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BeppoSAX study of the X-ray binary XB 1832−330 located in the globular cluster NGC 6652

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Abstract. Results of a 2001 March 17–20 BeppoSAX observation of the X-ray binary XB 1832−330 located in the globular cluster NGC 6652 are presented. In contrast to the majority of luminous globular cluster X-ray sources, the (0.1–200 keV) BeppoSAX spectrum cannot be fit with a disk-blackbody and COMPTT Comptonization model, unless partial covering is included. This confirms the ASCA detection of partial covering by Mukai & Smale (2000). The best-fit spectral parameters are similar to those of the globular cluster sources with orbital periods of <1 hr, implying that XB 1832−330 is also an ultra-compact system. A plausible optical candidate to XB 1832−330 has recently been discovered by Heinke et al. (2001) which shows evidence for possible 0.92, 2.22, or 4.44 hr periodicities. We find no evidence for any 2–10 keV periodic modulation at any of these periods with a 2σ upper limit to the semi-amplitude of any sinusoid of $\lesssim 1.5\%$.

Key words. accretion, accretion disks – stars: individual: XB 1832−330 – globular clusters: individual: NGC 6652 – X-rays: general

1. Introduction

The X-ray source XB 1832−330 in NGC 6652 is one of 12 bright ($L_x \gtrsim 10^{36}$ erg s^{-1}) low-mass X-ray binaries (LMXRBs) located in galactic globular clusters. Although the uncertainty region for the HEAO-1 source H 1825-331 contained NGC 6652, it was not originally considered to be a secure identification because of its 2.7 deg^2 area (Hertz & Wood 1985). A secure identification was obtained during the ROSAT All-Sky Survey when a bright source was detected co-incident with NGC 6652 (Predehl et al. 1991). The source was subsequently detected in pointed ROSAT observations (Johnston et al. 1996) and Type I X-ray bursts and persistent emission were observed by the BeppoSAX Wide Field Cameras (in't Zand et al. 1998) confirming that the compact object in the system is a neutron star. From HST observations, a relatively low luminosity star ($M_V = +4.7$), located 2.3σ from the ROSAT position, which exhibits a 43.6 ± 0.6 min modulation was proposed as the counterpart by Deutsch et al. (1998, 2000). However, recent *Chandra* High Resolution Camera-Imager (HRC-I) observations revealed three additional faint X-ray sources in NGC 6652 and the optical

counterpart proposed by Deutsch et al. (1998, 2000) is clearly associated with one of these (Heinke et al. 2001). Instead, XB 1832−330 is identified with a blue variable object with $M_V = +3.7$ (Heinke et al. 2001). Possible periods of 0.92, 2.22 or 4.44 hours as well as non-periodic flickering were observed. This absolute V band magnitude is comparable with those of ultra-compact LMXRBs in globular clusters (+3.7 for X 1820-303 in NGC 6624 and +5.6 for X 1850-087 in NGC 6712; van Paradijs & McClintock 1994), although a low-mass M dwarf companion cannot be excluded.

As part of a program to observe diffuse galactic emission XB 1832−330 was serendipitously observed by ASCA (Mukai & Smale 2000). Although the set-up was far from ideal (no GIS2 instrument, 4-CCD mode for both SIS instruments with the counts spread over all 4 CCD devices), a 0.7–10 keV spectrum was obtained. Mukai & Smale (2000) had difficulty in finding an acceptable spectral model and used partial covering of a power-law continuum as their best-fit model. However, as they comment, given the ASCA calibration uncertainties and the narrow energy range of the data, it is not possible to say whether this spectral shape is unique, or preferred. We note that the *Chandra* observation of Heinke et al. (2001) used the HRC-I which does not provide spectral information.

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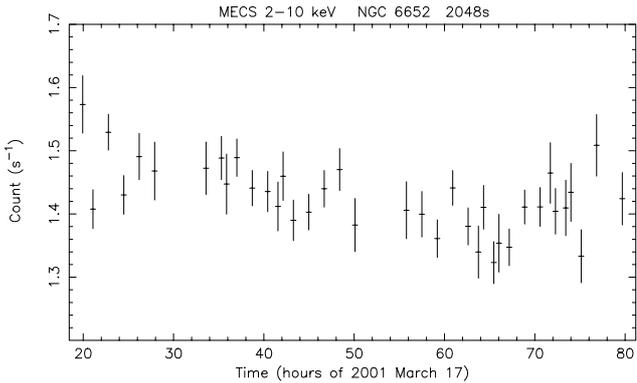
MECS 2–10 keV   NGC 6652   2048s

Fig. 1. The MECS 2–10 keV lightcurve of XB 1832−330 plotted with a time resolution of 2048 s.

We report on a BeppoSAX observation of XB 1832−330 made to complete the systematic study of the persistent luminous globular cluster X-ray sources reported in Sidoli et al. (2001) and references within. NGC 6652 is a compact globular cluster located ≈ 2 kpc from the Galactic center (Chaboyer et al. 2000). It has a low reddening ($E_{B-V} = 0.10 \pm 0.02$) and an abundance [Fe/H] ≈ -0.9 (Ortolani et al. 1994). This redenning corresponds to an absorption, N_{H}, of $\sim 7 \times 10^{20}$ atom cm^{-2}, using the relation between A_v and N_{H} of Predehl & Schmitt (1995).

2. Observations

Results from the Low-Energy Concentrator Spectrometer (LECS; 0.1–10 keV; Parmar et al. 1997), the Medium-Energy Concentrator Spectrometer (MECS; 1.8–10 keV; Boella et al. 1997), and the Phoswich Detection System (PDS; 15–300 keV; Frontera et al. 1997) on-board BeppoSAX are presented. The MECS consists of two grazing incidence telescopes with imaging gas scintillation proportional counters in their focal planes. The LECS uses an identical concentrator system as the MECS, but with an ultra-thin entrance window to extend the low-energy response to 0.1 keV. The non-imaging PDS consists of four units arranged in pairs each having a separate collimator.

The region of sky containing XB 1832−330 was observed by BeppoSAX on 2001 March 17 19:39 to March 20 08:59 UT. Good data were selected in the usual way using the SAXDAS 2.1.1 data analysis package. A PDS collimator dwell time of 96 s for each on- and off-source position was used with a rocking angle of 210′. LECS and MECS data were extracted centered on the position of XB 1832−330 using radii of 8′ and 4′, respectively. The exposures in the LECS, MECS, and PDS are 20.3 ks, 53.3 ks, and 29.3 ks, respectively. Background subtractions for the LECS and MECS were performed using standard files, but is not critical for such a bright source. Background subtraction for the PDS was performed using data obtained during intervals when the collimators were offset from the source.

3. Results

3.1. Lightcurve

Figure 1 shows the 2–10 keV MECS lightcurve of XB 1832−330 with a binning of 2048 s. There is no evidence for any X-ray bursts. The source exhibits variability, in excess of that predicted from counting statistics, with a root mean square variability of $2.7 \pm 0.7\%$ on a timescale of 2048 s. Searches for variability around the 0.92, 2.22 and 4.44 hour possible periods of Heinke et al. (2001) and the 0.73 hour period of Deutsch et al. (2000) were performed on a 2–10 keV MECS lightcurve with a 256 s binning using period-folding and a Lomb-Scargle periodogram. We find no evidence for significant signals near any of the above periods. The data were folded at each of the proposed periods and a folded profile produced using 8 phase bins. Unsurprisingly, no significant evidence for a modulation was present. The profiles were then fit with a sine function with a fixed period. The 2σ upper limits to the semi-amplitudes of any such modulations are 0.8%, 1.4% and 1.4% for the 0.92, 2.22 and 4.44 hr periods, respectively.

3.2. Spectrum

The overall spectrum of XB 1832−330 was first investigated by simultaneously fitting data from the LECS, MECS and PDS using XSPEC version 11. We note that the three faint X-ray sources detected in NGC 6652 by Heinke et al. (2001) using the *Chandra* HRC-I each have X-ray luminosities ~ 100 times lower than XB 1832−330, and are unlikely to contribute significantly to the observed counts. The LECS and MECS spectra were rebinned to oversample the full width half-maximum of the energy resolution by a factor 3 and to have additionally a minimum of 20 counts per bin to allow use of the χ^2 statistic. The PDS spectrum was rebinned using standard techniques in SAXDAS. 1% uncertainties were included to allow for systematic uncertainties in the instrumental responses. All spectral uncertainties are given at 90% confidence. Data were selected in the energy ranges 0.1–4.0 keV (LECS), 1.8–10 keV (MECS), and 15–200 keV (PDS), where the instrument responses are well determined and sufficient counts obtained. This gives background-subtracted count rates of 0.69, 1.45, and 1.74 s^{-1} for the LECS, MECS, and PDS, respectively. The photoelectric absorption cross sections of Morrison & McCammon (1983) are used throughout. We note that XB 1832−330 is detected at higher energies than any of the other globular cluster LMXRBs observed with BeppoSAX (see Sidoli et al. 2001).

Initially, simple models were tried, including absorbed power-law, thermal bremsstrahlung and a cutoff power-law ($E^{-\alpha} \exp - (E_{\mathrm{c}}/kT)$). Factors were included in the spectral fitting to allow for normalization uncertainties between the instruments. These factors were constrained to be within their usual ranges during the fitting. A power-law with a photon index, α, = 1.8 and low-energy

absorption equivalent to 4×10^{21} atom cm^{-2} and a 18 keV bremsstrahlung give unacceptable fits with χ^2's of 510 and 1127 for 255 degrees of freedom (d.o.f.), respectively.

Sidoli et al. (2001) conducted a spectral survey of the luminous globular cluster X-ray sources using BeppoSAX. They found that with the exception of the accretion disk corona source X 2127+119 (NGC 7078) and at times X 1820-303 (NGC 6624), all the other globular cluster LMXRB spectra may be acceptably fit using a multicolor disk-blackbody (Mitsuda et al. 1984; Makishima et al. 1986) where r_{in} is the innermost radius of the disk, i the disk inclination angle and kT_{in} the blackbody effective temperature at r_{in}, and the COMPTT Comptonization model (Titarchuk 1994) where kT_{e} is the temperature of the Comptonizing electrons, τ_{e} the plasma optical depth with respect to electron scattering and kT_{W} the temperature of the input photon (Wien) distribution. Surprisingly, this model does not provide an acceptable fit to the XB 1832−330 spectrum, giving a χ^2 of 532.2 for 252 d.o.f.

The same model as used by Mukai & Smale (2000) in the energy range 0.7–10 keV consisting of a partially absorbed power-law gives a significantly better fit with a χ^2 of 364.3 for 253 d.o.f., suggesting that partial covering may be important. Examination of the residuals shows that this model does not well account for an overall curvature in the spectrum and the power-law was replaced with a cutoff power-law to give a χ^2 of 334.5 for 252 d.o.f. The decrease in χ^2 corresponds to an F-statistic of 22.5. The probability of such a decrease occurring by chance is very small (3.6×10^{-6}). We note that the cutoff energy of $200 \pm^{130}_{45}$ keV is well above the upper energy of ASCA. This model accounts for the *overall* shape of the 0.1–200 keV spectrum *reasonably* well (Fig. 2, left panel). The best-fit parameters are given in Table 1.

Examination of Fig. 2 shows that there are still structured residuals remaining, especially between 2–3 keV and above 6 keV. The size of these features ($\sim$10%) is larger then the calibration uncertainties of the BeppoSAX instruments. Sidoli et al. (2001) demonstrate that the BeppoSAX spectra of most luminous globular cluster LMXRBs can be modeled using a combination of a disk-blackbody and a COMPTT Comptonized continuum, while the results of Mukai & Smale (2000) (and see above) indicate that partial covering may be important. We therefore investigated whether partial covering of the standard Sidoli et al. (2001) spectral model could produce the observed spectral shape. A fit using a partially covered disk-blackbody and COMPTT Comptonized component gives a χ^2 of 286.8 for 249 d.o.f. The best-fit parameters are given in Table 1 and the spectrum shown in Fig. 2. The residuals are significantly less structured. The decrease in χ^2 compared to the partially covered cutoff power-law corresponds to an F-statistic of 41.1. The probability of such a decrease occurring by chance is $<10^{-20}$. We thus conclude that the intrinsic X-ray spectrum of XB 1832−330 may be modeled in the same way as the majority of other globular cluster LMXRB, as long as partial covering is included. The N_{H} of $(4.6 \pm^{2.3}_{1.2}) \times 10^{20}$ atom cm^{-2} is

Table 1. Fits to the 0.1–200 keV BeppoSAX spectrum of XB 1832−330 using a partially covered cutoff power-law model (upper) and a partially covered disk-blackbody and COMPTT model (lower). f_{PCF} is the fraction of the flux that undergoes extra absorption, N_{PCF}. L is the luminosity in erg s^{-1} for a distance of 9.2 kpc (Chaboyer et al. 2000)

Parameter	Value
N_{H} (10^{22} atom cm^{-2})	$0.18 \pm^{0.05}_{0.10}$
f_{PCF}	$0.67 \pm^{0.09}_{0.03}$
N_{PCF} (10^{22} atom cm^{-2})	$0.83 \pm^{0.07}_{0.06}$
α	$1.90 \pm^{0.03}_{0.02}$
E_{c} (keV)	$200 \pm^{130}_{45}$
χ^2/d.o.f.	$334.5/252$
N_{H} (10^{20} atom cm^{-2})	$4.6 \pm^{2.3}_{1.2}$
f_{PCF}	0.41 ± 0.05
N_{PCF} (10^{22} atom cm^{-2})	$1.70 \pm^{0.32}_{0.25}$
kT_{in} (keV)	0.64 ± 0.04
$r_{\mathrm{in}}(\cos\theta)^{0.5}$ (km)	$2.9 \pm^{0.8}_{0.4}$
kT_{W} (keV)	0.41 ± 0.02
kT_{e} (keV)	25.3 ± 1.8
τ_{p}	1.77 ± 0.07
L (1.0–10 keV)	1.6×10^{36}
L (0.1–200 keV)	4.4×10^{36}
χ^2/d.o.f.	$286.8/249$

consistent with that predicted from the redenning to NGC 6652 of 7×10^{20} atom cm^{-2}. The absorption (both interstellar and partial covering) corrected 0.1–100 keV ratio of disk-blackbody to COMPTT fluxes is 0.07. The 95% confidence upper limit equivalent width to a narrow emission line at 6.4 keV is 50 eV. In order to investigate whether reflection from cold material with cosmic abundances could be important, we replaced the partial covering by the PEXRAV model in XSPEC and re-fitted the spectrum. We were unable to obtain an acceptable fit with a χ^2 of 354.7 for 247 d.o.f.

4. Discussion

Results of a BeppoSAX observation of the X-ray binary XB 1832−330 located in the globular cluster NGC 6652 are presented. Sidoli et al. (2001) showed that the BeppoSAX spectra of most luminous globular cluster LMXRBs can be modeled using a combination of a disk-blackbody and a COMPTT Comptonized continuum. However, this model does not provide an acceptable fit to the XB 1832−330 spectrum, unless partial covering is included. This confirms the result of Mukai & Smale (2000) who found that partial covering was required to obtain an acceptable fit to an ASCA spectrum of XB 1832−330. However, the above partially covered two-component model gives a significantly better fit to the BeppoSAX spectrum than the partially covered power-law (or cutoff power-law) used by Mukai & Smale (2000).

Sidoli et al. (2001) found that the luminous globular cluster sources can be divided into two groups. In the first group, consisting of the 3 known ultra-compact (orbital period <1 hr) sources, the disk-blackbody
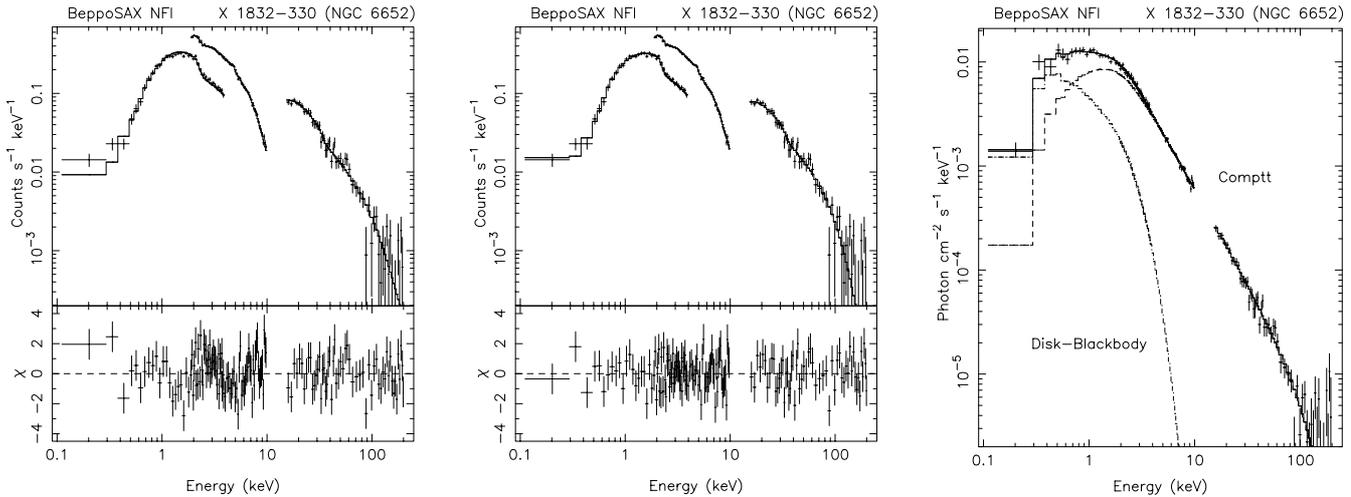
Fig. 2. The overall XB 1832−330 NFI spectrum together with the best-fit partially covered cutoff power-law (left) or disk-blackbody and COMPTT (center) model fits (see Table 1). The lower panels show the contributions to χ^2 for the two models with the same scaling. The right panel shows the assumed photon spectrum with the contributions of the disk-blackbody and COMPTT components indicated separately

temperatures and inner-radii appear physically realistic and the Comptonization seed photons temperatures and radii of the emission areas are consistent with the disk temperatures and inner radii. For all the other 7 sources studied, the disk-blackbody temperatures appear to be physically unrealistic and the Comptonization parameters are unrelated to those of the disk-blackbody emission. For XB 1832−330 the kT_{in} of 0.64 ± 0.04 keV is similar to those of the ultra-compact systems in NGC 1851, NGC 6712 and NGC 6624 all of which have $kT_{in} \lesssim 1$ keV, whereas the other sources have kT_{in} between 1.5–3.5 keV (Sidoli et al. 2001). The projected inner disk radius, r_{in} of 2.9 ± $^{0.8}_{0.4}$ km is also closer to those of the above ultra-compact sources which all have $r_{in} \gtrsim 4$ km, whereas the other sources have $r_{in} \lesssim 1$ km. Additionally, as with the above ultra-compact sources, the temperature of the Comptonization seed photons, kT_W, of 0.41 ± 0.02 keV is comparable to kT_{in} whereas in the other sources it is a factor ~5 lower. These comparisons lead us to propose that XB 1832−330 is also an ultra-compact system.

Following a precise *Chandra* position for XB 1832−330, a plausible optical candidate has recently been proposed by Heinke et al. (2001). The candidate is variable with evidence for either a 0.92 or 2.22 hr (or 4.44 hr for ellipsoidal variations) periodicity. The first of these is favored by the X-ray spectral properties discussed above. We find no evidence for any 2–10 keV periodic modulation at any of the above periods with 2σ upper limits to the semi-amplitude of any sinusoids of $\lesssim 1.5\%$. If the optical variations are indeed periodic, then the non-detection of an X-ray modulation is surprising. It is interesting to speculate on the origin of the partial covering. One explanation for the absorbed spectral component is that it is due to X-rays that pass through the outer layers of an accretion disk. This implies that the source is viewed close to the orbital plane and would probably result in an X-ray orbital modulation, which is not seen. Alternatively, the lack of an X-ray

orbital modulation may indicate that the absorbing material is located in an optically thick accretion disk corona surrounding the neutron star, or in a circum-binary disk or shell, perhaps resulting from the accumulation of outflowing material.

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