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Letter to the Editor

Discovery of pulsations from the Be/X-ray binary RX J0101.3−7211 in the SMC by XMM-Newton*

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Abstract. We report pulsations in the X-ray flux of RX J0101.3−7211 in the Small Magellanic Cloud (SMC) with a period of (455 ± 2) s in XMM-Newton EPIC-PN data. The X-ray spectrum can be described by a power-law with a photon index of 0.6 ± 0.1. Timing analysis of ROSAT PSPC and HRI archival data confirms the pulsations and indicates a period increase of $\sim$5 s since 1993. RX J0101.3−7211 varied in brightness during the ROSAT observations with timescales of years with a maximum unabsorbed flux of 6 10^{-13} erg cm^{-2} s^{-1} (0.1–2.4 keV). The flux during the XMM-Newton observation in the ROSAT band was lower than during the faintest ROSAT detection. The unabsorbed luminosity derived from the EPIC-PN spectrum is 2 10^{35} erg s^{-1} (0.2–10.0 keV) assuming a distance of 60 kpc. Optical spectra of the proposed counterpart taken at the 2.3 m telescope of MSSSO in Australia in August 2000 show strong Hα emission and indicate a Be star. The X-ray and optical data confirm RX J0101.3−7211 as a Be/X-ray binary pulsar in the SMC.

Key words. *Stars:* binaries: general – stars: emission-line, Be – galaxies: Magellanic Clouds – X-rays: stars

1. Introduction

The investigation of X-ray binary populations in nearby galaxies allows to study source samples at a similar distance. The Magellanic Clouds which are heavily interacting with our Galaxy and which show different metalicities are of particular interest in this respect.

Over the last decade observations of the Small Magellanic Cloud with ASCA, Beppo-SAX, ROSAT and Rossi-XTE revealed a large number of X-ray pulsars in this neighboring galaxy. The majority of these are accreting neutron stars in a binary system with a Be star as mass donor. These so-called Be/X-ray binaries form the major sub-class of high mass X-ray binary systems. Haberl & Sasaki (2000) list 47 Be/X-ray binaries (including candidates) in the SMC from which 15 were known as pulsars at the time of publication of their catalogue. From three more listed objects X-ray pulsations were reported (Corbet et al. 2001b; Yokogawa et al. 2000b,c) and three new pulsars were discovered recently (Yokogawa & Koyama 2000; Yokogawa et al. 2000d; Corbet et al. 2001a). Together with SMC X-1, a supergiant high mass X-ray binary pulsar, this results in a total of 22 X-ray pulsars known in the SMC (Mereghetti 2001).

One of the Be/X-ray binary candidates proposed by Haberl & Sasaki (2000) is the X-ray source RX J0101.3−7211 (source No. 43 in Haberl & Sasaki 2000) which may be related to the ASCA source No. 27 in Yokogawa et al. (2000a). The high variability of a factor of $\sim$10 (Sasaki et al. 2000b) and the presence of an emission line object (Meyssonnier & Azzopardi 1993) in the X-ray error circle makes this interpretation most likely. In this letter we report the discovery of X-ray pulsations in the flux of RX J0101.3−7211 in XMM-Newton observations of the nearby SNR 0102−72.3 in the SMC. Optical spectra taken at MSSSO confirm the pulsar as Be/X-ray binary.

2. XMM-Newton observations

RX J0101.3−7211 was detected serendipitously in XMM-Newton (Aschenbach et al. 2000) observations pointed at SNR 0102−72.3 in April 2000 during the calibration phase of the satellite (Table 1). It was located in the EPIC-PN (Strüder et al. 2001) image, but outside the field of view of the EPIC-MOS cameras (Turner et al. 2001). The two EPIC-PN observations were carried out in full frame mode with thin and medium filter inserted and the data processed with the XMM-SAS software. A comparison of coordinates derived from EPIC-PN data and the more accurate ROSAT HRI positions for sources which were identified with known objects resulted in a discrepancy of $\sim 10''$. Therefore the coordinates of the EPIC-PN images were corrected using the HRI coordinates as reference. The remaining $\sim 6''$ statistical uncertainty in the EPIC-PN position of RX J0101.3−7211 makes the identification with the ROSAT source most likely. The events from the source were selected from both observations resulting in effective exposure times of $\sim$18 ks each. The background

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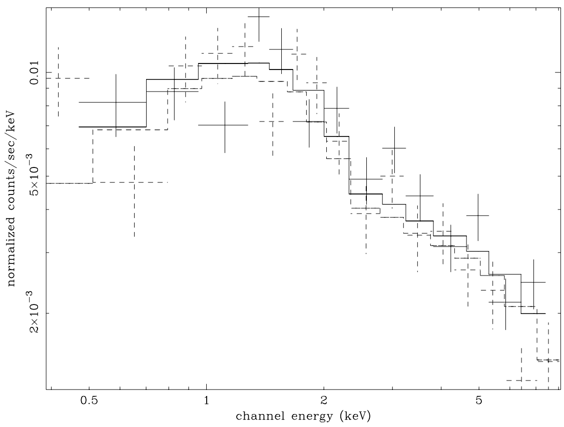

Fig. 1. XMM-Newton EPIC-PN spectrum and the fitted power-law model. Solid line is used for thin filter data and fitted model, dashed line for medium filter data and model

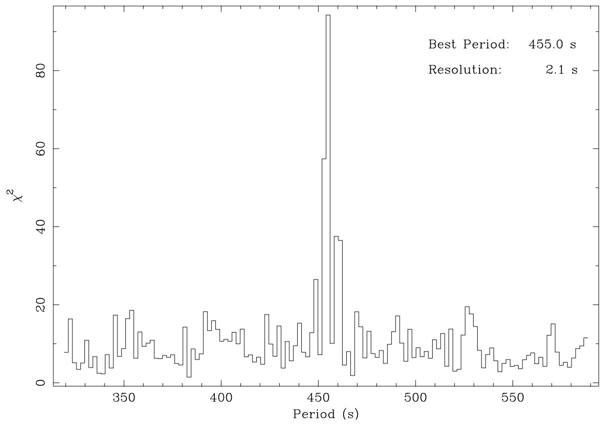

Fig. 2. χ^2-test periodogram for RX J0101.3−7211 from EPIC-PN thin and medium filter observations

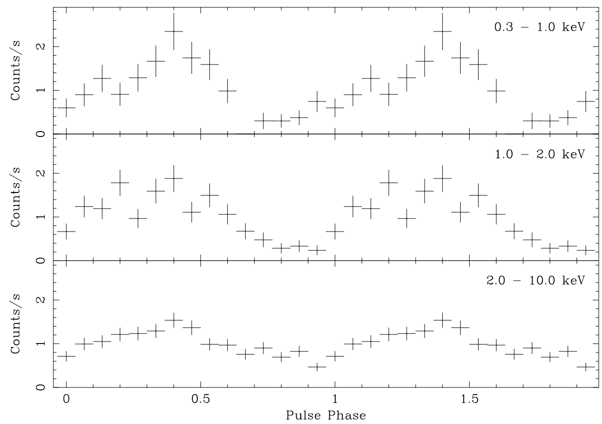

Fig. 3. Folded lightcurves of RX J0101.3−7211 in three energy bands derived from EPIC-PN thin and medium filter observations with binning time of 30.33 s. Phase 0 is 16 Apr. 2000 19:56:48.9 (UTC)

for the spectral analysis was estimated from regions at 40″ to 90″ distance from the source.

2.1. X-ray spectrum

X-ray spectra of RX J0101.3−7211 were extracted from thin and medium filter data separately and both vignetting corrected. The two spectra were fitted simultaneously with a power-law model using XSPEC with the Nov. 2000 version of the response matrix. We fixed the foreground absorption at the Galactic $N_{\rm H\,gal}$ of 5.8 10^{20} cm^{-2} (Dickey & Lockman 1990), and fitted an additional absorption column density with fixed elemental abundances of 0.2 solar to account for the interstellar gas in the SMC (Russell & Dopita 1992). The best fit was achieved with a photon index $\Gamma = 0.6 \pm 0.1$ and SMC absorption of $N_{\rm H\,int} = 1.3^{+2.8}_{-1.3}$ 10^{21} cm^{-2}. The unabsorbed flux calculated from the thin filter data is 4.2 10^{-13} erg cm^{-2} s^{-1} (0.2–10.0 keV), with a luminosity of $L_{\rm X} = 1.8$ 10^{35} erg s^{-1} for an assumed distance of 60 kpc.

2.2. Variability

The XMM-Newton EPIC-PN observations with a time resolution of 73.3 ms (Strüder et al. 2001) allow to search for pulsations in the X-ray flux of RX J0101.3−7211 which was known as Be/X-ray binary candidate (Haberl & Sasaki 2000). Source events from both thin and medium filter observations in the energy band of 0.2–10.0 keV were analyzed with XRONOS FTOOLS. Based on power spectra and following detailed period search in a time interval of 330–590 s with a resolution of 2.1 s revealed pulsations with a period of $P = (455 \pm 2)$ s (see Fig. 2). The data was separated in three energy bands in order to analyze the energy dependence of the flux variation: 0.3–1.0 keV (soft), 1.0–2.0 keV (medium), and 2.0–10.0 keV (hard). As can be seen in the folded lightcurves of the different bands in Fig. 3 including thin and medium observations, the pulsations in the medium and hard bands are similar, whereas in the soft band, the minimum comes earlier than in the harder bands. The maximum is reached almost at the same time in all three bands. Thus the increase in the soft band is significantly flatter and the decrease steeper than in the medium and the hard band.

3. Long-term X-ray variability

3.1. ROSAT observations

Searching the ROSAT (Trümper 1982) archive, six pointed observations with PSPC (Pfeffermann et al. 1987) and HRI (David et al. 1996) as focal instruments were found in which RX J0101.3−7211 was detected. Further four pointings yield upper limits for the source flux (Table 1). The count rates and upper limits were determined using the source detection routine of EXSAS (Zimmermann et al. 1994). In order to compare the count rates of the PSPC and HRI detectors, the PSPC count rate was converted into HRI count rate by dividing by a factor of 3.0, a typical value for sources with a hard X-ray spectrum like that of X-ray binaries (Sasaki et al. 2000a).

3.2. Flux variations

Variability of RX J0101.3−7211 was reported by Sasaki et al. (2000b) based on ROSAT PSPC and HRI

Table 1. ROSAT and XMM-Newton observations of RX J0101.3−7211

Telescope	Detector	Obs. ID	Start Time	End Time	Pointing Direction RA	Pointing Direction Dec	Exposure [ks]	Filter
ROSAT	PSPC	400300p	29 Mar. 1993	30 Mar. 1993	00 58 33.6	−71 36 00	5.2	
		500142p	12 May 1993	13 May 1993	01 04 02.4	−72 01 48	4.9	
		400300p-1	01 Oct. 1993	09 Oct. 1993	00 58 33.6	−71 36 00	7.2	
ROSAT	HRI	500137h	17 Apr. 1993	21 Apr. 1993	01 03 16.8	−72 09 36	14.1	
		900445h	19 Apr. 1994	09 Jun. 1994	00 59 28.8	−72 09 36	14.9	
		900445h-1	13 Apr. 1995	12 May 1995	00 59 28.8	−72 09 36	34.6	
		500418h	31 May 1995	02 Jun. 1995	00 59 26.4	−72 10 12	2.0	
		500418h-1	15 Oct. 1995	30 Oct. 1995	00 59 26.4	−72 10 12	8.3	
		500418h-2	11 May 1997	10 Jun. 1997	00 59 26.4	−72 10 12	7.5	
		500418h-3	27 Mar. 1998	01 Apr. 1998	00 59 26.4	−72 10 12	11.0	
XMM-Newton	EPIC-PN	0123110201	16 Apr. 2000	17 Apr. 2000	01 03 50.0	−72 01 55	18.8	thin
		0123110301	17 Apr. 2000	17 Apr. 2000	01 03 50.0	−72 01 55	18.3	medium

observations. Figure 4 shows the lightcurve including both ROSAT PSPC and HRI observations, as well as the new EPIC-PN data. The luminosity was calculated assuming the same spectrum for all observations as determined from the EPIC-PN data and extrapolated to the ROSAT band, and a distance of 60 kpc. Long term variation can been seen with a maximum unabsorbed flux of 5.7 10^{-13} erg cm^{-2} s^{-1} (0.1–2.4 keV). The unabsorbed flux during the XMM-Newton observation in the ROSAT band was 5.9 10^{-14} erg cm^{-2} s^{-1} corresponding to a luminosity of $L_X = 2.5\ 10^{34}$ erg s^{-1}, about a factor of two lower than during the faintest ROSAT detection.

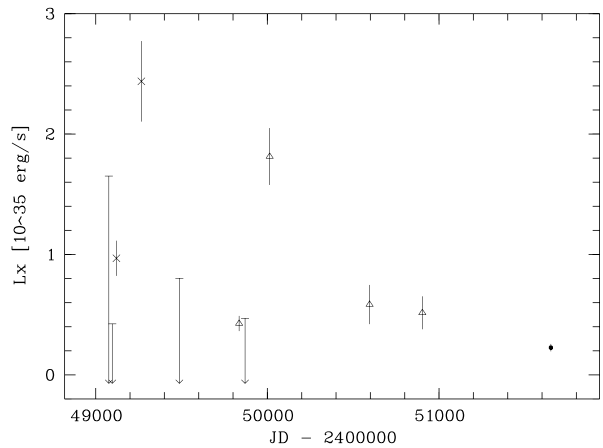

Fig. 4. X-ray lightcurve of RX J0101.3−7211 derived from ROSAT PSPC (marked with x), HRI (triangles) and XMM-Newton EPIC-PN (last data point) data. Upper limits determined from ROSAT observations are plotted with arrows

3.3. Pulse period history

Archival ROSAT PSPC and HRI data were analyzed to look for pulsations in earlier observations. Knowing the period from XMM-Newton observations allowed us to restrict the search around the expected value. Two observations (400300p-1, when the source was brightest and 900445h-1, the longest ROSAT observation) provided sufficient source counts, that a Z^2 test yielded pulse periods of $P = (450.2 \pm 1.5)$ s and (452 ± 3) s, respectively. The large errors are caused by possible aliases due to the interrupted ROSAT observations. The derived pulse periods indicate a period increase of ∼5 s since Oct. 1993. This corresponds to a spin down rate of $\dot{P} = (2.3 \pm 2.0)\ 10^{-8}$ s s^{-1} (90% confidence).

4. Optical counterpart

An emission line object from the catalogue of Meyssonnier & Azzopardi (1993) was suggested as optical counterpart for RX J0101.3−7211 by Haberl & Sasaki (2000). A medium resolution (0.6 Å px^{-1}) spectrum of the star was obtained on 20 August 2000 using the Double Beam Spectrograph on the MSSSO 2.3 m in Australia. The spectra consist of two simultaneously recorded non-overlapping segments: blue (4150–5200) Å and red (6200–6800) Å, as shown in Fig. 5. The segments were wavelength calibrated using a CuAr arc. The red segment shows prominent Hα emission (equivalent width 11 Å). The blue segment shows weak Hβ emission and the absence of Hγ absorption due to emission infill of the line. Lines of He I are seen most prominently at 4471 Å and 4388 Å.

5. Discussion

RX J0101.3−7211 was detected in ROSAT observations and proposed as Be/X-ray binary candidate. In the error circle of the ROSAT HRI data with a radius of 3.″6 (source No. 95 in Sasaki et al. 2000b) an emission line object was suggested by Haberl & Sasaki (2000) as counterpart. Optical follow-up observations presented here show a spectrum with strong Hα emission confirming the Be star nature of the proposed counterpart.

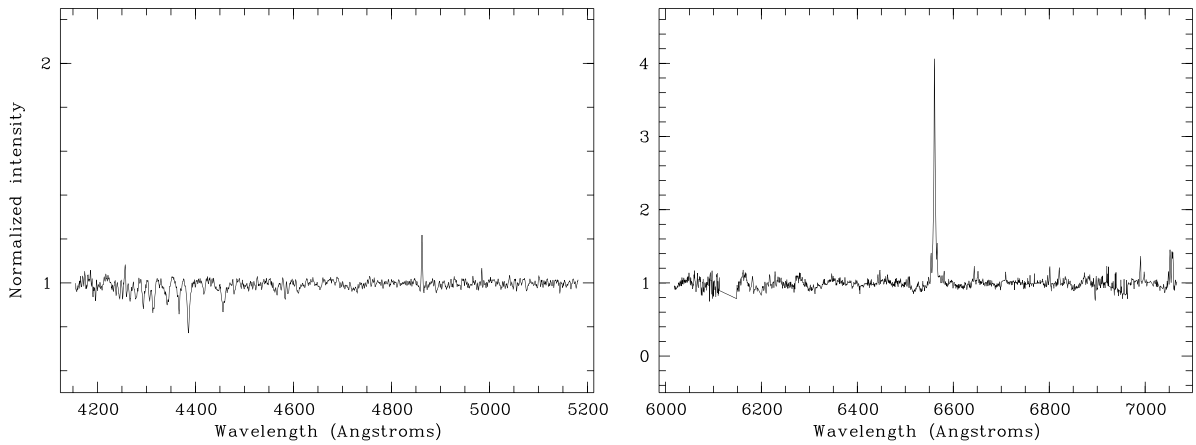

Fig. 5. Spectrum of the optical counterpart taken at the 2.3 m telescope of MSSSO in Australia in August 2000. The features around 6100 Å in the red segment are artefacts of the observation. The blue segment shows the Hβ emission line in spite of the low signal to noise ratio

The X-ray spectrum obtained from the XMM-Newton EPIC-PN data is well described by a power-law model ($\Gamma = 0.6 \pm 0.1$) with an absorption of $N_{\rm H\,int} = 1.3^{+2.8}_{-1.3}\ 10^{21}$ cm^{-2} besides to the Galactic foreground absorption. The luminosity in the energy range of 0.2–10.0 keV was 1.8 10^{35} erg s^{-1} indicating a faint phase. X-ray luminosities determined for Galactic and Magellanic Cloud X-ray binaries normally range from $L_{\rm X} \approx 10^{34}$ erg s^{-1} to 10^{38} erg s^{-1} (Apparao 1994; Haberl & Sasaki 2000, and references therein). The spectrum of the nearby ASCA source which probably coincides with RX J0101.3−7211 was also described with a power-law model with $\Gamma = 0.6$ and a total $N_{\rm H}$ of 1 10^{21} cm^{-2} (Yokogawa et al. 2000a), consistent with the EPIC-PN spectrum. The ASCA source was brighter with a luminosity of 7.3 10^{35} erg s^{-1} (0.7–10.0 keV) which would indicate a bright state, but no pulsations were found (Yokogawa et al. 2000a).

We discovered pulsations in the X-ray flux of RX J0101.3−7211 with a period of $P = (455 \pm 2)$ s in EPIC-PN data, indicating the spin period of a neutron star. Therefore RX J0101.3−7211 is one of the X-ray binaries with longer spin periods detected in the SMC (see Haberl & Sasaki 2000 and references therein). The longest spin period of a SMC Be/X-ray binary measured so far is (755.5 ± 0.6) s for AX J0049.5-7323 (Yokogawa et al. 2000b). The analysis of archival ROSAT data suggest a spin period increase of $\dot{P} = (2.3 \pm 2.0)\ 10^{-8}$ s s^{-1} over the last seven years. Similar values for spin up and spin down have been reported for the compact object in various Be/X-ray binary systems (Apparao 1994). The X-ray results combined with the optical spectrum assure that RX J0101.3−7211 is an X-ray binary in the SMC with a neutron star orbiting a Be star companion.

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