SPECTRAL STATES AND TRANSIENT BEHAVIOUR OF A SAMPLE OF X-RAY BURSTERS OBSERVED BY BEPPOSAX

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ABSTRACT

During observation campaigns of the Galactic Bulge region, BeppoSAX detected a total of 21 new X-ray bursters in about 6 years of operation. These sources are mostly transient and often feature a hard X-ray spectrum, extending up to $\sim 200$ keV. A hard spectrum is generally found in weak, relatively short outbursts. On the other hand two sources, SAX J1747.0-2853 and SAX J1750.8-2900, have been seen with soft X-ray transient behaviour. In both low/hard and high/soft state, a thermal component is observed at energies below 10 keV and the spectra are compatible with the same model consisting of a blackbody or disk blackbody plus a hard or Comptonized component. Light curves are characterized by either weak, short flares or longer, high luminosity eruptions with exponential decay.

1. INTRODUCTION

High energy transient events from compact sources are characterized by rapid increases in X-ray luminosity (greater than $\sim 2$ orders of magnitude) out of a normal or quiescent state. Many studies in the particular topic of X-ray transients are related to accreting Galactic Black Holes (GBH) and to the weakly magnetized Neutron Stars (NS) in Low Mass X-ray Binaries (LMXB). In these sources, the X-ray outburst is originated by sudden increases of accretion rate probably triggered by a viscous-thermal instability in the accretion disk (Lasota, 2001 and refs. therein). The sources are often discovered in coincidence with the outbursts, as these are usually separated by very long quiescence periods ($\sim$ months to decades). The ASM on board RXTE and the WFC on board BeppoSAX have provided a wealth of new discoveries in less than a decade, resulting in a big increase in the number of known LMXB objects. For BeppoSAX, the systematic monitoring of the Galactic Bulge region as part of the mission Core Programme (see in ’t Zand et al. 2004 for review) was complemented by a Target Of Opportunity (TOO) program aimed at the detailed spectral study on a wide spectral band (0.2-200 keV). This led to successful observations for a sample of X-ray bursters (see Table 1).

2. OUTBURST LIGHT CURVES

In transient bursters, outbursts have a typical duration of days to weeks and type-I X-ray bursts (thermonuclear flashes on a NS surface, lasting $\sim$ seconds to minutes) are often observed during source activity. As for GBH transients, bursters may behave as soft X-ray transients (SXT) with short rise, exponential decay light curves at high luminosities, or undergo weak outburst ($L \leq 10^{37}$ erg/s). In Fig.1 the light curves of two transient bursters are shown. In the case of SAX J1747.0-2853 (1998 outburst) the flux is slowly rising and the luminosity of the source is a small fraction ($\leq 3\%$) of the Eddington luminosity. Both curves have been obtained with the WFC instrument (Jager et al. 1997) on board BeppoSAX. For SAX J1750.8-2900 the outburst is typical of SXT and the luminosity is $10^{37}$ erg/s or less. For this source, an upper limit to the distance of $\sim 7$ kpc is available by the observation of the peak luminosity of X-ray bursts. References to these observations are given in Table I.

Both SAX J1747.0-2853 and SAX J1750.8-2900 experienced further activity. In the spring of 2000, SAXJ1747.8-2900 had a luminous outburst with SXT behaviour (Natalucci et al., 2004). A light curve with multiple peaks was measured by RXTE/PCA (Werner et al. 2004) indicating the presence of variations on the time scale of days. An important characteristic of this source is that after this long, exponential decay outburst, the source did not return to quiescence but entered a period of low luminosity activity (Wijnands et al 2002) for more than one year. Very recently (March 2004), the source brightened to an intensity greater than 200 mCrab (Markwardt & Swank, 2004; Deluit et al., 2004).

SAX J1750.8-2900 had also a second, luminous out-
Table 1. TOO of X-ray bursters performed by BeppoSAX within the Galactic Bulge Monitoring Program.

| Source                  | References                          | Remarks                                      |
|-------------------------|-------------------------------------|----------------------------------------------|
| SAX J1712.6-3739        | in ‘t Zand et al. 1999a, Cocchi et al. 1999 | Detection of 15-min long burst                |
|                         | Natalucci 2001                       |                                              |
| SLX 1737-282            | in ‘t Zand et al. 2002               | Soft transient, recurrent                    |
| SAX J1750.8-2900        | Natalucci et al. 1999 + this work    | Recurrent, eclipsing source. Detection of long, peculiar burst (in’t Zand et al. 2003) |
| GRS 1747-312 in Terzan 6| in ‘t Zand et al. 2000               |                                              |
| SAX J1810.8-2609        | Ubertini et al.1998; Natalucci et al. 2000a | Low state outburst. Hard spectrum, no visible cutoff. |
| GS 1826-238             | in’t Zand et al. 1999b              | Persistent source. Clocked burster (Ubertini et al. 1999) |
| SAX J1747.0-2853        | Natalucci et al. 2000b; Werner et al. 2004 | Recurrent outbursts.                          |
|                         | Natalucci et al. 2004               |                                              |
| SAX J1748.9-2021 in NGC6440 | In ‘t Zand et al. 1999c            | Long activity spanning 2000-2001             |

burst in the spring of 2001. During this outburst, ms oscillations in the rise of an X-ray burst and kHz QPOs were recently discovered with RXTE (Kaaret et al. 2004). In this paper, we present detection of further X-ray bursts and the results of a preliminary study of the broadband spectrum obtained by the NFI (Boella et al. 1997) on board BeppoSAX.

3. STUDY OF BROAD BAND SPECTRA

Spectra of transient bursters were obtained in both low/hard and high/soft states. Due to the low energy extension (down to \(\sim 0.2\) keV) of the NFI, both the thermal emission from disk or NS and the low energy tail of the Comptonized spectrum could be modelled. In the low/hard state the thermal component is generally weak, contributing a fraction of \(\sim 10\%\) of the total flux in the 2-10 keV energy band. Modelled by a pure blackbody, the thermal emission has a typical colour temperature below \(\sim 1\) keV. The spectra of these bursters during a low/hard state outburst is very similar to the ones of low luminosity, persistent bursters (see e.g. Barret et al., 2000) and their high energy spectrum is generally well described by thermal Comptonization with a plasma temperature \(kT_e \sim 25-30\) keV. A notable exception is the source SAX J1810.8-2900, discovered by the WFC in March 1998, with its very hard spectrum compatible with a pure power-law (see Fig.2, compared to the low state spectrum of SAX J1747.0-2853).

SAX J1747.0-2853 was also observed by the NFI in a high state. Unfortunately, due to its vicinity to the Galactic Centre, the high energy instrument PDS was affected by source confusion and could not be used effectively for this observation. In Fig.3 the high state spectrum of the March 2000 outburst is shown. For this event, the X-ray emission is characterized by a soft component with temperature \(kT \sim 1.3\) keV and by a second component, which is most likely non-thermal (see details in Natalucci et al. 2004). Since for this observation we could not obtain valid spectral measurements above 10.5 keV, in Fig.3 two model spectra are shown corresponding to spectral...
fits with or without a hard Comptonization tail.

Figure 2. Spectra of two X-ray bursters measured by BeppoSAX/NFI during a low luminosity outburst. The spectrum of SAX J1810.8-2609 has no visible high energy cutoff. References in Table I.

Figure 3. Two different spectral states of SAX J1747.0-2853 (from Natalucci et al 2004). The best model spectra are shown up to 200 keV. See text for details.

4. THE 2001 OUTBURST OF SAX J1750.8-2900

After the outburst of 1997, SAX J1750.8-2900 had a second eruption in 2001. On this occasion, the BeppoSAX/NFI performed successfully two observations. During the 1st one on 23-24 March, the source intensity was \( \sim 4 \) mCrab (2-10 keV) and the source was in a rising phase; on 9-10 April, the intensity was slowly decaying with an average value of 43 mCrab. The light curve of this observation is shown in Fig. 4 for the MECS instrument (units 2+3). In this dataset we detect the presence of three X-ray bursts, which are visible in the 100 s binned curve.

In Fig. 5 the profile of the first X-ray burst is shown for two different energy bands. From the plot itself we see clear evidence of spectral softening with time (as expected from a type-I X-ray burst). The intensity of this burst corresponds to a bolometric fluence of \( \sim 10^{-7} \) erg cm\(^{-2}\) s\(^{-1}\), similar to the other bursts observed from this source. No X-ray bursts were observed during the first observation, when the intensity was 10 times lower. This is reminiscent of the behaviour observed in 1997, where most X-ray bursts occurred at an intermediate level of persistent flux (see Fig. 1, right panel).

In Fig. 6 the count rate spectrum is shown for the two NFIs, after subtraction of the data sections corresponding to the detected bursts. Both observations were fitted with a model consisting of two components: a multicolor disk blackbody plus thermal Comptonization. A standard systematic error of 1% was used to account for calibration related uncertainties. The above model is found to provide good fits: \( \chi^2 = 0.84 \) (61 dof) and \( \chi^2 = 1.07 \) (144 dof) for the 1st and 2nd observation, respectively. For the second observation, the model is in good agreement with the spectrum found by RXTE/PCA (Kaaret et al. 2002) in a quasi-simultaneous observation, yielding a relatively low plasma temperature \( (kT_e \sim 5.5 \) keV in
Figure 6. NFI count rate spectra for the two observations of SAX J1750.8-2900, performed during the most recent outburst of March-April 2001. The two observations are separated by 2 weeks, showing a factor of $\sim 10$ difference in intensity.

our fit). However, the temperature is not well constrained. We attempted to add the PDS data (15-200 keV) but due to possible significant source contamination, this analysis is difficult and work is still in progress.

5. CONCLUSIONS

A significant sample of the X-ray bursters detected by the BeppoSAX WFC during the Galactic Centre Monitoring program has been studied by dedicated follow-up observations with the NFI instruments. One of the sources (SAX J1747.0-2853) had outbursts in both low/hard and high/soft state besides showing very long ($\sim 1$ year or more), low luminosity activity. Another recurrent transient, SAX J1750.8-2900, showed two relatively luminous episodes with SXT behaviour, the latest occurring in March 2001. In this paper we have presented the main spectral characteristics of these sources along with some preliminary results of the second outburst of SAX J1750.8-2900. During this event, at least three X-ray bursts were present in the light curve, which were clearly spot by the sensitive NFI.

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