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PERIOD CHANGES OF BRIGHT SOUTHERN CEPHEIDS

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ABSTRACT

O-C diagrams have been constructed for 44 bright southern Cepheids, mainly for 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 velocities of the programme stars have been studied, as well. Light-time effect is found or suspected in eleven cases (V496 Aql, AX Cir, AG Cru, BG Cru, BF Oph, AP Pup, AT Pup, Y Sgr, AP Sgr, R TrA, and V Vel), and a preliminary value of the orbital period is suggested for 14 Cepheid binaries (V496 Aql, AX Cir, AG Cru, Y Oph, BF Oph, AP Pup, AT Pup, U Sgr, Y Sgr, AP Sgr, BB Sgr, RV Sco, R TrA, and V Vel). The phenomenon of the phase jump (i.e. the return of the pulsation period to an earlier value) is present in the O-C diagram of eight Cepheid binaries (U Aql, YZ Car, KN Cen, S Mus, S Nor, Y Oph, U Sgr, and V350 Sgr).

INTRODUCTION

Period changes of more than a hundred northern Cepheids were studied in a series of papers (*Szabados*, 1977, 1980, 1981, 1983, and 1984). The large number of the programme stars and the homogeneous method of the analysis enabled the determination of the period changes as a function of the pulsation period. A general agreement of the observed period changes with the theoretically calculated values was found. In addition to the frequently occurring parabolic O-C diagrams corresponding to the continuous period change as a result of the stellar evolution, 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. stepwise O-C graph, i.e. rejump (return) of the pulsation period to an earlier value. In what follows, the term "phase jump" will be used for this phenomenon.

This paper is dealing with a similar study: period changes of 44 (mostly bright) southern Cepheids are discussed here. Because the southern Cepheid variable stars were observed on rare occasions before the photoelectric era, secular period variations have remained undiscovered in most cases. The time interval of less than fifty years covered with photoelectric observations is not long enough to reveal the evolutionary period changes unambiguously (there are, however, some exceptions). At the same time, due to their accuracy, these photoelectric observations can be used successfully for searching for both light-time effect and phase jump in the O-C diagrams.

For this reason the sample of stars studied here is arbitrarily chosen: it contains the bright southern Cepheids for which presence of a companion has been suspected or discovered. In addition, some other bright Cepheids without any evidence for duplicity have also been included, considering that any evolutionary period changes are likely to be expected in these very bright Cepheids with the longest available coverage of photometric observations.

The current ephemerides (the moment of the light maximum, and the value of the pulsation period) are also determined, and these pieces of information may be useful for planning future observations in any wavelength interval, or for determining their phases.

Due to the inhomogeneous (and arbitrary) selection of the programme stars, the statistical study of the period changes has not been attempted. Instead, duplicity effects are placed in the centre of interest. Because the most straightforward way to discover the presence of a companion is to detect variations in the mean radial velocity (so called γ-velocity), the radial velocity data are also analysed and intercompared with the relevant parts of the O-C diagrams.

O-C DIAGRAMS

In order to study the period changes, all the available photometric observations have been analysed. At the final step, however, the results based on visual observations were omitted because of their very low accuracy. Nevertheless, there are one or two cases where the very early visual data have been used but after J.D.2420000 only the photographic and photoelectric observations were taken into account.

Homogeneity of the O-C diagrams has been achieved by re-analysing all observations without accepting the originally published moments of normal maxima. The new moments of normal maxima were determined by fitting the master light curve to the light curve to be analysed. The master light curve has been the most reliable seasonal light curve available in the literature for the given star (mostly but not necessarily from the paper by *Moffett* and *Barnes*, 1984). Whenever it was possible, the longer observational series were grouped into seasonal light curves.

Depending on the number and quality of the observations and the distribution of the data points, a weight has been assigned to each light curve. This weight is 3 for the master curves and other best quality light curves, and 2 or 1 is assigned to the light curves of poorer coverage and/or showing wide scatter. Note that these weights were determined before performing the curve fitting procedure, i.e. without knowing how much the corresponding O-C residual will deviate from the final O-C curve.

The weight was never larger than 1 in the case of the photographic observations, and there are numerous O-C residuals in the tables of this paper where no weight has been assigned (these are based on visual or photographic observations without exception). These latter O-C residuals are still useful but have not been taken into account when determining the shape of the O-C curve.

The exact calculation of the error for each O-C residual would have been extremely time-consuming. Instead, based on the large body of the previous O-C diagrams (*Szabados*, 1977, 1980, 1981) the following average uncertainties could be deduced: for w=3, 2, and 1 the standard deviation is about 0.002 , 0.004 and 0.008 part of the pulsation period.

Throughout this study the blue (or closest to Johnson's B band) light curves were analysed. There are quite a few series of photometric observations obtained in red and/or infrared bands. Although these observations are very important in some respects, they were omitted from this study because the shape of the light curve at long wavelength differs from the blue light curve, and the necessary corrections to be applied for removing the systematic differences between the moments of maxima in different spectral regions have not been determined yet.

The O-C residuals are given in tabular form and shown plotted in figures. The successive columns in the tables of the O-C residuals contain the following data:

1. Moment of normal maximum ;

2. The corresponding epoch;
3. O-C residual (in days);
4. Type of observation and the weight assigned to the residual (pe for photoelectric, pg for photographic, and vis for visual observations);
5. Source of the observational data.

The O-C diagram (usually the upper panel of the figure) shows the O-C residuals listed in the corresponding table, and the curve thought to be the best interpretation of the O-C plot is also drawn. These curves were obtained by the weighted least squares method applied to the data points. The weights are visualized in the figure as circles of increasing diameter. Photoelectric observations are denoted with filled circles, while open circles refer to the O-C residuals based on photographic observations. If no weight has been assigned to an O-C residual, it is shown plotted as a small dot.

RADIAL VELOCITIES

Because one of the main aims of this study is to search for light-time effect in the O-C diagrams, it was appropriate to carry out a simultaneous investigation of the radial velocity measurements in order to check the results on duplicity obtained from the O-C diagrams.

The radial velocity data have been collected from the literature, and they were analysed after the trend of the period variation had been determined from the O-C diagram. This step is crucial because any fitting error due to the use of an inaccurate pulsation period can be eliminated, and only the observational (and in some cases a systematic zero-point) error of the radial velocity measurements remains as a possible source of error.

It is almost impossible to get rid of the systematic errors because most of the early papers containing radial velocity data do not give enough information for converting the data into a common system. Nevertheless, thanks to the existence of the IAU standard radial velocity system, these systematic errors have become much smaller in the last decades, e.g. according to *Welch* et al. (1987) the zero-point correction applied to the radial velocity measurement series of U Aql is less than 1 km/s for eight instruments, and the correction slightly exceeds 1 km/s in only one case.

In view of this, no corrections have been applied to the observational data analysed here, and, of course, this can be an additional source of error. The only exception is *Paddock*'s (1917) radial velocity measurement series, for which *Lloyd Evans* (1982) introduced +4 km/s correction, and this value is so large that it was also applied here.

The individual radial velocity series were used for constructing the seasonal radial velocity curves using the accurate value of the pulsation period. The centre-of-mass velocity of the Cepheid (i.e. the γ-velocity) was then determined in two steps. At first, the γ-velocity of the best radial velocity curve was determined graphically for each variable, then these radial velocity normal curves were fitted to the properly phased other radial velocity curves. If the γ-velocity seemed to be constant, the radial velocity measurement series were not always divided into seasonal curves.

As to variability of the γ-velocity, there is a reasonable lower limit (4-5 km/s), and if the fluctuation of the γ-velocity exceeds this value, the presence of a companion to the Cepheid is suspected. It is hoped that the above limit overestimates the real threshold of detection because much smaller variations in the γ-velocity can be revealed by using the recent radial velocity measurement techniques. Unfortunately most of the available radial velocity data have been obtained at a higher level of uncertainty.

Because the relative errors of the radial velocity measurements are larger than those of the photometric measurements, the standard deviations have been calculated for the individual radial velocity measurement series. The standard deviation of the date of observation is formal, and it only indicates the length of the observational interval. The standard deviation of the γ-velocity does not contain the contribution of the possible zero-point error.

The successive columns in the tables of the γ-velocities give the following data:

1-2. Mean date of the observations and its standard deviation;
3-4. γ-velocity and its standard deviation;
5. Number of radial velocity observations used;
6. Source of the observational data.

The γ-velocity data of the individual Cepheids are plotted in most cases in the lower panel of the figures. The plot is missing in those cases where no obvious change in the γ-velocity is seen. Error bars (according to the standard deviations listed in the tables) are only shown, if the bar exceeds the size of the circle.

REMARKS ON THE INDIVIDUAL VARIABLES

The list of the programme stars can be found in Table 1. The ordinal number following the name of the Cepheid gives the page number where the discussion on the given star begins. The Cepheids involved in this study are arranged in alphabetical order of constellations, and within one constellation, according to the IAU nomenclature of variable stars.

Table 1. Programme stars

It was not my intention to give a comprehensive history on each variable. I do hope, however, that neither photoelectric or photographic, nor radial velocity observation published in the literature escaped my attention. The additional remarks on the individual Cepheids mostly concern the previous studies on both the changes in the γ-velocity and the period variations. The available other evidence regarding the duplicity of these stars is also discussed briefly. A systematic application of the known duplicity tests is beyond the scope of this paper but such a study is planned for the near future. The compilation on the binary Cepheids will be published in due time.

Although the phase difference between the γ-velocity variations and the sinusoidal wave in the O–C diagram is a good indicator whether this phenomenon can be interpreted as a light-time effect, there is an additional criterion that makes use of the amplitude of these oscillations. Assuming a circular orbit, the radial velocity and O-C variations have to obey the following relationship in a binary system:

$$2K = a \cdot sini \cdot P_{orb}^{-1} \cdot 3.77 \cdot 10^{6} \qquad (1)$$

where 2K is conventionally the total amplitude of the γ-velocity variation (in km/s), a·*sini* is the projected radius of the orbit, and at the same time this quantity is the half amplitude of the wave in the O-C diagram (in days), and P_{orb} is the orbital period (in days). This test is frequently used during this study as a very strong criterion when deciding whether light-time effect is expected or not (if the orbital period has been known from radial velocity measurements), and to judge reality of interpreting the O-C wave in terms of duplicity.

U Aquilae

U Aql is one of the spectroscopic binary Cepheids with known orbit (*Welch* et al., 1987). According to various estimates, the companion is a main-sequence B8-A1 star (*Leonard* and *Turner*, 1986). The radial velocity observations have not been re-analysed here, the orbital period of 1856.4 days (*Welch* et al., 1987) is accepted, although the more recently published radial velocity data (*Wilson* et al., 1989) may slightly alter this value.

The O-C residuals are listed in Table 2, and are shown plotted in Figure 1. The O-C diagram of U Aql can be well approximated by two lines showing a phase jump (i.e. rejump of the period). The O-C residuals have been calculated with the formula:

$$C = 2434922.400 + 7^{d}.023958 \cdot E \qquad (2)$$
$$\pm.031 \quad \pm.000029$$

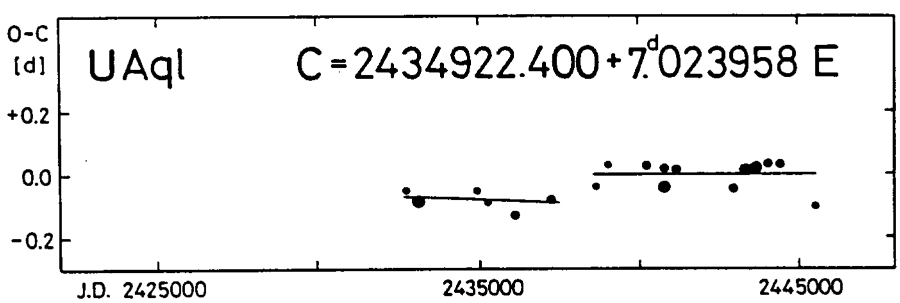

Figure 1. **O-C diagram of** U Aql

Table 2. O-C residuals for U Aql

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
32765.994	-307	$-0^{d}.051$	pe 2	Eggen (1951)
33110.132	-258	-0.087	pe 3	Eggen (1951)
34950.444	+ 4	-0.052	pe 1	Walraven et al. (1958)
35294.581	+ 53	-0.089	pe 1	Irwin (1961)
36109.319	+169	-0.130	pe 1	Svolopoulos (1960)
37233.200	+329	-0.082	pe 2	Mitchell et al. (1964)
38673.155	+534	-0.039	pe 1	Wisniewski and Johnson (1968)
39059.541	+589	+0.030	pe 1	Wisniewski and Johnson (1968)
40253.609	+759	+0.025	pe 2	Feltz and McNamara (1980)
40801.469	+837	+0.016	pe 2	Feltz and McNamara (1980)
40822.484	+840	-0.041	pe 3	Pel (1976)
41194.809	+893	+0.015	pe 2	Feltz and McNamara (1980)
42922.639	+1139	-0.049	pe 2	Dean (1977)
43365.210	+1202	+0.012	pe 3	Moffett and Barnes (1984)
43674.270	+1246	+0.018	pe 3	Moffett and Barnes (1984)
44039.528	+1298	+0.031	pe 2	Moffett and Barnes (1984)
44467.988	+1359	+0.029	pe 2	Eggen (1985)
45563.595	+1515	-0.101	pe 1	Eggen (1985)

This period is valid after J.D.2438600 , while between J.D.2432700 and J.D.2437300 the pulsation period was $7.023920 \pm 3.0 \cdot 10^{-5}$ days. The phase jump occurred at about J.D.2438000, and it amounts to 0.1 day.

There are no early photographic observations available in the literature, therefore the longer time-scale behaviour of the O-C diagram of U Aql cannot be studied. According to the phase relations of the radial velocity curves, the O-C residuals might be even more negative at about J.D.2421840 . A single straight line fitted to the photoelectric O-C residuals is almost as good as the phase jump approximation. In view of the values of the orbital period and the orbital radial velocity amplitude, the expected light-time effect has such a low amplitude (see equation (1)) that the effect cannot be detected.

V496 Aquilae

Its spectroscopic binary nature was revealed by *Gieren* (1982) but there is no agreement on the type of the companion (*Leonard* and *Turner*, 1986). The variable γ-velocity of V496 Aql is well illustrated in Figure 2 (lower panel), and in Table 3. There is a number of periods that fits the data points reasonably well: 1200, 1780, 2700, 3600, 5350, and 10750 days. It is impossible to choose the true value of the orbital period from the available radial velocity measurements alone.

Table 3. γ-velocities of V496 Aql

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
33918	31	6.8	0.8	15	Stibbs (1955)
34202	28	0.6	1.5	5	Stibbs (1955)
40448	27	6.8	0.4	4	Lloyd Evans (1980)
44053	10	18.0	4.0	2	Barnes et al. (1988)
44423	4	7.7	0.4	25	Gieren (1981a)
44486	46	14.5	1.6	7	Barnes et al. (1988)
44822	47	4.6	2.3	4	Barnes et al. (1988)

The O-C diagram (see Table 4 and the upper panel of Figure 2) can be approximated by a straight line with the light-time effect superimposed on it. The sine-wave was fitted by using the method of weighted least squares, and the 1500 - 13000 day interval was analysed. The best fit was achieved assuming an orbital period of 1882 ± 23 days. The moments of the light maxima can be predicted as follows:

$$C = \underset{\pm.004}{2436017.084} + \underset{\pm.000008}{6\overset{d}{.}807055}E - \underset{\pm.008}{0\overset{d}{.}023}\cos(2\pi(\underset{\pm.00004}{0.00362}E - \underset{\pm.031}{0.006})) \qquad (3)$$

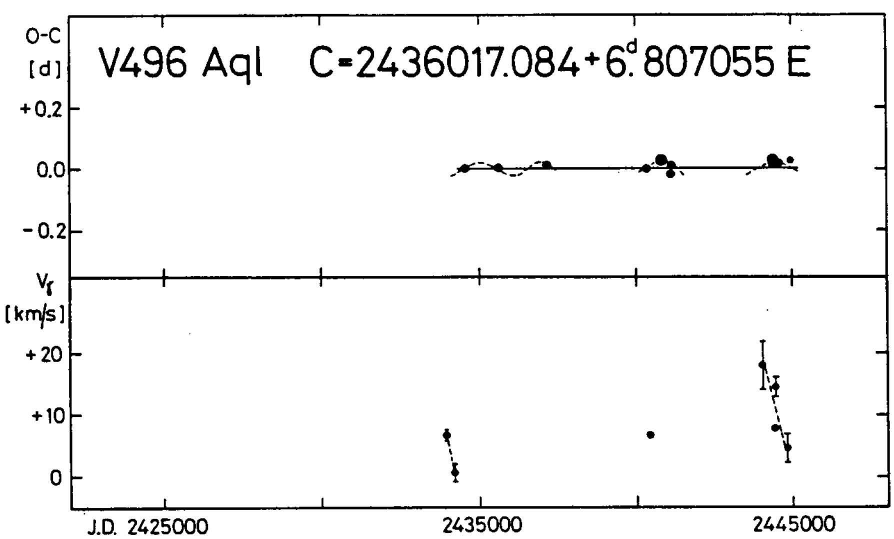

Figure 2. Upper panel: O-C diagram of V496 Aql
Lower panel: γ-velocities for the same Cepheid

Table 4. O-C residuals for V496 Aql

Norm.max JD2400000+	E	O-C	Type, weight	Reference
34567.181	-213	$0^{d}.000$	pe 2	Eggen et al. (1957)
35608.663	- 60	+0.002	pe 2	Walraven et al. (1958)
37187.908	+172	+0.011	pe 2	Mitchell et al. (1964)
40366.791	+639	-0.001	pe 2	Stobie (1970)
40809.275	+704	+0.024	pe 3	Pel (1976)
41122.357	+750	-0.018	pe 2	Pel (1976)
41149.613	+754	+0.010	pe 2	Feltz and McNamara (1980)
44410.200	+1233	+0.017	pe 3	Moffett and Barnes (1984)
44410.214	+1233	+0.031	pe 3	Gieren (1981b)
44621.218	+1264	+0.016	pe 2	Eggen (1985)
44907.121	+1306	+0.023	pe 1	Moffett and Barnes (1984)

This value of the orbital period is in reasonable agreement with the 1780 day period, one of the values suggested by the radial velocity data. The amplitude of the wave is, however, twice larger than the value expected from equation (1). This suggests that the orbital period may be longer. More spectroscopic and photometric data are necessary to determine the value of the orbital period unambiguously.

The O-C residuals have been calculated with the elements:

$$C = \underset{\pm.004}{2436017.084} + \underset{\pm.000008}{6^{d}.807055} \cdot E \qquad (4)$$

If no sinusoidal term is assumed in the O-C diagram, then the least squares fit results in the following formula:

$$C = \underset{\pm.004}{2436017.085} + \underset{\pm.000005}{6^{d}.807070} \cdot E \qquad (5)$$

which is practically identical with the linear part of the sinusoidal fit (i.e. with equation (4)).

V Carinae

V Car was reported to be a suspected binary (*Lloyd Evans*, 1968) but later on *Lloyd Evans* (1982) explained the scatter in the radial velocity data as due to the variability of the bump on the velocity curve. Here the scatter in the radial velocity data is attributed to the variation in the γ-velocity (see Table 5 and the lower panel of Figure 3).

Table 5. γ-velocities of V Car

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
34009	20	15.2	0.8	14	Stibbs (1955)
34095	20	14.0	1.2	7	Stibbs (1955)
39252	64	8.7	1.1	4	Lloyd Evans (1968)
39611	41	8.3	1.1	4	Lloyd Evans (1968)
39932	48	12.2	0.6	2	Lloyd Evans (1980)
40338	16	12.5	0.3	5	Lloyd Evans (1980)
40666	51	13.2	0.3	6	Lloyd Evans (1980)

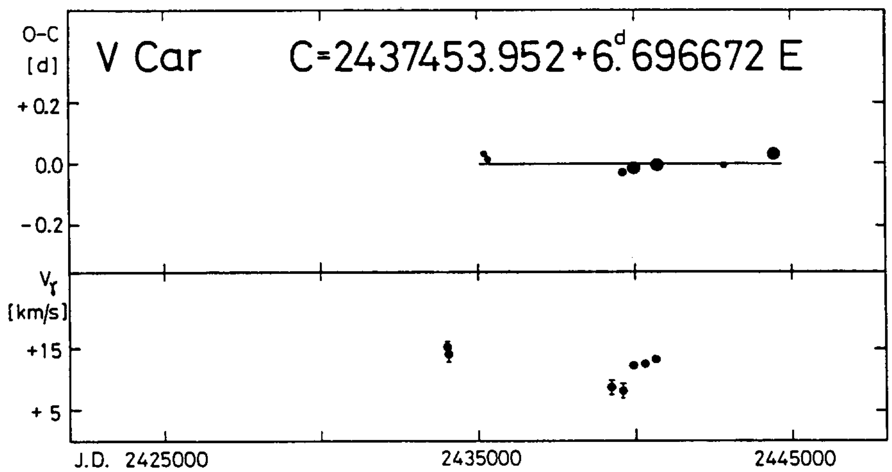

Figure 3. Upper panel: O-C diagram of V Car
Lower panel: γ-velocities for the same Cepheid

Table 6. O-C residuals for V Car

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
35230.691	-332	$+0^d.034$	pe 1	Irwin (1961)
35351.218	-314	+0.021	pe 1	Walraven et al. (1958)
39630.343	+325	-0.027	pe 2	Cousins and Lagerweij (1968)
39958.494	+374	-0.013	pe 3	Cousins and Lagerweij (1968)
40742.012	+491	-0.006	pe 3	Pel (1976)
42858.163	+807	-0.003	pe 1	Dean (1977)
44425.219	+1041	+0.031	pe 2	Eggen (1985)

The O-C diagram (Table 6 and the upper panel of Figure 3) contains very few points, and for the sake of simplicity it is approximated by a straight line:

$$C = 2437453.952 + 6\overset{d}{.}696672 \cdot E \qquad (6)$$
$$\pm.009 \quad \pm.000016$$

Further observations are to be obtained in order to decide whether a parabola fits better, and even the light-time effect cannot be excluded.

YZ Carinae

According to *Coulson* (1983) YZ Car belongs to a binary system with an orbital period of about 850 days. *Coulson* also derived tentative orbital parameters, and concluded that the companion is probably a main-sequence A0 star. The radial velocity measurements of YZ Car have not been analysed again here.

Table 7. O-C residuals for YZ Car

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
34725.613	- 10	$+0\overset{d}{.}197$	pe 2	Walraven et al. (1958)
35216.089	+ 17	+0.202	pe 3	Irwin (1961)
37831.903	+161	+0.173	pe 3	Walraven et al. (1964)
41737.333	+376	+0.006	pe 3	Madore (1975)
43989.866	+500	+0.008	pe 2	Coulson and Caldwell (1985)
44280.475	+516	-0.033	pe 2	Coulson and Caldwell (1985)
44280.593	+516	+0.085	pe 1	Eggen (1983b)
44680.082	+538	-0.068	pe 2	Coulson and Caldwell (1985)
44771.006	+543	+0.028	pe 2	Eggen (1983b)
45007.127	+556	-0.004	pe 3	Coulson and Caldwell (1985)
45715.615	+595	+0.027	pe 2	Coulson and Caldwell (1985)

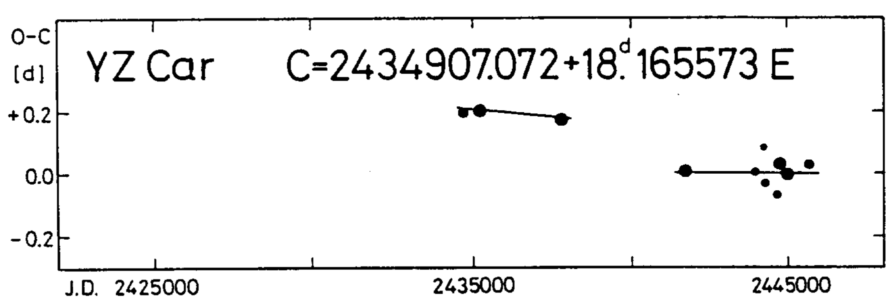

Figure 4. O-C diagram of YZ Car

The O-C diagram has been constructed on the basis of the available observations listed in Table 7. The plot of the O-C residuals (see Figure 4) can be well approximated by two sections of straight lines showing the phenomenon of the phase jump seen in numerous binary Cepheids.

The O-C residuals have been calculated with the elements:

$$C = 2434907.072 + 18\overset{d}{.}165573 \cdot E \qquad (7)$$
$$\pm.071 \qquad \pm.000137$$

The previous value of the pulsation period (between J.D.2434700 and 2437900) was $18.165412 \pm 2.0 \cdot 10^{-5}$ days, therefore it can be stated that the star returned to the same pulsation period after an 0.16 day phase jump, occurred at about J.D.2440000 .

Another fact worth mentioning is that the pulsation period differs considerably from the value given in the GCVS (*Kholopov* et al., 1985-1987). *Coulson* (1983) used an almost correct value of the pulsation period but did not call the attention explicitly to the correction to be applied to the period in the catalogue.

<u>ℓ Carinae</u>

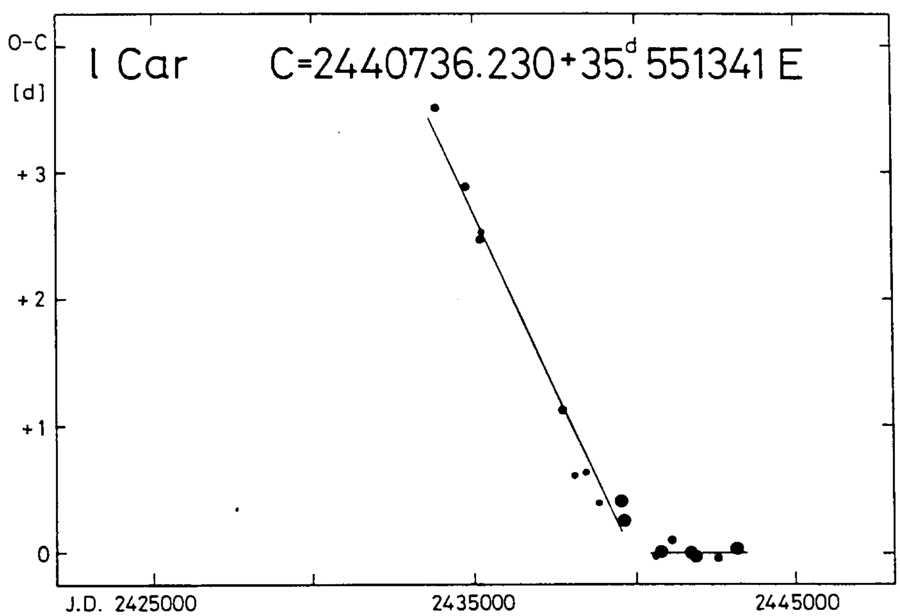

Figure 5. **O-C diagram of** ℓ Car

The γ-velocity of this long period Cepheid can be considered as being constant (see Table 8), therefore the individual values of the γ-velocity are not plotted in a diagram.

The O-C diagram (see Table 9 and Figure 5) is based on only the photoelectric normal maxima. The previous values of the pulsation period can be followed in *Parenago*'s (1956) paper. The O-C residuals have been calculated with the formula:

$$C = 2440736.230 + 35^{d}.551341 \cdot E \quad (8)$$
$$\pm.015 \qquad \pm.000397$$

Table 8. γ-velocities of ℓ Car

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
17441	402	2.2	0.8	17	Jacobsen (1934)
21655	25	2.0	0.8	15	Jacobsen (1934)
22435	19	1.8	0.6	28	Jacobsen (1934)
34086	61	1.0	0.7	21	Stibbs (1955)
35641	19	0.7	1.0	5	Lloyd Evans (1968)
37722	52	4.4	0.7	21	Dawe (1969)
39238	33	0.9	1.1	4	Lloyd Evans (1968)
39901	38	2.0	0.3	5	Lloyd Evans (1980)
40307	61	3.2	0.2	12	Lloyd Evans (1980)
40663	44	0.0	0.3	6	Lloyd Evans (1980)

Table 9. O-C residuals for ℓ Car

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
33807.235	-195	$+3^{d}.516$	pe 2	Eggen et al. (1957)
34766.489	-168	+2.884	pe 2	Eggen et al. (1957)
35228.242	-155	+2.470	pe 2	Irwin (1961)
35263.849	-154	+2.526	pe 1	Walraven et al. (1958)
37751.037	- 84	+1.120	pe 2	Lake (1962)
38141.594	- 73	+0.612	pe 1	Feinstein and Muzzio (1969)
38461.577	- 64	+0.633	pe 1	Feinstein and Muzzio (1969)
38852.400	- 53	+0.391	pe 1	Feinstein and Muzzio (1969)
39563.259	- 33	+0.223	pe 3	Feinstein and Muzzio (1969)
39563.437	- 33	+0.401	pe 3	Landolt (1971)
40629.547	- 3	-0.029	pe 2	Eggen (1971)
40736.226	0	-0.004	pe 3	Pel (1976)
41127.387	+ 11	+0.092	pe 2	Pel (1976)
41731.656	+ 28	-0.012	pe 3	Madore (1975)
41838.299	+ 31	-0.023	pe 3	Dean et al. (1977)
42549.300	+ 51	-0.048	pe 2	Dean et al. (1977)
43189.300	+ 69	+0.027	pe 3	Dean (1981)

Two values of the pulsation period are apparent in Figure 5: before J.D.2440000 the period was $35.531758 \pm 6.21 \cdot 10^{-4}$ days, while after this epoch the value of the period has been $35.551341 \pm 3.97 \cdot 10^{-4}$ days. Although Figure 5 suggests a continuous period increase, a parabolic fit was not attempted because the early part of the O-C diagram (*Parenago*, 1956) would contradict to this interpretation.

V Centauri

Although *Gieren* (1982) found no evidence for the variable γ-velocity, according to the present study variability in the γ-velocity cannot be ruled out (see Table 10 and the lower panel of Figure 6). Especially *Stibbs*' (1955) seasonal curves suggest a short period (several hundred days) variation.

Table 10. γ-velocities of V Cen

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
33848	22	-25.1	1.1	9	Stibbs (1955)
34165	54	-19.5	1.1	8	Stibbs (1955)
39268	37	-23.9	1.0	5	Lloyd Evans (1968)
40371	28	-23.2	0.3	4	Lloyd Evans (1980)
40759	15	-20.8	0.3	3	Lloyd Evans (1980)
44422	4	-23.9	0.4	26	Gieren (1981a)

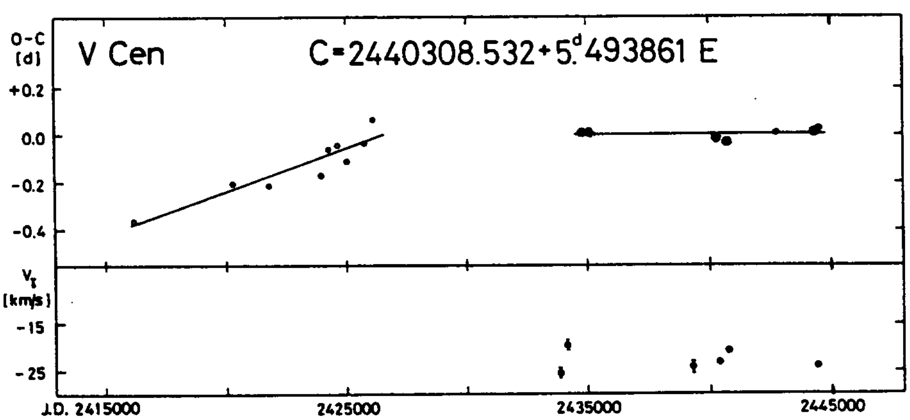

Figure 6. Upper panel: O-C diagram of V Cen
Lower panel: γ-velocities for the same Cepheid

Table 11. O-C residuals for V Cen

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
16162.649	-4395	$-0^d.364$	pg 1	Shapley (1930)
17953.707	-4069	-0.305	pg 1	Shapley (1930)
20272.216	-3647	-0.205	pg 1	Shapley (1930)
21794.004	-3370	-0.216	pg 1	Shapley (1930)
23986.101	-2971	-0.170	pg 1	Shapley (1930)
24260.903	-2921	-0.061	pg 1	Voute (1927b)
24656.476	-2849	-0.046	pg 1	Voute (1927b)
25035.485	-2780	-0.113	pg 1	Voute (1927b)
25793.717	-2642	-0.034	pg 1	Dartayet et al. (1949)
26139.928	-2579	+0.064	pg 1	Dartayet et al. (1949)
34869.621	- 990	+0.011	pe 3	Walraven et al. (1958)
35193.758	- 931	+0.011	pe 3	Irwin (1961)
40335.980	+ 5	-0.021	pe 3	Stobie (1970)
40748.007	+ 80	-0.034	pe 3	Pel (1976)
42852.197	+ 463	+0.007	pe 2	Dean (1977)
44417.952	+ 748	+0.012	pe 3	Gieren (1981b)
44494.877	+ 762	+0.023	pe 2	Eggen (1985)

The O-C diagram (Table 11 and the upper panel of Figure 6) shows one period change. The O-C residuals have been computed using the ephemeris:

$$C = \underset{\pm.005}{2440308.532} + \underset{\pm.000007}{5^d.493861} \cdot E \qquad (9)$$

The period change occurred at about J.D.2427000 , and before that epoch the pulsation period was $5.494058 \pm 2.6 \cdot 10^{-5}$ days.

XX Centauri

Spectroscopic binary nature of XX Cen was discovered by *Coulson* et al. (1985). The value of the orbital period was determined recently (*Szabados*, 1989), its value is 909.4 ± 29.0 days.

According to equation (1), no detectable light-time effect is expected in the O-C diagram, therefore the phase shift mentioned by *Coulson* et al. (1985) is not caused by the orbital motion but, instead, it reflects the strong period change determined here.

The O-C residuals have been calculated with the formula:

$$C = \underset{\pm.010}{2440366.125} + \underset{\pm.000027}{10^d.954027} \cdot E \qquad (10)$$

As is seen in the O-C diagram (see Table 12 and Figure 7), the period of

XX Cen is continuously decreasing as follows:

$$P = 10^{d}.954027 - 15^{d}.5 \cdot 10^{-7} \cdot E \qquad (11)$$
$$\pm.000027 \qquad \pm.6$$

where the E epoch number is the same as in equation (10).

Table 12. O-C residuals for XX Cen

Norm.max JD2400000+	E	O-C	Type, weight	Reference
26398.368	-1275	$-1^{d}.373$	pg 1	van Gent and Oosterhoff (1948)
27691.409	-1157	-0.907	pg 1	van Gent and Oosterhoff (1948)
34812.261	- 507	-0.172	pe 1	Walraven et al. (1958)
35206.584	- 471	-0.194	pe 3	Irwin (1961)
35469.522	- 447	-0.153	pe 1	Walraven et al. (1958)
37846.692	- 230	-0.007	pe 3	Walraven et al. (1964)
40377.080	+ 1	+0.001	pe 3	Stobie (1970)
41110.923	+ 68	-0.076	pe 2	Grayzeck (1978)
41592.936	+ 112	-0.040	pe 1	Grayzeck (1978)
41768.228	+ 128	-0.012	pe 2	Madore (1975)
42874.573	+ 229	-0.024	pe 3	Dean (1977)
44068.488	+ 338	-0.098	pe 3	Coulson et al. (1985)
44659.979	+ 392	-0.125	pe 3	Coulson et al. (1985)
45010.518	+ 424	-0.114	pe 3	Coulson et al. (1985)

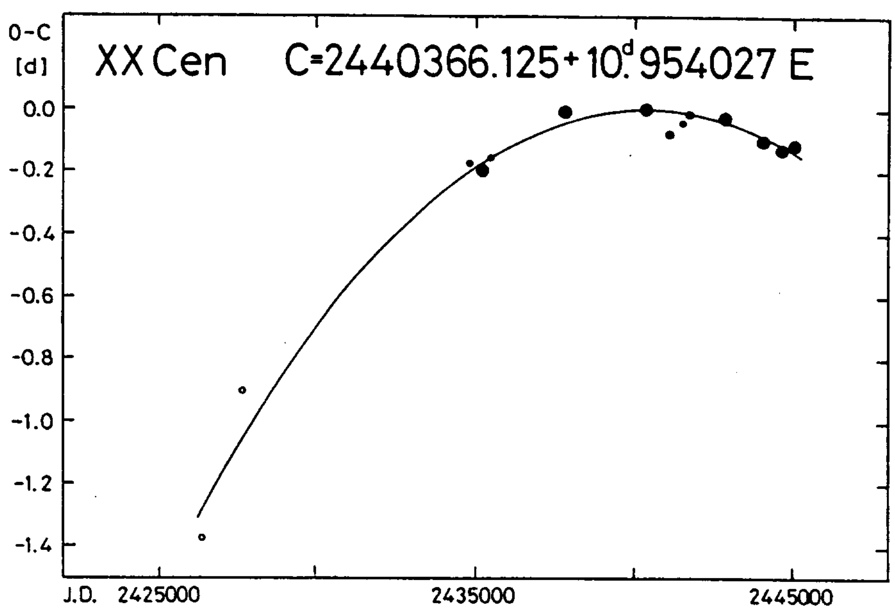

Figure 7. O-C diagram of XX Cen

AZ Centauri

AZ Cen may be a spectroscopic binary because *Balona* found a strongly discordant γ-velocity in comparison with other radial velocity measurements (*Gieren*, 1982). Unfortunately *Balona*'s observations have remained unpublished, and the available radial velocity data show a constant γ-velocity (see Table 13).

The O-C residuals have been computed with the formula:

$$C = \underset{\pm .011}{2435223.389} + \underset{\pm .000004}{3\overset{d}{.}212279} \cdot E \qquad (12)$$

It should be emphasized that this pulsation period strongly differs from that given in the GCVS (*Kholopov* et al., 1985-1987). The O-C diagram is parabolic (see Table 14, and Figure 8) showing a continuous decrease in the period. The instantaneous value of the pulsation period can be obtained from the formula:

$$P = \underset{\pm .000004}{3\overset{d}{.}212279} - \underset{\pm .35}{9\overset{d}{.}79} \cdot 10^{-8} \cdot E \qquad (13)$$

where the E epoch number is the same as in equation (12).

Table 13. γ-velocities of AZ Cen

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
34138	33	-12.1	0.9	11	Stibbs (1955)
43178	4	-11.5	0.4	7	Stobie and Balona (1979)
43311	37	-13.1	0.3	10	Stobie and Balona (1979)
43531	4	-12.5	0.6	4	Stobie and Balona (1979)
44423	4	-12.7	0.4	22	Gieren (1981a)

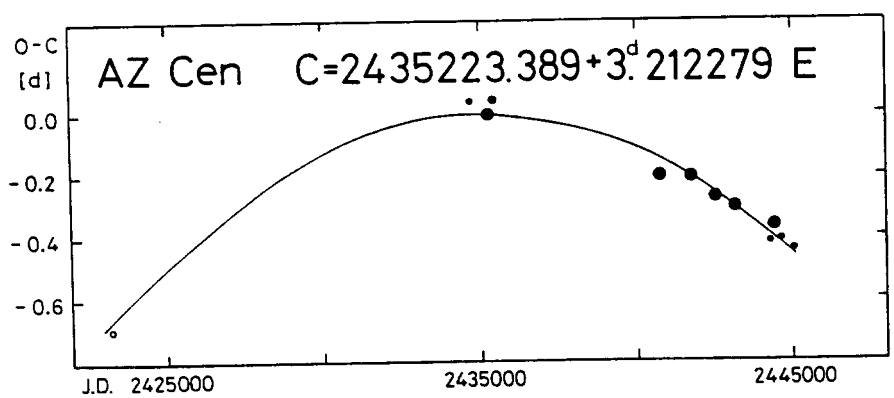

Figure 8. O-C diagram of AZ Cen

Table 14. O–C residuals for AZ Cen

Norm.max. JD2400000+	E	O–C	Type, weight	Reference
23253.740	−3726	$-0^d.697$	pg 1	de Jager (1947)
34709.464	− 160	+0.040	pe 1	Walraven et al. (1958)
35220.172	− 1	−0.005	pe 3	Irwin (1961)
35451.504	+ 71	+0.043	pe 2	Walraven et al. (1958)
40738.672	+1717	−0.200	pe 3	Pel (1976)
41795.508	+2046	−0.204	pe 3	Dean et al. (1977)
42540.691	+2278	−0.270	pe 3	Dean et al. (1977)
43179.904	+2477	−0.300	pe 3	Stobie and Balona (1979)
44316.936	+2831	−0.415	pe 1	Eggen (1985)
44400.508	+2857	−0.362	pe 3	Gieren (1981b)
44634.956	+2930	−0.410	pe 1	Eggen (1985)
45055.732	+3061	−0.443	pe 1	Eggen (1985)

KN Centauri

The presence of a companion to the Cepheid KN Cen has been suspected on various grounds: large UV excess (*Walraven* et al., 1964), peculiar loop in the two-colour diagram (*Stobie*, 1970; *Madore*, 1977; and *Pel*, 1978), the shape of the Ca II K line (*Lloyd Evans*, 1968), and finally the companion was revealed with the help of an IUE spectrum (*Böhm Vitense* and *Proffitt*, 1985). The available radial velocity observations also give evidence for the binary nature (see Table 15 and the lower panel of Figure 9). This variation has not been reported before.

Table 15. γ-velocities of KN Cen

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
41539	194	−48.8	4.5	6	Grayzeck (1978)
43975	5	−40.8	0.4	6	Coulson and Caldwell (1985)
44400	56	−40.0	0.4	9	Coulson and Caldwell (1985)
44703	35	−39.5	0.3	16	Coulson and Caldwell (1985)
45092	2	−38.0	0.5	3	Coulson and Caldwell (1985)

The O–C residuals (see Table 16 and upper panel of Figure 9) have been calculated with the elements:

$$C = 2436242.009 + 34^d.029641 \cdot E \quad (14)$$
$$\pm.195 \qquad \pm.000787$$

Table 16. O-C residuals for KN Cen

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
34638.470	- 47	$-4^{d}.146$	pe 2	Walraven et al. (1958)
35216.974	- 30	-4.146	pe 3	Irwin (1961)
35250.816	- 29	-4.333	pe 1	Walraven et al. (1958)
37871.756	+ 48	-3.676	pe 1	Walraven et al. (1964)
40356.990	+121	-2.606	pe 2	Stobie (1970)
41106.302	+143	-1.946	pe 3	Pel (1976)
41582.839	+157	-1.824	pe 2	Grayzeck (1978)
44034.776	+229	-0.021	pe 2	Coulson and Caldwell (1985)
44647.361	+247	+0.031	pe 3	Coulson and Caldwell (1985)
45123.728	+261	-0.017	pe 3	Coulson and Caldwell (1985)

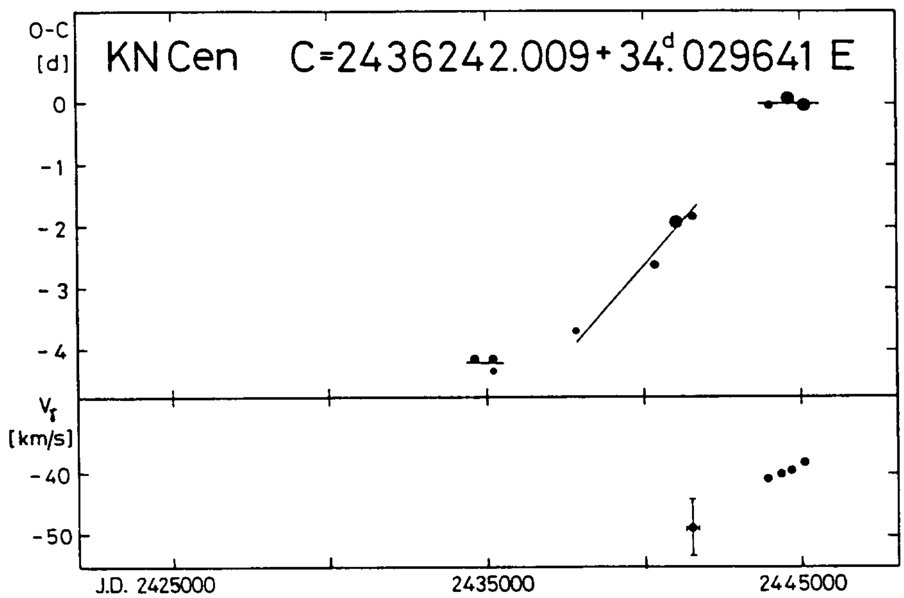

Figure 9. Upper panel: O-C diagram of KN Cen
Lower panel: γ-velocities for the same Cepheid

Three values of the pulsation period could be determined:

before J.D.2437000 $P = 34^{d}.026583 \pm {}^{d}.003999$

between J.D.2437000 and J.D.2444000 $P = 34^{d}.047490 \pm {}^{d}.001315$

after J.D.2444000 $P = 34^{d}.029641 \pm {}^{d}.000787$.

The first and the third value is nearly the same, i.e. a phase jump occurred, although not very suddenly.

Additional photometric and radial velocity measurements on this binary Cepheid are urgently needed both for confirming the rejump in the pulsation period, and in order to determine the orbital period.

AX Circinis

Its composite spectrum was discovered by *Jaschek* and *Jaschek* (1960). *Lloyd Evans* (1971) revealed the spectroscopic binary nature of AX Cir, while *Böhm Vitense* and *Proffitt* (1985) were able to detect the companion using IUE spectra.

The variable γ-velocity is shown in the lower panel of Figure 10 (see also Table 17). The observed extrema of the γ-velocity correspond to the full amplitude of the γ-velocity variation, as is seen in the O-C wave to be discussed below (see Figure 10).

Table 17. γ-velocities of AX Cir

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
38570	6	-17.7	0.9	6	Evans (1965)
39618	50	-26.0	1.1	4	Lloyd Evans (1968)
39900	33	-26.4	0.2	7	Lloyd Evans (1980)
40258	11	-26.8	0.6	2	Lloyd Evans (1980)
40387	46	-30.9	0.2	14	Lloyd Evans (1980)
40745	71	-33.3	0.2	15	Lloyd Evans (1980)

Table 18. O-C residuals for AX Cir

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
38220.425	+ 4	$-0\overset{d}{.}006$	pe 3	Cousins and Evans (1967)
39533.527	+253	+0.043	pe 3	Cousins and Evans (1967)
39617.878	+269	+0.021	pe 3	Mauder and Schöffel (1968)
42855.659	+883	-0.008	pe 3	Dean (1977)
42971.687	+905	+0.007	pe 3	Dean (1977)
44474.595	+1190	+0.023	pe 2	Eggen (1985)
45381.576	+1362	-0.005	pe 2	Eggen (1985)

The O-C residuals listed in Table 18 have been computed with the formula:

$$C = \underset{\pm .002}{2438199.338} + \underset{\pm .000008}{5\overset{d}{.}273306} \cdot E \tag{15}$$

A sinusoidal term is superimposed on the straight line in the O-C graph. A weighted least squares fit applied to the O-C residuals resulted in the

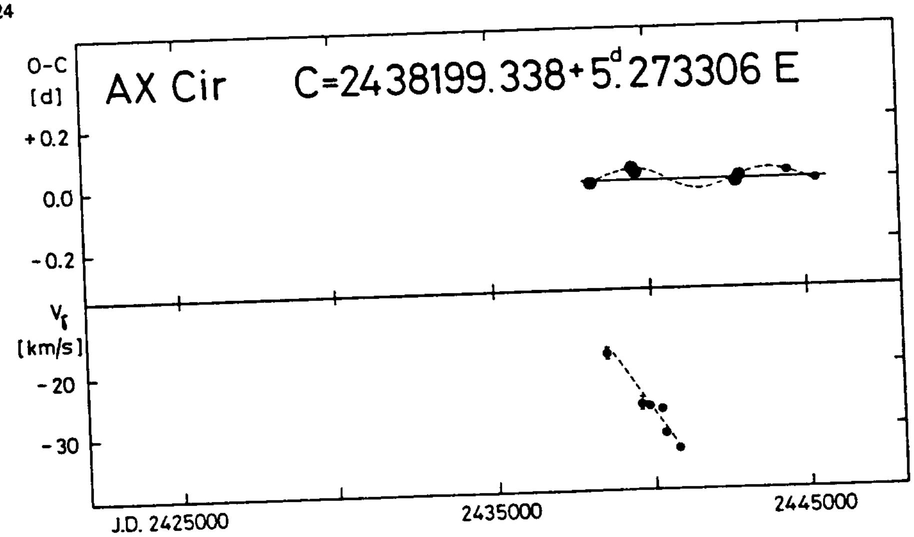

Figure 10. Upper panel: O–C diagram of AX Cir
Lower panel: γ-velocities for the same Cepheid

value of 4600 ± 83 days for the orbital period. The moments of the normal maxima can be predicted as follows:

$$C = \underset{\pm .002}{2438199.338} + \underset{\pm .000008}{5\overset{d}{.}273306} \cdot E - \underset{\pm .002}{0\overset{d}{.}032}\cos(2\pi(\underset{\pm .00002}{0.00115}E + \underset{\pm .018}{0.222})) \qquad (16)$$

Although each parameter (amplitude, phase, period) of this wave are in agreement with the pattern of the γ-velocity changes, further observations are desirable to confirm or refine the above value of the orbital period.

S Crucis

The γ-velocity of S Cru seems to be constant (see Table 19).

Table 19. γ-velocities of S Cru

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
33832	9	-6.0	1.3	6	Stibbs (1955)
34167	46	-6.9	1.1	8	Stibbs (1955)
40383	46	-5.0	0.2	7	Lloyd Evans (1980)
44423	4	-7.8	0.4	25	Gieren (1981a)

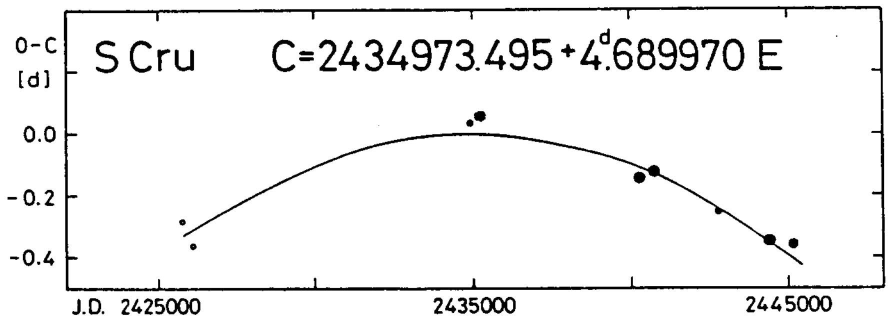

Figure 11. **O–C diagram** of S Cru

Table 20. **O–C residuals** for S Cru

Norm.max. JD2400000+	E	O–C	Type, weight	Reference
25785.558	-1959	$-0^d.286$	pg 1	Dartayet et al. (1949)
26109.086	-1890	-0.366	pg 1	Dartayet et al. (1949)
34921.939	- 11	+0.034	pe 1	Walraven et al. (1958)
35208.046	+ 50	+0.053	pe 2	Irwin (1961)
40310.536	+1138	-0.145	pe 3	Stobie (1970)
40774.862	+1237	-0.126	pe 3	Pel (1976)
42852.392	+1680	-0.253	pe 1	Dean (1977)
44414.058	+2013	-0.347	pe 3	Gieren (1981b)
45126.915	+2165	-0.365	pe 2	Eggen (1985)

The O–C residuals (listed in Table 20) have been computed with the elements:

$$C = 2434973.495 + 4^d.689970 \cdot E \qquad (17)$$
$$\pm.015 \quad \pm.000007$$

As is seen in Figure 11, the pulsation period is continuously decreasing. The instantaneous value of the period is:

$$P = 4^d.689970 - 1^d.747 \cdot 10^{-7} \cdot E \qquad (18)$$
$$\pm.000007 \quad \pm.109$$

where the E epoch number is the same as in equation (17).

T Crucis

On the basis of the available radial velocity measurements, variability in the γ-velocity can be suspected (see Table 21 and the lower panel of Figure 12). *Jaschek* and *Jaschek* (1956) found strong Ca II emission which may be partly caused by the presence of the companion.

Table 21. γ-velocities of T Cru

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
33831	9	-5.5	1.1	8	Stibbs (1955)
34106	19	-7.8	1.1	9	Stibbs (1955)
40363	34	-12.8	0.3	6	Lloyd Evans (1980)

Table 22. O-C residuals for T Cru

Norm.max JD2400000+	E	O-C	Type, weight	Reference
25794.799	-1299	$-0^d.022$	pg 1	Dartayet et al. (1949)
26117.971	-1251	-0.044	pg 1	Dartayet et al. (1949)
33814.110	- 108	+0.052	pe 2	Eggen et al. (1957)
34871.193	+ 49	+0.023	pe 3	Eggen et al. (1957)
34958.726	+ 62	+0.025	pe 1	Walraven et al. (1958)
35214.551	+ 100	-0.012	pe 2	Irwin (1961)
40318.333	+ 858	+0.008	pe 1	Stobie (1970)
40742.458	+ 921	-0.059	pe 3	Pel (1976)
41819.814	+1081	-0.014	pe 3	Dean et al. (1977)
42102.620	+1123	-0.002	pe 3	Dean et al. (1977)
42587.418	+1195	+0.006	pe 2	Dean et al. (1977)
43260.823	+1295	+0.091	pe 1	Dean (1981)

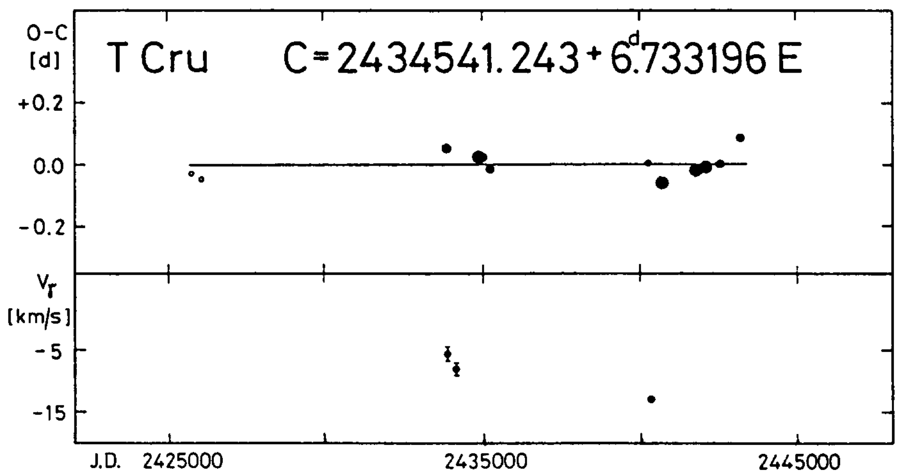

Figure 12. Upper panel: O-C diagram of T Cru
Lower panel: γ-velocities for the same Cepheid

The O-C diagram contains very few data points (see Table 22). The residuals have been calculated with the elements:

$$C = 2434541.243 + 6^d.733196 \cdot E \qquad (19)$$
$$\pm.010 \quad \pm.000011$$

The photographic observations have also been taken into account in the fitting procedure. If the deviations from the straight line (see Figure 12, upper panel) are caused by a light-time effect, the γ-velocity variations may well exceed the range observed so far. In any case, more photometric and spectroscopic observations are needed.

AG Crucis

Gieren (1982) already noted that AG Cru might belong to a spectroscopic binary. The present study based on the same radial velocity data (see Table 23 and the lower panel of Figure 13) confirm his conclusion. The presence of a blue companion is also suspected in *Pel*'s (1978) photometry.

Table 23. **γ-velocities of** AG Cru

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
34154	41	-4.4	0.8	17	Stibbs (1955)
40577	199	-6.5	0.3	5	Lloyd Evans (1980)
44423	4	-8.5	0.4	23	Gieren (1981a)

Table 24. O-C residuals for AG Cru

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
27439.121	-1947	$+1\overset{d}{.}523$	pg	O'Herne (1937)
34778.239	- 34	-0.026	pe 2	Walraven et al. (1958)
35219.538	+ 81	-0.012	pe 3	Irwin (1961)
39559.471	+1212	-0.013	pe 3	Landolt (1971)
40760.517	+1525	-0.027	pe 3	Pel (1976)
41098.205	+1613	-0.018	pe 2	Pel (1976)
42894.075	+2081	+0.017	pe 2	Dean (1977)
44421.305	+2479	+0.020	pe 3	Gieren (1981b)

Although the O-C diagram contains very few data points (see Table 24 and the upper panel of Figure 13), a sine wave can be reliably fitted to the O-C residuals. Moreover, the parameters of the light-time effect wave are in agreement with the changes in the γ-velocity. The O-C residuals have been computed with the elements:

$$C = \underset{\pm.001}{2434908.732} + \underset{\pm.000001}{3\overset{d}{.}837254}\cdot E \qquad (20)$$

and the moments of the light maxima can be predicted as follows:

$$C = \underset{\pm.001}{2434908.732} + \underset{\pm.000001}{3\overset{d}{.}837254}\cdot E - \underset{\pm.001}{0\overset{d}{.}026}\cos(2\pi(\underset{\pm.000008}{0.000604}E + \underset{\pm.012}{0.110})) \qquad (21)$$

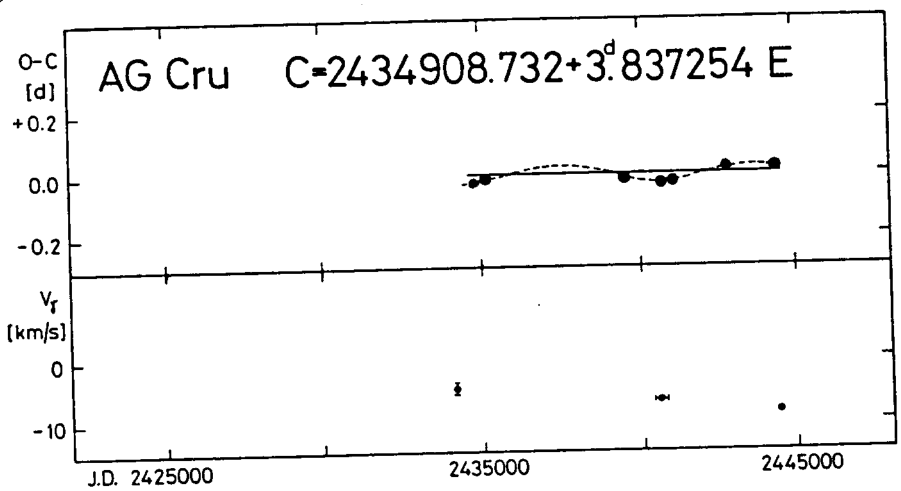

Figure 13. Upper panel: O-C diagram of AG Cru
Lower panel: γ-velocities for the same Cepheid

The orbital period is 6350 ± 90 days. According to the phase relations no radial velocity observation of AG Cru was performed during the epochs when the Cepheid was strongly moving away on its orbit. Therefore the expected amplitude of the γ-velocity variations may reach 10 km/s (see equation 1).

If the first O-C residual is correct, a period change might have occurred before J.D.2435000, but *O'Herne*'s (1937) photographic normal maximum seems to be of very low quality (this O-C residual has not been plotted in Figure 13).

BG Crucis

According to the available radial velocity observations, BG Cru is a new spectroscopic binary. Its duplicity can also be suspected on the basis of the extremely low amplitude light variations in the ultraviolet band (*Dean*, 1981). In addition to the data points listed in Table 25 (shown plotted in the lower panel of Figure 14), there is one more series of radial velocity observations (*Lunt*, 1921). These latter data, however, cannot be used because the moments of these three observations have not been published. The average value of these radial velocity measurements is -14.9 km/s, being more positive than any other γ-velocity determined for BG Cru.

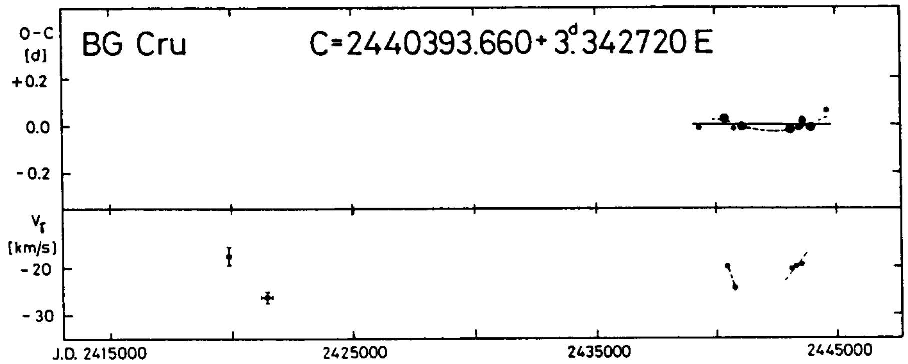

Figure 14. Upper panel: O-C diagram of BG Cru
Lower panel: γ-velocities for the same Cepheid

Table 25. γ-velocities of BG Cru

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
19902	1	-17.4	2.0	2	Campbell and Moore (1928)
21449	175	-26.2	1.2	4	Campbell and Moore (1928)
40449	9	-19.9	0.4	3	Lloyd Evans (1980)
40728	62	-24.4	0.2	16	Lloyd Evans (1980)
43178	4	-20.9	0.4	9	Stobie and Balona (1979)
43319	29	-20.0	0.3	10	Stobie and Balona (1979)
43533	4	-19.6	0.3	10	Stobie and Balona (1979)

Table 26. O-C residuals for BG Cru

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
39327.323	-319	$-0\overset{d}{.}009$	pe 1	Stobie and Alexander (1970)
40393.683	0	+0.023	pe 3	Stobie and Alexander (1970)
40771.369	+113	-0.018	pe 1	Cousins and Lagerwey (1971)
41112.338	+215	-0.007	pe 3	Cousins and Lagerwey (1971)
43181.468	+834	-0.021	pe 3	Stobie and Balona (1979)
43562.551	+948	-0.008	pe 2	Dean (1981)
43636.112	+970	+0.014	pe 2	Eggen (1985)
43997.102	+1078	-0.010	pe 3	Arellano Ferro (1981)
44622.258	+1265	+0.057	pe 1	Eggen (1985)

More than ten values could be determined as possible orbital periods using a least squares sinus fit but after comparing these values with the O-C diagram to be discussed below, three values remained as the most probable ones: 4050, 4950, and 6650 days.

The O-C residuals have been computed with the formula:

$$C = \underset{\pm .008}{2440393.660} + \underset{\pm .000010}{3\overset{d}{.}342720} \cdot E \qquad (22)$$

Although the light-time effect is apparent (see Table 26 and the upper panel of Figure 14), an exact determination of the orbital period cannot be carried out because of the limited time interval covered with photometric observations. The pattern of the O-C graph is in agreement with a nearly 5000 day long orbital period. Both much shorter and much longer values can be excluded.

β Doradus

The γ-velocity of this Cepheid variable is constant (see Table 27). *Lloyd Evans* (1968) could not find any variation larger than 3 km/s in the γ-velocity of β Dor either. Moreover, this star has not been suspected as having a companion by any other method.

Table 27. γ-velocities of β Dor

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
16619	191	5.1	1.3	6	Lunt (1924)
17297	798	7.9	0.7	12	Applegate (1927)
19129	921	6.1	1.7	4	Lunt (1924)
21712	564	8.0	0.3	54	Applegate (1927)
22815	136	6.9	0.5	35	Lunt (1924)
34024	29	8.8	0.6	23	Stibbs (1955)
40281	514	7.9	0.5	13	Lloyd Evans (1968, 1980)

Table 28. O-C residuals for β Dor

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
25639.776	-1551	$+0^d.108$	pg	Dartayet et al. (1949)
25993.962	-1515	-0.033	pg	Dartayet et al. (1949)
26397.617	-1474	+0.082	pg	Dartayet et al. (1949)
34438.765	- 657	-0.031	pe 1	Eggen et al. (1957)
34812.843	- 619	+0.035	pe 2	Eggen et al. (1957)
35216.360	- 578	+0.013	pe 2	Irwin (1961)
35570.654	- 542	-0.021	pe 1	Walraven et al. (1958)
40511.600	- 40	+0.028	pe 2	Hutchinson et al. (1975)
40796.967	- 11	-0.035	pe 3	Hutchinson et al. (1975)
40924.940	+ 2	-0.014	pe 3	Pel (1976)
41732.014	+ 84	-0.019	pe 3	Dean et al. (1977)
43198.610	+ 233	+0.056	pe 1	Dean (1981)
43493.849	+ 263	+0.022	pe 2	Eggen (1985)
43887.415	+ 303	-0.109	pe 1	Schmidt and Parsons (1982)
44665.128	+ 382	+0.053	pe 2	Eggen (1985)

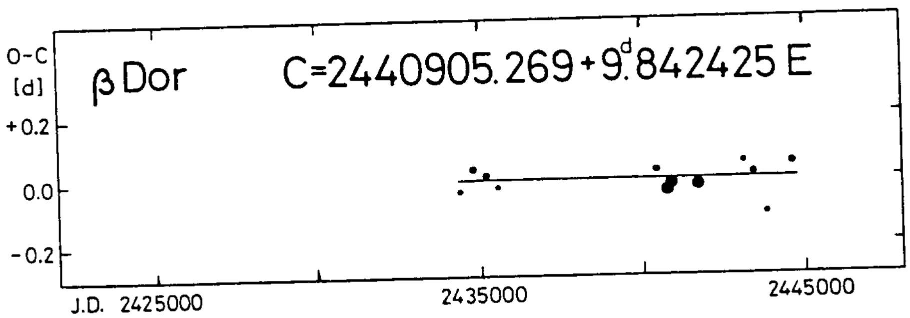

Figure 15. O-C diagram of β Dor

The early part of the O-C diagram of β Dor was published by *Iroshnikov* (1958). In the present study the O-C residuals have been calculated with the elements:

$$C = 2440905.269 + 9\overset{d}{.}842425 \cdot E \qquad (23)$$
$$\pm.008 \quad \pm.000024$$

The photoelectric part of the O-C diagram (see Table 28 and Figure 15) can be well approximated by a straight line, assuming a constant period during the last decades. A parabolic fit to these O-C residuals (including the photographic points at about J.D.2426000) would contradict to the O-C pattern determined by *Iroshnikov* (1958).

GH Lupi

The variation in the γ-velocity of GH Lupi has not been reported yet. Although the effect is not very large, it can be readily detected especially in the radial velocity observational series obtained by *Coulson and Caldwell* (1985) (see Table 29 and the lower panel of Figure 16). This variation might have been hidden till now because the pulsation period was not known accurately enough. The unusually low amplitude light variation

Table 29. γ-velocities of GH Lup

JD 2400000+	σ [d]	$v_γ$ [km/s]	σ [km/s]	n	Reference
41602	214	-21.5	4.5	6	Grayzeck (1978)
43974	5	-15.0	0.4	7	Coulson and Caldwell (1985)
44408	52	-16.0	0.3	10	Coulson and Caldwell (1985)
44721	32	-16.9	0.3	17	Coulson and Caldwell (1985)
45092	2	-18.9	0.6	4	Coulson and Caldwell (1985)

Table 30. O-C residuals for GH Lup

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
38202.145	-315	$-0^d.474$	pg	Strohmeier (1967)
41088.014	- 4	-0.047	pe 3	Pel (1976)
41413.010	+ 31	+0.221	pe 1	Grayzeck (1978)
44029.154	+313	-0.017	pe 3	Coulson and Caldwell (1985)
44455.880	+359	-0.076	pe 3	Coulson and Caldwell (1985)
44651.017	+380	+0.224	pe 1	Eggen (1985)
44734.257	+389	-0.038	pe 3	Coulson and Caldwell (1985)
45142.455	+433	-0.069	pe 2	Coulson and Caldwell (1985)
45569.543	+479	+0.233	pe 1	Eggen (1985)

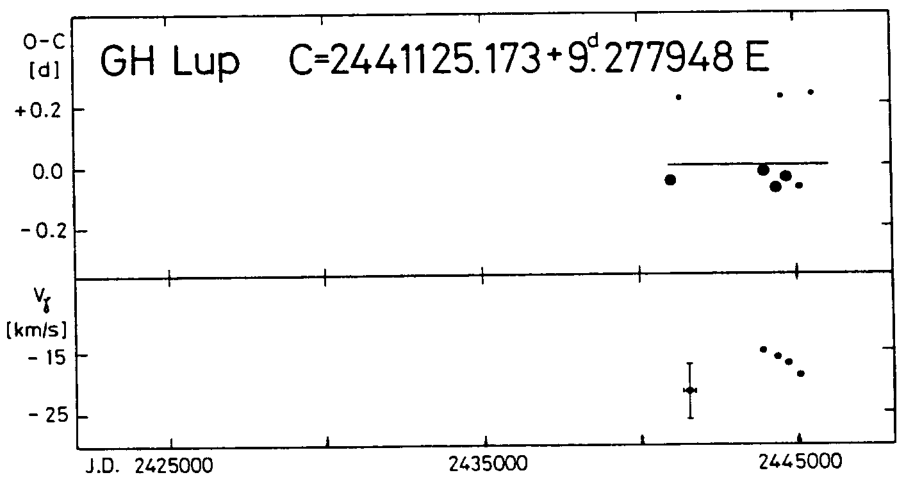

Figure 16. Upper panel: O-C diagram of GH Lup
Lower panel: γ-velocities for the same Cepheid

may be also due to the presence of a companion. *Pel*'s (1978) photometry gives evidence for a red companion.

The O-C residuals listed in Table 30 and plotted in Figure 16 (upper panel) have been computed by the formula:

$$C = \underset{\pm .056}{2441125.173} + \underset{\pm .000167}{9^d.277948} \cdot E \qquad (24)$$

This value of the pulsation period, assumed to be constant between J.D.2441000 and 2445600, considerably differs from the value given in the GCVS (*Kholopov* et al., 1985-1987). A change in the period might have occurred before J.D.2441000, if the photographic O-C residual obtained from *Strohmeier*'s (1967) data is real.

R Muscae

The Cepheid R Muscae is probably a spectroscopic binary (*Lloyd Evans*, 1982). This earlier conclusion is confirmed here (see Table 31 and the lower panel of Figure 17). There is, however, no sign of any companion in the study made by *Eichendorf* et al. (1982) covering an exceptionally wide wavelength range.

The O-C residuals listed in Table 32 have been calculated with the elements:

$$C = \underset{\pm .020}{2426496.033} + \underset{\pm .000028}{7\overset{d}{.}510159} \cdot E \qquad (25)$$

As is readily seen in Figure 17, R Mus has a continuously increasing period:

$$P = \underset{\pm .000028}{7\overset{d}{.}510159} + \underset{\pm .10}{1\overset{d}{.}25} \cdot 10^{-7} \cdot E \qquad (26)$$

where the E epoch number is the same as in equation (25). The photographic O-C residuals were also taken into account during the fitting procedure. A sine-wave superimposed on the parabola was also searched for but without any physically acceptable result.

Table 31. γ-velocities of R Mus

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
33832	9	+4.2	1.2	7	Stibbs (1955)
34125	31	+2.4	1.2	7	Stibbs (1955)
40389	43	-2.0	0.2	14	Lloyd Evans (1980)
40727	67	+1.3	0.2	18	Lloyd Evans (1980)

Table 32. O-C residuals for R Mus

Norm.max JD2400000+	E	O-C	Type, weight	Reference
19346.327	- 952	$-0\overset{d}{.}035$	pg	Hertzsprung (1928)
26105.508	- 52	+0.003	pg 1	Dartayet et al. (1949)
26473.501	- 3	-0.002	pg 1	Dartayet et al. (1949)
34141.479	+1018	+0.104	pe 1	Eggen et al. (1957)
34839.906	+1111	+0.086	pe 3	Walraven et al. (1958)
34907.506	+1120	+0.094	pe 3	Eggen et al. (1957)
35207.854	+1160	+0.037	pe 3	Irwin (1961)
37836.518	+1510	+0.145	pe 3	Walraven et al. (1964)
42853.512	+2178	+0.359	pe 2	Dean (1977)
43596.970	+2277	+0.305	pe 3	Eggen (1985)
44648.445	+2417	+0.358	pe 3	Eggen (1985)

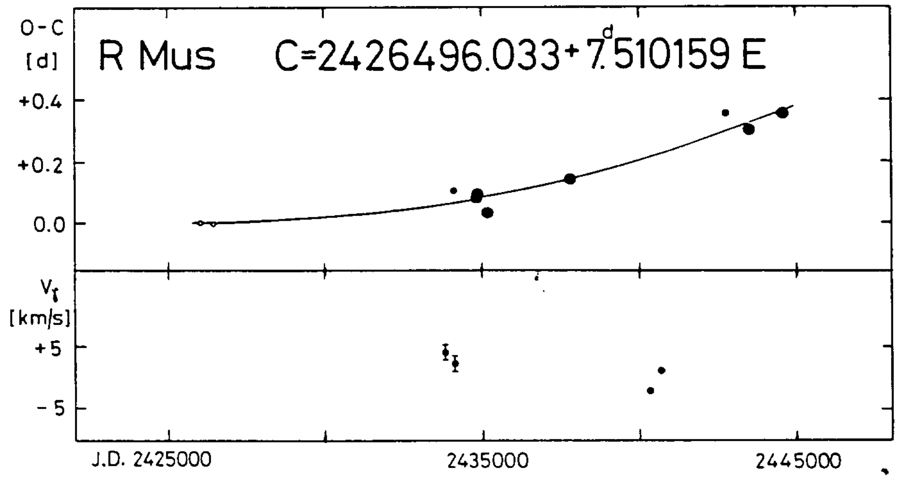

Figure 17. **Upper panel: O-C diagram of** R Mus
Lower panel: γ-velocities for the same Cepheid

S Muscae

This Cepheid has long been known as a spectroscopic binary. Its orbital period is 506 days (*Lloyd Evans*, 1971). The presence of a blue companion is predicted by the two-colour diagrams (*Stobie*, 1970; *Dean*, 1977 ; *Pel*, 1978). *Böhm-Vitense* and *Proffitt* (1985) detected the effect of the companion in the IUE spectrum of S Mus. The radial velocity observations of S Muscae are not re-discussed here.

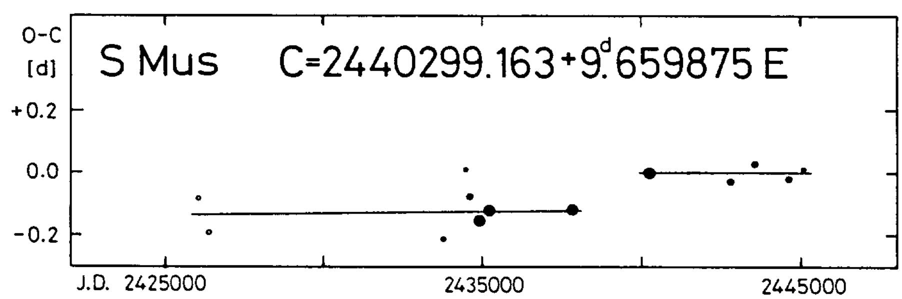

Figure 18. **O-C diagram of** S Mus

Table 33. O-C residuals for S Mus

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
26128.045	-1467	$-0\overset{d}{.}081$	pg 1	Dartayet et al. (1949)
26466.032	-1432	-0.190	pg 1	Dartayet et al. (1949)
33807.521	- 672	-0.206	pe 1	Eggen et al. (1957)
34541.889	- 596	+0.012	pe 1	Eggen et al. (1957)
34628.743	- 587	-0.073	pe 2	Walraven et al. (1958)
34918.458	- 557	-0.155	pe 3	Eggen et al. (1957)
35227.609	- 525	-0.120	pe 3	Irwin (1961)
37845.449	- 254	-0.106	pe 3	Walraven et al. (1964)
40308.825	+ 1	+0.002	pe 3	Stobie (1970)
42859.006	+ 265	-0.024	pe 2	Dean (1977)
43602.870	+ 342	+0.030	pe 2	Eggen (1985)
44694.391	+ 455	-0.015	pe 2	Eggen (1985)
45148.433	+ 502	+0.013	pe 1	Eggen (1985)

The light curve of this Cepheid is double-peaked. The moment of the first maximum was used when constructing the O-C diagram. The O-C residuals listed in Table 33 have been calculated with the elements:

$$C = \underset{\pm .012}{2440299.163} + \underset{\pm .000036}{9\overset{d}{.}659875} \cdot E \qquad (27)$$

The O-C diagram in Figure 18 can be best approximated by two almost parallel lines. The phase jump occurred at about J.D.2439000, before that epoch the pulsation period was $9.659899 \pm 4.0 \cdot 10^{-5}$ days (taking into account the photographic O-C residuals, as well). The value of the phase jump was about 0.1 day, and after the phase jump the elements given in equation (27) have been valid. The parabolic fit would be somewhat worse. The amplitude of the light-time effect expected according to equation (1) is about 0.01 day, therefore this effect can hardly be pointed out in the O-C diagram of S Muscae.

S Normae

S Nor is one of the most important stars among the Cepheid variables because of its membership in the open cluster NGC 6087. This calibrating Cepheid may belong to a spectroscopic binary system (*Breger*, 1970). Its duplicity is also suspected on the basis of photometric evidence (*Madore*, 1977). The γ-velocities listed in Table 34, including more recent than *Breger*'s data suggest a variation with a period of either 3300 or 6350 days (see the lower panel of Figure 19). Even longer periods can be excluded because the corresponding light-time effect is not seen in the O-C diagram (see below).

Table 34. γ-velocities of S Nor

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
18418	11	-5.8	1.0	5	Campbell and Moore (1928)
33905	22	+3.8	0.9	12	Stibbs (1955)
34213	22	+3.5	1.2	7	Stibbs (1955)
38514	44	+5.6	0.3	12	Feast (1967)
38619	7	+9.4	0.5	5	Feast (1967)
38953	17	+7.1	0.1	20	Breger (1970)
39288	121	+8.0	1.9	2	Lloyd Evans (1968)
40377	29	+3.4	0.2	8	Lloyd Evans (1980)
40814	12	+3.1	0.3	3	Lloyd Evans (1980)
41412	4	+2.6	7.1	3	Grayzeck (1978)
41793	4	-2.4	5.8	4	Grayzeck (1978)
45772	198	+5.9	0.2	10	Mermilliod et al. (1987)
46286	53	+5.8	0.1	13	Mermilliod et al. (1987)

Table 35. O-C residuals for S Nor

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
16580.963	-2813	$+0^d.767$	pg	Shapley (1930)
18199.911	-2647	+0.511	pg	Shapley (1930)
20248.050	-2437	+0.259	pg	Shapley (1930)
21350.020	-2324	-0.001	pg	Shapley (1930)
23203.204	-2134	-0.123	pg	Shapley (1930)
24276.419	-2024	+0.125	pg 1	ten Bruggencate (1927a)
24676.279	-1983	+0.061	pg 1	ten Bruggencate (1927a)
25037.357	-1946	+0.232	pg 1	ten Bruggencate (1927a)
34576.828	- 968	+0.052	pe 3	Walraven et al. (1958)
35230.372	- 901	+0.062	pe 3	Irwin (1961)
36830.115	- 737	+0.109	pe 2	Fernie (1961)
37844.464	- 633	+0.016	pe 3	Walraven et al. (1964)
38888.164	- 526	+0.012	pe 3	Breger (1970)
39268.525	- 487	-0.042	pe 3	Breger (1970)
39678.266	- 445	+0.021	pe 2	Schmidt (1971)
41424.213	- 266	-0.042	pe 1	Grayzeck (1978)
41882.705	- 219	0.000	pe 3	Dean et al. (1977)
42545.994	- 151	+0.001	pe 3	Dean et al. (1977)
43492.182	- 54	+0.027	pe 3	Dean (1981)
43784.761	- 24	-0.021	pe 2	Eggen (1980)

The O-C residuals have been computed with the ephemeris:

$$C = \underset{\pm .009}{2444018.884} + \underset{\pm .000024}{9^d.754244} \cdot E \qquad (28)$$

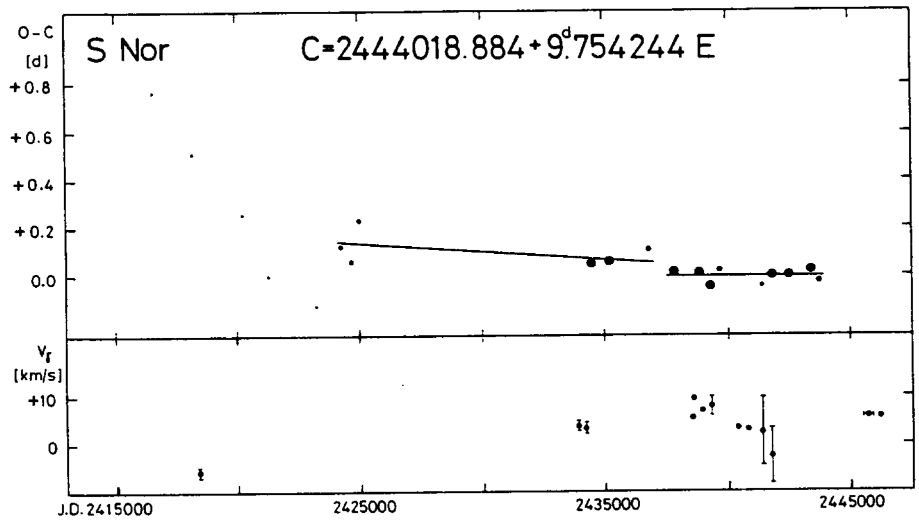

Figure 19. Upper panel: O-C diagram of S Nor
Lower panel: γ-velocities for the same Cepheid

The O-C diagram is approximated by two sections of almost parallel lines (see Table 35 and the upper panel of Figure 19). Before the phase jump the most reliable photographic observations have been taken into account in the fitting procedure which resulted in the period P = 9.754190 $\pm 3.0\cdot 10^{-5}$ days. The phase jump might have occurred at about J.D.2437500, and it amounted to 0.06 day. The observed changes in the γ-velocity are too small to cause any noticeable light-time effect, assuming an orbital period of several thousand days.

RS Normae

RS Nor has been completely neglected spectroscopically: there is not a single radial velocity measurement published in the literature. The situation is not much better as far as photometric observations are concerned, because the O-C diagram (see Table 36 and Figure 20) contains a few scattered points. *Madore* (1977) gives evidence for a B8 dwarf photometric companion.

The O-C residuals have been computed with the elements:

$$C = \underset{\pm .009}{2435308.175} + \underset{\pm .000012}{6\overset{d}{.}198136}\cdot E \qquad (29)$$

Table 36. **O-C residuals for** RS Nor

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
25583.330	-1569	$+0^d.030$	pg 1	Kruytbosch (1930b)
34737.872	- 92	-0.074	pe 1	Walraven et al. (1958)
35227.600	- 13	+0.001	pe 3	Irwin (1961)
35332.962	+ 4	-0.006	pe 1	Walraven et al. (1958)
40768.737	+ 881	+0.004	pe 3	Pel (1976)
41103.449	+ 935	+0.017	pe 2	Pel (1976)

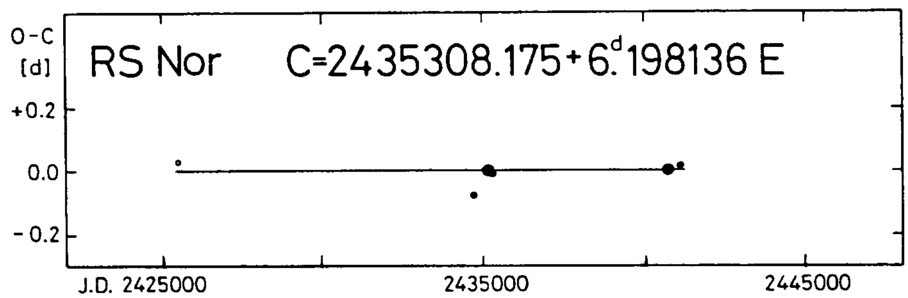

Figure 20. **O-C diagram of** RS Nor

The early photographic observations were also used when determining the average pulsation period.

SY Normae

An early type photometric companion to this Cepheid was suspected by *Madore* (1977). A companion was later found using IUE measurements (*Böhm-Vitense* and *Proffitt*, 1985) but it cannot be ruled out that these two stars form only an optical pair. Radial velocity measurements would be very important in order to find the physical relation between the two stars, if it really exists. The only available radial velocity data published by *Grayzeck* (1978) are not suitable for drawing any conclusion.

The O-C residuals listed in Table 37 and plotted in Figure 21 have been calculated with the elements:

$$C = 2440731.750 + 12^d.645687 \cdot E \qquad (30)$$
$$\pm.004 \qquad \pm.000016$$

The pulsation period has been stable since J.D.2434700. It is worth mentioning that the moment of the normal maximum given in equation (30) strongly differs from the value given in the GCVS (*Kholopov* et al.,

Table 37. O-C residuals for SY Nor

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
25600.646	-1197	+5.783	pg	Kruytbosch (1930a)
34750.337	- 473	-0.003	pe 3	Walraven et al. (1958)
35218.235	- 436	+0.005	pe 3	Irwin (1961)
40390.261	- 27	-0.055	pe 1	Stobie (1970)
40769.693	+ 3	+0.006	pe 3	Pel (1976)
41111.126	+ 30	+0.005	pe 3	Pel (1976)
41591.643	+ 68	-0.014	pe 2	Grayzeck (1978)
41920.457	+ 94	+0.012	pe 3	Madore (1975)

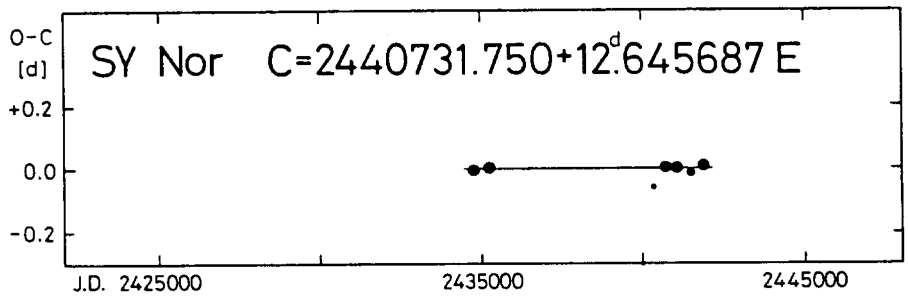

Figure 21. **O-C diagram of** SY Nor

1985-1987). This deviation is probably caused by *Kruytbosch*'s (1930a) ephemeris. Unfortunately the original photographic observations have not been published, therefore it cannot be decided whether there was a real period change, or *Kruytbosch* published an erroneous ephemeris.

Y Ophiuchi

Y Oph belongs to a spectroscopic binary system. Its orbital period was determined by *Abt* and *Levy* (1978) as being 2612 days. *Evans* and *Lyons* (1986) questioned this value of the orbital period, and even doubted the variability in the γ-velocity. The presence of a blue photometric companion is suspected by *Pel* (1978) but such a blue star is not seen in an IUE spectrum (*Evans* and *Lyons*, 1986). All the available radial velocity data were subjected to a period analysis which resulted in the value of 1222.5 $\pm$ 10 days for the orbital period. The γ-velocities are listed in Table 38, and the orbital radial velocity curve folded with the recently determined period is shown in Figure 22. In this figure open circles denote

Table 38. γ-velocities of Y Oph

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
17066	27	-4.9	0.3	42	Albrecht (1907)
17440	6	-9.4	2.0	2	Albrecht (1907)
25356	13	-4.8	1.0	5	Sanford (1935)
26549	32	-1.0	0.6	14	Sanford (1935)
26911	35	-8.3	0.8	7	Sanford (1935)
27226	45	-11.8	0.6	11	Sanford (1935)
34482	29	-7.0	0.6	12	Abt (1954)
34599	32	-7.9	1.1	4	Abt (1954)
40365	36	-5.8	0.2	9	Lloyd Evans (1980)
40718	25	-7.8	0.5	4	Abt and Levy (1978)
40762	50	-6.4	0.2	7	Lloyd Evans (1980)
40792	28	-7.3	0.4	4	Evans and Lyons (1986)
41110	23	-6.3	0.5	3	Evans and Lyons (1986)
41116	36	-7.2	0.6	4	Abt and Levy (1978)
41534	79	-6.1	0.3	6	Abt and Levy (1978)
42228	86	-6.5	0.2	3	Abt and Levy (1978)
42565	35	-7.3	0.3	2	Abt and Levy (1978)
42900	27	-10.1	0.5	6	Abt and Levy (1978)
43281	26	-8.2	0.5	4	Abt and Levy (1978)
43350	46	-9.4	1.1	13	Wilson et al. (1989)
43639	46	-5.1	1.0	17	Barnes et al. (1987)
43976	5	-5.8	0.5	5	Coulson and Caldwell (1985)
44013	58	-10.1	1.1	12	Barnes et al. (1987)
44049	4	-9.0	0.5	3	Evans and Lyons (1986)
44181	3	-10.0	1.0	2	Coulson and Caldwell (1985)
44415	47	-6.4	0.4	9	Coulson and Caldwell (1985)
44446	23	-7.9	0.5	3	Evans and Lyons (1986)
44449	1	-12.5	1.3	1	Beavers and Eitter (1986)
44759	36	-8.8	0.6	4	Coulson and Caldwell (1985)
44819	25	-6.2	0.7	2	Evans and Lyons (1986)
45092	2	-7.2	0.7	3	Coulson and Caldwell (1985)
45388	1	-9.5	2.7	3	Barnes et al. (1987)
45501	21	-8.6	0.3	6	Evans and Lyons (1986)
45875	1	-9.9	0.7	1	Evans and Lyons (1986)

those low weight γ-velocities that are based on one or two radial velocity measurements. The semi-amplitude of the orbital radial velocity variations is 1.60 ± 0.47 km/s. In spite of its low amplitude, the orbital effect seems to be real because its consequences also appear in the O-C diagram (see below).

The early part of the O-C diagram was constructed by *Detre* (1970). In the present paper all the photoelectric and photographic series of observations are discussed. The O-C residuals listed in Table 39 have been calculated with the elements:

$$C = 2439853.173 + 17\overset{d}{.}126908 \cdot E \qquad (31)$$
$$\pm.033 \qquad \pm.000139$$

Table 39. O-C residuals for Y Oph

Norm.max JD2400000+	E	O-C	Type, weight	Reference
25077.192	-863	$+4^{d}.541$	pg	ten Bruggencate (1927b)
32781.493	-413	+1.733	pe 2	Eggen (1951)
33106.646	-394	+1.475	pe 3	Eggen (1951)
34322.185	-323	+1.003	pe 3	Abt (1954)
34733.130	-299	+0.902	pe 2	Walraven et al. (1958)
35281.188	-267	+0.899	pe 3	Irwin (1958)
35691.858	-243	+0.524	pe 2	Prokof'yeva (1961)
37079.101	-162	+0.487	pe 2	Mitchell et al. (1964)
37472.819	-139	+0.286	pe 1	Mitchell et al. (1964)
37815.507	-119	+0.436	pe 1	Williams (1966)
38603.166	- 73	+0.257	pe 1	Wisniewski and Johnson (1968)
39014.145	- 49	+0.190	pe 3	Wisniewski and Johnson (1968)
39682.123	- 10	+0.219	pe 3	Schmidt (1971)
40401.559	+ 32	+0.325	pe 1	Feltz and McNamara (1980)
40778.016	+ 54	-0.010	pe 3	Pel (1976)
40812.402	+ 56	+0.122	pe 1	Feltz and McNamara (1980)
40829.354	+ 57	-0.053	pe 2	Evans (1976)
41188.978	+ 78	-0.093	pe 2	Feltz and McNamara (1980)
42953.217	+181	+0.074	pe 3	Dean (1977)
43038.950	+186	+0.172	pe 2	Dean (1981)
43312.747	+202	-0.061	pe 3	Moffett and Barnes (1984)
43672.337	+223	-0.136	pe 2	Moffett and Barnes (1984)
44015.145	+243	+0.133	pe 3	Moffett and Barnes (1984)
44032.132	+244	-0.007	pe 2	Coulson and Caldwell (1985)
44443.162	+268	-0.022	pe 3	Coulson and Caldwell (1985)
44460.261	+269	-0.050	pe 3	Eggen (1983b)
44871.342	+293	-0.015	pe 3	Coulson and Caldwell (1985)
46292.876	+376	-0.014	pe 3	Berdnikov (1987)
46601.179	+394	+0.004	pe 1	Lloyd et al. (1987)

Table 40. Changes in the pulsation period of Y Oph

J.D. interval	P
2432781 - 2433106	$17^{d}.113288$ ±.000010
34733 - 35281	17.126813 ±.000007
35281 - 35691	17.111255 ±.000001
39014 - 39682	17.127643 ±.000001
40778 - 46601	17.126908 ±.000139

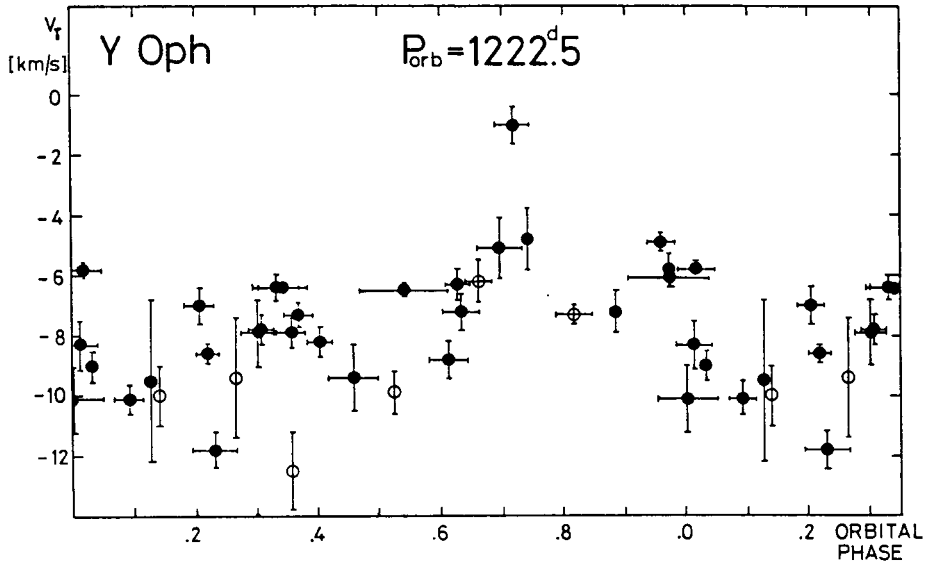

Figure 22. Orbital velocity curve of Y Oph

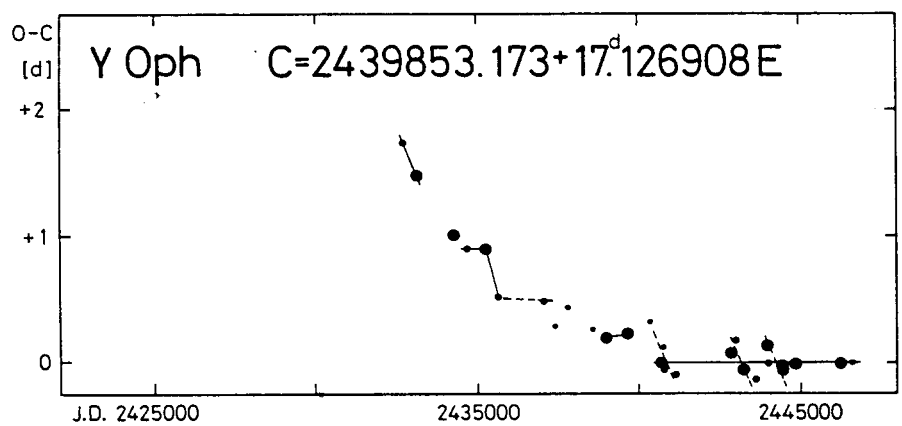

Figure 23. O-C diagram of Y Oph

The O-C diagram (see Figure 23) is of complex structure. It is approximated with sections of straight lines, representing two characteristic periods: either 17.112 or 17.127 days. Table 40 summarizes the individual periods and the time intervals in which the given period was valid.

The alternating periods can be considered as a special case of the phase jump: there is an interval of finite length when the star pulsates with another period before returning to the "original" pulsation period. As in the previous cases, the phase jump is a characteristic feature of binary Cepheids. Moreover, the final part of the O-C diagram (after J.D.2440000) shows unusually wide scatter, if approximated by a single period. The dashed lines, however, suggest that this part also consists of several phase jumps, and the predominant period is the shorter one (17.112 days). The cyclic occurrence of this pulsation period can also be suspected, the cycle length being about 2400 days in the first case, and about 1200 days in the second case (N.B. the orbital period determined above is just over 1200 days). This phenomenon cannot be interpreted as a light-time effect because of the large amplitude but it gives a further support to the reality of the 1222.5 day spectroscopic orbital period, and calls the attention that the binary companion is able to control the changes in the pulsation period.

BF Ophiuchi

According to *Mianes* (1963) and *Balona* (1977), BF Oph has a red photometric companion, while *Gieren* (1982) already suspected the spectroscopic binary nature of this Cepheid. The analysis of the available radial velocity data (see Table 41) suggests an orbital period of 4420 ± 80 days. The orbital velocity curve is shown in Figure 24. Although the plot of the data is not too convincing, this period is also supported by the features in the O-C diagram (see below).

Table 41. γ-velocities of BF Oph

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25597	219	-32.5	2.6	4	Joy (1937)
26152	45	-33.2	2.2	5	Joy (1937)
33905	21	-30.0	1.1	9	Stibbs (1955)
34199	14	-31.8	1.5	5	Stibbs (1955)
40559	210	-29.4	0.2	13	Lloyd Evans (1980)
44233	207	-28.3	1.1	13	Barnes et al. (1988)
44423	4	-29.2	0.4	22	Gieren (1981a)
44945	295	-28.2	2.3	4	Barnes et al. (1988)

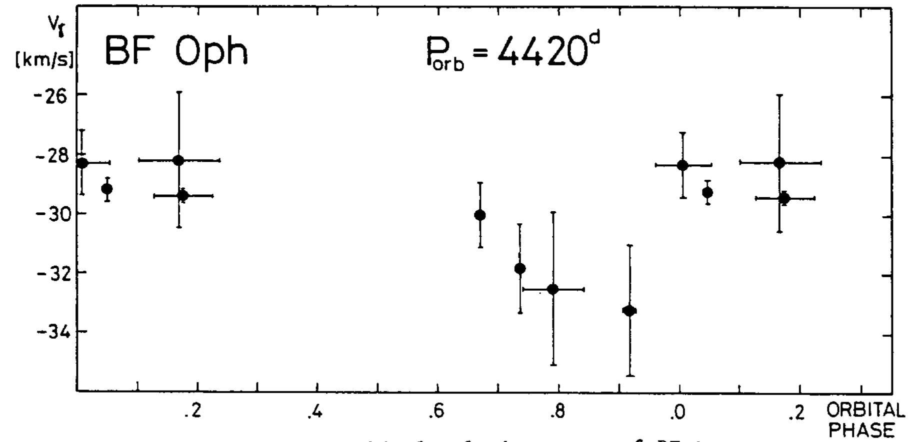

Figure 24. Orbital velocity curve of BF Oph

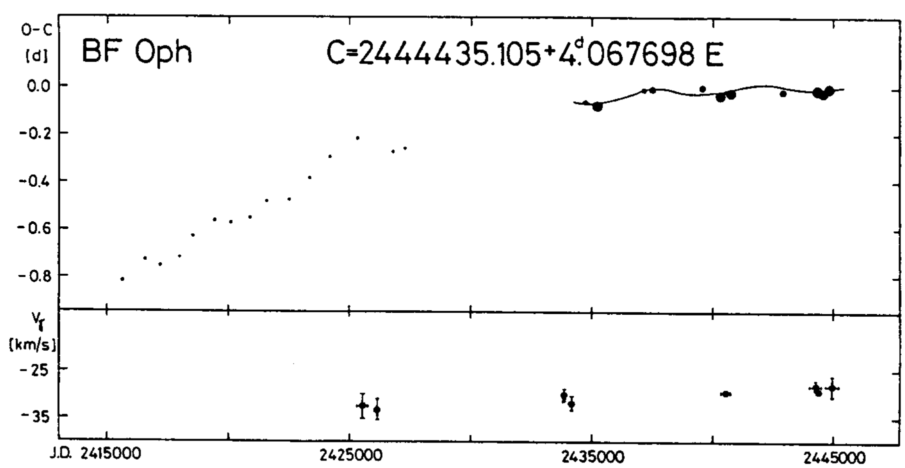

Figure 25. Upper panel: O-C diagram of BF Oph
Lower panel: γ-velocities for the same Cepheid

The O-C residuals listed in Table 42 have been calculated with the elements:

$$C = 2444435.105 + 4\overset{d}{.}067698 \cdot E \qquad (32)$$
$$\pm.005 \quad \pm.000001$$

The O-C diagram (Figure 25) can be best represented by a sine-wave superimposed on a parabola. The moments of the normal maxima can be predicted as follows:

$$C = 2444435.105 + 4\overset{d}{.}067698E - 4\overset{d}{.}87 \cdot 10^{-9} E^2 - 0\overset{d}{.}017 \cos(2\pi(0.000904E + 0.046)) \qquad (33)$$
$$\pm.005 \quad \pm.000001 \quad \pm.89 \quad \pm.005 \quad \pm.000073 \quad \pm.081$$

Table 42. O-C residuals for BF Oph

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
15618.712	-7084	$-0\overset{d}{.}820$	pg	Shapley (1930)
16558.440	-6853	-0.731	pg	Shapley (1930)
17180.773	-6700	-0.755	pg	Shapley (1930)
18030.957	-6491	-0.720	pg	Shapley (1930)
18572.053	-6358	-0.628	pg	Shapley (1930)
19479.214	-6135	-0.564	pg	Shapley (1930)
20069.022	-5990	-0.572	pg	Shapley (1930)
20870.376	-5793	-0.554	pg	Shapley (1930)
21541.624	-5628	-0.477	pg	Shapley (1930)
22440.589	-5407	-0.473	pg	Shapley (1930)
23351.842	-5183	-0.384	pg	Shapley (1930)
24149.199	-4987	-0.296	pg	Shapley (1930)
25320.776	-4699	-0.216	pg	Shapley (1930)
26781.021	-4340	-0.275	pg	O'Connell (1937)
27269.159	-4220	-0.260	pg	O'Connell (1937)
34790.528	-2371	-0.065	pe 1	Walraven et al. (1958)
35229.827	-2263	-0.077	pe 3	Irwin (1961)
37113.244	-1800	-0.005	pe 1	Mitchell et al. (1964)
37471.204	-1712	-0.002	pe 2	Mitchell et al. (1964)
39549.798	-1201	-0.002	pe 2	Takase (1969)
40338.898	-1007	-0.035	pe 3	Stobie (1970)
40761.959	- 903	-0.015	pe 3	Pel (1976)
42856.824	- 388	-0.014	pe 2	Dean (1977)
44361.869	- 18	-0.017	pe 3	Moffett and Barnes (1984)
44414.749	- 5	-0.018	pe 3	Gieren (1981b)
44809.332	+ 92	-0.001	pe 3	Eggen (1985)

Here only the photoelectric O-C residuals have been taken into account. According to the cosine term, the orbital period is 4500 $\pm$ 360 days, being in a very good agreement with the spectroscopic value. The amplitude and the phase of the wave is also adequate to the spectroscopic binary interpretation of the γ-velocity changes. It is worth mentioning that, according to this value of the orbital period, BF Oph has not been observed spectroscopically during the orbital phases when the Cepheid is strongly moving away from us, i.e. the amplitude of the γ-velocity variations is larger than observed so far.

A simple parabolic fit applied to the whole set of O-C residuals resulted in the pulsation period as a function of time:

$$C = 4\overset{d}{.}067665 - 4\overset{d}{.}12\cdot 10^{-8}\cdot E \qquad (34)$$
$$\quad \pm.000008 \quad \pm.22$$

where the E epoch number is the same as in equations (32) and (33).

AP Puppis

This Cepheid is likely to be a spectroscopic binary with one of the largest orbital velocity amplitude (see Table 43 and the lower panel of Figure 26). The extremely large shift between *Joy*'s (1937) and the more recent radial velocity data was already noted by *Lloyd Evans* (1982) but no subsequent radial velocity observations followed this discovery.

The O–C residuals have been calculated with the elements:

$$C = \underset{\pm .019}{2440689.133} + \underset{\pm .000027}{5^{d}.084274} \cdot E \qquad (35)$$

Table 43. γ-velocities of AP Pup

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
28620	27	46.1	2.3	5	Joy (1937)
33980	26	17.0	0.7	21	Stibbs (1955)
34138	36	18.5	3.0	2	Stibbs (1955)
40335	17	13.7	0.3	4	Lloyd Evans (1980)
40629	8	13.0	0.4	3	Lloyd Evans (1980)

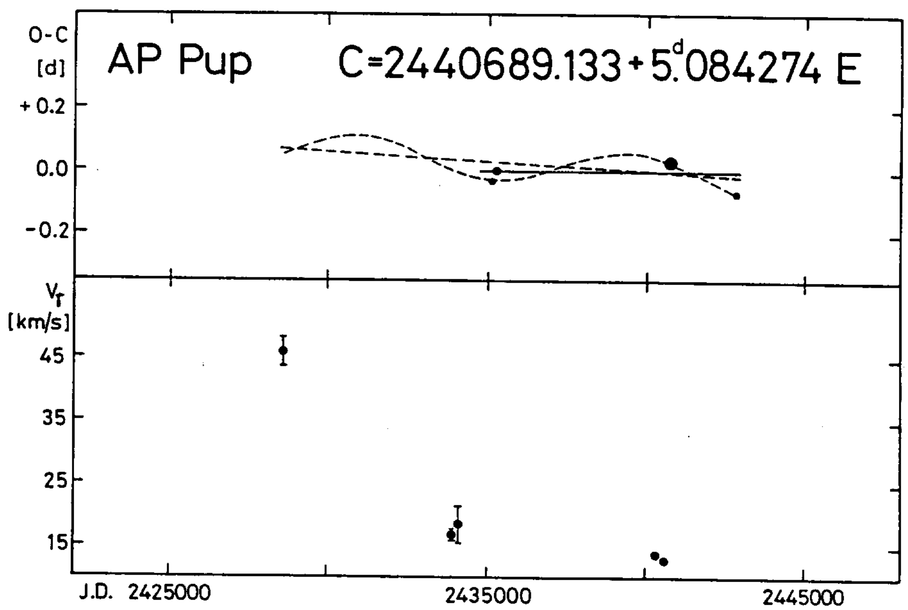

Figure 26. Upper panel: O–C diagram of AP Pup
Lower panel: γ-velocities for the same Cepheid

Table 44. O-C residuals for AP Pup

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
35182.832	-1083	$-0^{d}.032$	pe 1	Irwin (1961)
35299.806	-1060	+0.003	pe 2	Walraven et al. (1958)
40740.008	+ 10	+0.032	pe 3	Pel (1976)
42854.964	+ 426	-0.070	pe 1	Dean (1977)

The small number of the photometric observational series (see Table 44 and the upper panel of Figure 26) does not allow a reliable search for the light-time effect expected in this binary system. The plot of the O-C residuals can be approximated by a free-hand sinusoidal term (taking into account the phases prescribed by the γ-velocity variations) suggesting a long (about 9000 - 10000 days) orbital period, and a slightly shorter pulsation period than used in equation (35). Any further photometric and/or spectroscopic observations may play a decisive role in determining the orbital period of this neglected star.

AT Puppis

The changing γ-velocity of AT Pup was first reported by *Gieren* (1985). His conclusion is confirmed here (see Table 45 and the lower panel of Figure 27).

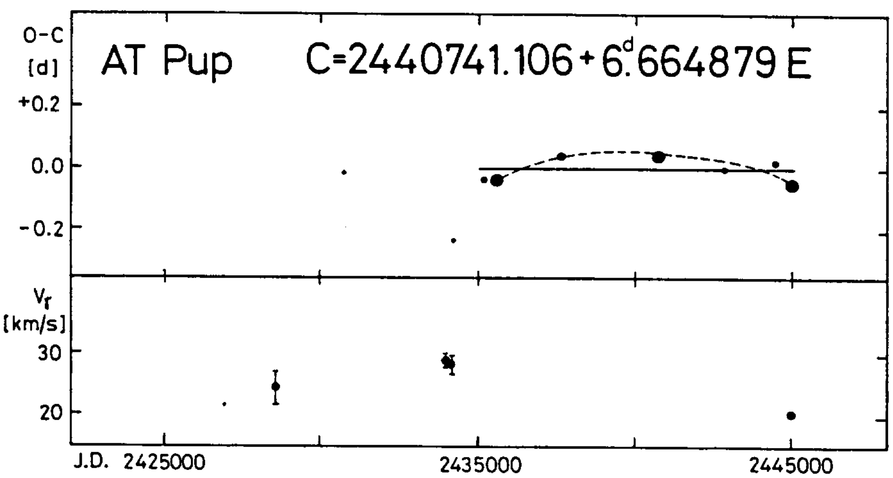

Figure 27. Upper panel: O-C diagram of AT Pup
Lower panel: γ-velocities for the same Cepheid

Table 45. γ-velocities of AT Pup

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
28614	25	24.2	2.6	4	Joy (1937)
34019	42	29.1	0.8	16	Stibbs (1955)
34163	20	28.2	1.5	5	Stibbs (1955)
45042	2	20.6	0.5	20	Gieren (1985)

Table 46. O-C residuals for AT Pup

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
30750.437	-1499	$-0^d.015$	pg	Erleksova (1961)
34142.642	- 990	-0.234	pg	Erleksova (1961)
35215.887	- 829	-0.034	pe 1	Irwin (1961)
35589.121	- 773	-0.034	pe 3	Walraven et al. (1958)
37648.645	- 464	+0.043	pe 2	Mitchell et al. (1964)
40741.152	0	+0.046	pe 3	Pel (1976)
42893.867	+ 323	+0.005	pe 1	Dean (1977)
44513.455	+ 566	+0.027	pe 1	Eggen (1985)
45046.576	+ 646	-0.042	pe 3	Gieren (1985)

The O-C residuals have been calculated with the ephemeris:

$$C = 2440741.106 + 6^d.664879 \cdot E \qquad (36)$$
$$\pm.011 \qquad \pm.000020$$

Gieren's (1985) observations made in 1981 were omitted because there can be a systematic error of unknown origin in the published moments of the observations in the case of each of the three stars (AT Pup, T Vel, V Vel) studied here from his sample. Such an error is not present in *Gieren*'s 1982 observations, both the O-C residual, and the light curve is the most reliable among the observations on AT Pup. This latter statement is also true for the 1982 observations on T Vel and V Vel.

The wave-like pattern of the photoelectric O-C residuals (see Table 46 and the upper panel of Figure 27), together with the variation in the γ-velocity, is in accord with a very long (about 20000 days) orbital period. From the radial velocity observations alone the orbital period can be much shorter but in that case the light-time effect interpretation of the O-C diagram fails.

<u>MY Puppis</u>

No variability in the γ-velocity of MY Pup is seen in the available data (see Table 47).

The O-C residuals have been computed with the elements:

$$C = 2441043.597 + 5\overset{d}{.}694998 \cdot E \quad (37)$$
$$\pm.013 \quad \pm.000031$$

The plot of the O-C residuals (see Table 48 and Figure 28) can be well approximated by a parabola. This is the only star in this sample where

Table 47. γ-velocities of MY Pup

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
24422	301	11.4	1.0	5	Neubauer (1929)
43172	56	13.4	0.2	23	Stobie and Balona (1979)
43533	4	12.8	0.4	9	Stobie and Balona (1979)

Table 48. O-C residuals for MY Pup

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
24421.80	-2919	+1$\overset{d}{.}$90	v_r 1	Neubauer (1929)
39107.348	- 340	+0.050	pe 1	Stobie (1972)
41043.599	0	+0.002	pe 3	Stobie (1972)
43184.919	+ 376	+0.003	pe 3	Stobie and Balona (1979)
44284.122	+ 569	+0.071	pe 1	Eggen (1985)
44568.948	+ 619	+0.147	pe 1	Eggen (1985)

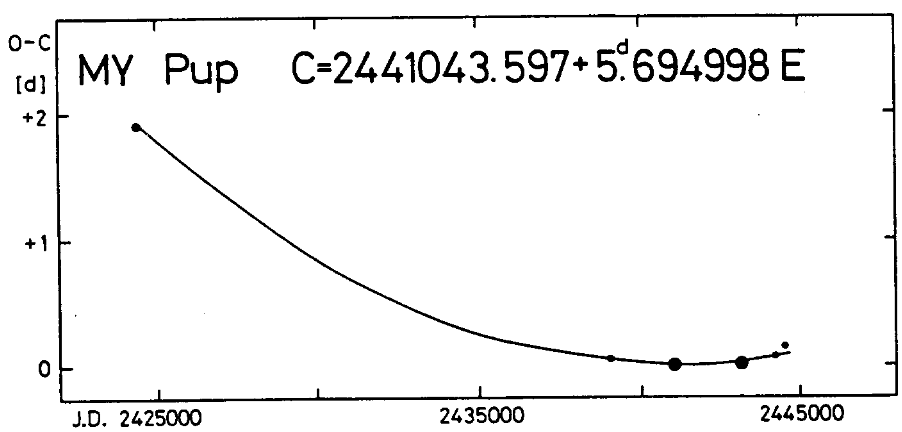

Figure 28. O-C diagram of MY Pup

radial velocity measurements were also used when determining the shape of the O-C graph. The period change has been so strong since the twenties that it could not be avoided making exceptions lacking suitable photometric observations. The continuously increasing period can be calculated as follows:

$$P = 5\overset{d}{.}694998 + 4\overset{d}{.}47 \cdot 10^{-7} \cdot E \qquad (38)$$
$$\pm.000031 \quad \pm.12$$

where E corresponds to the epoch number used in equation (37).

U Sagittarii

U Sgr is the other "classical" cluster-member Cepheid, it belongs to the open cluster M25. Duplicity of U Sgr has long been debated, the various pieces of evidence are summarized by *Leonard* and *Turner* (1986). *Gieren* (1982) suspected the variation in the γ-velocity, preferring a long orbital period, similarly to an earlier study performed by *Wallerstein* (1960). Table 49 summarizes the γ-velocities of U Sgr. *Joy*'s (1937) and *Hayford*'s (1932) data have been omitted because of much lower quality of those early observations. The 800 - 8000 day interval was studied when searching for the possible orbital period. The best curve was obtained at P_{orb} = 4550 ± 230 days. The γ-velocities folded with this period are shown

Table 49. γ-velocities of U Sgr

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
33916	33	3.5	0.8	14	Stibbs (1955)
34202	27	5.1	2.1	3	Stibbs (1955)
37223	151	3.8	0.6	11	Jacobsen (1970)
38200	28	3.7	2.0	2	Jacobsen (1970)
38955	19	6.8	0.5	14	Breger (1967)
39314	1	5.0	2.0	1	Jacobsen (1970)
39377	5	3.5	1.9	2	Lloyd Evans (1968)
40392	49	3.0	0.2	7	Lloyd Evans (1980)
40816	12	1.4	0.4	3	Lloyd Evans (1980)
43361	42	3.4	1.2	12	Wilson et al. (1989)
43668	31	7.1	1.2	11	Barnes et al. (1987)
44015	61	2.7	1.4	8	Barnes et al. (1987)
44112	146	2.9	0.2	6	Mermilliod et al. (1987)
44423	4	0.1	0.4	26	Gieren (1981a)
45182	18	2.0	0.5	2	Mermilliod et al. (1987)
45880	3	2.0	0.3	4	Mermilliod et al. (1987)
46275	10	2.6	0.1	30	Mermilliod et al. (1987)

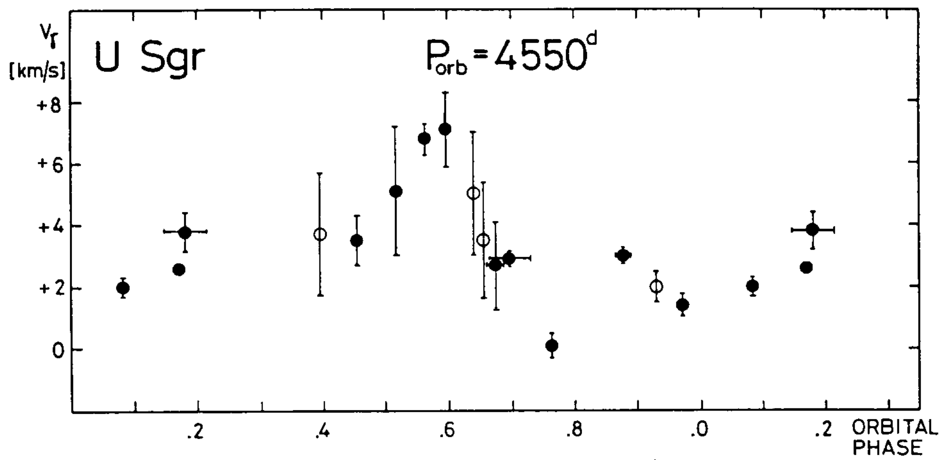

Figure 29. Orbital velocity curve of U Sgr

Table 50. O-C residuals for U Sgr

Norm.max JD2400000+	E	O-C	Type, weight	Reference
14496.341	-2316	$+0^d.336$	vis	Pickering (1904)
15946.443	-2101	+0.214	pg	Shapley (1930)
17329.147	-1896	+0.146	pg	Shapley (1930)
18475.855	-1726	+0.165	pg	Shapley (1930)
19609.067	-1558	+0.179	pg	Shapley (1930)
20459.006	-1432	+0.219	pg	Shapley (1930)
21308.978	-1306	+0.292	pg	Shapley (1930)
23244.642	-1019	+0.075	pg	Shapley (1930)
24674.684	- 807	+0.129	pg	Voute and ten Bruggencate (1927)
24694.765	- 804	-0.026	pg	Shapley (1930)
25059.149	- 750	+0.116	pg	Voute and ten Bruggencate (1927)
33133.030	+ 447	-0.042	pe 2	Eggen (1951)
34758.595	+ 688	-0.078	pe 2	Walraven et al. (1958)
35284.729	+ 766	-0.071	pe 3	Irwin (1961)
35952.493	+ 865	-0.085	pe 2	Johnson (1960)
36782.149	+ 988	-0.092	pe 3	Sandage (1960)
37099.195	+1035	-0.072	pe 3	Wampler et al. (1961)
37119.444	+1038	-0.059	pe 2	Mitchell et al. (1961)
37180.138	+1047	-0.072	pe 2	Mitchell et al. (1964)
37800.793	+1139	+0.022	pe 1	Williams (1966)
38920.467	+1305	-0.012	pe 2	Wisniewski and Johnson (1968)
39675.918	+1417	-0.026	pe 2	Schmidt (1971)
40788.948	+1582	+0.041	pe 3	Pel (1976)
40829.379	+1588	0.000	pe 1	Feltz and McNamara (1980)
42448.200	+1828	-0.034	pe 2	Dean et al. (1977)
43486.971	+1982	-0.028	pe 3	Dean (1981)
43608.399	+2000	-0.014	pe 3	Moffett and Barnes (1984)
44411.081	+2119	-0.014	pe 3	Gieren (1981b)
44458.345	+2126	+0.033	pe 3	Eggen (1985)
44721.388	+2165	+0.012	pe 3	Berdnikov (1986)

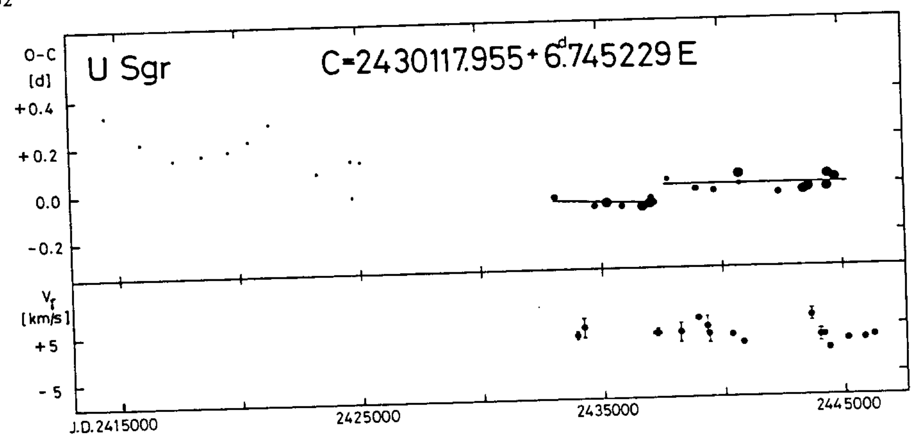

Figure 30. Upper panel: O-C diagram of U Sgr
Lower panel: γ-velocities for the same Cepheid

in Figure 29 (the zero phase is arbitrarily chosen at J.D.2400000). In this figure open circles denote those γ-velocities which are only based on two velocity measurements. Assuming that this orbital period is correct, the full amplitude of the orbital radial velocity variation is $2K = 3.6 \pm 1.3$ km/s.

Although Figure 29 is not fully convincing, i.e. another value of the orbital period cannot be excluded, the O-C diagram gives a further support to binary nature of U Sgr. The O-C residuals have been computed with the elements:

$$C = \underset{\pm .030}{2430117.955} + \underset{\pm .000016}{6\overset{d}{.}745229} \cdot E \qquad (39)$$

As is seen in Figure 30 (based on the data listed in Table 50), the O-C diagram can be characterized by a phase jump occurred at about J.D.2437500. Before the phase jump (of an amplitude of 0.07 day) the pulsation period was $6.745192 \pm 1.5 \cdot 10^{-5}$ days. This pattern of the O-C diagram cannot be explained with a light-time effect because its expected amplitude is less than 0.01 day. According to numerous other cases, the rejumping period is a typical feature of binary Cepheids, therefore duplicity of U Sgr can be stated beyond doubt.

W Sagittarii

This Cepheid belongs to a multiple star system: at present four components are identified (*Babel* et al., 1989, and references therein). The

Cepheid itself is a member of a spectroscopic binary system in this hierarchy. The orbital period is 1780 $\pm$ 5 days, and the orbital velocity amplitude is the least among the well-studied spectroscopic binary Cepheids (K = 2.35 ± 0.47 km/s , - *Babel* et al., 1989).

The O-C residuals have been calculated with the elements:

$$C = 2443374.622 + 7\overset{d}{.}594904 \cdot E \qquad (40)$$
$$\pm.006 \quad \pm.000008$$

The O-C diagram (see Table 51 and Figure 31) can be well described assuming a constant period. Although *Babel* et al. (1989) approximate the

Table 51. O-C residuals for W Sgr

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
14491.629	-3803	+0$\overset{d}{.}$427	vis	Pickering (1904)
15220.531	-3707	+0.218	pg	Shapley (1930)
16306.666	-3564	+0.282	pg	Shapley (1930)
17392.573	-3421	+0.118	pg	Shapley (1930)
18471.022	-3279	+0.090	pg	Shapley (1930)
19640.603	-3125	+0.056	pg	Shapley (1930)
20605.127	-2998	+0.027	pg	Shapley (1930)
21782.113	-2843	+0.197	pg	Shapley (1930)
23232.817	-2652	-0.120	pg	Shapley (1930)
24440.488	-2493	-0.038	pg	Shapley (1930)
24577.282	-2475	+0.047	pg	Voute (1927a)
25443.229	-2361	+0.175	pg	Shapley (1930)
34572.151	-1159	+0.023	pe 2	Walraven et al. (1958)
34868.304	-1120	-0.026	pe 3	Eggen et al. (1957)
35248.090	-1070	+0.015	pe 3	Irwin (1961)
37253.091	- 806	-0.039	pe 1	Mitchell et al. (1964)
37883.539	- 723	+0.033	pe 3	Walraven et al. (1964)
38650.553	- 622	-0.039	pe 2	Wisniewski and Johnson (1968)
40017.674	- 442	0.000	pe 3	Cousins and Lagerweij (1968)
42858.147	- 68	-0.022	pe 2	Dean (1977)
43617.650	+ 32	-0.009	pe 3	Moffett and Barnes (1984)
43754.383	+ 50	+0.016	pe 3	Babel et al. (1989)
45508.797	+ 281	+0.007	pe 3	Babel et al. (1989)

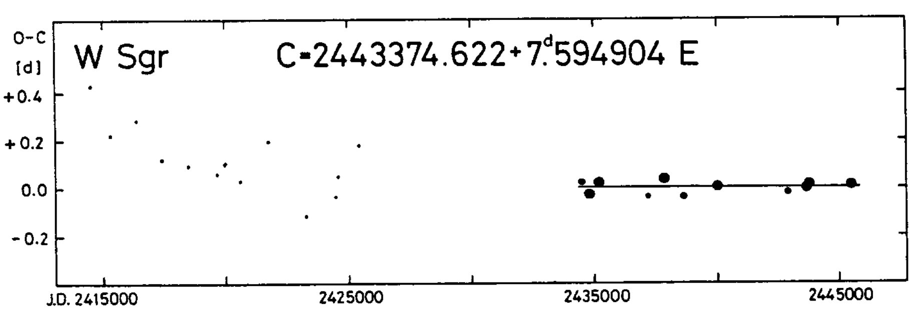

Figure 31. O-C diagram of W Sgr

O-C graph by a parabola (continuous period increase), the parabolic fit to the data in Table 51 has been of much lower accuracy as compared with the linear fit. No effect of duplicity is seen in the O-C diagram, since the amplitude of the light-time effect is much smaller than the limit of detection.

X Sagittarii

X Sgr belongs to a spectroscopic binary system with an orbital period of 507.25 days (*Szabados*, 1989). Because the effect of the orbital motion on the radial velocity variations is rather small, the value of the orbital period is tentative, and needs confirmation. Nevertheless, a blue photometric companion to X Sgr has been suspected by *Pel* (1978).

The O-C residuals listed in Table 52 have been calculated with the elements:

$$C = \underset{\pm .015}{2440741.492} + \underset{\pm .000028}{7^{d}.012777} \cdot E \qquad (41)$$

Table 52. O-C residuals for X Sgr

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
15531.897	-3595	$+1^{d}.338$	pg 1	Shapley (1930)
16422.246	-3468	+1.065	pg 1	Shapley (1930)
17228.609	-3353	+0.958	pg 1	Shapley (1930)
17922.830	-3254	+0.914	pg 1	Shapley (1930)
18652.136	-3150	+0.892	pg 1	Shapley (1930)
19144.481	-3037	+0.793	pg 1	Shapley (1930)
20152.889	-2936	+0.910	pg 1	Shapley (1930)
20888.857	-2831	+0.537	pg 1	Shapley (1930)
21569.130	-2734	+0.570	pg 1	Shapley (1930)
22501.724	-2601	+0.465	pg 1	Shapley (1930)
23329.154	-2483	+0.387	pg 1	Shapley (1930)
24353.118	-2337	+0.486	pg 1	Shapley (1930)
24514.329	-2314	+0.403	pg 1	Voute (1927a)
25440.009	-2182	+0.396	pg 1	Shapley (1930)
34871.956	- 837	+0.158	pe 1	Eggen et al. (1957)
35222.549	- 787	+0.112	pe 3	Irwin (1961)
35250.607	- 783	+0.119	pe 2	Walraven et al. (1958)
37129.933	- 515	+0.021	pe 2	Mitchell et al. (1964)
39051.428	- 241	+0.015	pe 3	Wisniewski and Johnson (1968)
40762.530	+ 3	0.000	pe 3	Pel (1976)
42852.333	+ 301	-0.005	pe 3	Dean (1977)
43658.808	+ 416	0.000	pe 3	Moffett and Barnes (1984)
44437.218	+ 527	-0.007	pe 3	Eggen (1985)

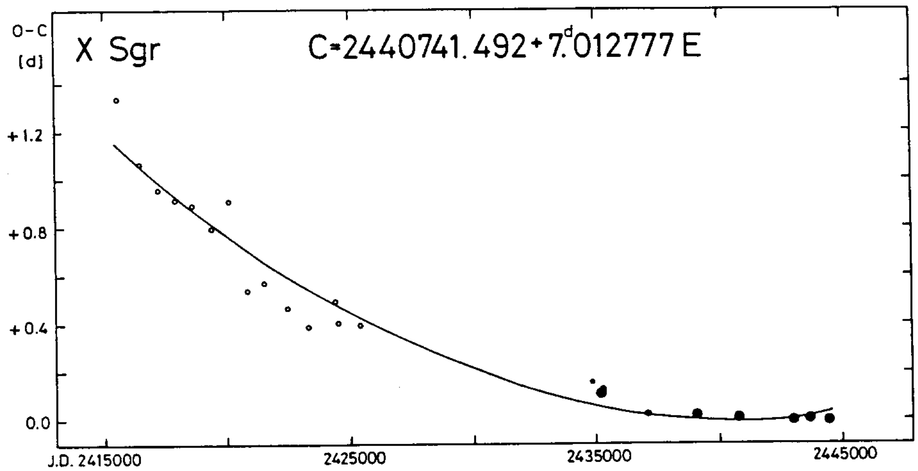

Figure 32. O-C diagram of X Sgr

As is seen in Figure 32, the O-C diagram of X Sgr is parabolic. The parabola fitted to the photographic and photoelectric O-C residuals has resulted in the following temporal variation in the pulsation period:

$$P = 7^{d}.012777 + 1^{d}.65 \cdot 10^{-7} \cdot E \qquad (42)$$
$$\pm.000028 \quad \pm.21$$

where the E epoch number is the same as in equation (41). It has to be noted, however, that the period increase used to be even stronger during the visual observations made by *Schmidt* (*Hertzsprung*, 1934) in the last century.

Y Sagittarii

Table 53. γ-velocities of Y Sgr

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
16615	173	+1.5	1.1	8	Duncan (1908)
18152	22	+2.7	0.6	27	Duncan (1908)
22691	368	-6.0	0.6	24	Duncan (1922)
23377	165	-6.0	0.4	22	ten Bruggencate (1930)
23550	363	-3.0	0.5	16	Campbell and Moore (1928)
24134	141	-4.9	0.6	14	ten Bruggencate (1930)
25089	90	-3.5	0.6	15	ten Bruggencate (1930)
25794	20	-4.0	0.5	16	ten Bruggencate (1930)
40380	47	-3.3	0.2	8	Lloyd Evans (1980)
40765	51	-1.8	0.2	7	Lloyd Evans (1980)
43354	45	-1.1	1.2	12	Wilson et al. (1989)
43649	41	-3.6	1.1	14	Barnes et al. (1987)
44014	62	-2.7	1.4	8	Barnes et al. (1987)
44796	1	-6.6	1.3	1	Beavers and Eitter (1986)

The changing γ-velocity of Y Sgr was first reported by *ten Bruggencate* (1930). The recent determination of the γ-velocities confirms this conclusion (see Table 53 and the lower panel of Figure 33). The pattern of the γ-velocity changes suggests a very long (P > 10000 days) orbital period.

Table 54. O-C residuals for Y Sgr

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
14499.428	-4549	$+0^{d}.205$	vis	Pickering (1904)
18176.856	-3912	-0.010	vis	Nijland (1923)
18962.147	-3776	+0.101	vis	Nijland (1923)
24712.345	-2780	+0.012	pg	ten Bruggencate (1928)
25070.247	-2718	-0.035	pg	ten Bruggencate (1928)
25439.689	-2654	-0.089	pg	ten Bruggencate (1928)
29839.040	-1892	-0.054	pg	Filin (1950b)
30681.845	-1746	-0.163	pg	Filin (1950b)
31449.885	-1613	+0.018	pg	Filin (1950b)
32408.117	-1447	-0.131	pg	Filin (1950b)
33118.360	-1324	-0.014	pe 2	Eggen (1951)
33141.471	-1320	+0.004	pg	Filin (1950b)
34879.244	-1019	-0.011	pe 2	Walraven et al. (1958)
35271.837	- 951	-0.008	pe 3	Irwin (1961)
36097.317	- 808	-0.121	pe 1	Svolopoulos (1960)
37130.873	- 629	0.000	pe 2	Mitchell et al. (1964)
37800.726	- 513	+0.141	pe 1	Williams (1966)
38937.984	- 316	+0.043	pe 1	Wisniewski and Johnson (1968)
40779.682	+ 3	+0.033	pe 3	Pel (1976)
40820.055	+ 10	-0.008	pe 2	Feltz and McNamara (1980)
42881.153	+ 367	-0.006	pe 2	Dean (1977)
43441.162	+ 464	-0.015	pe 3	Moffett and Barnes (1984)
44041.585	+ 568	-0.024	pe 3	Moffett and Barnes (1984)
44821.027	+ 703	+0.012	pe 1	Eggen (1985)

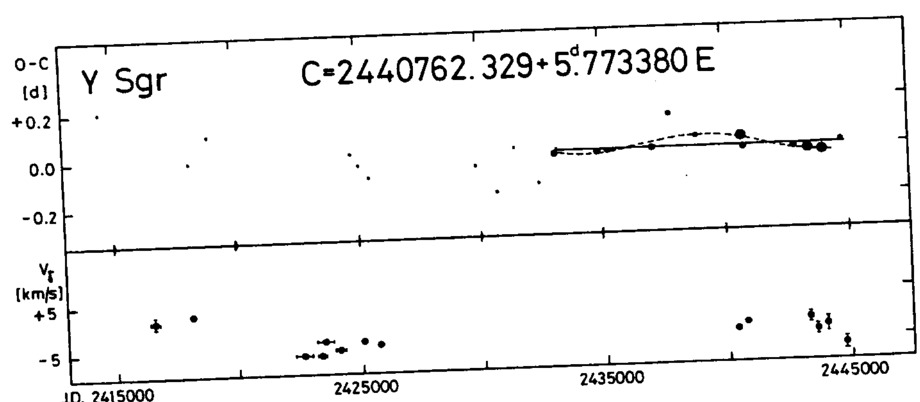

Figure 33. Upper panel: O-C diagram of Y Sgr
Lower panel: γ-velocities for the same Cepheid

The O-C residuals have been computed with the elements:

$$C = 2440762.329 + 5^{d}.773380 \cdot E \qquad (43)$$
$$\pm.009 \qquad \pm.000013$$

The light-time effect expected in such a long period spectroscopic binary is present in the O-C diagram (see Table 54 and the upper panel of Figure 33) but the limited time-base of the photoelectric observations does not allow the successful determination of the long orbital period. A cycle length as long as 10000 - 12000 days is in accordance with the photoelectric O-C residuals but a much longer period cannot be ruled out, either.

WZ Sagittarii

The available radial velocity measurements might indicate a variable γ-velocity (see Table 55 and the lower panel of Figure 34). *Joy*'s (1937) first two observations have not been taken into account here. Further good quality radial velocity data are necessary.

Table 55. γ-velocities of WZ Sgr

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25985	282	-10.6	1.8	8	Joy (1937)
44327	231	-12.5	2.8	3	Barnes et al. (1988)
44589	297	-18.3	0.2	21	Coulson and Caldwell (1985)

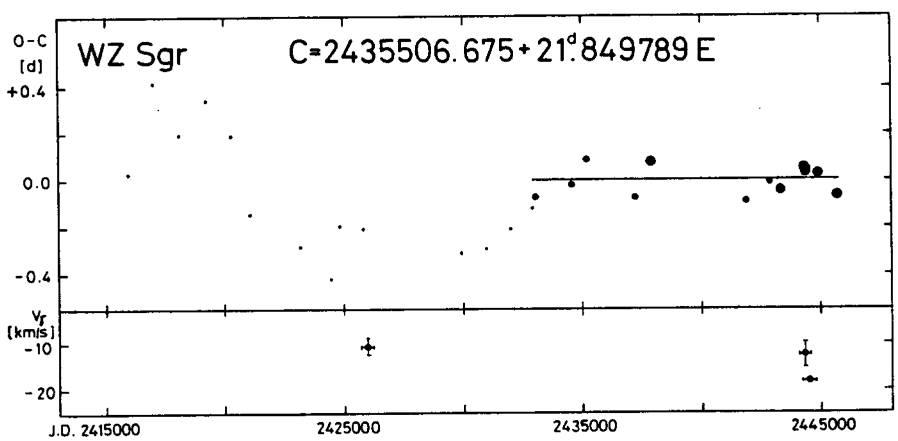

Figure 34. Upper panel: O-C diagram of WZ Sgr
Lower panel: γ-velocities for the same Cepheid

Table 56. O-C residuals for WZ Sgr

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
15929.289	-896	$+0^{d}.025$	pg	Shapley (1930)
17022.168	-846	+0.414	pg	Shapley (1930)
18114.435	-796	+0.192	pg	Shapley (1930)
19250.773	-744	+0.341	pg	Shapley (1930)
21129.367	-658	-0.147	pg	Shapley (1930)
23183.108	-564	-0.286	pg	Shapley (1930)
24450.260	-506	-0.422	pg	Shapley (1930)
24865.634	-487	-0.194	pg	Voute (1930a)
25805.161	-444	-0.208	pg	Voute (1930a)
29956.518	-254	-0.311	pg	Filin (1950b)
30983.476	-207	-0.293	pg	Filin (1950b)
32010.500	-160	-0.209	pg	Filin (1950b)
32971.974	-116	-0.125	pg	Filin (1950b)
33124.977	-109	-0.071	pe 2	Eggen (1951)
34632.661	- 40	-0.022	pe 2	Walraven et al. (1958)
35244.562	- 12	+0.084	pe 2	Irwin (1961)
37232.733	+ 79	-0.075	pe 2	Mitchell et al. (1964)
37910.227	+110	+0.075	pe 3	Walraven et al. (1964)
41908.570	+293	-0.093	pe 1	Madore (1975)
42870.045	+337	-0.009	pe 2	Dean (1977)
43372.555	+360	-0.044	pe 3	Dean (1981)
44399.590	+407	+0.051	pe 3	Coulson and Caldwell (1985)
44486.967	+411	+0.029	pe 3	Moffett and Barnes (1984)
44508.828	+412	+0.040	pe 1	Eggen (1983b)
44923.961	+431	+0.027	pe 3	Coulson and Caldwell (1985)
45776.012	+470	-0.064	pe 3	Berdnikov (1986)

The O-C residuals have been computed with the elements:

$$C = \underset{\pm .017}{2435506.675} + \underset{\pm .000053}{21^{d}.849789} \cdot E \qquad (44)$$

The pulsation period has been constant since the early photoelectric observations (see Table 56 and the upper panel of Figure 34), while before J.D.2433000 some changes occurred in the period. However, those earlier variations were not secular ones (such long period Cepheids usually show much larger continuous period changes indicating stellar evolution (*Szabados*, 1981)).

AP Sagittarii

The present study confirms *Gieren*'s (1982) statement concerning the variable γ-velocity of AP Sgr. The data in Table 57 (shown plotted in the lower panel of Figure 35) were analysed for possible periodicity. A number of periods (5625, 6725, 7200, and 7500 days) describe the variable γ-velocity reasonably well, the most probable value of the orbital period

Table 57. γ-velocities of AP Sgr

JD 2400000+	σ [d]	V_γ [km/s]	σ [km/s]	n	Reference
21733	1	- 6.4	4.5	1	Joy (1937)
24694	700	-18.9	2.6	3	Joy (1937)
26313	157	-18.3	2.0	6	Joy (1937)
39279	19	-19.7	0.8	6	Lloyd Evans (1968)
40592	219	-18.6	0.2	10	Lloyd Evans (1980)
44062	2	- 8.3	2.3	4	Barnes et al. (1988)
44423	4	-14.7	0.4	22	Gieren (1981a)
44579	168	-13.5	1.4	9	Barnes et al. (1988)

Table 58. O-C residuals for AP Sgr

Norm.max JD2400000+	E	O-C	Type, weight	Reference
16021.186	-3959	$-0^d.053$	pg	Shapley (1930)
17381.853	-3690	+0.035	pg	Shapley (1930)
18469.235	-3475	-0.035	pg	Shapley (1930)
19652.935	-3241	+0.113	pg	Shapley (1930)
20750.509	-3024	+0.119	pg	Shapley (1930)
21640.649	-2848	+0.066	pg	Shapley (1930)
23679.094	-2445	+0.171	pg	Shapley (1930)
25868.992	-2012	-0.009	pg 1	Voute (1930b)
29829.379	-1229	+0.030	pg	Filatov (1966)
31280.959	- 942	-0.012	pg	Filatov (1966)
32540.355	- 693	-0.037	pg	Filatov (1966)
33369.887	- 529	-0.003	pg	Filatov (1966)
34391.562	- 327	-0.027	pg	Filatov (1966)
34720.309	- 262	-0.045	pe 2	Walraven et al. (1958)
35276.695	- 152	-0.030	pe 2	Irwin (1961)
36010.163	- 7	+0.040	pg	Filatov (1966)
37208.869	+ 230	+0.020	pe 1	Mitchell et al. (1964)
39282.603	+ 640	+0.009	pe 1	Takase (1969)
40370.067	+ 855	+0.021	pe 2	Stobie (1970)
40794.903	+ 939	-0.008	pe 3	Pel (1976)
44077.489	+1588	-0.010	pe 3	Moffett and Barnes (1984)
44426.508	+1657	+0.013	pe 3	Gieren (1981b)
44492.235	+1670	-0.013	pe 3	Moffett and Barnes (1984)
44659.170	+1703	+0.011	pe 2	Eggen (1985)

being the longest one (see the discussion below).

The O-C residuals listed in Table 58 have been calculated with the elements:

$$C = \underset{\pm.004}{2436045.528} + \underset{\pm.000003}{5^d.057916} \cdot E \tag{45}$$

The O-C diagram (see the upper panel of Figure 35) shows a wave-like pattern, the weighted least squares fit to the data points results in the following formula for predicting the moments of the normal maxima:

$$C = \underset{\pm.004}{2436045.528} + \underset{\pm.000003}{5^d.057916} \cdot E - \underset{\pm.006}{0^d.035} \cos(2\pi(\underset{\pm.000017}{0.000665}E + \underset{\pm.024}{0.151})) \tag{46}$$

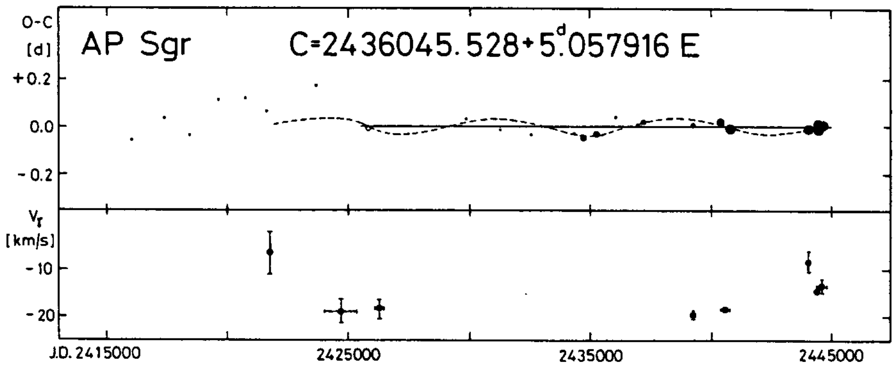

Figure 35. Upper panel: O-C diagram of AP Sgr
Lower panel: γ-velocities for the same Cepheid

indicating an orbital period of 7608 ± 194 days. The combination of the photometric and spectroscopic evidence (including the amplitude and phase relations) suggests that the orbital period is near 7500 days.

BB Sagittarii

The Cepheid BB Sgr may be a coronal member of the open cluster Cr394 (*Turner* and *Pedreros*, 1985). Its spectroscopic binary nature was first suspected by *Gieren* (1982), and later on confirmed by *Barnes* et al. (1988). *Gieren* assumes a red companion to BB Sgr. The study of the available observational data confirms the changing γ-velocity (see Table 59 and the lower panel of Figure 36) but the orbital period cannot be determined yet.

The O-C residuals have been calculated with the elements:

$$C = \underset{\pm .009}{2436053.475} + \underset{\pm .000005}{6\overset{d}{.}637005}\, E \qquad (47)$$

Table 59. γ-velocities of BB Sgr

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25558	368	+ 8.6	2.6	4	Joy (1937)
26314	158	- 1.5	2.3	5	Joy (1937)
39284	16	+ 7.5	0.8	6	Lloyd Evans (1968)
40407	44	+ 8.2	0.3	4	Lloyd Evans (1980)
40799	27	+ 7.3	0.3	5	Lloyd Evans (1980)
44062	2	+15.1	4.0	2	Barnes et al. (1988)
44423	4	+ 4.1	0.4	24	Gieren (1981a)
44486	45	+11.1	1.8	6	Barnes et al. (1988)
44821	44	+ 8.3	2.3	4	Barnes et al. (1988)

Table 60. O-C residuals for BB Sgr

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
15644.972	-3075	$+0^{d}.287$	pg 1	Shapley (1930)
16680.382	-2919	+0.325	pg 1	Shapley (1930)
17788.766	-2752	+0.329	pg 1	Shapley (1930)
18837.317	-2594	+0.233	pg 1	Shapley (1930)
19958.922	-2425	+0.184	pg 1	Shapley (1930)
21067.273	-2258	+0.155	pg 1	Shapley (1930)
22096.026	-2103	+0.173	pg 1	Shapley (1930)
23337.157	-1916	+0.184	pg 1	Shapley (1930)
25819.325	-1542	+0.112	pg 1	Voute (1930d)
34938.469	- 168	+0.011	pe 1	Walraven et al. (1958)
35283.586	- 116	+0.004	pe 2	Irwin (1961)
36756.971	+ 106	-0.027	pe 1	Weaver et al. (1961)
37141.943	+ 164	-0.001	pe 1	Mitchell et al. (1964)
40374.151	+ 651	-0.014	pe 1	Stobie (1970)
40447.184	+ 662	+0.012	pe 1	Lloyd Evans and Stobie (1971)
40805.592	+ 716	+0.021	pe 3	Pel (1976)
41157.395	+ 769	+0.063	pe 1	Feltz and McNamara (1980)
42239.185	+ 932	+0.021	pe 3	Dean et al. (1977)
42551.084	+ 979	-0.019	pe 3	Dean et al. (1977)
43526.814	+1126	+0.071	pe 2	Dean (1981)
44409.527	+1259	+0.063	pe 3	Moffett and Barnes (1984)
44422.808	+1261	+0.070	pe 3	Gieren (1981b)
44721.439	+1306	+0.035	pe 2	Turner and Pedreros (1985)
44907.311	+1334	+0.071	pe 3	Moffett and Barnes (1984)
45040.034	+1354	+0.054	pe 3	Turner and Pedréros (1985)
45212.646	+1380	+0.104	pe 3	Eggen (1985)

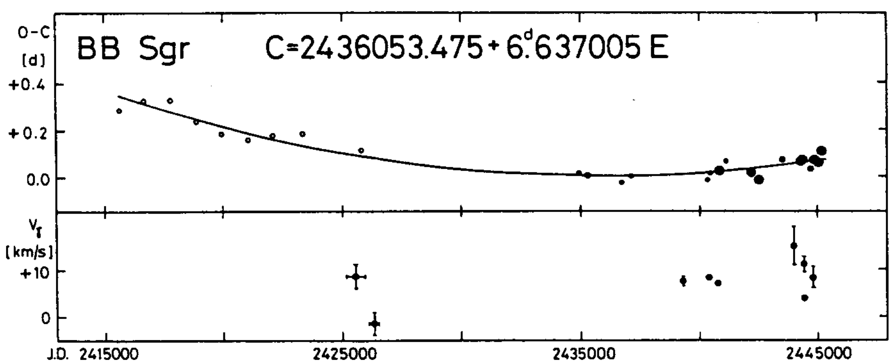

Figure 36. **Upper panel: O-C diagram of BB Sgr**
Lower panel: γ-velocities for the same Cepheid

The pattern of the O-C diagram (see Table 60 and the upper panel of Figure 36) shows a continuously increasing period:

$$P = 6^{d}.637005 + 7^{d}.2\cdot10^{-8}\cdot E \qquad (48)$$
$$\pm.000005 \qquad \pm.6$$

where the E epoch number has to be calculated from the zero-point indicated in equation (47). A check on the presence of a possible light-time effect was also performed, and there is weak evidence for an approximately 4550 day orbital period (using only the photoelectric O-C residuals). Although this value is consistent with the tendency of the γ-velocity changes, a completely different orbital period cannot be ruled out.

V350 Sagittarii

Its spectroscopic binary nature was suspected by *Lloyd Evans* (1971), later on confirmed by *Gieren* (1982), and *Lloyd Evans* (1982). The orbital period was determined recently (*Szabados*, 1989), and its value is 1129 days.

The O-C residuals listed in Table 61 have been computed with the ephemeris:

$$C = \underset{\pm .020}{2435317.170} + \underset{\pm .000012}{5\overset{d}{.}154178} \cdot E \qquad (49)$$

The O-C diagram in Figure 37 offers two obvious approximations: a phase jump, or a parabolic O-C graph. Equation (49) has been obtained assuming that the first approximation is correct. In this case the formex value of the pulsation period was $5.154139 \pm 1.9 \cdot 10^{-5}$ days. The 0.06 day phase jump

Table 61. O-C residuals for V350 Sgr

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
25560.345	-1893	+0ᵈ034	pg	Voute (1930c)
26106.715	-1787	+0.061	pg	Voute (1930c)
33075.072	- 435	-0.031	pe 1	Eggen (1951)
34940.902	- 73	-0.013	pe 2	Walraven et al. (1958)
35306.827	- 2	-0.035	pe 2	Irwin (1961)
37244.780	+ 374	-0.053	pe 2	Mitchell et al. (1964)
40373.404	+ 981	-0.015	pe 1	Stobie (1970)
40435.281	+ 993	+0.012	pe 1	Feltz and McNamara (1980)
41136.257	+1129	+0.020	pe 1	Feltz and McNamara (1980)
42883.488	+1468	-0.015	pe 1	Dean (1977)
44373.048	+1757	-0.013	pe 2	Moffett and Barnes (1984)
44414.287	+1765	-0.007	pe 3	Gieren (1981b)
44888.487	+1857	+0.008	pe 2	Moffett and Barnes (1984)
44919.423	+1863	+0.019	pe 2	Eggen (1985)

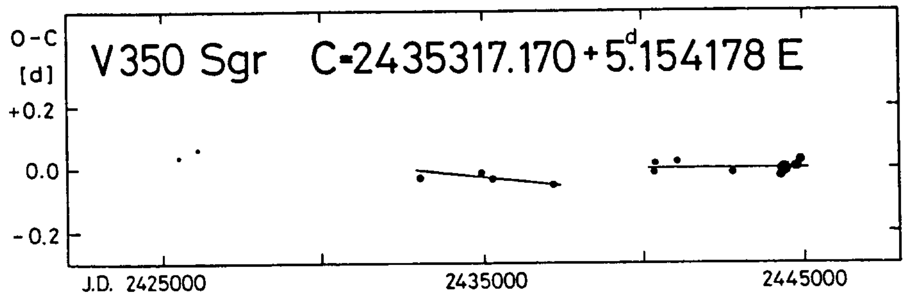

Figure 37. O-C diagram of V350 Sgr

occurred between J.D.2437500 and 2440000. If, however, the continuous period increase interpretation is accepted, the pulsation period can be calculated as follows:

$$P = 5\overset{d}{.}154168 + 3\overset{d}{.}04\cdot10^{-8}\cdot E \qquad (50)$$
$$\quad \pm.000004 \quad \pm.58$$

where the E epoch number has to be calculated according to equation (49). Additional observations are necessary to decide which of the above interpretations is the correct one.

RV Scorpii

Moffett and *Barnes* (1987) found almost 6 km/s discrepancy between their own and the previous γ-velocity determinations. The variable γ-velocity is also seen in the present study (see Table 62 and the lower panel of Figure 38).

The O-C residuals have been computed with the elements:

$$C = 2434925.379 + 6\overset{d}{.}061352\cdot E \qquad (51)$$
$$\quad \pm.009 \quad \pm.000004$$

The whole data set (see Table 63) can be well approximated by a parabola,

Table 62. γ-velocities of RV Sco

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
18433	15	-23.0	1.2	7	Paddock (1917)
25104	238	-17.7	1.8	7	Joy (1937)
25983	338	-20.9	2.3	5	Joy (1937)
33942	145	-18.8	0.8	15	Stibbs (1955)
40530	213	-21.6	0.2	7	Lloyd Evans (1980)
44055	9	-13.0	1.6	7	Barnes et al. (1988)
44423	4	-18.9	0.4	24	Gieren (1981a)
44456	18	- 7.5	2.0	5	Barnes et al. (1988)
44798	1	-14.4	2.8	3	Barnes et al. (1988)

Table 63. O-C residuals for RV Sco

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
14474.195	-3374	$-0^{d}.181$	vis 1	Pickering (1904)
16274.495	-3077	-0.103	pg 1	Shapley (1930)
18141.361	-2769	-0.133	pg 1	Shapley (1930)
19638.618	-2522	-0.030	pg 1	Shapley (1930)
20753.897	-2338	-0.040	pg 1	Shapley (1930)
23196.583	-1935	-0.079	pg 1	Shapley (1930)
24342.277	-1746	+0.020	pg 1	Shapley (1930)
24711.873	-1685	-0.127	pg 1	Voute (1927c)
25075.607	-1625	-0.074	pg 1	Voute (1927c)
34901.138	- 4	+0.005	pe 1	Walraven et al. (1958)
35240.579	+ 52	+0.011	pe 3	Irwin (1961)
37277.192	+ 388	+0.009	pe 1	Mitchell et al. (1964)
40344.212	+ 894	-0.015	pe 3	Stobie (1970)
40780.652	+ 966	+0.008	pe 3	Pel (1976)
41574.662	+1097	-0.019	pe 3	Dean et al. (1977)
41950.453	+1159	-0.032	pe 3	Dean et al. (1977)
43538.527	+1421	-0.032	pe 3	Dean (1981)
44023.428	+1501	-0.039	pe 3	Gieren (1981b)
44247.691	+1538	-0.046	pe 3	Moffett and Barnes (1984)
44835.688	+1635	0.000	pe 2	Eggen (1985)

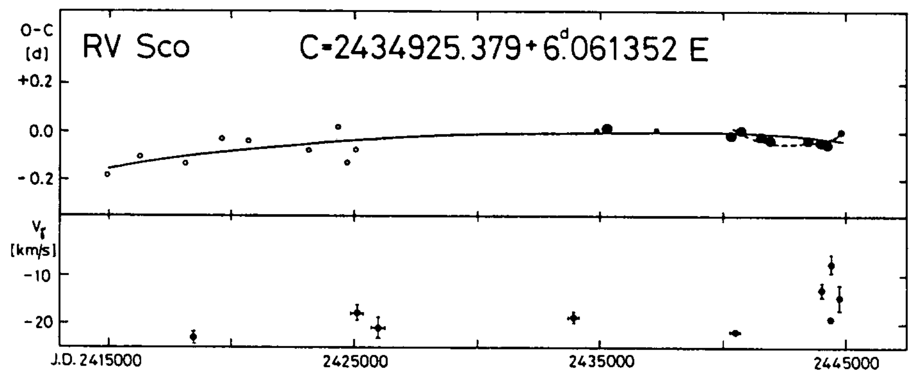

Figure 38. Upper panel: O-C diagram of RV Sco
Lower panel: γ-velocities for the same Cepheid

corresponding to a continuously decreasing period:

$$P = 6^{d}.061352 - 2^{d}.75\cdot10^{-8}\cdot E \qquad (52)$$
$$\pm.000004 \quad \pm.54$$

where the E epoch number is calculated according to equation (51). The O-C residuals based on the photoelectric observations made after J.D.2440000 seem to form a part of a wave superimposed on the parabola, indicating a possible light-time effect. Assuming an orbital period of about 8000 days, this interpretation is in agreement with the trend of the γ-velocity variations (see Figure 38). Further observations are needed before carrying out a more thorough analysis.

RY Scorpii

RY Sco is a member of a visual triple star system (*Proust* et al., 1981). The faint companions may or may not influence the photometric behaviour of this Cepheid. A blue photometric companion was reported by *Madore* (1977) and *Pel* (1978) but *Böhm-Vitense* and *Proffitt* (1985) failed to find any evidence for a blue companion using IUE spectra. The available spectroscopic data do not allow to draw any conclusion regarding the variation in the γ-velocity (see Table 64).

Table 64. γ-velocities of RY Sco

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
22868	1	-17.7	4.5	1	Joy (1937)
25515	270	-17.2	1.8	7	Joy (1937)
27034	315	-17.2	4.5	2	Joy (1937)
33934	94	-19.3	1.0	10	Stibbs (1955)
40579	242	-20.5	0.3	4	Lloyd Evans (1980)
44123	158	-15.4	1.8	6	Barnes et al. (1988)
44250	198	-17.8	0.2	18	Coulson and Caldwell (1985)
44785	149	-17.6	0.3	17	Coulson and Caldwell (1985)

Table 65. O-C residuals for RY Sco

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
16415.032	-583	$+8^d.149$	pg	Shapley (1930)
17938.584	-508	+7.690	pg	Shapley (1930)
19563.398	-428	+6.893	pg	Shapley (1930)
20762.244	-369	+6.850	pg	Shapley (1930)
23281.083	-245	+5.991	pg	Shapley (1930)
24439.079	-188	+5.739	pg	Shapley (1930)
25047.825	-158	+4.881	pg	Wallenquist (1928)
26673.167	- 78	+4.611	pg	Wallenquist (1928)
31019.120	+136	+2.053	pg	Filatov (1966)
33335.314	+250	+1.751	pg	Filatov (1966)
35244.432	+344	+0.775	pe 2	Irwin (1961)
35244.615	+344	+0.958	pg	Filatov (1966)
35487.784	+356	+0.286	pe 1	Mitchell et al. (1964)
38251.601	+492	+0.563	pg	Filatov (1966)
40343.964	+595	-0.049	pe 3	Stobie (1970)
41075.606	+631	+0.068	pe 3	Pel (1976)
41908.631	+672	-0.033	pe 1	Madore (1975)
44062.665	+778	+0.066	pe 1	Moffett and Barnes (1984)
44326.737	+791	-0.024	pe 3	Coulson and Caldwell (1985)
44529.910	+801	-0.052	pe 2	Moffett and Barnes (1984)
44875.432	+818	+0.027	pe 3	Coulson and Caldwell (1985)

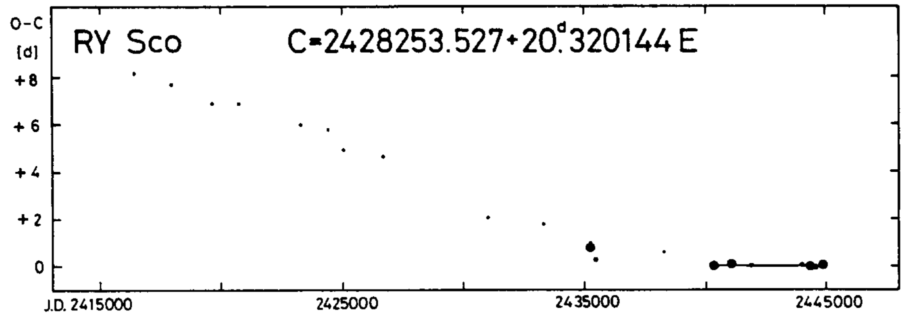

Figure 39. O-C diagram of RY Sco

The O-C residuals listed in Table 65 have been calculated with the elements:

$$C = 2428253.527 + 20^{d}.320144 \cdot E \qquad (53)$$
$$\pm.101 \qquad \pm.000139$$

Figure 39 shows that the above elements are only valid after J.D.2440000. Before that epoch the pulsation period cannot be characterized by a single value.

V500 Scorpii

The discrepancy between the γ-velocities reported by *Moffett* and *Barnes* (1987) is confirmed here (see Table 66 and the lower panel of Figure 40). *Madore* (1977) assumed a blue photometric companion. Such a companion is not suspected on the basis of *Pel*'s (1978) photometry, nor in

Table 66. γ-velocities of V500 Sco

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
34182	37	-14.0	0.9	12	Stibbs (1955)
44359	343	- 7.4	1.3	10	Barnes et al. (1988)

Table 67. O-C residuals for V500 Sco

Norm.max JD2400000+	E	O-C	Type, weight	Reference
34729.921	-1038	$-0^{d}.038$	pe 1	Walraven et al. (1958)
35251.730	- 982	+0.028	pe 3	Irwin (1961)
37282.750	- 764	-0.023	pe 2	Mitchell et al. (1964)
37869.731	- 701	-0.003	pe 3	Walraven et al. (1964)
44335.597	- 7	-0.023	pe 3	Moffett and Barnes (1984)
44782.853	+ 41	+0.025	pe 3	Eggen (1985)

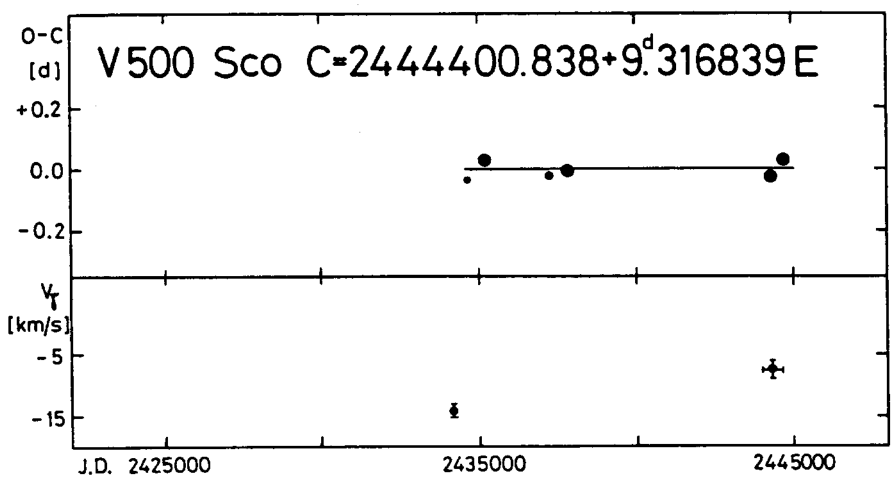

Figure 40. **Upper panel: O–C diagram of** V500 Sco
Lower panel: **γ-velocities for the same Cepheid**

the study of an IUE spectrum obtained by *Böhm-Vitense* and *Proffitt* (1985).

The O–C residuals listed in Table 67 have been computed with the elements:

$$C = 2444400.838 + 9^{d}.316839 \cdot E \qquad (54)$$
$$\pm.010 \quad \pm.000015$$

The O–C diagram (in the upper panel of Figure 40) simply shows a constant period.

V636 Scorpii

This Cepheid belongs to a spectroscopic binary system with an orbital period of 1318 days (*Lloyd Evans*, 1971). The blue companion has been discovered in an IUE study (*Böhm-Vitense* and *Proffitt*, 1985).

Table 68. O–C residuals for V636 Sco

Norm.max. JD2400000+	E	O–C	Type, weight	Reference
34743.483	-827	$+0^{d}.064$	pe 2	Walraven et al. (1958)
35232.792	-755	-0.001	pe 3	Irwin (1961)
37849.532	-370	-0.051	pe 3	Walraven et al. (1964)
40350.817	- 2	-0.010	pe 2	Stobie (1970)
42852.033	+366	-0.038	pe 2	Dean (1977)
44456.179	+602	+0.049	pe 2	Eggen (1985)
45020.306	+685	+0.037	pe 1	Eggen (1985)
45706.740	+786	-0.012	pe 1	Eggen (1985)

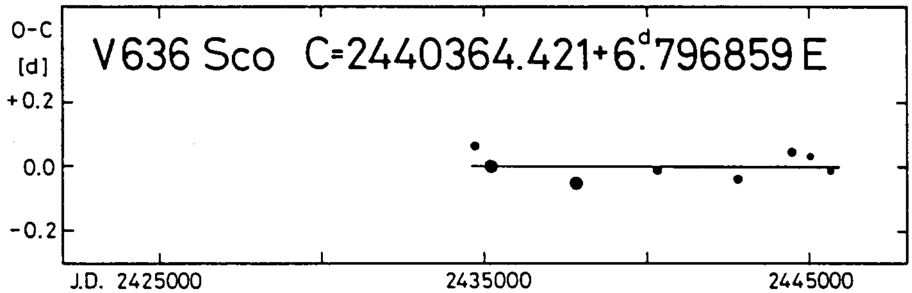

Figure 41. O-C diagram of V636 Sco

The O-C residuals listed in Table 68 have been calculated with the elements:

$$C = 2440364.421 + 6.^{d}796859 \cdot E \qquad (55)$$
$$\pm.011 \qquad \pm.000018$$

The O-C diagram plotted in Figure 41 has been approximated by a straight line. According to equation (1) no detectable light-time effect is expected.

Y Scuti

The variable γ-velocity of Y Scuti was first noticed by *Moffett* and *Barnes* (1987). Their conclusion is confirmed here (see Table 69 and the lower panel of Figure 42). The orbital period can be as long as several thousand days because the radial velocity data obtained by *Barnes* et al. (1988) cover three consecutive years, and no obvious change in the γ-velocity is seen in their data.

The O-C residuals have been calculated with the elements:

$$C = 2434947.209 + 10.^{d}341483 \cdot E \qquad (56)$$
$$\pm.007 \qquad \pm.000008$$

Photographic observations were also taken into account in the fitting procedure. The O-C graph can be best represented by a straight line (see Table 70 and the upper panel of Figure 42). The number of the O-C residuals

Table 69. γ-velocities of Y Sct

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
25362	371	12.0	2.6	4	Joy (1937)
28080	425	3.5	2.0	6	Joy (1937)
44521	339	18.5	1.3	11	Barnes et al. (1988)

Table 70. O-C residuals for Y Sct

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
16342.813	-1799	$-0\overset{d}{.}068$	pg 1	Shapley (1930)
18028.602	-1636	+0.059	pg 1	Shapley (1930)
19631.411	-1481	-0.062	pg 1	Shapley (1930)
21337.791	-1316	-0.026	pg 1	Shapley (1930)
23220.027	-1134	+0.060	pg 1	Shapley (1930)
24347.261	-1025	+0.072	pg 1	Shapley (1930)
29869.583	- 491	+0.042	pg 1	Filin (1950a), Solov'yov (1956)
31317.362	- 351	+0.014	pg 1	Filin (1950a), Solov'yov (1956)
32610.015	- 226	-0.019	pg 1	Filin (1950a), Solov'yov (1956)
33106.422	- 178	-0.003	pg 1	Filin (1950a)
33178.761	- 171	-0.054	pg 1	Solov'yov (1956)
34833.443	- 11	-0.010	pe 1	Walraven et al. (1958)
36767.263	+ 176	-0.047	pe 2	Weaver et al. (1961)
37491.251	+ 246	+0.037	pe 2	Ponsen and Oosterhoff (1966)
40841.857	+ 570	+0.003	pe 3	Pel (1976)
44285.578	+ 903	+0.010	pe 3	Moffett and Barnes (1984)
44947.444	+ 967	+0.021	pe 3	Moffett and Barnes (1984)
45495.492	+1020	-0.030	pe 1	Berdnikov (1986)
45878.138	+1057	-0.019	pe 3	Berdnikov (1986)

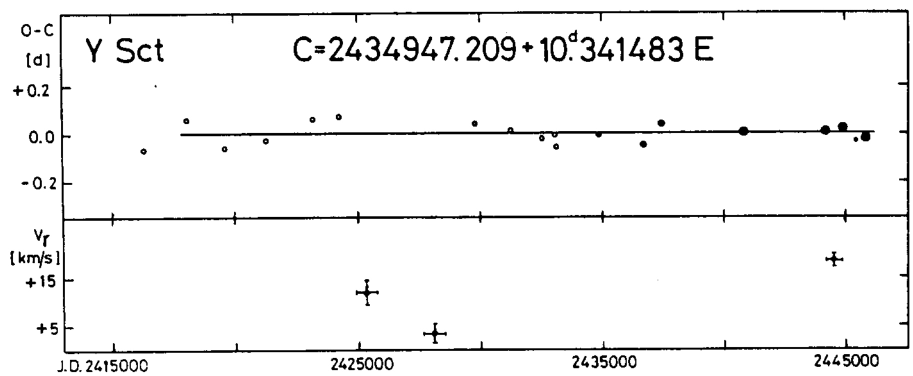

Figure 42. Upper panel: O-C diagram of Y Sct
Lower panel: γ-velocities for the same Cepheid

obtained from photoelectric observations is not enough to reveal the light-time effect expected in this case.

R Trianguli Australis

Its spectroscopic binary nature was already suspected by *Gieren* (1982). His conclusion is confirmed here (see Table 71 and the lower panel of Figure 43). It has to be noted that the γ-velocity obtained from *Paddock*'s

Table 71. γ-velocities of R TrA

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
18432	24	-16.4	0.9	13	Paddock (1917)
33849	23	- 7.5	1.1	8	Stibbs (1955)
34172	44	-10.2	1.2	7	Stibbs (1955)
39265	36	-14.9	0.8	6	Lloyd Evans (1968)
40364	28	-12.9	0.3	4	Lloyd Evans (1980)
40792	12	-14.1	0.3	4	Lloyd Evans (1980)
44423	4	-13.1	0.4	26	Gieren (1981a)

Table 72. O-C residuals for R TrA

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
16259.101	-7252	$+0^d.032$	pg 1	Shapley (1930)
18119.820	-6703	+0.033	pg 1	Shapley (1930)
20278.701	-6066	-0.062	pg 1	Shapley (1930)
21648.047	-5662	+0.012	pg 1	Shapley (1930)
23810.290	-5024	-0.110	pg 1	Shapley (1930)
25728.752	-4458	+0.015	pg 1	Dartayet et al. (1949)
34920.515	-1746	+0.032	pe 1	Walraven et al. (1958)
35201.826	-1663	+0.032	pe 3	Irwin (1961)
40339.938	- 147	-0.015	pe 1	Stobie (1970)
40770.398	- 20	+0.006	pe 3	Pel (1976)
42410.823	+ 464	+0.016	pe 3	Dean et al. (1977)
43234.389	+ 707	-0.015	pe 3	Dean (1981)
44417.257	+1056	-0.008	pe 3	Dean (1981)
44681.614	+1134	-0.015	pe 3	Eggen (1985)

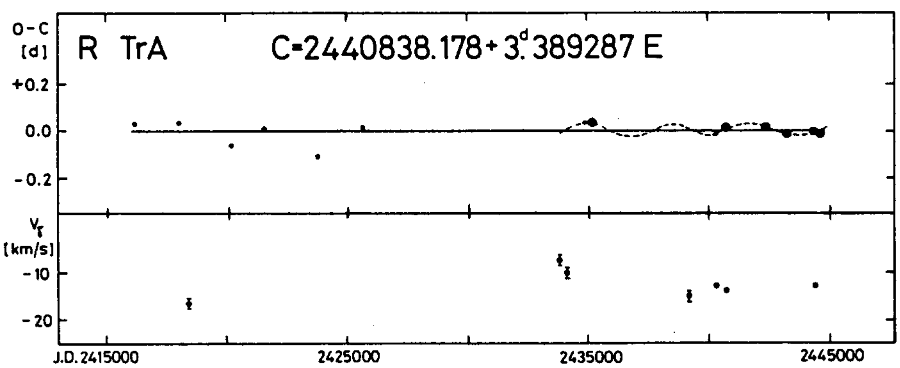

Figure 43. Upper panel: O-C diagram of R TrA
Lower panel: γ-velocities for the same Cepheid

(1917) observations still has the most negative value, although a +4 km/s correction has been applied to his data as discussed in the Introduction.

The O-C residuals have been calculated with the ephemeris:

$$C = \underset{\pm .007}{2440838.178} + \underset{\pm .000002}{3^d.389287} \cdot E \qquad (57)$$

The O-C residuals listed in Table 72 and shown plotted in the upper panel of Figure 43 suggest an orbital period of about 3500 days, if the wave-like pattern of the photoelectric O-C residuals is caused by a light-time effect. This value is in accord with the γ-velocity variations but further photometric and spectroscopic observations are necessary to confirm that the above hypothesis is correct.

S Trianguli Australis

The variability of the γ-velocity may or may not be real (see Table 73 and the lower panel of Figure 44). *Gieren* (1982) also noticed these changes but the question on the spectroscopic binary nature of S TrA is still open.

Table 73. γ-velocities of S TrA

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
18416	12	2.0	0.8	7	Campbell and Moore (1928)
20680	2	3.5	2.0	2	Campbell and Moore (1928)
33855	23	8.1	1.1	8	Stibbs (1955)
34173	38	5.0	1.1	8	Stibbs (1955)
39265	36	2.2	1.0	5	Lloyd Evans (1968)
40554	202	3.6	0.4	3	Lloyd Evans (1980)
44423	4	4.3	0.4	23	Gieren (1981a)

Table 74. O-C residuals for S TrA

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
15895.762	-3928	$-0^d.053$	pg 1	Shapley (1930)
17995.176	-3596	-0.030	pg 1	Shapley (1930)
20277.932	-3235	-0.045	pg 1	Shapley (1930)
21745.045	-3003	+0.024	pg 1	Shapley (1930)
24027.839	-2642	+0.048	pg 1	Shapley (1930)
25482.306	-2412	+0.118	pg 1	Dartayet et al. (1949)
25798.453	-2362	+0.091	pg 1	Dartayet et al. (1949)
34575.331	- 974	0.000	pe 3	Walraven et al. (1958)
35207.668	- 874	-0.010	pe 3	Irwin (1961)
37092.091	- 576	+0.021	pe 1	Eggen (1961)
40342.320	- 62	-0.011	pe 3	Stobie (1970)
40753.357	+ 3	0.000	pe 3	Pel (1976)
41518.515	+ 124	+0.019	pe 2	Dean et al. (1977)
42176.137	+ 228	+0.001	pe 3	Dean et al. (1977)
42555.556	+ 288	+0.012	pe 3	Dean et al. (1977)
43605.266	+ 454	+0.027	pe 1	Eggen (1985)
43681.122	+ 466	+0.001	pe 1	Dean (1981)
44420.971	+ 583	+0.005	pe 3	Gieren (1981b)
44642.260	+ 618	-0.027	pe 3	Eggen (1985)

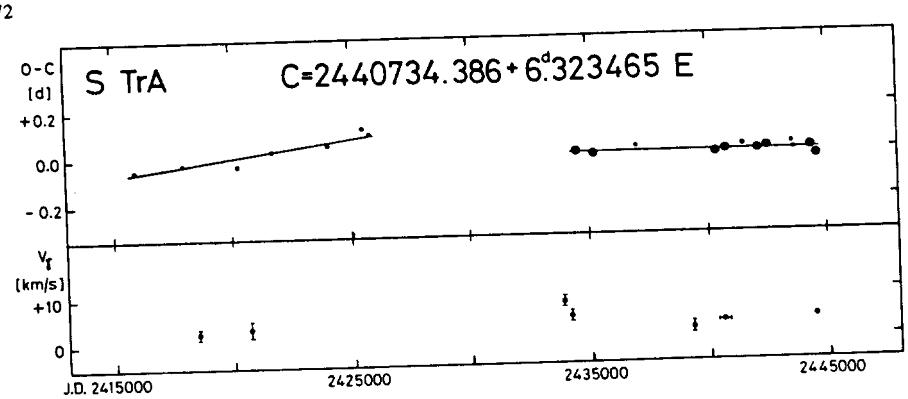

Figure 44. Upper panel: O-C diagram of S TrA
Lower panel: γ-velocities for the same Cepheid

The O-C residuals have been computed with the elements:

$$C = 2440734.386 + 6^{d}.323465 \cdot E \qquad (58)$$
$$\pm.003 \quad \pm.000005$$

As one can see in the upper panel of Figure 44 (based on the data listed in Table 74), a period change occurred between J.D.2426000 and 2434500. The former value of the pulsation period was 6.323570 $\pm$ $1.8 \cdot 10^{-5}$ days.

T Velorum

Gieren (1985) suspects the presence of a red companion on the basis of the amplitude of the light variation in different colours. The γ-velocity study performed here (see Table 75 and the lower panel of Figure 45) is still inconclusive as far as variability in the γ-velocity is concerned.

The O-C residuals have been calculated with the elements:

$$C = 2440713.286 + 4^{d}.639819 \cdot E \qquad (59)$$
$$\pm.004 \quad \pm.000004$$

Table 75. γ-velocities of T Vel

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
34063	53	8.6	0.7	20	Stibbs (1955)
40473	190	6.3	0.3	5	Lloyd Evans (1980)
45042	2	5.2	0.5	20	Gieren (1985)

Table 76. O-C residuals for T Vel

Norm.max JD2400000+	E	O-C	Type, weight	Reference
18201.069	-4852	$+0^{d}.185$	pg	Hertzsprung (1937)
26302.088	-3106	+0.080	pg	Hertzsprung (1937)
33786.067	-1493	+0.031	pe 1	Eggen et al. (1957)
34741.844	-1287	+0.005	pe 1	Walraven et al. (1958)
34843.895	-1265	-0.020	pe 2	Eggen et al. (1957)
35205.814	-1187	-0.007	pe 2	Irwin (1961)
40745.774	+ 7	+0.009	pe 3	Pel (1976)
41803.658	+ 235	+0.015	pe 3	Dean et al. (1977)
42555.282	+ 397	-0.012	pe 3	Dean et al. (1977)
44299.894	+ 773	+0.028	pe 3	Eggen (1985)
44800.940	+ 881	-0.027	pe 2	Eggen (1985)
45052.229	+ 933	-0.008	pe 3	Gieren (1985)

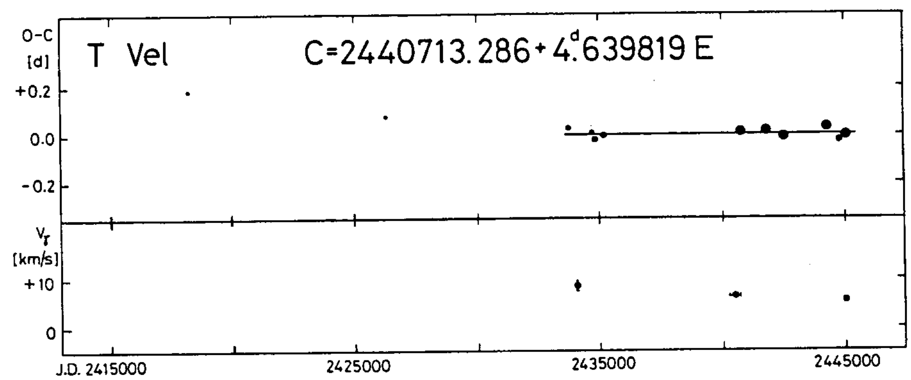

Figure 45. Upper panel: O-C diagram of T Vel
Lower panel: γ-velocities for the same Cepheid

The O-C residuals listed in Table 76 and shown plotted in the upper panel of Figure 45 show constancy of the period, at least in the photoelectric era. *Hertzsprung*'s (1937) observations suggest that the pulsation period of T Vel is increasing. Further observations will decide whether a parabolic fit is better. Similarly to AT Pup, *Gieren*'s (1985) observations made in 1981 have not been taken into account (see the remarks on AT Pup).

V Velorum

Pel (1978) suspects a blue photometric companion to this Cepheid. Variability of the γ-velocity is suspected here (see Table 77 and the lower panel of Figure 46).

Table 77. γ-velocities of V Vel

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
34092	45	-29.0	0.8	17	Stibbs (1955)
39245	40	-30.7	1.1	4	Lloyd Evans (1968)
40381	23	-29.4	0.3	4	Lloyd Evans (1980)
40690	57	-27.5	0.3	6	Lloyd Evans (1980)
45042	2	-26.3	0.4	21	Gieren (1985)

Table 78. O-C residuals for V Vel

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
34809.091	-1356	$+0^{d}.001$	pe 2	Walraven et al. (1958)
35233.090	-1259	+0.009	pe 2	Irwin (1961)
40268.520	- 107	-0.002	pe 3	Stobie (1970)
40766.834	+ 7	+0.013	pe 3	Pel (1976)
41789.624	+ 241	-0.021	pe 3	Dean et al. (1977)
42585.158	+ 423	-0.017	pe 3	Dean et al. (1977)
44412.289	+ 841	+0.018	pe 3	Eggen (1985)
45037.336	+ 984	+0.006	pe 3	Gieren (1985)

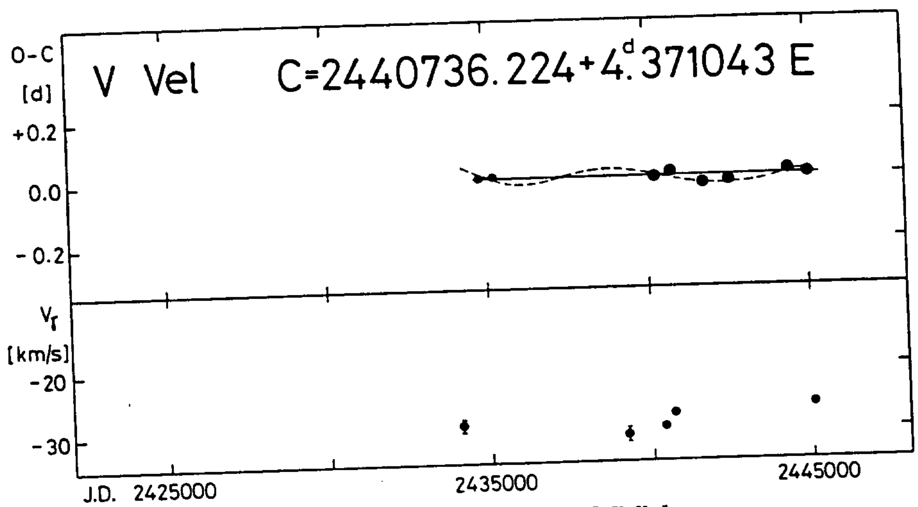

Figure 46. Upper panel: O-C diagram of V Vel
Lower panel: γ-velocities for the same Cepheid

The O-C residuals have been calculated with the elements:

$$C = 2440736.224 + 4^{d}.371043 \cdot E \qquad (60)$$
$$\pm.003 \qquad \pm.000006$$

These elements have been obtained by a linear least squares fit to the O-C residuals listed in Table 78. The upper panel of Figure 46, however, shows that a light-time effect interpretation of these data is also possible.

Assuming an orbital period of about 7500 days, the γ-velocity variations are properly phased with respect to the O-C wave. Similarly to AT Pup and T Vel, *Gieren*'s (1985) photometric observations obtained in 1981 have not been taken into account here (see the remark on AT Pup).

AH Velorum

AH Vel belongs to a binary system based on both photometric (*Gieren*, 1980b) and spectroscopic (*Lloyd Evans*, 1968 and 1982, and *Gieren*, 1980a) criteria. The orbital period cannot be determined yet. The individual γ-velocities are listed in Table 79 and shown plotted in the lower panel of Figure 47.

The O-C residuals have been calculated with the elements:

$$C = 2442035.703 + 4\overset{d}{.}227231 \cdot E \qquad (61)$$
$$\pm.007 \qquad \pm.000007$$

Table 79. γ-velocities of AH Vel

JD 2400000+	σ [d]	v_γ [km/s]	σ [km/s]	n	Reference
33979	22	25.8	0.7	18	Stibbs (1955)
34108	38	28.5	1.3	6	Stibbs (1955)
39230	44	22.5	0.8	6	Lloyd Evans (1968)
39643	72	21.3	0.8	7	Lloyd Evans (1968)
39899	30	23.0	0.2	8	Lloyd Evans (1980)
40300	54	23.2	0.2	12	Lloyd Evans (1980)
40653	49	21.0	0.2	9	Lloyd Evans (1980)
42036	7	24.5	0.3	37	Gieren (1977)

Table 80. O-C residuals for AH Vel

Norm.max. JD2400000+	E	O-C	Type, weight	Reference
33889.864	-1927	$+0\overset{d}{.}035$	pe 2	Eggen et al. (1957)
34824.060	-1706	+0.013	pe 1	Walraven et al. (1958)
35187.584	-1620	-0.005	pe 3	Irwin (1961)
40256.017	- 421	-0.022	pe 3	Stobie (1970)
40725.254	- 310	-0.007	pe 3	Pel (1976)
41765.136	- 64	-0.024	pe 3	Dean et al. (1977)
42035.677	0	-0.026	pe 3	Gieren (1980a)
43895.726	+ 440	+0.041	pe 1	Eggen (1980)
44681.992	+ 626	+0.042	pe 3	Eggen (1983a)

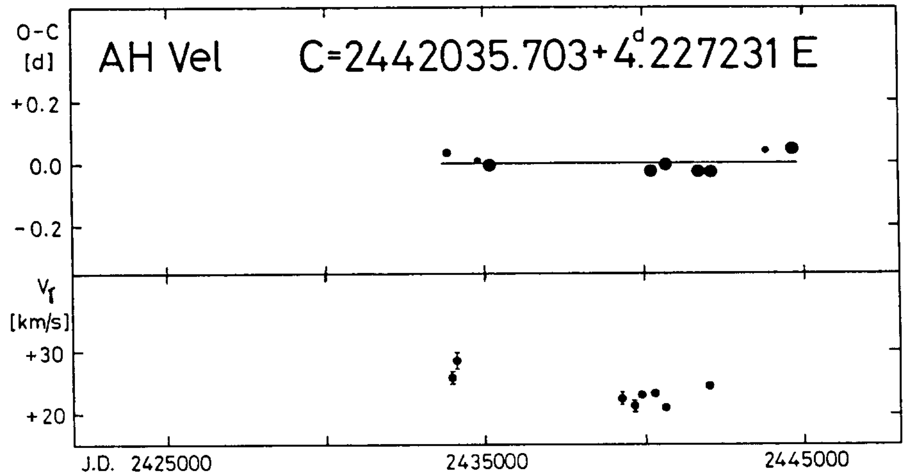

Figure 47. Upper panel: O-C diagram of AH Vel
Lower panel: γ-velocities for the same Cepheid

Although a constant period is assumed here (see the upper panel of Figure 47 and Table 80), neither a parabolic O-C graph, nor a light-time effect with a very long orbital period can be excluded. Further photometric and radial velocity observations are needed as for most of the previously discussed Cepheids.

GENERAL REMARKS

Because the sample of Cepheids studied here is inhomogeneous and is not large enough, any statistics concerning the period changes, including a comparison with previous results, may lead to false conclusions. It is, however, important to note that all kinds of period changes known from earlier studies are observed here, too. Particularly important among them are: the continuous period increase or decrease (due to stellar evolution), the wave-like pattern of the O-C graph (due to the light-time effect in binary systems), and the phase jump (return to an earlier value of the pulsation period). This latter kind of period change also occurs in binary Cepheids.

Table 81 summarizes the results on the period changes and variability of the γ-velocity of the Cepheids studied here. Because the normal maxima published in the GCVS (*Kholopov* et al., 1985-1987) were only modified in the discussion on the individual variables instead of transferring them to a more recent epoch, it is worthwhile to give the actual values of the normal maximum and the pulsation period valid for e.g. J.D.2445000, taking into account the period variations when necessary. The successive columns of Table 81 give the following data:

1. Name of the Cepheid
2. Moment of the normal maximum just following J.D.2445000
3. Pulsation period at J.D.2445000
4. Characteristic features in the O-C diagram (∿: light-time effect, -: decreasing period, +: increasing period)
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.

There are four stars in this sample for which the catalogued value of the pulsation period needs a considerable correction: YZ Car, AZ Cen, KN Cen, and GH Lup. In addition, the starting epoch needs a big correction in the case of SY Nor.

Light-time effect has been discovered in the O-C diagram of V496 Aql, AX Cir, AG Cru, BG Cru (uncertain), BF Oph, AP Pup, AT Pup, Y Sgr, AP Sgr, R TrA, and V Vel. A preliminary value of the orbital period has been suggested on the basis of the light-time effect and/or the variations in the γ-velocity for the following Cepheids: V496 Aql, AX Cir, AG Cru, Y Oph, BF Oph, AP Pup, AT Pup, U Sgr, Y Sgr, AP Sgr, BB Sgr, RV Sco, R TrA, and V Vel. A phase jump is revealed in the O-C diagram of U Aql, YZ Car, KN Cen, S Mus, S Nor, Y Oph, U Sgr, and V350 Sgr. If an O-C diagram can be equally well represented by a phase jump or a constant period of another value, the phase jump interpretation is preferred here. This more or less provocative step may encourage others to observe these stars photometrically. Similarly, some of the orbital periods, and even the variation in the γ-velocity assumed for a particular Cepheid variable can be doubted. In any case, more regular photometric and radial velocity observations would be desirable on each Cepheid studied here.

Even if some of the orbital periods suggested in Table 81 is not well determined, the half of the programme stars belongs to spectroscopic binary systems. Keeping in mind that the spectroscopic binaries can only be revealed in favourable cases (depending on the value of the orbital inclination), and that the binary nature can also be discovered on the

Table 81. Summary on the periods, period changes, and duplicity

Cepheid	Norm.max. JD2400000+	P	O-C diagram	V_γ	P_{orb} [day]	Source
U Aql	45001.780	$7^d.023958$	linear with phase jump	variable	1856.4	Welch et al. (1987)
V 496 Aql	45002.397	6.807055	linear ∿	variable	1780·n	present paper
V Car	45001.101	6.696672	linear	variable		
YZ Car	45007.131	18.165573	linear with phase jump	variable	∿ 850	Coulson (1983)
ℓ Car	45002.391	35.551341	two linear sections	constant		
V Cen	45000.289	5.493861	two linear sections	variable ?		
XX Cen	45010.493	10.953370	parabolic (-)	variable	909.4	Szabados (1989)
AZ Cen	45001.112	3.211981	parabolic (-)	variable ?		
KN Cen	45021.656	34.029641	linear with phase jump	variable		
AX Cir	45001.903	5.273306	linear ∿	variable	∿ 4600	present paper
S Cru	45000.251	4.689596	parabolic (-)	constant		
T Cru	45004.630	6.733196	linear	variable		
AG Cru	45000.710	3.837254	linear ∿	variable	∿ 6350	present paper
BG Cru	45003.271	3.342720	linear ∿:	variable		
β Dor	45009.560	9.842425	linear	constant		
GH Lup	45003.355	9.277948	linear :	variable		
R Mus	45001.446	7.510467	parabolic (+)	variable		
S Mus	45003.522	9.659875	linear with phase jump	variable	506	Lloyd Evans (1971)
S Nor	45004.063	9.754244	linear with phase jump	variable		
RS Nor	45002.060	6.198136	linear	not observed!		
SY Nor	45005.992	12.645687	linear	one series only		
Y Oph	45008.372	17.126908	linear with phase jumps	variable	1222.5	present paper

Table 81. (cont.)

Cepheid	Norm.max. JD2400000+	P	O-C diagram	V_γ	P_{orb} [day]	Source
BF Oph	45000.515	$4^{d}.067510$	parabolic ∿ (-)	variable	∿ 4500	present paper
AP Pup	45000.597	5.084274	linear ∿	variable	∿ 10000	present paper
AT Pup	45006.629	6.664879	linear ∿	variable	∿ 20000	present paper
MY Pup	45001.729	5.695309	parabolic (+)	constant		
U Sgr	45004.675	6.745229	linear with phase jump	variable	4550	present paper
W Sgr	45007.526	7.594904	linear	variable	1780	Babel et al. (1989)
X Sgr	45005.293	7.012877	parabolic (+)	variable	507.25	Szabados (1989)
Y Sgr	45005.763	5.773380	linear ∿	variable	≥10000 :	present paper
WZ Sgr	45011.333	21.849789	linear + earlier changes	variable ?		
AP Sgr	45003.097	5.057916	linear ∿	variable	∿ 7500	present paper
BB Sgr	45000.224	6.637102	parabolic (+)	variable	∿ 4550 ?	present paper
V 350 Sgr	45002.267	5.154178	linear with phase jump	variable	1129	Szabados (1989)
RV Sco	45005.369	6.061306	parabolic (-)	variable	∿ 8000 ?	present paper
RY Sco	45017.646	20.320144	linear with period change	variable ?		
V 500 Sco	45006.433	9.316839	linear	variable		
V 636 Sco	45006.676	6.796859	linear	variable	1318	Lloyd Evans (1971)
Y Sct	45009.472	10.341483	linear	variable		
R TrA	45000.222	3.389287	linear ∿	variable	∿ 3500	present paper
S TrA	45002.725	6.323465	linear with period change	variable ?		
T Vel	45000.479	4.639819	linear	constant		
V Vel	45002.362	4.371043	linear ∿	variable	∿ 7500	present paper
AH Vel	45003.219	4.227231	linear	variable		

basis of a number of photometric methods not discussed here, the following conclusion may not be an exaggeration: the frequency of Cepheid binaries is higher than thought ever since these variables have been known as pulsating stars.

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