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Blackbody excess in persistent Be pulsars

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Abstract. We report on the main results obtained thanks to an observation campaign, performed with *XMM–Newton*, of four persistent, low–luminosity ($L_{\rm X} \sim 10^{34}$ erg s^{-1}) and long–period ($P > 200$ s) Be accreting pulsars. We found that all sources considered here are characterized by a spectral excess that can be described with a blackbody component of high temperature ($kT_{\rm BB} > 1$ keV) and small area ($R_{\rm BB} < 0.5$ km). We show that: 1) this feature is a common property of several low–luminosity X–ray binaries; 2) for most sources the blackbody parameters (radius and temperature) are within a narrow range of values; 3) it can be interpreted as emission from the NS polar caps.

Key words. X–rays: binaries – accretion, accretion disks – stars: emission line, Be – X–rays: individual: 4U 0352+309, RX J0146.9+6121, RX J0440.9+4431, RX J1037.5–5647

1. Introduction

We have analyzed the *XMM–Newton* observations of the four *persistent* Be pulsars originally identified by Reig & Roche (1999), i.e. RX J0146.9+6121 (La Palombara & Mereghetti 2006), 4U 0352+309 (La Palombara & Mereghetti 2007), RX J1037.5-5647 (La Palombara et al. 2009), and RX J0440.9+4431 (La Palombara et al. 2012); their main parameters are reported in Table 1. These sources have persistently low luminosity ($L_{\rm X} \sim 10^{34-35}$ erg s^{-1}) and long pulse period ($P > 200$ s), two properties which suggest that the neutron star (NS) orbits the Be star in a wide and nearly circular orbit, continuously accreting material from the low–density outer regions of the circumstellar envelope.

The *XMM–Newton* spectra of these Be pulsars cannot be described with a single-component model: the fits with a power–law (PL) or a blackbody (BB) model are affected by large residuals, while other models are rejected by the data. On the other hand, a good fit is obtained with a PL+BB model. In all cases the BB component is characterized by a high temperature ($kT_{\rm BB} > 1$ keV) and a small emission radius ($R_{\rm BB} < 0.5$ km), and contributes to 30–40 % of the source flux below 10 keV (Table 1): therefore this *hot–BB* spectral component can be considered as an additional common property of the persistent Be pulsars, which stands beside those previously known.

Based on the emission models proposed by Hickox et al. (2004), the low luminosity of these pulsars suggests that the observed *BB* component is due to thermal emission from the NS polar cap. Assuming the standard NS parameters $M_{\rm NS} = 1.4\ M_{\odot}$, $R_{\rm NS} = 10^6$ cm, and $B_{\rm NS} = 10^{12}$ G, from the source luminosities we can estimate the accretion rate and, then, the radius of the accretion column $R_{\rm col}$. For all

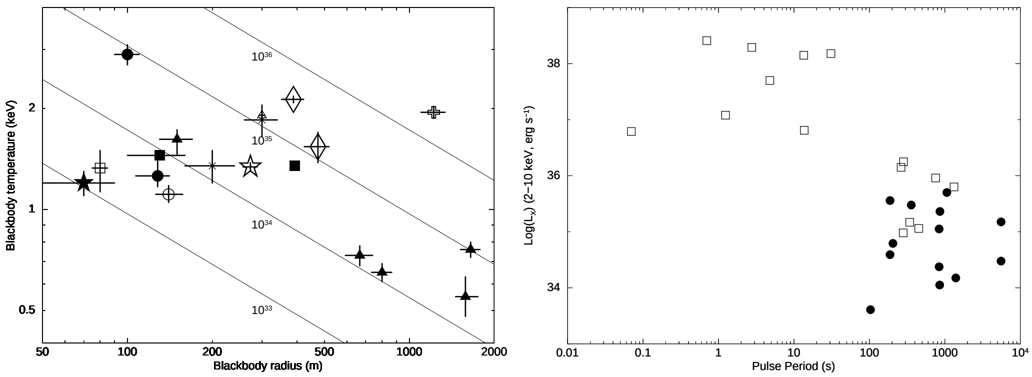

Fig. 1. *Left*: Best–fit values for $R_{\rm BB}$ and $kT_{\rm BB}$ of the low–luminosity high–mass X–ray binaries with a *hot–BB* spectral component (different symbols refer to different sources); the continuous lines connect the BB parameters corresponding to four different levels of $L_{\rm X}$ (in erg s^{-1}). *Right*: X–ray luminosity (in the 2–10 keV energy range) of the pulsars with a detected thermal excess as a function of the pulse period; *filled circles* refer to the *hot–BB* pulsars, *empty squares* to the *soft–excess* sources.

Table 1. Main parameters of the persistent Be X–ray binaries

Source	4U 0352+309	RX J0146.9+6121	RX J1037.5-5647	RX J0440.9+4431
Optical Spectral Type	09.5 IIIe	B0 IIIe	B0 III-Ve	B0.2 Ve
Distance (kpc)	$\simeq 1$	$\simeq 2.5$	$\simeq 5$	$\simeq 3.3$
Pulse Period (s)	839.3	1396.1	853.4	204.98
$L_{\rm X}$ (0.3–10 keV, erg s^{-1})	1.4×10^{35}	1.5×10^{34}	1.2×10^{34}	8.3×10^{34}
$L_{\rm BB}$ (0.3–10 keV, erg s^{-1})	5.5×10^{34}	3.6×10^{33}	5.0×10^{33}	2.9×10^{34}
$L_{\rm BB}/L_{\rm X}$ (%)	39	24	42	35
$T_{\rm BB}$ (keV)	1.42 ± 0.03	1.11 ± 0.06	$1.26^{+0.16}_{-0.09}$	1.34 ± 0.04
$R_{\rm BB}$ (m)	361 ± 3	140 ± 15	128^{+13}_{-21}	273 ± 16
$R_{\rm col}$ (m)	~ 330	~ 230	~ 200	~ 320

sources we found that $R_{\rm col} \sim R_{\rm BB}$, thus confirming the previous hypothesis.

A spectral feature similar to the *hot BB* of the persistent Be pulsars has been observed also in other low–luminosity ($L_{\rm X} \leq 10^{36}$ erg s^{-1}) high–mass X–ray binaries (La Palombara et al. 2012). In Fig. 1 (*left panel*) we report the best–fit radius and temperature for the BB component of these sources: it shows that, for all the sources, $kT_{\rm BB} > 0.5$ keV and $R_{\rm BB} <$ 2 km; moreover, for the less luminous sources ($L_{\rm X} \sim 10^{34}$ erg s^{-1}), the spectral parameters are within a narrow range of values ($kT_{\rm BB} \sim 1$–2 keV and $R_{\rm BB} < 200$ m), with a 20–40 % contribution of the blackbody component. In contrast to this sample of sources, several pulsars are characterized by a *soft* excess, since the fit of this component with a thermal emission model provides low temperatures ($kT_{\rm SE} < 0.5$ keV) and large emitting regions ($R_{\rm SE} > 100$ km). In Fig. 1 (*right panel*) we report the luminosity and pulse period of both types of pulsars. On the average, the *hot–BB* pulsars are characterized by the lowest luminosities and the longest periods; their *hot–BB* spectral component is a common feature which separates them from all the other pulsars, strongly suggesting that they form a distinct and well–defined class of binary pulsars.

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