Be COMPONENTS IN X-RAY BINARIES

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GENERAL CHARACTERISTICS

The Be X-ray binaries show rather weak and variable X-rays. They can be divided into two types, the transient sources and the permanent sources. Two ranges for the X-ray luminosity L_X can be discerned: a) $L_X \sim 10^{34}$erg s^{-1} (X Per, γ Cas, 2S0114+65, all permanent sources); b) $L_X \sim 10^{36}$erg s^{-1}. They have long periods, hence wide orbits, they ar not eclipsing and their mass loss rates are low. The optical spectra are generally very variable and irregular, masking periodic changes. No optical orbits exist and only for 4U0115+63 an X-ray orbit is known (Rappaport et al.1978). An overview of the Be X-ray binaries with some of their characteristics is given in Table 1.

Object	V	Spectral type	d (kpc)	P (days)	P_{pulse} (s)	L_X/L_{opt}	$M/M_\odot$	$R/R_\odot$
2S0050-727T	15	O9(III-V)e	63	-	-	0.5	24	8
2S0052-739T	16.0	B1Ve	63	-	-	3	14	6
4U0053+604	2.3	B0.5(II-V)e	0.30	>1000?	-	6E-6	25	15
2S0114+650	11.0	B0.5IIIe	-	-	-	1.5E-4	-	-
4U0115+634T	15.6	Be	<7	24.3	3.6	2	-	-
4U0352+306	6.0-6.7	O9.5(III-V)e	0.35	581?	835	1E-4	-	-
A0535+262T	9.1	O9.7IIIe	1.8	28?77?	104	0.08	27	12
4U0538-669T	13.0-15.7	Be?	-	16.7	-	-	-	-
A1118-615	12.1	O9.5(III-V)e	5	-	405	2	33	15
4U1145-619	9	B0.5(III-V)e	1.5	187.5	291	0.2	15	6
4U1258-613T	14.7	B2Vne	2.4	>20	272	0.3	14	11

Table 1. Be X-ray binaries with some of their parameters (T=transient).

VARIABILITY AND THE BINARY HYPOTHESIS

Be primaries in X-ray binaries as well as classical Be stars present variability with all sorts of timescales (minutes,days,years). For example the rapid variations of the Balmer lines in γ Cas, X Per (Hutchings,1976) and Hen 715 (Hammerschlag-Hensberge et al.1980)(see Fig.1) are similar to these observed in o And and χ Oph (Doazan,1976). Changes in luminosity and photometric irregular behaviour in the three Be X-ray sources mentioned above are also found in most of the classical Be stars (Hutchings,1976).

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due to heating by the X-ray flux) or in an accretion disk around the compact source. In some Be X-ray stars HeII λ4686 is also seen weakly in emission. The mechanism of formation of this line is not as well understood as for the close X-ray binaries. The behaviour of the line seems to be correlated with the ratio of the X-ray to the optical luminosity. Emission is observed in systems with a large ratio, absorption in systems with a small ratio.

X Per (Hubert-Delplace and Hubert, 1979)	1953-63	Hα , Hβ , Hγ emission Hγ very weak emission on diffuse absorption FeII, SiII emission (FeII maximum in 1961) HeI filled
	1963-74	FeII lines disappear, other emission lines diminish
	after 1974	Hβ weak emission, Hγ large diffuse absorption
A1118-61 (Janot-Pacheco et al. 1981)	1975-77	Hα , Hγ emission Hδ partially filled in with emission HeI lines filled; FeII, |FeII| many emission lines
Hen 715	1978-80	Hβ emission Hγ absorption - central emission FeII, |FeII| detected

Few FeII lines observed in A1118-61 are present in Hen 715.

Table 2. The most important spectral lines in 3 Be X-ray sources.

EVOLUTIONARY SCENARIO FOR BE X-RAY BINARIES

The masses of the Be components in X-ray binaries can be derived from comparison of the position in the HRD (T_{eff},M_{bol}) with calculated evolutionary tracks (Table 1). The temperatures T_{eff} were taken from Underhill et al. (1979) and the bolometric corrections from Code et al. (1976). The Be components of the Be X-ray binaries are all situated near the ZAMS, hence they are not evolved stars (Figure 2). The masses range between 15 and 30 $M_\odot$. As a typical scenario for such systems the evolution of a $15M_\odot$+$8M_\odot$ (De Grève and de Loore (1977)) can be used (Table 3). The primary evolves up to its supernova explosion and becomes a compact companion to the optical secondary. According to Packet (1981) matter accreted by the secondary in the case of Roche lobe overflow will spin up the star to rotational velocities near the brake-up velocity. Hence most of the matter expelled by the overflowing primary has to leave the system. Probably this overflowing material is stored in a ring around the secondary and then leaves the system in a radial symmetric outflow pattern, leading to a considerable widening of the system and consequently large orbital periods. In the case of a $15M_\odot$+$8M_\odot$ system with 50% of the matter leaving the system the period is increased with a factor of 6 to 7. This is in contrast with the bulk of massive X-ray binaries where short periods are found, a consequence of substantial mass and angular momentum losses. The systematic longer periods and fast rotational velocities of the Be systems would point to a larger accretion by the secondary. A number of classical Be binaries contain red components; such systems could represent intermediate stages between massive main sequence systems and Be X-ray systems, either before or after mass transfer (17 Lep:B9Ve+M2III, P=276d - AX Mon:B0.5e+K2II, P=232.5d - HD 218393:B3e+K1III, P=38d).

All these phenomena are obviously related to variations in the shell or envelope structure. Probably the variations in the X-ray flux observed in the Be X-ray sources are also due to changes in their envelopes. 4U1145-61(Hen 715) is a good illustration of the different types of variability that may occur in a Be X-ray source. A dramatic change in the behaviour of the Hβ line was observed in April 78. Normally Hβ is seen in emission, sometimes superimposed on a broad absorption feature, but on 28 April 1978 Hβ appeared purely in absorption. Also Hγ and Hδ were strongly in absorption, the HeI lines were enhanced and the λλ4640-4650 blend was weakened. Figure 1 illustrates this strong variation in Hβ and changes in the emission profile on short and long timescales.

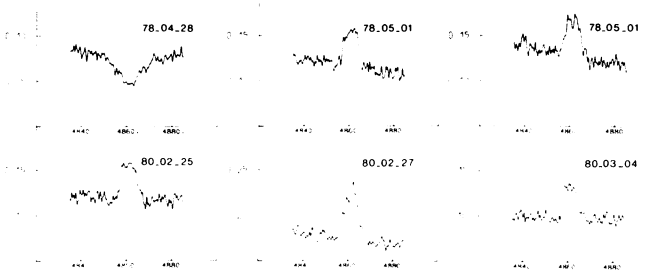

Figure 1. The variations of Hβ at different timescales. The intensities are relative to the clear plate.

At the epoch when Hβ was in absorption no X-ray flux was detected. On 1 May 1978 Hβ appeared in strong emission (Hammerschlag-Hensberge et al. 1980). On 7 May 1978 the X-ray source was active and very bright (Jernigan et al.1978). From 30 December 1979 to April 1980 Hen 715 became fainter by 0.25 magnitude. Simultaneously the IR excess disappeared, suggesting the loss of the circumstellar envelope (Pakull et al.1980). Between 25 February and 8 March 1980 Hβ was in emission as well as the FeII lines.

It is necessary to study the variability over the whole spectral range (from X-rays to infrared) to determine whether the Be X-ray sources are binaries or not. Although for none of these sources an optical orbit has been derived some arguments point to their binary character :

a) X-ray pulsation which is the signature of a rotating compact object (modulated by orbital motion in the case of 4U0115+63)

b) several classical Be stars are known to be binaries (17 Lep, AX Mon, HR 894). Such systems could be precursors of Be X-ray systems.

THE OPTICAL SPECTRA OF BE PRIMARIES IN X-RAY SOURCES

In comparing the optical spectra of some Be primaries in X-ray sources we concentrate on the emission lines. Table 2 lists the behaviour of the strongest lines of three Be X-ray sources : X Per, A1118-61, Hen 715. We conclude that Hen 715 is a Be star intermediate between A1118-61 (strong emission lines) and X Per (1976-77). A1118-61 looks like X Per during the beginning of the sixties.

For massive X-ray binaries with short orbital periods the HeII λ4686 line is often observed in emission indicating that this line is formed in the atmosphere of the primary (either by the process occurring in Of stars or

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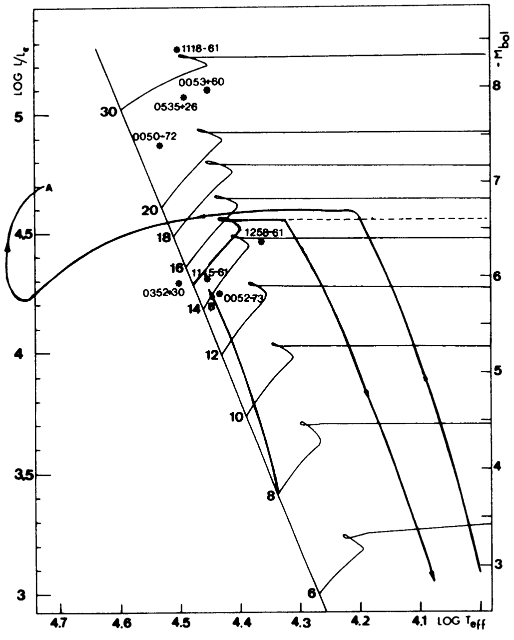

Figure 2. Evolutionary tracks and the positions of the Be components of Table 1. Note that X Per is found below the ZAMS (cf. Persi et al.1977). To reach the ZAMS a distance of 430 pc would be necessary.

	$T/10^6$yrs	$M/M_\odot$	$R/R_\odot$	log L	log Teff	P(d)
Start ZAMS	0	15	5	4.26	4.48	5
Start mass transfer	8.4028	15	15	4.59	4.32	5
Min luminosity	8.4086	8.53	11.1	2.10	3.76	4.6
He ignition	8.4299	3.48	26	4.55	4.19	23
End mass transfer	8.4384	3.3	28.6	4.6	4.19	31
C ignition	9.446	3.3	1.8	4.64	4.79	31

Table 3. Evolution of a binary system with initial masses of $15M_\odot + 8M_\odot$.

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DISCUSSION

Viotti: Since you mentioned the presence of Fe II emission lines in the optical spectra of some x-ray/Be stars, I would like to stress the importance of the "Fe II problem" in the Be phenomenon. These lines, which have a large range of excitation potentials, oscillator strengths and wavelengths might give important information on the outer envelopes or rings or so of Be stars.
I also noted the large range of ionization energies (from Si II to N V) you quoted. If I am correct this large range is mostly concerned with resonance lines, while excited lines (N III, O IV) belong to a smaller ionization energy range.

Giovannelli: About Hen 715: Have you searched the correlation between the variations of the doubling in Hβ and the orbital period?

de Loore: The analysis of the spectra of Hen 715 is in progress, but what you mention has not been performed.

Pakull: There seems to be a correlation between the He II 4686 emission and L_x/L_{opt} in the close roche-lobe filling steady x-ray binaries. In the case of the Be star x-ray systems, which are mostly transients, however, optical observations have been carried out mostly some time after the x-ray outbursts. Accordingly one would not expect such a correlation.

de Loore: I agree with this remark. The He II 4686 A intensity is in massive x-ray systems connected with the L_x/L_{opt} ratio (Hutchings, 1980). Probably this is related with the geometry of these systems, presence of disks, etc., and in long period systems, as the Be x-ray binaries, the conductors for the existence of the He II emission are not there.
However, the correlation seems to be present, although I see no explanation, since, as you mention, the x-ray value is unknown at the moment of the observations in the visual for variable transient sources.