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INTEGRAL⋆ high energy behaviour of 4U 1812-12

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ABSTRACT

The low mass X-ray binary system 4U 1812-12 was monitored with the INTEGRAL observatory in the period 2003−2004 and with BeppoSAX on April 20, 2000. We report here on the spectral and temporal analysis of both persistent and burst emission. The full data set confirms the persistent nature of this burster, and reveals the presence of emission up to 200 keV. The persistent spectrum is well described by a comptonization (CompTT) model plus a soft blackbody component. The source was observed in a hard spectral state with a 1−200 keV luminosity of 2×10^{36} erg s^{-1} and $L/L_{\rm Edd} \sim 1\%$ and no meaningful flux variation has been revealed, as also confirmed by a 2004 RXTE observation. We have also detected 4 bursts showing double peaked profiles and blackbody spectra with temperatures ranging from 1.9 to 3.1 keV.

Key words. X-rays: binaries – stars: neutron – X-rays: bursts – gamma rays: observations

1. Introduction

4U 1812-12 was discovered as a weak galactic source by the Uhuru satellite in 1970 (Forman et al. 1976).

Type 1 X-ray bursts were detected for the first time with Hakucho and the burst detection allowed the determination of the nature of the compact object as a neutron star in a Low Mass X-ray Binary (LMXB) system (Murakami et al. 1983). During the Galactic Bulge monitoring campaign performed in the period 1996−2001 with the WFCs on board BeppoSAX, several X-ray bursts were detected and in most of them a clear photospheric radius expansion due to Eddington-limited burst luminosity was observed. This allowed the estimation of the source distance at 4.1 ± 0.5 kpc. At energies above 5 keV, the bursts showed a double peaked profile that became more evident at higher energy (Cocchi et al. 2000).

A broad band spectrum of the persistent emission and rapid X-ray variability has been revealed during simultaneous observations with BeppoSAX and RXTE on April 20, 2000. Emission above 20 keV has been reported while the source was in a hard spectral state with a 1−200 keV flux of 1.1×10^{-9} erg s^{-1} cm^{-2} (Barret et al. 2003).

The persistent emission, revealed by Chandra on June 14, 2000, is characterized by a 2−10 keV flux of about 4×10^{-10} erg s^{-1} cm^{-2} (Wilson et al. 2003). The source was still in the hard state during the RXTE observation in June and July 2001 with a 2−10 keV flux of 3.8×10^{-10} erg s^{-1} cm^{-2} (Muno et al. 2005).

Like most of the bursters, 4U 1812-12 is classified as an atoll source (Wijnands et al. 1999).

Since March 2003, this source has been observed, and is still being monitored, by the INTEGRAL observatory (Winkler et al. 2003a) in the framework of the Galactic Centre Deep Exposure programme (Winkler et al. 2003b).

In this paper we report on the analysis performed with IBIS/INTEGRAL (Ubertini et al. 2003) during the period 2003 March 11th up to 2004 October 20th, on both the persistent and bursting behaviour. For the first time a hard X-ray continuum emission up to 200 keV has been detected, and moreover 4 bursts have been revealed during this long observation period.

2. Observations and data analysis

The IBIS instrument onboard the INTEGRAL satellite is a coded mask imager with a wide field of view (29° × 29° at zero response and 9° × 9° fully coded). IBIS is composed of two detector layers: ISGRI (15 keV−1 MeV) (Lebrun et al. 2003) and PICsIT (175 keV−10 MeV) (Labanti et al. 2003). An INTEGRAL observation consists of a group of pointings, called science windows (scws) each lasting about 2000 s (Winkler et al. 1999). We analysed all the data

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in which 4U 1812-12 was within the ISGRI/IBIS detector field of view (14° from the field centre).

The observations covered a non-continuous period from 2003 March 11th to 2004 October 20th (from orbit 49 to 246) for a total of 1322 scws. We extracted the light curves in four energy bands and computed the 40−60/20−40 keV hardness ratio for the whole period.

For the spectral analysis only, we selected and used a data set with a total time of about 165 ks when the source was in the fully coded field of view (within 4.5 degrees from the centre of the field of view). With this data set, the source intensity determination is not affected by possible systematic errors due to calibration uncertainties in the off-axis response.

During the observing compaign, 4 bursts triggered the INTEGRAL Burst Alert System (IBAS) (Mereghetti et al. 2003) from a direction consistent with the 4U 1812-12 error box. For each burst, we have extracted the light curve with a temporal bin of 1 s allowing analysis of the burst profiles. We have also extracted the burst spectra in order to compare the spectral parameters of the bursts.

The IBIS data were processed using the 4.2 version of the Off-Line Scientific Analysis (OSA) (Goldwurm et al. 2003) software, released by the INTEGRAL Scientific Data Centre (ISDC) (Courvoisier et al. 2003).

The response matrix used for the spectral analysis is the standard 2048 channels matrix, logarithmically rebinned to 64 channels.

We do not report on JEM-X (Lund et al. 2003) results, because when 4U 1812-12 was in the JEM-X field of view, it was not detected in the mosaic image.

For the continuum emission study, it is essential to have as broad a spectral coverage as possible. For this reason we have combined the IBIS (20−200 keV) data with the BeppoSAX LECS (0.5−4 keV) and MECS (1.5−10 keV) data obtained in 2000. Even if these data are not simultaneous, combining spectra is meaningful in view of the low observed variability of this source (see Sect. 3 for more details). We have examined the public data obtained with BeppoSAX between 20 April at 18:51 UT to 21 April 2000 at 13:23 UT. The publicly available data from the MECS and LECS instruments have been downloaded from the on line archive of BeppoSAX[1].

The XANADU software package XSPEC (version 11.3.2) has been used for the spectral analysis.

3. Continuum emission results

During the INTEGRAL monitoring of the Galactic Centre, the burster 4U 1812-12 was detected at position RA = $18^{h}15^{m}07^{s}$ Dec = $-12°{:}05'{:}45''$ (J2000) with an error of 1′. Figure 1 shows the ISGRI/IBIS light curves in the 20−40, 40−60, 60−80 and 80−200 keV energy bands for the whole monitoring period. Each point corresponds to the source count rate (at a signal to noise ratio $>3\sigma$) for a single pointing. As can be seen, the source is significantly detected up to 200 keV and shows the same time behaviour in all energy bands, revealing a persistent and moderately variable continuum emission. In the 20−40 keV band, the average source flux corresponds to ∼26 mCrab.

To search for a possible correlation between flux and spectral variation, we derived the hardness ratio in the 40−60/20−40 keV flux. The null slope (with a $\chi^2_{\rm red} \sim 1$) in the bottom panel of Fig. 1 indicates that there is no spectral variability.

Spectra have been extracted for each pointing and, in view of the lack of flux variation, it has been possible to add all the spectra to increase the signal to noise ratio. The final spectrum has been obtained for a total time of 165 ks, and does not include any of the burst events.

This spectrum is well represented by a thermal comptonization model that indicates that the source was in the hard spectral state, the same state in which the source was found during the contemporaneous BeppoSAX and RXTE observation in 2000 (Barret et al. 2003). Because of this and of the weak variability of the source, we combined the 2000 BeppoSAX low energy data with the IBIS data, even though they are not simultaneous. The intercalibration between the three instruments shows agreement: the relative normalizzation factor of ISGRI with respect to LECS and MECS is 1.03 ± 0.05, while the relative normalisation factor of LECS with respect to MECS is 0.67 ± 0.07. The spectrum thus obtained has been fitted with different models. We always assume a systematic error of 0.01 for the MECS and LECS and of 0.02 for ISGRI. The best fit model, a comptonization model compTT (Titarchuk 1994) plus a low energy blackbody component, is reported in Table 1, while the spectrum is shown in Fig. 2. The low energy data can also be fitted by the multicolor disk black body (diskbb) model (Mitsuda et al. 1984), leading to similar parameters and χ^2_r results.

The ISGRI high energy sensitivity provides a better evaluation and error constraint of the comptonization parameters ($kT_{\rm e} = 17.5^{+1.7}_{-1.4}$ keV and $\tau = 2.3^{+0.2}_{-0.2}$ with $\chi^2_r = 1.03$) compared to the ones obtained by BeppoSAX in 2000 ($kT_{\rm e} = 36.0^{+78.0}_{-9.0}$ keV, $\tau = 3.0^{+0.7}_{-1.8}$ with $\chi^2_r = 1.03$, Barret et al. 2003). The 20−200 keV flux value, derived from ISGRI, is 4.2×10^{-10} erg cm^{-2} s^{-1}, and the 1−200 keV flux value, combining LECS MECS and ISGRI, is 9.1×10^{-10} erg cm^{-2} s^{-1}. Assuming a source distance of 4.1 kpc (Cocchi et al. 2000), the bolometric luminosity is 2×10^{36} erg s^{-1}, that corresponds to $L/L_{\rm Edd} \sim 0.01$ (for a neutron star mass $M = 1.4\ M_{\odot}$).

We have also analysed the recent publicly available RXTE/PCA spectrum data[2] of a 4U 1812-12 observation in July 15, 2004 to check for a possible source spectral state change. The analysis of this data shows the flux in agreement with the SAX/IBIS one and the spectrum has similar parameters and χ^2_r value.

4. Burst emission results

Four bursts were detected during the INTEGRAL GCDE campaign; the light curves (with a temporal bin of 1 s) for two energy bands (15−20 and 20−30 keV) and the whole band 15−30 keV are shown in Fig. 3. Above 30 keV there is no

[1] http://www.asdc.asi.it/

[2] Downloaded from the on line archive of HEASARC http://heasarc.gsfc.nasa.gov/docs/archive.html

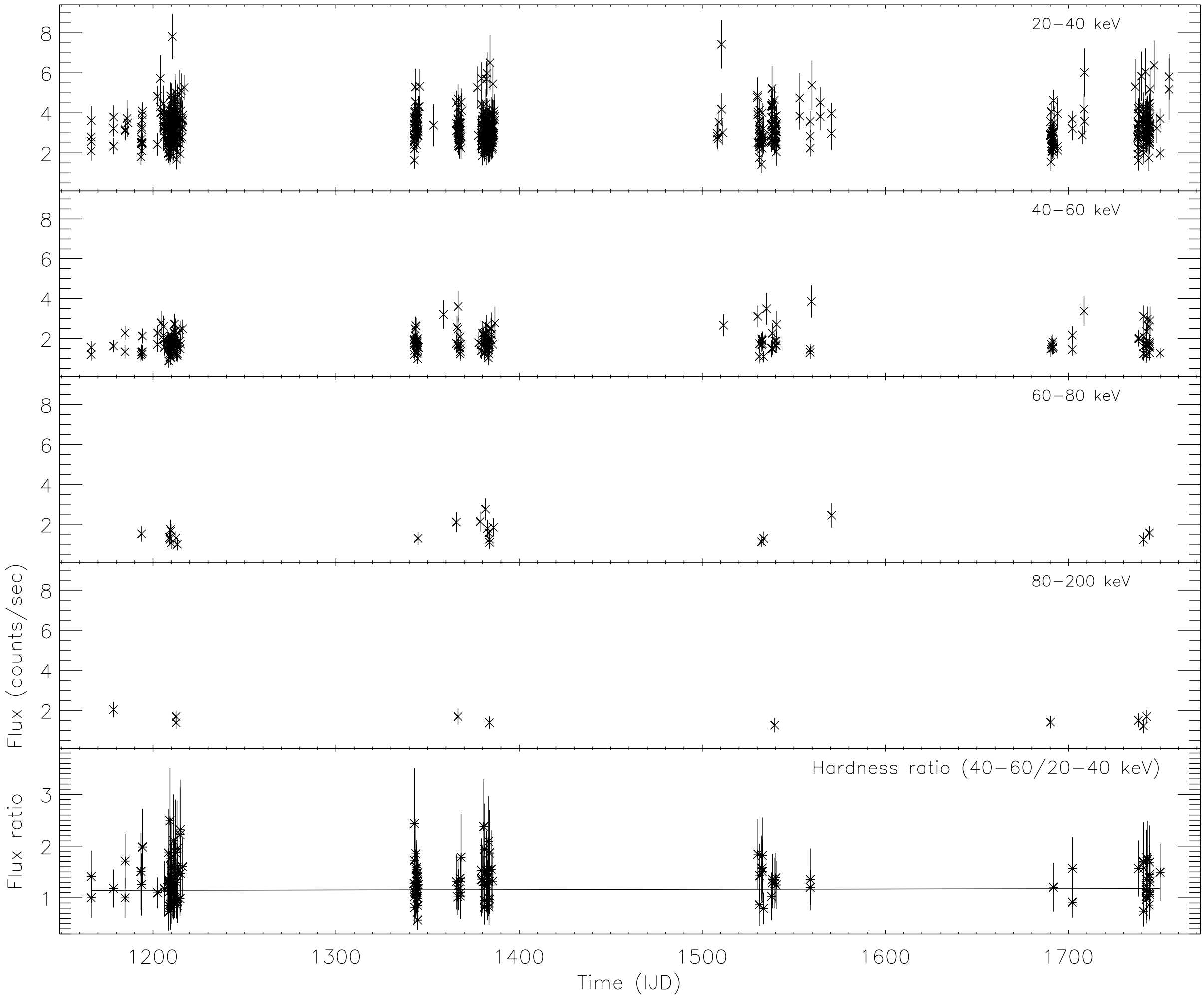

Fig. 1. 4U 1812-12 IBIS/ISGRI light curves in the 20−40, 40−60, 60−80, 80−200 keV energy bands; and the hardness ratio of the 40−60 to 20−40 keV flux. The observation period is between 2003 March 11th to 2004 October 20th, and each data point represents a single pointing.

Table 1. Spectral fitting parameters of the 4U 1812-12 persistent emission. The best fit is a sum of comptonization (CompTT) and blackbody (bb) models.

Spectral Model: wabs×(bb+CompTT)	
Parameters	Value
$N_{\rm H}$	$1.5^{+0.1}_{-0.1} \times 10^{22}$ cm^{-2}
T_0(keV)	$0.3^{+0.1}_{-0.1}$
$kT_{\rm e}$(keV)	$17.5^{+1.7}_{-1.4}$
τ	$2.3^{+0.2}_{-0.2}$
norm$_{\rm comptt}$	$7.6^{+1.0}_{-0.9} \times 10^{-3}$
$kT_{\rm bb}$(keV)	$0.6^{+0.1}_{-0.1}$
norm$_{\rm bb}$	$7.5^{+1.4}_{-1.4} \times 10^{-4}$
χ^2_r(d.o.f.)	1.03 (514)
Flux$_{20-200\ \rm keV}$	4.2×10^{-10} erg cm^{-2} s^{-1}
Flux$_{1-10\ \rm keV}$	3.2×10^{-10} erg cm^{-2} s^{-1}

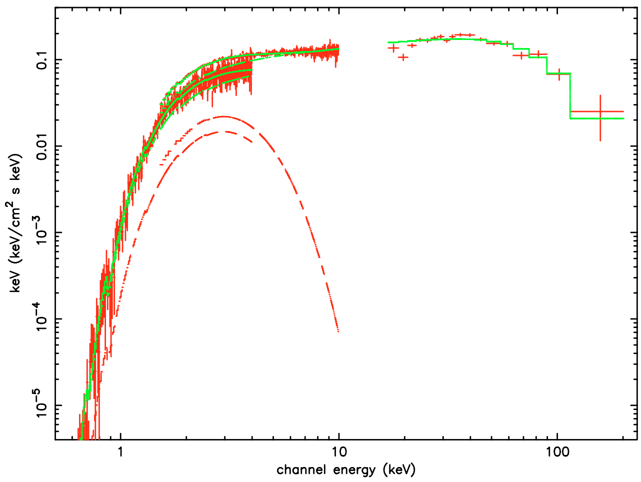

Fig. 2. INTEGRAL/IBIS/ISGRI and BeppoSAX/LECS and MECS spectrum of the persistent emission of 4U 1812-12, with the CompTT plus blackbody best fit models.

detection of the burst emission. The upper limit of the persistent emission up to 30 keV during the bursts is about 20 counts s^{-1}.

The burst profiles are clearly double peaked and in each case the first pulse shows a fast rise (∼1 s) shape. The burst fluxes reach up to 2 Crab in the 15−30 keV band. In Table 2 we

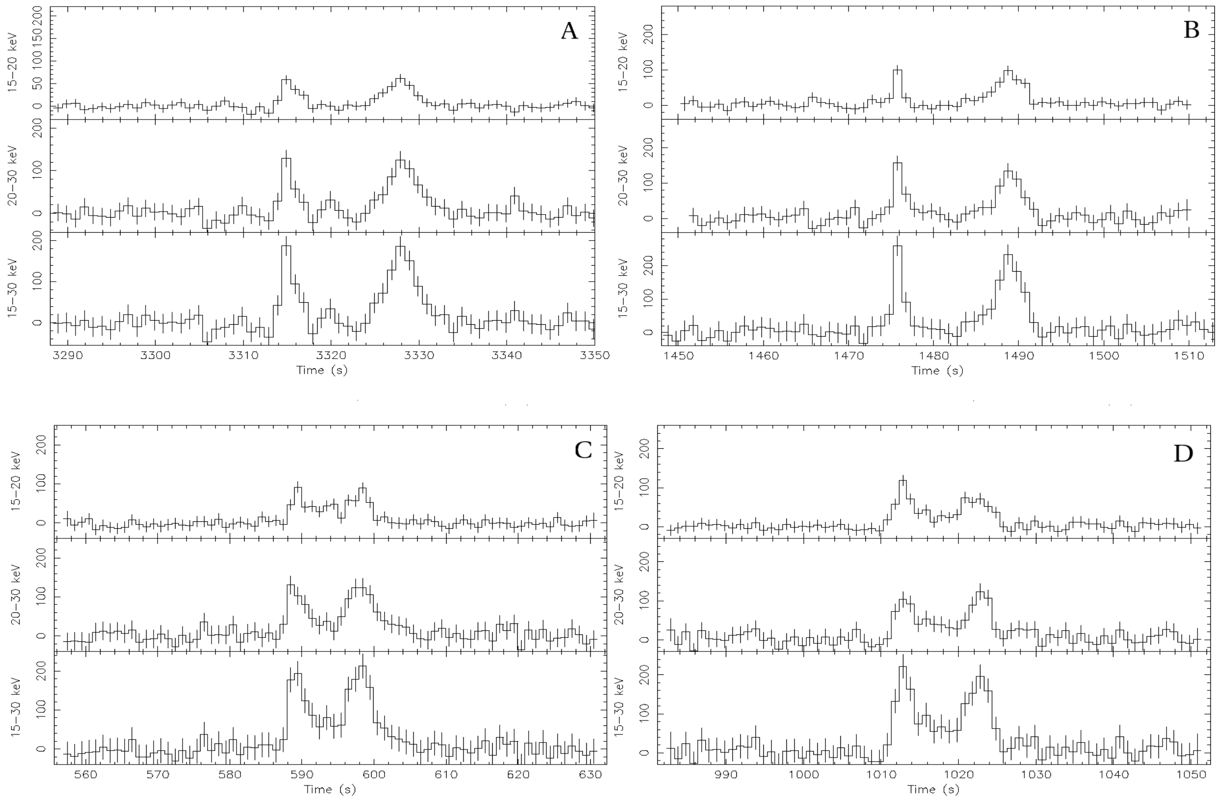

Fig. 3. IBIS/ISGRI light curves (counts s^{-1} vs. time) of the 4 bursts of 4U1812-12 in the 15−20, 20−30, 15−30 keV energy bands, with temporal bin of 1 s.

report the characteristic parameters of the 4 bursts (burst A, B, C, D taken in chronological order).

The burst average spectra are affected (in the ISGRI band) by "switch off" during the expansion so we have extracted a separate spectrum from each burst peak. We have fitted them with a black body model and the best fit parameters are reported in Table 2.

A comparison between the burst and persistent emission spectra is shown in Fig. 4.

5. Discussion and conclusions

The IBIS/ISGRI observation has allowed us to follow the high energy behaviour of 4U 1812-12. During the long monitoring period, the light curves show that the persistent source flux is almost constant and with the same behaviour in the 20−40, 40−60, 60−80 and 80−200 keV energy bands.

Combining the ISGRI spectrum with the non-contemporaneous LECS and MECS spectra, taken when the source was in the same spectral state, we obtain a broad band energy spectrum well represented by a soft thermal component (with a temperature of 0.6 keV) plus a Compton emission with an electron temperature, kT_e, of ∼18 keV and an optical depth of the plasma, τ, of ∼2.3. The 1−200 keV luminosity is 2×10^{36} erg s^{-1}. These results are in agreement with the high energy behaviour of an atoll source in the so called Low-Hard state (Di Salvo & Stella 2002). Then, we confirm that 4U 1812-12 spends most of its time in this hard state (as is also shown by results from recent 2004 RXTE/PCA data) as well as the presence of a hard emission extending up to 200 keV.

The hard component is due to the comptonization of soft photons in a hot region between the neutron star and the accretion disk. The soft component can be represented by a single-temperature black body model or alternatively by a multicolor disk black body, so we cannot determine if the origin of this emission is from the neutron star surface or from the accretion disk.

The 4U 1812-12 IBIS data also allowed us to study the bursting activity, even if most of the burst emission is well below the ISGRI low energy threshold (15 keV). In fact, because of the relatively high bursts fluxes and the well-defined instrument response, we can still derive the spectral parameters of the bursts.

Type I bursts are due to thermonuclear flashes on to neutron star surface. The spectral softening, typical of this type of burst, is not evident because of the high energy band (15−30 keV) in which we have observed the burst events, but the type I nature of the bursts is very well established by previous measurements at lower energy (Cocchi et al. 2000).

The energy spectra of the detected bursts are satisfactorily described by a blackbody model whose temperature changes in the range kT = 1.9−3.1 keV, according to the thermal nature of these events. This range of temperature is compatible with the temperature of other bursts previously detected from 4U 1812-12.

Table 2. Parameters of the burst peaks. The spectral model applied is the blackbody model (bbodyrad).

	Burst A		**Burst B**		**Burst C**		**Burst D**	
	2003-04-25 UT 10:54:28		2003-09-06 UT 00:23:49		2003-09-27 UT 16:08:52		2004-10-04 UT 03:15:53	
Parameters	1st peak	2nd peak	1st peak	2nd peak	1st peak	2nd peak	1st peak	2nd peak
kT_{bb}(keV)	$2.7^{+0.6}_{-0.5}$	$3.1^{+0.5}_{-0.4}$	$2.7^{+0.6}_{-0.5}$	$2.2^{+0.4}_{-0.3}$	$2.3^{+0.5}_{-0.4}$	$2.7^{+0.4}_{-0.3}$	$1.9^{+0.4}_{-0.3}$	$2.3^{+0.3}_{-0.3}$
$R_{km}/d_{10\ kpc}$	10.5 ± 5.1	7.0 ± 2.5	10.9 ± 5.8	33.1 ± 10.7	22.1 ± 10.4	10.3 ± 3.7	76.3 ± 26.8	28.3 ± 9.8
χ^2_r	1.6	1.2	1.0	1.3	1.4	1.3	1.9	1.8
duration (s)	4	9	5	8	5	9	4	6
Counts s^{-1}	116 ± 18	104 ± 12	64 ± 17	153 ± 14	143 ± 19	129 ± 15	177 ± 21	176 ± 17
$Flux^a_{15-30\ keV}$	1.18	1.03	1.12	2.05	1.86	1.35	3.08	2.28

[a] In unit of 10^{-8} erg cm^{-2} s^{-1}.

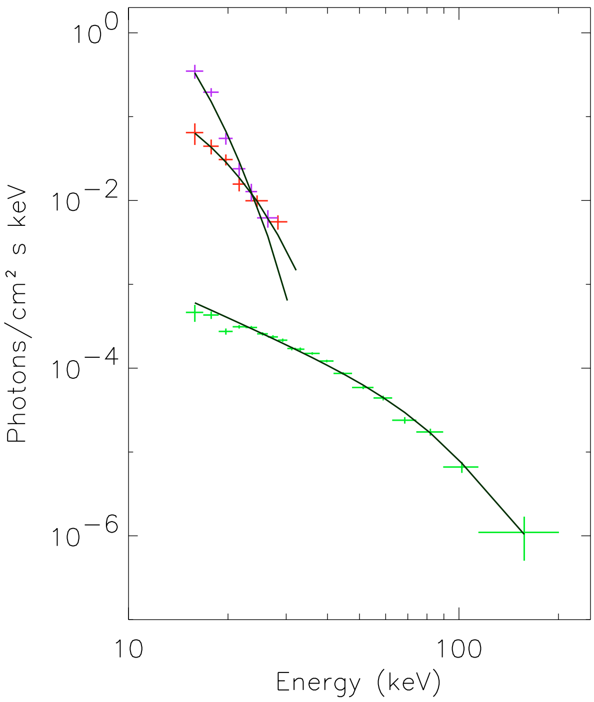

Fig. 4. IBIS/ISGRI spectrum of the persistent emission compared with spectrum of the most and the least intense bursts. The solid lines describe the spectral models: blackbody for the bursts and comptonization for continuum emission.

The observed high energy emission of the 4 bursts has a double peaked profile, typical of Eddington-limited events (Lewin et al. 1995). The burst profiles are similar in the 15–20 and 20–30 keV ranges, and the duration of the second peak is always longer than the first one as expected for double peaked bursts (Lewin et al. 1995). Decay times and energy release are typical of the helium burning regime (Strohmayer & Bildsten 2003). No evidence for different types of bursts such as superbursts (Kuulkers et al. 2004) has been observed in our data set.

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