occurred between J.D. 2419000 and 2434500. This phenomenon cannot be followed in Figure 64, because the early visual observations have not been analysed here. Another kind of phase jump can, however, be suspected in the recent part of the O-C graph. In Figure 64 dashed lines indicate these assumed phase jumps. The quasi-period in the recurrence of these jumps is the same as the value of the orbital period of T Vul discussed below. This phenomenon is similar to that observed in Y Oph (see Paper IV, p. 39).

The variation in the γ-velocity exceeds the limit that could be attributed to the observational uncertainty. The considerably large number of the γ-velocities listed in Table 101 (and partly plotted in the lower panel of Figure 64) has been analysed for the possible periodicity. A reasonably good "orbital" radial velocity curve could be obtained at a period of 1745 days. This phase diagram is plotted in Figure 65. The only strongly deviating γ-velocity is the point determined from *Frost*'s (1904) two radial velocity measurements, being the earliest velocity data for T Vul. Interestingly enough, *Kovács* et al. (1990) also found a long periodicity in the radial velocity data (their sample was a subset of the data studied here), but the period of 738 days discovered by them cannot be revealed from the present sample. The strong coincidence of the 1745 day period with the cycle length of the subtle phase jumps in the O-C diagram

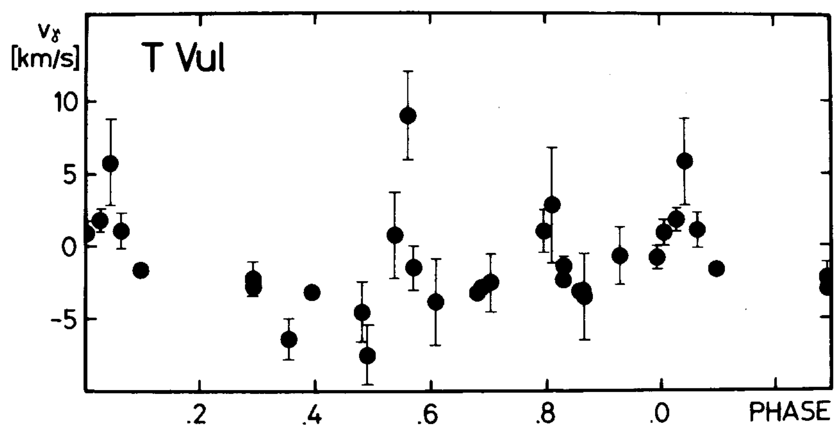

Figure 65. γ-velocity values of T Vul folded with the 1745 day period

confirm the author's belief that this longer period represents the orbital period of the binary system containing T Vul. The presence of a companion star has already been suspected by *Kurochkin* (1966).

Extensive photometric and spectroscopic observations would be necessary to obtain a more reliable picture on the duplicity of T Vul.

U Vulpeculae

The O-C diagram covering almost a century was approximated with a single straight line in Paper II. The photoelectric O-C residuals supplemented with some more data published in the eighties (see Table 102 and Figure 66) are better represented by two linear sections. It has to be noted that the extrapolation of this alternating period change towards the earlier visual observations also gives a reasonably good fit to the O-C residuals. The O-C residuals listed in Table 102 have been obtained with the elements:

$$C = 2442526.312 + 7^{d}.990821 \cdot E \qquad (75)$$
$$\pm.006 \quad \pm.000026$$

The γ-velocities of U Vul show an intrinsic variation (see Table 103 and the lower panel of Figure 66) which can be explained with the duplicity of U Vul. The existence of a companion was already suspected by *Kurochkin* (1966). The γ-velocities derived from *Sanford*'s (1928) radial velocity data indicate that the orbital period might not be too long (i.e. much longer than 1000 days). The formal period search routine applied to

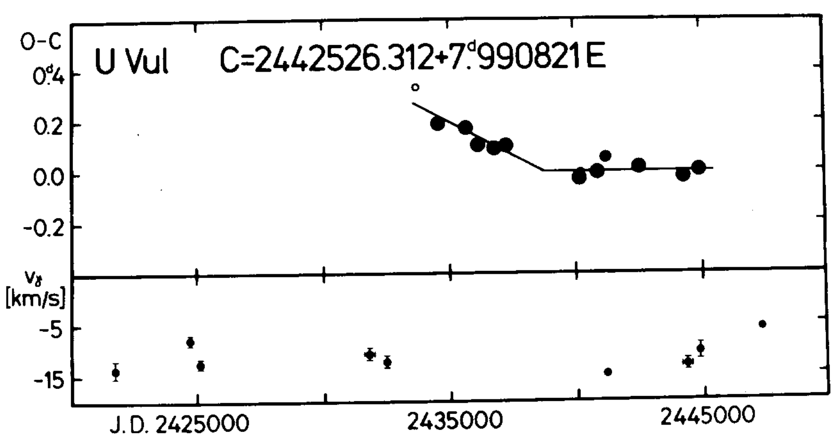

Figure 66. Upper panel: O-C diagram of U Vul
Lower panel: γ-velocities for the same Cepheid

Table 102. O-C residuals for U Vul

Norm.max. JD2400000+	E	O-C	W	Reference
33704.781	-1104	0.335	1	Chuprina (1952)
34591.618	-993	0.191	3	Szabados (1980)
35638.397	-862	0.173	3	Walraven et al. (1958)
36125.772	-801	0.108	3	Bahner & Mavridis (1971)
36781.008	-719	0.096	3	Weaver et al. (1960)
37244.483	-661	0.104	3	Mitchell et al. (1964)
40121.046	-301	-0.029	3	Asteriadis et al. (1977)
40208.971*	-290	-0.003	1	Feltz & McNamara (1980)
40840.247	-211	-0.002	3	Evans (1976)
41199.889*	-166	0.053	2	Feltz & McNamara (1980)
42526.328	0	0.016	3	Szabados (1980)
44292.262*	221	-0.021	3	Moffett & Barnes (1984)
44923.562*	300	0.004	3	Moffett & Barnes (1984)

Table 103. γ-velocities of U Vul

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
21759	28	-13.5	1.7	4	Sanford (1928)
24745	39	-7.9	0.9	13	Sanford (1928)
25111	48	-12.5	0.9	13	Sanford (1928)
31776	185	-10.5	1.2	7	Sanford (1951)
32494	128	-12.1	1.2	7	Sanford (1951)
41067	116	-14.7	0.3	6	Evans (1976)
44369	219	-13.0	1.1	15	Barnes et al. (1988)
44877	76	-10.5	1.6	7	Barnes et al. (1988)
47365	1	-6.1	0.4	1	Samus (1990)

the γ-velocity values of U Vul resulted in the orbital period of 868 days. This value, however, cannot be accepted without reservation. The determination of the true value of the orbital period is not possible without performing new radial velocity measurements. Photometric observations would be necessary, as well, in order to study whether the alternating period changes represent a kind of phase jump (or phase slide) characteristic of binary Cepheids. It is clear, however, that the alternating period changes cannot be replaced with a sinusoidal wave caused by the light-time effect, because the γ-velocity data indicate an oscillation in the O-C diagram that would hardly be detected.

X Vulpeculae

The O-C residuals of X Vul listed in Table 104 have been obtained using the ephemeris:

$$C = 2442665.932 + 6.^{d}319490 \cdot E \qquad (76)$$
$$\pm.012 \quad \pm.000022$$

Instead of a single straight line, the O-C plot has been approximated with two sections and a phase jump in between (see Figure 67). This phase jump, however, has to be confirmed.

The γ-velocity of X Vul varies, and this Cepheid probably belongs to a long period spectroscopic binary (see Table 105 and the lower panel of Figure 67). *Moffett* and *Barnes* (1987) also noted the discrepancy between the γ-velocity values determined at two epochs, while *Janot-Pacheco* (1976) suspected a photometric companion.

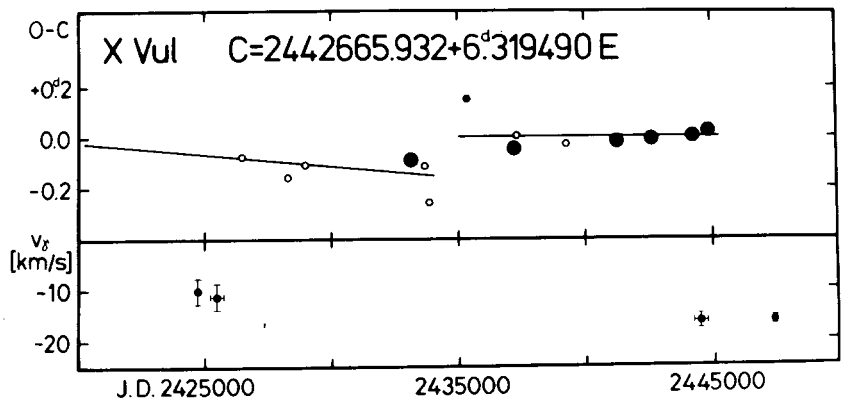

Figure 67. Upper panel: O-C diagram of X Vul
Lower panel: γ-velocities for the same Cepheid

Table 104. O-C residuals for X Vul

Norm.max. JD2400000+	E	O-C	W	Reference
17470.166	-3987	0.041	1	Luizet (1907)
26481.643	-2561	-0.075	1	Kukarkin (1940)
28314.212	-2271	-0.158	1	Azhusenis (1956)
28984.128	-2165	-0.108	1	Azhusenis (1956)
33117.093	-1511	-0.090	3	Eggen (1951)
33692.141	-1420	-0.115	1	Chuprina (1954b)
33868.946	-1392	-0.256	1	Chuprina (1954b)
35354.434	-1157	0.152	1	Walraven et al. (1958)
37205.847	-864	-0.046	3	Mitchell et al. (1964)
37357.564	-840	0.004	1	Boyko (1970)
39291.295	-534	-0.029	1	Boyko (1970)
41294.584*	-217	-0.019	3	Feltz & McNamara (1980)
42665.923	0	-0.009	3	Szabados (1980)
44296.367*	258	0.007	3	Moffett & Barnes (1984)
44909.375*	355	0.024	3	Moffett & Barnes (1984)

Table 105. γ-velocities of X Vul

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
24748	2	-10.1	2.6	4	Joy (1937)
25490	233	-11.2	2.6	4	Joy (1937)
44504	273	-16.2	1.4	9	Barnes et al. (1988)
47361	1	-16.2	0.8	1	Samus (1990)

SV Vulpeculae

SV Vul is a very important Cepheid because of several reasons. Not only is SV Vul one of the longest period Cepheids in our Galaxy, but it is a possible member of the Vul OB1 association (see *Walker*, 1987 and the references therein).

Table 106. O–C residuals for SV Vul

Norm.max. JD2400000+	E	O–C	W	Reference
23244.975	-454	-38.321	1	Kristensen (1923, 1924)
23470.600	-449	-37.730	1	Leiner (1924)
23651.731	-445	-36.626	1	Zakharov (1924a, 1924b)
23877.517	-440	-35.874	1	Kristensen (1926)
23923.562	-439	-34.836	1	Beyer (1930)
23967.607	-438	-35.798	1	Ahnert (1931)
24013.407	-437	-35.004	1	Zakharov (1928)
24148.197	-434	-35.235	1	Leiner (1929)
24329.463	-430	-33.996	1	Zakharov (1928)
24374.633	-429	-33.833	1	Beyer (1930)
24419.533	-428	-33.940	1	Nielsen (1927b)
24511.449	-426	-32.037	1	Ahnert (1931)
24736.039	-421	-32.481	1	Leiner (1929)
24736.624	-421	-31.896	1	Beyer (1930)
24781.299	-420	-31.228	1	Zakharov (1928)
25142.885	-412	-30.696	1	Beyer (1930)
25143.425	-412	-30.156	1	Ahnert (1931)
25369.366	-407	-29.249	1	Leiner (1929)
25550.091	-403	-28.552	1	Beyer (1930)
25865.787	-396	-27.903	1	Ahnert (1931)
25866.102	-396	-27.588	1	Kukarkin (1940)
25955.541	-394	-28.163	1	Zakharov (1954)
26180.987	-389	-27.751	1	Ahnert (1931)
26406.522	-384	-27.250	1	Zverev (1936)
26453.088	-383	-25.691	1	Terkán (1935)
26677.903	-378	-25.910	1	Kukarkin (1940)
26904.924	-373	-23.923	1	Florya & Kukarkina (1953)
27265.565	-365	-23.336	1	Florya & Kukarkina (1953)
28077.230	-347	-21.793	1	Nassau & Ashbrook (1942)
28754.097	-332	-20.028	1	Dziewulski & Iwanowska (1946)
32948.126	-239	-11.632	3	Eggen (1951)
33535.518	-226	-9.328	1	Chuprina (1953)
35340.791	-186	-4.327	1	Walraven et al. (1958)
37232.711	-144	-2.693	3	Mitchell et al. (1964)
37952.866	-128	-2.647	1	Williams (1966)
38268.336	-121	-2.224	3	Fernie et al. (1965)
40654.719*	-68	-1.202	2	Feltz & McNamara (1980)
41329.910*	-53	-1.113	2	Feltz & McNamara (1980)
43085.550	-14	-0.738	3	Fernie (1979a)
43625.769*	-2	-0.600	3	Moffett & Barnes (1984)
43715.229	0	-1.154	3	Szabados (1981)
44075.401*	8	-1.036	3	Moffett & Barnes (1984)
44480.354*	17	-1.145	1	present paper
44525.619*	18	-0.886	2	Eggen (1983b)
45652.558*	43	0.883	3	Berdnikov (1986)
46283.295*	57	1.524	3	Berdnikov (1987)

The behaviour of the period changes of this classical Cepheid continues to be very interesting. As it was pointed out in Paper III, erratic changes appear superimposed on the general parabolic trend of the O-C diagram. The new O-C residuals, as well as the earlier ones (corrected according to the new normal light curve) are listed in Table 106. The plot of these residuals shown in Figure 68 has been obtained with the elements:

$$C = \underset{\pm.181}{2443716.383} + \underset{\pm.0026}{45^{d}\!.0068}\cdot E \tag{77}$$

The parabolic fit, also shown in Figure 68 corresponds to the continuous period decrease:

$$P = \underset{\pm.0026}{45^{d}\!.0068} - \underset{\pm.12}{3^{d}\!.64}\cdot 10^{-4}\cdot E \tag{78}$$

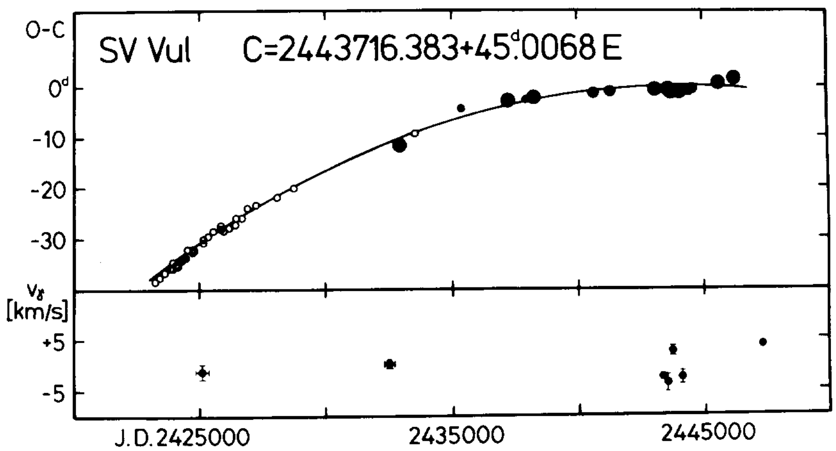

Figure 68. Upper panel: O-C diagram of SV Vul
Lower panel: γ-velocities for the same Cepheid

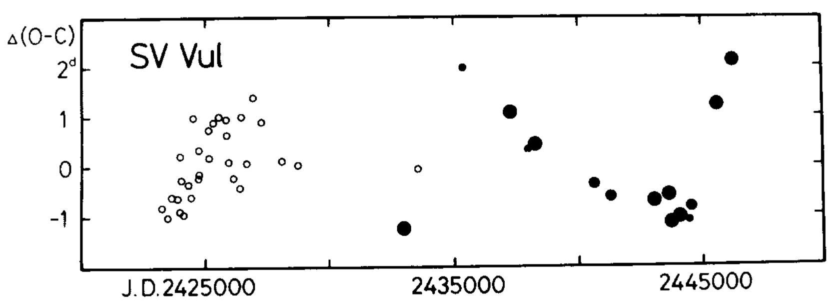

Figure 69. Δ(O-C) diagram of SV Vul

Table 107. γ-velocities of SV Vul

J.D. 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25121	249	-1.2	1.4	11	Joy (1937)
32503	181	0.4	0.8	15	Sanford (1956)
43336	63	-2.4	0.3	5	Fernie (1979a)
43502	5	-3.6	1.6	7	Wilson et al. (1989)
43709	75	2.7	1.0	15	Barnes et al. (1987)
44110	67	-2.5	1.2	11	Barnes et al. (1987)
47311	1	4.0	0.6	2	Samus (1990)

The deviation of the individual O-C residuals from this parabola, i.e. the Δ (O-C) diagram is shown in Figure 69. Figures 68 and 69 clearly indicate the commencement of a new positive deviation in the mid-eighties. The oscillation about the parabola seems to be cyclic with a cycle-length of slightly longer than ten thousand days (see also *Schröder*, 1978). The amplitude of this oscillation is considerable: it reaches 0.03 pulsation phase, and by no means is caused by the light-time effect. Since the recent deviation has not been taken into account in calculating the forthcoming maxima, the numerical data for SV Vul in Table 110 may be in error. Regular photometric study of SV Vul is desirable.

The γ-velocity values determined for SV Vul are collected in Table 107. Although the extreme values differ from each other by more than 7 km/s, the variability in the γ-velocity cannot be stated, because the extreme values have been determined from radial velocity data, either of poor quality or small in number.

GENERAL REMARKS

A considerable fraction of the Cepheids in this sample has been known to exhibit characteristic period changes. In order to achieve a more complete coverage in the O-C diagram, selected programme stars have been observed with the 50 cm Cassegrain telescope at Piszkéstető Mountain Station of Konkoly Observatory. This telescope is equipped with an integrating photoelectric photometer (containing an EMI 9058QB type multiplier) and standard UBV filters. The individual observational data are listed in Table 108. The mean error of these new photometric measurements is about $0\overset{m}{.}01$ in V and B, and somewhat larger in U. The observations have been transformed into the standard UBV system, but the data on V636 Cas are only differential magnitudes with respect to the comparison star BD+62°259.

Table 108. New photoelectric observations of selected Cepheids

FF Aql

J.D.Hel. 2440000+	V	B-V	U-B
3287.491	5.45	0.79	
3304.438	5.56	0.78	
3337.388	5.29	0.69	
3382.375	5.22	0.68	
3385.336	5.51	0.83	
3386.312	5.36	0.74	
3388.350	5.41	0.78	
3401.363	5.33	0.73	
3438.255	5.50	0.81	
3599.595	5.52	0.84	
3647.441	5.39	0.75	
3737.333	5.44	0.80	
3739.338	5.39	0.74	
3743.424	5.47	0.80	
3765.345	5.51	0.82	
3772.280	5.32	0.71	
3789.305	5.20	0.65	
3800.218	5.49	0.80	
6597.372	5.23	0.66	0.46
6612.424	5.50	0.80	0.47
6614.374	5.36	0.72	0.50
6652.382	5.45	0.79	0.64
6653.339	5.54	0.80	0.52

RW Cam

J.D.Hel. 2440000+	V	B-V	U-B
6466.268	8.32	1.21	0.90
6467.275	8.16	1.19	0.95
6489.364	8.67	1.48	1.02
6490.360	8.76	1.49	0.93
7174.467	8.28	1.29	0.95
7175.473	8.35	1.39	0.98
7443.581	8.84	1.51	0.92
7444.530	8.93	1.49	0.87

BY Cas

J.D.Hel. 2440000+	V	B-V	U-B
3382.524	10.13	1.23	
3420.472	10.36	1.21	
3425.456	10.48	1.36	
3426.433	10.48	1.33	
3437.474	10.23	1.12	
3489.328	10.26	1.30	
3490.319	10.59	1.37	
3572.247	10.24	1.25	
4108.530	10.51:	1.20:	
4143.422	10.29	1.21	
4157.406	10.62	1.31	
4159.392	10.37	1.10	

(BY Cas)

J.D.Hel. 2440000+	V	B-V	U-B
4162.493	10.24	1.19	
4166.325	10.43	1.28	
4167.490	10.61	1.30	
4203.302	10.54	1.19	
4251.285	10.62	1.30	

DD Cas

J.D.Hel. 2440000+	V	B-V	U-B
4874.397	10.26:	1.35:	
4972.244	10.09	1.34	
5229.432	10.25	1.30	
5259.352	10.15	1.30	
5294.352	9.91	1.21	

V636 Cas

J.D.Hel. 2440000+	ΔV	Δ(B-V)
5200.515	-0.322	0.832
5229.408	-0.293	0.800
5259.464	-0.311	0.823
7791.437	-0.294	0.896

IR Cep

J.D.Hel. 2440000+	V	B-V	U-B
7316.500	7.80	0.82	0.48
7387.529	7.65	0.75	0.51
7388.462	7.85	0.86	0.55
7438.233	7.65:	0.71:	0.46:
7438.385	7.62	0.73	0.52
7439.360	7.90	0.88	0.56
7439.439	7.91	0.89	0.53
7440.268	7.71	0.78	0.49
7441.236	7.82	0.84	0.55

SU Cyg

J.D.Hel. 2440000+	V	B-V	U-B
3304.451	7.15	0.69	
3337.375	6.73	0.58	
3351.527	6.65	0.49	
3363.513	6.45	0.42	
3375.464	6.66	0.48	
3388.415	7.03	0.68	
3401.387	6.84	0.54	
3403.325	6.98	0.65	
3424.256	7.05	0.61	
3440.234	6.46	0.41	
4372.461	7.01	0.63	

Table 108. (cont.)

J.D.Hel. 2440000+	V	B-V	U-B
		(SU Cyg)	
4402.459	6.73	0.55	
4455.393	6.45	0.41	
4458.535	7.16	0.63	
4811.391	7.15	0.67	
4822.436	7.01	0.63	
4840.386	6.54	0.46	
4862.346	7.18	0.61	
4870.303	6.96	0.58	
4874.308	6.75	0.51	
5200.451	7.19	0.70	
5224.376	6.59	0.44	
5229.331	6.76	0.55	
5259.286	6.46	0.40	
5294.273	6.58	0.47	
6222.490	7.06	0.70	0.46
6266.455	6.70	0.52	0.44
6268.445	7.02	0.69	0.45
6271.433	6.74	0.56	0.45
6387.241	6.90	0.64	0.45
6597.429	6.46	0.40	0.47
6652.413	6.84	0.63	0.49
6653.372	7.11	0.70	0.48
7791.361	7.05	0.69	0.43
7792.321	7.19	0.71	0.44

J.D.Hel. 2440000+	V	B-V	U-B
		DT Cyg	
3351.538	5.83	0.48	
3363.538	5.92	0.55	
3375.426	5.82	0.49	
3382.359	5.68	0.45	
3382.477	5.70	0.44	
3386.349	5.90	0.53	
3388.452	5.93	0.55	
3403.312	5.94	0.56	
3437.229	5.69	0.44	
3440.248	5.75	0.49	
3489.228	5.74	0.46	
3714.543	5.72	0.38	
3722.566	5.78	0.47	
3736.444	5.83	0.49	
3743.463	5.90	0.54	
3765.357	5.86	0.54	
3772.433	5.73	0.47	
3789.372	5.63	0.44	
3798.260	5.98	0.54	
4108.449	5.91	0.52	
4111.473	5.73	0.47	
4129.387	5.67	0.42	
4157.326	5.75	0.47	

J.D.Hel. 2440000+	V	B-V	U-B
		(DT Cyg)	
4159.271	5.66	0.42	
4166.277	5.80	0.50	
4215.191	5.83	0.50	
4458.423	5.92	0.51	
4486.328	5.76	0.44	
4811.473	5.71	0.42	
4822.468	5.86	0.51	
4840.417	5.93	0.55	

J.D.Hel. 2440000+	V	B-V	U-B
		V532 Cyg	
3353.552	9.23	1.14	
3375.562	9.08	1.12	
3382.460	9.18	1.14	
3388.498	9.05	1.09	
3401.451	8.96	1.06	
3403.349	9.11	1.08	
3437.297	8.92	0.99	
3440.262	8.94	0.99	
3476.218	8.88	1.01	
3481.227	9.25	1.14	
3489.218	8.97	1.02	
4108.486	9.30	1.19	
4111.589	9.23	1.18	
4113.401	8.91	1.06	
4157.350	9.15	1.15	
4162.418	9.02	1.07	
4166.338	8.94	1.06	
4173.267	9.05	1.10	
4203.267	9.30:	1.05:	
4811.503	9.25	1.15	
4822.498	8.90	1.05	
4840.439	9.23	1.14	
4862.391	9.02	1.07	
4870.347	9.27	1.17	
4874.347	9.14	1.16	
5224.403	9.19	1.19	
5229.359	8.94	1.08	
5259.316	8.93	1.06	
5294.318	9.22	1.12	
6268.511	9.14	1.12	
6387.309	9.26	1.15	
6652.496	9.10	1.13	
6653.475	9.24	1.17	
7388.421	9.20	1.15	
7438.346	9.25	1.14	
7439.405	8.93	1.01	
7443.435	8.99	1.04	
7444.328	9.21	1.17	
7791.339	8.94	1.04	
7792.353	9.20	1.17	

Table 108. (cont.)

J.D.Hel. 2440000+	V	B-V	U-B
			TX Del
4458.468	8.98	0.62	
4462.399	9.33	0.82	

J.D.Hel. 2440000+	V	B-V	U-B
			Y Lac
4458.516	8.99	0.68	

J.D.Hel. 2440000+	V	B-V	U-B
			CV Mon
6466.360	10.54	1.46	
6467.353	10.45	1.37	

J.D.Hel. 2440000+	V	B-V	U-B
			RS Ori
4633.470	8.69	1.14	
4637.453	8.11	0.87	
4661.392	8.23	0.96	

J.D.Hel. 2440000+	V	B-V	U-B
			SV Per
4633.448	8.99	1.19	
4661.358	9.04	1.02	

J.D.Hel. 2440000+	V	B-V	U-B
			VX Per
4638.304	9.07	1.18	
4661.299	9.11	1.13	

J.D.Hel. 2440000+	V	B-V	U-B
			AS Per
3385.570	9.33	1.45	
3420.592	9.47	1.44	
3423.588	9.93	1.61	
3424.576	9.12	1.28	
3437.460	9.85	1.67	
3458.651	9.70	1.56	
3481.315	9.72	1.56	
3490.492	9.49	1.52	
3546.247	9.79	1.55	
3560.415	9.54	1.58	
3572.261	9.98	1.72	
3598.293	9.28	1.36	

J.D.Hel. 2440000+	V	B-V	U-B
			AW Per
4633.429	7.86	1.22	
4637.427	7.42	1.14	
4661.337	7.07	0.93	
6466.321	7.41	1.09	0.73
6467.326	7.56	1.15	0.75
6489.403	7.63	1.09	0.68
6490.400	7.06	0.89	0.68
7174.389	7.73	1.13	0.71
7175.407	7.06	0.87	0.71
7443.568	7.64	1.18	0.79
7444.574	7.80	1.21	0.78

J.D.Hel. 2440000+	V	B-V	U-B
			S Sge
4811.440	5.65	0.86	
6597.447	5.74	0.93	0.78
6614.423	5.82	0.91	0.84
6652.399	5.32	0.61	0.53
6653.356	5.38	0.69	0.53
6691.254	5.98	0.98	0.83

J.D.Hel. 2440000+	V	B-V	U-B
			SZ Tau
4633.409	6.66	0.90	
4661.261	6.52	0.84	

J.D.Hel. 2440000+	V	B-V	U-B
			S Vul
4811.458	9.44	1.73	
4822.451	9.14	1.56	
4840.400	8.96	1.57	
4870.318	9.31	1.83	
4874.327	9.40	1.77	

J.D.Hel. 2440000+	V	B-V	U-B
			SV Vul
4455.426	7.32	1.70	
4458.550	7.41	1.72	

Table 109. New radial velocity measurements of selected Cepheids

Cepheid	J.D.Hel. 2440000+	radial velocity	σ [km/s]	number of lines	dispersion (Å/mm)
FF Aql	6727.269	-23.8 km/s	1.6	17	9
DT Cyg	5270.297	1.9	2.3	17	9
AW Per	6726.512	9.7	3.9	21	18
AW Per	6727.498	19.7	2.9	18	18
S Sge	6726.281	-12.9	2.4	22	9

Several spectrograms of binary Cepheids were also taken with the coudé spectrograph attached to the 2 m telescope of Rozhen Observatory (Bulgaria). The spectra were obtained at a dispersion of either 9 Å/mm or 18 Å/mm at H_γ. The individual radial velocity values are listed in Table 109.

A brief summary on the period, period changes and γ-velocity variations is compiled in Table 110. The subsequent columns of this table contain the following data:

1. Name of the Cepheid,
2. Moment of the normal maximum just following J.D. 2450000,
3. Pulsation period expected at J.D. 2450000. This value is calculated with the help of the corresponding (linear or parabolic) ephemeris published in the previous discussion on the given star,
4. Characteristic features in the O-C diagram,
5. Variability in the γ-velocity,
6. Value of the orbital period,
7. Reference to the paper where the value cited in the previous column has been published.

The use of J.D. 2450000 seems to be a reasonable compromise, because the extrapolation of the current elements for 1995 is not hazardous in the overwhelming majority of the cases. There are only eight stars (V572 Aql, BY Cas, DT Cyg, DX Gem, T Mon, VX Per, V440 Per, and SV Vul) in this sample, exhibiting either a quite recent period change or a deviation from the parabolic fit, that may cause some uncertainty in the prediction of the ephemeris.

The extension of the O-C diagrams to a larger time-base and the use of more accurate observations resulted in a different from the previous interpretation of the period changes in a number of cases. Instead of a single sudden period change (i.e. two linear sections in the O-C diagram) a continuous change in the period (i.e. parabolic O-C graph) is suggested for VZ Cyg, W Gem, RZ Gem, RR Lac, S Sge, and SW Tau.

The phase jump interpretation proposed in Papers I-III has been confirmed in most cases, and in additon, this phenomenon seems to have happened to some more Cepheids. The list of the northern Cepheids showing a phase jump in their pulsation is as follows: FF Aql, BY Cas, DD Cas, DL Cas, X Cyg, SU Cyg, SZ Cyg, DT Cyg, V532 Cyg, V924 Cyg, TX Del, DX Gem, X Lac, CV Mon, RS Ori, SV Per, SZ Tau, T Vul, X Vul. The phase jump appears most clearly in the case of FF Aql and SU Cyg, while its occurrence has to be confirmed in the case of some stars listed above (see Table 110). For FF Aql the phase shift has also been detected in the radial velocity data (*Evans* et al. 1990b). SU Cyg is unique in the respect that the phase jump was accompanied with a noticeable change in the shape of the light curve.

The phenomenon of the phase shift is a feature occurring in binary Cepheids, and its repeated occurrence in the same star (Y Oph in Paper IV, TX Del and T Vul in this paper) suggests that the jump is triggered by the orbital motion.

The orbital motion itself can be followed in the O-C diagram via the light-time effect. This phenomenon is best seen in AW Per, but may also be present in the O-C plot of FM Aql, RW Cam, Y Lac, and RS Ori. This latter Cepheid is especially important because RS Ori might be the first case of exhibiting a phase jump and the light-time effect in the same O-C diagram.

The alternating period changes on a time-scale of several years or decades can be attributed to solar type activity cycles (*Hall*, 1990). The present sample contains several Cepheids showing quasi-cyclic changes in the pulsation period, viz. ζ Gem, T Mon, S Vul, and SV Vul. Although the number of Cepheids forming this group is small, it may be significant that the shortest pulsation period for a member is longer than 10 days. A problem to be solved in the future is the differentiation between the phase slip (a slower or more gradual phase jump) and the alternate period changes due to magnetic effects. The solar type activity cycle does not necessitate the duplicity of the star involved, although a companion star usually strengthens the activity.

The analysis of the radial velocity observations has resulted in revealing a number of new spectroscopic binary Cepheids or candidates. The most promising cases are: KL Aql, η Aql, SU Cas, V636 Cas, BZ Cyg, MW Cyg, V386 Cyg, W Gem, RZ Gem, AD Gem, RS Ori, SV Per, SW Tau, T Vul, U Vul. An attempt was made to find the value of the orbital period for Cepheids with ample radial velocity data, but each spectroscopic period derived here has to be confirmed with the help of additional measurements.

Table 110. Summary on the periods, period changes and duplicity

Cepheid	Norm.max. 2400000+	Period [d]	O-C graph	v_γ	P_{orb} [d]	Source
SZ Aql	50012.262	17.141745	parabolic (+)	?		
TT Aql	50000.687	13.754954	linear	var.?		
FF Aql	50004.063	4.470936	lin. with PHJ	var.	1430	Evans et al. (1990)
FM Aql	50003.142	6.114265	linear (+LTE?)	const.?	2800 ?	this paper
KL Aql	50002.539	6.108015	linear	var.	short	this paper
V 572 Aql	50000.287	3.768001	linear (?)	-		
V 1344 Aql	50000.187	7.476787	linear	var.?		
η Aql	50000.175	7.176758	parabolic (+)	var.	926 ?	this paper
RT Aur	50000.279	3.728198	linear	const.		
AN Aur	50003.628	10.289563	linear	var.		
RW Cam	50012.740	16.415015	lin. with LTE or PHJ	var.	7000 ?	this paper
SU Cas	50000.720	1.949325	linear	var.	462.5 ?	this paper
SZ Cas	50009.120	13.645356	parabolic (+)	var.?		
BY Cas	50000.908	3.222199	lin. with PHJ	?		
DD Cas	50001.805	9.811656	lin. (+ PHJ?)	var.?		
DL Cas	50004.712	8.000598	lin. with PHJ	var.	688.0	Harris et al. (1987)
IX Cas	50003.203	9.154549	irregular	var.	110.29	Harris and Welch (1989)
V 636 Cas	50005.366	8.375735	linear	var.		
IR Cep	50000.719	2.114088	linear (+EPCH)	one		
V 351 Cep	50000.179	2.806052	linear (+EPCH)	-		
X Cyg	50007.657	16.385692	lin. with PHJ	var.?		
SU Cyg	50000.682	3.845512	lin. with PHJ	var.	549.16	Evans (1988)
SZ Cyg	50000.868	15.110228	lin. with PHJ	var.		
TX Cyg	50003.317	14.711635	linear (+EPCH)	var.?		
VZ Cyg	50004.454	4.864372	parabolic (-)	var.?		
BZ Cyg	50001.523	10.142222	linear	var.		
DT Cyg	50002.270	2.499086	lin. with PHJ	var.		
MW Cyg	50004.005	5.954666	linear	var.		
V 386 Cyg	50001.131	5.257635	linear	var.		
V 532 Cyg	50000.792	3.283494	lin. with PHJ	var.?		
V 924 Cyg	50002.268	5.571305	lin. with PHJ	-		
V 1334 Cyg	50002.920	3.332804	linear	var.	<1240	this paper
V 1726 Cyg	50003.570	4.236978		one		
TX Del	50000.932	6.165904	lin. (+ PHJ?)	var.	133.15	Harris and Welch (1989)

Table 110. (cont.)

Cepheid	Norm.max. 2400000+	Period [d]	O-C graph	v_γ	P_{orb} [d]	Source
W Gem	50003.897	7.913277	parabolic (-)	var.		
RZ Gem	50002.248	5.528942	parabolic (-)	var.	886 ?	this paper
AD Gem	50002.061	3.787990	linear	var.		
DX Gem	50001.290	3.136779	lin. with PHJ	var.?		Burki (1985)
ζ Gem	50007.231	10.149414	parabolic (-)	var.?		
V Lac	50000.245	4.983002	parabolic (-)	var.?		
X Lac	50000.890	5.444322	lin. with PHJ	var.?		
Y Lac	50000.797	4.323769	linear	var.?		
Z Lac	50000.760	10.885600	parabolic (-)	var.	short	this paper
RR Lac	50001.448	6.416335	parabolic (+)	var.		
BG Lac	50004.552	5.331902	linear	var.?		
T Mon	50025.601	27.020097	lin. on par. (+)	var.	very long	Gieren (1989b)
SV Mon	50009.142	15.232582	linear	const.		
CV Mon	50002.177	5.378804	lin. with PHJ	one		
V 465 Mon	50000.505	2.713006	linear (+EPCH)	var.		Burki (1985)
RS Ori	50001.701	7.566841	lin. with LTE and PHJ	var.	long ?	this paper
GQ Ori	50001.590	8.616283	linear	one		
SV Per	50004.946	11.129319	lin. (+ PHJ?)	var.		
VX Per	50008.306	10.886972	linear (+EPCH)	const.		
AS Per	50003.220	4.972540	linear	one		
AW Per	50000.041	6.463622	lin. with LTE	var.	13100	Welch and Evans (1989)
V 440 Per	50003.336	7.572498	linear (?)	const.		
S Sge	50004.834	8.382184	parabolic (+)	var.	676.2	Slovak and Barnes (1987)
SW Tau	50001.443	1.583540	parabolic (-)	var.		
SZ Tau	50001.329	3.149138	lin. with PHJ	var.?		
S Vul	50038.692	68.500	lin. sections	?		
T Vul	50003.860	4.435453	lin. with PHJ	var.	1745	this paper
U Vul	50005.698	7.990821	linear (+EPCH)	var.	868 ?	this paper
X Vul	50002.860	6.319490	lin. (+ PHJ?)	var.		
SV Vul	50013.768	44.9558	parabolic (-)	const.?		

Legend: LTE : light-time effect
PHJ : phase jump(s)
EPCH : earlier period change(s)
one : only one series of radial velocity data

(+) and (-) : continuous period increase or decrease
? : poorly covered radial velocity curve, the γ-velocity cannot be determined
- : radial velocity observations have not been made

A new method, independent from the previously used ones, has been proposed for revealing the presence of a companion. This evidence is based on the amplitude ratio of the light and radial velocity variability (see V440 Per).

The new discoveries and uncertainties confirm the fact that there is a huge number of Cepheid variables deserving regular attention (photometric and radial velocity studies), and/or occasional close inspection in the form of a detailed spectroscopic analysis.

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