3-200 keV SPECTRAL STATES AND VARIABILITY OF THE INTEGRAL BLACK HOLE BINARY IGR J17464-3213¹

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ABSTRACT

On March 2003, IBIS, the gamma-ray imager on board the INTEGRAL satellite, detected an outburst from a new source, IGR J17464-3213, that turned out to be a HEAO 1 transient, H1743-322. In this paper we report on the high-energy behavior of this black hole candidate (BHC) studied with the three main instruments on board INTEGRAL. The data, collected with unprecedented sensitivity in the hard X-ray range, show a quite hard Comptonized emission from 3 up to 150 keV during the rising part of the source outburst, with no thermal emission detectable. A few days later, a prominent soft-disk multicolor component appears, with the hard tail luminosity almost unchanged: $\sim 5 \times 10^{-9}$ ergs cm⁻² s⁻¹. Two months later, during a second monitoring campaign near the end of the outburst, the observed disk component was unchanged. Conversely, the Comptonized emission from the central hot part of the disk reduced by a factor of ~ 10 . We present here its long-term behavior in different energy ranges and the combined JEM-X, SPI, and IBIS wideband spectral evolution of this source.

Subject headings: black hole physics — gamma rays: observations — methods: data analysis — X-rays: binaries

1. INTRODUCTION

On 2003 March 21 during the Galactic Center Deep Exposure (GCDE) Program. INTEGRAL detected a relatively bright source (~60 mcrab at 15-40 keV) named IGR J17464-3213 (Revnivtsev et al. 2003). The source was then localized at R.A. = $17^{h}46^{m}3$, decl. = $-32^{\circ}14.4$ (J2000), with an error box of 1.'6 (90% confidence) and associated with H1743-322 (Markwardt & Swank 2003), a bright BHC observed by HEAO 1 in 1977 with an intensity of 700 mcrab at 2-10 keV and localized with two possible positions (Doxsey et al. 1977). The error box of IGR J17464-3213 was compatible with only one of these two, thereby resolving this 25 yr old ambiguity. After the 2003 outburst, follow-up observations with RXTE and INTEGRAL reported strong flux and possible spectral variability (Parmar et al. 2003). RXTE observed the source for the first time on 2003 March 29 during a PCA Galactic bulge scan followed by a pointed observation. The mean PCA fluxes, in the bands 2-10, 15-40, and 40-100 keV, were 50, 200, and 220 mcrab, respectively. The spectrum was consistent with an absorbed power law with a photon index 1.49 ± 0.02 , and a column density: $N_{\rm H} = 2.4 \times 10^{22} \text{ cm}^{-2}$ (Markwardt & Swank 2003). In this paper we focus on the data collected with the coded mask coaligned telescopes IBIS (15 keV-10 MeV; Ubertini et al. 2003),

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SPI (20 keV-8 MeV: Vedrenne et al. 2003), and JEM-X (3-35 keV; Lund et al. 2003) on board INTEGRAL (Winkler et al. 2003). The source was monitored by INTEGRAL in the framework of the Core Programme (CP) observations (Kretschmar et al. 2003; Grebenev et al. 2003). The data analyzed here cover the period from the beginning of the outburst (2003 March) to its end (2003 October).

2. DATA ANALYSIS

The analyzed data set consists of all CP observations in which IGR J17464-3213 was within the high-energy detectors' field of view. In particular, the observations were performed in three different periods: from 2003 March 12 to 2003 April 15, from 2003 August 19 to 20, and from 2003 October 4 to 9. The first period contains four observations of the preoutburst state of the source; the other two shorter observations cover the end of the outburst phase. All the CP observations are organized into uninterrupted 2000 s long science windows (SCW): light curves, hardness ratios, and spectra are then extracted for each individual SCW. Wideband spectra of the source are obtained using data from the three high-energy instruments (JEM-X, IBIS, and SPI). In particular, the IBIS data were processed using the Off-line Scientific Analysis (OSA version 3; Goldwurm et al. 2003) software released by the INTEGRAL Scientific Data Centre (ISDC; Courvoisier et al. 2003) with a modified pipeline in order to optimize the source spectral extraction. The IBIS data set has been divided in two subsets according to whether the source position is located within the partially coded field of view (PCFOV) or the narrower fully coded field of view (FCFOV). Both data sets have been used, after source intensity correction for off-axis detectors response, to produce the source light curves in different energy ranges. The off-axis correction was made using the available calibration data, the accuracy on the flux ranging from 10% at low energy (15-20 keV) to 5% at higher energy (>60 keV). Only FCFOV data, less affected by the off-axis response of the gamma-ray instruments, were selected for spectral extraction and fitting. SPI spectra were extracted using software specially developed for fitting the

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Fig. 1.—*RXTE* ASM one-day-averaged light curve. Shaded rectangles represent the simultaneous *INTEGRAL* observation periods corresponding to the spectra in Fig. 4. Timescale is represented in MJD.

positions and the fluxes of all significant sources in the field of view. The background model used for the SPI data is based on a uniformity map determined for each energy band from empty fields observation. JEM-X spectra were derived with the ISDC OSA version 4 release and updated spectral matrices. While IBIS and SPI provide a very large FOV (>30°), JEM-X has a narrower FOV (>10°), thus providing only a partial overlap with the high-energy detectors. When spectral data are obtained in the same time interval from more then one instrument, the proper normalizing constant is added in the data fit, taking into account the best knowledge of the instrument cross calibration. In optimum conditions, the *INTEGRAL* spectra we produced cover the range from 3 to 200 keV.

3. RESULTS

3.1. The Time Evolution of the Outburst

The source was continuously monitored by the *RXTE* ASM and whenever possible by *INTEGRAL*, as shown in Figure 1,

where the simultaneous *INTEGRAL* observation periods are represented by shaded rectangles. The monitoring of the source was continuous during the preoutburst episode (from revolution 53 to 61), and then only two deep observations were performed after about 4 (revolution 103) and 5.5 months (revolutions 119–120). In our work we have not analyzed the data of the outburst itself, as they are proprietary data published elsewhere (Parmar et al. 2003). We have produced light curves in the 20–30, 30–40, and 40–80 keV energy ranges and investigated the hardness ratio, defined as

$$HR = \frac{flux_{40-80} - flux_{20-30}}{flux_{40-80} + flux_{20-30}}$$

The IBIS 20–30 and 40–80 keV light curves of the initial part of the outburst, flux-averaged over one SCW, are shown in Figure 2. The IBIS light curves show strong variations and it is possible to note several short peaks in the flux intensity, with



Fig. 2.—(a) 20-30 and (b) 40-80 keV IBIS light curves from revolution 53 to revolution 61. (c) Hardness ratio derived from the two energy ranges.



 $\ensuremath{\text{Fig. 3.}}\xspace{--}\ensuremath{\text{Fig. 3.}}\xspace{--}\xspace$

different shapes in the lower and higher energy bands. From the beginning of the IBIS observation, Modified Julian Date (MJD) \sim 52,729 to \sim 52,731, the source-averaged intensity increases monotonically in the lower energy range, while the flux is almost unchanged at higher energies: this is reflected in the anticorrelation shown by the HR, which decreases continuously in the same week, as can be seen in Figure 2c. The few points sampled in the next 20 days, owing to a limited coverage, show a decrease in both low energy flux and HR. Starting from day \sim 52,744, the source shows a clearly visible flux increase in a few hours by a factor of 2.6, 3.0, and 3.2 in the 20–30, 30–40, and 40-80 keV ranges, respectively, without any corresponding hardening. After the peak, the source emission falls by a factor of \sim 4.5 in the following hours (20–30 keV) with a small decrease of the HR; at this time, the soft part of the spectrum becomes more prominent (Fig. 2). This corresponds to a dip in the flux emission, lasting a few hours (around day 52,745.1), during which the source shows the lowest observed value for the HR. Finally, the high-energy component, and the HR, increase again (MJD = 52,745.5). The source shows a similar behavior around MJD = 52,750. To look for a possible correlation of the flux versus spectral index, we have fitted the available IBIS spectra during revolutions 53, 57, 59-61, and 119-120 with a cutoff power-law model. We noted that the cutoff energy of the model had substantially the same value in each fit, so we froze it to an average value of E = 53.3 keV. The reduced spectral fit χ^2 covers a range from 0.8 to 1.3. The result, summarized in Figure 3, shows that the spectral index has a circular or hysteresis-like behavior. In fact, at the end of the main outburst (revolutions 103-120), the source goes back into a hard state, very similar to one of the preoutburst IBIS measurements (revolution 53), but in the lower energy range a disk blackbody component is still present. This behavior is not unusual for BHC, even if the physical reason is not fully understood (Zdziarski & Gierlinski 2004).

3.2. Spectral Evolution of the Source

The whole set of data has been fitted with standard XSPEC tools, and the best fits have been obtained with a multicolor disk blackbody (DiskBB) model (Mitsuda et al. 1984) for the low-energy data and a thermal Comptonization model (CompTT; Titarchuk 1994) for the nonthermal component. CompTT generally provides lower values for the plasma temperature kT_e



FIG. 4.—IBIS JEM-X and SPI common spectra in different states of the source outburst. Numbers on the top of each spectrum indicate the revolution number of the corresponding *INTEGRAL* observation.

when compared with other models (i.e., Comps) while modeling hard state spectra of BH transients, the advantage being the proper modeling of plasma with high optical thickness. The detailed spectral behavior of the source is shown in Figure 4. At the beginning of the outburst, (revolution 53) the source is very weak, and therefore the flux in the lower part of the JEM-X spectrum is below the instrument's sensitivity. Therefore, it was possible to extract only a few points from JEM-X data in the range 15–22 keV and only a 2 σ upper limit at lower energy. A single CompTT model fits the whole data set (15–150 keV) well, as shown in Table 1 with $kT_e \sim 20$ keV and $\tau_p \sim 3$. The point corresponding to revolution 53 in Figure 3 shows the correlation between the photon index and the flux for this data,

TABLE 1								
Fit Parameter	VALUES	(90%	CONFIDENCE)					

Revolution	$T_{\rm in}$ (keV)	N _{DiskBB}	kT_e (keV)	$ au_p$	N_{CompTT} (×10 ²)	$\chi^2_{ u}$	DOF	Flux $(\times 10^9 \text{ ergs cm}^{-2} \text{ s}^{-1})$	Flux Band (keV)
53			20^{+15}_{-5}	3^{+4}_{-2}	2.38 ± 0.01	0.7	7	~0.3	(15-250)
56			24 ± 3	$1.5_{-0.3}^{+0.2}$	$8.3^{+0.8}_{-0.7}$	0.96	14	~ 7	(20-250)
57-59			19^{+5}_{-3}	$1.3_{-0.4}^{+0.2}$	1.5 ± 0.3	1.03	57	~ 6	(3-250)
60-61	1.5 ± 0.1	77^{+16}_{-18}	33^{+14}_{-8}	0.4 ± 0.2	8.3 ± 2	1.01	106	~ 20	(3-250)
103	1.09 ± 0.02	357^{+39}_{-26}				1.09	57	~ 3	(3-20)
119–120	0.87 ± 0.02	402_{-214}^{+344}	>13	<3	$1.5^{+5}_{-0.3}$	1.10	68	~ 1	(3-250)

indicating a low/hard state (Grebenev et al. 2003). In a few days the source flux is increasing quickly, and the statistics enables extraction of the SPI spectra as well (revolutions 56 and 60-61). The high-energy spectral evolution clearly indicates that the source makes a transition to the soft state, as also shown in the HR evolution (see Fig. 2c). During revolution 56 the source was out of the JEM-X FOV, so, only in this case, there are no data for E < 20 keV. However the source is quite luminous in the hard X-ray, as shown by IBIS; moreover, looking at the time spectral evolution (Fig. 4), it is possible to infer that the source is still in a low/hard state. In revolutions 57-59 the 3-200 keV data can be fitted with a cutoff power law or with a thermal Comptonization model without adding any blackbody component (Table 1). Conversely, in revolutions 60-61 the disk blackbody appears very bright, and the emission of this component accounts for 45% of the total luminosity. During the phase of decreasing flux (revolution 103), there was no evidence of a hard tail in the IBIS data (20–250 keV, 2 σ upper limit corresponding to 0.2×10^9 ergs cm⁻² s⁻¹), while the source was clearly detected by JEM-X (see Fig. 4), and the data fitted with a DiskBB component showed a large value of the normalization constant (N_{DiskBB}; see Table 1) that is proportional to the square of the inner accretion disk radius (Mitsuda et al. 1984). The presence of a DiskBB in IGR J17464-3213 soft state is confirmed by the RXTE observation performed in 2003 May 28 (MJD = 52,787; Homan et al. 2003). Two months later, close to the end of the outburst (revolutions 119–120), most of the flux is still due to the disk emission, but a clear, though faint, Comptonized high-energy tail is present in the IBIS data. The IBIS spectra taken at revolutions 53 and 119-120 (i.e., at the beginning and the end of the outburst) are compatible with the same CompTT model parameters: it is clear that in both cases the source shows a hard tail in the high-energy spectrum. Moreover, at the end of the outburst a disk component is still present, as was also confirmed by the RXTE analysis of the data collected immediately before this INTEGRAL observation (from 2003 August 26 to 2003 September 23; Lutovinov et al. 2005).

4. DISCUSSION AND CONCLUSION

The picture obtained from the spectral analysis in Figure 4 is quite clear and is summarized as follows. In phase 1, the source is in a "hard state." At the beginning of the *INTEGRAL* monitoring campaign (revolution 53), the source has a low luminosity and the bulk of the emission is in the energy range 50–90 keV via Comptonization of soft photons in an optically thick hot inner part of the disk or corona ($kT_e \sim 20$ keV and $\tau_p \sim 3$). In this phase there is no evidence of a soft disk component emission; the disk is eventually truncated far from the

hot inner region, although injecting soft photons that are upscattered by the inner hot flow. In the next few days the amount of accreted matter is increasing dramatically, and in revolution 56 (\sim 10 days later), the total emitted energy has increased by a factor of 30; the temperature of the Comptonized plasma is not changed, and the optical thickness of the inner part of the corona becomes smaller, i.e., from $\tau_p \sim 3$ to $\tau_p \sim 1.3$ (revolution 57-59). There is still no evidence of soft emission from the system. Slowly, the peak emission shifts from 70 keV (revolution 53) to 40 keV (revolution 56) to finally 20 keV (revolution 57–59). The spectral evolution is shown in Figure 4 (top panel). In phase 2, the source is in a "soft/intermediate state" (revolution 60-61). Over a few days the average amount of energy released increases by a factor of 3-5, the optical thickness of the inner part of the corona becomes lower ($\tau_p \sim 0.4$), the temperature of the hot Comptonized part of the corona increases accordingly, up to ~ 40 keV, and a bright soft disk component becomes visible, being responsible for the majority of the system energy release. The fit parameters are compatible with a $T_{\rm in}$ temperature of 1.5 keV and a disk close to the last stable orbit. The spectrum obtained with JEM-X, IBIS, and SPI (Fig. 4, *middle panel*) has a high statistical significance, showing the presence of a substantial Comptonized component. A few days later the source has reached its maximum, showing a factor of 2 more flux but basically unchanged high energy behavior (Parmar et al. 2003). In phase 3, the source enters the "soft state." The last observations were performed a few months after the main peak of the outburst (revolution 103-120). The energy release has substantially decreased (factor of \sim 3), the hard emission has basically switched off, and the Comptonized photons energetics have dropped by a factor of more than 10, with emission peaking at about 70 keV, as in the preoutburst state (revolution 53). This primarily indicates that the temperature of the disk has dropped to 0.9 keV, and that the disk is substantially outside of the last stable orbit. Soon afterward, the source was no longer detectable by INTEGRAL; one month later, it was also below the RXTE ASM detection capability. The INTEGRAL observation of IGR J17464-3213 has been essential to disentangling the source behavior and its spectral state evolution, and in turn, to better understanding the physical processes active in the system in the different states.

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