ON THE ASYNCHRONOUS ROTATION OF ACCRETORS IN INTERACTING BINARIES

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Abstract. We show that the gaining component in interacting binaries can rotate faster than its orbital revolution as a consequence of the accretion process. We derive an approximative analytical formula for the Roche lobe radius of asynchronously rotating accretors. We present the case of the semi-detached interacting binary TX UMa, for which we measured directly asynchronous rotation of its accretor. We suggest a method to detect indirectly a fast spinning of accretors in symbiotic binaries based on the the X-ray luminosity of the boundary layer. We demonstrate this possibility for the case of EG And.

Keywords: stars, binaries, asynchronous rotation

1. Introduction

At a certain stage of binary evolution the process of mass transfer from the donor star onto the gaining star (the accretor) can lead to a high activity of the binary including effects of accretion, outbursts, mass outflows, etc. Accretion of part of the matter lost by the donor star can happen by means of Roche lobe overflow or stellar wind. The former mainly concerns short-period binaries (e.g. cataclysmic variables) and the latter takes place in long-period systems (e.g. symbiotic stars). Generally, effects of interaction in a binary system depend on the accretion rate. Part of the energy of the accreted material is used for spinning up the accreting star at its final stage of accretion. As a result, the accretor will rotate faster than the orbital revolution. This situation leads to a shrinking of its critical equipotential surface, which can affect the efficiency of the accretion process.

In this paper, we introduce a possibility of spinning up the accreting star, derive a formula for the approximate Roche lobe radius for asynchronous rotation, and as an example, demonstrate the case of the interacting binaries TX UMa and EG And.

2. Limiting Case for Spinning Up the Accretor

Here we derive the angular velocity of the accretor, $\Omega_*(t)$, as a consequence of mass accretion at the rate $dM/dt = \dot{M}$ for the extreme case, in which the total

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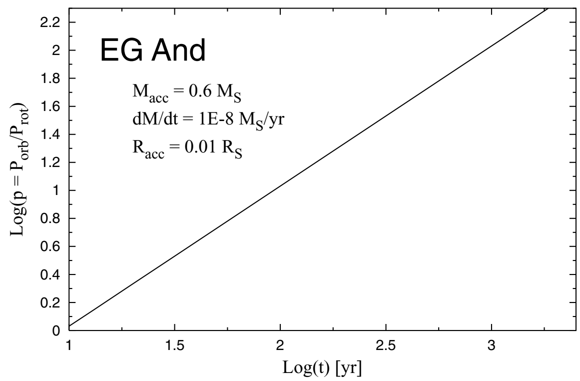

Figure 1. Spinning up of the accretor with time in the symbiotic binary EG And.

kinetic energy of the accreted matter converts into spinning up the accreting star. In addition, we assume that the changes in radius and the star's momentum of inertia due to the mass infall can be neglected. This strong simplification allows us to express the angular velocity of the accretor in the form

$$\Omega_*(t) = \frac{v_K}{R_*}\left[1 - \exp\left(-\frac{5\dot{M}}{2M_*}t\right)\right] + \Omega_0 \exp\left(-\frac{5\dot{M}}{2M_*}t\right), \tag{1}$$

where M_* and R_* are parameters of the accretor and v_K is the Keplerian velocity. Figure 1 shows the case of such spinning up due to a direct-impact accretion for parameters of the symbiotic star EG And for the initial angular velocity $\Omega_0 = 0$ (i.e. the synchronous case).

3. The Roche Lobe Radius for Asynchronos Rotation

In this section, we derive a suitable analytical expression of the Roche lobe radius, R_L, for the case of an asynchronously rotating star in a binary system. For this purpose, we used a generalized binary potential as derived by Kruszewski (1963). For a circular orbit, we found that

$$\frac{R_L}{A} = 0.361 - 0.0904 \ln(p) + [0.0710 - 0.0183 \ln(p)] \ln(q), \tag{2}$$

which is valid for the mass ratio $0.05 < q < 1$ and the ratio of the orbital to the rotational period $1 < p < 20$. This relation reproduces the numerical values to better than 6%. Example is given in Figure 2.

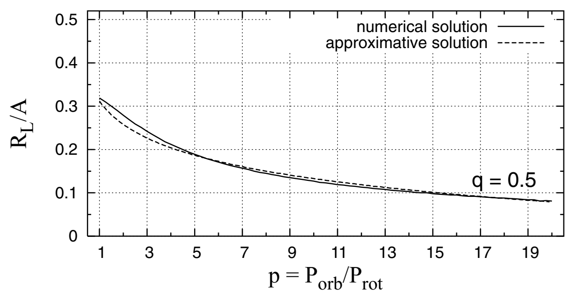

Figure 2. Comparison of the numerically calculated Roche lobe radius with R_{L} approximated by relation (2); A is the separation of the binary components.

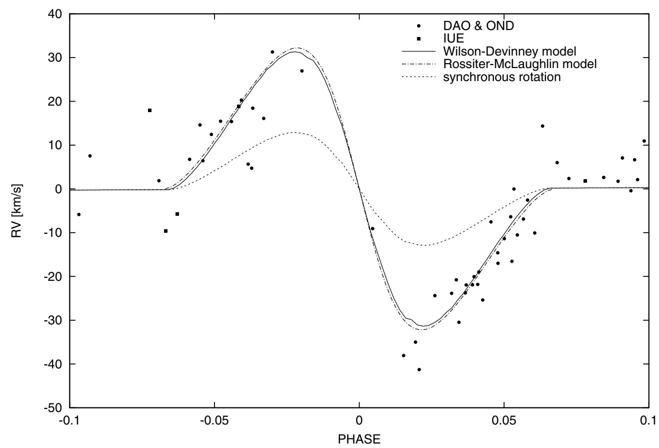

Figure 3. Rotational effect during the TX UMa primary eclipse (Komžík, 1998).

4. TX UMa – A Direct Evidence for Asynchronous Rotation

TX UMa is an Algol-type binary with an orbital period of 3.06 days consisting of a G0 III–IV lobe filling star and a gaining primary of type B8 V (e.g. Albright and Richards, 1993). Based on radial velocities of absorption hydrogen lines, we revealed the effect caused by rotation of the eclipsed component (Figure 3). This result suggests an asynchronous rotation of the primary component in TX UMa with factor $p = 2.39 \pm 0.004$.

5. A Fast Spinning Accretor in EG And?

EG And is a quiet symbiotic binary. Its orbital period is 482 days, and it consists of a red M3 III giant and a white dwarf accreting from the giant's wind with a rate of $\dot{M} \sim 10^{-8}\,M_\odot\,\mathrm{yr}^{-1}$ (Kolb et al., 2003). The hot component luminosity is about $60\,(d/590\,\mathrm{pc})^2\,L_\odot$. In this case, there are no direct signatures of a faster than synchronous rotation of the accretor. Therefore, we suggest an indirect method to detect a (possible) fast spinning of the accretor in this long-period system. The approach is based on the luminosity of the boundary layer, L_{BL}, which depends on the angular velocity of the accretor (Popham and Narayan, 1995). For the luminosity of the accretion disk, L_{AD}, we can write the ratio

$$\frac{L_{\mathrm{BL}}}{L_{\mathrm{AD}}} = (1-u)^2, \tag{3}$$

where $u = \Omega_*/\Omega_{\mathrm{K}}(R_*)$ and Ω_{K} is the Keplerian velocity. For a synchronously rotating star ($\Omega_* = 0$), the ratio $L_{\mathrm{BL}}/L_{\mathrm{AD}} = 1$, but $L_{\mathrm{BL}} < L_{\mathrm{AD}}$ indicates a faster rotation of the accretor ($\Omega_* > 0$). The luminosity of the EG And BL can be estimated from its X-ray luminosity,

$$L_{\mathrm{X}} = 4\pi d^2 \times 1.5\,10^{-10}\eta^{-1}\,\mathrm{erg\,s^{-1}}, \tag{4}$$

derived from a strong He II 1640 Å emission line (we used the HST spectrum Z27E0307N) as proposed by Patterson and Raymond (1985). Assuming that $L_{\mathrm{X}} = L_{\mathrm{BL}}$ and for $L_{\mathrm{AD}} = 60\,L_\odot$ we get

$$\frac{L_{\mathrm{BL}}}{L_{\mathrm{AD}}} = 0.03\eta^{-1} = 0.3\text{–}0.15 \tag{5}$$

for $\eta = 0.1$–0.2 (Vrtilek et al., 1994). With the aid of relation (3), this result implies a very fast rotation of the accreting star in EG And at $\Omega_*(\mathrm{EG\ And}) = 0.3 - 0.5\,\Omega_{\mathrm{K}}(\mathrm{R}_*)$.

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