STATE TRANSITION AND FLARING ACTIVITY OF IGR J17464–3213/H1743–322 WITH INTEGRAL SPI

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ABSTRACT

IGR J17464–3213, already known as the HEAO 1 transient source H1743–322, has been detected during a state transition by INTEGRAL SPI. We describe the spectral evolution and flaring activity of IGR J17464–3213/H1743–322 from 2003 March 21 to 2003 April 22. During the first part, the source followed a continuous spectral softening, with the peak of the spectral energy distribution shifting from 100 keV down to ~a few keV. However, the thermal disk and the hard X-ray components had a similar intensity, indicating that the source was in an intermediate state throughout our observations and evolving toward the soft state. In the second part of our observations, the RXTE ASM and INTEGRAL SPI light curves showed a strong flaring activity. Two flare events lasting about 1 day each have been detected with SPI and are probably due to instabilities in the accretion disk associated with the state transition. During these flares, the low (1.5–12 keV) and high (20–200 keV) energy fluxes monitored with the RXTE ASM and INTEGRAL SPI are correlated, and the spectral shape (above 20 keV) remains unchanged while the luminosity increases by a factor greater than 2.

Subject heading: X-rays: individual (J17464–3213, H1743–3221)

Online material: color figures

1. INTRODUCTION

On 2003 March 21, during a scan of the Galactic center region, the new INTEGRAL (International Gamma-Ray Astrophysics Laboratory) source IGR J17464–3213 was detected with the IBIS imager (Revnivtsev et al. 2003a). Following this INTEGRAL observation, RXTE (Rossi X-Ray Timing Explorer) observed the same field and found XTE J1746–322 at a position consistent with that of IGR J17464–3213 (Markwardt & Swank 2003) with a hard spectrum (with a power-law photon index $\Gamma$ of $\approx 1.49 \pm 0.01$), while a radio counterpart has been identified with the VLA (Very Large Array; Rupen et al. 2003a). All the positions were compatible (Remillard 2003) with the H1743–322 transient source discovered during its outburst in 1977 by Ariel 5 and HEAO 1 (High Energy Astronomical Observatory; Kaluzienski & Holt 1977a), which had a maximum observed flux of 730 mcrab (Kaluzienski & Holt 1977b).

Early 2003 INTEGRAL observations showed a slowly rising hard X-ray flux. That was the beginning of a long outburst, which lasted until the end of 2003 November. During this period, the source was monitored by RXTE (Homan et al. 2005; Remillard et al. 2005) and Chandra (Miller et al. 2004), and showed various spectral/timing states. Some of the states showed high-frequency quasi-periodic oscillations at 240 and 160 Hz (therefore in the 3:2 ratio, which has recently emerged in a few Galactic black hole systems), compatible with the dynamical timescale at the innermost stable orbit around a 10 M$_\odot$ black hole. The presence of dips in the X-ray light curves suggests a large inclination (~60°–70°; Homan et al. 2005). Observations with the VLA showed intense radio activity; in particular, a strong radio flare associated with a jet was reported on April 8 (Rupen et al. 2003b). Infrared (Baba et al. 2003) and optical (Steeghs et al. 2003) counterparts were reported and found to be consistent with emission from a jet. The RXTE All-Sky Monitor (ASM) light curve of the 2003 outburst is presented in Figure 1. Its profile is more complex than the fast rise/slow decay of classical X-ray novae, but shows some similarities with other transient black hole X-ray binaries in outburst, such as XTE J1859+226 (Brocksopp et al. 2002), GRO J1655–40 (Remillard et al. 1999), or XTE J1550–564 (Sobczak et al. 2000).

Due to the source location near the Galactic center, further INTEGRAL observations of IGR J17464–3213 were carried out in the framework of the Galactic Center Deep Exposure (GCDE) of the core program (Winkler et al. 2003) in 2003 March, April, August, and September (Parmar et al. 2003; Lutovinov et al. 2005; Capitanio et al. 2005). While these monitoring campaigns may suggest a smooth evolution from the hard to the soft state, RXTE observations, together with a bigger set of data, allow us to study in more detail the single phases of the source evolution during the rising part of the outburst. The timing results, which can be seen in Table 1 of the H17433–322 paper by Remillard et al. (2005) together with the overall X-ray color evolution, suggest, referring to the McClintock & Remillard (2005) classification, the spectral state evolution: “off” → hard → intermediate → SPL (steep power-law) → thermal dominant → SPL → intermediate → SPL → thermal dominant → hard → “off” (shown in Fig. 1).

To summarize, the timing and spectral properties of the source indicate a low-mass X-ray binary harboring a black hole observed at large inclination (Homan et al. 2005; Lutovinov et al. 2005). We present here the results of the SPI (Spectrometer for INTEGRAL) instrument observations on board INTEGRAL together with RXTE Proportional Counter Array (PCA) data for the X-ray emissions during spring 2003, at the beginning of the outburst when the source was evolving through an intermediate state.

Some IBIS and JEM-X (Joint European X-Ray Monitor) data obtained during the same observations have already been published in Parmar et al. (2003) and Capitanio et al. (2005). Here we use a much larger set of SPI data (all the publicly
available data) to study in more detail the spectral evolution of H1743—322.

2. INTEGRAL SPI

SPI (Vedrenne et al. 2003) is one of INTEGRAL’s two main instruments. Working in the 20 keV–8 MeV energy domain with 19 hexagonal germanium detectors, it possesses an excellent energy resolution on a 16' (corner to corner) field of view. Careful calibration performed before launch, using radioactive sources (Attie et al. 2003) and extensive modeling of the instrument, led to a precise determination of its response. The imaging and spectral performance has since been verified in flight (Roques et al. 2003). The knowledge of the SPI instrument along with its spectroscopic capabilities allows us to obtain precise results for the spectral behavior of X-ray/γ-ray sources.

SPI’s imaging capability is limited, but it reaches a 2.5 angular resolution thanks to a HURA (Hexagonal Uniform Redundant Array) coded mask whose cells are the same size as the individual detectors. Due to the small number of detectors (pixels), SPI image reconstruction methods are based on a combination of data from several pointings, separated by 2' and covering the same sky region (“dithering strategy”; see Jensen et al. 2003).

During the ∼3 day INTEGRAL revolution, the observing schedule consists of fixed pointings lasting approximately 30–40 minutes, with a complete dithering pattern made up of 7 (in hexagonal mode) or 25 (in rectangular mode) pointings, separated by a 2' angular distance. The latter is the most commonly used mode. This method increases the amount of data in excess of the number of unknowns and allows us to better determine the background, position, and flux of sources on the detector plane.

3. DATA

The analysis presented here is based on the data recorded from revolution 53, starting 2003 March 21, to revolution 63, finishing 2003 April 22 (it corresponds to MJD 52719–52751). Some pointings had to be removed, for several reasons. For strong sources, if the projected area onto the detector plane and/or the number of pointings is insufficient, it leads to a lack of sensitivity and/or number of equations to solve (eq. [1]). Consequently, the source flux is determined with huge error bars. Sco X-1 and, in certain cases, 4U 1700–377 appear in a part of a dithering pattern that is too small, leading to artifacts during the image reconstruction process. We excluded such pointings and also those affected by a solar flare or by exit from/entry into the radiation belts. Otherwise, the background is generally stable. Table 1 gives the details of each revolution. The 230 pointings used for the SPI data analysis give a useful exposure time of ∼333 ks.

Public RXTE PCA data, covering some part of the INTEGRAL SPI data observation periods, were available. Table 1 summarizes the set of RXTE PCA observations performed under program IDs 80138 and 80146.

4. ANALYSIS METHOD

4.1. SPI Data Analysis

The signal recorded by the SPI camera on the 19 Ge detectors is composed of the contribution from each source in the field of view through the instrument aperture plus the background, which comes mainly from the interaction of high-energy particles (from cosmic rays or due to solar activity) with the instrument. For \( N_i \) sources present in the field of view, the data obtained during a pointing \( p \) for a given energy band, \( D_p \), can be expressed by the relation

\[
D_p = \sum_{i=1}^{N_i} R_{p,i} S_{p,i} + B_p, \tag{1}
\]

where \( R_{p,i} \) is the response of the instrument for the source \( i \), \( S_{p,i} \) is the flux of the source \( i \), and \( B_p \) is the background recorded during the pointing \( p \). The \( D_p \), \( R_{p,i} \), and \( B_p \) are vectors of 19 elements. It is mandatory to reduce the number of unknowns related to the background. In the present work, we describe the background as \( B_p = A_p U \), where \( A_p \) is the normalization coefficient per pointing, and \( U \) is the “uniformity map” of the SPI camera. This uniformity map is derived from an empty field observation. The system consists of \( N_p \) (number of detectors) times \( N_f \) (number of pointings) equations solved simultaneously by a \( \chi^2 \) minimization method. The number of unknowns (free parameters) is \( N_p \times (N_f + 1) \) (for the \( N_f \) sources and the background fluxes), but we can limit them by assuming that the time variability for the sources and the background are longer than a single pointing. The timescales are chosen depending on the goal of the analysis. For the image reconstruction, performed by the SPIROS detection algorithm (Skinner & Connell 2003), source and background fluxes are assumed to be constant during the whole set of observations. Using an iterative source research technique, implemented for the coded mask telescope INTEGRAL SPI, the source positions are extracted. The fluxes determined in this way are thus rough mean fluxes; the main goal is to extract source positions.

When wishing to build the light curves of the sources detected in the field of view, we must choose the appropriate timescales for each component (source and background). Concerning the background flux, the global count rates registered with the anticoincidence system (ACS) indicate that the background flux evolves within a single revolution. A timescale of 6 hr seemed to be the best value to describe the background variability during our observations. For the pointlike sources, it is important not to oversample the temporal variability, as this increases the error bars and gives no further scientific information. We have chosen a timescale for each source, mainly as a function of its intensity.
and temporal behavior. The fainter sources have been considered to have a constant flux within a revolution. For the brightest sources, we test several values and choose the longest timescale to have a constant flux within a revolution. For the brightest sources, we test several values and choose the longest timescale to have a constant flux within a revolution. For the brightest sources, we test several values and choose the longest timescale to have a constant flux within a revolution. For the brightest sources, we test several values and choose the longest timescale to have a constant flux within a revolution. For the brightest sources, we test several values and choose the longest timescale to have a constant flux within a revolution.

Spline functions are used to divide one interval of observations (one revolution or part of it) into several subintervals over which the source is found not to vary (see below). Spline functions are used to divide one interval of observations (one revolution or part of it) into several subintervals over which the source is found not to vary (see below). Spline functions are used to divide one interval of observations (one revolution or part of it) into several subintervals over which the source is found not to vary (see below). Spline functions are used to divide one interval of observations (one revolution or part of it) into several subintervals over which the source is found not to vary (see below).

4.2. RXTE Spectral Reduction

We analyzed the RXTE PCA (Bradt et al. 1993) data. The data reduction in the 3–20 keV energy range was performed using the ftool routines in the HEASoft software package distributed by NASA’s HEASARC. The spectrum extraction was performed from data taken in Standard 2 mode. The response matrix and the background model were created using ftool programs. Background spectra were made using the latest “bright source” background model. We used all available PCUs for the first part of our observations. Since PCU 2 was the detector always in use during the observations from revolutions 60 up to 63, it has been used for the data extraction in order to sum several spectra. We added 0.8% up to 7 keV and 0.4% above 7 keV as systematic error.

5. RESULTS

5.1. Images

The SPI images were built with the SPIROS detection algorithm (Skinner & Connell 2003). We used a catalog of known sources with their theoretical positions and searched for 15 sources in this catalog, plus five possible new sources. The image of the sky observed by SPI in the 20–36 keV energy range in the crowded region of the Galactic center can be seen in Figure 2, where H1743–322 is in the field of view. H1743–322 is the strongest source (247 mcrab), with a significance of 127σ during the total exposure time. H1743–322 is relatively isolated since there are no detected sources within a distance of 2′5. Table 2 summarizes the 13 sources surrounding H1743–322 in the 20–36 keV energy range. Beyond 90 keV, there are only three sources having a significance greater than 5σ, and H1743–322 is the most significant one.

5.2. Light Curves

The light curve of H1743–322 (Fig. 3) in the 20–36 keV energy range was constructed using the method described in § 3, taking into account the 14 sources identified in the field of view (Table 2). We have kept the flux of fainter sources constant and fixed timescales for the three most intense sources on the basis of their variability and of their flux intensity: 7200 s for H1743–322, 86,400 s for 1E 1740.7–2942, and 10,800 s for 4U 1700–377, which is known to be variable. The SPI light curve is similar to that published in Capitanio et al. (2005) from IBIS data, except for the bursts around MJD 52743 and 52749, for which we added new released data to complete our analysis. In order to extend the spectral coverage toward lower energy, we extracted the light
Fig. 2.—SPIROS image obtained using revolutions 56, 58, 59, 60, 61, 62, and 63 in the 20–36 keV energy range with a significance higher than 5 $\sigma$. The horizontal axis corresponds to the Galactic longitude, and the vertical axis to the Galactic latitude. The number corresponding to sources are (1) 1E 1740.7–2942, (2) H1743–322, (3) IGR J17475–2822, and (4) OAO 1657–415. [See the electronic edition of the Journal for a color version of this figure.]

curve obtained by RXTE ASM in the 2–12 keV domain in the same period of observation. From the beginning of the RXTE measurements in 1996 until the beginning of our observations (i.e., 7 years), the source remained in an “off” state. Then its intensity increased rapidly over a month, culminating in a huge outburst that spanned several months, with a maximum at MJD 52753.

We see a clear variability of the source on various timescales with, initially, an enormous flux increase over 3 days. From the “off” state (with an upper limit at 2 $\sigma$ of 20 mcrab at MJD 52719), the 20–36 keV flux increases by a factor of 3.7 between MJD 52724–52727 (89 $\pm$ 13 mcrab) and MJD 52729 (328 $\pm$ 11 mcrab). Meanwhile, the ASM flux increases up to ~200 mcrab by the same factor.

Then, while the SPI fluxes decrease from MJD 52729 to MJD 52742, the ASM flux follows an opposite behavior. Note that a radio flare occurs around revolution 58 (MJD 52736), with a radio flux increase of a factor 5 between April 6 and April 8 (Rupen et al. 2003b; see Fig. 3).

In a second phase, both emissions are dominated by flaring activity with ~1 day bursts (MJD 52744.6 in revolution 61, and MJD 52749.7 in revolution 63), during which the flux is typically multiplied by 2 or 3. Although the long timescale trends are opposite, the soft X-ray and hard X-ray emission are perfectly correlated inside these flares. We can thus conclude that two distinct timescale modes contribute to the observed light curves: (1) a timescale of weeks, which we relate to a state transition (see below), and (2) a 1 day timescale, which produces simultaneously soft and hard X-rays. This behavior is reminiscent of Cygnus X-1; one recent observation shows a basically constant spectral shape on short timescale (=hours) variability (Bazzano et al. 2003).

5.3. Hardness Evolution

In order to study the spectral evolution of the source, we have examined the hardness ratios in the 20–90 keV energy range, defined as $H = \text{counts}(36–90 \text{ keV})/\text{counts}(20–36 \text{ keV})$. All the fluxes are expressed in mcrab to allow comparison with other instruments.

Figure 4 shows the evolution of the hardness for revolutions 54 to 63. We clearly see two groups of points, with mean fluxes of ~220 and ~460 mcrab, respectively. During the low-level flux periods, there is a clear hardness-flux anticorrelation with a linear correlation factor of $\sim -0.7$. It clearly shows the transition from the hard state to a softer state on a timescale of ~2 weeks. Conversely, the flux increases at constant hardness during the flare events of revolutions 61 and 63. We also note that data from revolution 56 are not in the continuity of revolutions 54–55 and 57. But they could correspond to a flux increase with a constant

| Number | Source Name | Flux (20–36 keV) (mcrab) | Significance |
|--------|-------------|--------------------------|--------------|
| 1$^a$  | H1743–322   | 266.98 ± 2.09            | 127.2        |
| 2$^b$  | 1E region   | 108.31 ± 2.35            | 46.1         |
| 3$^b$  | 4U 1700–377 | 158.47 ± 3.30            | 48.0         |
| 4$^b$  | XTE J1720–318 | 39.82 ± 2.34         | 17.0         |
| 5$^b$  | OAO 1657–415 | 134.20 ± 4.21           | 31.9         |
| 6$^b$  | Ginga 1826–24 | 73.23 ± 2.65           | 27.6         |
| 7$^b$  | IGR J17475–2822 | 51.17 ± 2.49       | 20.5         |
| 8$^b$  | GX 5–1      | 69.99 ± 2.06            | 33.9         |
| 9$^b$  | GX 354–0    | 60.51 ± 2.36            | 25.6         |
| 10$^b$ | H 1702–429  | 46.12 ± 4.80            | 9.6          |
| 11$^b$ | GX 1+4      | 28.69 ± 2.28            | 12.6         |
| 12$^b$ | GX 3–1      | 32.73 ± 2.36            | 13.9         |
| 13$^a$ | H 1820–303  | 27.62 ± 2.35            | 11.7         |
| 14$^a$ | 3A 1822–371 | 30.15 ± 2.50            | 12.0         |

Table 2: Catalog of sources surrounding H1743–322 in the 20–36 keV (and 90–120 keV) energy range.

Note.—One crab $= 0.19$ counts s$^{-1}$ in the 20–36 keV energy range.

$^a$ Flux (90–120 keV) is 96.70 ± 7.36 mcrab at a significance of 13.1.

$^b$ Flux (90–120 keV) is 79.00 ± 7.14 mcrab at a significance of 11.1.

$^c$ Due to the modest angular resolution, SPI cannot distinguish all the sources present around 1E 1740.7–2942.

$^d$ Flux (90–120 keV) is 55.03 ± 8.83 mcrab at a significance of 6.2.
### Table 3

| Revolution   | $\Gamma_X$  | $\chi^2$ (dof) | $\Gamma_Y$ | $\chi^2$ (dof) |
|--------------|-------------|----------------|------------|----------------|
| 55           | $1.40^{+0.06}_{-0.11}$ | 2.88 (17) | $1.8^{+0.2}_{-0.2}$ | 0.9 (10) |
| 56           | $1.33^{+0.17}_{-0.36}$ | 2.07 (18) | $2.5^{+0.1}_{-0.1}$ | 2.7 (14) |
| 58           | $2.36^{+0.06}_{-0.08}$ | 2.61 (13) | $2.9^{+0.11}_{-0.1}$ | 0.9 (15) |
| 60–63 (nf)   | $2.65^{+0.04}_{-0.05}$ | 1.59 (18) | $3.1^{+0.1}_{-0.1}$ | 1.2 (15) |
| 61, 63 (f)   | $2.57^{+0.01}_{-0.02}$ | 1.34 (17) | $3.0^{+0.11}_{-0.1}$ | 1.0 (14) |

**Note.** — INTEGRAL SPI and RXTE PCA data have been fitted using a power-law model and SMEDGE×PHABS×(DISKBB+POWERLAW+GAUSSIAN). (See § 5.4 concerning the parameters of each component.) The iron line width was kept free (except for revolutions 55, 56, and 58; it was fixed at 1.0 keV). The $\Gamma_X$ and $\Gamma_Y$ are the photon power-law indices in the 3–14 keV energy band and the 20–100 keV energy band, respectively.

* Nonflare events.

* Flare events.
5.4. Spectral Modeling

Following the temporal evolution described above, we have compared the spectra corresponding to revolutions 54–55, 56, and 58 in Figure 5. For each of them, we have put together the deconvolved SPI and RXTE PCA spectra. The spectral evolution is characterized by the peak of the maximum of the energy moving progressively from 80 keV to a few keV, illustrating the hard-to-intermediate-state transition.

To study the intermediate and SPL states (revolutions 58 to 63), we separate flare and no-flare emissions, the flare state being defined by a 20–36 keV flux greater than 350 mcrab (see Fig. 3). Figure 6 shows an increase in the X-ray emission alone between revolutions 58 and 60–63, flares excluded, while the flare spectrum is shifted by a factor of 2 above the nonflare spectrum, keeping roughly the same shape from 5 to 200 keV.

To better quantify the spectral evolution, we have first fitted PCA and SPI data separately. We used the standard XSPEC 11.3.1 fitting package to fit the PCA data in a 3–20 keV range.

Table 5: Simultaneous PCA/SPI Fit with a Comptonization Model

| Revolution | $T_{\text{in}}$ (keV) | $\tau$ | $kT$ (keV) | $\Phi_{\text{ph}} \times 10^{-9}$ (ergs cm$^{-2}$ s$^{-1}$) | $\Phi_{\text{ph}} \times 10^{-9}$ (ergs cm$^{-2}$ s$^{-1}$) | $\Phi_{\text{disk}}$ (%) | EW (eV) | FN | $\chi^2$ (dof) |
|------------|-----------------|------|------------|---------------------------------|---------------------------------|----------------|------|-----|-------------|
| 55         | $0.20^{+0.02}_{-0.01}$ | $3.13^{+0.03}_{-0.04}$ | $17^{+3}_{-2}$ | 0.08                           | 2                               | 74             | 0.9  | 1.99 (37) |
| 56         | $0.41^{+0.02}_{-0.01}$ | $3.39^{+0.03}_{-0.04}$ | $15^{+1}_{-1}$ | 0.05                           | 0.4                             | 147            | 0.9  | 1.58 (48) |
| 58         | $0.39^{+0.02}_{-0.01}$ | $1.00^{+0.08}_{-0.1}$ | $22^{+5}_{-6}$ | 1.58                           | 5.9                             | 245            | 1.5  | 0.74 (50) |
| 60–63 (nf)$^a$ | $0.64^{+0.04}_{-0.03}$ | $0.23^{+0.03}_{-0.02}$ | $38^{+2}_{-2}$ | 1.02                           | 7.2                             | 145            | 0.7  | 2.00 (44) |
| 61, 63 (f)$^b$ | $0.64^{+0.03}_{-0.01}$ | $0.26^{+0.03}_{-0.02}$ | $37^{+2}_{-2}$ | 4.89                           | 6.7                             | 173            | 0.5  | 2.57 (41) |

Note.—The model used was described by the XSPEC components (explained in § 5.4) $\Phi_{\text{ph}}$ = SMEDGE × PHABS × (DISKBB + POWERLAW + GAUSSIAN). The $T_{\text{in}}$ is the inner disk temperature, $\tau$ is the optical depth, and $kT$ is the plasma temperature. The $\Phi_{\text{ph}}$ and $\Phi_{\text{disk}}$ (with an error of 10%) are the flux in the 20–100 keV energy range and the flux of the disk blackbody component in the 2–20 keV energy range, respectively. The $\Phi_{\text{disk}}$ is the disk-flux fraction in the 2–20 keV energy range. The iron line width was kept free (except for revolutions 61 and 63 during the flaring activity; it was fixed at 0.1 keV), and EW is the equivalent width. FN is the normalization factor between INTEGRAL SPI and RXTE PCA.

$^a$ Nonflare events.

$^b$ Flare events.
replaced first by a power-law plus cutoff model (CUTOFFPL in XSPEC), then by COMPTT and PEXRAV models to adjust the high-energy emission. First we found, using ftest (in XSPEC), that an exponential cutoff is required for all revolutions. However, from revolution 60, the energy cutoff is poorly constrained (see Table 4). Moreover, the power-law slope was found to be equal to the one determined when the XSPEC model used was described by the XSPEC components (explained in § 5.4) FN× SMEDGE× PHABS×(DISKBB+PEXRAV+GAUSSIAN). The $T_{\text{in}}$ is the inner disk temperature, $\Gamma$ is the power-law photon index, and $E_{\text{cut}}$ is the energy cutoff. The $\Omega/2\pi$ is the reflection scaling factor. The iron line width was kept free (except for revolutions 61 and 63 during the flaring activity; it was fixed at 0.1 keV). FN is the normalization factor between INTEGRAL SPI and RXTE PCA.

With the Comptonization model COMPTT (in XSPEC), the temperature of the disk ($T_{\text{in}}$) in the multicolor disk blackbody model is forced to be equal to the soft photon temperature ($T_0$) of the Comptonization model. We see in Table 5 that the optical depth decreases from about 3.0 down to 0.3, while the temperature increases from 15 up to $\approx 40$ keV. We notice that the best-fit parameters obtained for the data set of revolutions 60 to 63 without flaring activity are very close.

Then, we used a reflection model (PEXRAV in XSPEC), which is justified by the presence of an iron line in all the spectra. The fit parameters are described in Table 6. During the hard-to-intermediate-state transition, the energy cutoff increases as the power-law photon index increases, while a reflection scaling factor of about 0.5 has been found (or fixed) but is poorly constrained.

### 6. DISCUSSION

The spectral evolution of the source during the rise to the peak of the outburst can be described in two phases:

1. During the first two weeks, the spectrum undergoes a gradual softening associated with the peak of the spectral energy density (SED), shifting from 80 keV in the hard state down to 10 keV on April 8 (revolution 58; Fig. 5) and leading to a clear hardness-flux anticorrelation (Fig. 4).

2. Once this softer state is reached, the source shows no significant spectral evolution despite substantial changes in luminosity. The source exhibits flaring activity on a timescale of 1 day, during which the spectral shape remains unchanged from soft to hard X-rays, while the flux intensity changes by a factor of 2–3.

This spectral evolution is illustrated in Figure 7, which displays the evolution of the source in the bolometric luminosity versus hardness plane. During phase 1 the hardness decreases with little change in luminosity, while during the second phase (after revolution 58) the source exhibits large variations in luminosity at nearly constant hardness.

In Chandra and RXTE observations taken in 2003 May (Miller et al. 2004), the blackbody component dominates the spectral emission. The same behavior is observed in 2003 August in JEM-X data, with a nondetection by IBIS (Capitani et al. 2005). On the other hand, during our observing period the contribution of the thermal disk component to the 2–20 keV flux remained below 32% (see Table 4), and well below the 75% criterion defining the thermal dominant state (McClintock & Remillard 2005). Therefore the source remained in an intermediate state (IS) or in a steep power-law state (according to the classification of McClintock & Remillard 2005), at least until April 22 (MJD 52751).

In the hard state, the hard X-ray emission is generally believed to be dominated by a hot, geometrically thick, optically thin accretion flow (Shapiro et al. 1976; Narayan & Yi 1994) surrounded by a cold, geometrically thin disk (Shakura & Sunyaev 1973). Phase 1 of the outburst could be due to the gradual decrease of the inner radius of the cold accretion disk, associated with either the cold disk penetrating the hot inner flow, or the latter collapsing into an optically thick accretion disk with small active regions of hot plasma on top of it (Zdziarski et al. 2002). In

![Figure 7](image_url)

**Figure 7.** Evolution of the bolometric luminosity ($L/L_{\text{Edd}}$) in Eddington luminosity (for $L_{\text{bol}}$, a distance of 8.5 kpc has been assumed) and in the 2–200 keV range, as a function of the hardness in the 23–200 keV energy range.
both cases the enhanced soft photon flux from the disk tends to cool down the hot phase, leading to softer spectra. Our observations tend to support this picture; our fits indicate that as the hard X-ray spectrum softens, both the inner disk temperature and flux grow progressively, as expected when the accretion disk surface and emission increase (see Table 5). Although the best-fit parameters obtained with the Comptonization model show an increase of the hot plasma temperature, the Compton parameter $y = 4\pi kT/m_e c^2$ decreases by a factor of 5. As the $y$ parameter is related to the ratio of Compton luminosity $l'_{\text{c}}$ (heating of the hot plasma) to the soft seed photon luminosity $l_s$ ($y \approx l'_s/l_s$), this evolution is consistent with an increase of soft photon flux relative to the heating power. This enhanced cooling can be seen more directly from luminosity measurements by estimating the ratio $l'_s/l_s$ as $\Phi_{\text{bol}}/\Phi_{\text{bb}}$ ($\Phi_{\text{bol}}$ is the bolometric luminosity in the 2–200 keV energy range shown in Fig. 7), which, from the numbers shown in Table 5 and in Figure 7, decreases by a factor of about 5, i.e., roughly consistent with the evolution independently deduced from the Comptonization model. The observed increase of the hot plasma temperature, despite an enhanced soft cooling, is due to the fact that the optical depth decreased by a larger amount, reducing the efficiency of the energy transfer from electrons to photons.

The diminishing optical depth could have several causes. For instance, the presence of a strong hot Comptonizing corona is known to be closely associated with the steady compact jet of the hard state (Corbel 2004; Fender et al. 2004, hereafter FBG04), and it has been suggested that the hot corona forms the base of the jet. The decrease of the coronal optical depth as the source evolves toward the soft state could be related to the disappearance of the compact jet. The fact that the transition from phase 1 to phase 2 appears coincident with a major radio outburst, most likely associated with an ejection event (Rupen et al. 2003b), suggests that most of the coronal material could have been wiped out or ejected during this and possibly other less prominent ejections. Alternatively, it is possible that, as the hot plasma condenses into an optically thick disk, the remaining material in the hot corona has a lower density.

During phase 2, the overall geometry would be globally stable despite instabilities leading to chaotic light curves with little spectral variability. Such a strong variability could be due to local disk instabilities or strong flares in the corona associated with magnetic reconnection events, such as those inferred in the soft states of Cygnus X-1 (see Zdziarski et al. 2002). Radio emissions naturally assume the presence of a jet, at least temporarily. Alternative models including jets should thus be considered, as they can contribute to hard X-ray emission, as already proposed by different teams (e.g., Petrucci et al. 2005; Markoff et al. 2001; Georganopoulos et al. 2002).

The presence of a strong radio flare during the state transition seems to be common among black hole transients (Corbel 2004; FBG04). FBG04 provide an interesting interpretation: during the initial softening, the mildly relativistic jet associated with the canonical low/hard state persists, but as the disk makes its inward collapse, the jet becomes unstable and the Lorentz factor rapidly increases, resulting in an internal shock in the outflow, which is the cause of the strong, optically thin radio emission.

As we compare the behavior of H1743–322 with that of other transients, it is worth noting that, although appearing during the softening period near the transition from the intermediate to the SPL state, the radio emission occurs during the rising part of the outburst and precedes the soft/hard X-ray peak emission. From this point, H1743–322 is clearly atypical. From Table 3 in Brocksopp et al. (2002), we see that the radio emission occurs after and sometimes (in two cases) simultaneously with the X-ray maximum emission. The flaring activity following the radio emission could be related to the unstable state of the jet, as proposed by FBG04.

7. CONCLUSIONS

The (re)discovery by INTEGRAL of IGR J17464–3213/H1743–322 led to the collection of an important amount of data on this source. H1743–322 shows rather typical behavior of black hole candidates with the presence of various spectral states. We analyzed the INTEGRAL SPI and RXTE PCA observations recorded in 2003 March and April, which cover the rising part of the outburst up to the beginning of the maximum of the X-ray emission. Initially in a standard hard state, the source spectrum gradually softened until around April 8, when a major radio flare was reported. In the framework of the Comptonization model, this softening phase can be associated with an optical depth decrease (from $\sim 3$ down to $\sim 0.3$). After the radio flare, the hard X-ray spectral shape seemed to remain unaffected by a strong (X-ray and $\gamma$-ray) flaring activity. We tentatively identified the softening phase as the intermediate state, and the flaring phase as the SPL, and we note that during the outburst of the H1743–322 X-ray transient, the end of the softening phase and the optically thin radio outburst are not associated with the peak of the soft/hard X-ray luminosity.

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