Chandra observations of the neutron star soft X–ray transient RX J170930.2-263927 returning to quiescence

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ABSTRACT

We present our analysis of Chandra observations obtained when the soft X–ray transient RX J170930.2-263927 (XTE J1709–267) returned to quiescence after an outburst. Using the type I burst peak luminosity found by Cocchi et al. (1998) and the value of \(N_H\) we derived from our spectral fits, the distance to RX J170930.2-263927 can be constrained to 2.5–10 kpc. RX J170930.2-263927 is probably associated with the low–metallicity Globular Cluster NGC 6293, which has a tidal radius of 14.2 arcminutes, since the projected distance to the centre of the cluster is approximately 25 parsec (9–10 arcminutes). If the association is correct, RX J170930.2-263927 would be at \(\sim 8.5\) kpc. We determined that \(L_{\text{outburst}} > 10^5\) for this outburst. If the quiescent luminosity is caused by cooling of the neutron star core then enhanced core cooling processes were at work implying a neutron star mass of \(\sim 1.7–1.8\) \(M_\odot\). Combining our Chandra observations with archival ROSAT observations we show that the source most likely exhibits periods of sustained low–level accretion. Variable, low–level activity could provide an alternative explanation for some of the sources in the recently proposed category of faint soft X–ray transients. We found excess emission at \(\sim 0.6\) keV. If such an excess is a unique feature of ultracompact systems, as was recently proposed, RX J170930.2-263927 must have a short orbital period as well. From the constraints on the distance and the non–detection of the optical counterpart with \(m_V < 20.5\), we conclude that this system must have a low–mass companion.

Key words: stars: individual (RX J170930.2-263927) — stars: neutron — X-rays: stars

1 INTRODUCTION

Low–mass X–ray binaries (LMXBs) are binary systems in which a \(< 1 M_\odot\) star transfers matter to a neutron star or a black hole. A large fraction of the LMXBs are transient, the so called soft X–ray transients (SXTs; see Chen, Shrader & Livio 1997). Characterising properties of SXTs are i) the accretion rate drops several orders of magnitude when the source returns to quiescence (van Paradijs & Verbunt 1984) and ii) the spectra become soft when in outburst.

There are several mechanisms which can produce the low–level X–ray emission observed in quiescence (see [Campana et al. 1998a] for an overview). Firstly, mass accretion may be ongoing at a low level possibly via an ADAF type flow (e.g. Narayan & Yi 1994). Secondly, provided the neutron star has a substantial magnetic field (\(\geq 10^7–8\) Gauss) and a short spin period (milliseconds), centrifugal forces may prevent accretion onto the neutron star (the propeller mechanism; Illarionov & Sunyaev 1975). Shocks produced by this propeller mechanism are then responsible for the X–ray emission. Thirdly, the switch–on of a radio pulsar mechanism may produce X–rays (Campana & Stella 2000). Finally, the neutron star core and crust are heated by accretion episodes during outburst; subsequent cooling of the neutron star in quiescence produces (soft) X–rays, (e.g. van Paradijs et al. 1987 Brown, Bildsten & Rutledge 1998).

SXTs have been studied both in outburst and in quiescence with various satellites (e.g. with ROSAT Verbunt et al. 1994 with ASCA Asai et al. 1998 with RXTE Swank & Markwardt 2001 with BeppoSAX...
From these studies a basic picture of the outburst mechanism has emerged: the thermal-viscous disk instability model (Smak 1983; Cannizzo, Chen & Livio 1993; van Paradijs 1996) for a recent review and a more detailed account see Lasota 2001.

Recent observations of neutron star SXTs in quiescence with the *Chandra* and XMM–*Newton* satellites have fueled the debate on the nature of the quiescent X–ray emission (e.g. see Wijnands et al. 2002 and Rutledge et al. 2002). Furthermore, using data obtained with the BeppoSAX satellite (Heise et al. (1999)) and in’t Zand (2001) suggested that ~10 bursting neutron stars form a separate class of faint SXTs. Some may have a low peak–luminosity (typically ~ 10^{36.5} \text{erg s}^{-1}), possibly like the accreting millisecond X–ray pulsar SAX J1808.4–3658 (Wijnands & van der Klis 1998; Chakrabarty & Morgan 1998). Later, King (2000) showed that a class of faint SXT is expected on evolutionary grounds. These are systems which have evolved beyond the period minimum of ~80 minutes to orbital periods of 80–120 minutes.

Recently, Juett, Psaltis & Chakrabarty (2001) proposed that the excess emission near 0.6 keV, unaccounted for by continuum models, found in a handful of SXTs, can be explained by varying the absorption abundances of circumstellar O and Ne with respect to solar. The abundances and the ultra–short orbital periods of several of these systems can be explained providing these systems are accreting from a degenerate companion (Juett, Psaltis & Chakrabarty 2001; see Yungelson, Nelemans & van den Heuvel 2002 for detailed evolutionary considerations). Recently, two other transient accreting millisecond X–ray pulsars have been found, XTE J1751–305 (Markwardt & Swank 2002; Markwardt et al. 2002) and XTE J0929–314 (Galloway et al. 2002a; Galloway et al. 2002a) with orbital periods of ~42 and ~43 minutes, respectively. These systems fit–in with the class of ultra-short period binaries. However, in fact the debate that these millisecond pulsars have short orbital periods XMM–*Newton* observations of XTE J1751–305 and Chandra observations with the Low Energy Transmission Grating Spectrometer of XTE J0929–314 did not show evidence for excess emission near 0.6 keV, complicating the picture (Miller et al. 2002; Juett, Galloway & Chakrabarty 2002).

**RX J170930.2–263927** was discovered by the ROSAT All Sky Survey (Voges et al. 1999). In 1997 the source was found in outburst with the Proprietary Counter Array onboard the RXTE satellite (Marshall et al. 1997). Using BeppoSAX’s Wide Field Camera (Cocchi et al. (1998) found that the source exhibits bursts, probably type I X–ray bursts, which would establish the compact object in RX J170930.2–263927 as a neutron star.

In this paper we present results from *Chandra* observations of the SXT RX J170930.2–263927 obtained during the decay after an X–ray outburst.

**3 RESULTS**

**3.1 Source position and optical observations**

Observation 5 was obtained using the TE–mode. This provided us with an X–ray image of the region around RX J170930.2–263927. We detected only one source at a count rate of (2.4±0.2)×10^{-2} counts per second. We corrected the aspect solution using the CIAO tool *FIX OFFSETS*; next using CELLDTECT we obtained an accurate position for RX J170930.2–263927 of R.A. = 17h09m30.4s, Decl. = −26°39′19.9″ (uncertainty 0.6″, equinox 2000.0).

Given the accurate position and the relatively low N_H, a log of the observations is given in Table 2. To mitigate the effects of pile–up the ACIS S3 chip was read out in continuous clocking mode during the first four observations (CC–mode, providing a time resolution as high as 2.85 ms) and in a windowed timed exposure mode during the last observation (TE–mode; time resolution of 2.24 s).

The data were processed by the *Chandra* X–ray Center; events with ASCA grades of 1, 5, and 7 were rejected. We used the standard CIAO software to reduce the data (version 2.2.1). During the second observation a background flare occurred after ~5.6 ksec which lasted for the rest of the observation. Therefore, we only used the first ~5.6 ksec of the total ~15 ksec of this observation in our analysis. In the first two observations dips in the source count rate at periods of 1000 seconds and ~700 seconds were found. These dips are caused by the spacecraft dither, moving the source over a bad pixel or a CCD node boundary. Events in such a dip have been discarded. At the end of the first observation an X–ray burst occurred. We fitted the burst data separately (see Section 3). In order to study the timing properties of the source the recorded event times were corrected to the approximate photon arrival times using the method explained by Patel et al. (2001).

The spectrum of the background in TE–mode ACIS–S observations displays an emission feature just below 2 keV (see figure 6.15 of the *Chandra* Proposers’ Observatory Guide v.4 1). Furthermore, the response of the high resolution monitors jumps at ~2 keV (due to an iridium edge) and in CC–mode the background levels are 1024 times higher than in TE–mode making the background emission feature just below 2 keV more significant. All these effects make it very difficult to distinguish source and background features and to model the background and effective area of the telescope in the spectral area near 2 keV. Therefore, we excluded the 1.75–2.15 keV energy range from our spectral analysis. The spectra were extracted with 10 counts per bin except for the spectrum in the last exposure which has only 5 counts per bin. The CC–mode spectral response is not calibrated but in principle there should be no major differences with respect to the TE–mode spectral response (this has been verified by Patel et al. 2001). We excluded energies below 0.35 and above 8 keV from our spectral analysis since the TE–mode spectral response is not well calibrated for those energies.
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The rms uncertainty of the astrometrical solution was 0.13″. Hence, the overall uncertainty in the astrometry is dominated by the Chandra positional uncertainty. In Figure 1 we show the central part of the V–band image with the Chandra error–circle overplotted. Comparing the optical V–band image with an older DSS R–band image we find no new sources with a 5σ upper limit magnitude of 20.5, nor did we find a strongly variable source in or near the Chandra error–circle. We conclude that we did not detect the optical counterpart of RX J170930.2–263927 with an upper limit of \( m_V = 20.5 \).

### 3.2 Spectral analysis

We fitted the extracted spectra using XSPEC (Arnaud 1996) version 11.2.01. In the spectral fits an extra multiplicative absorption component (called ACIS-ABS) was included to account for absorption caused by contamination of the ACIS optical blocking filters. This ACIS-ABS model is only accurate to ~10 per cent. Hence, we included a 10 per cent systematic uncertainty to the channels below 1 keV (channels 1-62). We note that, below, with the word “absorption” we denote the composite of interstellar absorption and this extra absorption component. However, the \( N_H \) we quote is only interstellar absorption, unless otherwise mentioned.

The fit results for the first two observations were statistically unacceptable for two component models such as an absorbed blackbody plus a power law model or an absorbed blackbody plus thermal Bremsstrahlung model. The largest residuals appear in the soft part of the spectrum. Adding another blackbody component to the fit–function improved the fit significantly, e.g. for the first observation a fit using a model consisting of two absorbed blackbodies plus a power law gives \( \chi^2_{red} = 1.05 \) for 461 degrees of freedom (d.o.f.), whereas a fit using a single absorbed blackbody and power law model gives \( \chi^2_{red} = 1.47 \) for 463 d.o.f. Therefore, we studied in detail a model consisting of two blackbodies and a power law component, all reduced by absorption. Although the fits of the models were formally acceptable (see the reduced \( \chi^2 \) and the d.o.f. given in Table 2), systematic residuals near ~0.6 keV were apparent in the first two observations (e.g. see Figure 2). Such residuals have been seen before in the X–ray spectra of several LMXBs (see Juett, Psaltis & Chakrabarty 2001 and references therein for figures showing residuals at ~0.6 keV). These residuals have been fitted with a Gaussian emission line \( \chi^2_{red} = 1.01 \) and, more recently, by varying the O/Ne abundance of the circumstellar material (Juett, Psaltis & Chakrabarty 2001 and references therein for figures showing residuals at ~0.6 keV).

Due to the low number of counts per bin during the last observation, we used the C–statistic to estimate the goodness of fit and the error bars on the fit parameters. The data were fit both with a blackbody (see Table 2) and with an absorbed neutron star hydrogen atmosphere model \((\text{Zavlin}, \text{Shibanov} & \text{Zavlin} \ 1991)\). The mass and the radius of the neutron star were held fixed in the neutron star hydrogen atmosphere model was \( (1.4 \pm 0.2) \times 10^{30} \) K.

We defined a hard colour by taking the logarithm of the ratio between the count rates in the 5 to 8 keV and that in the 2 to 5 keV band (see Table 2).

### 3.3 Temporal analysis

We created power density spectra of data stretches of 512 s in length with a Nyquist frequency of 4 Hz using the CC–mode data and with a Nyquist frequency of 0.2 Hz using the windowed ACIS–TE mode data. All power spectra were added and averaged for each observation. No dead–time cor-
Table 2. Spectral fits\textsuperscript{a,b}

<table>
<thead>
<tr>
<th>Obs.</th>
<th>PHABS $N^H$ ($\times 10^{22}$ cm$^{-2}$)</th>
<th>BB kT (keV)</th>
<th>BB $cR^2/D_{10}^2$ (km)</th>
<th>BB kT (keV)</th>
<th>BB $cR^2/D_{10}^2$ (km)</th>
<th>PL $\Gamma$</th>
<th>$A_{D}^{d}$</th>
<th>$E_{L}$ (keV)</th>
<th>FWHM (eV)</th>
<th>$A_{g}$</th>
<th>$\chi^2$/d.o.f.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.44$\pm$0.02</td>
<td>0.60$\pm$0.01</td>
<td>29$\pm$3</td>
<td>0.132$\pm$0.004</td>
<td>(2.9$^{+2.1}_{-1.0}$)$\times 10^{4}$</td>
<td>1.31$\pm$0.08</td>
<td>(9.4$\pm$0.8)</td>
<td>...</td>
<td>...</td>
<td>1.05/461</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.44$^{e}$</td>
<td>0.52$\pm$0.02</td>
<td>25$\pm$6</td>
<td>0.115$\pm$0.002</td>
<td>(8.6$\pm$1.0)$\times 10^{4}$</td>
<td>1.7$\pm$0.1</td>
<td>14$^{+0.7}_{-1.7}$</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1.03/404</td>
</tr>
<tr>
<td>3</td>
<td>0.44$^{e}$</td>
<td>0.28$\pm$0.09</td>
<td>0.20$^{+0.10}_{-0.07}$</td>
<td>0.22$\pm$0.01</td>
<td>139$\pm$30</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1.03/103</td>
</tr>
<tr>
<td>4</td>
<td>0.44$^{e}$</td>
<td>0.38$\pm$0.05</td>
<td>1.1$^{+1.0}_{-0.6}$</td>
<td>0.12$\pm$0.01</td>
<td>800$^{+800}_{-460}$</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1.07/19</td>
</tr>
<tr>
<td>5$^{f}$</td>
<td>0.44$^{e}$</td>
<td>0.22$\pm$0.03</td>
<td>14$^{+2}_{-6}$</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>9$^{g}$</td>
<td></td>
</tr>
<tr>
<td>1$^{f}$</td>
<td>0.44$^{e}$</td>
<td>0.60$\pm$0.01</td>
<td>28$\pm$3</td>
<td>0.139$\pm$0.004</td>
<td>(2.1$\pm$0.3)$\times 10^{4}$</td>
<td>1.28$^{+0.03}_{-0.11}$</td>
<td>8.8$\pm$0.7</td>
<td>0.60$\pm$0.02</td>
<td>50$^{f}$</td>
<td>(8$\pm$2)$\times 10^{-3}$</td>
<td>1.02/457</td>
</tr>
<tr>
<td>2$^{f}$</td>
<td>0.44$^{e}$</td>
<td>0.54$\pm$0.01</td>
<td>31$^{+5}_{-5}$</td>
<td>0.136$\pm$0.006</td>
<td>(2.8$\pm$0.8)$\times 10^{4}$</td>
<td>1.5$\pm$0.2</td>
<td>9.3$\pm$2.0</td>
<td>0.57$\pm$0.02</td>
<td>83$^{+19}_{-13}$</td>
<td>(3.0$\pm$0.5)$\times 10^{-2}$</td>
<td>0.96/401</td>
</tr>
</tbody>
</table>

\textsuperscript{a} All quoted errors are at the 68\% confidence level (1 $\sigma$ single parameter).
\textsuperscript{b} PHABS = interstellar absorption, PL = power law, BB= blackbody
\textsuperscript{c} Blackbody normalisation in units of the radius of the emitter squared divided by the distance in units of 10 kpc squared.
\textsuperscript{d} Power Law normalisation at 1 keV in units of $10^{-3}$ photons keV$^{-1}$ cm$^{-2}$ s$^{-1}$.
\textsuperscript{e} Parameter was fixed at this value during the fit.
\textsuperscript{f} Including a Gaussian line in the fit to account for the excess near 0.6 keV
\textsuperscript{g} C–statistics used
\textsuperscript{h} The value of the interstellar absorption is determined taking the local absorption due to the \textit{Chandra} optical blocking filters into account.
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5

average power spectrum obtained during the second observations was
was
was 1.2
was
its on the broken power law component were determined

\[ \chi^2 = 1 \] (1 \( \sigma \) single parameter), whereas upper limits on the broken power law component were determined using

\[ \Delta \chi^2 = 2.71 \] (95 per cent confidence).

3.4 Burst properties

At the end of the first observation an X–ray burst occurred

\[ 5–10 \text{ s}, 10–15 \text{ s}, 15–20 \text{ s}, 20–40 \text{ s}, 40–60 \text{ s}, 60–80 \text{ s}, \text{ and } 80–160 \text{ s after burst–onset. This also allows us to investigate} \]

whether there are signs of cooling establishing the nature of the X–ray burst as an type I X–ray burst. We subtracted the average persistent emission as observed during the first part of the observation from the burst data. We found that during the first \( \sim 15 \) seconds of the burst the blackbody temperature was unconstrained (best–fit values were as high as 170–190 keV). We conclude that due to the high count rate during the first 15 to 20 seconds of the burst even in CC–mode the data suffered from severe pile–up. Therefore, the dip in the count rate during the rising phases of the burst could well be due to pile–up. We therefore excluded the first 20 seconds of the burst from further analysis.

The best–fit blackbody spectral parameters for the remainder of the burst are given in Table 3. Clearly, the blackbody temperature decreased during the decay of the burst. This establishes that the burst is a type I X–ray burst, although 20–40 seconds after burst onset the count rate was still high enough to cause some pile–up (the mean count rate in that data segment was 38.1±1.6 counts per second, which results in a pile–up fraction of a few per cent for the CC–mode). We fitted an exponential decay model to the 1 second lightcurve profile; we found an e–folding time of 38±3 seconds (excluding burst data before \( t \sim 20 \text{ s} \)).

3.5 RXTE/ASM observations

To determine the duration and decay profile of the outburst we obtained data from RXTE’s All Sky Monitor (ASM; Bradt, Rothschild & Swank 1993; Levine et al. 1996) for

Figure 1. V–band image (∼ 100″ × 60″; 5 minute integration) of RX J170930.2–263927 obtained with the 2.5 m INT on La Palma. North is up and East is to the left. The Chandra error circle is overplotted.

rrections have been applied. The average Poisson noise level was determined by averaging the power in the 1.4–3.9 Hz region. This average white noise level was subtracted. We fitted the power density spectra with a broken power law. For the third, forth, and fifth observation only an upper limit on the fractional rms amplitude of the broken power law component was determined

\[ \sigma = 1 \] (95 per cent confidence).

\[ \chi^2 = 1 \] (95 per cent confidence).
Figure 2. Upper panel: Chandra X–ray spectrum (0.35–8 keV; observation 2) of the neutron star SXT RX J170930.2–263927. The best–fit model consisting of a linear combination of two blackbodies and a power law component modified by the combined effects of interstellar absorption and absorption due to contamination of the optical blocking filters of the ACIS instrument is overplotted. This contamination forced us to add an uncertainty of 10 per cent to the data for channels below 1 keV. Lower panel: Data minus model residuals in units of counts s$^{-1}$ keV$^{-1}$. The excess emission near $\sim0.6$ keV is clearly visible.

Table 3. Best fit parameters of the blackbody fits to the type I X–ray burst in RX J170930.2–263927$^a$

<table>
<thead>
<tr>
<th>Data segment</th>
<th>$kT$ (keV)</th>
<th>$R^2/D_r^2$ (km)</th>
<th>0.1–10 keV flux (erg cm$^{-2}$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–40</td>
<td>2.1±0.1</td>
<td>5.6±1.0</td>
<td>$8.1\times10^{-10}$</td>
</tr>
<tr>
<td>40–60</td>
<td>1.3±0.1</td>
<td>9.5±2.0</td>
<td>$2.8\times10^{-10}$</td>
</tr>
<tr>
<td>60–80</td>
<td>1.3±0.1</td>
<td>4.9±1.0</td>
<td>$1.3\times10^{-10}$</td>
</tr>
<tr>
<td>80–160</td>
<td>1.15±0.10</td>
<td>3.1±0.8</td>
<td>$5.8\times10^{-11}$</td>
</tr>
</tbody>
</table>

$^a$ All quoted errors are at the 68% confidence level (1 $\sigma$ single parameter).

$^b$ Times are given with respect to burst onset.

$^c$ Blackbody normalisation in units of the radius of the emitter squared divided by the distance in units of 10 kpc squared.

the 2002 outburst of RX J170930.2–263927. Using PIMMS and a power law model with index 2 as input we converted the ASM count rate to a flux in the 0.1–10 keV band. From previous observations of other LMXBs and our own Chandra observations of this source it is known that the source spectrum changes as the outburst progresses and that such a single–component spectrum can serve only as a first approximation of the spectral shape. Hence, the flux determinations from the ASM count rates are provided as reference only (Figure 3 right panel).

From the best–fit spectra we derived the source flux in the 0.1–10 keV energy band for each of the Chandra observations; these are the five rightmost points in each of the panels of Figure 4. In Table 4 we provide the unabsorbed fluxes for the five Chandra observations. Using PIMMS we converted these Chandra fluxes assuming a blackbody model temperature of 0.3 keV into ASM count rates (Figure 3 left panel).
The source outburst decay is two-fold. Until MJD $\sim 52331$ the decay is slow, but after that the rate of decay increases by a factor $\sim 10$ (a fit of a broken power law to the ASM count rate data gives a power law index of $(-7.6 \pm 1.4) \times 10^{-3}$ before $t = 50 \pm 1$ days and $(-7.4 \pm 0.2) \times 10^{-2}$ after that).

### 3.6 Archival ROSAT spectra

The ROSAT satellite observed and detected RX J170930.2–263927 twice. The source was first detected in the ROSAT All Sky Survey observations on August 21, 1990 (Voges et al. 1999). We analysed these archival ROSAT data using the ftool xselect (LHEASOFT version 5.2). The 0.2–2.4 keV ROSAT spectrum was fitted with an absorbed blackbody. Fixing the amount of absorption to the value we found using the Chandra observations ($N_H = 0.44 \times 10^{22}$ cm$^{-2}$) a blackbody temperature of $0.22 \pm 0.01$ keV and radius of $(2 \pm 0.5) \times 10^3$ km were found. The unabsorbed source flux (0.1–10 keV) was $4.8 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$.

The source was also in the field of view of a $\sim 900$ s pointed PSPC observation of the source V2051 Oph obtained on September 22, 1992 (see also Verbiest 2001). The 0.2–2.4 keV source spectrum was well fit by an absorbed blackbody of a temperature of $0.22 \pm 0.02$ keV and a radius of $(2.9 \pm 1.0) \times 10^3$ km (again the $N_H$ was fixed at $0.44 \times 10^{22}$ cm$^{-2}$). The unabsorbed source flux (0.1–10 keV) was $7.3 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$.

### 4 DISCUSSION

We observed the soft X-ray transient (SXT) RX J170930.2–263927 five times with the Chandra satellite in March–April 2002 after an X-ray outburst. The spectrum of the source was well fit by a model consisting of two blackbodies and a power law, all absorbed by interstellar absorption (taking into account excess absorption due to contamination of the ACIS optical blocking filters.) The best-fit blackbody temperatures and radii (see Table 2) imply that the accretion disk contribution is soft (blackbody temperature of 0.1–0.2 keV) and that there is a contribution from a hotter (blackbody temperature of $\sim$0.6 keV), smaller site, possibly the neutron star or the neutron star boundary layer. In the accreting millisecond pulsar XTE J0929–314 an 0.6 keV blackbody component has been found as well (Juett, Galloway & Chakrabarty 2002), whereas in XTE J1751–305 the blackbody temperature is $\sim$1 keV (Miller et al. 2002). With a power law index of 1.1–1.5 the power law index is somewhat harder than typical for LMXBs; they have indices’s of $\sim$2 (White, Nagase & Parmar 1995; Christian & Swank 1997).

The spectral fits of the first two Chandra observations showed evidence for excess emission at $\sim$0.6 keV. Such an excess has been found in other LMXBs as well and has been identified with a blend of emission lines from O VII–O VIII and/or Fe XVII–Fe XIX (Christian, White & Swank 1994). Recently, Juett, Psaltis & Chakrabarty (2001) showed that this excess can also be explained by an enhanced Ne/O ratio with respect to solar. Since two of the sources which show such an excess have an ultra short orbital period...
and the other sources have low absolute visual magnitudes, it was proposed that this enhanced Ne/O ratio is due to the fact that the compact objects are accreting matter of a neon–rich degenerate dwarf in ultracompact systems. In RX J170930.2–263927 the excess can be well–fit by a Gaussian line with an equivalent width of \(\sim 50–80\) eV centred at \(\sim 0.59\) keV.

Could the extra emission component in the spectrum be due to the enhanced absorption due to the contamination of the optical blocking filters? Tests performed by the Chandra X–ray Center show that the model describing the excess absorption as a function of time is better than 10% except near the C K–edge but this edge falls outside the spectral range we considered. We included this 10 per cent as a systematic uncertainty in our fits for channels below 1 keV; still we found excess emission near 0.6 keV. We conclude that it is unlikely that this excess emission is due to the imperfect correction for the contamination of the optical blocking filters. Hence, if the 0.6 keV excess is a unique feature of ultracompact X–ray binaries RX J170930.2–263927 has a short orbital period as well.

So far, two outbursts of RX J170930.2–263927 have been observed with RXTE’s ASM since the launch of RXTE (December 1995). Both outburst profiles show a steepening of the decay approximately 50 days after the start of the outburst (see for a figure of the first outburst profile Cocchi et al. 1998, and Figure for the profile of this outburst). Such a steepening in the decay of the outburst has been observed in other SXTs as well; this steepening has been interpreted as evidence for the onset

![Figure 4. Lightcurve of the burst in observation 1. Time zero corresponds to burst onset MJD 52345.73059 (TT). From X–ray spectral analysis it was found that it is likely that the observation suffered from severe pile–up. The burst e–folding time is 38±3 s.](image)
Figure 5. ASM count rate (left panel) and flux (right panel) evolution of the 2002 outburst of RX J170930.2–263927. The five crosses in each of the panels are derived from the Chandra measurements. The decay profile is two-fold. Note that (i) given the uncertainties involved in converting flux to ASM counts and vice versa (see text) no error bars are given for the right panel nor for the five Chandra points in the left panel (ii) the fluxes are not corrected for the interstellar absorption of the propeller mechanism (Illarionov & Sunyaev 1975; Aql X–1; Campana et al. 1998b; SAX J1808.4–3658, Gilfanov et al. 1998). However, since type I X–ray bursts are observed after the alleged onset of the propeller mechanism (Cocchi et al. 1998; this work) this means that mass accretion must be ongoing after the steepening of the decay. Furthermore, Psaltis & Chakrabarty (1999) found that in the accreting millisecond X–ray pulsar SAX J1808.4–3658 pulsation were found after the supposed onset of the propeller effect. Together, these findings pose a serious problem for the interpretation of the steepening of the decay as being due to the onset of the propeller mechanism. No pulsations have been reported for RX J170930.2–263927 (we determined a 95 per cent upper limit to pulsations in the frequency range 100–1000 Hz of 4.4 per cent fractional rms amplitude using the archival RXTE/PCA observation [2–60 keV; ID 20208-01-02-00] obtained during the previous outburst).

From the spectral fits and the hardness ratio (see Table 4) it was found that the source spectrum softened considerably between the third and fourth observation. Typically the spectra of SXTs become soft when $L < 10^{34}$ erg s$^{-1}$ (Tanaka & Shibazaki 1996). It is unclear what causes this softening, but it has been shown that the spectra of accreting neutron stars become soft for low mass accretion rates (Zampieri et al. 1995).

The best-fit interstellar absorption ($0.44 \times 10^{22}$ cm$^{-2}$) we found is somewhat higher than the interstellar absorption expected on the basis of the source location (Dickey & Lockman 1996). A more accurate calculation of the interstellar absorption in the direction of RX J170930.2–263927 based on the work of Schlegel, Finkbeiner & Davis (1998) finds $N_H =0.34 \times 10^{22}$ cm$^{-2}$. Possibly, some of the absorption is local to the system. Given the high Galactic latitude of the source this provides a lower limit to the source distance of 2.5 kpc.

We detected a burst from RX J170930.2–263927. Due to effects of pile-up, the first 20 s of the burst could not be used for spectral analysis. Analysis of the data obtained during the later stages of the burst showed evidence of spectral cooling, making it likely that this is a type I X–ray burst, establishing the nature of the compact object of this transient as a neutron star (confirming the findings of Cocchi et al. 1998). The burst e–folding time of 38±3 seconds makes it a typical mixed He/H burst; this is not contradicting the possibility that RX J170930.2–263927 is accreting from a hydrogen deficit donor star as Bildsten, Salpeter & Wasserman (1992) showed that nearly all metals will be destroyed in the atmosphere of the neutron star due to spallation processes. Cocchi et al. (1998) derived an upper limit to the distance of RX J170930.2–263927 of 10±1 kpc by assuming that the peak burst flux is less than the Eddington luminosity for a 1.4 M$_\odot$ neutron star ($L_{\text{Edd}} \sim 2 \times 10^{38}$ erg s$^{-1}$). Approximately the same upper limit is derived assuming that the peak outburst flux (1–2×10$^{-8}$ erg cm$^{-2}$ s$^{-1}$) is less than the Eddington limit for a 1.4 M$_\odot$ neutron star. If the distance to RX J170930.2–263927 is less then 4–5 kpc the source outburst luminosity is low and the source outburst luminosity fits in with that of the proposed class of faint SXTs (Heise et al. 1999; in’t Zand 2001).

We analysed data of RX J170930.2–263927 obtained by the ROSAT satellite. ROSAT observed and detected the source twice; once in August 1991 at a 0.1–10 keV
unabsorbed flux level of $4.8 \times 10^{-12} \text{ erg cm}^{-2} \text{s}^{-1}$ ($L = 5.4 \times 10^{34} \text{ erg cm}^{-2} \text{s}^{-1}$), and once in September 1992 at an unabsorbed flux level (0.1–10 keV) of $7.3 \times 10^{-11} \text{ erg cm}^{-2} \text{s}^{-1}$ ($L = 8.3 \times 10^{33} \text{ erg cm}^{-2} \text{s}^{-1}$). Since the possibility that ROSAT observed the source during an outburst is low given the fact that the ASM only observed two outbursts in over 6 years, we conclude that RX J170930.2–263927 must either have had a much shorter outburst interval time when the ROSAT observations were made, or that the source is active for a long time at a low luminosity level, similar to the neutron star SXTs SAX J1808.4–3658 (Wijnands et al. 2001), 4U 1608–52 (Wachter et al. 2002), Aql X–1 (Wachter et al. 2002), SAX J1747.0–2853 (Wijnands, Miller & Wang 2002), and EXO 0748–676. Variability of ongoing low–level accretion in these transient systems could provide an alternative explanation for some of the faint SXT sources (Heise et al. 1999). As was explained by Cornelisse et al. (2002) low level accretion in transient sources and variability therein could also explain the properties of several of the faint burst sources detected with the BeppoSAX satellite. Variability up to a factor of 10 has been observed during ongoing low–level accretion in 4U 1608–52 (Wachter et al. 2002); whereas much larger variations (up to a factor 1000 in 5 hours) have been observed in SAX J1808.4–3658 (Wijnands et al. 2001). Black hole candidate SXTs have also shown activity after the decay of an outburst (e.g. 4U 1630–47, Knuckles et al. 1999).

It is unclear whether RX J170930.2–263927 was already in quiescence during our last Chandra observation. The source luminosity during the last observation was between $1.8 \times 10^{32}–2.8 \times 10^{33} \text{ erg cm}^{-2} \text{s}^{-1}$ for a distance of 2.5–10 kpc, respectively. This luminosity range is consistent with the luminosity expected from cooling of a neutron star core (Brown, Bildsten & Rutledge 1998), although for a distance of 2.5 kpc the luminosity is rather low. The ratio between the outburst flux and quiescence flux is $\gtrsim 10^7$ (see Fig. 3); this is similar to that of Cen X–4. The outburst recurrence time is 5–10 years (cf. van Paradijs & McClintock 1995). Since it is unknown how much RX J170930.2–263927 brightened in outburst it is unclear what the absolute optical magnitude was. However, from the upper limit on the absolute visual magnitude we derive that the spectral type of the companion is large for an LMXB (cf. van Paradijs & McClintock 1994). Although, since our optical observations were performed when RX J170930.2–263927 was most likely in quiescence it is difficult to compare this absolute optical magnitude with the work of van Paradijs & McClintock (1994) as those authors considered actively accreting sources. During periods of accretion SXTs are known to be much brighter in optical than in quiescence (in case of the black hole candidate A 0620–00 the optical magnitude decreased by $\sim 7$ magnitudes, see van Paradijs & McClintock 1995). Since it is unknown how much RX J170930.2–263927 brightened in outburst it is unclear what the absolute optical magnitude was. However, from the upper limit on the absolute visual magnitude we derive that the spectral type of the companion must be later than F5–G0, making RX J170930.2–263927 a low–mass X–ray binary, unless the distance to the source is much larger than 8.5 kpc.

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From the Chandra ACIS–TE observation we derived an accurate position for RX J170930.2–263927. We note that this position is $\sim 9–10$ arcminutes away from the centre of the metal–poor Globular Cluster NGC 6293 at a distance of 8.5 kpc (although the uncertainties in the cluster distance are considerable; James & Heasley 1991). This Globular Cluster has a tidal radius of 14.2 arcminutes (Harris 1996). It is not unfeasible that the source was slung out of the Globular Cluster by interactions with other more massive components in the Globular Cluster. If the association is real and not a chance alignment, RX J170930.2–263927 has a projected distance of $\sim 25$ pc from the centre of the cluster. If the source is unassociated with the Globular Cluster it has travelled from the plane of the Galaxy, e.g. for a distance of 8.5 kpc RX J170930.2–263927 is 1.2 kpc above the Galactic plane; assuming RX J170930.2–263927 was born in the Galactic plane and it is at the highest point in its Galactic orbit, the initial space velocity must at least have been 120 km s$^{-1}$ (we used the potential for the Galaxy used by Lorimer 1994 in the implementation of Hartman et al. 1997).

We did not detect the optical counterpart with a five sigma upper limit of $m_\nu < 20.5$. The upper limit on the absolute magnitude of the counterpart to RX J170930.2–263927 is $\sim 3.5$ for an optical visual extinction of 2.4 magnitudes (taking $N_H = 0.44 \times 10^{22} \text{ cm}^{-2}$, the relation between $N_H$ and $A_V$ of Predehl & Schmitt 1993 and a distance of 8.5 kpc [if the source is closer than that the absolute optical magnitude will be larger]). This absolute optical magnitude is large for an LMXB (cf. van Paradijs & McClintock 1994). Although, since our optical observations were performed when RX J170930.2–263927 was most likely in quiescence it is difficult to compare this absolute optical magnitude with the work of van Paradijs & McClintock (1994) as those authors considered actively accreting sources. During periods of accretion SXTs are known to be much brighter in optical than in quiescence (in case of the black hole candidate A 0620–00 the optical magnitude decreased by $\sim 7$ magnitudes, see van Paradijs & McClintock 1995). Since it is unknown by how much RX J170930.2–263927 brightened in outburst it is unclear what the absolute optical magnitude was. However, from the upper limit on the absolute visual magnitude we derive that the spectral type of the companion must be later than F5–G0, making RX J170930.2–263927 a low–mass X–ray binary, unless the distance to the source is much larger than 8.5 kpc.
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