

# On the nature of two low- $\dot{M}$ X-ray bursters: 1RXS J170854.4–321857 and 1RXS J171824.2–402934

J. J. M. in 't Zand<sup>1,2</sup>, R. Cornelisse<sup>3</sup>, and M. Méndez<sup>1,2</sup>

<sup>1</sup> SRON National Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands

<sup>2</sup> Astronomical Institute, Utrecht University, PO Box 80000, 3508 TA Utrecht, The Netherlands

<sup>3</sup> Department of Physics and Astronomy, University of Southampton, Hampshire SO17 1BJ, UK

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**Abstract.** We carried out Chandra observations of two low-luminosity low-mass X-ray binaries, 1RXS J170854.4–321857 and 1RXS J171824.2–402934, for which previously single X-ray bursts were detected with the Wide Field Cameras (WFCs) on board BeppoSAX. Both were detected in our Chandra observations in an actively accreting state three to eight years after the X-ray bursts, with 0.5–10 keV luminosities between  $5 \times 10^{34}$  and  $2 \times 10^{36}$  erg s<sup>-1</sup>. The apparently persistent nature is remarkable for 1RXS J171824.2–402934 given its low luminosity of  $10^{-3} L_{\text{Edd}}$ . The persistence of both sources also distinguishes them from 5 other low- $L$  bursters, which have also been seen during bursts with the WFCs but were not detected during Chandra observations above a luminosity of  $10^{33}$  erg s<sup>-1</sup>. Those are probably transient rather than persistent sources.

**Key words.** X-rays: binaries – X-rays: bursts – X-rays: individual: 1RXS J170854.4–321857 = 4U 1705–32 = 1M 1704–321 = 1H 1659–317; 1RXS J171824.2–402934 = RX J1718.4–4029

## 1. Introduction

Currently almost 200 low-mass X-ray binaries (LMXBs) are known in our galaxy (150 are cataloged by Liu et al. 2001 and several tens have been discovered since then). Roughly half exhibit type-I X-ray bursts (e.g., In 't Zand et al. 2004) which are due to thermonuclear flashes on neutron star surfaces (for reviews, see Lewin et al. 1993; Bildsten 1998 and Strohmayer & Bildsten 2005). Most (type-I) X-ray bursters have accretion rates in excess of 1% of the Eddington limit for a canonical neutron star ( $10^{-8} M_{\odot} \text{yr}^{-1}$ ) and burst recurrence times between hours and months. However, at least seven bursters may have lower accretion rates (see Tables 1 and 2). These were discovered through observations with the Wide Field Cameras (WFCs; Jager et al. 1997) on BeppoSAX (Boella et al. 1997). During its 1996–2002 operational life this instrument gathered 1 to 12 Ms (depending on exact position) of exposure along the Galactic plane which resulted in the detection of rare bursters like the seven bursters without persistent emission' (in 't Zand et al. 1998; Kaptein et al. 2000; Cocchi et al. 2001; Cornelisse et al. 2002a and in 't Zand et al. 2004). Each of these bursters exhibited a single burst. The flux limit on the persistent emission of these rare bursters translates (for a canonical 8 kpc distance) to a luminosity limit of  $\sim 10^{36}$  erg s<sup>-1</sup> or roughly 1% of the Eddington limit. Five bursters were previously unknown sources while two, 1RXS J170854.4–321857 and 1RXS J171824.2–402934, were detected with ROSAT (Kaptein et al. 2000; In 't Zand et al. 2004).

Cornelisse et al. (2002b) followed up four of the five low- $L$  bursters without ROSAT counterparts, with the Chandra

observatory for 5 ksec each. No unique counterparts could be identified. In three cases multiple candidate counterparts were identified with persistent luminosity levels of  $10^{32-33}$  erg s<sup>-1</sup> for 8 kpc distances, while in the fourth case a similar-valued upper limit was inferred. These levels are typical for neutron star transients in quiescence (Verbunt et al. 1994; Asai et al. 1998; Campana et al. 1998; Rutledge et al. 1999; Menou et al. 1999) suggesting that, if they are truly type-I X-ray bursters, they are transient sources whose peak flux during outburst was too low to be detected with monitoring devices such as the WFCs or the All-Sky Monitor (ASM) on RXTE (Levine et al. 1996).

The two low- $L$  bursters with ROSAT counterparts may be of a different nature. Since ROSAT detected them several years prior to the WFCs, the suggestion is that these are *persistent* low-luminosity systems. In order to confirm this, we followed them up with Chandra with the Advanced CCD Imaging Spectrometer spectroscopic array (ACIS-S) in the focal plane. Also, we carried out a more detailed analysis of the WFC-detected burst of 1RXS J170854.4–321857, searched through RXTE data for detections, and browsed the literature for historical detections. The results, as well as a discussion of the implication of these observations for the nature of these sources, are presented here.

## 2. Observations of 1RXS J170854.4–321857

### 2.1. BeppoSAX/WFC

The burst from 1RXS J170854.4–321857 started at 05:11:35 UT on Sep. 16, 2000 (MJD 51 803.216379) and

**Table 1.** Overview of the burst sources at low persistent emission as detected with the Wide Field Cameras on board BeppoSAX. The distances were determined by assuming burst peak fluxes to be equal (for radius-expansion bursts) to or smaller than the Eddington limit of a canonical neutron star, and have a typical uncertainty of 30%.  $\tau$  is the overall e-folding decay time of the burst.

Object	$l^{\text{II}}$	$b^{\text{II}}$	Distance (kpc)	$L_{\text{pers}}$ ( $10^{32}$ erg s $^{-1}$ )	Follow up instr. (delay in yr)	$\tau$ (s)	Ref. <sup>‡</sup>
SAX J1324.5–6313	306:6	–0:6	<6.2	<4	Chandra (+4.1)	6.0	1, 2
1RXS J170854.4–321857	352:8	+4:7	13	15 000	Chandra (+3.4)	300	3
1RXS J171824.2–402934	347:3	–1:7	8	700	Chandra (+7.8)	47.5	3, 4
SAX J1752.4–3138	358:4	–2:6	9.2	<3	Chandra (+2.0)	21.9	2, 5
SAX J1753.5–2349	5:3	+1:1	<8	<4	Chandra (+5.1)	8.9	2, 6
SAX J1818.7+1424	42:3	+13:7	<9.4	<4	Chandra (+3.9)	4.5	1, 2
SAX J2224.9+5421	102:6	–2:6	<7.1	<12	BeppoSAX (+0.001)	2.6	1

<sup>‡</sup> 1) Cornelisse et al. (2002a); 2) Cornelisse et al. (2002b); 3) this paper; 4) Kaptein et al. (2000); 5) Cocchi et al. (2001); 6) in 't Zand et al. (1998).

**Table 2.** List of sources previously considered as low- $L$  bursters but now established as transients.

Object	$L_{\text{pers}}$ ( $10^{32}$ erg s $^{-1}$ )	Ref. <sup>‡</sup>
GRS 1741.9–2853	$2 \times 10^5$	1
SAX J1828.5–1037	340 (0.02 yr after burst)	2
SAX J1806.5–2215	$3 \times 10^4$	3

<sup>‡</sup> 1) Munro et al. (2003); 2) Hands et al. (2004); 3) Cornelisse et al. (2002a).

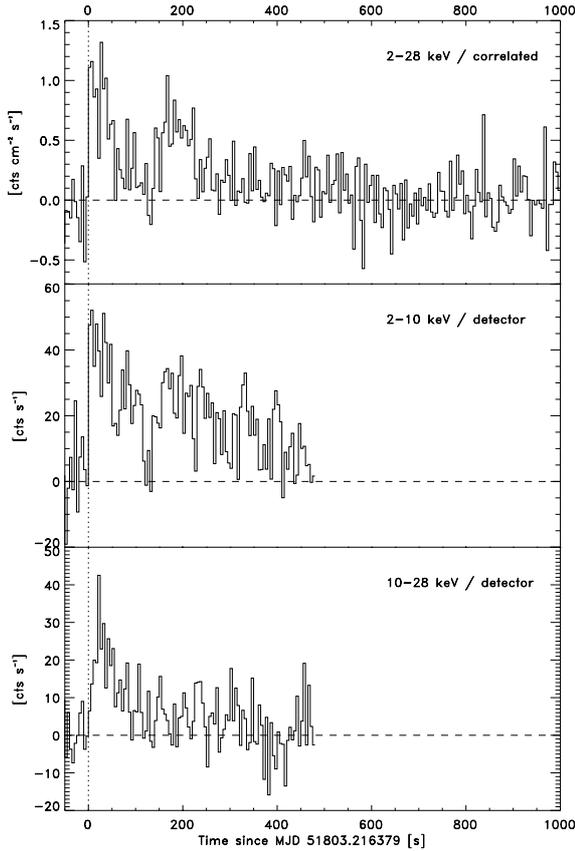
lasted fairly long, with a duration of approximately 10 min. This burst was previously reported by in 't Zand et al. (2004), but we here provide a more detailed analysis. Figures 1 and 2 present the light curve and time-resolved spectroscopy. The burst is relatively faint. Only 4 meaningful time bins could be employed for spectroscopy. Nevertheless, the data are consistent with a blackbody spectrum and exhibit softening during decay. Combined with a sub-second rise this provides ample evidence for identification as a type-I X-ray burst (Hoffman et al. 1978). There are two peculiarities about the burst. First, the flux shows a slower increase in 10–28 keV than in 2–10 keV. This suggests that there is mild photospheric radius expansion due to near-Eddington luminosities. Unfortunately, the faintness of the burst precludes a spectral confirmation of such an expansion. If we translate the peak bolometric flux to the Eddington limit of a canonical neutron star ( $2 \times 10^{38}$  erg s $^{-1}$  for a hydrogen-rich and  $3.8 \times 10^{38}$  erg s $^{-1}$  for a hydrogen-poor photosphere; e.g. Kuulkers et al. 2003), we estimate a distance between 11 and 15 kpc. Therefore, the faintness of the burst seems to be due to a large distance. The second peculiarity involves a drop in flux around 100 s after the onset. The indication is that the drop is to zero. This may or may not be related to temporarily increased absorption by intervening material. This is impossible to test with these data. The burst bolometric fluence is  $(1.5 \pm 0.5) \times 10^{-6}$  erg cm $^{-2}$  which for the distance of  $13 \pm 2$  kpc translates to a radiative energy output of  $3.0^{+2.4}_{-1.5} \times 10^{40}$  erg.

We evaluated the position of the source that produced this burst from a 500-s data stretch in the 2–10 keV bandpass and find  $\alpha_{2000.0} = 17^{\text{h}}08^{\text{m}}52^{\text{s}}.5$ ,  $\delta_{2000.0} = -32^{\circ}19'26''$  with a 99%-confidence error circle of radius 1'.8. This is 0'.6 from the centroid position of 1RXS J170854.4–321857, well within the WFC error circle. The nearest other ROSAT source is 14'.7 from this position, which implies that source confusion is not an issue and that the burst can be fairly confidently associated with this source.

## 2.2. Chandra/ACIS-S

1RXS J170854.4–321857 was observed with Chandra for 13.7 ks (net exposure time) with ACIS-S (Garmire et al. 2003) in the focal plane starting Jan. 28, 2004, at 00:13:30 UT (obsid 4549). The pointing direction was nominal so that the source was focused on chip S3. The CCD frame time was set to the nominal 3.2 s. The image shows a heavily piled-up source with the typical hole in the center of the point spread function and readout trails. We determined the average of the photon positions within a circle with a 12'.5 radius. This translates to  $\alpha_{2000.0} = 17^{\text{h}}08^{\text{m}}54^{\text{s}}.269$ ,  $\delta_{2000.0} = -32^{\circ}19'57''.13$  ( $l^{\text{II}} = -7:22$ ,  $b^{\text{II}} = +4:67$ ) with a nominal uncertainty of 0'.6 (all forthcoming uncertainties in this paper are for a confidence level of 90% for a single parameter of interest). This is 1'.7 from the ROSAT position which is consistent given that the ROSAT position has an accuracy of 8''. Searches in red and infrared plates of the Digital Sky Survey and in the USNO-B1.0 catalog have not revealed an optical counterpart. The nearest star is 1'.6 from the centroid. Typical magnitude limits of these searches are 20 mag. The nearest near-infrared object in the 2MASS catalog is at 10'.7.

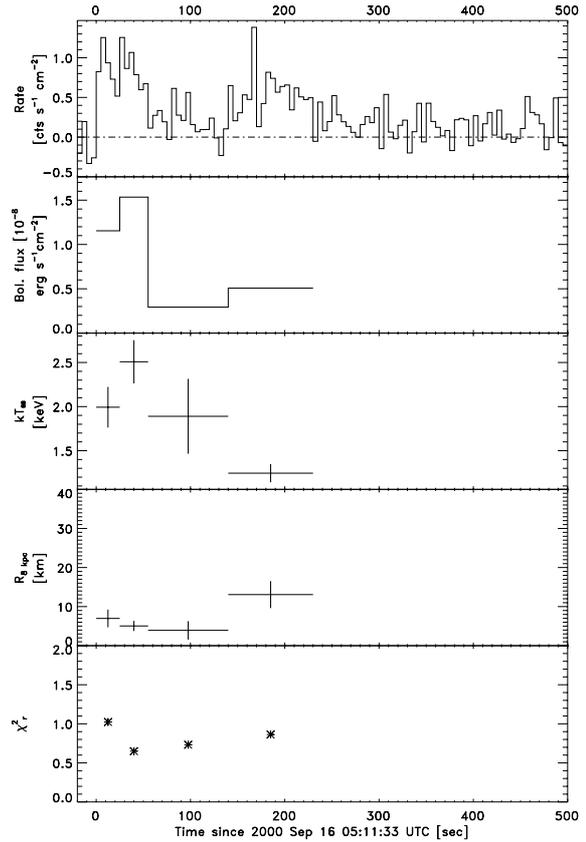
Since the pile up is heavy, we resorted to the photons in the readout trails for a spectral analysis. The photons from the readout trails are not subject to pile up as long as the count rate is below a few thousand s $^{-1}$ , because during CCD readout the pixels have a readout time of only 40  $\mu$ s instead of 3.2 s. We extracted the readout source spectrum through CIAO tool `acisreadcorr` with an extraction region that is 2'.5 wide, starts at 25'' from the source centroid and ends at



**Fig. 1.** WFC light curves of 1RXS J170854.4–321857. *Top*: in total bandpass, from reconstructed source images (“correlated” with coded aperture; see Jager et al. 1997). *Middle and bottom*: at low and high photon energies, from photon rates on the detector. Detector photon rates are not calibrated but we have chosen to present those rather than the imaged rates as in the top panel, because they have a slightly better statistical quality which for this faint burst enables easier visual comparison of the profiles in two bandpasses. These profiles are cut at  $t = 500$  s because the subsequent data show a burst from a different source in the same field of view. The time resolution is 5 s.

the CCD edges. The background spectrum was extracted in a similar region 100 pixels to the north. The source spectrum contains 1161 photons and the background spectrum 243. The spectrum was rebinned so that each photon energy bin contains at least 15 photons to ensure applicability of the  $\chi^2$  statistic. The effective exposure time is 1.16% of the total exposure time. An absorbed power law model fits this spectrum satisfactorily ( $\chi^2_\nu = 1.24$  for  $\nu = 53$ ) and yields  $N_{\text{H}} = (4.0 \pm 1.0) \times 10^{21} \text{ cm}^{-2}$ , a photon index of  $\Gamma = 1.9 \pm 0.2$  and a 0.5–10 keV flux of  $(7.3 \pm 0.6) \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ . For a distance of 11–15 kpc, this translates to a luminosity of  $(1\text{--}2) \times 10^{36} \text{ erg s}^{-1}$ .

The spectrum is typical of low- $L$  LMXBs. Wilson et al. (2003) performed a Chandra study of 8 low- $L$  LMXBs, also using ACIS-S. Half of these are X-ray bursters. The spectra of those could be modeled with an absorbed power law with a photon index of 1.8–2.2. Such indices are typical of faint non-quiet neutron-star LMXBs in general (cf., Barret et al. 1996).



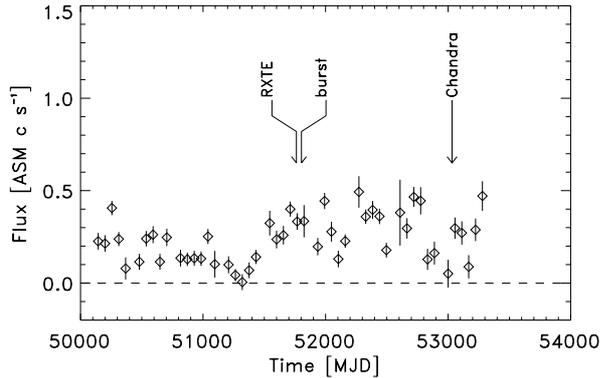
**Fig. 2.** Time-resolved spectroscopy of the burst from 1RXS J170854.4–321857.

We inspected the light curve for photons in an annulus around the PSF centroid with an inner and outer radius of  $1'5$  and  $5'0$  respectively. There are no noticeable features at a time resolution of 32 to 320 s. We also inspected the lightcurve of the trailed photons which allow studying frequencies up to  $10^4$  Hz due to the fast readout. No signal was found in the power spectrum above a  $3\sigma$  upper limit in the pulsed fraction of  $\sim 25\%$ .

### 2.3. Other

Interestingly, 1RXS J170854.4–321857 appears to have a long history of X-ray detections prior to ROSAT. A source was detected at the same position at 5–25 mCrab (2–6 keV) already in 1971–1973 by UHURU (4U 1705–32; Forman et al. 1978), at  $6 \pm 2$  mCrab (3–10 keV) with OSO-7 in 1971–1973 (1M 1704–321; Markert et al. 1979) and at 1.6 mCrab with HEAO-1/A-1 in late 1977 (1H 1659–317; Wood et al. 1984).

Figure 3 shows the 3–12 keV light curve as measured since 1996 with the ASM at a time resolution of 8 weeks, based on 2.9 Ms worth of data. There is a small signal with a factor of 10 variability which appears to change in strength at MJD 51300 (approximately one year before the WFC detected the burst). Before that the average flux is  $2.4 \pm 0.1$  mCrab and afterwards  $3.4 \pm 0.1$  mCrab (3–12 keV). For a Crab-like spectrum, as measured with Chandra, these numbers translate to 0.5–10 keV fluxes of 7 and  $10 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ .



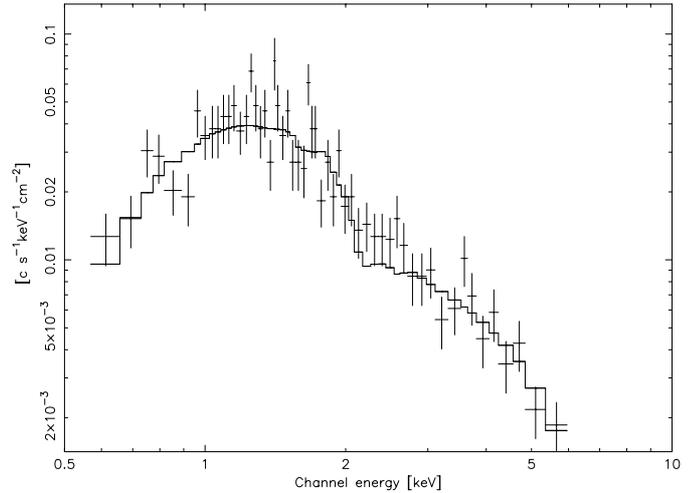
**Fig. 3.** ASM light curve of 1RXS J170854.4–321857 with a time resolution of 8 weeks. All data point with errors in excess of 0.1 ASM  $\text{c s}^{-1}$  have been eliminated. No bias level was subtracted. The arrows indicate the times of the WFC-detected burst, and the Chandra and RXTE pointed observations.

The fractional rms does not change. We note that these flux levels are rather low for the ASM and may be liable to systematic errors. At higher fluxes this error is negligible. A check of the dwell data reveals that the ASM for certain did not detect any X-ray bursts like seen with the WFC.

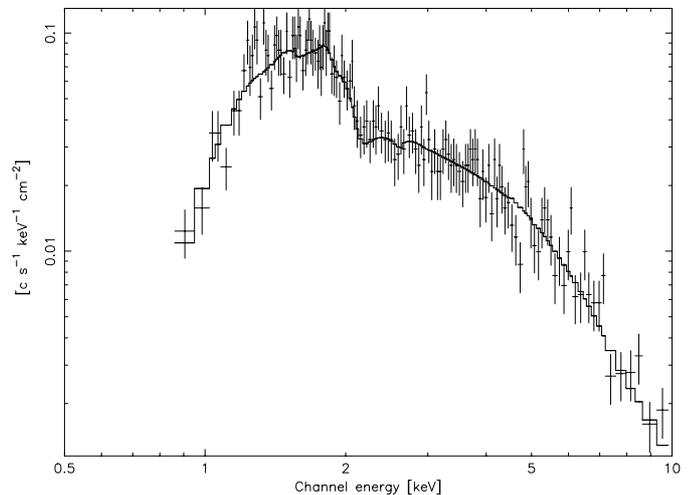
RXTE also made a pointed observation of 1RXS J170854.4–321857. It was a target-of-opportunity observation on Aug. 6, 2000, at 02:37:20 UT for 3.4 ks after it was detected during a slew maneuver. This is 41 d prior to the WFC-detected burst. All PCUs of the Proportional Counter Array (PCA; Jahoda et al. 1996) were active during this observation. No burst was detected. The overall 3–20 keV spectrum, as distributed through the “standard products”, could be satisfactorily modeled ( $\chi^2_\nu = 1.44$  for  $\nu = 37$ ) with an absorbed power law with  $N_{\text{H}} = (1.5 \pm 0.7) \times 10^{22} \text{ cm}^{-2}$  and  $\Gamma = 2.09 \pm 0.05$ . The value for  $N_{\text{H}}$  is inconsistent with that determined through the Chandra spectrum which is more sensitive to  $N_{\text{H}}$  because of its lower energy coverage. If we fix  $N_{\text{H}}$  to the Chandra value, the fit is only slightly worse with  $\chi^2_\nu = 1.56$  ( $\nu = 38$ ) and  $\Gamma = 2.02 \pm 0.03$ . The 3–20 keV flux is  $1.0 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$ . The unabsorbed 0.5–10 keV flux is  $1.7 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$  which is 2 times higher than during the Chandra observation. The extrapolated 0.5–40 keV flux is  $2.4 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$  which translates to a luminosity of  $(3\text{--}6) \times 10^{36} \text{ erg s}^{-1}$ .

Finally, 1RXS J170854.4–321857 was detected with INTEGRAL during a long campaign in Aug.–Sep. 2003 at a 18–60 keV flux of  $(3.4 \pm 0.3) \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$  (Revnivtsev et al. 2004; see also Stephen et al. 2005). For a spectrum like the one measured with Chandra, this extrapolates to a 0.5–10 keV flux of  $5.5 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ , which is close to that measured with Chandra during the same year. For a power law index as measured with RXTE (with the same  $N_{\text{H}}$  as measured with Chandra) the extrapolated 0.5–10 keV flux is 20% higher than measured with Chandra.

In conclusion, the source shows a rather consistent unabsorbed flux between 8 and  $17 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ .



**Fig. 4.** Chandra/ACIS-S3 trail spectrum of 1RXS J170854.4–321857.



**Fig. 5.** Chandra/ACIS-S3 spectrum of 1RXS J171824.2–402934.

### 3. Observations of 1RXS J171824.2–402934

The burst from 1RXS J171824.2–402934 was already discussed in detail by Kaptein et al. (2000); we summarize that discussion here. The burst onset was on Sep. 23, 1996, at 07:30:55 UT (MJD 50349.31314). The 2–28 keV photon flux remained at a plateau for approximately 70 s after that. The burst lasted fairly long: after 3.5 min the source set behind the earth when the 2–28 keV flux had decayed to about 20% of the peak value. The time-resolved spectroscopy revealed clear signs of photospheric radius expansion which allowed a distance estimate of  $6.5 \pm 0.5 \text{ kpc}$  for a canonical neutron star if the photosphere is rich in hydrogen.  $N_{\text{H}}$  was measured to be  $(3.1 \pm 1.3) \times 10^{22} \text{ cm}^{-2}$ . The unabsorbed bolometric peak flux was  $3.9 \times 10^{-8} \text{ erg cm}^{-2} \text{ s}^{-1}$ . The energy output is  $>3 \times 10^{40} \text{ erg}$ .

Chandra observed 1RXS J171824.2–402934 with ACIS-S in the focal plane on Jul. 2, 2004, for a total of 14.8 ks (net exposure time) starting 06:49:19 UT (obsid 4548). The CCD frame time was set at the nominal 3.2 s. The source position, by averaging of the photon positions, was determined to be  $\alpha_{2000.0} = 17^{\text{h}}18^{\text{m}}24^{\text{s}}.144$ ,  $\delta_{2000.0} = -40^{\circ}29'33''.04$  ( $l^{\text{II}} = -12^{\circ}.72$ ,  $b^{\text{II}} = -1^{\circ}.65$ ) with a nominal uncertainty of 0'.6. This

is  $2''.0$  from the ROSAT position which is consistent given that the ROSAT position has an accuracy of  $15''.7$  (Motch et al. 1998). Searches in red and infrared plates of the Digital Sky Survey and in the USNO-B1.0 catalog failed to identify an optical counterpart brighter than 20 mag. The nearest near-infrared object in the 2MASS catalog is at  $6''.3$ .

The raw source intensity is  $0.18 \text{ c s}^{-1}$ . This implies significant pile up for the nominal CCD frame time of 3.2 s, although the image does not show an obvious drop at the center of the point spread function (PSF) nor a readout streak. In order to correct for pile up, the level-1 data were reprocessed to allow inclusion of “afterglow” events. From the resulting new level-2 data we extracted the photons within  $2''$  from the centroid position, while we determined the background from a nearby circular region with a radius of  $56''$ . The source region encompasses 2623 events. The background is negligible and the source count rate in the full bandpass is  $0.176 \pm 0.003 \text{ s}^{-1}$ . We modeled the data with an absorbed power law with pile up following Davis et al. (2001). Of the pile-up model we left free two parameters. One is  $\alpha$ , the “grade morphing” parameter (i.e., the probability that  $n$  piled-up photons are not rejected is proportional to  $\alpha^{n-1}$ ). We found that the fits prefer  $\alpha$  between 0.7 and 1, but are not sensitive to any particular value in that range. The other free pile-up parameter is the fraction of the PSF subject to pile up. This was found to be  $0.83 \pm 0.04$ . The fit is satisfactory with a goodness of fit of  $\chi^2_\nu = 0.94$  for  $\nu = 135$  degrees of freedom. We find for the source spectrum  $N_{\text{H}} = 1.32^{+0.16}_{-0.12} \times 10^{22} \text{ cm}^{-2}$  and a photon index of  $\Gamma = 2.09^{+0.22}_{-0.24}$ . The spectrum is so much absorbed that data below 0.8 keV were excluded in the fits. The (extrapolated) unabsorbed 0.5–10 keV flux before pileup correction is  $(7.1 \pm 0.1) \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$  and after  $(2.2 \pm 0.8) \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ . The pileup correction is rather uncertain because the photon flux is very close to the peak in the curve of the observed versus CCD-incident photon flux (see Fig. 6 in Davis 2001). Therefore, we attempted to extract a trail spectrum as well (see Sect. 2.2), despite the apparent absence of the trail, to obtain a flux unaffected by pile up. We detect a significant amount of 89 excess photons above a background of  $268 \pm 4$ . This is not sufficient to model the spectral shape accurately, but it does provide a better handle on the flux than the piled-up spectrum. Fixing  $N_{\text{H}}$  and  $\Gamma$  to the values found for the PSF spectrum, we find an unabsorbed 0.5–10 keV flux of  $(9.7 \pm 1.7) \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ . For a distance of 6.5 kpc it corresponds to  $4.9 \times 10^{34} \text{ erg s}^{-1}$ . If the photosphere is helium-rich, the distance may be up to 9.0 kpc. The implied luminosity would be  $9.4 \times 10^{34} \text{ erg s}^{-1}$ .

We extracted the light curve for photons in the source region. There are no noticeable features in the light curve at a time resolution of 32 to 320 s.

A search through archival data revealed no further detections of 1RXS J171824.2–402934 except for the ROSAT ones, including ASM data (note that no other imaging instrument than ROSAT observed this region). There were two ROSAT observations in March and September of 1994 with the HRI and the count rates were  $0.048 \pm 0.008$  and  $0.019 \pm 0.003 \text{ c s}^{-1}$  respectively. The number of detected photons was too small for an accurate spectral analysis. For a spectrum as measured with Chandra, the count rates translate to unabsorbed 0.5–10 keV

fluxes of  $3.0 \times 10^{-11}$  and  $1.2 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$  which is 3.1 and 1.2 times brighter than with Chandra, respectively.

#### 4. Discussion

The Chandra measurements show that 1RXS J170854.4–321857 and 1RXS J171824.2–402934 are actively accreting. The luminosity levels are clearly above quiescent levels and the spectra are atypical for quiescence. This confirms the suspicion that they are persistent rather than classical transient X-ray sources. We employ as definition for a classical LMXB transient a source whose flux rises out of a quiescent luminosity of less than  $10^{33} \text{ erg s}^{-1}$  and returns to that level within at most a few months. This excludes so-called “long-duration” transients like KS 1731-260 and MXB 1658-298 (e.g., Wijnands et al. 2001) that stay on for up to more than a decade, possibly because the mass transfer rate from the donor to the accretion disk is temporarily increased. We regard the latter as temporary persistence, because it is the mass transfer rate which most likely determines the disk instability condition.

Most unusual, 1RXS J171824.2–402934 appears to be consistently sub-luminous (i.e., below  $10^{36} \text{ erg s}^{-1}$ ) for a typical persistent source. It is unlikely that this is due to a smaller-than-usual efficiency in transforming liberated gravitational energy into radiation, because one would then expect a burst recurrence time shorter than observed. For a nuclear energy production between  $1.6 \times 10^{18}$  and  $6 \times 10^{18} \text{ erg g}^{-1}$  (for pure helium and hydrogen burning, respectively) it takes an accumulation of 6 to  $36 \times 10^{21} \text{ g}$  of fuel to power a  $10^{40} \text{ erg}$  burst as observed from 1RXS J171824.2–402934 (Kaptein et al. 2000). At an accretion rate of  $\approx 6 \times 10^{-12} M_{\odot} \text{ yr}^{-1}$  as seen with Chandra this takes at least 0.6 years. For a coverage as with the WFCs ( $\sim 70$  d net exposure) the chance probability is only 4% to observe two or more bursts. If the efficiency at which gravitational energy is converted into radiation would have been 10 times less, this probability would increase to 83% and it would have been likely to detect multiple bursts. There are other uncertainties about the luminosity, such as the extrapolation of 0.5–10 keV to bolometric luminosity and fluctuations that cannot be observed due to the insufficient sensitivity of monitoring devices, but the lack of further burst detections remains a strong indication for a small accretion level, and we conclude that the low  $L$  is truly due to a smaller  $\dot{M}$ .

1RXS J170854.4–321857 appears to be more luminous by an order of magnitude, but still less luminous than most persistent LMXBs, hovering around the  $10^{36} \text{ erg s}^{-1}$  mark. It may be regarded as the far-away equivalent of systems like 2S 0918–549 (e.g., Jonker et al. 2001 and Cornelisse et al. 2002a), 4U 0614+091 (Piraino et al. 1999) and various other faint LMXBs.

The persistent nature at such a low accretion level suggests the possibility of a relatively small binary orbit. Smaller orbits generally harbor smaller accretion disks which are easier to photo-ionize completely through X-ray irradiation from the central source and, thus, can easier keep the accretion onto the neutron star going at lower levels (e.g., van Paradijs 1996). For a donor of solar composition, the critical mass accretion

rate  $\dot{M}_{\text{crit}}$  below which the disk becomes unstable was by Dubus et al. (1999) derived to be

$$\dot{M}_{\text{crit}} = 6.6 \times 10^{-22} R_{\text{rim}}^{2.1} C^{-0.5} M_{\odot} \text{ yr}^{-1}$$

where  $R_{\text{rim}}$  is the radius of the outer disk edge in km and  $C$  a somewhat uncertain factor  $C \approx 1$ ; a neutron star mass of  $1.4 M_{\odot}$  has been assumed. The actual accretion rate needs to be higher than this for the source to be persistent. The mass accretion rate for 1RXS J171824.2–402934 was the lowest of our two sources, between  $\dot{M}_{\text{obs}} = 4.1 \times 10^{-12}$  and  $2.4 \times 10^{-11} M_{\odot} \text{ yr}^{-1}$  (assuming that all liberated gravitational energy is transformed to radiation). This implies  $R_{\text{rim}} < 1.0 \times 10^5$  km. The uncertainty in this number is considerable. A  $C$  value between  $-50$  to  $+50\%$  from the nominal value gives rise to an uncertainty in  $R_{\text{rim}}$  of  $\pm 20\%$ .

Given the persistence, the accretion rate may be a good representation of the mass transfer rate from the donor. One then wonders whether it is possible to “construct” a binary with the implied transfer rate and accretion disk size. Such a low mass transfer rate implies a degenerate donor star. If the donor is a white dwarf and the accretor a  $1.4 M_{\odot}$  neutron star, the mass transfer rate fixes directly the basic binary parameters through the mass-radius relation of the white dwarf<sup>1</sup>, the requirement that the donor fills its Roche lobe, gravitational radiation driving the mass transfer and Kepler’s third law. The donor mass then is given by  $M_{\text{WD}} = 3.28 \dot{M}^{3/14} M_{\odot}$  with  $\dot{M}$  in  $M_{\odot} \text{ yr}^{-1}$ . For  $\dot{M}$  between  $4.1 \times 10^{-12}$  and  $2.4 \times 10^{-11} M_{\odot} \text{ yr}^{-1}$ , this implies  $M_2 = 0.012\text{--}0.017 M_{\odot}$ ,  $P_{\text{orb}} = 0.6\text{--}0.9$  h, and a neutron star Roche lobe average radius of  $(2.3\text{--}3.0) \times 10^5$  km. Therefore, the Roche lobe size is at least two times larger than the part of the accretion disk that can be ionized by irradiation from the central source and the picture for 1RXS J171824.2–402934 is not completely consistent. Perhaps the 3 flux measurements with ROSAT and Chandra are not representative for the source. We hope to find out by carrying out more flux measurements with Chandra in the future.

Our observations show that the two low- $L$  bursters investigated here are clearly different from the four other cases studied with Chandra by Cornelisse et al. (2002b) as well as SAX J2224.9+5421 (Cornelisse 2002a), see Table 1. Those were *never* seen in an actively accreting state, suggesting that they are *transient* instead of *persistent* low- $L$  sources. It is also interesting to note that the X-ray bursts in those other cases are rather short compared to the  $>3.5$  min for 1RXS J171824.2–402934 and 10 min for 1RXS J170854.4–321857. All are shorter than 1 min, with the most extreme case being SAX J2224.9+5421 which lasted less than 10 s. The persistent character of our two systems may be consistent with the long duration of the bursts. If the accretion on the neutron star remains low, like in the persistent sources, instead of briefly becoming high during fast accretion events in transients, ignition conditions may take longer to develop and flashes to be more energetic and, thus, longer.

<sup>1</sup> the white dwarf mass-radius relation is parameterized by  $R/R_{\odot} = 0.0115 (M_{\odot}/M_{\text{WD}})^{1/3}$  which compares well to the helium white dwarf models in Deloye & Bildsten (2003). Note that we need a helium white dwarf in order to fuel the X-ray burst.

It is difficult to obtain independent evidence for a short orbital period explanation. The X-ray light curves show no evidence for orbital modulation. Perhaps the easiest way to confirm this is to search for the optical or infrared counterparts and determine the optical to X-ray flux ratio, which is presumed to be a good indicator for the orbital period (van Paradijs & McClintock 1994). The limits obtained from the Digitized Sky Survey are not constraining to make a distinction between short and long (cf., Wachter et al. 2005a,b). A deeper search is necessary. The excellent Chandra positions will be instrumental in this.

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