Publ. Astron. Obs. Belgrade No. 80 (2006), 107 - 116 *Invited lecture*

PERIOD CHANGES OF CLOSE BINARIES AND METHODS OF ANALYSIS OF THE $(O-C)$ DIAGRAMS OF ECLIPSING BINARIES

HELEN ROVITHIS-LIVANIOU

Section of Astrophysics, Astronomy & Mechanics, Dept. of Physics, Athens University, Panepistimiopolis, Zografos 157 84, Athens, Greece
E–mail: elivan@cc.uoa..gr

Abstract. In this short review the mechanisms that are capable to produce orbital period changes in close binaries are referred, and the relations connecting them with the binaries elements are presented. Moreover, since the study of the period changes is based on the $(O-C)$ diagrams of eclipsing binaries, their analyses methods are referred, too. Finally, a general discussion is given.

1. INTRODUCTION

The subject of the orbital period changes of close binaries is very important, since it is related to their formation, structure and evolution. At the same time it is not simple at all, but on the contrary this is a very difficult task.

Various theories have been developed to explain the origin of orbital period changes. Strictly periodic and of alternating sign period changes, for example, can be caused by apsidal motion or by the presence of a third body in the close pair. They are also referred to as *apparent* changes to be distinguished from the *real* ones due to other reasons. The orbital period changes produced by apsidal motion are easily recognizable from those due to the light-time effect, since in the first case the primary and secondary minima behave differently.

Various mechanisms have been proposed so far to explain real period changes in close binary systems. Mass and angular momentum transfer and/or loss -based on different causes were the first to be considered, (e.g. Huang, 1956; Landau and Lifshitz, 1965; Piotrowski, 1964; Kruszewski, 1966 etc.). Later, magnetic activity cycles were added to them, too, (e.g. Applegate and Patterson, 1987; Applegate, 1992).

Our knowledge of period changes in close binaries is mainly -and almost exclusively-based on eclipsing binaries, and especially on their $(O-C)$ diagrams analysis. Thus, the aim of this short review is -passing very briefly through the proposed mechanisms that with their action are able to produce orbital period variations in close binariesfirstly to mention some of the proposed so far ($\dot{m} - \dot{P}$) relations and secondly to refer the methods used to analyze the ($O - C$) diagrams of eclipsing binaries.

2. THEORETICAL ASPECTS

Binary components lose or gain mass and angular momentum in a manner that is controlled by the Roche geometry, because of the existence of an upper limiting volume around a star being member of a binary system. The speed with which the stars react to such changes is important, too.

From Kepler's third law:

$$P^2 = \frac{4\pi^2\alpha^3}{G(m_1 + m_2)} \tag{1}$$

it is evident that a *real* change in the period must imply a change of either the major semi-axis, α, or of the total mass of the system, $(m_1 + m_2) = M_{tot}$, or of both.

And if α remains constant, $\frac{\Delta m}{m} = -2\frac{\Delta P}{P}$; but this assumption can be valid only if the system loses mass isotropically, which is extremely rare, if happens at all.

Mass and angular momentum transfer and/or loss were, thus, the first proposed mechanisms to explain the observed period changes. Both of them can either increase or decrease the period of a binary system. And it was very early shown (e.g. Huang, 1956; Piotrowski, 1964) that transfer of mass between the two components could be more efficient in changing the period of a binary than could be the loss of mass from the system. Moreover, according to Kruszewski (1966) the effect of mass transfer depends on the direction of flow within the binary, while that of mass loss depends on the direction of speed of the escaping mass.

Mass and angular momentum transfer and/or loss can be achieved through stellar wind, via the second Lagrangian point L_2, or through a process in which when one of the two components of the binary fills its Roche lobe, matter will be transferred through the inner Lagrangian point L_1 to its mate, (i.e. Roche lobe over flow, RLOF), if we are restricted to usual cases, and not to sudden catastrophic events like novae or supernovae.

The originally more massive star (primary) will evolve faster, so it will be the first to expand and fill its Roche lobe. Depending on the evolutionary stage of the mass-losing star there are various outcomes. A very simple case, i.e. is that in which the primary loses big amounts of mass to the secondary, so that they will finally change their roles; (in which case the mass transfer will be now from the secondary towards the primary component).

Conservative mass transfer was the simplest case to be originally considered. In this case all mass lost by one component was gained by its mate, i.e. $dm_1 = -dm_2$. So the total mass of the binary is conserved, i.e. $m_1 + m_2 = M_{tot} = constant$, together with the total orbital angular momentum. If, moreover q denotes the two components mass ratio, and $\dot{m}_1$ the mass transfer, it is easy to show that:

$$\frac{\dot{P}}{P} = \frac{3\dot{m}_1(m_1 - m_2)}{m_1 m_2} = 3\frac{1-q^2}{qM_{tot}}\dot{m}_1 \tag{2}$$

that is the orbital period change is proportional to the mass transfer.

The term $(m_1 - m_2)$, on the right hand side of Eq. (2), can be either positive or negative, and thus the period increases or decreases, depending towards which of the two components the mass is transferred. According to several authors i.e. the components of contact binaries are not in thermal equilibrium and can exchange matter between themselves. And when the total mass and angular momentum are conserved, the system oscillates and undergoes cycles -known as TRO- around the marginal contact state, (e.g. Lucy, 1976; Flannery, 1976; Robertson and Eggleton, 1977). Some others considered that AML by magnetic braking plays an important role in the evolution of contact binaries, (e.g. van't Veer, 1979; Vilhu, 1982; van't Veer and Maceroni, 1989 etc.); while Rahunen (1981) showed that a critical AML can keep *W UMa*-type binaries in shallow contact that avoids the break of contact predicted by the TRO theory.

Regarding stellar wind-driven mass-loss rates in binaries, they depend on the components spectral types and their evolutionary status. A general review can be found in Hilditch (2001).

The simplest presentation for mass loss due to a wind is to consider it shperically symmetrical, which does not interact with its companion. In such a case, differentiating Kepler's third equation, we get a simple relation for the orbital period changes:

$$\frac{\dot{P}}{P} = \frac{-2\dot{m}_1}{m_1 + m_2} \tag{3}$$

Tout and Hall (1991) considered enhanced stellar winds for binaries revolving in circular orbits, because it was found that the evolved component of a binary just before becoming a semi-detached *Algol*-type system loses its mass at a rate 2 or 3 orders of magnitude greater than the conservative case B evolution nuclear rate. In this case, the final relation for the period changes and the rates of mass transfer and loss are:

$$\frac{\dot{P}}{P} = -\frac{2\dot{m}}{m_1 + m_2} - \frac{3\dot{m}_2(m_1 - m_2)}{m_1 m_2} + 3K \tag{4}$$

where $\dot{m}_1$ is the mass loss rate by the donor, $\dot{m}_2$ is the rate of mass gained by the other star, and $\dot{m} = \dot{m}_1 + \dot{m}_2$ is the rate of mass lost from the system. Using quantitative estimates Tout and Hall (1992) found that the mass transfer rate and the mass loss rate are similar.

Eq. (4) gives the previous results for the conservative mass transfer via RLOF, when $\dot{m} = K = 0$ and $dm_1 = -dm_2$, while the last term K, on its right-hand side, permits to introduce an additional mechanism for AML, which might be via magnetic braking (e.g. Skumanich, 1972; Maceroni, 1992), or by gravitational-wave radiation, GWR, (Landau and Lifshitz, 1965). Both GWR and AML will reduce the orbital period of a binary.

All $(\dot{m} - \dot{P})$ relations proposed so far were developed under special conditions or particular phases of binaries evolution. Very recently, Kalimeris and Rovithis-Livaniou (2005), proposed a more general relation. Starting from the total angular momentum of the binary, that is from equation:

$$J = J_{orb} + J_1 + J_2 = \mu\sqrt{(1-e^2)}D^2\Omega + \sum_{i=1}^{2} m_i k_i R_i^2 \omega_i \tag{5}$$

where D and Ω are the orbital radius and the angular velocity; R_i, ω_i and k_i^2 are the radius of the equivalent volume, the spin velocity and the dimensionless gyration radius of the i-component, respectively; and μ denotes the ratio: $\mu = \frac{m_1 m_2}{M_{tot}}$, which is also expressed as: $\mu = \frac{qm_1}{1+q} = \frac{m_2}{1+q}$. And it was finally found that:

$$\begin{aligned} \frac{\dot{J}}{J_{orb}} &= \left[\frac{1-q}{M_2}\dot{M}_2 + \frac{2q+3}{3qM}\dot{\mu}_l - \frac{e}{1-e^2}\dot{e} + \frac{\dot{\Omega}}{\Omega} + \frac{4}{3}\frac{\dot{P}}{P} + \right] \\ &+ \sum_{i=1}^{2} \frac{J_i}{J_{orb}} \left(5\frac{\dot{R}_i}{R_i} + \frac{\dot{\omega}_i}{\omega_i} + \frac{\dot{I}_{N,i}}{I_i}\right) \end{aligned} \tag{6}$$

where $I_{N,i}$ is the normalized moment of inertia of the i-component, given by: $I_{N,i} = \int_0^1 \rho_i(x) \cdot x^4 \, dx$.

Depending on the evolutionary state of each binary, some terms of Eq. (6) can be ignored as being too small, while others can be estimated theoretically or through semi-empirical relations. Thus, under certain assumptions both Eqs. (2) and (4) can be reproduced from (6).

Another mechanism that could cause orbital period changes in close binaries is magnetic activity cycles in one -or even both- of its components. Because, a variable quadrupole moment produced by magnetic activity in the outer convection zone of one of the components of a close binary can cause orbital period changes on a short time scale, of the order of a few years or decades, (Applegate and Patterson, 1987). Similarly, the magnetic field of a star could produce angular momentum transfer among its internal and external layers, which could vary its quadrapole moment and cause orbital period changes, (Applegate, 1992). His model requires variability at the $\Delta L/L \sim 0.1$ level and a variable differential rotation of $\Delta\Omega/\Omega \sim 0.01$ to explain an orbital period modulation of the order of $\Delta P/P \sim 10^{-5}$. It is now believed that in solar-type stars there are two dynamos in action. One is in the convection zone producing aperiodic small-scale fields, and the other one in the weakly turbulent overshoot layer -just below the convection zone- where the strong periodic cycle fields are generated (Hoyng, 1996). As a result, semi-regular or quasi-periodic period changes of close binaries, with a solar-type component, are generally attributed to cycles of magnetic activity, although there are some observational criteria of Applegate's mechanism, which are not always fulfilled. And recently, Rüdiger et al. (2002) examined whether dynamo-degenerated fields are able to produce such quadrupole terms in the gravity potential, which can explain the observed cyclic orbital period changes of *RS CVn*-type active binaries.

3. KNOWLEDGE FROM THE OBSERVATIONS

3. 1. ABOUT THE $(O - C)$ DIAGRAMS

The minima of light of an eclipsing binary are by definition expected to occur when the apparent separation of the centers of its components becomes minimum. The time at which a minimum is expected to occur is given by this formula: $MinI = t_o + PE$ known as the ephemeris of the binary star; where t_o is the time when a minimum was originally observed and E, the Epoch, denotes the number of cycles passed from t_o.

If P is constant, the time at which a primary minimum occurs (observed time, symbolized by O) will coincide with that predicted by its appropriate ephemeris formula. That is, with the so-called calculated minimum, (C). If P varies, the time of an observed minimum will differ from that of the calculated one. In such a case the difference $O - C$ is not equal to zero and in this way an $(O - C)$ diagram is build up. So, the $(O - C)$ diagrams of eclipsing binaries are used to study their orbital period changes. Thus, the way, in which such a diagram is constructed and analyzed, is important.

The main problems in the construction of an $(O-C)$ diagram are the quality of the observational material and the time interval they cover. Because, long time intervals together with very small orbital periods (mainly for contact binaries), might yield wrong results and conclusions, (Rovithis-Livaniou, 2001). Moreover, since the values of the $C's$ are calculated according to an ephemeris formula, the $(O - C)$ diagrams shape strongly depends on it, (e.g. Rovithis-Livaniou, 2003). For this reason, some investigators use different ephemeris formulae to "detect" the existence of a possible hidden periodic term.

3. 2. ANALYSIS METHODS OF THE $(O - C)$ DIAGRAMS

Almost all old methods used to analyze the $(O - C)$ diagrams of close binaries are problematic. To be more specific: the main problems of the old analysis methods -linear and piecewise approximation, or step variation- is that the period is assumed to be **constant** for a time interval, and then to change suddenly. In such a case the $(O - C)$ diagram was divided into a number of small linear segments, each one of which was interpreted by a different linear ephemeris, (e.g. Yamasaki, 1975; Kreiner, 1977). Although sudden phenomena can not be excluded, using a method as described above, both the number of segments and the choice of time are not objective, (e.g. Sterken, 2000).

Another old technique is the quadratic approximation -the well known parabola fitting-in which the period varies with a constant rate. This might describe well the $(O - C)$ diagrams of some binaries (e.g. of $RTAnd$, Rovithis-Livaniou et al., 1994), but it is not appropriate for all of them (i.e. for $AHVir$, Kalimeris et al., 1994; or $TUHer$, Rovithis-Livaniou et al., 2002, etc.).

The sinusoidal variation and the combined descriptions -assuming light-time effect and/or apsidal motion can be valid and pretty good for some systems', too, but generally they don't. Because, they describe the observed orbital period variations of a binary system in a pre-defined way. And since an $(O-C)$ diagram's shape depends on the ephemeris used, in general they are not able to describe another $(O-C)$ diagram for the same binary that has taken a different form, (because another ephemeris was used for its construction), using the same sinusoidal term. More details are given in Rovithis-Livaniou et al. 2005.

Fortunately, during the last $(10 - 11)$ years a few new techniques were suggested, i.e. by Kalimeris et al. (1994), Jetsu et al. (1997), and Koen (1996); the latter being a statistical method. The first two analysis methods are characterized as *continuous*, because in both the orbital period and its rate of change are considered to be continuous functions of time. Their difference is that in the first case the analysis is made in the time domain, while in the second one it is carried out in the frequency domain. In both continuous methods, the orbital period changes for a close binary are calculated with a simple and accurate mathematical procedure, and they are not affected by the ephemeris used for the description of the $(O - C)$ diagram. Many systems have been analyzed by using the Kalimeris et al. (1994) method. More details and comparison of the methods of analysis of the $(O - C)$ diagrams are given in Rovithis-Livaniou (2001).

Very recently Tsantilas and Rovithis-Livaniou (2005), described the observed orbital period changes of an active close binary by a variable sinusoidal term. This new approach is not considered as a new analysis method, but it is mentioned since it is able to explain the **different periodicities** detected for the **same binary** by the various investigators. And assuming that the orbital period variations are due to magnetic activity **only** - as expressed through Applegate's (1992) formalism- offers the possiblility to find the variation of the magnetic field for the active star.

4. DISCUSSION

As has been mentioned, eclipsing binaries are used to study the orbital period changes of close binaries analyzing their $(O - C)$ diagrams, because the photometric observations of their minima can be timed with high accuracy. And according to Watson and Dhillon (2004) the *(O-C)* measurements can be especially accurate for close binaries where a compact object such as a WD is eclipsed, since these provide sharp eclipse transitions.

Observations have shown that in general there are small but definite changes in the orbital periods of close binaries due to various reasons. Since, i.e., the periastron of the relative orbit of a close binary can be changed - because of the tidal interaction of the two components, or the presence of a third body in the close pair-, these phenomena were very early considered as capable to produce orbital period changes, (e.g. Slavenas, 1927; Martynov, 1948; Kopal, 1959, etc.).

The presence of a third body in a close binary, except its affection to the periastron of the close pair orbit, also produces a periodic change of its center of mass as it is observed from the Earth. As a result there is either a delay or advance in the time when a minimum is expected, (e.g. Irwin, 1959; Martynov, 1973). All these effects have been extensively investigated in the past as well as recently (e.g. Mayer, 1990; Claret and Giménez, 1993; Eggleton et al., 2005). In all of these cases the $(O - C)$ diagrams exhibit a *strictly periodic* sinusoidal *apparent* period variation.

On the other hand, the expected monotonic *apparent* period changes of close binaries because of their curved orbits around the center of our Galaxy (Kordywski, 1965), found to be smaller than the uncertainties of the observational material used, (Kreiner, 1977).

Some investigators attributed orbital period changes to stellar spots, because star spots can change the time of a minimum; but Kalimeris et al. (2002) showed that the star spots do not cause any real period change. Similarly, depressed star-spots can cause a jitter in the residuals of *(O-C)* diagrams which can also result in the false detection of spurious orbital period changes. Such changes resulting from star-spots would be distinguishable from other mechanisms that cause period changes, (Watson and Dhillon, 2004).

The analysis of the observational data shows that most of the *periodicities* detected by various investigators might not be real (e.g. Rovithis-Livaniou et al., 2000; Rovithis-Livaniou, 2005). In spite of this fact the detected periodic terms are attributed to the presence of a third body in the close pair. And recently there is a tendency to consider that all contact binaries are triples. This is quit strange considering the *different periodic terms* found for the *same binary* by various investigators. The new approach proposed by Tsantilas and Rovithis-Livaniou (2005) possibly offers an explaination to this.

Similarly, periodic or quasi-periodic period changes are considered as being a result of the magnetic activity cycles, or *Applegate's mechanism.* But the analysis of the $(O - C)$ diagrams of some close binary systems that cover some decades show that both the amplitude and the P_{mod} of this "periodic" or "quasi-periodic" term are not repeated, but go on -in most of the examined cases- with a more or less damping way, (Rovithis-Livaniou, 2005).

Causes of *real* orbital period changes of close binaries can be mass and angular momentum transfer and/or loss due to a variety of mechanisms. Each one of these acting on different time scales, and producing *short* or *long*-term orbital period changes. According to Maceroni (1999), i.e., orbital period changes due to AML would be observable with certainty over a time span of a century. TRO cycles models, on the other hand, predicted that the variation of the orbital period must be in the thermal time scale.

Moreover, mass and angular momentum transfer and/or loss rates are different, depending on the two components type, evolutionary status, or special conditions. They have been found for specific cases only, and mostly in synchonized circular binaries; while, little has been done for the cases of eccentric systems. Average mass transfer rates have been derived for Algols, (Hall and Neff, 1976), and for CVs, (King and Watson, 1987); while Taam (1983) considering the influence of AML on the evolution of low-mass binaries with collapsed companions, found that typical mass transfer rates are larger than, or approximately equal to, $10^{-9} M_{\odot} y^{-1}$. In general the mass transfer rate is numerically unstable, (e.g. Kolb and Ritter, 1990; Sarna, 1992; Schenker et al., 2002; Büning and Ritter, 2005).

Theoretical estimates of AML - based on different assumptions for magnetic braking law for binaries with solar-type components- have been made, too, (e.g. Skumanich, 1972; van't Veer and Maceroni, 1989; Maceroni and van't Veer, 1991; Maceroni, 1992; Stepien, 1995 etc.).

From the above, it is obvious that orbital period changes can be used, in turn, to test the theories of binary star evolution. In pairs like [WD-WD], i.e., RLOF is triggered by the gradual shrinking of the orbit through the emission of gravitational radiation. And if the total mass of the pair is above the Chandresekhar mass, the system will be a progenitor to a SN of type I. Similarly, the orbit of a [NS-MS] or [NS-WD] binary will shrink due to the emission of gravitational radiation. At the onset of RLOF, the binary will become either a LMXB (if the donor star is a WD or a MS with mass $< 2M_{\odot}$, or a HMXB, if the donor is a more massive MS star.

Considering the evolution of Algols, according to de Loore and van Rensbergen (2005), from a sample of 240 Algols with a B-type star as primary, conservative RLOF reproduces the observed distribution of orbital periods well, but it underestimates the observed mass-ratios in the range $[0.4 - 1.0]$. And in order to obtain a better fit *the systems have to lose significant amounts of matter without losing much angular momentum*, (van Rensbergen et al., 2005).

On the other hand, it has been shown that the binary *AS Eri* is the result of non-conservative evolution, (Refsdal et al., 1974). And according to Eggleton et al. (2005) binaries containing low-mass, cool stars are subject to several non-conservative evolutionary processes.

Very recently, Koen (2005) suggested that dealing with period changes of variable stars the approaches must be different for long period variables, LPVs, and short-period ones, since in the latter case most cycles are not observed. Moreover, two distinct problems have to be considered: to test the significance level of possible changes and to extract the precise form of period changes that may be present in the data; an important consideration is the presence of small random variations that are intrinsic to the star. This must be considered very seriously especially after the realization that primary components of Algol-type eclipsing binaries are pulsating variables (Mkrtichian et al., 2003). The $(O - C)$ diagrams carry much and valuable information that has to be treated correctly to yield reliable results concerning the evolution of close binaries.

Acknowledgements. I express my thanks to all LOC members and especially Dr. Gojko Djurasevic, for the invitation, and hospitality during my stay in Beograd. This work was financially supported by Athens University.

References

Applegate, J.H.: 1992, *Astrophys. J.*, **385**, 621.
Applegate, J.H., Patterson, J.: 1987, *Astrophys. J.*, **322**, L99-L102.
Büning, A., Ritter, H.: 2005, *Astron. Astrophys.*, in press (ESO pre-print).
Claret, A., Giménez, A.: 1993, *Astron. Astrophys.*, **277**, 487.
de Loore, C., van Rensbergen, W.: 2005, *Astrophys. Space Sci.*, **296**, 337 and 353.
Eggleton, P.P., Kisseleva-Eggleton, L.: 2005, *Astrophys. Space Sci.*, **296**, 327.
Flannery, B.P.: 1976, *Astrophys. J.*, **205**, 217.
Jetsu, L., Pagano, I., Moss, D., Rodono, M., Lanza, A.F., Tuominen, I.: 1997, *Astron. Astrophys.*, **326**, 698.
Hall, D.S., Neff, S.G.: 1976, *IAU Symp.* **73**, 283.

Hilditch, R.W.: 2001, An Introduction to Close Binary Stars, Cambridge Univ. Press.
Hoyng, P.: 1996, *PASP Conf. Ser.*, **109**, (Pallavicini R. and Dupree A.K., Eds.), p.59.
Huang, S.S.: 1956, *Astron. J.*, **61**, 49.
Irwin, J.B.: 1959, *Astron. J.*, **64**, 149.
Kalimeris, A., Rovithis-Livaniou, H., Rovithis, P.: 1994, *Astron. Astrophys.*, **282**, 775.
Kalimeris A., Rovithis-Livaniou H., Rovithis P.: 2002, *Astron. Astrophys.*, **387**, 969.
Kalimeris, A., Rovithis-Livaniou, H.: 2005, *PASP Conf. Ser.*, in press.
King, A.R., Watson, M.G.: 1987, *Mon. Not. Royal Astron. Soc.*, **227**, 205.
Koen, C.: 1996, *Mon. Not. Royal Astron. Soc.*, **283**, 471.
Koen, C.: 2005, *ASP Conf. Ser.*, Sterken C., Ed., **335**, 25.
Kolb, U., Ritter, H.: 1990, *Astron. Astrophys.*, **236**, 385.
Kopal, Z.: 1959, Close Binary Stars, Wiley.
Kordywski, H.: 1965, *Acta Astron.*, **15**, 133.
Kreiner, J.M.: 1971, *Acta Astron.*, **21**, 365.
Kruszewski, A.: 1966, *Advances in Astron. Astrophys.*, **4**, 233.
Landau, L.D., Lifshitz, E.M.: 1965, Quantum Mechanics (Pergamon Press, Oxford).
Lucy, L.B.: 1976, *Astrophys. J.*, **205**, 208.
Martynov, D.Ya.: 1948, Izv. Engelbardt Obs. Kazan No. 25.
Martynov, D.Ya.: 1973, in "Eclipsing Variable Stars", (Tsesevich V.T., Ed.), p. 270, Wiley.
Maceroni, C.: 1992, *ASP Conf. Ser.* **40**, (Weiss W.W., Baglin A., Eds.), p. 374.
Maceroni, C.: 1999, *New Astron.*, **43**, 481.
Maceroni, C., van't Veer, F.: 1991, *Astron. Astrophys.*, **246**, 91.
Mayer, P.: 1990, *Astron. Astrophys.*, **324**, 988.
Mkrtichian, D.E., Nazarenko, V., Gamarova, A.Yu, Lehmann, H., Rodriguez, E., Olson, E.C., Kim S-L, Kusakin, A.V., Rovithis-Livaniou, H.: 2003, *ASP Conf. Ser.*, **292**, (Sterken C., Ed.), p. 113.
Piotrowski, S.L.: 1964, *Acta Astron.*, **14**, 4 and 251.
Rahunen, T.: 1981, *Astron. Astrophys.*, **102**, 81.
Robertson, J.A., Eggleton, P.P.: 1977, *Mon. Not. Royal Astron. Soc.*, **179**, 359.
Rovithis-Livaniou, H.: 2001, *Odessa Astron. J.*, **14**, 91.
Rovithis-Livaniou H., Rovithis P., Kalimeris A., Oprescu G., Dumitrescu A., Suran M.D.: 1994, *Rom. Astron. J.*, **4**, 135.
Rovithis-Livaniou, H., Fragoulopoulou, E., Sergis, N., Rovithis, P., Kranidiotis, A.: 2001, *Astrophys. Space Sci.*, **275**, 337.
Rovithis-Livaniou, H., Tsantilas, S., Kalimeris, A.: 2002, Proc. 33rd Conf. on "Variable Stars", (Zejda M., Ed.), p. 153.
Rovithis-Livaniou, H.: 2003, in "New Directions for Close Binaries Studies: The Royal Road to Stars", (Demircan O., Budding E., Eds.), p. 39.
Rovithis-Livaniou, H.: 2005, *Astrophys. Space Sci.*, **296**, 91.
Rovithis-Livaniou, H., Tsantilas, S., Rovithis, P., Chochol, D., Skopal, A., Pribulla, Th.: 2005, *Astrophys. Space Sci.*, **296**, 101.
Rüdiger, G., Elstener, D., Lanza, A.F., Granzer, Th.: 2002, *Astron. Astrophys.*, **392**, 605.
Sarna, M.J.: 1992, *Mon. Not. Royal Astron. Soc.*, **259**, 17.
Schenker, K. and King, A.R.: 2002, *ASP Con. Ser.*, **261**, 242.
Skumanich, A.: 1972, *Astrophys. J.*, **171**, 565.
Slavenas, P.: 1927, *Trans. Astron. Obs. Yale Univ.*, **6**, 3.
Stepien, K.: 1995, *Mon. Not. Royal Astron. Soc.*, **274**, 1019.
Sterken, C.: 2000, in "Variable Stars as Essential Astrophysical Tools", (Ibanoglu C., Ed.), p. 529, Kluwer.
Taam, R.E.: 1983, *Astrophys. J.*, **268**, 361.
Tout, C.A., Hall, D.S.: 1991, *Mon. Not. Royal Astron. Soc.*, **253**, 9.
Tout, C.A., Hall, D.S.: 1992, in "Evolutionary Processes in Interacting Binary Stars", (Kondo Y. et al., Ed.), p. 363.

Tsantilas, S., Rovithis-Livaniou, H.: 2005, in "The Light-Time Effect in Astrophysics", *ASP Conf. Ser.*, (Sterken C., Ed.), **335**, p. 147.
van Rensbergen, W., de Loore, C., de Greve, J.P., Jansen, K.: 2005, pre-print to Elsevier Sci.
van't Veer, F.: 1979, *Astron. Astrophys.*, **80**, 287.
van't Veer, F. and Maceroni C.: 1989, *Astron. Astrophys.*, **220**, 128.
Vilhu, O.: 1982, *Astron. Astrophys.*, **109**, 17.
Watson, C.A., Dhillon, V.S.: 2004, *Mon. Not. R. Astron. Soc.*, **.**351, 110.
Yamasaki, A.: 1975, *Astrophys. Space Sci.*, **34**, 413.