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LETTER

Letter to the Editor

ROSAT archival observations of 1SAX J0054.9–7226 = 2E 0053.2–7242, a newly discovered X-ray pulsar in the SMC

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Abstract. We analysed 13 archival *ROSAT* PSPC and HRI observations which included the position of a newly discovered 59 s X-ray pulsar in the Small Magellanic Cloud, 1SAX J0054.9–7226 = 2E 0053.2–7242. The source was detected three times between 1991 and 1996 at a luminosity level ranging from $\sim 8\times10^{34}$ - $4\times\ 10^{35}$ erg s^{-1} (0.1–2.4 keV). Highly significant pulsations at 59.072 s were detected during the 1991 October 8–9 observation. The *ROSAT* period, together with those measured by *R*XTE and *Beppo*SAX yields a period derivative of $\dot{\rm P}$= – 0.016 s yr^{-1}. A much more accurate source position (10″ uncertainty) was obtained through the *ROSAT* HRI detection on 1996 April restricting to three $m_V > 15.5$ stars the likely counterpart of 1SAX J0054.9–7226 = 2E 0053.2–7242.

Key words: binaries: general – stars: neutron – pulsars: individual (1SAX J0054.9–7226; 2E 0053.2–7242) – galaxies: Magellanic Clouds – X-rays: stars

1. Introduction

On 1998 January 20 during a *R*XTE observation in the direction of the Small Magellanic Cloud (SMC), a previously unknown X-ray source, namely XTE J0055–724, was detected at a flux level (2–10 keV) of $\sim 6.0 \times 10^{-11}$ erg s^{-1} cm^{-2}. The source showed pulsations at a period of ∼59 s (Marshall & Lochner, 1998a). A previous *R*XTE observation of the same field performed on 1998 January 12 failed to detect the source.

In response to these findings, simultaneous *Beppo*SAX and *R*XTE observations of a region including the *R*XTE error circle (∼10′ radius) of XTE J0055–724, were carried out on 1998 Jannuary 28. The results of these observations are reported elsewhere (Santangelo et al. 1998a; Marshall et al. 1998b). Thanks to the spatial capabilities of the imaging X-ray concentrators on board *Beppo*SAX, an improved position (∼40″ radius) was obtained for the pulsating source, named 1SAX J0054.9–7226 (Santangelo et al. 1998a,b). The new *Beppo*SAX error circle contains only the previously classified *ROSAT* and *Einstein* X-ray sources 1WGA J0054.9–7226 and 2E 0053.2–7242, which are likely the same source. In the following we adopt the earliest source name, i.e. *Einstein*'s. 2E 0053.2–7242 is a variable X-ray source in the SMC, which was already considered a candidate High Mass X-ray Binary by Wang & Wu (1992; source #35), Bruhweiler et al. (1987; source # 9) and by White et al. (1994; in the WGACAT), based on its high spectral hardness.

We report in this letter on the results from the analysis of the Position Sensitive Proportional Counter (PSPC) and High Resolution Imager (HRI) observations from the *ROSAT* public archive.

2. *ROSAT* observations

The PSPC (0.1–2.4 keV) and HRI (0.1–2.4 keV) detectors on board *ROSAT* observed the SMC field including 2E 0053.2–7242 several times. In the *ROSAT* public archive there are 13 observations performed between 1991 October and 1996 April: 9 were carried out with the PSPC and 4 with the HRI. The PSPC images, spectra and light curves were accumulated and corrected for the effective exposure map. This is particularly relevant to minimize the effects of the wobble in the pointing direction on count rate measurements of sources near the edge of the field of view or the ribs of the detector window support structure. The vignetting correction was also taken into account and the effective exposure time $T_{\rm eff}$ obtained for each PSPC pointing.

A sliding cell detection algorithm was used in order to characterise the physical parameters, such as position, count rate (90% confidence level), S/N ratio, etc., of 2E 0053.2–7242 when detected, and to obtain a $3\,\sigma$ count rate upper limit in case of non–detections. Table 1 summarises the results of this analysis.

2E 0053.2–7242 was only detected on three occasions: twice with the PSPC (1991 October 8–9 and 1992 April 17–27) and once with the HRI (1996 April 26 – June 10).

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Table 1. *ROSAT* observations of 2E 0053.2–7242

Pointing Number	Instr.	Expos. (s)	Start Time	Stop Time	Count rate† (cts s^{-1})	Notes‡
600195A00	PSPC	16978	1991 Oct 08 03:10	Oct 09 02:38	0.048±0.002	T_{eff}=11820s; [1]
600196A00	PSPC	1346	1991 Oct 09 03:06	Oct 10 04:47	< 0.080	T_{eff}=740s
600196A01	PSPC	22223	1992 Apr 15 15:30	Apr 25 16:41	< 0.010	T_{eff}=10920s; [2]
600195A01	PSPC	9443	1992 Apr 17 17:01	Apr 27 16:28	0.008±0.001	T_{eff}=7202s
600452N00	PSPC	14207	1993 Apr 10 11:54	Apr 25 01:20	< 0.030	T_{eff}=6815s
600453N00	PSPC	17593	1993 May 09 07:17	May 12 20:14	< 0.005	T_{eff}=7330s
500142N00	PSPC	4909	1993 May 12 22:41	May 13 04:11	< 0.015	T_{eff}=2743s
600452A01	PSPC	16663	1993 Oct 01 08:24	Oct 14 16:54	< 0.014	T_{eff}=8509s; [3]
500250N00	PSPC	20845	1993 Oct 14 21:10	Oct 29 08:45	< 0.014	T_{eff}=10430s; [4]
400237A01	HRI	1167	1993 Apr 17 09:33	Apr 17 10:08	< 0.008	
400237N00	HRI	1096	1992 Oct 23 13:41	Oct 24 08:45	< 0.010	
400237A02	HRI	1301	1994 Apr 15 10:26	Apr 15 11:05	< 0.008	
600810N00	HRI	6726	1996 Apr 26 02:09	Jun 10 14:45	0.004±0.001	

† Errors are at 1 σ level and upper limits at 3 σ.
‡ The effective times, T_{eff}, are vignetted and exposure corrected.
[1] – Pulsations at a period of 59.072 s.
[2] – Strong contamination by 1WGAJ0054.0–7226 and 1WGAJ0053.8–7226 due to the degrading PSF at large off–axis angles.
[3] – Contamination by 1WGAJ0053.8–7226.
[4] – Strong contamination by 1WGAJ0053.8–7226.

2.1. PSPC data

The *ROSAT* event list and spectrum of 2E 0053.2–7242 were extracted from a circle of $\sim$1′.5 radius (corresponding to an encircled energy of $\sim$95%) around the X-ray position. On 1991 October 8–9 (sequence number 600195A00) the source count rate was 0.047 cts s^{-1}, while on 1992 April 17–27 (600195A01) it had decreased to about 0.01 cts s^{-1}. Of the $\sim$ 600 and $\sim$ 150 photons contained in the extraction circle of each of the two pointings, we estimated that about 45 and 20 photons derive from the background around the source, respectively.

The 1991 October observation is the only one that contains a sufficiently high number of photons to perform a detailed periodicity search. The photons arrival times were corrected to the barycenter of the solar system and a 1 s binned light curve accumulated. The corresponding power spectrum, calculated over the entire observation duration ($\sim$1 day), is shown in Fig. 1, together with the 3 σ preliminary peak detection threshold described by Israel & Stella (1996). The search was performed over a period interval around that detected by *Beppo*SAX and assuming a maximum $|\dot{P}|$ of $\sim$3 s yr^{-1} (the highest ever observed from an X-ray pulsar: GX1+4). This translates into a search over an interval of $\sim$1100 Fourier frequencies centered on 0.017 Hz. Significant peaks were detected around a frequency of $\sim$0.0169 Hz. These are unique to 2E 0053.2–7242. The multiple peak structure is due to the sidelobes arising from the satellite orbital occultation. The highest of these peaks has a significance of 7.4 σ over the explored frequency interval, and corresponds to a period of 59.072 ± 0.003 s (90% uncertainties are used through this letter). The modulation is energy independent in the PSPC band (within the statistical uncertainties). The shape is fairly asymmetric with a pulse fraction of $\sim$ 40% (Fig. 1, inner panel). By using the period measured by *Beppo*SAX a period derivative of – 0.016 s yr^{-1} was obtained.

The PSPC Pulse Hight Analyser (PHA) rates were grouped so as to contain a minimum of 20 photons per energy bin. The spectrum of the 1991 October observation was well fit with an absorbed power–law model (see Fig. 2; upper curve). The best fit (χ^2/degree of freedom – dof = 21/24) was obtained for a photon index of Γ = 0.90 $\pm^{0.62}_{0.85}$ and a column density of N_H = (1.3 $\pm^{1.6}_{0.8}$) × 10^{21} cm^{-2} (see Table 2). Note that the Galactic hydrogen column in the direction of the SMC is $\sim 6 \times 10^{20}$ cm^{-2}. The 0.1–2.4 keV luminosity at the source is $L_X \sim 4.2 \times 10^{35}$ erg s^{-1} for an assumed distance of 65 kpc (Wang & Wu 1992). We note that any further spectral component added to the power–law model in order to fit the data excess around 1.2 keV did not significantly improve the fit. For the 1992 April observation the number of photons (150) is too low to obtain an indipendent estimate of the spectral parameters. By keeping the photon index fixed to the best fit value of the 1991 October observation, an unabsorbed X-ray luminosity of $L_X \sim 1.5 \times 10^{35}$ erg s^{-1} was derived (see Table 2 and Fig. 2).

2.2. HRI data

The *ROSAT* HRI observation during which 2E 0053.2–7242 was detected (sequence 600810; 1996 April–June) provided a significantely improved source position (Israel 1998). This was determined to be R.A. = 00^h 54^m $56^s.5$ and DEC = –72^o $26'$ $47''.3$ (equinox 2000; error radius of 1.1″ with a 90% confidence level) by using both a sliding cell and a Wavelet transform–based detection algorithm (Lazzati et al. 1998; Campana et al. 1998).

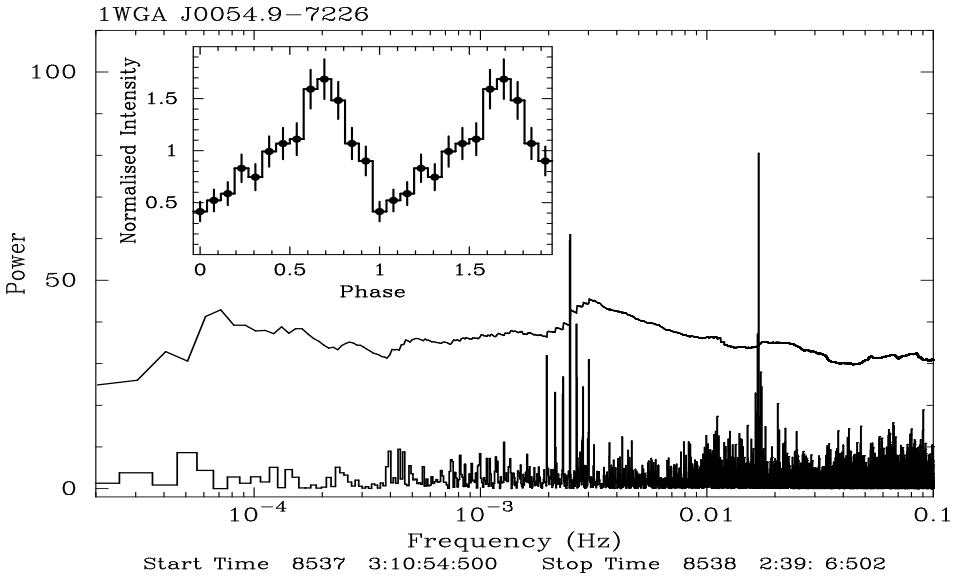

Fig. 1. Oct 1991 power spectrum of the 0.1–2.4 keV *ROSAT* PSPC light curve of 2E 0053.2–7242. The preliminary $3\,\sigma$ detection threshold is also shown. A folded light curve at the best period of 59.072 s is shown as an insert. The peak structures around a frequency of $\sim$2.5 $\times\ 10^{-3}$ Hz are due to the wobble in the pointing direction

Table 2. *ROSAT* PSPC spectral results for 2E 0053.2–7242

Parameter	Oct 1991	Apr 1992
N_H (10^{22} cm^{-2}).....	$0.13\pm^{0.16}_{0.08}$	$0.16\pm^{0.55}_{0.16}$
Γ.....	$0.90\pm^{0.62}_{0.85}$	0.9 (fixed)
Count rate (10^{-3} counts s^{-1}).....	45.0±2.0	8.0±1.0
F_X (10^{-13} erg cm^{-2} s^{-1}).....	8.7	2.4
L_X (N_H=0; 10^{35} erg s^{-1}).....	4.2	1.5
Reduced χ^2/(*dof*).....	0.96/(24)	–

Note. – the X-ray flux (absorbed) and the luminosity (unabsorbed) refer to the 0.1–2.4 keV energy band.

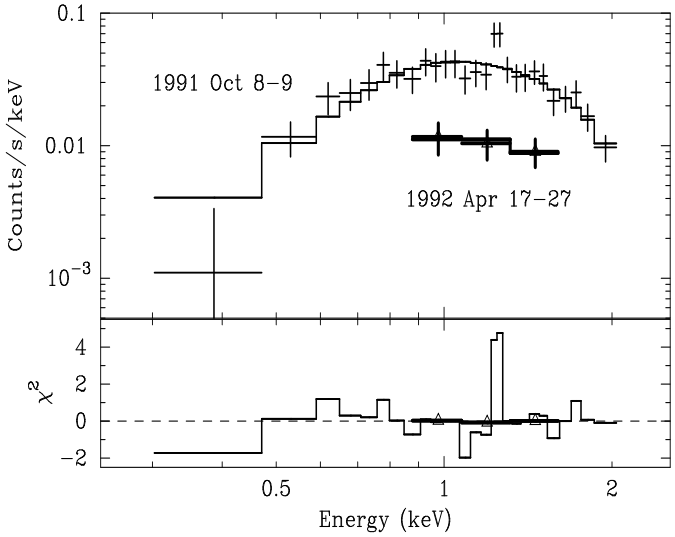

Fig. 2. *ROSAT* PSPC spectrum of 2E 0053.2–7242 during 1991 October and 1992 April. The best fit power–law is shown, together with the corresponding residuals. The 1992 Apr 17–27 data and residuals are marked with triangles

However due to the unknown boresight correction the uncertainty radius increases up to $10''$.

A 0.1–2.4 keV source flux level of $\sim$ 1.8$\times$ 10^{-13} erg cm^{-2} s^{-1} was determined assuming the best fit spectral parameters of the 1991 October 8–9. This translates into an unabsorbed luminosity of $L_X \sim 8.5 \times 10^{34}$ (Israel 1998).

3. *Einstein* observation

2E 0053.2–7242 was discovered during a survey of the SMC by means of the Imaging Proportional Counter (IPC) on board the *Einstein* spacecraft (Bruhweiler et al. , 1987; Wang & Wu, 1992) and classified as an hard X-ray source based on its hardness ratio. It was observed at a count rate of $\sim$0.009±0.002 cts s^{-1} corresponding to an X-ray luminosity of $\sim$1.5$\times$ 10^{35} erg s^{-1} (0.16–3.5 keV band).

4. Discussion

2E 0053.2–7242 was detected three times between 1991 and 1996 in the *ROSAT* archival data. Highly significant pulsations, at a period of 59.072 s were detected on 1991 October 8–9. These findings, together with the *Beppo*SAX results, yield a mean period derivative of ~ -0.016 s yr^{-1} between 1991 and 1998.

In one case a spectral analysis could be performed. The spectrum was found to be consistent with a relatively flat low absorbed power–law model that is typical of accreting X-ray pulsars in this energy range.

The 0.1–2.4 keV luminosity of 2E 0053.2–7242 as observed with *ROSAT* ranges between $\sim$4.2$\times 10^{35}$ erg s^{-1} (1991 October 8–9) and $\sim$8.5$\times 10^{34}$ erg s^{-1} (1996 April 26 – June 10). Moreover *R*XTE detected 2E 0053.2–7242 at a luminosity level of $\sim 3\times 10^{37}$ erg s^{-1} in the 2–10 keV energy band. Extrapolating to the *ROSAT* energy range the luminosity measured by *R*XTE on 1998 January 20, a 0.1–2.4 keV luminosity of

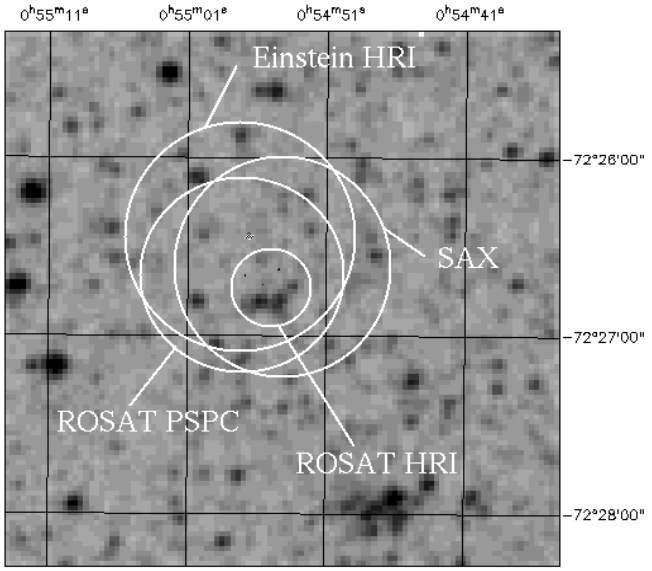

Fig. 3. ESO plate including the position of 2E 0053.2–7242. The X-ray error circles obtained from different instruments and satellites are shown

$\sim 2.5\times10^{36}$ erg s^{-1} is derived, implying a pronounced long–term variability of 2E 0053.2–7242 (a factor of $>$30). This indicates that the source is probably a transient X-ray pulsar in a high–mass binary containing a Be star.

A 10″ accurate position was obtained thanks to a *ROSAT* HRI observation during which the source was detected (1996 April; 0.1–2.4 keV luminosity of $\sim 8.5\times10^{34}$ erg s^{-1}). The *ROSAT* HRI error circle of contains only three stars in the ESO plates with $m_V > 15.5$, the likely optical counterpart of 2E 0053.2–7242(see Fig. 3). Assuming a B–V = –0.2 and a distance modulus of 19 mag, these optical counterpart candidates are consistent with main sequence A9 – B2 stars. We note that a similar spectral–type star (B1.5Ve; m_V = 16) is the companion of the nearby X-ray source SMC X–2. Future optical follow–up observations of these candidates should determine the counterpart of 2E 0053.2–7242 and its probable Be star X-ray transient nature. The optical and/or infrared activity brightening of the counterpart will allow further X-ray triggers and studies.

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