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Mass transfer in Algols and its implications to the mass transfer theory

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Abstract. The average mass transfer rates in four Algol-type binary stars RZ Cas, TV Cas, SW Cyg and DI Peg are derived from their observed period changes in the light of alternate period change model. The results have been used to discuss the anomalies in the mass transfer theory, namely dynamical instability of the mass losing component and the conservation of orbital angular momentum during the mass transfer.

Key words : mass transfer—binaries

1. Introduction

The rate of mass transfer is an important quantity in the theoretical studies pertaining to the evolution of close binary systems. In this paper, we have computed the mass transfer rate in four Algol-type binaries, namely RZ Cas, TV Cas, SW Cyg and DI Peg using the observed times of their minimum light. The interpretation of the result leads to a number of conclusions pertinent to mass transfer process and casts doubt on a number of presuppositions. The term Algols means those eclipsing binaries in which the more massive component is a main sequence star, while less massive component is a subgiant filling up its Roche-lobe. Throughout this paper subscript 'h' refers to the mass gaining component while subscript 'c' refers to the mass losing component.

2. Data and procedure

This study is based on the observed instants of primary minima of RZ Cas, TV Cas, SW Cyg and DI Peg listed by several investigators. Figures 1, 2, 3 and 4 represent the $O - C$ curves for RZ Cas, TV Cas, SW Cyg and DI Peg, respectively.

According to B-H Model (Biermann & Hall 1973) a dynamical instability causes a sudden out-flow of mass from the cooler star, which has already filled its Roche-lobe. This may cause some mass transfer to the hotter star (alongwith the associated angular momentum) and/or mass-loss from the system (alongwith loss of systemic angular momentum). In either case, the orbital angular momentum decreases and the orbital period shortens. If the period subsequently increases, this increase indicates that mass was accreted by the hotter star and

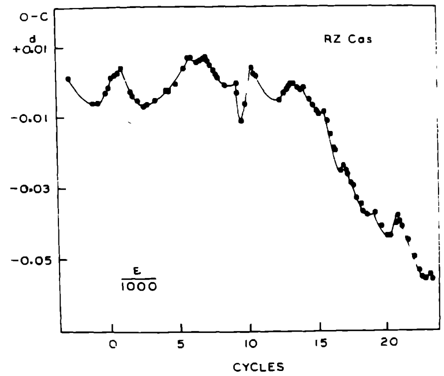

Figure 1. The $O - C$ curve of RZ Cas. Points are the normal $O - C$ i.e. residuals of the times of the minimum light of RZ Cas based on the linear ephemeris : $M(E)$ JD(Hel) = 2417355.4233 + $1^d.1952519E$.

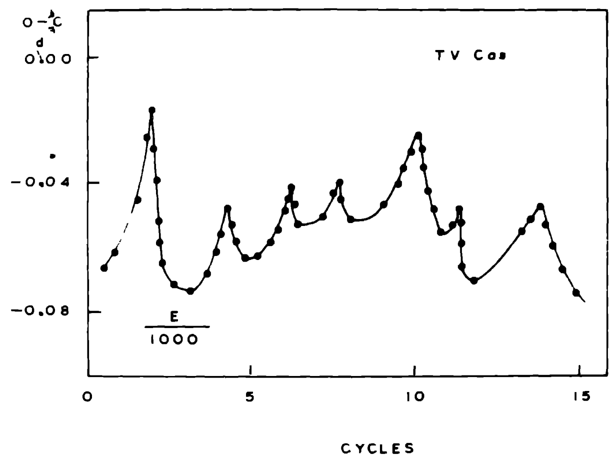

Figure 2. The $O - C$ curve of TV Cas. Points are the normal $O - C$ i.e. residuals of the times of minimum light of TV Cas based on the linear ephemeris : $M(E)$ JD(Hel) = 2415698.66 + $1^d.81260983E$.

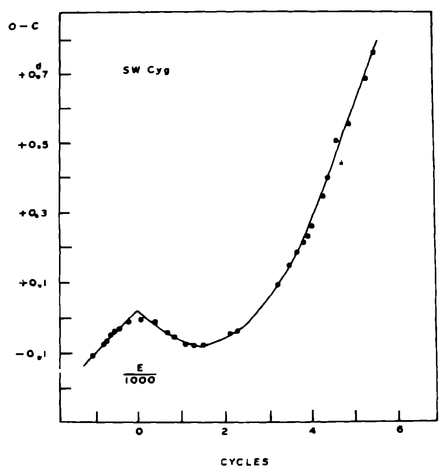

Figure 3. The $O - C$ curve of SW Cyg. Points are the normal $O - C$ i.e. residuals of the times of minimum light of SW Cyg based on the linear ephemeris : $M(E)$ JD(Hel) = 2418440.758 + $4^d.572923E$.

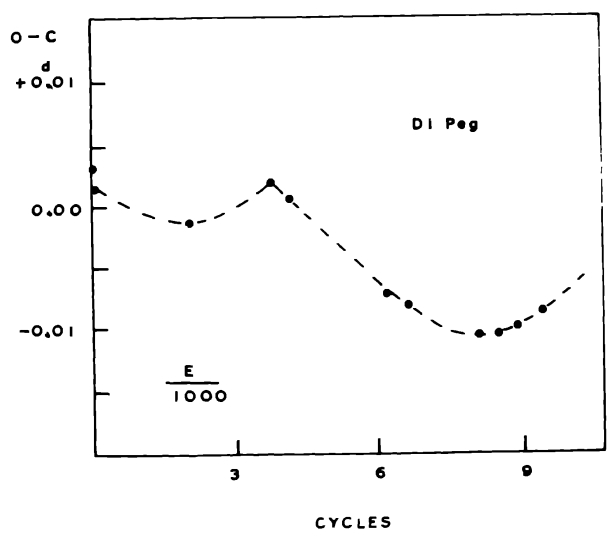

Figure 4. The $O - C$ curve of DI Peg. Points are the normal $O - C$ i.e. residuals of the times of minimum light of DI Peg based on the linear ephemeris : $M(E)$ JD(Hel) = 2437522.3946 + $0^d.7118175E$.

angular momentum returned to the orbit. One such possibility is when O-C diagram is represented by a series of upward curving parabolas intersecting at the moments of sudden period decrease. The O-C curves of RZ Cas, TV Cas, SW Cyg and DI Peg (figures 1-4) appear to be of such a type, being composed of parabolas, curved upwards. These stars are thus well suited to study in the light of the B-H model.

In order to calculate the mass transfer rate $\dot{M}_c$, we assume that the matter ejected from the cooler star is stored around the hotter star within its Roche-lobe and we use the relation (Hall & Neff 1976) :

$$\frac{\dot{P}}{P} = 3\left[\left(\frac{M}{M_c}\right)\left(\frac{M}{M_h}\right)^{1/2}\left(\frac{R_r}{A}\right)^{1/2}\right]\frac{\dot{M}_c}{M}, \qquad \dots (1)$$

where P is the period, M the mass, A the semi-major axis and R_r the radius of gyration of transferred material which lets the angular momentum to be stored temporarily as rotation in or around the hotter star. The computed mass transfer rate alongwith the used parameters in our calculation of $\dot{M}_c$ are listed in table 1. These values of $\dot{M}_c$ represent the lower limit of mass loss from the cooler stars for the reasons that some mass may have been lost from the system and/or that some angular momentum may not have returned to the orbit.

Table 1. Ephemerides of studied Algol-type binary stars

	RZ Cas	TV Cas	SW Cyg	DI Peg
$M_h/M_\odot$	1.8	3.1	2.8	1.5
$M_c/M_\odot$	0.5	1.4	0.7	0.7
$A/R_\odot$	6.2	10	17	4.4
P (in days)	1.195	1.813	4.572	0.712
$\dot{M}_c$ (in $M_\odot$ yr^{-1})	3.3(−7)	4.3(−7)	4.6(−7)	3.9(−7)

3. Interpretations of the results

3.1. *Dynamical instability of mass losing star*

Kuiper (1941) first noted that if a more massive synchronously rotating primary over-flowed its Roche-lobe radius during the course of evolution, it would transfer the excess mass to the secondary and in doing so would cause the Roche-lobe to contract. If new Roche-lobe is smaller than the new equilibrium radius, the primary is unstable to mass transfer (cf. Pratt & Strittmatter 1976).

Considering the mass transfer to a companion in a binary and assuming the conservation of orbital angular momentum, Smak showed theoretically, that ρ_c, Roche radius would increase more than that of r_c provided q was small enough, i.e. $q < 0.63$ (Smak 1962). Since, with few exceptions, all Algol-type binaries have mass ratio smaller than this limit, thus Algols are stable on dynamical time scale (Paczynski 1965). But, in the following, it can be shown that the Roche-lobe around the cooler star in TV Cas as in Algols general, does not expand enough to free it from dynamical instability, it shrinks.

There are two factors governing the size of Roche-lobe. The first one is the increasing (or decreasing) value of A which scales both ρ_c and ρ_h up (or down). The second factor is the mass transfer itself, which decreases q and thereby makes ρ_c smaller. For TV Cas, the data in figure 2 show that the net period decreases. $\Delta P/P$ to be $= 2 \times 10^{-10}$ yr^{-1} on the average. With the differential form of the Kepler's harmonic law, and the assumption of no systemic mass loss, we see that the decrease in dA/A, and therefore also in $d\rho_c/\rho_c$, is of the order of 1.3×10^{-10} yr^{-1}. On the other hand mass transfer dM_c/M_c, taken to be about 4.3×10^{-7} yr^{-1} on the average, produces a decrease in $d\rho_c/\rho_c$ about 4.3×10^{-7} yr^{-1}. Thus above findings confirm that Roche-lobe of cooler star in TV Cas is shrinking instead of expanding.

This conclusion is also applicable to Algols in general. If P, on the average, and M are constant, then Kepler's harmonic law states that A remains constant on the average. But due to occurrence of mass transfer, q decreases and makes ρ_c smaller. Thus the argument that the Algols as a group are free from instability because Roche-lobe are expanding as mass transfer proceeds (Paczynski 1965), is unjustified.

3.2. *Conservation of orbital angular momentum*

For all Algol-type binaries, including TV Cas, it can be shown that, during mass transfer, the orbital angular momentum is not conserved. According to equation :

$$\frac{\dot{P}}{P} = 3\left(\frac{M}{M_{\rm h}} - \frac{M}{M_{\rm c}}\right) \cdot \frac{\dot{M}_{\rm c}}{M}; \qquad \ldots (2)$$

i.e. the expression for period change due to mass transfer in conservative mode (Singh & Chaubey 1986), as for all Algol-type binaries, including TV Cas, a net increase in period must be expected.

Substituting the adopted parameters and the average mass transfer rate for TV Cas equation (2) yields

$$\dot{P} = 3.6 \times 10^{-7}\ \text{day yr}^{-1}, \qquad \ldots (3)$$

Since 1.4×10^4 cycles elapsed between 1901 to 1977. Thus the value of $O - C$ of the order of $0^d.04$ must be expected for TV Cas in 1977. This is not the case. Thus during the mass transfer the orbital angular momentum is not conserved. This orbital angular momentum is either lost from the system or stored for a long time in the hot main-sequence star or both.

4. Conclusion

In this paper, period variability of binary stars RZ Cas, TV Cas, SW Cyg and DI Peg have been discussed in the light of period change model proposed by Biermann & Hall (1973) and the mass transfer rates have been calculated. From the results obtained, the anomalies in the mass transfer theory have been discussed. The conclusions are as follows :

(i) The Roche-lobe of the secondary components in Algol-type binaries are shrinking as mass transfer proceeds. Thus they are not free from dynamical instability.

(ii) The orbital angular momentum in Algol-type binaries is not conserved during the mass transfer.

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