X-RAY BURSTS FROM 1RXS J170930.2—263927 = XTE J1709—267

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ABSTRACT

We report evidence of type I X-ray–bursting activity from the transient source 1RXS J170930.2—263927 when it was in outburst in early 1997. This identifies the source as a probable low-mass X-ray binary containing a neutron star. The error boxes of the detected bursts and of the persistent emission, as obtained with the Wide Field Cameras on board the BeppoSAX satellite, rule out an association with the proposed radio counterpart (Hjellming & Rupen). Subject headings: binaries: close — stars: individual (1RXS J170930.2—263927) — X-rays: bursts

1. INTRODUCTION

The transient source 1RXS J170930.2—263927 was first observed in hard X-rays with the Proportional Counter Array (PCA) on board the Rossi X-Ray Timing Explorer (RXTE) (Marshall et al. 1997). The source, reported as a new XTE transient source (XTE J1709—267), was detected for about 20 s during two different satellite maneuvers, on 1997 January 16.016 and 18.147, respectively. The uncertainty of the source position was estimated to be 6′, suggesting a possible association of XTE J1709—267 with the soft X-ray source 1RXS J170930.2—263927 included in the ROSAT All-Sky Survey Catalogue (Voges et al. 1996), 5′ from the PCA centroid position (see Fig. 3 below).

A possible radio counterpart of the source was found in the 1.42 and 4.9 GHz bands (Hjellming & Rupen 1997). The radio position, given with better than 1′ uncertainty, is 2.8′ from the PCA centroid position and 6′ from the ROSAT position. So the hard X-ray source could only be associated either with 1RXS J170930.2—263927 or with the proposed radio counterpart, but not with both.

The X-ray characteristics of the RXTE source are not known in detail. The spectrum obtained by the PCA could be fitted with a power-law function1 with a 3.06 ± 0.06 photon index or by a thermal bremsstrahlung model with $kT = 4.7 ± 0.2$ keV. In both cases, the column density was found in excess of $2 \times 10^{22}$ cm$^2$, thus indicating the source to be close to the Galactic center. During the PCA observations, the source had an intensity of 140 mcrab in the 2–10 keV band, while the 1–2.4 keV flux of 1RXS J170930.2—263927 at its detection time (spring 1996) was only 13 mcrab.

After its detection in hard X-rays, 1RXS J170930.2—263927 was monitored by the All-Sky Monitor (ASM) on board RXTE in the 2–10 keV range. The source was still bright (140–200 mcrab) up until February 20; it has declined to 80–120 mcrab (March 12–18) and to 25–65 mcrab since March 19. The source was no longer in outburst by April 7, its daily averaged flux being below 13 mcrab.

The RXTE-ASM light curve of the outburst is displayed in Figure 1. The light curve does not show uncommon features when compared with the average light curves of the X-ray novae. Following the morphological classification proposed by Chen, Shrader, & Livio (1997), we can associate the source with the fast-rise exponential-decay class, even if the decay looks almost linear and perhaps drops faster about 50 days after the maximum. The ASM peak luminosity of the outburst is 0.21 crab, a rather low but not uncommon value among the X-ray novae, where selection effects in the studied samples are not negligible. We can derive that at the outburst epoch, the source intensity increased by more than an order of magnitude.

In the next section, we summarize the BeppoSAX Wide Field Camera telescope characteristics and report on the observations of 1RXS J170930.2—263927. In § 3 the performed spectral and time analyses are presented, while in § 4 the implications of our results on the knowledge of the source characteristics are briefly discussed. In particular, the association of 1RXS J170930.2—263927 with the class of transient neutron star low-mass X-ray binaries is proposed.

2. OBSERVATIONS

The Wide Field Cameras (WFCs) on board the BeppoSAX satellite consist of two identical coded mask telescopes (Jager et al. 1997). The two cameras point in opposite directions, each covering a $40° \times 40°$ field of view. This field of view is the largest ever flown for an X-ray–imaging device. With its source location accuracy better than 0.6 (68% confidence level), a time resolution of 0.244 ms, and an energy resolution of 18% at 6 keV, the WFCs are very effective in studying hard X-ray (2–30 keV) transient phenomena. The imaging capability, combined with the good instrument sensitivity (a few mcrab in 10$^4$ s), allows an accurate monitoring of complex sky regions, like the Galactic bulge.

The data of the two cameras are systematically searched for bursts and flares by analyzing the time profiles of the detectors in the 2–11 keV energy range with a 1 s time resolution. Reconstructed sky images are generated for any statistically meaningful enhancement, to identify possible bursters. The accuracy of the reconstructed position, which of course depends on the burst intensity, is typically better than 5′. This analysis procedure demonstrated its effectiveness throughout the Galactic bulge WFC monitoring (Cocchi et al. 1998a), leading to the identification of ~530 X-ray bursts, 156 of which are from the

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2 That is, $n(E) \propto E^{-\Gamma}$, where $n(E)$ is the number of photons with energy $E$ and $\Gamma$ is the photon index.
Bursted pulsar GRO J1744-28, in a total of about 1100 ks of observing time (the exposure time values are corrected for all dead times due to Earth occultation and the South Atlantic Anomaly). A total of 12 new X-ray–bursting sources were found.

The transient source 1RXS J170930.2–263927 is in the field of view whenever the WFCs point at the Galactic center region, being 9°4 away from the Sgr A position. The Galactic bulge field was observed for a total of about 1100 ks, the monitoring being divided in four observation campaigns during 1996 through 1998. Unfortunately, 1RXS J170930.2–263927 was out of visibility at the epoch of the outburst onset (1997 January), so only data from the declining phase and quiescence are available.

During a 102.6 ks observation started on 1997 March 18.04, a burst was detected at a position consistent with that of 1RXS J170930.2–263927 on March 18.21058 UT (Cocchi et al. 1998b). The event occurred during the egress from the Earth’s occultation. Two more bursts were detected from the same position in a different observation shift that started on April 13.16 and lasted for 97.8 ks. The time profiles of the three bursts are plotted in Figure 2. The displayed profiles of the bursts are detector profiles constructed by integrating the photons in the source-illuminated part of the detector. This improves the signal-to-noise ratio of the event. The background is the sum of the diffuse X-ray background, the particles background, and the contamination of other sources in the field of view. Source contamination is the dominating background component for crowded fields like the Galactic bulge. Nevertheless, the probability of source confusion during a short timescale event, like an X-ray burst, is negligible. Details of the three observed bursts are summarized in Table 1. Burst searches from

![Fig. 1.—The 2–10 keV light curve of 1RXS J170930.2–263927. The markers 1, 2, and 3 indicate the epochs of the observed WFC bursts.](image1)

![Fig. 2.—The 2–11 keV time profiles of the observed bursts](image2)

| Parameter | Burst 1     | Burst 2     | Burst 3     |
|-----------|-------------|-------------|-------------|
| Burst time | Mar 18.21058 | Apr 13.52963 | Apr 14.59554 |
| Burst e-folding time (2–11 keV) | 5.2 ± 1.8 s | 7.2 ± 2.8 s | 10.0 ± 3.5 s |
| Maximum burst intensity flux (2–11 keV) | 0.48 ± 0.13 crab | 0.50 ± 0.12 crab | 0.48 ± 0.13 crab |
| Steady intensity flux (2–10 keV) | 26 ± 1 mcrab | <3 mcrab<sup>a</sup> | <3 mcrab<sup>a</sup> |
| Burst e-folding time (2–6 keV) | 6.6 ± 3.2 s | 7.5 ± 3.5 s | 11.9 ± 4.8 s |
| Burst e-folding time (6–18 keV) | 2.6 ± 1.4 s | 5.5 ± 2.8 s | 7.1 ± 4.2 s |
| Blackbody temperature (keV) | 2.10 ± 0.16 | 1.79 ± 0.16 | 1.73 ± 0.16 |
| Reduced χ² (26 dof) | 0.93 | 0.65 | 0.91 |
| Peak blackbody kT (keV) | 1.3 ± 0.6 | 1.83 ± 0.26 | ... |
| Tail blackbody kT (keV) | ... | 1.69 ± 0.28 | ... |
| R<sub>q</sub>/d<sub>bol</sub> | 7.9 ± 2.3 | 11.0 ± 3.3 | 11.6 ± 3.7 |

<sup>a</sup> 3 σ upper limit.
IRXS J170930.2–263927 were performed on all the data available from the 1996–1998 BeppoSAX-WFC Galactic bulge monitoring campaigns, but no other events were detected.

3. DATA ANALYSIS

The steady emission of IRXS J170930.2–263927 during its declining phase in 1997 March has been investigated. We analyzed data from two observations that started on March 13.52 and 18.04 (UT) for a total of 170.6 ks exposure time.

The intensity of the source was found to be fairly constant throughout the two observations, the average flux being about 28 mcrab. The data were split into five data subsets in order to investigate possible spectral variability on a 1 day timescale.

The fitted parameters over all the subsets are consistent with a constant spectrum, thus excluding spectral variability during the involved epochs. Two spectral models were applied to the average spectrum over all the five subsets: an absorbed power-law function and a thermal bremsstrahlung spectrum. The calculated parameters, which are consistent with the ones reported by the RXTE PCA, are shown in Table 2.

An absorbed blackbody model was adopted to fit the spectra of the three bursts. To better constrain the fit, the $N_H$ parameter was kept fixed ($N_H = 2 \times 10^{22} \text{cm}^{-2}$) according to what was obtained from the spectral analysis of the steady emission by using WFC and RXTE-PCA data. Moreover, two time-resolved spectra were obtained for the second burst, i.e., a “peak spectrum” (data from the first 6 s of the burst) and a “tail spectrum” (the next 9 s of burst data). A summary of the spectral parameters of the three bursts is given in Table 1.

Blackbody spectra allow us to determine the relationship between the average radius of the emitting sphere $R_{\text{km}}$ (in units of kilometers) and the source distance $d_{\text{10 kpc}}$ (in units of 10 kpc). In Table 1, the values of the $R_{\text{km}}/d_{\text{10 kpc}}$ ratios are given, assuming isotropic emission and not correcting for gravitational redshift and conversion to true blackbody temperature from color temperature (see Lewin, van Paradijs, & Taam 1993 for details).

The calculated WFC centroid position of the observed hard X-ray source was found to be consistent with that of the soft ROSAT source IRXS J170930.2–263927 (Cocchi et al. 1998a). In Figure 3, a sky map is shown with the error circles of the position that we calculated for the March 18 persistent emission and for the three bursts. The WFC position is almost coincident with the ROSAT one, thus associating the hard X-ray XTE source with the soft X-ray ROSAT source IRXS J170930.2–263927. A possible association of both the soft and hard X-ray sources with the proposed radio counterpart, which lies more than 5' away, is ruled out.

4. DISCUSSION

Up to date, transient phenomena like hard X-ray bursts with typical durations less than a few minutes are classified in two main types (Hoffman, Marshall, & Lewin 1978). Type I bursts originate from thermonuclear flashes onto a neutron star surface (Woosley & Taam 1976; Joss 1978; Taam & Picklum 1979). All the type I–bursting sources are associated with low-mass X-ray binary (LMXB) systems, following the identification of their optical counterparts or, indirectly, from spectral or stellar population (e.g., globular cluster sources) characteristics (van Paradijs 1995). The observed spectra of the bursts are typically well fitted by thermal blackbody emission models having temperatures $kT \leq 3$ keV (Swank et al. 1977). The time profiles of type I bursts show fast rise times, ranging from less than 1 s up to 10 s, and longer decay times, ranging from seconds to minutes. They depend strongly on photon energy, with decays being shorter at higher energies, so that bursts appear to soften during the decay. This softening has been suggested to originate from the cooling of the neutron star photosphere (see, e.g., Lewin, van Paradijs, & Taam 1995).

Type II bursts have been observed only in two peculiar cases, namely, the Rapid Burster MXB 1730–335 (Lewin et al. 1976) and the Bursting Pulsar GRO J1744–28 (Kouveliotou et al. 1996). They show no spectral softening and are frequently repeated in time, with intervals ranging from a few seconds to hours. Blackbody fits to the type II bursts are unacceptably poor. Comptonized models for MXB 1730–335 (Stella et al. 1988) and a power-law function model for GRO J1744–28 (Giles et al. 1996) fitted the data better. Moreover, the Bursting Pulsar spectra of the steady emission and the bursts are very similar. Type II bursts are thought to originate from accretion instabilities (Lewin et al. 1995).

On the basis of their spectral properties and time profiles, we interpret the three bursts detected from IRXS J170930.2–263927 as type I bursts. Even though the statistical quality of the data is limited, the blackbody emission and the

### Table 2

| Model         | Model Parameter | $N_H$ (10$^{22}$ cm$^{-2}$) | Reduced $\chi^2$ (144 dof) |
|---------------|-----------------|----------------------------|-----------------------------|
| Bremsstrahlung| $kT = 5.77 \pm 0.63$ keV | 0.148 $\pm$ 0.453 | 0.94 |
| Power law     | $\Gamma = 2.67 \pm 0.13$ | 2.27 $\pm$ 0.63 | 1.02 |

Fig. 3.—A sky map of relevant error regions. Small solid circle: IRXS J170930.2–263927 error circle (Voges et al. 1996); large solid circle: WFC-SAX steady source error circle (99% confidence); dotted circles: error circles of the three WFC-detected bursts (99% confidence); large dashed circle: XTE J1709–267 error circle (only systematic errors; Marshall et al. 1997); asterisk: position of the suspected radio counterpart (Hjellming & Rupen 1997).
measured color temperatures are consistent with type I bursts. Spectral softening is marginally observed in time-resolved spectra of burst 2 and energy-resolved time profiles of all the bursts (see Table 1). Average decay times of $8 \pm 2$ s (2–6 keV) and $4 \pm 1$ s (6–18 keV) are obtained. Type I bursts strongly suggest a neutron star nature for the binary system. This indicates that 1RXS J170930.2–263927 is a transient neutron star LMXB.

In principle, it is possible that 1RXS J170930.2–263927 had bursting behavior even before the 1997 January outburst, since the bursts occurrence does not seem to be related to the persistent flux (bursts 2 and 3 occurred when the steady flux had dropped by a factor of $\geq 10$ with respect to the time of burst 1; see Table 1). On the other hand, it is possible that the outburst itself triggered the type I burst mechanism, because of an increased accretion rate from the companion star, and that the physical conditions that activated the bursts persisted even after the source entered a quiescent phase. This scenario seems likely since no bursting activity was detected from 1RXS J170930.2–263927 in the autumn 1996 and autumn 1997 observation campaigns.

Bursting activity from LMXB transients have already been reported in about 10 cases (e.g., Rapid Burster, Aql X-1, Cen X-4, 0748–673, 1658–298, and SAX J1808.4–3658; see Hoffman et al. 1978, Tanaka & Shibazaki 1996, Lewin et al. 1995, references therein, and in ‘t Zand et al. 1998), thus indicating that the sources are neutron star binaries. Most ($\sim 85\%$) of the LMXBs harboring a neutron star are persistent sources, while all the black hole candidates in low-mass systems are transient sources (van Paradijs 1995). Among the LMXB transients, quite a large fraction of sources ($\sim 50\%$, according to Chen et al. 1997; $\sim 45\%$, according to Tanaka & Shibazaki 1996) are neutron star systems, the rest being black hole binaries. The population of black hole LMXBs could be underestimated, since most of them are suggested as black hole candidates on the basis of their spectral characteristics only. Actually, for only seven out of about 40 known transient LMXBs, the available mass functions suggest black hole systems (Chen et al. 1997). Thus, the detection of type I X-ray bursts in X-ray novae can help to better constrain the populations.

Due to the uncertainty in the distance of the source, interesting parameters such as the luminosity of 1RXS J170930.2–263927 both in outburst and in quiescence, the blackbody-emitting region radius during the bursts, and the peak luminosities of the bursts cannot be satisfactorily constrained. The interpolated $N_H$ value computed at the ROSAT given position is $2.3 \times 10^{23}$ cm$^{-2}$ (Dickey & Lockman 1990), about an order of magnitude lower than the measured value, thus suggesting intrinsic absorption. This makes it difficult to use the observed $N_H$ as a distance indicator.

A rough upper limit for the source distance can be obtained by assuming that the observed bursts had luminosities below the Eddington limit ($L_{\text{edd}} \approx 2 \times 10^{38}$ ergs s$^{-1}$). Low blackbody temperatures (<2.5 keV) and no evidence of double-peaked profiles (a clue to photospheric radius expansion) support this assumption for type I bursts (Lewin et al. 1995). Correcting for interstellar absorption, for burst 2 we obtain a bolometric flux of $L_b = 1.6 \times 10^{37}$ ergs s$^{-1}$ cm$^{-2}$. Assuming $L_b \leq L_{\text{edd}}$, this leads to a maximum distance of 10 $\pm$ 1 kpc, but a lower distance value is likely since the source is at relatively high (79°) galactic latitude. We then derive upper limits of $\sim 8 \times 10^{37}$ ergs s$^{-1}$ for the outburst peak luminosity and $\sim 1 \times 10^{36}$ ergs s$^{-1}$ for the persistent emission at the epochs of bursts 2 and 3. An upper limit of $\sim 10$ km is also obtained for the average radius of the blackbody-emitting region during the observed bursts, a value that supports the neutron star identification.

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