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The GO Cygni system: a near contact eclipsing binary

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Abstract. The GO Cygni system is a short period -0.7177 days- eclipsing binary with a β Lyrae-type light curve. In this study our new BV photoelectric observations of the system, made at the Bucharest Observatory during 1993-94 are presented. These, and our old ones -made at the Kryonerion Astronomical Station of the National Observatory of Athens, Greece, in 1985- are analysed using Wood's program. The geometrical elements of the system -derived from the present analysis- correspond to a contact configuration suggesting that it belongs to the so-called *near contact* binaries. Moreover, its physical parameters lead to an unevolved system with both of its components located very close to the ZAMS. Finally, its orbital period is examined and found to show continuous increased.

Key words: stars: GO Cyg – binaries: close-binaries: eclipsing

1. Introduction

The variability of GO Cyg (BD+34°4095) was discovered photographically by Schneller (1928) and the system was classified as a short-period eclipsing binary by Kukarkin (1929). From its early photographic (Liau, 1935) and visual (Pierce, 1939) observations contradictory results were found for both its light curve shape and the eccentricity of its orbit (for details see Ovenden, 1954).

Photoelectric observations and/or light curves analyses of GO Cyg have been made in the past by Ovenden (1954), Popper (1957), Mannino (1963) and recently by Rovithis et al. (1990) and Sezer et al. (1992).

The first spectroscopic elements of the system were published by Pearce (1933) and a new spectroscopic orbit was obtained by Holmgren using the cross-correlation techniques (see e.g. Sezer et al., 1992).

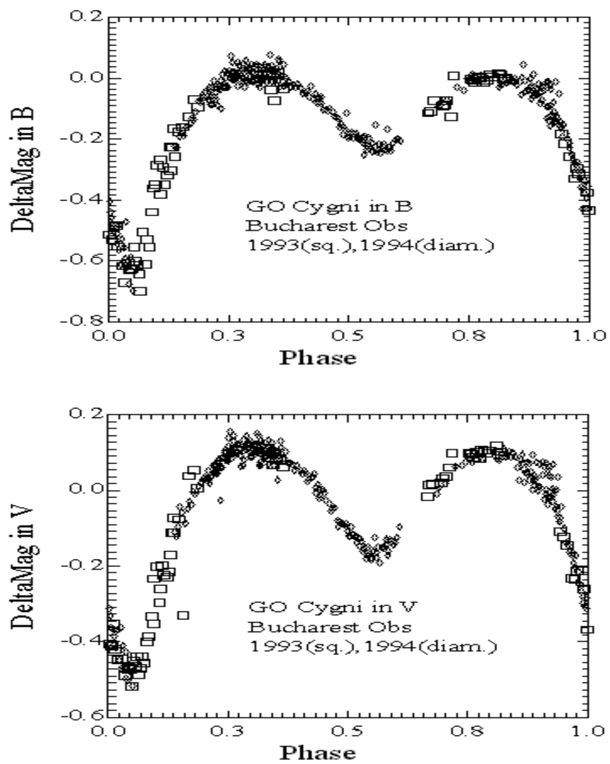

Fig. 1a and b. B and V light curves of GO Cyg during 1993 (squares) and 1994 (diamonds) obtained at the Bucharest Observatory.

Many minima times for GO Cyg can be found in the literature, while studies of its period have been made by Purgathofer & Prochazka (1967), Cester et al. (1979), Hall & Louth (1990) and Jones et al. (1994).

Here we shall present and discuss our old and new photoelectric observations of the GO Cyg system and study its period behaviour.

2. The data

Our first photoelectric observations of GO Cyg were made during 1985 at the Kryonerion Astronomical Station of the Na-

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Table 4 is only available in electronic form at the CDS (Strasbourg) via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

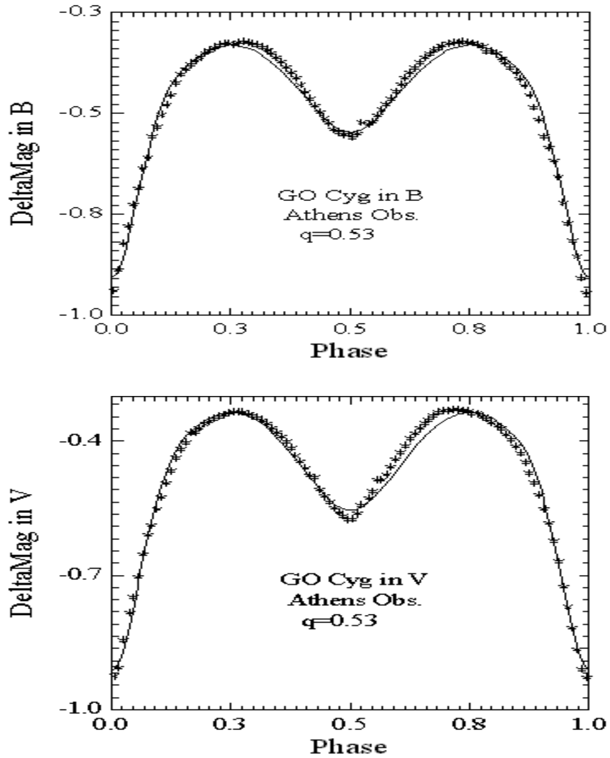

Fig. 2a and b. Normal points and theoretical light curves for the B **a** & V **b** observations of GO Cyg made at the Kryonerion Astron. Station of the National Obs. of Athens, Greece, in 1985, for q=0.53.

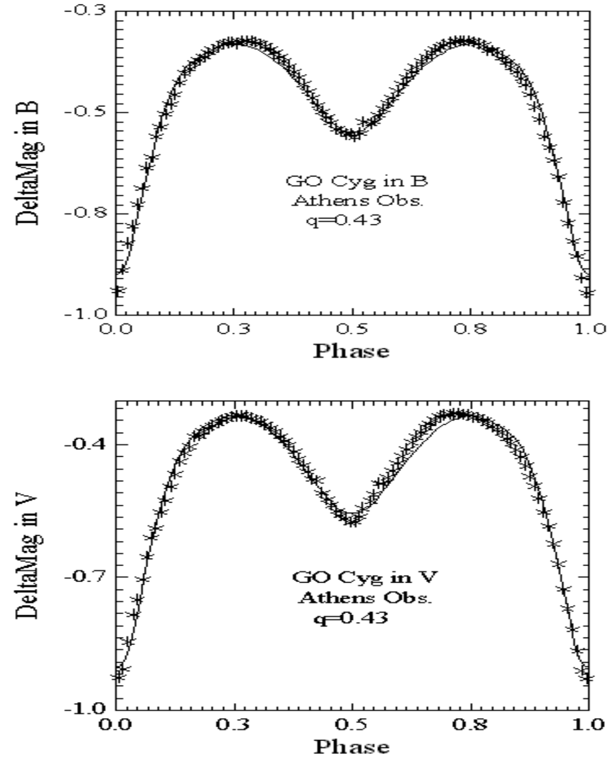

Fig. 3a and b. Same as Fig. 2, but for q=0.43.

tional Observatory of Athens, Greece (Rovithis et al., 1990). The system was re-observed with an EMI 9502 B type photocell attached to the 50 cm Cassegrain telescope at the Bucharest Observatory during 1993-1994. The B and V filters used in both cases are in close accordance with the standard UBV system. During its re-observation, the stars BD +35°4197 and BD +34°4098 were used for comparison and checking, respectively and they are the same as those used by Cester et al. (1979). Reduction of the observations has been made in the usual way (Hardie, 1962; Heuden & Kaitchuk, 1987).

From our new observations - made on 5 nights during 1993 (4 in September and 1 in October) and 13 during 1994 (2 in August, 7 in September and 4 in October) - 414 individual points in B and 413 in V were obtained and are available in electronic form. The corresponding light curves are presented in Fig. 1.

3. Light curves analysis procedure

From all individual observations (old=Athens & new=Bucharest) mean values were formed, which were analyzed using Wood's (1971) model to get the physical and geometrical parameters of the system. The initial parameters used were taken from the previous analysis by Rovithis et al. (1990); the limb-darkening coefficients u_h, u_c from Al-Naimiy's (1987) tables; the T_h was assumed to be equal to 10350 °K (the temperature corresponding to a B9 star; see e.g. Popper, 1980) and considering radiative envelopes the gravity darkening coefficients were fixed to 0.25.

Results were obtained from our old and new data improving the values of (i, $k=r_h/r_c$, r_h) and then the T_c, as well; keeping in all cases the limb-darkening coefficients constant. On the other hand, changing the gravity darkening coefficients -considering convective envelopes (=0.08)- the theoretical model did not fit well the observations.

As regards the mass-ratio q, we worked with two different values: q=0.53 and q=0.43; (for details concerning these choices see Rovithis et al. 1990 and Sezer et al. 1992, respectively). In the first case q was kept constant, while in the second one it was considered as a free parameter. In this latter case the solutions converged to q=0.426 or 0.427. The derived results are given in Tables 1 and 2, for q=0.53 & q=0.43, respectively. The corresponding theoretical light curves are shown as continuous lines in Figs. 2-5, for the two foregoing mentioned cases, and they are compared to the normal observational points.

Moreover, a comparison of our mean B & V results and those derived from different light curves analysis for T_h =10350 and q=0.43 is presented in Table 3.

4. Orbital period study

The first light elements of GO Cyg were given by Szczyrbak (1932). Later Purgathofer & Prochazka (1967) noticed some variation in its orbital period and gave the following linear and

Table 1. Results from the B & V light curve analysis of GO Cyg (for mass ratio equal to 0.53)

Element	$\mathbf{B}_{Athens}$	$\mathbf{V}_{Athens}$	$\mathbf{B}_{Bucharest}$	$\mathbf{V}_{Bucharest}$
i	77.3±.5	77.4±.4	78.3±.5	77.9±.4
u_h	0.55	0.41	0.55	0.41
u_c	0.79	0.61	0.79	0.61
k	0.585	0.568	0.578	0.537
r_h	0.472±.004	0.491±.004	0.488±.006	0.515±.007
r_c	0.276±.009	0.279±.008	0.282±.010	0.277±.009
a_h	0.511	0.536	0.532	0.570
b_h	0.472	0.490	0.487	0.514
c_h	0.433	0.445	0.443	0.460
a_c	0.290	0.294	0.297	0.290
b_c	0.273	0.277	0.279	0.274
c_c	0.265	0.267	0.269	0.265
β_h	0.25	0.25	0.25	0.25
β_c	0.25	0.25	0.25	0.25
T_h	10350	10350	10350	10350
T_c	5990±300	6200±280	6200±300	6200±290
q	0.53	0.53	0.53	0.53
L_h	0.969	0.974	0.970	0.951
L_c	0.031	0.026	0.030	0.049
$(O-C)^2$	0.0182	0.0182	0.0201	0.0191

Table 2. Results from the B & V light curve analysis of GO Cyg (for mass ratio equal to 0.43)

Element	$\mathbf{B}_{Athens}$	$\mathbf{V}_{Athens}$	$\mathbf{B}_{Bucharest}$	$\mathbf{V}_{Bucharest}$
i	78.1±.5	78.5±.4	78.4±.5	78.4±.4
u_h	0.55	0.41	0.55	0.41
u_c	0.79	0.61	0.79	0.61
k	0.582	0.567	0.587	0.579
r_h	0.491±.004	0.510±.004	0.484±.006	0.492±.005
r_c	0.286±.009	0.289±.009	0.284±.008	0.285±.007
a_h	0.529	0.555	0.580	0.531
b_h	0.492	0.512	0.515	0.493
c_h	0.450	0.463	0.440	0.451
a_c	0.305	0.310	0.303	0.304
b_c	0.281	0.285	0.280	0.281
c_c	0.270	0.273	0.260	0.269
β_h	0.25	0.25	0.25	0.25
β_c	0.25	0.25	0.25	0.25
T_h	10350	10350	10350	10350
T_c	5800±290	6200±270	6675±320	7150±310
q	0.427	0.426	0.428	0.427
L_h	0.954	0.958	0.949	0.914
L_c	0.046	0.042	0.051	0.086
$(O-C)^2$	0.0194	0.0171	0.0252	0.0308

quadratic light elements:

$$Min\ I = 2433930.40561 + 0^d71776382\ E$$

and

$$Min\, I \;=\; 2433930.40614 + 0^d71776314\, E \\ +0^d108\ \times\ 10^{-9}E^2,$$

respectively.

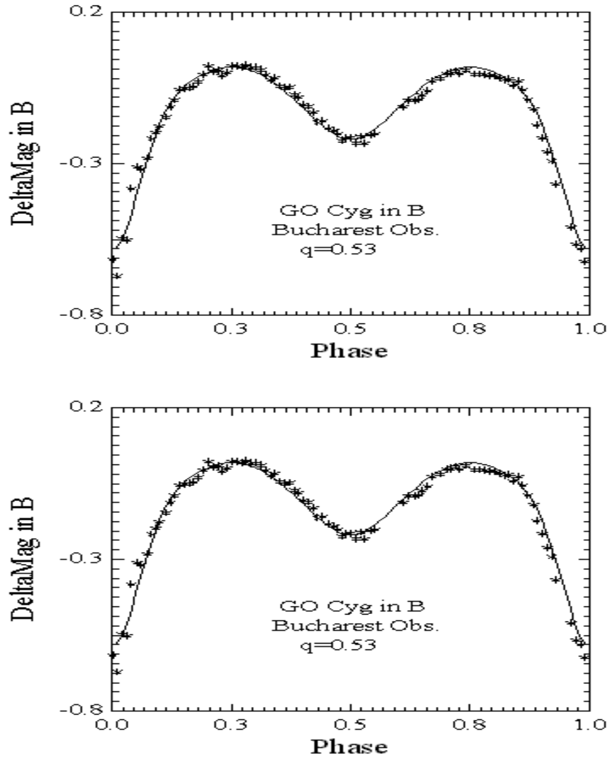

Fig. 4a and b. Normal points and theoretical light curves for the B **a** & V **b** observations of G0 Cyg made at the Bucharest Obs. during 1993-94, for q=0.53.

Cester et al. (1979) and Sezer et al. (1985), calculated and proposed new linear ephemeris and improved the foregoing quadratic one; the latter found an increase in the period of the system by about 0.99±0.11 sec/century. Finally, Jones et al. (1994) improved the quadratic ephemeris of Purgathofer & Prochazka, but they have not taken into account all minima times considering many of them as discordant; and they found a periodicity of 37.8 years.

Fig. 6 presents the (O-C) diagram of the system based on all (121) minima times found in the literature (Table 4). It is described by a quadratic (dashed line) and a third order polynomial (continuous line). Both quadratic and third order approximations show clearly the continuous increase of the orbital period of GO Cyg and as it is obvious from Table 5, where the coefficients of the polynomials and their RMS errors are given, the third one is much better. The constant c in this table is a scale constant used to avoid very small coefficients (see Kalimeris et al., 1994).

5. Summary, results and discussion

GO Cyg is a short period eclipsing binary exhibiting a β Lyrae-type light curve. According to Pearce (1933), the spectral types of its components are A9n and A0n. But, Pierce (1939)and Ovenden (1954), from their light curves solutions, noted that the secondary's spectrum might be of type F5 and F8 or later, respectively; while Popper (1957) questioned, if it is visible

Table 3. Comparison of the results obtained from various light curve analysis of GO Cyg for mass-ratio equal to 0.43.

Param.	Ovenden	Mannino	Popper	Sezer et al.	Present Athens	Study Bucharest
i	78.777	79.880	77.606	79.722	78.288	78.414
T_h	10350	10350	10350	10350	10350	10350
T_c	5605	5904	5966	6043	6000	6912
L_h	0.969	0.961	0.972	0.954	0.956	0.931
L_c	0.031	0.039	0.028	0.046	0.044	0.069
a_h	0.482	0.482	0.482	0.482	0.542	0.555
b_h	0.455	0.455	0.455	0.455	0.505	0.504
c_h	0.427	0.427	0.427	0.427	0.456	0.445
a_c	0.283	0.271	0.221	0.278	0.307	0.303
b_c	0.265	0.256	0.214	0.261	0.283	0.280
c_c	0.257	0.249	0.210	0.254	0.271	0.265

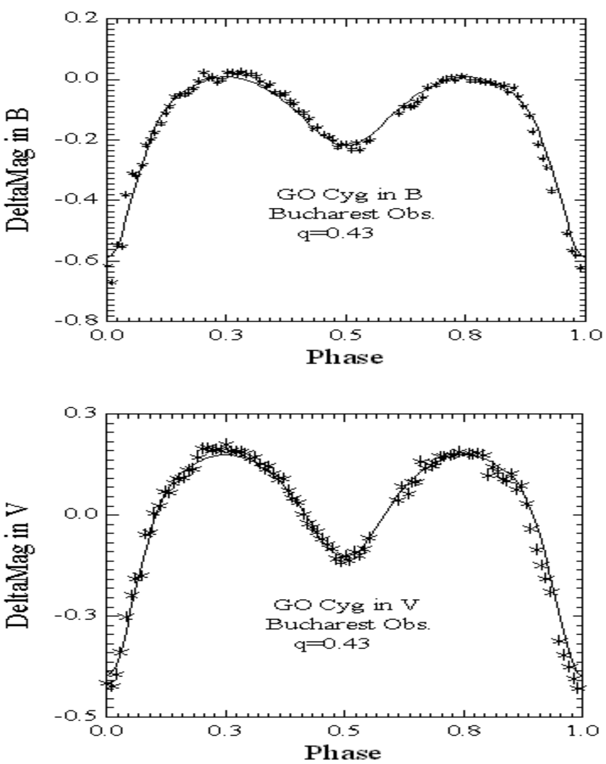

Fig. 5a and b. Same as Fig. 4, but for q=0.43.

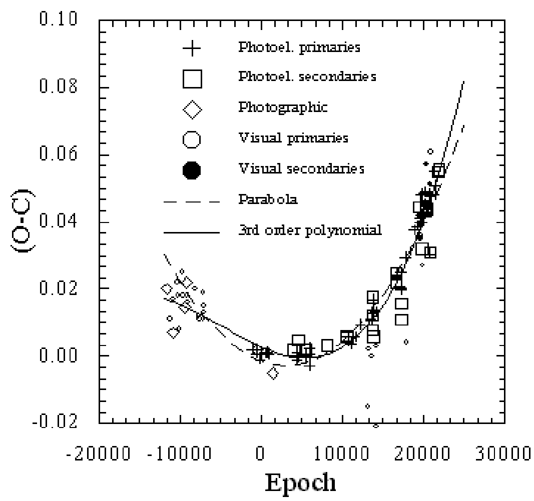

Fig. 6. The (O-C) diagram of GO Cyg based on 121 minima times: 84 photoelectric (diamonds for primaries, crosses for secondaries), 6 photographic (squares) and 31 visual (dots). Dashed line presents quadratic while the continuous one third order approximation.

Table 5. Coefficients of second and third order approximation of the (O-C) diagram of GO Cyg.

	Second	Third
a_o	-0.001471	0.002639
a_1	-0.032667	-0.038842
a_2	0.202446	0.086650
a_3		0.214041
RMS	0.0025	0.0022
c	37000	37000

at all. Moreover, the spectroscopic mass-ratio found by Pearce (1933) differs significantly not only from the new one (see Sezer et al., 1992), but also from many photometric ones.

Comparing the mean light curves obtained at Athens and Bucharest we found the depths of the primary minima to coincide; but, the secondaries are deeper and wider in the Bucharest curves. Moreover, the latter shows a small hump at phase 0.2. In the V filter the above mentioned features are less evident than in B. Taking into account that the observations were performed in periods separated by 8 years, those features could be due to the activity of the system.

Using Wood's method, solutions were obtained for our old and new observations and each colour, for q=0.53 & q=0.43 and T_h =10350. From Tables 1 & 2, where they are presented, the existing small differences can be noticed. The residuals $(O-C)^2$ are close to each other and the fit is satisfactory for all the solutions. The $(O-C)^2$'s for Bucharest light curves are larger due to a larger scatter in the observations. Because all solutions lie in the same value range, it is difficult to choose the best one and to optimize the second order parameters (u_i, β_i, q). Moreover, we try to get solutions considering T_h as a free parameter. In these

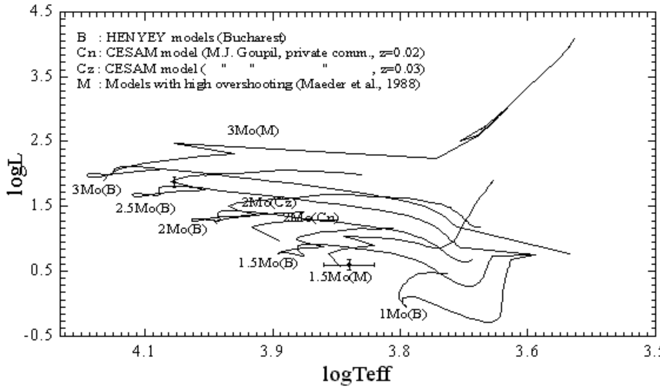

Fig. 7. Positions of the two components of GO Cyg in an H-R diagrams. The various evolutionary tracks correspond to different models.

cases T_h was converged to values around 11000 °K, starting with an initial value of 10350 °K.

On the other hand, from the results presented in Table 3, one can notice small differences in the geometrical elements of GO Cyg among them, a large difference in the temperature of the cool star for the Bucharest data and very small values of the cool star radii for Popper's data. These results have been found by Sezer et al. (1992) from B & V light curve solutions using W-D code and they are not those obtained by the authors themselves, who have used different analysis methods.

As regards the degree of contact of the two components of GO Cyg, one can get an idea from a comparison of the derived r_h and r_c values to the corresponding Roche lobes taken from the Plavec & Kratochvil's (1964) tables. Doing so, we get (for q=0.53) r_{hR} =0.435 & r_{cR} =0.317 and (for q=0.43) r_{hR} =0.455 & r_{cR} =0.300, respectively. So, GO Cyg is an eclipsing binary system, in which the primary (massive and hotter) component is slightly greater than its Roche lobe, while the cool component is slightly smaller than it. And since it exhibits a β Lyrae-type light curve, it belongs to the so called *near-contact* systems (Shaw, 1990; 1994).

It is also interesting to see the evolutionary status of GO Cyg. This can be done, if its absolute parameters are known. We used well known standard relations (e.g. Kopal, 1959), the derived mean values of the geometrical elements of the system and adopted for K_h the old value given by Pearce (since no new is known). For the K_c we computed another value (for q=0.53 only), since the old one yields to a mass-ratio equal to 0.85, which is certainly wrong. Results are given in Table 6, while the positions of the two components of GO Cyg are denoted with crosses in an H-R diagram (Fig. 7), where different evolutionary tracks are included (based on various models). From this figure, as well as from the positions in the mass-radius (M-R) and mass-luminosity (M-L) diagrams of Hilditch et al. (1988) it is concluded that GO Cyg is an unevolved system with both its components very close to the ZAMS.

Finally, the orbital period of GO Cyg was studied from its (O-C) diagram (Fig. 6), which is based on 6 photographic(diamonds), 31 visual(dots for primaries & full dots for secondaries) and 84 photoelectric(crosses for primaries & squares for secondaries) minima times. It is obvious that the period of GO Cyg continues to increase, either described by a quadratic or a third order polynomial. And since there are not significant differences in both the coefficients of the second and third order approximations, as well as to their RMS errors, that's why the (O-C) diagram of GO Cyg can be described pretty good either with a simple parabola or using a third order approximation. The only difference being in the rate of change (see e.g. Kalimeris et al., 1994). When more data will be available, we shall be able not only to study the period changes of the system in much more detail, but also to find the mechanisms that produce them, following the new method proposed and developed by Kalimeris et al. (1994, 1997).

Table 6. Absolute parameters of GO Cyg.

a_h(Km)	1.31X10^6
a_c(Km)	2.48X10^6
a(Km)	3.79X10^6
$M_h(M_\odot)$	2.73
$M_c(M_\odot)$	1.45
$R_h(R_\odot)$	2.67
$R_c(R_\odot)$	1.51
$L_h(L_\odot)$	73.5
$L_c(L_\odot)$	2.7
$M_{bol,h}$	0.078
$M_{bol,c}$	3.68

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References

Al Naimiy H.M.:1978, ApSS 53, 181.
Cester B., Giuricin G., Mardirossian F., Mezzetti M.:1979, Acta Astron. 29, 433.
Hall D., Lough H.:1990, J. A&A 11, 271.
Hardie R.H.:1962, Stars and Stellar Systems, Vol. II, *Astronomical Techniques*, (W.A.Hiltner Ed.), University of Chicago Press, Chicago, p.178.
Heuden A.A., Kaitchuk R.H.:1987, *Astronomical Photometry*, Chapter 4, p. 80, VanNostand Reinhold Company Inc.
Hilditch R.W., King D.J., McFarlane T.M.: 1998, MNRAS 231, 341.
Jones R.A., Snyder LR, Frey G., et al.:1994, I.A.P.P.P. Com. No. 54, 34.
Kalimeris A., Rovithis-Livaniou H., Rovithis P.:1994, A&A 282, 775.
Kalimeris A., Rovithis-Livaniou H., Rovithis P.: in preparation.
Kopal Z.:1959, *Close Binary Systems*, Hall & John Wiley, London and New York.
Kukarkin B.W.:1929, Mon. Not. Var. Stars 2, 26.
Liau S.P.:1935, Publ. Obs. Lyon, Ser. 1,1. Fasc. 13.
Maeder A., Meynet G.:1988, Publ. l'Obs. de Geneve, 29.
Mannino G.:1963, Mem. Soc. Astron. Italiana, Vol. XXXIV (Publ.Obs. Astron. Bologna Vol. VIII, No. 15).
Ovenden M.W.:1954, MNRAS 114, 569.
Pearce J.A.:1933, J.R. Astron. Soc. Canada 27, 62.

Pierce N.L.:1939, AJ 48, 113.
Plavec M., Kratochvil P.: 1964, Bull. Astron. Inst. Czech. 15, 165.
Popper D.M.:1957, ApJS 3, 107.
Popper D.M.:1980, Annual Review A&A 18, 115.
Purgathofer A., Prochazka F.:1967, Mitt. Univ. Stern Wien 13, 151.
Rovithis P., Rovithis-Livaniou H., Niarchos P.G.:1990, A&AS 83, 41.
Sezer C., Gülmen Ö., Güdür N.:1985, I.B.V.S. No. 2743.
Sezer C., Gülmen Ö., Güdür N.:1992, ApSS 203, 121.
Schneller H.:1928, AN 235, 85.
Shaw J.S.:1990, in *Active Close Binaries* (Ed. Ibanoglu), Kluwer Acad. Publ., p. 241.
Shaw J.S.:1994, in *Evolutionary Links in the Zoo of Interactive Binaries*, (Eds. D'Antona, Caloi, Maceroni, Giovanelli), Mem.S.A.Il. Vol. 5, p.95.
Szczyrbak S.:1931, SAC 10, 44.
Wood D.B.:1971, AJ 76, 701.

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