Astron. Astrophys. 355, 171–175 (2000)

ASTRONOMY AND ASTROPHYSICS

Orbital period studies of the two contact binaries TZ Bootis and Y Sextantis*

S. Qian[1,2,3] **and Q. Liu**[1,2,3]

[1] Yunnan Observatory, Chinese Academy of Sciences, P.O. Box 110, 650011 Kunming, P.R. China (qsb@netease.com)
[2] National Astronomical Observatories, Chinese Academy of Science (NAOCAS)
[3] United Laboratory of Optical Astronomy, Chinese Academy of Science (ULOAC)

Received 19 February 1999 / Accepted 9 December 1999

Abstract. The physical properties of the two A-type contact binaries TZ Boo and Y Sex are nearly the same. In the present paper, many of their published times of light minima are collected and the changes in their orbital periods are analyzed. It is indicated that the orbital period of TZ Boo shows several alternating jumps while it undergoes a secular decrease of -11.8×10^{-8} days/year. Several random jumps superposed on a secular decrease (-5.5×10^{-8} days/year) are also found in the period of Y Sex. The secular decrease is usually interpreted as mass transfer from the more to the less massive components, or mass and angular momentum loss (AML) from the systems. According to the AML theory, on the contact stage, the orbital AML is mainly caused by the mass transfer from the less to the more massive component and the mass ratio decreasing and orbital period gradually increasing are the corresponding results. The extremely low mass ratio and orbital angular momentum of the two systems show that they are evolved via AML and the present secular decrease in the periods may suggest that the magnetic activity in the two systems are very strong. The relation between the changes of the orbital periods and the magnetic activity in the two systems are discussed. We think that the interplay between the variable AML and variable magnetic coupling can explain both the jumps and secular decrease in the orbital periods of the two systems.

Key words: stars: binaries: close – stars: individual: TZ Boo – stars: late-type – stars: magnetic fields – stars: individual: Y Sex

1. Introduction

TZ Boo and Y Sex are two A-type contact binaries with an extremely lower mass ratio (Maclean & Hildith 1983). Table 1 lists the parameters (in solar units) of the two binaries given by Kaluzny (1985). As we can see in Table 1, the mass and radii of the two components, the mass ratio q and the orbital inclination i of the two systems are almost equal, which indicates that their physical properties are nearly the same. These almost identical physical properties of the two contact binaries and their extremely lower mass ratio and orbital angular momentum make them two very interesting systems. In the present paper, we study the variations in the orbital periods of the two systems.

Table 1. Parameters for TZ Bootis anf Y Sextantis

name	M_1	M_2	R_1	R_2	q	i	P(days)
TZ Boo	0.65	0.09	0.94	0.37	0.13	78°	0.297
Y Sex	0.68	0.13	1.17	0.53	0.18	77°	0.420

TZ Boo was detected as an eclipsing variable by Guthnick and Prager in 1927. Since its discovery, it has been frequently observed (e.g., Binnendijk 1969; Carr 1971; Güdür et al. 1976; Hoffmann 1978, 1980a,b, 1981; Al-Naimiy 1982; Awadalla 1989 and others). The peculiar behavior of the light curve is the cyclic nature of the variations in the depth of both minima (Hoffmann 1980a; Awadalla 1989). Epochs and periods of the system have been given by various authors. Wolfschmidt et al. (1979) found a "U shaped" O-C curve, indicating a continuous period change; Hoffmann (1980b) suggested, however, that the "V shaped" O-C diagram cannot be ruled out, indicating an abrupt period change; Later, Lipari & Sistero (1987) pointed out that the orbital period shows a cyclic variation with a period of 30 years; Grobel (1989) confirmed Hoffmann's (1980b) conclusion, and suggested that a marked period shortening took place in 1977/78, he also suspected that another period change took place around the year 1968. The O-C curve formed by the new collected minima shows a period increase has been occurring recently, implying some complexity to the period change.

Y Sex is another W UMa-type contact eclipsing binary with orbital period 0.4198 days, discovered by Hoffmeister and classified as "short period" variable in 1934. Later, the system was observed by several authors (e.g. Prikhodko 1947; Gaposchkin 1953; Tanabe & Nakamura 1957; Hill 1979; Yang & Liu 1982; and others). Payne-Gaposchkin (1952) pointed out the orbital period of the system is variable. Although the orbital period has been studied by Herczeg (1993), the system is neglected for period study.

Send offprint requests to: Shengbang Qian

* Table 2 and Table 4 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strabg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

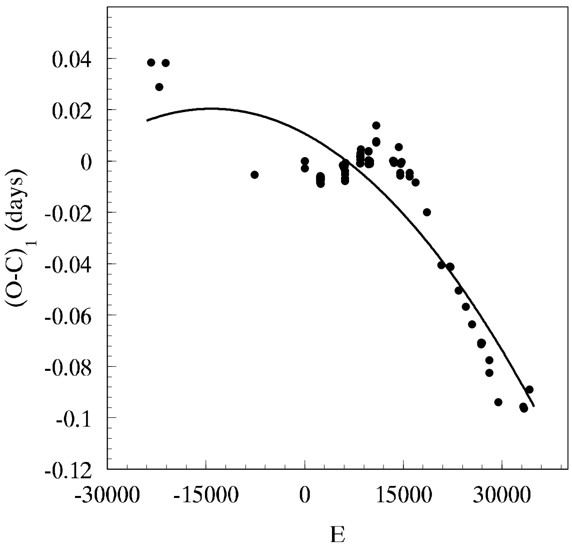

Fig. 1. The O-C curve of TZ Bootis from Hoffmann's (1980a) ephemeris. The solid line is its description by a quadratic fit.

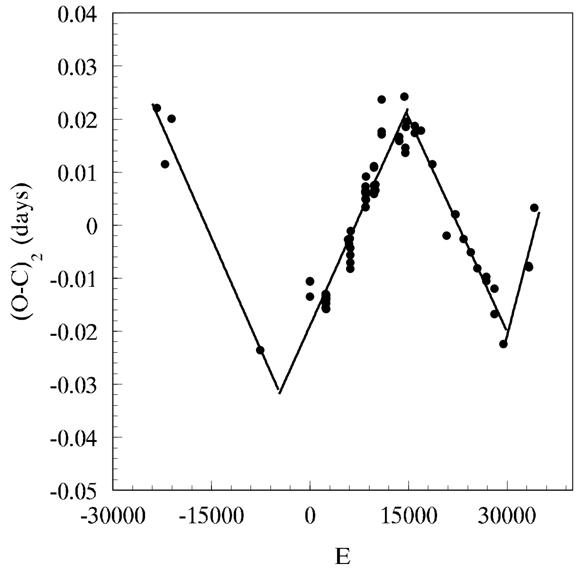

Fig. 2. Residuals of TZ Bootis from the quadratic ephemeris and their description by several linear ephemerides

2. Changes in the orbital period of TZ Boo

In order to study the variations in the orbital period, various published times of light minima of the contact binary are collected and listed in the first column of Table 2. In all, 82 timings of TZ Boo have been compiled. Fortunately, except for three, the others are photoelectric ones. In order to see the general behavior of the variations in the period of the system, the $(O-C)_1$ values of these minima, which are based on the following ephemeris:

$$MinI = 2439632.8418 + 0.^{d}2971620 \times E \quad (1)$$

given by Hoffmann (1980a), are calculated. These $(O-C)_1$ values are listed in the fourth column of Table 2 and presented graphically against epoch number in Fig. 1. The first visual minimum 2424609.241 given by Guthnick and Prager (1927) is not used in the period analysis and not shown in Fig. 1, because the time interval between the minimum time and the others is very long.

As displayed in Fig. 1, the general trend of the $(O-C)_1$ diagram may show a parabolic variation indicating a long-time decrease in the orbital period. The second-order least-squares solution of the $(O-C)_1$ values yield the following ephemeris:

$$MinI = \underset{\pm 4}{2439632.8525} + \underset{\pm 7}{0.29716063} \times E - \underset{\pm 3}{4.8} \times 10^{-11} \times E^2 \quad (2)$$

and a rate of decrease in the period: $dP/dE = -9.6 \times 10^{-11}$ days/cycle $= -1.18 \times 10^{-7}$ days/year. The secular decrease only indicates the general trend of the $(O-C)_1$ diagram without describing any particular characteristics.

All the times of light minimum used in this analysis are examined. Although three timings, epochs less than 5000, are visual, their O-C values can correspond with those of the photoelectric timings near them. The mean errors of some photoelectric times of light minmum have been given by the original authors (e.g., Lipari & Sistero 1987; Schaub 1990; Agerer & Hubscher 1995, 1996) and the values of the errors are not larger than $0.^{d}0009$. As shown in Fig. 1, the scatters of the photoelectric minima are generally within $0.^{d}005$, which is rather large for photoelectric observations. This scatter, as discussed by Maceroni & Van't Veer (1994) in other contact binaries such as YY Eri, may result from a possible asymmetry of the minima due to dark spots on the surface (Van't Veer 1973; Maceroni & Van't Veer 1994). However, we note that such a scatter would not affect the general long-time pattern of the period variation and the quadratic ephemeris can give a good fit to the general trend of the O-C curve.

The $(O-C)_2$ residuals from the quadratic ephemeris are also listed in Table 2 and displayed in Fig. 2. The $(O-C)_2$ values in Fig. 2 clearly suggest that their variations are not continuous, which demonstrates that apart from the secular decrease, three jumps have taken place in the period of TZ Boo within a time interval of 47 years between the middle 1948 and early 1995. Between these jumps the period is assumed to have undergone a steady decrease. With the method of least square, a linear function in each portion is used to get the best fit to the $(O-C)_2$ values:

$$(O-C)_2 = \Delta T + \Delta P \times E. \quad (3)$$

The values of ΔT and ΔP in each portion are listed in Table 3. The period at any cycle E have been computed with the following equation:

$$P(E) = Pe + \Delta P - dP/dE \times E \quad (4)$$

and the results are shown in Fig. 3, where we have plotted the difference between the real period P(E) and the ephemeris period Pe (0.297162 days) in units of 10^{-6} d as a function of time.

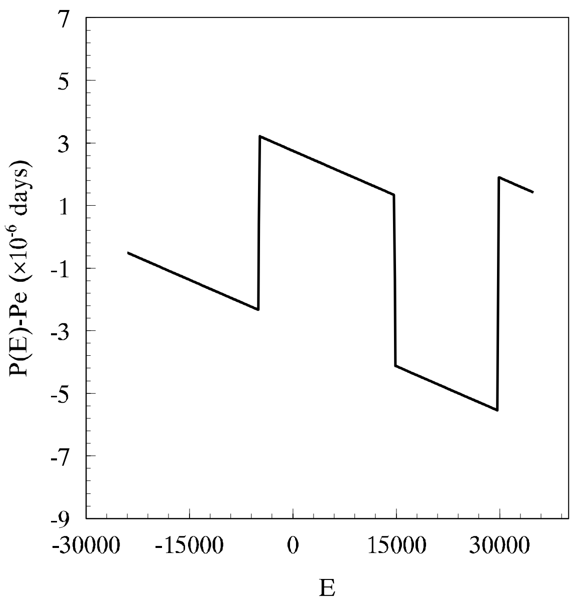

Fig. 3. Changes in the orbital period of TZ Bootis

Table 3. Several jumps in the orbital period of TZ Bootis

Interval of cycles	ΔT (days)	ΔP (10^{-6} days)
-24000 to -4800	-0.0446(89)	-2.81(45)
-4800 to 14800	-0.0190(9)	+2.75(12)
14800 to 29800	+0.0607(30)	-2.69(13)
29800 to 34900	-0.1639(367)	+4.77(113)

3. Changes in the orbital period of Y Sex

As for Y Sex, 45 times of light minima are collected, but starting with the first available photoelectric timing, only photoelectric times are shown in Table 3 and are used for its orbital period study. Although the first three are photographic or visual minimum timings, they are the mean values of several timings and are reliable. With the following ephemeris given by Herczeg (1993):

$$Min I = 2434445.9912 + 0.^{d}41981391 \times E \quad (5)$$

the $(O - C)_1$ values of these minima have been computed. These values are listed in the fourth column of Table 4 and are displayed in Fig. 4. The types of some minima obtained from Besancon Data Base by Internet and from IBVS 4562, 4606 are misleading, because their O-C values show very large deviation from the general O-C trend formed by other points, so the types of these minima are corrected.

As shown in Fig. 4, the general trend of the $(O-C)_1$ values also show a parabolic variation. With the least squares method, we obtain the following quadratic light elements:

$$Min I = 2434445.9786 + 0.41981527 \times E + 3.14 \times 10^{-11} \times E^2$$
$$\pm 1 \qquad \pm 2 \qquad \pm 2 \quad (6)$$

and a rate of decrease in the period: $dP/dE = -6.28 \times 10^{-11}$ days/cycle $= -5.5 \times 10^{-8}$ days/year. The $(O - C)_2$ residuals from the quadratic ephemeris are also listed in Table 4 and plotted in Fig. 5. As is in the case of TZ Boo, apart from the secular decrease, six jumps have also occurred in the period of Y Sex within an interval of 63 years between late 1935 and early 1998. Between these jumps the period is assumed to have undergone a steady decrease. With the same method used for TZ Boo, the jumps in the orbital period of Y Sex have been determined and listed in Table 5. The changes in the orbital period are plotted in Fig. 6.

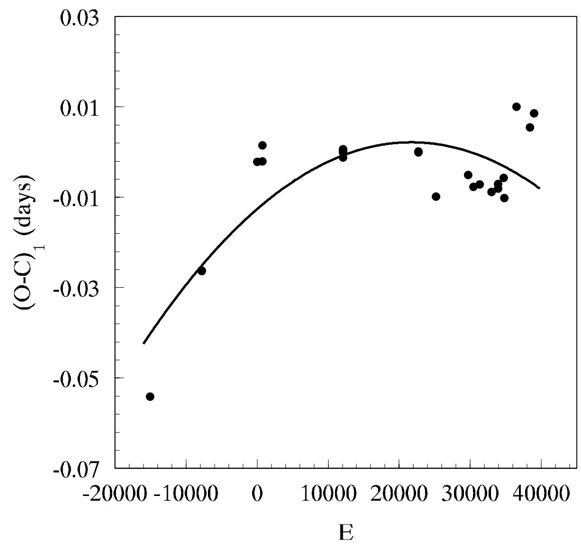

Fig. 4. The O-C curve of Y Sextantis from Herczeg's (1993) ephemeris. The solid line refers to its description by a quadratic fit.

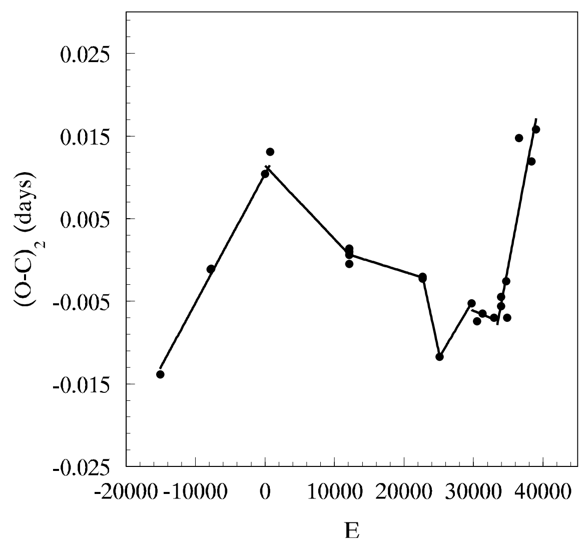

Fig. 5. The same as Fig. 2 for Y Sextantis.

4. Discussion and conclusion

The orbital periods of the two contact binaries TZ Boo and Y Sex, with the nearly same physical properties, are investigated. It is shown that the periods of the two system show the same kind of changes. Several jumps are superposed on the secular

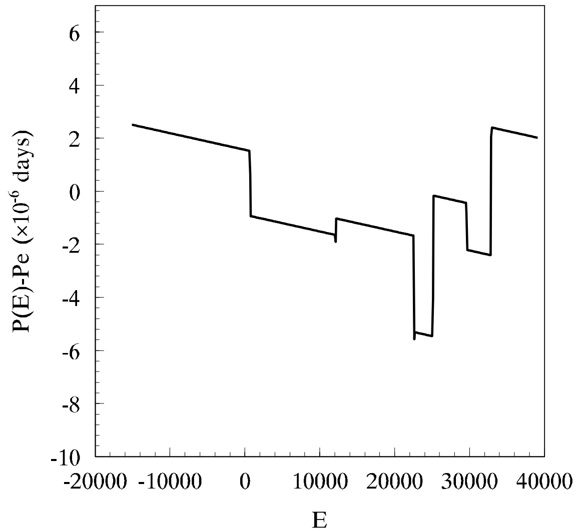

Fig. 6. The difference $P(E) - P_e$ of Y Sextantis as a function of time.

Table 5. Several jumps in the orbital period of Y Sextantis

Interval of cycles	ΔT (days)	ΔP (10^{-6} days)
-15100 to 700	+0.0104(7)	+1.56(5)
700 to 12100	+0.0114(59)	-0.89(9)
12100 to 22600	+0.0038(9)	-0.26(6)
22600 to 25100	+0.0861(10)	-3.89(4)
25100 to 29700	+0.0473	+1.42
29700 to 33000	+0.0044(127)	-0.35(41)
33000 to 39000	+0.1572(328)	+4.47(91)

decrease ($dP/dE = -11.8 \times 10^{-8}$ days/year for TZ Boo and -5.5×10^{-8} days/year for Y Sex).

The secular decrease components in the periods of the two systems might be the result of mass transfer from the more massive to the less massive components. If the mass transfer is conservative (with no magnetic effect), with the following well-known equation:

$$\Delta P/P = 3(M_1/M_2 - 1)\Delta M_1/M_1 \quad (7)$$

we determine the mass transfer rates would be $dM/dt = 1.4 \times 10^{-8}\, M_{\odot}/year$ for TZ Boo and $dM/dt = 1.2 \times 10^{-8}\, M_{\odot}/year$ for Y Sex.

The mass and angular momentum loss due to magnetic braking can also cause the secular decrease in the periods of TZ Boo and Y Sex. A rather general form of the braking torque, used in the literature (as described by Vilhu 1991 in detail), is:

$$dJ/dt = -1.0 \times 10^{42} K^2 f^{-2} M R^{\gamma} P_3^{-\alpha}. \quad (8)$$

In this equation, M and R are the mass and the radii of the components, and P_3 is the orbital periods (unit in 3 days). Take the parameters: $K^2 = 0.1$, $\gamma = 4$, and $\alpha = 3$, together with the values of f determined by the following equation given by Vilhu (1991):

$$f = (3.3 - 2.3m)^{-1} \quad (9)$$

we computed the angular momentum loss from the primaries of the two systems are -1.73×10^{44} for TZ Boo and -1.40×10^{44} $g.cm^2.esc^{-1}.year^{-1}$ for Y Sex. The corresponding decrease rates in periods are estimated to be -9.5×10^{-8} and -6.7×10^{-8} days/year for the two contact binaries respectively, which are nearly close to the observed decrease rate -11.8×10^{-8} and -5.5×10^{-8} days/year. These results suggest that the magnetic breaking mechanism can explain the decrease components in orbital periods of the two contact binaries.

Several authors (Van't Veer 1979; Rahunen 1981; Vilhu 1982; Runcinski 1985; Guinan & Bradstreet 1988; Hilditch et al. 1988; Van't Veer & Maceroni 1989 and others) have recognized more and more that magnetic fields play an important role for the dynamical evolution of close late-type binaries. The magnetic torque could not only bring together the separate components of a detached binary but also cause contact binaries to tend toward more extreme q's until they finally coalesce into rapidly rotating single stars. According to the AML theory, on the contact stage, the orbital AML are mainly caused by the mass transfer from the less to the more massive component and the mass ratio decrease and orbital period gradually increase are the corresponding results. The extremely low mass ratio and orbital angular momentum of TZ Boo and Y Sex show that they are evolved via AML. The present secular decrease in the period of the two systems may suggest that the magnetic activity of the two systems are quite strong. Their strengths are evidently sufficient to overcome any opposing effects such as mass exchange which may cause the period otherwise to increase. Apart from the orbital periods, the other parameters of the systems are nearly the same. The orbital period of TZ Boo ($P = 0.297162$ d) is less than that of Y Sex ($P = 0.41981391$ d), which suggests that the magnetic activity of TZ Boo is stronger than that of Y Sex, since dynamo produced magnetic fields increase with the stars rotational velocity. This can coincide with the present observed decrease rates of the periods in the two systems (i.e. the decrease rate of TZ Boo ($dP/dE = -11.8 \times 10^{-8}$ days/year) is larger than that of Y Sex ($dP/dE = -5.5 \times 10^{-8}$ days/year)).

The change of the orbital period in TZ Boo has been explained by Liparo & Sistero (1987) as light-times effect of a third body. But as displayed in Fig. 2, the residuals from the quadratic ephemeris (2) do not show a continuous variation, so the presence of the third body is not a reasonable mechanism caused the change in the orbital period.

In order to explain the alternating change in the orbital period, the magnetic activity was considered as the driving mechanism for angular momentum distribution and hence the orbital period change. This mechanism has been recently improved by Applegate (1992). According to Applegate's model, the luminosity variation is required to have the same period as that of the orbital period. Hoffmann (1980a) and Awadalla (1989) reported that the differences of the transit and occultation minima magnitudes vary with a period of 3.5 and 4.1 years. But the interval of the period jumps is about of 12 - 16 years. The alternating in the orbital period of TZ Boo may not be caused by Applegate mechanism. The alternating in the orbital period of Y Sex is in a random way. This magnetic activity cycle mechanism also has difficulty in explaining the random jumps in the period.

The changes, both secular decrease and jumps, in the orbital periods of TZ Boo and Y Sex can be explained by interplay between variable AML and variable magnetic coupling. As pointed out by Van't Veer (1993), when the coupling is strong AML will in the first phase slow down the locked binary (P increase), which is contrary to the AML law. However in a second phase angular momentum redistribution will readjust the system with a smaller period according to the new AM content of the binary. Generally, the orbital periods of the two systems show secular decrease via AML. When magnetic fields are variable, or the magnetic coupling is variable, the jumps in the orbital period take place. These need further study.

Acknowledgements. Many thanks are given to Prof. F. Van't Veer for his useful comments and suggestions. The author also would like to express his gratitude for the support from the Chinese National Science Foundation.

References

Agerer F., Hubscher J., 1995, IBVS 4222
Agerer F., Hubscher J., 1996, IBVS 4383
Agerer F., Hubscher J., 1998a, IBVS 4562
Agerer F., Hubscher J., 1998b, IBVS 4606
Al-Naimiy H.M.K., 1982, AJ 87, 104
Applegate J.H., 1992, ApJ 385, 798
Awadalla N.S., 1989, Ap&SS 162, 211
Binnendijk L., 1969, AJ 74, 211
Carr R.B., 1971, Publ. of the Godsell Obs. No. 16
Dueball J., Lehmann P.B., 1965, Astron. Nachr. 288, 167
Gaposchkin S., 1953, Harvard Ann. 113, No. 1
Grobel R., 1989, IBVS No. 3299
Güdür N., Ibaňoglu C., Gülmen O., Bozkurt S., 1976, IBVS No. 1086
Guinan E.F., Bradstreet D.H., 1988, In: Dupree A.K., Lago M.T.V.T. (eds.) Formation and Evolution of Low Mass Star. Kluwer Acad. Publ., p. 345
Guthnick P., Prager R., 1927, Kl. Veröff. Berlin-Babelsberg No. 4, 8
Herczeg T.J., 1993, PASP 105, 911
Hilditch R.W., King D.J., McFarlane T.M., 1988, MNRAS 231, 341
Hill G., 1979, Publ. Dom. Astrophys. Obs. Victoria 15, 297
Hoffmann M., 1978, A&As 33, 63
Hoffmann M., 1980a, A&As 40, 263
Hoffmann M., 1980b, IBVS No. 1877
Hoffmann M., 1981, IBVS No. 1980
Kaluzny J., 1985, Acta Astron. 35, 313
Keskin V., Pohl E., 1989, IBVS No. 3355
Kizilirmak A., 1974, IBVS No. 937
Koch R.H., 1956, AJ 61, 47
Koch R.H., 1961, AJ 66, 35
Lipari S.L., Sistero R.F., 1987, AJ 94, 792
Maceroni C., Van't Veer F., 1994, A&A 289, 871
Maclean B.J., Hilditch R.W., 1983, MNRAS 203, 1
Payne-Gaposchkin C., 1952, Harvard Ann. 118, No. 1
Pohl E., Tunca Z., Gulmen O. and Evren S., 1978, IBVS No. 1924
Pohl E., Gulmen O., 1985, IBVS No.2793
Prikhodko A., 1947, Perem. Zvezdy 6, 136
Rahunen T., 1981, A&A 102, 81
Rucinski S.M., 1985, In: Eggleton P.P., Pringle J.E. (eds.) Interacting Binary stars. D. Reidel Publ. Co., p. 85
Schaub D., 1990, IBVS No. 3524
Szafraniec R., 1953, Roczn. Astron. Obs. Krakow No. 24, 72
Szafraniec R., 1957, Roczn. Astron. Obs. Krakow No. 28, 107
Szafraniec R., 1962, Acta Astron. 12, 181
Tanabe H., Nakamura T., 1957, Ann. Tokyo Astro. Obs., 2nd Ser., 5
Van't Veer F., 1973, A&A 26, 357
Van't Veer F., 1979, A&A 80, 287
Van't Veer F., 1993, ASP Conference Series Vol. 38, 229
Van't Veer F., Maceroni C., 1989, A&A 220, 128
Vilhu O., 1982, A&A 109, 17
Vilhu O., 1991, IAU Symposium No. 151, 61
Wolfschmidt G., Rahe J., Schoffel E., 1979, Mitt. Astron. Ges. 45, 49
Wunder E., Wieck M., Kilinc B., et al., 1992, IBVS No. 3760
Yang Yulan, Liu Qingyao, 1982, IBVS No. 2202