Stellar Rotation
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Is there a Connection Between Non-Synchronous Rotation and X-Ray Emission in Massive Binary Systems ?

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Abstract. A correlation between orbital period and $\log(L_X/L_{bol})$ is found for a sample of B-type binary systems. We suggest that wind-wind collisions are the likely mechanism for generating the X-ray emission, and that the mass-loss rates may be enhanced in non-synchronously rotating systems due to the oscillations that are excited by the tidal forces.

Non-radial oscillations are excited in stars in binary systems where the orbital period ($P_{orb}=2\pi/\Omega$) is not synchronized with the stellar rotational period ($P_{rot}=2\pi/\omega$). In this paper we explore the possibility of an association of these oscillations with X-ray emission. When $P_{rot}=P_{orb}$, the system is in equilibrium and no oscillations are expected. A simple model for tidal interactions (Moreno & Koenigsberger 1999; Moreno et al. 2003) predicts that, excluding resonances, the maximum amplitudes of oscillation occur when P_{rot} approaches the value of P_{orb}. Defining $\beta = \omega/\Omega$, the hypothesis linking X-ray emission with non-synchronous rotation implies that in binary systems where $\beta = 1$ lower X-ray luminosities should be observed, as compared to similar systems in which β is close to, but different from unity.

In the general case of an eccentric orbit at periastron, we can write $\beta = 0.02\frac{v_e/(km/s)}{R_*/R_\odot}(P_{orb}/days)\frac{(1-e)^{3/2}}{(1+e)^{1/2}}$, where v_e is the equatorial velocity of the star, R_* its radius, and e is the eccentricity of the orbit. There are two major sources of uncertainty in β. The first is that the observational data generally provide only $v \sin i$. But, many of the binary systems are eclipsing, which provides a strong lower limit to $v \sin i$. The second problem concerns the radius of the star, although this problem is less severe if we concentrate on B-type stars, as opposed to O-type stars. In Figure 1 we plot the values of $\log(L_X/L_{bol})$ *vs.* β for B-type binaries in circular orbits having values of $v \sin i$ measured by Abt et al. (2002) and which were also detected by ROSAT (Berghoefer et al. 1996). Of the $\sim$220 binaries listed by Abt et al. (2002), $\sim$26 were detected by ROSAT. This sample is reduced to 8 objects when we restrict it to binaries with luminosity classes IV and V and with circular ($e < 0.11$) orbits. Fig. 1 displays a difference of two orders of magnitude in $\log(L_X/L_{bol})$ for the different systems, with a trend for lower $\log(L_X/L_{bol})$ associated with two of the three systems that have β closest to unity. This trend is not unique, however, since there is also a trend with orbital period, as illustrated in the top right panel of Fig. 1. The bottom right panel illustrates the behavior of our sample as a function of $v \sin i$, where a weak trend for increasing $\log(L_X/L_{bol})$ with $v \sin i$ might be present. This trend is certainly not present in the B8-9 single stars in Abt et al.'s list that were

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detected by ROSAT (plotted as open squares in Fig. 2). Hence, we tentatively conclude that there is a correlation between $\log(L_X/L_{bol})$ and orbital period, for $2 < P_{orb} < 8$ and that a possible trend for lower X-ray emission in $\beta = 1$ systems may be present.

Finally, there remains the issue of the mechanism responsible for generating the X-rays. In massive binary systems in which wind-wind collisions occur, the emitted X-ray luminosity is predicted to increase as the orbital separation decreases. The correlation of $\log(L_X/L_{bol})$ *vs.* P_{orb} is consistent with this prediction, and hence suggests that wind-wind collisions may be responsible for the observed X-ray emission. In addition, an indirect correlation between the X-ray emission and β may exist since large amplitude stellar pulsations could contribute towards enhancing the mass-loss rate of the stars, thus producing a more powerful collision between the two winds than in the case of a synchronized binary system.

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Table 1. B-star binaries with nearly circular orbits and ROSAT detections

HR	HD	Sp.	$\frac{R}{R_\odot}$	vsini	$\log(L_X)$	$\log(\frac{L_X}{L_{bol}})$	P_{orb}	e	β
936	19356	B8V	2.1	50	30.82	-5.13	2.87	0.02	1.37
1339	27295	B9IV	2.0	20	30.05	-5.73	4.45	0.06	0.89
1347	27376	B9V	2.0	20	28.54	-7.00	5.01	0.01	1.00
1471	29365	B8V	2.1	70	31.41	-4.46	2.05	0.0	1.37
1657	32964	B9V	2.0	30	29.88	-5.71	5.52	0.10	1.66
1788	35411	B1V	6.5	35	31.57	-6.93	7.98	0.0	0.86
7326	181182	B8III	8.0	60	31.56	-4.72	3.38	0.03	0.51
7792	193964	B9V	2.0	125	30.17	-5.42	5.30	0.04	6.62

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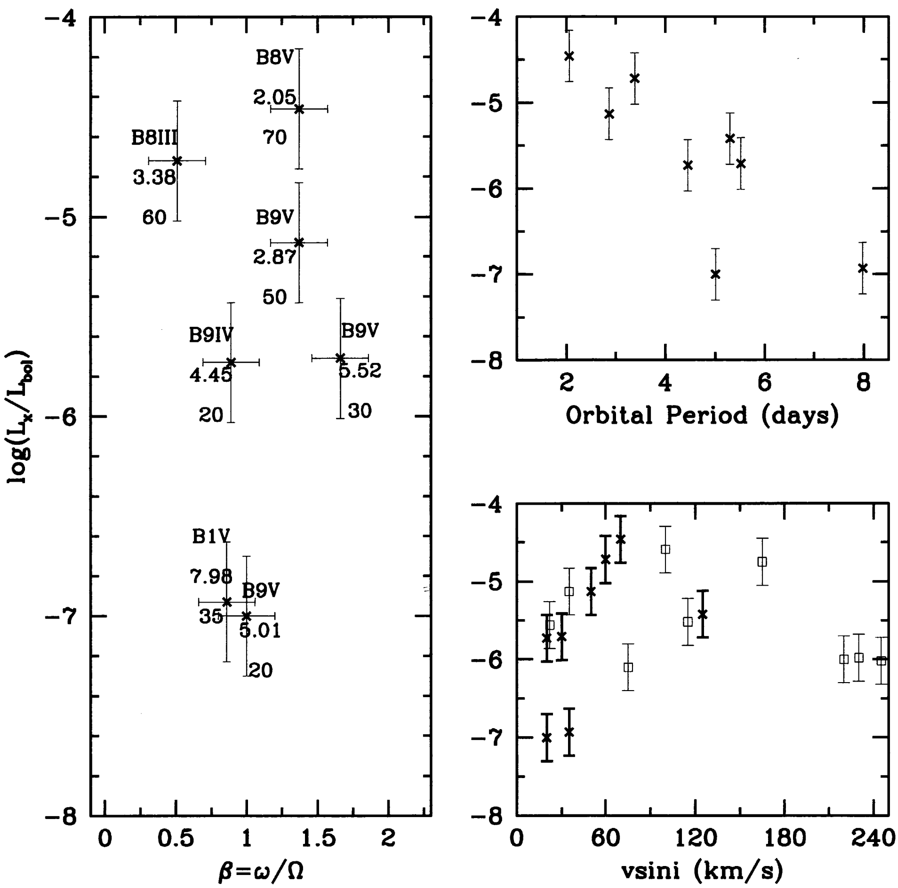

Figure 1. $\log(L_X/L_{bol})$ as a function of β, orbital period and $v \sin i$ for a sample of B-star binaries (crosses) from the catalogue of Abt et al. (2002). The open squares are single B8-9V stars with X-ray detections in Berghoefer et al. (1996). The decreasing trend with orbital period is reminiscent of the effects expected due to wind-wind collisions.

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