Are the Be/X-ray binaries synchronized?

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Abstract. We investigated the possible synchronization of the motions or the Be/X-ray binary stars. Our aim was to check whether the rotation of the mass donor synchronizes or pseudo-synchronizes the orbital motion of the compact object. We calculated the pseudo-synchronization period (P_{ps}) and compared it with the rotational period of the mass donor (P_{rot}). We found that the Be/X-ray binaries are far away from pseudo-synchronization.
Key words: stars: binaries: close – stars: rotation – X-rays: binaries

Дали двойките Be звезда – рентгенов източник имат синхронизирано въртене?

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Ние изследваме възможната синхронизация в движенията при двойките Be звезда – рентгенов източник. Нашата цел бе да проверим дали въртенето на донора на маса синхронизира или псевдо-синхронизира въртенето на компактния обект. Ние изчислихме периода на псевдо-синхронизация (P_{ps}) и го сревнихме с ротационния период на донора на маса (P_{rot}). Ние установихме, че двойките Be звезда – рентгенов източник са далеч от псевдо-синхронизация.

1 Introduction

The Be/X-ray Binaries consist of a main sequence star of spectral type Be as a donor and a compact object (neutron star or black hole) as a gainer. The mass donors in these binaries have a mass greater than 10 $M_{\odot}$. They are population I objects and are concentrated in the Galactic plane. The compact object accretes mainly from the dense circumstellar disk around the Be star (although the accretion from polar wind also has some contribution).

Our aim here is to check if the rotation of the mass donors in Be/X-ray binaries synchronized with the orbital motion of the compact object, and how the presence of an orbiting neutron star and the tidal force influences the rotation of the mass donor.

2 Synchronization and pseudo-synchronization

In a binary system with a circular orbit the rotational period of the donor, P_{rot}, reaches an equilibrium value at orbital period, $P_{rot} = P_{orb}$. It is synchronous rotation (synchronization) and it means that the rotational period

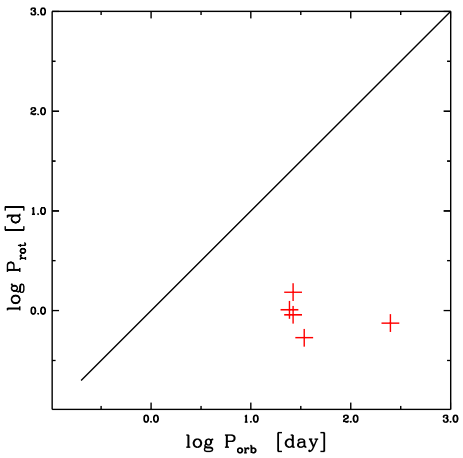

Fig. 1. P_{rot} versus P_{orb} in logarithmic scale. The straight line indicates $P_{rot} = P_{orb}$.

is equal to the orbital period. In a binary system with an eccentric orbit, this equilibrium is reached at a value of P_{rot} which is *less* than P_{orb}, the amount less being a function solely of the orbital eccentricity e. Practically in a binary with eccentric orbit the tidal force acts to synchronize the rotation of the mass donor with the motion of the compact object at periastron. This is called pseudo-synchronous rotation (Hall 1986). To calculate the period of pseudo-synchronization, P_{ps}, we use (Hut 1981):

$$P_{ps} = \frac{(1 + 3e^2 + \frac{3}{8}e^4)(1 - e^2)^{\frac{3}{2}}}{1 + \frac{15}{2}e^2 + \frac{45}{8}e^4 + \frac{5}{16}e^6} P_{orb}. \tag{1}$$

At low eccentricity of the orbit $e \to 0$ and $P_{ps} \approx P_{orb}$.

For the calculation of the P_{rot} we use

$$P_{rot} = \frac{2\pi R_1 \sin i}{v \, \sin i}, \tag{2}$$

where $v \, \sin i$ is the projected rotational velocity of the mass donor, i is the inclination of the orbit to the line of sight. The underlying assumption is that the rotational axis of the mass donor is perpendicular to the orbital plane.

Following Hurley et al. (2002) and Zahn (1975) the circularization timescale for stars with radiative envelopes can be estimated as:

$$\frac{1}{\tau_{\rm circ}} = \frac{21}{2} \left(\frac{GM_1}{R_1^3} \right)^{\frac{1}{2}} q_2 \, (1 + q_2)^{\frac{11}{6}} \, E_2 \left(\frac{R_1}{a} \right)^{\frac{21}{2}} . \tag{3}$$

where M_1 and R_1 are the mass and the radius of the donor respectively, q_2 is the mass ratio M_2/M_1, a is the semi-major axis. E_2 is a second-order tidal coefficient,

$$E_2 = 1.592 \times 10^{-9} M_1^{2.84}. \tag{4}$$

The synchronization time scale (Hurley et al. 2002) is given as

$$\tau_{\rm synch} = K \tau_{\rm circ}, \tag{5}$$

where K is:

$$K \approx \frac{0.015}{r_g} \frac{1+q_2}{q_2} \left(\frac{R_1}{a}\right)^2. \tag{6}$$

For the the gyration radius of the donor $r_g^2 = I/M_1 R_1^2$ (where I is the moment of inertia), we adopt $r_g \approx 0.25$ for main sequence stars (Claret & Gimenez, 1989). For each object, the calculated $\tau_{\rm circ}$ and $\tau_{\rm sync}$ are given in Table 2.

The lifetime of a star on the main sequence can be estimated as:

$$\tau_{MS} = 10^{10} (\frac{M_\odot}{M})^{2.5} \ \ \text{years}. \tag{7}$$

A B0V star with a mass ~ 20 $M_\odot$ spends $\sim 5.5\ 10^6$ yr on the main sequence. Comparing the lifetime, τ_{MS}, with τ_{sync} (Table 2), we see that among the Be/X-ray binaries only for LSI+$61^0$303 $\tau_{sync} \sim \tau_{MS}$. This is the only Be/X-ray binary for which we can expect considerable changes of the rotation of the primary during the lifetime of the Be star.

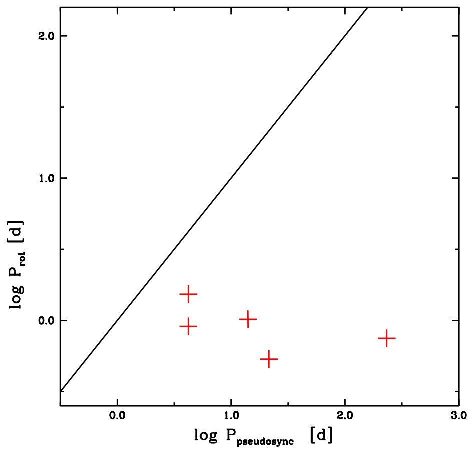

Fig. 2. P_{rot} versus P_{ps} in logarithmic scale. The straight line indicates P_{ps} =P_{orb}.

Table 1. Orbital parameters of Be/X-ray Binaries. Here are given as follows: name of the object, orbital period, eccentricity of the orbit, inclination of the orbit to the line of sight, semi-major axis of the orbit, projected rotational velocity ($v \sin i$) of the mass donor, the period of pseudo-synchronization (calculated using Eq.1), rotational period of the mass donor (calculated using Eq.2).

object	P_{orb} [d]	e	i [^{o}]	a [$R_\odot$]	$v \sin i$ [$\mathrm{km\,s^{-1}}$]	P_{ps} [d]	P_{rot} [d]
LSI+61^{0}303	26.496	0.72±15	30±20	35.45	113	1.10 - 7.33	0.45-2.61
			70-80		360		0.77-1.05
X Per	250±0.6	0.111±0.018	26-33	474	215±10	228 - 237	0.70 - 0.80
BQ Cam	34.25	0.31±0.03	$\leq$ 10.3 ±0.09	121	145	19.82 - 23.11	0.46 - 0.61
V635 Cas	24.3	0.34	40-60	95	300	14.06	0.87 - 1.17
V725 Tau	111	0.47±0.02	28.5	23.39	254	40.93 - 46.62	1.43

3 Non-synchronization in the Be/X-ray binaries

In Table 1 and Table 2 are given the data we have collected for the Be/X-ray Binaries. It contains 5 objects from the catalogue of (Liu, van Paradijs, & van den Heuvel 2000,2001) for which we were able to find the orbital and stellar parameters: spectral type of the mass donors, orbital period, eccentricity of the orbit, inclination (i), projected rotational velocity of the primary ($v \sin i$). On Fig.1 we plot P_{rot} versus P_{orb}. On this figure it is visible that the objects

Table 2. Be/X-ray Binaries parameters of the components. Here are given the name of the object, the spectral type of the primary, mass of the primary, mass of the secondary, radius of the primary, its luminosity, synchronization time scale, circularization time scale, the action of the tidal force.

object	Sp	M_1 [$M_\odot$]	M_2 [$M_\odot$]	R_1 [$R_\odot$]	L_1 [$L_\odot$]	τ_{syn} [yr]	τ_{circ} [yr]	Tidal force
LSI+61^{0}303	B0Ve	20.0	4.0	6.7 ± 0.9	3 10^3	3.1 10^6	6.8 10^7	pseudo-sync/spin-down
X Per	B0V	15.5	1.4	6.5	3 10^3	6.2 10^{17}	1.8 10^{21}	spin-down
BQ Cam	O8-9Ve	23.0	1.4	9.0	5.5 10^3	3.5 10^{11}	7.6 10^{13}	spin-down
V635 Cas	B0.2Ve	18.0	1.4	8.0	3.0 10^3	1.4 10^{11}	9.5 10^{12}	spin-down
V725 Tau	O9.4IIIe	23.0	1.4	15.0	2.0 10^5	2.8 10^{12}	8.0 10^{14}	spin-down

containing mass donors from spectral class V are far away from the line $P_{rot} = P_{orb}$. On Fig.2 we plot P_{rot} versus P_{ps}. P_{ps} is calculated using Eq.1 and the data collected in Table.1.

On the Fig.1 as well as on Fig.2, it is visible that the objects mass donors from spectral class V are far away from the equilibrium state.

4 Individual objects

LSI+61^0303 (V615 Cas, GT0236+610) - The system contains compact object (probably a black hole) orbiting around Be star in a highly eccentric orbit. We use two sets of orbital parameters - Casares et al. (2005) and Hutchings & Crampton (1981). Both they give similar results regarding P_{rot}. With $P_{ps}/P_{rot} \approx 2$, LSI+61^0303 is the object most close to pseudo-synchronization among the Be/X-ray binaries in our sample.

X Per (4U 0352+30) - the stellar parameters are taken from Roche et al.(1997), Delgado-Martí et al. (2001) and Luybimkov et al. (1997). The system is non synchronized with $P_{ps}/P_{rot} \approx 310 \pm 15$. The tidal force should spin down the rotation of the mass donor. However, as the tidal force in this system is very weak ($\tau_{sync} \sim 10^{17}$ yr), there should be no changes during the lifetime as Be/X-ray binary. It has persistent X-ray emission because the neutron star accretes from the outer parts of the stellar wind, where there are no changes in the density of the material.

BQ Cam (V0332+53) - we calculate ratio $P_{ps}/P_{rot} \approx 40 \pm 3$. The tidal force spins down the rotation of the mass donor. The stellar parameters are taken from Negueruela et al. (1999). The lack of recent X-ray activity is explained by the fact that the dense regions of the circumstellar disc around the Oe star do not reach the orbit of the neutron star.

V635 Cas (4U0115+63) - the system is transient X-ray emitter. We took the stellar parameters from Negueruela et al.(2001). The ratio $P_{ps}/P_{rot} \approx 14 \pm 2$ shows that the tidal force spins down the rotation of the mass donor. The disc around the Be star was modeled as a viscous decretion disc, i.e., a quasi-Keplerian disc held by the transport of angular momentum via viscous interactions. The outflow (radial) velocity in such a disc is expected to be strongly subsonic, in agreement with all the observations of Be stars in general and V635 Cas in particular. It was shown that such a disc cannot reach a steady state due to tidal and resonant interaction with the neutron star, and it is truncated at a radial distance which depends on the value of the viscosity.

V725 Tau (1A 0535+262) - the stellar parameters are taken from Clark et al. (1998), Haigh et al. (2004) and Grundstrom et al. (2007). $P_{ps}/P_{rot} \approx 30 \pm 2$. The tidal force spins down the rotation of the mass donor. The X-ray source A0535+262 was discovered by Ariel V during a large Type II outburst in 1975 (Coe et al. 1975; Rosenberg et al. 1975). Since then the source has been observed to undergo numerous outbursts, however there were no reported detections of X-ray outburst activity from 1994 to 2005 (Coe et al. 2006; Kretschmar et al. 2005). The source reappeared in a Type II outburst in May/June 2005 and was detected by Swift (Tueller et al. 2005) and RHESSI (Smith et al. 2005). It was subsequently seen to undergo a Type I outburst in August 2005 (Kretschmar et al. 2005; Caballero et al. 2007).

In respect to its X-ray behaviour and rotation of the mass donor (and ratio P_{ps}/P_{rot}) this object is similar to the transient Be/X-ray binaries.

5 Discussion

Our goal is to understand, if the rotation of the mass donors in the Be/X-ray binaries influenced by the orbiting companion (neutron star or stellar mass black hole). In these systems the compact object accretes material from the Be star envelope. The circumstellar disks around the Be stars in Be/X-ray binaries are axisymmetric and rotationally supported like the disks in the isolated Be stars, however they are smaller and denser (Zamanov et al., 2001). It seems that transient behaviour in the Be/X-ray binaries is observed when the neutron star is located at distance from the Be star $15 < r < 450$ $R_\odot$. In the Be/X-ray binaries BQ Cam, V635 Cas, V725 Tau, the transient behaviour can be connected with the tidal force spinning down the Be star. Excluding the peculiar object LSI+$61^0$303, for them typically $P_{ps}/P_{rot} > 10$.

In X Per the neutron star is far way from the Be star and the tidal force is weak.

For the galactic microquasar LSI+$61^0$303 the rotation of the mass donor is close to pseudo-synchronization. The system is ejected from cluster IC 1805 of about 1.5 Myr ago (Mirabel et al., 2004). This is the only Be/X-ray binary in which τ_{sync} is comparable with the life-time of the binary.

These results indicate that the tidal interaction with the neutron star is not the reason for the fast rotation of the Be stars in high mass X-ray binaries.

Conclusion

In this note we investigate the synchronization and pseudo-synchronization in the Be/X-ray Binary stars. For 5 systems with known orbital and stellar parameters, we calculate the synchronization and circularization timescales, the pseudo-synchronization period and compare them with the data for the rotation of the mass donors.

We find that the Be/X-ray binaries are far away from synchronization /pseudo-synchroni-zation. For most of them $P_{ps}/P_{rot} >> 1$. The tidal force in the Be/X-ray binaries acts as a deaccelerator of the rotation of the mass donors. The only Be/X-ray binary which is close to pseudo-synchronization is the peculiar object LSI+$61^0$303.

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References

Caballero, I., et al. 2007, A&A, 465, L21
Casares J., Ribas I., Paredes J. M., Martí J., Allende Prieto C., 2005, MNRAS, 360, 1105
Claret, A., & Gimenez, A. 1989, A&AS, 81, 37
Clark, J. S., Steele, I. A., Coe, M. J., & Roche, P. 1998, MNRAS, 297, 657

Coe, M. J., Carpenter, G. F., Engel, A. R., & Quenby, J. J., 1975, Nature, 256, 630
Coe, M. J., Reig, P., McBride, V. A., Galache, J. L., & Fabregat, J., 2006, MNRAS, 368, 447
Delgado-Martí, H., Levine, A. M., Pfahl, E., & Rappaport, S. A. 2001, ApJ, 546, 455
Grundstrom, E. D., et al. 2007, ApJ, 656, 431
Haigh, N. J., Coe, M. J., & Fabregat, J. 2004, MNRAS, 350, 1457
Hall, D. S., 1986, ApJ, 309, L83
Hurley, J. R., Tout, C. A., & Pols, O. R. 2002, MNRAS, 329, 897
Hut, P., 1981, A&A, 99, 126
Hutchings J.B., Crampton D.,1981, PASP 93, 486
Kretschmar, P., Pottsschmidt, K., Ferringo, C., et al., 2005, Proceedings of "The X-ray Universe 2005" Ed. A. Wilson, ESA SP-604, 273
Liu, Q. Z.; van Paradijs, J.; van den Heuvel, E. P. J. 2001, A&A, 368, 1021L
Lyubimkov, L. S., Rostopchin, S. I., Roche, P., & Tarasov, A. E. 1997, MNRAS, 286, 549
Mirabel, I.F., Rodriguez, L.F., Liu, Q.Z., 2004, A&A, 422, L29
Negueruela, I., Okazaki, A. T., Fabregat, J., Coe, M. J., Munari, U., & Tomov, T. 2001, A&A, 369, 117
Negueruela, I., Roche, P., Fabregat, J., & Coe, M. J. 1999, MNRAS, 307, 695
Roche, P., et al. 1997, A&A, 322, 139
Rosenberg, F. D., Eyles, C. J., Skinner, G. K., & Willmore, A. P., 1975, Nature, 256, 628
Smith, D. M., et al. 2005, ATEL, 557, 1
Tueller, J., Ajello, M., Barthelmy, S., Krimm, H., Makwardt, C., & Skinner, G. 2005, ATEL, 504, 1
Zahn, J.-P. 1975, A'&A, 41, 329
Zamanov, R. K., Reig, P., Martí, J., Coe, M. J., Fabregat, J., Tomov, N. A., & Valchev, T. 2001, A&A, 367, 884