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LETTER

Letter to the Editor

A BeppoSAX observation of XTE J0055–724 = 1SAX J0054.9–7226, a new X-ray pulsar in the SMC

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Abstract. We report on the result of a *BeppoSAX* Target of Opportunity Observation of the hard pulsating X-ray source XTE J0055–724 = 1SAX J0054.9–7226, in the Small Magellanic Cloud (SMC). The source was detected by *BeppoSAX* at a flux level of $\sim 2 \cdot 10^{-11}$ erg cm^{-2} s^{-1} (2–10 keV) and its position is consistent with that of the *ROSAT* PSPC source 1WGA J0054.9–7226 and the *Einstein* source 2E 0053.2–7242. Both these sources were known to possess a marked variability, on timescales ranging from months to years. The *BeppoSAX* energy spectrum of 1SAX J0054.0–7226 is hard and well modelled by an absorbed hard power–law model with a photon index ~ 0.81. *BeppoSAX* detected up to 40 keV the ~ 59 s pulsations originally discovered with by *R*XTE (Marshall & Lochner 1998a; Santangelo et al. 1998).

Key words: X-rays: binaries – individual (1SAX J0054.9–7226) – X-rays: pulsars – galaxies: Magellanic Clouds

1. Source identification

On 1998 January 22 during a scan observation of the Small Magellanic Cloud (SMC), follow-on to a previous pointed observation on Jan 20, the *R*XTE satellite detected a new X-ray source, designated as XTE J0055–724, at a best estimated position of R.A.=$0^{\rm h}55^{\rm m}.3$, Decl.=$-72^\circ\ 29'$ ($10'$ error circle, equinox 2000, Marshall & Lochner 1998a). The source flux was $\sim 6 \cdot 10^{-11}$ erg cm^{-2} s^{-1} in the 2–10 keV energy range. Coherent pulsations were discovered at a period of ~ 59 s. XTE J0055–724 had not been detected on a previous *R*XTE scan of the region carried out on January 12.

In an effort to determine a more accurate position, a *BeppoSAX* Narrow Field Instrument (NFI) Target of Opportunity Observation in the direction of pulsating *R*XTE source was carried out on 1998 January 28, for a total integration time of ~ 59.5 ks (Santangelo et al. 1998). The X-ray image obtained with the Medium Energy Concentrator Spectrometers (MECS, Boella et al. 1997a) is shown in Fig. 1.

Close to the center of the Field of View (FOV), both the MECS and the Low Energy Concentrator Spectrometer (LECS, Parmar et al. 1997) detected a bright X-ray source, 1SAX J0054.9–7226, at a flux of $\sim 1.9 \cdot 10^{-11}$ erg cm^{-2} s^{-1} (2–10 keV). Strong pulsations at a period of $\sim$ 58.9 s were found confirming that 1SAX J0054.9–7226 and XTE J0055–724 are the same source. The imaging instruments onboard *BeppoSAX* yielded an improved position of R.A.=$0^{\rm h}54^{\rm m}54.8^{\rm s}$, Decl.=$-72^\circ\ 26'\ 41''$ ($\sim 40''$ uncertainty radius,equinox 2000.0). At least three other sources were detected in the MECS FOV with a significance $> 6\sigma$ and flux $F_x \leq 10^{-12}$ erg cm^{-2} s^{-1}.

The *BeppoSAX* position of 1SAX J0054.0–7226 is not only consistent with the *R*XTE error box, but also with that of the WGACAT (*ROSAT* PSPC) source 1WGA J0054.9–7226 and the *Einstein* (HRI) source 2E 0053.2–7242. Both these sources (which are probably the same source) were classified as suspect High Mass X-Ray Binaries by Wang & Wu (1992), Bruhweiler et al. (1987) and by White et al. (1994, in the WGACAT), on the basis of their spectral hardness. The analysis of an October 1991 *ROSAT* PSPC observation of 1WGA J0054.9–7226, revealed the presence of strong pulsations at a period of 59.072 ± 0.003 s (Santangelo et al. 1998a; Israel et al. 1998), confirming the identification with XTE J0055–724 =1SAX J0054.9–7226. The same source remained undetected in a series of PSPC pointings performed between April and November 1993. The *BeppoSAX* position of the source is also included in an archival *ROSAT* HRI observation performed on 1996 April 26 (0.1–2.4 keV flux of $\sim 1.6 \cdot 10^{-13}$ erg cm^{-2} s^{-1}; Israel 1998) providing a $10''$ accurate position of the source. The results of an extensive analysis of the public archival *ROSAT* PSPC and HRI observation are reported elsewhere (Israel et al. 1998).

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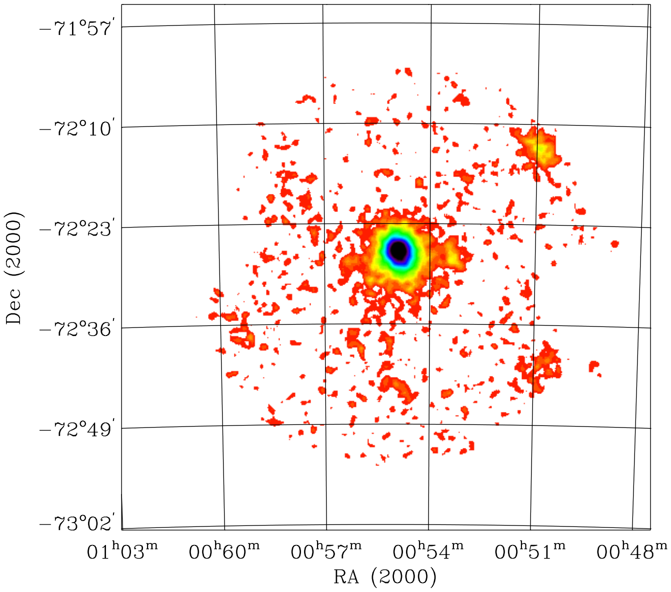

Fig. 1. Image of the Small Magellanic Cloud Field containing XTE J0055–724 =1SAX J0054.9–7226 as observed by the MECS onboard *BeppoSAX* . At least three other sources are detected in the MECS field of View.

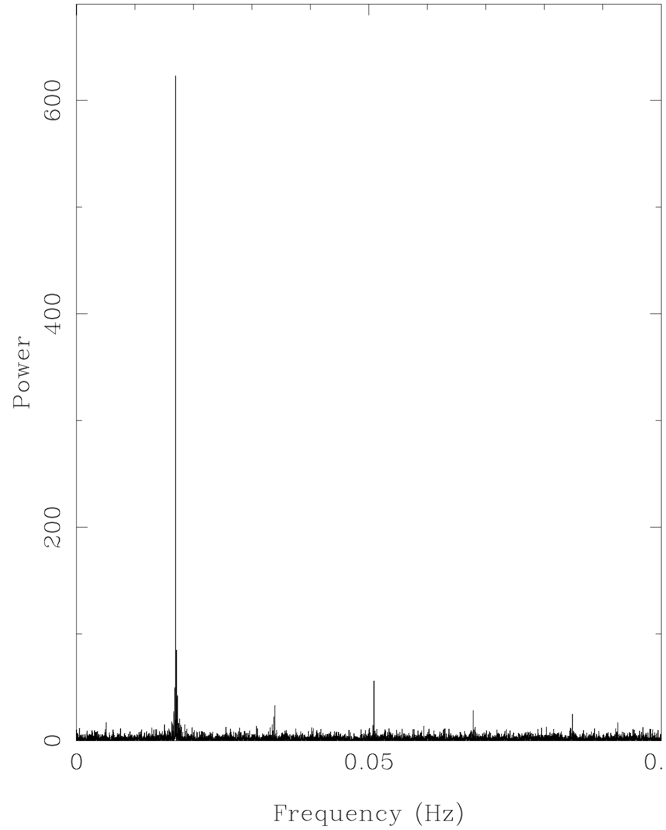

Fig. 2. Power spectrum of the 2–10 keV MECS light curve of 1SAX J0054.0–7226. The fundamental at ~ 0.0169 Hz, together with several higher harmonics are clearly detected.

In the rest of this *Letter* we present the results of the timing and spectral analysis of the *BeppoSAX* observation of XTE J0055–724 = 1SAX J0054.9–7226.

2. Observation

A detailed description of the *BeppoSAX*, *Satellite per Astronomia X*, can be found in (Boella et al. 1997a). The scientific payload comprises four co-aligned Narrow Field Instruments which include the Low Energy Concentrator Spectrometer (LECS, Parmar et al. 1997a), sensitive in the 0.1–10 keV energy range, the Medium Energy Concentrator Spectrometers (MECS, Boella et al. 1997b), sensitive in the 2–10 keV energy range, a High Pressure Gas Scintillation Proportional Counter (HPGSPC, 4–100 keV, Manzo et al. 1997) and a Phoswich Detection System (PDS, 15–200 keV, Frontera et al. 1997). The *BeppoSAX* Target of Opportunity Observation of XTE J0054.9–724 = 1SAX J0054.0–7226 started on 1998, January 28 at 13:39:49 and ended at on January 29 at 6:00:40 UT. All instruments were operated in their standard configuration. The LECS light curve and spectrum were extracted from a $8'$ radius region around the centroid of the source, so as to maximize the signal to noise ratio. The total exposure time with the LECS was ~ 12 ks. The MECS light curves and spectra were accumulated from a region of $4'$ radius centered on the source. The total exposure exposure time in the MECS was ~ 29.5 ks. The background was subtracted from the LECS and MECS spectra by using the spectra extracted from around the source position in detector coordinates during very long blank field observations. The source was too faint to be detected in the HPGSP. The PDS units were operated in collimator rocking mode with a dwell time of 96 s and an offest angle of $3°$ (which still encompassed the SMC). Background subtraction was performed following the standard procedure described in Frontera et al. (1998); however some level of contamination of the PDS spectra and light curves due other SMC sources included in the collimator response cannot be excluded. The net exposure in the PDS was ~ 18 ksec. XTE J0054.9–724 = 1SAX J0054.0–7226 was detected at a significance of $> 10\sigma$ in the PDS.

3. Timing analysis

The arrival times of the photons extracted from the region around the source position were corrected to the solar system barycenter and 1 s binned light curves accumulated. The power spectrum of the MECS 2–10 keV light curve is shown in Fig. 2. A main peak at a frequency of 0.0169 Hz corresponding to the fundamental of the ~ 59 s modulation, is apparent. Higher harmonics (up to the fifth) are clearly detected also. Based on the power spectrum analysis a best period of $P = 58.97 \pm 0.05$ s was obtained.

To refine the period determination and reduce its uncertainty, a folding technique was used. The best period was determined to be P = 58.963 ± 0.003 (90% uncertainties are used throughout this *Letter*). The corresponding light curves obtained by folding the LECS, MECS and PDS light curves in five different energy bands are shown Fig. 3. The modulation is somewhat asymmetric, with the main pulse peaking around phase 0.4 followed by

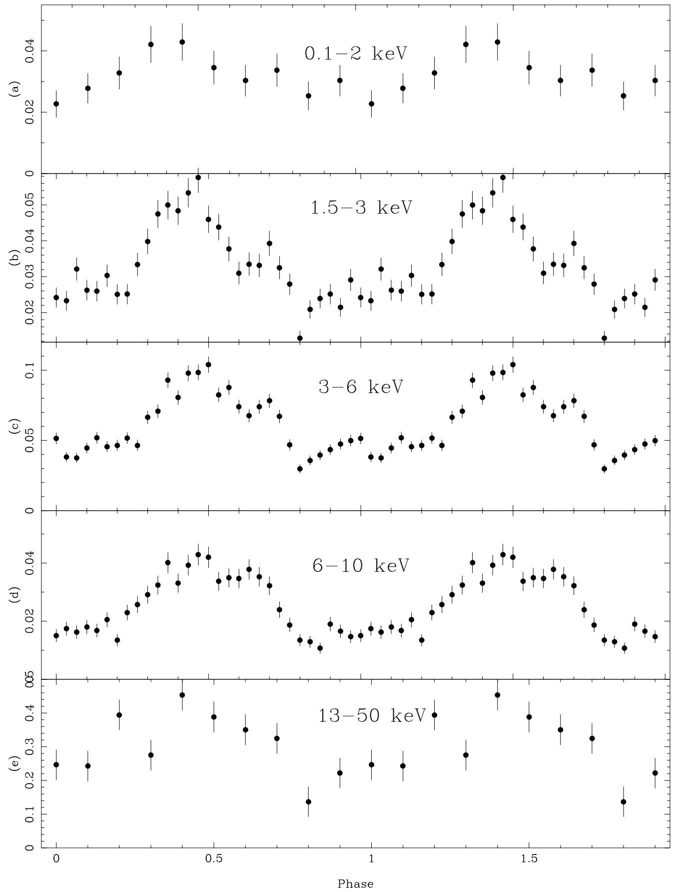

Fig. 3. Folded light curves in five different energy ranges: 0.2–2 keV (LECS), 1.5–3 keV, 3–6 keV, 6–10 keV (MECS), 13–50 keV (PDS). The adopted period and (arbitrary) zero phase are $P = 58.963$ s and MJD=50840.999817.

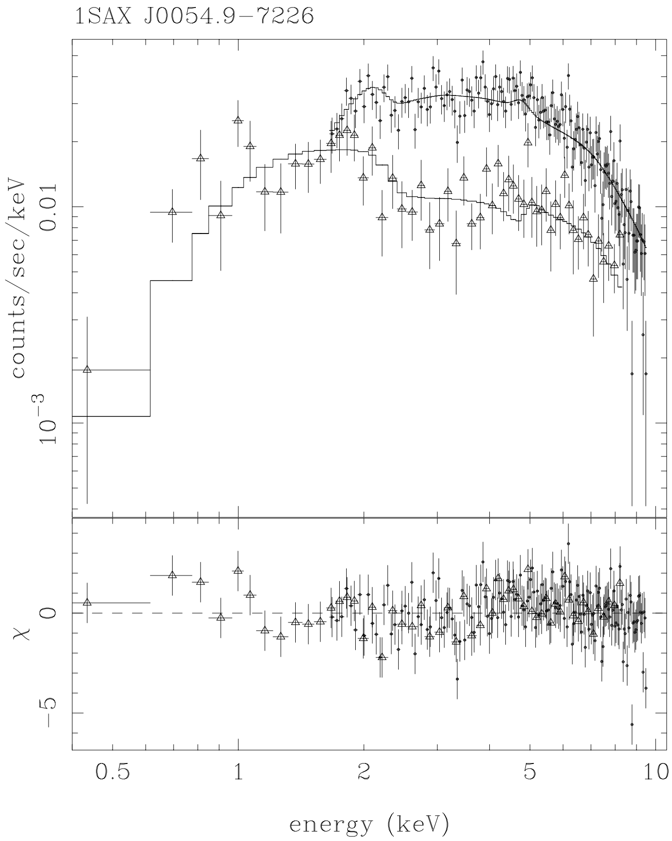

Fig. 4. LECS and MECS spectrum of 1SAX J0054.9–7226. The upper panel shows the spectrum together with the best fit absorbed power law model. The corresponding residuals are shown in the lower panel.

a secondary peak around phase 0.7. The interpulse interval is also fairly structured. The 13–50 keV folded light curve from the PDS (panel e in Fig. 3) shows a similar shape to that at lower energies, testifying to presence of the 59 s modulation also in the PDS data. Pulse fractions, defined as $((I_{max} - I_{min})/I_{max})$, with I_{max} is and I_{min} the maximum and minimum count rate, are 47%, 77%, 71%, 65%, 69% in the 0.1–2., 1.5–3, 3–6, 6–10, 13–50 keV bands, respectively. No clear evidence for an energy dependence of the pulse profile or its amplitude is found. The fact that the pulse fraction in 13–50 keV band is compatible with that at lower energies, might be an indication that the level of contamination from nearby sources in the PDS is low, if present at all.

4. Spectral analysis

The PHA data from different *BeppoSAX* instruments were grouped so as to contain $\gtrsim 20$ counts in each energy channel, such that the minumum χ^2 model fitting techniques could be used reliably. The LECS and MECS spectrum of 1SAX J0054.9–7226 is shown in Fig. 4 (upper panel), together with the best fit obtained using an absorbed power–law model. The cross sections for photoelectric absorption are taken from Morrison & McCammon (1983). The best fit, χ^2_ν= 1.368 (for 479 degrees of freedom, dof), is obtained for a photon index of $\alpha = 0.81 \pm 0.04$ and a column density of $N_H = (0.24 \pm 0.08) \times 10^{22}$ cm^{-2}. We note that the measured N_H is greater than the galactic hydrogen column in the direction of the Small Magellanic Cloud, typically $\sim 6 \cdot 10^{20}$ cm^{-2}. The absorbed 2–10 keV flux of the source is $F_x = 1.95 \cdot 10^{-11}$ erg cm^{-2} s^{-1} which for a distance of 65 kpc (Wang & Wu 1992) converts to a luminosity of $L_x = 8.9 \cdot 10^{36}$ erg s^{-1}.

As the (phase averaged) high energy spectrum of the source as observed by the PDS might be affected by the contribution from other hard sources within the intrument's collimator, the on-pulse (0.2–0.8 phase interval, see Fig. 3) minus off-pulse (0.8–1.2 phase range) spectra in the LECS, MECS and PDS spectra of 1SAX J0054.9–7226 were accumulated.

The broad band pulse spectrum obtained in this way (see Fig. 5) is well fit by a model consisting of an absorbed power law with an exponential high energy cut-off. This is a frequently used model for the spectrum of High Mass X-ray Binary Pulsars (White et al. 1985). The best fit, χ^2_ν= 1.081 (78 dof) is obtained for a photon index of $\alpha = 0.65 \pm 0.2$ and a cut-off energy of $E_{cutoff} = (7.7 \pm 2.0)$ keV and a folding energy $E_{fold} = (8.8 \pm 3.0)$ keV. The derived column density is $N_H = 1.21 \pm 0.9 \times 10^{22}$ cm^{-2}).

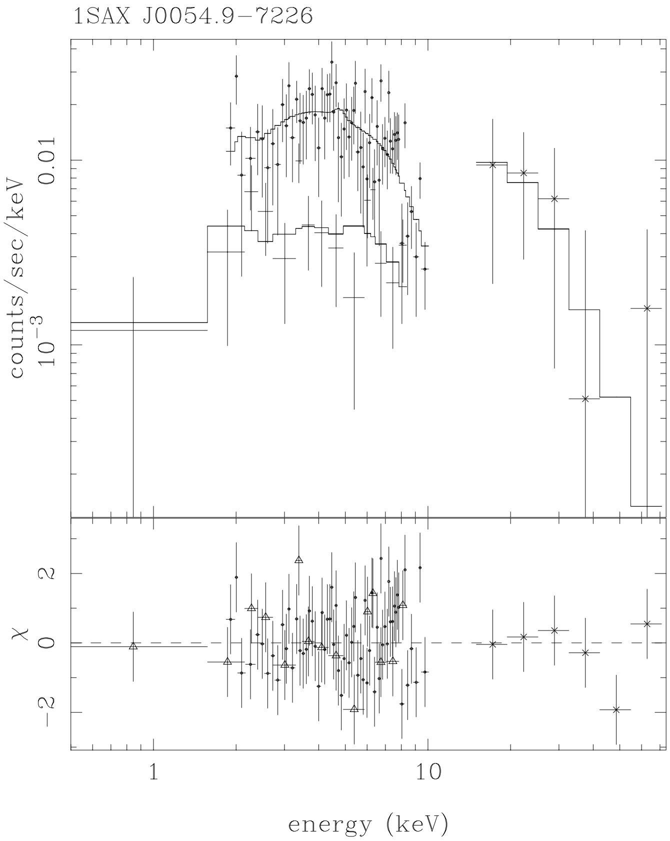

Fig. 5. On-pulse (0.2–0.8 phase interval) minus off-pulse (0.8–1.2 phase range) LECS, MECS and PDS spectra of 1SAX J0054.9–7226. The upper panel shows also the best fit obtained with a model consisting of an absorbed power law with exponential cut-off. Residuals are shown in the lower panel.

5. Discussion

The 1998 January 28 *BeppoSAX* Target of Opportunity Observation triggered by the *R*XTE discovery of a new 59 s pulsating X-ray source (XTE J0055–724), resulted in a more accurate determination of the source position, (R.A.=$0^{\rm h}54^{\rm m}54.8^{\rm s}$, Decl.=$-72^\circ\ 26'\ 41''$ $\sim 40''$ uncertainty radius), pulsation period ($P = 58.963 \pm 0.003$) and energy spectrum up to energies of ~ 40 keV. Following the *BeppoSAX* refined measurement of the source position, a detailed analysis of archival *ROSAT* PSPC and HRI observations was carried out (Israel et al. 1998). The source was detected in a 1991 October 8–9 PSPC observation at a flux level of $\sim 8.7 \cdot 10^{-13}$erg s^{-1}(0.1–2.4 keV), together with pulsations at a period of 59.072 ± 0.003 s. This yielded the first measurement of the period derivative (-0.016 s yr^{-1}). The source remained undetected during a series of other PSPC pointings performed between April and November 1993, implying a large flux variability (factor of > 30) with respect to the RXTE measurement.

The fairly flat power-law slope (photon index of ~ 0.8) derived from the *BeppoSAX* LECS and MECS spectra (from 0.2 up to 10 keV) is common among accreting X-ray pulsars. Moreover, the source was clearly detected at higher energies (up to 40 keV) in the PDS. The broader band on-pulse minus off-pulse spectrum obtained by using also the PDS data is very well fit by an absorbed power law with an exponential cutoff at higher energies, in turn a frequently adopted model to describe the energy spectrum of X-ray pulsars up to energies of many tens of keV.

These results clearly suggest that XTE J0055–724 = 1SAX J0054.9–7226 is a transient accreting X-ray pulsar in a binary system with a Be spectral-type companion star. This is further confirmed by the presence of three early type SMC stars in the $10''$ radius error circle obtained from a public archive *ROSAT* HRI observation (Israel et al. 1998). Recently analysis of optical data (Stevens, Coe, & Buckley, 1998) allowed to discover a strong Hα emission from one star inside the X-ray error circle. A February 1998 spectroscopic observation of this star confirmed the presence of a strong Hα emission line and the Be spectral-type star nature.

Finally, we note that, following the empirical relation between orbital and pulse periods in Be star X-ray pulsar binaries (Corbet 1986), an orbital period in the 20–30 day range is to be expected.

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