Rev. Mexicana Astron. Astrof., 21, 467-470 (1990)

ON THE HARD, PULSATING X-RAY TRANSIENTS

Eduardo Janot-Pacheco
Instituto Astronômico e Geofísico
Universidade de São Paulo /Brazil

ABSTRACT: It is shown that the X-ray luminosities observed in Be/X-ray systems can be explained by accretion from the extended, equatorially-concentrated, expanding envelope of the Be companion.

RESUMO: Mostra-se que as luminosidades em raios X observadas em sistemas Be/X podem ser explicadas por acreção a partir do envelope extenso, concentrado equatorialmente, do companheiro Be.

Key words: STARS-Be -- STARS-BINARIES -- X-RAYS-SOURCES

INTRODUCTION.

Optical studies and X-ray pulse timing analysis have shown that hard x-ray transients are binary systems consisting of a Be star and a magnetized, rotating neutron star, with orbital periods of the order of several weeks to months and high eccentricities (Van den Heuvel & Rappaport, 1987).

Many of these sources display periodically recurrent X-ray outbursts near periastron passage, when the neutron star accretes matter from the denser layers of the Be envelope.

Tn this paper we compare observed and calculated maximum X-ray luminosity of 8 Be/X-ray binaries by supposing that the neutron stars are in equatorial orbits and accrete from the dense, slowly expanding Be star envelopes responsible for the observed IR excess and Balmer emission. These results are an up-dated version of those presented earlier by Janot-Pacheco (1987). More recently, similar conclusions were independently published by Waters et al. 1988).

THE PEAK X-RAY LUMINOSITIES.

The X-ray luminosities in units of 10^{35} erg/s can be written apud (Davidson & Ostriker, 1973):

$$L_{35} = 1.4 \times 10^{-6}\, n(r).(Vrel/100\ km/s)^{-3} \quad , \qquad (1)$$

where n is the particle density of the accretion reservoir and V_{rel} is the relative velocity of the compact object with respect to the expanding envelope. We assume that the X-ray maximum occurs at periastron passage, so that L_{max} will be calculated at that orbital point. The relative velocity is given by:

$$V_{rel}{}^2 = V_{orb}{}^2 + V_{exp}{}^2 \quad , \qquad (2)$$

expansion velocity of the Be envelope (it can be shown that the rotation velocity component of the envelope at the typical periastron distances of

Be/X-ray systems can be neglected, see Janot-Pacheco, 1987). n(r) and V_{exp} are taken from the Be equatorial "standard" model of Poeckert & Marlborough (1978):

$$n(r) = n(R*).(r/R*)^{m} , \quad (3)$$

and

$$V_{exp}(r) = 0.2\ V_0.(r/R*)^{m-2} , \quad (4)$$

with V_0=5 km/s, m = 4, $n(R*)$ = 3.3 x 10^{13} cm^{-3} and the Be radius, R* = $7R_\odot$.

From Kepler's third law we obtain at periastron:

$$r/R* = (G\ M_{tot}\ P^2/4\pi^2\ R^3))^{1/3}.(1-e) , \quad (5)$$

and

$$V_{orb} = ((1 + e)/(1 - e))\ 1/2.(2\pi\ G\ M_{tot})^{1/3}.P^{-1/3} , \quad (6)$$

where M_{tot} is the total mass of the system (assumed to be = $15M_\odot$), P its orbital period and e the eccentricity of the orbit. Be/X-ray binaries have generally large orbital eccentricities (e. g. van den Heuvel & Rappaport, 1987). Janot-Pacheco (1987) computed a relation between the orbital period and the eccentricity using data from 8 HMXRB (Cen X-3, 4U1700-37, 4U1907+09, Vela X-1, 4U0115+63, V032+53 and 4U1223-62):

$$e = (0.27 \pm 0.12)\ log\ P - (0.06 \pm 0.15) , \quad (7)$$

where P is given in days. We used this relation to estimate e for the last four sources in Table 1. These estimated values are in fair agreement with independent suggestions given in the literature. Equations (1) through (6) or (7) were used to calculate the X-ray luminosities of 8 Be/X-ray binaries for which reasonable distances estimate exist. These calculated and the observed luminosities agree quite well (Table 1).

It should be pointed out that we have used for all sources the same values for the total mass of the system and for the Be envelope parameters.

TABLE 1.

Source	P	e	L_{max}(erg/s) calculated	L_{max}(erg/s) observed	Refs.
0338-668	16.7	0.4	1.3E38	1.0E39	1/8
0115+634	24.3	0.34	4.6E37	9.0E37	9
0332+53	34.2	0.31	1.3E37	1.7E36-1.2E37[b]	2
2030+375	46	0.4	7.9E36	2.5E36-1.0E38[b]	3
0535+262	111	0.49±0.12[a]	4.3E34-1.7E37	6.6E36	4/5
304-1	132.5	0.51±0.13[a]	1.3E34-1.8E36	7.7E35	6
1145-619	186.5	0.55±0.14[a]	3.3E33-8.6E36	6.0E36	7
0352+309	580	0.68±0.16[a]	1.1E32-3.3E35	1.0E34	1

[a]Calculated from (7) .
[b]For the extreme distances given in the literature.
References: (1) Bradt & McClintock 1983; (2) Corbet et al. 1986; (3) Angelini et al. 1989 (4) Janot-Pacheco et al. 1987; (5) Makino et al. 1989; (6) Priedhorsky & Terrell 1983; (7) Mereghetti et al. 1986; (8) van den Heuvel & Rappaport 1987; (9) Whitlock et al. 1988.

This indicates that the envelopes of Be stars are on the average rather similar, as has been stressed recently by some authors (e.g., Dachs et al., 1986; Hanuschik, 1986; Waters et al., 1987).

In a forthcoming paper we will show that the correlation between the orbital period and the (equilibrium) pulse period of the Be star X-ray binaries can be properly reproduced with our scheme, provided the orbital eccentricities and the neutron star surface magnetic field values are carefully taken into account. It will also be shown thet there is little latitude left for the variation of the parameters *n(R*)* and *m*, if the correlation is to be fulfilled (Janot-Pacheco, 1989) (see Figure 1).

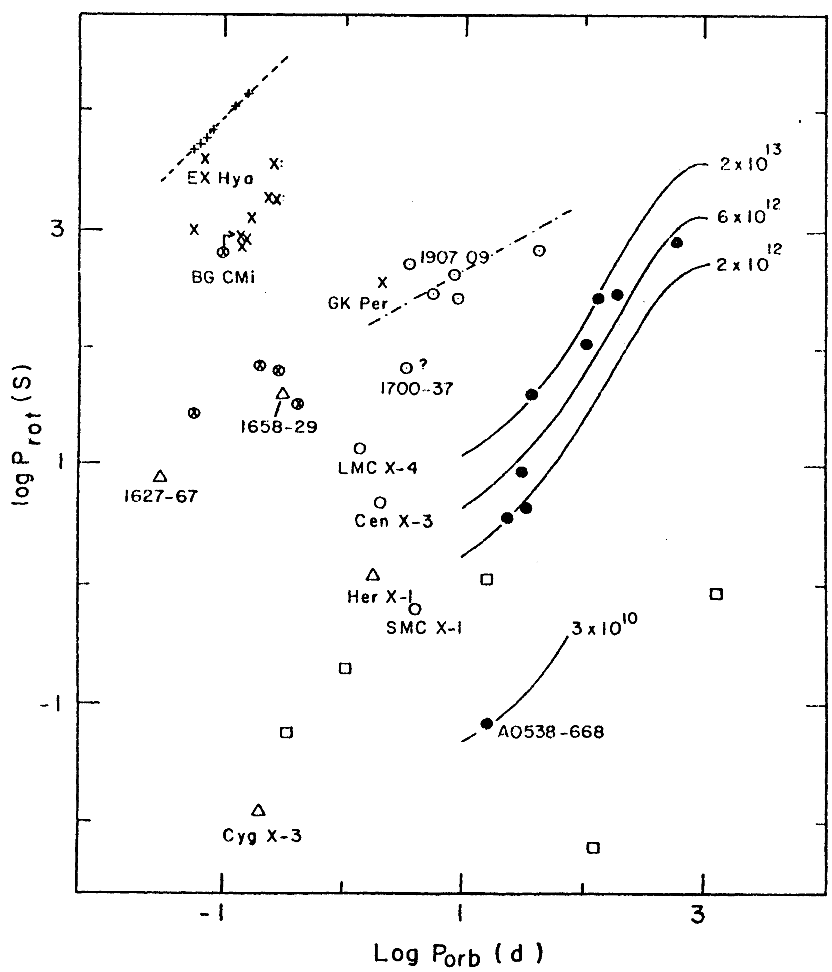

Fig. 1.- Rotation period - orbital period plane for X-ray binaries. Solid lines show the results of our model for Be/X -ray sources, figures give the neutron star magnetic field in gauss.

References.

Angelini, L., Steila, L., Parmar, A.N.: 1989, Exosat Preprint no 110.
Bradt, H.V.D., McClintock, J.E. 1983, *Ann. Rev. Astron. Astrophys.* 21, 13.
Corbet, R.H.V.D. et al. 1986, *Astron. Astrophys.* 162, 117.

Dachs, J. et al. 1986, *Astron. Astrophys.* 159, 276.
Davidson, K., Ostriker, J.P. 1973, *Astrophys. J.* 179, 585.
Hanuschik, R.W. 1986, *Astron. Astrophys.* 166, 185.
Van den Heuvel, E.P.J., Rappaport, S. 1987, in *Physics of Be Stars*, eds. A. Slettebak & T.P.Snow, p. 291.
Janot-Pacheco, E. 1987, Thesis, Université Paris VII.
Janot-Pacheco, E. 1989, in preparation.
Janot-Pacheco, E. Motch, C., Mouchet, M. 187, *Astron. Astrophys.* 117, 91.
Poeckert, R., Marlborough, J.M. 1978, *Astrophys. J.* 220, 940.
Makino, F. et al. 1989, *IAUC* no. 4769.
Mereghetti, H. et al. 1987, *Astrophys. J.* 312, 755.
Priedhorsky, W.C., Terrell, J. 1983, *Nature* 303, 681.
Waters, L.B.F.M. et al. 1987, *Astron. Astrophys.* 185, 206.
Whitlock, L. et al. 1988, Los Alamos Preprint no. 88-1770.

Eduardo Janot-Pacheco: Instituto Astronômico e Geofísico, Universidade de São Paulo, Brazil