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 ∼8.5 kpc. We determined that L_{outburst}/L_{quiescence} ∼ 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 ∼1.7–1.8 M⊙. 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 ∼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⊙ 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 Campa 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 (≥ 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...
We observed RX J170930.2–263927 five times with the Chandra satellite [Jonker et al. 2001]. From these studies a basic picture of the outburst mechanism has emerged; the thermal–viscous disk instability model [Smak 1983; Cannizzo, Chen & Livio 1995; 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 burst–induced neutron stars form a separate class of faint SXTs. Some may have a low peak–luminosity (typically ∼10^{35.5} \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 & Swanks 2002; Markwardt et al. 2002]) and XTE J0929–314 ([Galloway et al. 2002a; Galloway et al. 2002b]) with orbital periods of ∼42 and ∼43 minutes, respectively. These systems fit–in with the class of ultra–short period binaries. However, in contrast, the fact 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 Proportional Counter Array on 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.

2 OBSERVATIONS AND ANALYSIS

We observed RX J170930.2–263927 five times with the Advanced CCD Imaging Spectrometer (ACIS) back-illuminated S3 chip onboard the Chandra satellite [Weisskopf 1988]. A log of the observations is given in Table 1. 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 mirrors 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.

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 OFFSET; 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} of
Chandra observations of the neutron star soft X–ray transient RX J170930.2–263927

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 ACISABS 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 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 the largest residuals appear in the soft part of the spectrum.

We note that the F values decrease by that amount just by chance when the numbers of d.o.f. decrease by two or three for 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 and without a Gaussian gives an F statistic value of 4.7 for observation 1 and 10.8 for observation 2. The probability that the F values decrease by that amount just by chance when the numbers of d.o.f. decrease by two or three for the Gaussian is \( \leq 1 \times 10^{-4} \) and \( \leq 8 \times 10^{-7} \) for observation 1 and 2, respectively (in the fit of the first observation the line was weak and we fixed the FWHM to 50 eV; see Table 3.2).

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 hydro–
tergene model (Pavlov, Shibanov & Zavlin 1991, Zavlin, Pavlov & Shibanov 1996). The mass and the radius of the neutron star were held fixed in the neutron star hydrogen atmosphere model (Mendez, Cottam & Paerels 2002). We used a Gaussian line to account for this excess emission near 0.6 keV. The best–fit parameters of the model for each observation, including a 10 per cent uncertainty below 1 keV, are given in Table 2. The quoted errors on the best–fit parameters correspond to 68% confidence (1 \( \sigma \)).

In the first two observations (where the signal–to–noise is the highest) the inclusion of a Gaussian line centered near ~0.6 keV results in a better fit. Using an F–test to assess the significance of the reduction in the \( \chi^2 \) for the fit with and without a Gaussian gives an F statistic value of 4.7 for observation 1 and 10.8 for observation 2. The probability that the F values decrease by that amount just by chance when the numbers of d.o.f. decrease by two or three for the Gaussian is \( \leq 1 \times 10^{-4} \) and \( \leq 8 \times 10^{-7} \) for observation 1 and 2, respectively (in the fit of the first observation the line was weak and we fixed the FWHM to 50 eV; see Table 3.2).

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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 4).

### Table 1. Log of the observations.

<table>
<thead>
<tr>
<th>Observation # / ID</th>
<th>Observation date and start time (TT)</th>
<th>MJD</th>
<th>Total effective on source time (ksec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 / 3462</td>
<td>12–03–2002 13:34</td>
<td>52345.565</td>
<td>~14.2</td>
</tr>
<tr>
<td>2 / 3463</td>
<td>18–03–2002 11:25</td>
<td>52351.475</td>
<td>~5.6</td>
</tr>
<tr>
<td>3 / 3464</td>
<td>01–04–2002 00:27</td>
<td>52365.018</td>
<td>~5.1</td>
</tr>
</tbody>
</table>

<http://asc.harvard.edu/cal/Acis/Cal_prods/qeDeg/>

**Notes**: Table 1. Log of the observations.

**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-

Towards the source we obtained a 5 minute V–band image with the 2.5 m INT telescope on La Palma on June 6, 2002 to search for the optical counterpart of RX J170930.2–263927. We note that by that time the X–ray source was most likely back in quiescence. An astrometrical solution for the optical image was obtained using the USNO positions of 5 stars. The rms uncertainty of the astrometrical solution was 0.13 Arches. Hence, the overall uncertainty in the astrometry is dominated by the Chandra positional uncertainty. In Figure 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 5 \( \sigma \) 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 \( m_V = 20.5 \).
Table 2. Spectral fits\(^{a,b}\)

| Obs. | PHABS \(N_H\) (\(\times 10^{22}\) cm\(^{-2}\)) | BB \(kT\) (keV) | \(cR^2/D_1^2\) (km) | BB \(kT\) (keV) | \(cR^2/D_1^2\) (km) | PL \(\Gamma\) | \(A_{pl}\) \(\text{dpl}\) | \(E_0\) (keV) | FWHM (eV) | \(A_g\) | \(\chi^2/d.o.f.\) |
|------|--------------------------------|--|----------------|--------------------------------|--|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1    | 0.44\(\pm\)0.02 | 0.60\(\pm\)0.01 | 29\(\pm\)3 | 0.132\(\pm\)0.004 | \((2.9^{+2.4}_{-1.4})\times10^4\) | 1.31\(\pm\)0.08 | \((9.4\pm0.8)\) | ... | ... | ... | 1.05/461 |
| 2    | 0.44\(^e\) | 0.52\(\pm\)0.02 | 25\(\pm\)6 | 0.115\(\pm\)0.002 | \((8.6\pm1.0)\times10^4\) | 1.7\(\pm\)0.1 | \((14^{+0.7}_{-0.7})\) | ... | ... | ... | 1.03/103 |
| 3    | 0.44\(^e\) | 0.89\(\pm\)0.09 | 20\(^{+0.8}_{-0.7}\) | 0.22\(\pm\)0.01 | 139\(\pm\)30 | ... | ... | ... | ... | ... | 1.07/19 |
| 4    | 0.44\(^e\) | 0.38\(\pm\)0.05 | 1.1\(^{+0.9}_{-0.6}\) | 0.12\(\pm\)0.01 | 800\(^+300\)\(-400\) | ... | ... | ... | ... | ... | 1.07/19 |
| 5\(^f\) | 0.44\(^e\) | 0.22\(\pm\)0.03 | 14\(-6\) | ... | ... | ... | ... | ... | ... | ... | 1.07/19 |
| 1\(^f\) | 0.44\(^e\) | 0.60\(\pm\)0.01 | 28\(\pm\)3 | 0.139\(\pm\)0.004 | \((2.1\pm0.3)\times10^4\) | 1.28\(\pm\)0.11 | 8.8\(\pm\)0.7 | 0.60\(\pm\)0.02 | 50\(^f\) | \((8\pm2)\times10^{-3}\) | 1.02/457 |
| 2\(^f\) | 0.44\(^e\) | 0.54\(\pm\)0.01 | 31\(\pm\)5 | 0.136\(\pm\)0.006 | \((2.8\pm0.8)\times10^4\) | 1.5\(\pm\)0.2 | 9.3\(\pm\)2.0 | 0.57\(\pm\)0.02 | 83\(^f\) | \((3.0\pm0.5)\times10^{-2}\) | 0.96/401 |

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

\(^b\) PHABS = interstellar absorption, PL = power law, BB = blackbody

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

\(^d\) Power Law normalisation at 1 keV in units of \(10^{-3}\) photons keV\(^{-1}\) cm\(^{-2}\) s\(^{-1}\).

\(^e\) Parameter was fixed at this value during the fit.

\(^f\) Including a Gaussian line in the fit to account for the excess near 0.6 keV

\(^g\) C–statistics used

\(^h\) The value of the interstellar absorption is determined taking the local absorption due to the Chandra optical blocking filters into account.
observations of the neutron star soft X–ray transient RX J170930.2-263927

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average power spectrum obtained during the second observations was 0.1
± 0.2 for that above the break, (2.3±0.5)×10⁻² Hz for the break frequency, while the fractional rms amplitude was 12±1 per cent. Errors on the fit–parameters were determined using ∆χ² = 1.0 (1 σ single parameter), whereas upper limits on the broken power law component were determined using ∆χ² = 2.71 (95 per cent confidence).

3.4 Burst properties

At the end of the first observation an X–ray burst occurred (see Figure 3). Inspecting the lightcurve we noted a slow–down in the increase and even a decrease in count rate during the first stages of the burst. To investigate whether this is due to radius expansion or due to effects of pile–up we analysed the spectra of the burst by combining data 0–5 s, 5–10 s, 10–15 s, 15–20 s, 20–40 s, 40–60 s, 60–80 s, and 80–160 s after burst–onset. This also allows us to investigate whether there are signs of cooling estabilishing 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 ~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~20 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.
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 \(\sim 0.6\) 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

<table>
<thead>
<tr>
<th>Data segment</th>
<th>kT (keV)</th>
<th>(4R^2/D_g^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±0.1</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 4 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 4 left panel).
The source outburst decay is two-fold. Until MJD ∼52331 the decay is slow, but after that the rate of decay increases by a factor ∼10 (a fit of a broken power law to the ASM count rate data gives a power law index of (−7.6±1.4)×10^{−3} before t = 50±1 days and (−7.4±0.2)×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 = 0.44×10^{22} cm^{-2}) a blackbody temperature of 0.22±0.01 keV and radius of (2±0.5)×10^{3} km were found. The unabsorbed source flux (0.1–10 keV) was 4.8×10^{−12} erg cm^{-2} s^{-1}.

The source was also in the field of view of a ~900 s pointed PSPC observation of the source V2051 Oph obtained on September 22, 1992 (see also Verbunt 2001). The 0.2–2.4 keV source spectrum was well fit by an absorbed blackbody of a temperature of 0.22±0.02 keV and a radius of (2.9±1.0)×10^{3} km (again the N_H was fixed at 0.44×10^{22} cm^{-2}). The unabsorbed source flux (0.1–10 keV) was 7.3×10^{−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 ∼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 ∼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 index's of ∼2 (White, Nagase & Parmar 1995, Christian & Swank 1997).

The spectral fits of the first two Chandra observations showed evidence for excess emission at ∼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
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.

Table 4. Unabsorbed flux measurements of the best–fit spectral model and the hard colour (see text) of the five Chandra observations.

<table>
<thead>
<tr>
<th>Observation</th>
<th>flux (0.1–10 keV) (erg cm(^{-2}) s(^{-1}))</th>
<th>luminosity ((d_{10kpc}))^2 erg s(^{-1}))</th>
<th>hard colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.8(\times)10(^{-10})</td>
<td>2.0(\times)10(^{36})</td>
<td>-0.56</td>
</tr>
<tr>
<td>2</td>
<td>1.9(\times)10(^{-10})</td>
<td>2.1(\times)10(^{36})</td>
<td>-0.60</td>
</tr>
<tr>
<td>3</td>
<td>3.9(\times)10(^{-12})</td>
<td>4.4(\times)10(^{34})</td>
<td>-0.85</td>
</tr>
<tr>
<td>4</td>
<td>9.9(\times)10(^{-13})</td>
<td>1.1(\times)10(^{34})</td>
<td>-2.59</td>
</tr>
<tr>
<td>5</td>
<td>2.5(\times)10(^{-13})</td>
<td>2.8(\times)10(^{33})</td>
<td>-4.57</td>
</tr>
</tbody>
</table>

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 ∼50–80 eV centred at ∼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 5 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
Chandra observations of the neutron star soft X–ray transient RX J170930.2–263927

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. 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⊙ neutron star (L_{\text{Edd}} ∼ 2 × 10^{38} \text{ erg s}^{-1}). Approximately the same upper limit is derived assuming that the peak outburst flux (1–2 × 10^{−8} \text{ erg cm}^{-2} \text{ s}^{-1}) is less then the Eddington limit for a 1.4 M⊙ 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 $4.8 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ ($L = 5.4 \times 10^{34} \left(\frac{d}{10 \text{kpc}}\right)^2 \text{ erg s}^{-1}$), and once in September 1992 at an unabsorbed flux level of $(0.1–10 \text{ keV})$ of $7.3 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ ($L = 8.3 \times 10^{32} \left(\frac{d}{10 \text{kpc}}\right)^2 \text{ erg s}^{-1}$). 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 SAX J1747.0–2853 (Wijnands et al. 2001), 4U 1608–52 (Wachter et al. 2002), Aql X–1 (Wachter et al. 2002), and once in September 1992 (see Yungelson, Nelemans & van den Heuvel 2002). How- ever, the fluence of the March–April 2002 outburst of 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 1995 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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