A new bursting X-ray transient: SAX J1750.8-2900

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ABSTRACT

We have analysed in detail the discovery measurements of the X-ray burster SAX J1750.8-2900 by the Wide Field Cameras on board BeppoSAX in spring 1997, at a position \(\sim 1.2\) degrees off the Galactic Centre. The source was in outburst on March 13th when the first observation started and showed X-ray emission for \(\sim 2\) weeks. A total of 9 bursts were detected, with peak intensities varying from \(\sim 0.4\) to 1.0 Crab in the 2-10 keV range. Most bursts showed a fast rise time (\(\sim 1\) s), an exponential decay profile with e-folding time of \(\sim 5\) s, spectral softening during decay, and a spectrum which is consistent with few keV blackbody radiation. These features identify them as type-I X-ray bursts of thermonuclear origin. The presence of type I bursts and the source position close to the Galactic Centre favours the classification of this object as a neutron star low mass X-ray binary. X-ray emission from SAX J1750.8-2900 was not detected in the previous and subsequent Galactic bulge monitoring, and the source was never seen bursting again.

\textit{Subject headings:} binaries: close — stars: neutron, individual (SAX J1750.8-2900) — X-rays: bursts

1. Introduction

A long term program to survey the 40\times40 degrees around the Galactic Centre started on mid 1996 with the large field of view instruments on board the BeppoSAX satellite (Wide Field Cameras, hereafter WFC). Previous surveys of the region with similar instruments were limited by the lack of the combination of sufficiently long, repeated exposures and the wide angular coverage. In the last 10 years, however, the use of the coded mask imaging technique increased the total number of known X-ray emitters in the region (Skinner et al. 1993; Vargas et al. 1997)

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stimulating detailed measurements of individual sources and in turn their identification at different wavelengths.

The Galactic Bulge monitoring program carried out by BeppoSAX WFC in the energy range 2-30 keV has been especially prolific in the study of X-ray burst sources, increasing substantially (by about 50% in 2.5 years) the number of objects of this type which were known originally in this region. As of January 1999 it led to the discovery of 6 new burst sources and, in addition, found burst emission from 7 already known sources (Heise et al. 1999; Ubertini et al. 1999a; Cocchi et al. 1998 for earlier results) in a total time exposure of \(\approx 2.5 \times 10^6\)s. The new transient sources show dim X-ray outburst episodes during \(~1\) to a few weeks, with peak fluxes generally below a few \(10^{37}\) erg/s at 10 kpc distance (Heise et al. 1999). From one of these sources, SAX J1808.4-3658 (in ’t Zand et al. 1998) a modulation period of 2.5 ms was discovered by RXTE during a second outburst (Wijnands & van der Klis 1998, Chakrabarty & Morgan 1998).

Here we report results of one of these previously unknown transients showing bursting behaviour, discovered by the WFC on March 18th, 1997 (Bazzano et al. 1997a, Heise et al. 1997) in a celestial position 1.2 degrees off the Galactic Center. In particular, we analyse the spectral and temporal behaviour of the persistent emission and characterise the burst emission properties to determine the nature of the transient.

2. Observations and data analysis

The Wide Field Cameras experiment on board the BeppoSAX satellite comprises 2 identical coded aperture multi-wire proportional counter detectors viewing opposite sky directions (Jager et al. 1997), each one featuring a field of view of 40×40 degrees full width to zero response (i.e., 3.7% of the sky) and an angular resolution of 5 arcmin. The source location accuracy depends on the signal-to noise ratio and is 0.7 arcmin at best (99% confidence level). The energy range is 2-30 keV on-axis and the time resolution is 0.5 ms. The field of view (FOV) is the largest of any flown X-ray imaging device with arcmin resolution, which allows for the search of short duration and/or weak transient events. The on-axis sensitivity for the Galactic Bulge field is \(\approx 10\) mCrab in \(10^4\)s observing time. Detector data contain a superposition of background and of multiple source shadowgrams, the latter resulting from the coding of the sky object image with the instrument aperture pattern. The reconstruction of the sky image for point-like sources involves an algorithm that consist of a cross correlation of the detector data with the aperture (see e.g. Caroli et al. 1987). The position and intensity of any point source is determined by folding a sky model distribution through a point spread function (PSF), using iterative \(\chi^2\) minimisation (Jager et al. 1997). For WFC this can be carried out in each individual energy channel. The full-width at half maximum of the PSF is smallest on axis at \(\approx 5\) arcmin. SAX J1750.8-2900 is located only 1.2 degrees off the Galactic Centre and so in the most sensitive region for this type of observations. The Galactic Bulge was observed during spring 1997 for \(5 \times 10^5\) s, spread out along 28 days.
Burst phenomena are systematically searched in data from both cameras using time profiles of the total detector over the entire energy range with a time resolution of 1 s. When a burst occurs a reconstructed sky image is generated for the burst duration and different sky images corresponding to longer time exposure are generated for intervals just before and after burst. This allows to resolve the point source responsible for the intensity increase revealed in detector ratemeters. In crowded fields and in some not evident case an image subtraction is necessary to facilitate identification of bursting sources in the FOV.

3. Transient source position and lightcurve

Figure 1 shows the error region for SAX J1750.8-2900. The best fit position is R.A. = 17h 50m 24s, Dec = -29° 02’ 18” (equinox 2000.0), with an error radius of 1 arcmin (99% confidence). This is a position refined from the previously published value which resulted from a quick-look analysis (Heise et al. 1997). The deviation between both values is 0.4 arcmin. Also shown are the positions of two X-ray bursts that were observed simultaneously with the active phase of SAX J1750.8-2900, showing that they result from a position coincident with the transient. In March 1992 the ROSAT PSPC observed the region around SAX J1750.8-2900 four times (between MJD 48685.09 and MJD 48691.63 with exposure times up to 1976 s), during a raster scan of the Galactic Centre region. No source was detected during these observations within the 99% confidence error box of SAX J1750.8-2900. The source 1RXP J175029-2859.9 lies 1.5 arcmin outside the SAX J1750.8-2900 error box. This close-by source was marginally detected at $6.2 \pm 1.9 \times 10^{-3} \text{ counts s}^{-1}$ in the second observation (between MJD 48685.36 and MJD 48685.39). From this result we can derive an upper limit of $\sim 3 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ on the soft X-ray emission (0.5-2.0 keV) of SAX J1750.8-2900 during quiescence.

The RossiXTE All Sky Monitor (Levine et al. 1996) data retrieved from a public dataset (provided by the RXTE/ASM team, http://space.mit.edu/XTE) shows the onset of a fast rise, exponential decay outburst of SAX J1750.8-2900 peaking at $\sim 120\pm40 \text{ mCrab}$ in the 2-10 keV range, starting close to MJD 50518 (two days before the initial WFC observation) and lasting $\approx 2$ weeks. This transient behaviour is supported by WFC later detections as previously reported by in ’t Zand et al. (1997).

The X-ray persistent emission of SAX J1750.8-2900 (i.e., the emission detected during time intervals excluding bursts) was measured by the WFC starting from March 13th, 1997. The source flux was initially at a level of $\approx 70 \text{ mCrab}$ in the energy band 2-30 keV. The light curve detected in the 2-30 keV range is shown in Fig. 2, along with the burst occurrence time. The outburst profile decay is close to exponential, with intensity changes on the time scale of hours. The first two days measurements (when the source was more luminous) are affected by relatively large errors caused by the off-axis position of the source. The average luminosity in the 2-30 keV band, calculated for 10 kpc distance is $\approx 3 \times 10^{37} \text{ erg s}^{-1}$ on March 13th. The flux was about $\sim 1.5$ times weaker five days later, when the source was seen bursting for the first time, and dropped to...
less than $\sim 3$ mCrab ($\approx 10^{36}$ erg s$^{-1}$ at 10 kpc) on March 25th. The source was again visible at $\sim 10$ mCrab on March 30-31, when two more bursts were detected.

We fitted the emission spectra detected in the 2-30 keV band during six observing periods between MJD 50520 and MJD 50531 using a few spectral models. The results obtained for power law and thermal bremsstrahlung (both with low energy absorption) are shown in Table 1. The spectra can be described either by a power law shape having a photon index $\Gamma \approx 2.5$ and extinction parameter $N_H \approx 6 \times 10^{22}$ cm$^{-2}$, or by bremsstrahlung emission with $kT$ in the 3 to 10 keV range and $N_H \approx 2.5 \times 10^{22}$ cm$^{-2}$. The spectra cannot be fitted satisfactorily with single component blackbody emission.

The fit results give indication that the source has experienced spectral softening during the outburst decay. By performing an F-test on the two spectra taken at MJD 50520 and MJD 50527 we find that the probability that there is no softening is less than 1%. If the X-ray emission mechanism is thermal (as observed in many X-ray bursters) the softening could be ascribed to a temperature variation of the electron plasma, possibly due to the decrease in the accretion flow.

4. The X-ray bursts

A total of 9 X-ray bursts were detected from SAX J1750.8-2900 during an overall time span of 14 days in spring 1997. The first one (the faintest observed) occurred on MJD 50525.48150, with a peak flux of $\approx 0.4$ Crab. 7 out of 9 bursts were detected during three days from March 18th (see Table 2 for burst occurrence times), having similar bolometric fluences in the range $\approx 2$ to $3 \times 10^{-7}$ erg cm$^{-2}$. In Fig.3 burst profiles in two energy bands are plotted for two of these events.

The study of the burst frequency is limited by the fact that during observation the effective exposure time is only a fraction ($\approx 60\%$) of the total pointing time, due to earth occultations and other shorter non-coverage periods. The observed values of time intervals are in fact an upper limit to the real burst interval time. It is then possible that SAX J1750.8-2900 made bursts during the first observation period when its persistent flux was above $\sim 50$ mCrab. In spite of this, there is evidence that the burst frequency decreased when the source flux dropped below $\sim 20$ mCrab, i.e. in observations performed after MJD 50530 (see Fig.2).

The primary question concerning the bursts is whether they are type I X-ray bursts. All burst profiles detected from SAX J1750.8-2900 show a fast rise ($\approx 1$ s), exponential decay shape, with e-folding time in the range $\approx 5$-10 s (see Fig.3). The decay times in the energy band 8-26 keV are systematically shorter than those observed in the band 2-8 keV. However, the spectral softening cannot be proven by examining the individual bursts, due to the large statistical error (see Table 2). In order to increase significance we summed up the profiles of the last 7 bursts in the energy bands 2-8 and 8-26 keV, with a time resolution of 0.1 s. The first two bursts were excluded because their detection was affected by the earth atmosphere. The start channel of each burst was determined as the first point in the time profile which differed more than $\sim 4\sigma$ from the
mean persistent emission. The fit of the two profiles obtained with an exponential function gives an e-folding decay time $\tau = 5.3 \pm 0.7$ s in the low energy band and $\tau = 2.8 \pm 0.2$ s in the high energy band, and proves that spectral softening is occurring during burst decay. Together with a consistency of the burst spectrum with that of a few keV blackbody emission (see Table 2) this identifies the bursts as type-I.

Among the bursts detected, there is no clear evidence of an X-ray burst with double peaked or flat profile, which might have suggested saturation of the luminosity to near-Eddington level and resulting photospheric radius expansion (Lewin, van Paradijs, & Taam 1995). However we can derive an upper limit on the source distance assuming that the maximum burst luminosity was below Eddington. The maximum observed peak flux (burst F, see Table 2) is consistent with a 3 $\sigma$ upper limit of $\approx 7$ kpc.

Burst spectra are rather soft and generally compatible with blackbody emission having colour temperatures between 2 and 3 keV (see Table 2). Under given assumptions (Lewin, van Paradijs, & Taam 1993) the effective temperature $T_{\text{eff}}$ and the bolometric flux of a burst can determine the ratio between the blackbody radius $R_{\text{bb}}$ (that is, the radius of the emitting sphere) and the distance $d$ of the neutron star. Assuming $d=10$ kpc and the observed colour temperatures as $T_{\text{eff}}$, and not correcting for gravitational redshift the measured blackbody radius is $\approx 8$ km. For the above upper limit of 7 kpc, this value of $R_{\text{bb}}$ scales to a corresponding upper limit of $\approx 6$ km. This value could be underestimated, due to the uncertainties in the relationship between colour and effective temperature. If, as suggested by Ebisuzaki (1987) the colour temperature exceeds $T_{\text{eff}}$ by a factor $\approx 1.5$, then the neutron star radius should be at least two times the measured blackbody radius. These values are therefore consistent with a neutron star nature of the compact object.

5. Discussion

5.1. Burst emission properties

In the simplest interpretation of the thermonuclear flash model which successfully explains type-I X-ray bursts (Lewin, van Paradijs, & Taam 1995 for review) the matter accreted onto a neutron star surface prior to an observed type-I burst is converted into nuclear fuel and the fraction of the total accreted energy available for burning depends on the actual reaction process and fuel composition. If the thermonuclear flash is isotropic and the accreted material is totally converted into fuel, the ratio between the mass and radius of the NS is given by $M_* / R_{10\text{km}} = (0.01-0.04) \times \alpha$, where 0.01 and 0.04 hold for helium and hydrogen burning respectively. Here $M_*$ is the mass of the compact object in units of solar masses, $R_{10\text{km}}$ is the NS radius in units of 10 km and $\alpha$ is the ratio between the bolometric flux of the persistent emission (integrated over the burst interval) and the bolometric fluence of the burst. A 1.4 $M_\odot$ neutron star would then result in a value of $\alpha \approx 100$ for pure helium burning. For the four shortest observed burst times intervals B-C,C-D,D-E and F-G (see Table 2) we estimated the $\alpha$ parameter and found values of $85 \pm 20$,
120±30, 170±30 and 210±40 respectively. These intervals are monotonically increasing from 4.1 to 5.9 h on a time scale of 1.5 days, and all the related bursts show similar profiles and fluences. This suggests that perhaps no bursts were missed in between. The fast rise time of the bursts (< 2 s) and the measured values of α seem to favour a pure helium flash respect to combined hydrogen-helium shell burning. (Lewin, van Paradijs, & Taam 1993).

5.2. SAX J1750.8-2900 and the transients of the Galactic Bulge

Most X-ray burst sources known so far are type-I bursters associated with low-mass X-ray binaries (LMXBs) containing old, weakly magnetized neutron stars, and show concentration in the direction of the Galactic Centre (van Paradijs, 1995). They can be persistent (though variable) or transient, and may have recurrence periods with nearly constant burst activity, like the recently studied GS 1826-338 (Ubertini et al. 1999b), or conversely show only episodic burst emission, like for example SLX 1735-26 (Bazzano et al. 1997b) and XTE J1709-267 (Cocchi et al. 1998b). Correlation between burst frequency and persistent emission is not an uncommon feature. In general, type-I bursts are observed when the source persistent luminosity is comprised between \( \sim 10^{-2} \) and \( \sim 0.3 \) of the Eddington limit. For the bursting soft X-ray transients (White, Kaluziensky, & Swank 1984; see Campana et al. 1998 for recent review) the burst activity is usually detected during the occurrence of outburst episodes, which show peak luminosity of up to \( \sim 10^{38} \) erg s\(^{-1} \) and often recur on time scales of \( \sim 1 \) to \( \sim 10 \) years.

SAX J1750.8-2900 shows this type of transient phenomenology. The outburst light curve has a rather clear fast rise and exponential decay shape. In spite of the incomplete sampling it evidently shows variable decay behaviour, as observed in other LMXB transients (Chen, Shrader & Livio 1997). So there is no real evidence that the source had a secondary outburst after MJD 50535 as it could appear at a first glance. The X-ray flux decreased of a factor \( \approx 20 \) in a period of \( \sim 3 \) weeks in spring 1997, after which the source remained undetected (the RossiXTE ASM and BeppoSAX data do not show any other evident outburst in the period 1996 to 1999 May). We provide evidence that SAX J1750.8-2900 has been observed bursting only whenever the intensity was above \( \sim 10 \) mCrab, and that the burst frequency was positively correlated with the persistent emission (at least when the persistent flux was in the range \( \sim 10 \) to \( \sim 50 \) mCrab). The spectral softening seen by analysis of burst profiles is an evidence that SAX J1750.8-2900 is a type-I burster, and hence that the compact object is a neutron star. The observed peak luminosity of bursts suggests an upper limit of 7 kpc on the source distance. Due to the lack of optical identification and/or visible X-ray modulation it is not possible to classify with certainty the binary source as a low mass system. Nevertheless, the detection of type-I bursts is sufficient to firmly set SAX J1750.8-2900 as a candidate member of the LMXB class.

The current sample of known LMXB could be biased towards bright X-ray transients, due to instrument selection effects and the established occurrence of weak, short lasting transients with long recurrence time (like e.g., 2S 1803-245, Muller et al. 1998; and SAX J1748.9-2021, in ’t Zand
In fact, the recent observations by BeppoSAX and RXTE are significantly growing the number of weak LMXB. Among them, most are NS transients which are also burst sources and often show high energy tails. For this reason, these have been suggested as a possible new subclass of low mass binaries (Heise et al. 1999). Indeed these systems could be NS soft X-ray transients (of the type of Cen X-4 or Aql X-1), which are harboured within the Galactic Bulge at quite large distances. This is what should be expected, as increasing the sensitivity and coverage will push the limit of observable distances up to a range in which many more sources are available, due to their concentration towards the Galactic Centre.

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REFERENCES

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Ubertini, P., et al. 1999a, in Proc. 3rd INTEGRAL Workshop, ”The Extreme Universe”, in press.


Table 1. Summary of spectral fitting for persistent emission

<table>
<thead>
<tr>
<th>Period MJD</th>
<th>Model</th>
<th>Model Parameter</th>
<th>Flux 2-30 keV</th>
<th>$\chi^2_b$</th>
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</thead>
<tbody>
<tr>
<td>50520.52-50521.68</td>
<td>Power Law</td>
<td>$\Gamma = 2.40\pm0.17$</td>
<td>15.6$\pm0.9$</td>
<td>0.6</td>
</tr>
<tr>
<td>50521.68-50522.35</td>
<td>Bremsstrahlung</td>
<td>$kT (\text{keV}) = 9.2\pm1.1$</td>
<td>14.1$\pm1.2$</td>
<td>1.0</td>
</tr>
<tr>
<td>50525.04-50526.19</td>
<td>Power Law</td>
<td>$\Gamma = 2.70\pm0.08$</td>
<td>8.46$\pm0.4$</td>
<td>1.5</td>
</tr>
<tr>
<td>50526.19-50527.35</td>
<td>Bremsstrahlung</td>
<td>$kT (\text{keV}) = 6.1\pm0.3$</td>
<td>4.69$\pm0.2$</td>
<td>1.0</td>
</tr>
<tr>
<td>50530.21-50531.04</td>
<td>Power Law</td>
<td>$\Gamma = 3.59\pm0.50$</td>
<td>1.79$\pm0.2$</td>
<td>0.6</td>
</tr>
</tbody>
</table>

*a units of $10^{-10}\text{erg cm}^{-2}\text{s}^{-1}$

*b reduced $\chi^2$ for 24 d.o.f.

Table 2. Parameter fit results of bursts

<table>
<thead>
<tr>
<th>Burst id.</th>
<th>Time$^a$</th>
<th>Peak flux$^b$</th>
<th>$K\theta_{col}(\text{keV})$</th>
<th>$R_{bb}^c$</th>
<th>$\chi^2_d$</th>
<th>$\eta^e$</th>
<th>$\tau$ $^e$</th>
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<tr>
<td>A</td>
<td>0.48151</td>
<td>1.2 $\pm$ 0.2</td>
<td>1.6 $\pm$ 0.3</td>
<td>10.4$\pm3.2$</td>
<td>1.3</td>
<td>10.1 $\pm$ 5.6</td>
<td>2.5 $\pm$ 1.4</td>
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<tr>
<td>B</td>
<td>1.25676</td>
<td>3.9 $\pm$ 0.5</td>
<td>2.3 $\pm$ 0.2</td>
<td>8.3$\pm1.2$</td>
<td>0.8</td>
<td>7.5 $\pm$ 2.6</td>
<td>2.4 $\pm$ 0.6</td>
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<tr>
<td>C</td>
<td>1.42773</td>
<td>3.8 $\pm$ 0.6</td>
<td>2.4 $\pm$ 0.2</td>
<td>8.0$\pm1.1$</td>
<td>0.9</td>
<td>5.0 $\pm$ 1.6</td>
<td>3.0 $\pm$ 1.0</td>
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<tr>
<td>D</td>
<td>1.62039</td>
<td>2.2 $\pm$ 0.3</td>
<td>2.2 $\pm$ 0.2</td>
<td>10.7$\pm2.1$</td>
<td>1.2</td>
<td>5.2 $\pm$ 2.4</td>
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<tr>
<td>E</td>
<td>1.82726</td>
<td>4.5 $\pm$ 0.7</td>
<td>2.1 $\pm$ 0.2</td>
<td>9.2$\pm1.4$</td>
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<td>2.2 $\pm$ 0.1</td>
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<td>2.4 $\pm$ 0.2</td>
<td>7.4$\pm1.1$</td>
<td>1.3</td>
<td>11.2 $\pm$ 6.1</td>
<td>4.4 $\pm$ 1.0</td>
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<td>2.4 $\pm$ 0.2</td>
<td>8.4$\pm1.2$</td>
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<td>5.4 $\pm$ 2.1</td>
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<tr>
<td>I</td>
<td>13.30355</td>
<td>4.2 $\pm$ 0.5</td>
<td>2.4 $\pm$ 0.2</td>
<td>7.8$\pm1.2$</td>
<td>1.0</td>
<td>6.7 $\pm$ 2.1</td>
<td>3.1 $\pm$ 0.9</td>
</tr>
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</table>

*a time of burst rise in days (MJD-50525)

*b in units of $10^{-8}\text{erg cm}^{-2}\text{s}^{-1}$, 2-26 keV

*c for source at 10 kpc distance

*d reduced $\chi^2$ for 23 d.o.f.

e $\tau_l$ is the decay time in the 2-8 keV energy band, and $\tau_h$ the decay time in the 8-26 keV energy band.

*f burst detection affected by the earth atmosphere
Fig. 1.— Position of SAX J1750.8-2900 computed by analysis of both persistent and burst images. Dashed contours are the source positions estimated from two X-ray bursts, and the solid line circle (1 arcmin radius) is the error circle of the transient source. Also shown (dotted circle) is the position of the ROSAT source 1RXP J175029-2859.9. All contours represent 99% confidence.
Fig. 2.— Light curve of the persistent emission from SAX J1750.8-2900 in the 2-30 keV band. The markers indicate the epoch of the observed bursts.
Fig. 3.— Time profiles of two X-ray bursts from SAX J1750.8-2900 detected on 1997 March 19th and March 20th (from left to right).