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# Unveiling the hard X-ray spectrum from the 'burst-only' source SAX J1753.5−2349 in outburst★

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## ABSTRACT

Discovered in 1996 by *BeppoSAX* during a single type-I burst event, SAX J1753.5−2349 was classified as 'burst-only' source. Its persistent emission, either in outburst or in quiescence, had never been observed before 2008 October, when SAX J1753.5−2349 was observed for the first time in outburst. Based on *INTEGRAL* observations, we present here the first high-energy emission study (above 10 keV) of a so-called 'burst-only'. During the outburst, the SAX J1753.5−2349 flux decreased from 10 to 4 mCrab in 18–40 keV, while it was found being in a constant low/hard spectral state. The broad-band (0.3–100 keV) averaged spectrum obtained by combining *INTEGRAL*/IBIS and *Swift*/XRT data has been fitted with a thermal Comptonization model and an electron temperature $\gtrsim$24 keV inferred. However, the observed high column density does not allow the detection of the emission from the neutron star surface. Based on the whole set of observations of SAX J1753.5−2349, we are able to provide a rough estimate of the duty cycle of the system and the time-averaged mass-accretion rate. We conclude that the low to very low luminosity of SAX J1753.5−2349 during outburst may make it a good candidate to harbour a very compact binary system.

**Key words:** accretion, accretion discs – stars: individual: SAX J1753.5−2349 – stars: neutron – Galaxy: bulge – X-rays: binaries – X-rays: bursts.

## 1 INTRODUCTION

SAX J1753.5−2349 is a neutron star Low Mass X-ray Binary (LMXB) discovered in 1996 by *BeppoSAX*/Wide Field Camera (WFC) during a single type-I X-ray burst (in't Zand et al. 1999). However, no steady emission was detected from the source leading to an upper limit of about 5 mCrab (2–8 keV) for a total exposure of 300 ks (in't Zand et al. 1999). Cornelisse et al. (2004) proposed SAX J1753.5−2349 being member of a possible non-homogeneous class of LMXBs, the so-called 'burst-only' sources (see also Cocchi et al. 2001). These are a group of nine bursters discovered by *BeppoSAX*/WFC when exhibiting a type-I burst without any detectable persistent X-ray emission.

Recently, *INTEGRAL* identified two new members of this class. In fact, photospheric radius expansion bursts have been caught in two previously unclassified sources, namely XMMU J174716.1−281048 (Brandt et al. 2006) and AX J1754.2–2754 (Chelovekov & Grebenev 2007). Afterwards, both have been classified as 'quasi-persistent' Very Faint X-ray Transients (VFXTs), since they undergo prolonged accretion episodes of many years at low $\dot{M}$ (Del Santo et al. 2007; Bassa et al. 2008).

VFXTs are transients showing outbursts with low peak luminosity ($10^{34}$–$10^{36}$ erg s$^{-1}$ in 2–10 keV), mainly discovered with high-sensitivity instruments on-board *Chandra* and *XMM–Newton* during surveys of the Galactic Centre region (Wijnands et al. 2006). They are believed to be the faintest known accretors, and are very likely a non-homogeneous class of sources. A significant fraction (∼1/3) of VFXTs are X-ray bursters (Cornelisse et al. 2004; Del Santo et al. 2007, 2008; Degenaar & Wijnands 2009); thus they can be identified with neutron stars accreting matter from a low-mass companion ($M \lesssim 1\,M_{\odot}$).

In 2002 observations with *Chandra* and *XMM–Newton* allowed us to reveal the nature of four *BeppoSAX* 'burst-only' sources:

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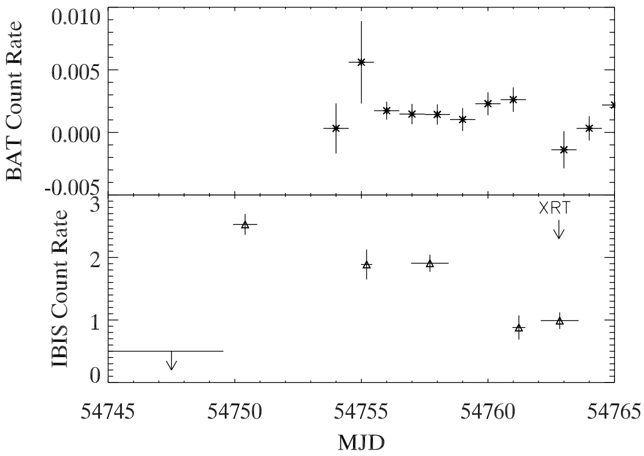


**Figure 1.** SAX J1753.5−2349 BAT (top) and IBIS/ISGRI (bottom) count rate evolution in the 15–50 keV and 18–40 keV energy ranges, respectively. The XRT detection time is also shown on the bottom plot. The public BAT light curve starts from 547 54 MJD; after MJD = 547 64 SAX J1753.5−2349 was no longer pointed by *INTEGRAL*.

**Table 1.** Log of the *INTEGRAL* observations of the SAX J1753.5−2349 region: orbit number (Rev.), start and end time of the observations, exposures time for each orbit taking into account the whole data set, and number of pointings (SCW) are reported. Observations within a single orbit are not continuous. The first *INTEGRAL* detection of SAX J1753.5−2349 occurred in rev. 732. A data subset from rev. 732 to 736 has been used to compute the averaged spectra. The last column reports the exposures of spectra in each orbit.

| Rev. | Start (MJD) | End (MJD) | Total Exp. (ks) | SCW | Spec. Exp. (ks) |
|---|---|---|---|---|---|
| 724 | 547 27.50 | 547 28.23 | 58 | 17 | – |
| 725 | 547 29.11 | 547 31.52 | 198 | 56 | – |
| 726 | 547 32.52 | 547 34.46 | 160 | 45 | – |
| 729 | 547 41.37 | 547 41.86 | 42 | 12 | – |
| 731 | 547 49.22 | 547 49.55 | 20 | 8 | – |
| 732 | 547 49.90 | 547 50.85 | 83 | 32 | 26.2 |
| 733 | 547 54.96 | 547 55.46 | 38 | 11 | 10.8 |
| 734 | 547 56.87 | 547 58.54 | 128 | 48 | 36.5 |
| 735 | 547 60.91 | 547 61.53 | 43 | 13 | 23.2 |
| 736 | 547 62.03 | 547 63.63 | 38 | 49 | 30.0 |

one persistent very-faint source, two faint transient systems (with 2–10 keV peak luminosity in the range $10^{36}$–$10^{37}$ erg s$^{-1}$), and one VFXT (see Wijnands et al. 2006 and reference therein). For the other five bursters, including SAX J1753.5−2349, only the quiescent emission could be derived ($\sim 10^{32}$ erg s$^{-1}$; Cornelisse et al. 2004). Wijnands et al. (2006) proposed these systems, as good candidates to be classified as VFXTs (see also Campana 2009).

In 2008 October 11, *RXTE*/PCA, *Swift*/BAT (Markwardt, Krimm & Swank 2008) and *INTEGRAL*/IBIS (Cadolle Bel 2008) detected an outburst from SAX J1753.5−2349 at 10 mCrab flux level. Then, *Swift*/XRT pointed SAX J1753.5−2349 on October 23 (Degenaar & Wijnands 2008), during the decline phase of the outburst (Fig. 1). An improvement in the source position, RA(J2000) = $17^{\mathrm{h}}53^{\mathrm{m}}31\overset{\mathrm{s}}{.}90$, Dec.(J2000) = $-23°48'16\overset{''}{.}7$, has been provided (Starling & Evans 2008). On 2009 March 13, it was repointed by *Swift* and a 3$\sigma$ upper limit derived. This translates in a luminosity level $\lesssim 5 \times 10^{32}$ erg s$^{-1}$ (Del Santo, Romano & Sidoli 2009).

In this Letter, we present the hard X-ray outburst of SAX J1753.5−2349 observed by *INTEGRAL*/IBIS, as well as the first broad-band spectral analysis of the steady emission of a 'burst-only'. We estimate the long-term mass-accretion rate, and discuss the nature of the transient system.

## 2 OBSERVATION AND DATA ANALYSIS

### 2.1 *INTEGRAL*

This Letter is based on *INTEGRAL* observations of the Galactic Centre region carried out in the framework of the AO6 Key-Programme. Moreover, we used data from a public ToO on the source H 1743−322, at $8\overset{\circ}{.}6$ from SAX J1753.5−2349, performed on 2008 October, for a total exposure time of 800 ks (see Table 1). We reduced the data of the IBIS (Ubertini et al. 2003) low-energy detector ISGRI (Lebrun et al. 2003), and JEM-X (Lund et al. 2003) data using the *INTEGRAL* Off-Line Scientific Analysis, release 8.0. Due to the source weakness, no signal was found in the JEM-X data. On October 10, the first IBIS detection of SAX J1753.5−2349 was found (revolution 732). We extracted the IBIS/ISGRI light curves from each revolution as reported in Table 1 (binning size as the total exposure column) in the energy range 18–40, 40–80 and 80–150 keV. For the spectral extraction, we used a subset of the data reported in Table 1, selecting only pointings including SAX J1753.5−2349 in the IBIS field of view up to 50 per cent coding ($15° \times 15°$ deg$^2$). We obtained four averaged spectra from revolutions 732, 733, 734 and 735–736 (the latests have been added together because of the poor statistics). Spectral fits were performed using the spectral X-ray analysis package XSPEC v. 11.3.1.

### 2.2 *Swift*

A *Swift* ToO was performed on October 23 (Degenaar & Wijnands 2008). The *Swift*/XRT data of observation 00 035 713 002 were collected in photon counting mode between 2008 October 23 17:48:53 and 21:08:57 UT, for a total on-source net exposure of 1 ks.

They were processed with standard procedures (XRTPIPELINE v0.12.1), filtering and screening criteria by using the HEASOFT package (v.6.6.1). Moderate pile-up was present, so source events were extracted from an annular region (radii of 20 and 3 pixels; 1 pixel $\sim$2.36 arcsec), while background events were extracted from an annular region (radii 120 and 80 pixels) away from background sources. An XRT spectrum was extracted and ancillary response files were generated with XRTMKARF, to account for different extraction regions, vignetting and point spread function corrections. We used the spectral redistribution matrices v011 in the Calibration Data base maintained by HEASARC. All spectra were rebinned with a minimum of 20 counts per energy bin.

We retrieved the BAT daily light curves (15–50 keV) available starting from MJD = 547 54, from the *Swift*/BAT transient monitor (Krimm et al. 2006, 2008; http://heasarc.gsfc.nasa.gov/docs/swift/results/transients/) page.

## 3 RESULTS

The IBIS/ISGRI and BAT count rate of SAX J1753.5−2349 are shown in Fig. 1. Based on the IBIS data, the hard X-ray outburst started on October 10 at a flux level of 10 mCrab (18–40 keV) and lasted at least 14 d (last pointing at 4 mCrab). This outburst is hence characterized by a fast increase of the flux and a linear decay with a slope of $-0.13 \pm 0.01$.

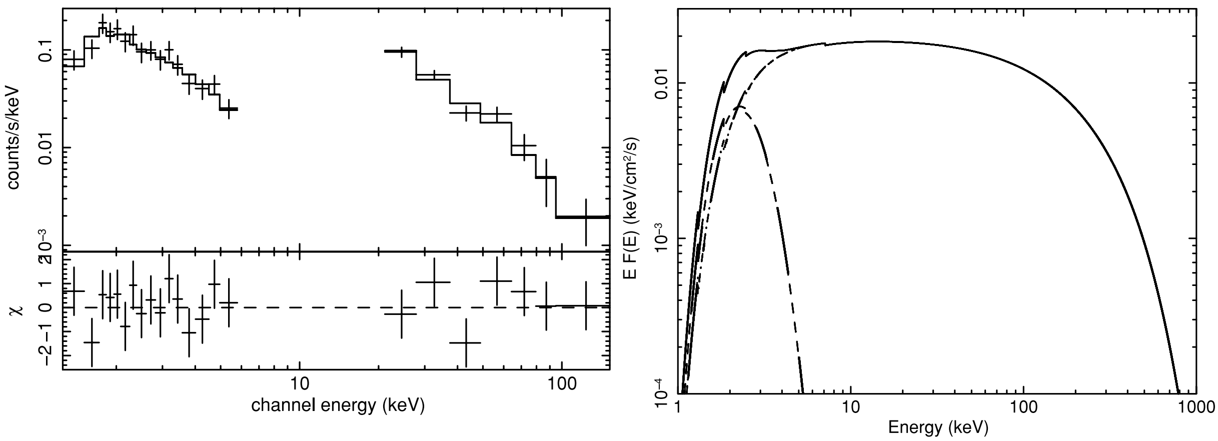


**Figure 2.** XRT and IBIS/ISGRI count rate spectra fitted with a simple power-law (left-hand panel); the total bb+comptt model (continuous line) and the two single components (dashed lines) (right-hand panel).

**Table 2.** The parameters the XRT/IBIS spectra fitted four different models.

| Model | $N_{\mathrm{H}}$ $10^{22}$ (cm$^{-2}$) | $kT_{\mathrm{BB}}$ (keV) | $\Gamma$ | $E_c$ (keV) | $kT_e$ (keV) | $\tau$ | $\chi^2_\nu$(d.o.f.) | $F_{\mathrm{bol}}$[a] (erg cm$^{-2}$ s$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| POW | $2.2^{+0.5}_{-0.4}$ | – | $2.3 \pm 0.3$ | – | – | – | 0.91(19) | $1.3 \times 10^{-9}$ |
| BB+POW | $2.8^{+2.0}_{-1.0}$ | $0.4^{+0.3}_{-0.1}$ | $2.1 \pm 0.3$ | – | | | 0.82(17) | $5.6 \times 10^{-10}$ |
| Comptt | $1.9 \pm 0.4$ | – | – | – | >24 | $0.2^{+1.3}_{-0.1}$ | 1.07(18) | $1.1 \times 10^{-9}$ |
| BB+Comptt | $2.7^{+2.0}_{-1.0}$ | $0.4^{+0.3}_{-0.2}$ | – | – | >17 | $0.8^{+2.2}_{-0.6}$ | 0.86(16) | $6.3 \times 10^{-10}$ |

[a]The bolometric flux of the unabsorbed best-fitting model spectrum.

An *INTEGRAL* pointing with no SAX J1753.5−2349 detection was performed eight hours before the outburst started. We also averaged all our data (from rev. 724 to 731) collected before the first source detection for a total of 500 ks, resulting in a 3$\sigma$ upper limit of 1 mCrab (Fig. 1).

In order to look for any possible spectral variability, we fitted the four averaged IBIS spectra with a simple power law. We obtained a constant value (within the errors) of the photon index ($\Gamma \sim 2$) which indicates, in spite of the flux variation, a steady spectral state.

The lack of spectral parameter variation led us to average the IBIS spectra of different revolutions. The 18–100 keV averaged spectrum is well described by a simple power-law model with a slope as $2.2 \pm 0.3$. A mean 18–100 keV flux of $1.5 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$ can be derived.

The XRT spectrum can be fitted by an absorbed power-law model with a hydrogen column density of $N_{\mathrm{H}} = 1.8(\pm 0.6) \times 10^{22}$ cm$^{-2}$. The photon index is $\Gamma = 2.0 \pm 0.5$ and the resulting 2–10 keV absorbed and unabsorbed fluxes are ∼4.4 and $\sim 5.2 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$, respectively.

We note that the derived $N_{\mathrm{H}}$ is higher than the absorption column of $0.83 \times 10^{22}$ cm$^{-2}$ (Cornelisse et al. 2002) found by interpolating the H I maps of Dickey & Lockman (1990). In fact, the two values are perfectly consistent within the errors, given the large range of values (about 0.4–1.5 $\times 10^{22}$ cm$^{-2}$) obtained in the box adopted to calculate weighted average $N_{\mathrm{H}}$ (with the nH column density tool)[1] from the H I maps.

The joint IBIS and XRT spectrum (0.3–100 keV) was then fitted with different models. First, we used an empirical model such as the power law (Fig. 2, left-hand panel), then the more physical Comptonization model. Indeed, the 1–200 keV spectrum of X-ray bursters in low/hard state is most likely produced by the upscattering of soft seed photons by a hot optically thin electron plasma (i.e. Barret et al. 2000 and references therein). Moreover, a blackbody emission from the neutron star surface is also expected to be observed in the low/hard states of bursters (i.e. Natalucci et al. 2000 and references therein). We tried to add a BB component to the two models. The best-fitting parameters and mean fluxes are reported in Table 2.

Thus, using a physical thermal Comptonization model, COMPTT (Titarchuk 1994) in XSPEC, the electron temperature is not constrained, while a lower limit of ∼24 keV (at 90 per cent) can be inferred (see Table 2 and contour levels in Fig. 3). This is consistent

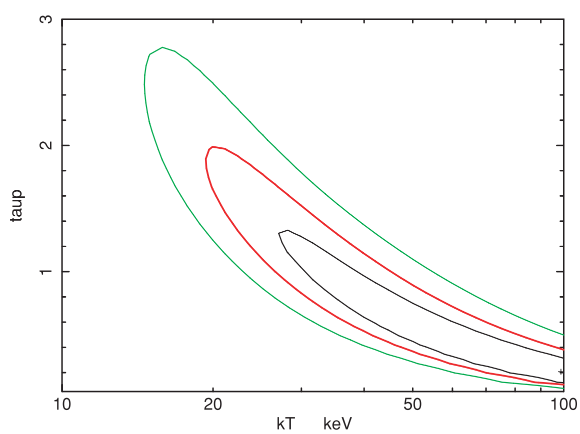


**Figure 3.** Confidence contour levels of electron temperature and plasma optical depth for the comptt model fitting the broad-band spectrum.

[1] http://heasarc.gsfc.nasa.gov/docs/tools.html

 

with the electrons temperature observed in burster systems, even brighter than SAX J1753.5−2349 (Barret et al. 2000).

With the addition of the BB component to the thermal Comptonization, a typical value of the blackbody temperature ($kT_{\rm BB} \sim 0.3$ keV) is obtained (Fig. 2, right-hand panel), even though this component is not requested by the F-test probability ($7 \times 10^{-2}$). We may argue that the high absorption observed in SAX J1753.5−2349 could be a strong obstacle to the firm detection of this component.

As a first approximation, the accretion luminosity $L_{\rm acc}$ is coincident with the bolometric luminosity of the source (0.1–100 keV). Using the mean 0.1–100 keV flux obtained with the COMPTT model fit and assuming a distance of 8 kpc (Galactic Centre), a value of $L_{\rm acc} = 4.3 \times 10^{36}$ erg s$^{-1}$ ($\sim$0.02 $L_{\rm Edd}$) is derived. The averaged mass-accretion rate ($\langle \dot{M}_{\rm ob} \rangle = RL_{\rm acc}/GM$, where $G$ is the gravitational constant, $M = 1.4\,{\rm M}_{\odot}$ and $R = 10$ km for a neutron star accretor) during the outburst is $6.7 \times 10^{-10}\,{\rm M}_{\odot}\,{\rm yr}^{-1}$.

## 4 DISCUSSION

We report here for the first time the broad-band spectrum, from soft to hard X-rays, of the persistent emission from a so-called 'burst-only' source. In particular, none of these sources has ever been studied above 10 keV during their persistent emission.

The outburst from SAX J1753.5−2349 observed with *INTEGRAL*/IBIS has a duration of at least 14 d, without any evidence for type-I X-ray bursts, all along the performed *INTEGRAL* observations of the Galactic Centre region started in 2003.

From the *RXTE*/PCA flux detection at 8 mCrab (Markwardt et al. 2008), we can derive an absorbed 2–10 keV peak flux of about $1.7 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$ which translates in an unabsorbed luminosity higher than $1.3 \times 10^{36}$ erg s$^{-1}$. This value seems to indicate SAX J1753.5−2349 being a hybrid system (such as AX J1745.6–2901 and GRS 1741.9–2853, see Degenaar & Wijnands 2009) which displays very-faint outbursts with 2–10 keV peak luminosity $L_X < 10^{36}$ erg s$^{-1}$ (as resulted from WFC observations in 1996), as well as outbursts with luminosities in the range $10^{36-37}$ erg s$^{-1}$, which are classified as faint (FXT; Wijnands et al. 2006). However, it is worth knowing that the $L_X$ boundary as $10^{36}$ erg s$^{-1}$ is somewhat arbitrary (such as the VFXT/FXT classification). Nevertheless, our result reinforces the hypothesis that the so-called 'burst-only' sources belong to the class of the subluminous neutron star X-ray binaries.

A rough estimate of the duty cycle (as the ratio of $t_{\rm ob}/t_{\rm rec}$) can be obtained. The time interval between the two 2008 measurements of the quiescence (February 2008–March 2009) is about 13 months while the outburst recurrence ($t_{\rm rec}$) is about 12 yr (from the burst event in 1996). However, it is possible that we missed other outbursts of SAX J1753.5−2349 that occurred between 1996 and 2008 within periods not covered by Galactic Centre monitoring. The outburst duration ($t_{\rm ob}$) ranges from a minimum of 14 d (as observed) and a maximum of 13 months, since there are not any other X-ray observations but the ones in October. In fact, we cannot exclude that the hard X-ray outburst may be part of a longer outburst occurred at a lower luminosity level, only detectable by high-sensitivity X-ray telescopes.

This translates into a duty cycle ranging from a minimum of 0.3 per cent to a maximum of 9 per cent and into a long-term time-averaged accretion rate ($\langle \dot{M}_{\rm long} \rangle = \langle \dot{M}_{\rm ob} \rangle \times t_{\rm ob}/t_{\rm rec}$) ranging from $2.2 \times 10^{-12}$ to $6.0 \times 10^{-11}\,{\rm M}_{\odot}\,{\rm yr}^{-1}$.

King & Wijnands (2006) suggested that neutron star in transient LMXBs with low time-averaged mass accretion rate might pose difficulties explaining their existence without invoking exotic scenarios such as accretion from a planetary donor. However, the regime of $\langle \dot{M}_{\rm long} \rangle$ estimated for SAX J1753.5−2349 can be well explained within current LMXB evolution models.

In spite of the flux variability along the outburst, the spectral state of SAX J1753.5−2349 remains steady, in low/hard state. This is in agreement with the fact that a really low X-ray luminosity, $L_X \lesssim 0.01 L_{\rm Edd}$ or so, produces a hard state in most sources (van der Klis 2006).

Following in't Zand, Jonker & Markwardt (2007), we have estimated the hardness ratio 40–100/20–40 keV within each *INTEGRAL* revolutions. We find a value consistent with one which confirms the hard nature of the system. This is also consistent with the low mass accretion rate inferred (see also Paizis et al. 2006), i.e. SAX J1753.5−2349 is not a fake faint system and there would be no reason to assume that the system is obscured to explain the low $\dot{M}$.

Moreover, King (2000) argued that the faint low-mass X-ray transients are mainly neutron star X-ray binaries in very compact binaries with orbital periods lower than 80 min. We suggest that the SAX J1753.5−2349 system is a good candidate to harbour an accreting neutron star in a very compact system.

In conclusion, SAX J1753.5−2349 joins a sample of low-luminosity transient LMXBs (Degenaar & Wijnands 2009), which display different behaviour in terms of peak luminosity, outburst duration and recurrence time from year to year. Up to now, it is not understood whether these variations should be interpreted as being due to changes in the mass-transfer rate or as results of instabilities in the accretion disc (Degenaar & Wijnands 2009 and reference therein).

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