HIGH ENERGY EMISSION FROM IGR J16320-4751

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ABSTRACT

IGR J16320 − 4751 was re–discovered by IBIS/ISGRI on board INTEGRAL in early February 2003 during the observation of the black hole candidate 4U1630 − 47 (PI Tomick). This source, already observed by ASCA and BeppoSAX, belongs to the class of heavily absorbed objects ($N_H > 10^{23}$ cm$^{-2}$) that populate some arms of the Galaxy. Soon after the rediscovery by IBIS/ISGRI, the source was observed by XMM-Newton: the arcsec position found with XMM allowed ones to find the most likely infrared counterpart. We present here the reanalysis of the high energy emission from IGR J16320 − 4751 detected by IBIS/ISGRI, including the spectral and temporal characteristics. We also present a reanalysis of the XMM-Newton and optical/IR data.

Key words: X–rays: binaries; X–rays: individuals: IGR J16320-4751.

1. INTRODUCTION

IGR J16320 − 4751 was serendipitously discovered on February 1.4, 2003 UT, with the IBIS/ISGRI detector (Ubertini et al. 2003, Lebrun et al. 2003) on board the INTEGRAL satellite during the AO1 observation of the black hole candidate 4U 1630 − 47 (PI Tomick). The coordinates (J2000) were $\alpha = 16^h : 32^m : 01^s.9$ and $\delta = -47^\circ : 52^\prime : 29^\prime\prime$ with an uncertainty of 4" (Rodriguez et al. 2003a). In this reduced error circle it was possible to identify two reliable infrared counterparts in the 2MASS catalog (Tomsick et al. 2003b).

A preliminary analysis of the XMM-Newton observation, together with the identification of the infrared counterpart was presented in Rodriguez et al. (2003b). Here we present a reanalysis of the INTEGRAL AO1 observation, together with a reanalysis of the XMM-Newton ToO data.

2. INTEGRAL DATA ANALYSIS

INTEGRAL observed the Norma region from 1 February 2003 05h : 40m : 58s to 5 February 2003 07h : 53m : 01s UT for an elapsed time of 300 ks and with the dither pattern 5 × 5. The screening, reduction, and analysis of the IBIS/ISGRI data have been performed by using the INTEGRAL Offline Scientific Analysis (OSA) v. 3 (Goldwurm et al. 2003a), available to the public through the INTEGRAL Science Data Centre1 (ISDC).

2.1. Imaging

An initial analysis was performed by deconvolving the ISGRI shadowgrams to obtain images. IGR J16320 − 4751 was detected in the imaging pipeline in the energy bands 20 − 40 keV (signal–to–noise ratio $SNR = 30\sigma$) and 40 − 60 keV ($SNR = 11\sigma$). The mosaic images are shown in Fig. 1. Given the present uncertainties in the validation of the software for the off–axis sources, it was adopted the same procedure described by Goldoni et al. (2003). We divided the count rate of IGR J16320 − 4751 by the count rate of the Crab in a similar off–axis angle, extracted from the calibration observations. We added a 5% of systematic error, to take into account the residual fluctuations in the count rate (cf Goldwurm et al. 2003b).

The calculated flux is $(8.0 \pm 0.5) \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$

1http://isdc.unige.ch/index.cgi?Soft+download
Figure 1. IBIS/ISGRI mosaic of the Norma region centered on the BH 4U1630 − 47. (left) Energy band 20 − 40 keV, (right) Energy band 40 − 60 keV, with a total exposure of 297 ks. Equatorial coordinates are superimposed.

and $(2.0 \pm 0.2) \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$, in the energy bands 20 − 40 keV and 40 − 60 keV respectively. No significant detection was recorded at higher energy.

2.2. Timing

IGR J16320 − 4751 was detected in most of the individual ScWs with $3 < S/N R < 6\sigma$. Therefore, to study the variability of the source it was decided to rebin the lightcurve so that each time bin contains 8 ScW, corresponding approximately to 15 − 20 ks. The obtained lightcurve shows a clear outburst at the time of the discovery, plus some other periods with a certain variability (Fig. 2). During the outburst, the flux in the band 20 − 40 keV raised from about 7 − 8 mCrab to 30 mCrab (Fig. 2 left). The time scale of the variations occurs on $\approx 10^4$ s or even more. A similar behaviour is clearly seen in the 40 − 60 keV energy band (Fig. 2 right).

Since in a coded–mask instrument the brightest sources in the field of view (FOV) can – under certain conditions – significantly affect the detection of the other nearby sources, we investigated also the time variability of the three brightest sources in the FOV, namely 4U1630 − 47, 4U1700 − 377, and GX340 + 0. All the analysed sources display different variability patterns and therefore we conclude that the variability of IGR J16320 − 4751 is genuine.

2.3. Spectral extraction

To extract the spectrum of the whole observation and also during the outburst we used both the spectral extraction pipeline and the results from the image analysis, to perform a check of the results. This is necessary to take into account that IGR J16320 − 4751 is located in a crowded region, with at least two nearby sources (4U 1630 − 47 and IGR J16318 − 4848), and therefore the different approach in the deconvolution of images and extraction of spectra (see Goldwurm et al. 2003a for a full explanation of the algorithms) could generate results not always consistent each others.

For the spectral extraction pipeline we rebinned the latest RMF matrix from the original 2048 channels to 21 channels, by putting all the channels above 200 keV into the last channel of the rebinned matrix. The remaining channels in the range 15 − 200 keV were grouped in bin of about 10 keV in size. This approach has been selected to emphasize the energy range 15 − 200 keV and to have enough statistics to perform the $\chi^2$ test in the spectral fit with xspec (v 11.3). Nonetheless, the source is faint and does not allow a fit with multiple component models. We decided to fit with a simple power law model to measure if there is hardening/softening during the outburst.

The spectrum of the whole observation has $\Gamma = 3.8 \pm 0.9$, with a flux of about $9 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ in the energy band 20 − 60 keV, consistent with the results from the imaging analysis. Also in the spectral extraction pipeline no flux is detected for energies greater than $\approx 60$ keV.

The spectrum extracted during of the outburst (bins 2−4 in Fig. 2) has the photon index varying from $\Gamma \approx 3.1$ to
38° UT to 5 March 2003 03h : 47m : 18° UT, with an elapsed time of about 26 ks. Due to soft-proton flares, the effective exposure was about 5 ks, but sufficient to clearly identify (uncertainty < 4") the X-ray counterpart at coordinates (J2000) α = 16h : 32m : 01.9 and δ = −47° : 52m : 29s (Rodriguez et al., 2003a,b; see Fig. 3).

Figure 3. IBIS/ISGRI lightcurves of IGR J16320 − 4751 in the energy band 20 − 40 keV (left) and 40 − 60 keV (right). Each bin is composed of 8 ScW, corresponding to about 15 − 20 ks. Upper limits are at 3σ level.

We succeeded to save 17 ks from the elapsed time of 26 ks, with a loss of only 9 ks (to be compared with the loss of 21 ks of the early analysis). We found that the best fit model is still an absorbed power law with Γ = 1.4±0.2 and $N_H = (2.2±0.2) \times 10^{23}$ cm$^{-2}$ ($\chi^2 = 204.5$, d.o.f.= 184), consistent with the results of the early analysis (see Fig. 4). The unabsorbed flux in the 0.2 − 12 keV energy band is $2.8 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$. We refer to the reader to the paper by Rodriguez et al. (2003b) for more details.

For the present work, we decided to reanalyze the XMM-Newton data to extract the better spectrum. We used still the XMM SAS v. 5.4.1 software to process and screening the data and the same procedures described in Rodriguez et al. (2003b). We adopted a different procedure only to extract the spectrum. Since the source is bright enough to be clearly visible still in the flared image, we avoided the selection of a time region not affected by soft-proton flares, and we extracted directly from the contaminated image the source plus background counts from a circular region centered on IGR J16320 − 4751 with radius of 30". Therefore, we extracted the background from another circular region with radius 2′, and close to the source. We performed the background (now including the soft–proton flares) subtraction directly in xspec.

The unabsorbed flux in the 20 − 40 keV energy band is $2.8 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$.

We note that there are some interesting features between...
Figure 4. EPIC–PN spectrum in the 3 – 12 keV energy band, with 17 ks of exposure and fitted with a single power law model. The deviations of data versus model are shown in the bottom window.

4 and 10 keV, and particularly some hints for emission lines of the iron complex, between 6 and 7 keV. The addition of a thermal plasma model (mekal model in xspec) with a temperature $kT = 5.5$ keV is able to reproduce some of these features, and particularly the emission lines of the iron complex. However, this model is statistically required only at 91% confidence level. A simple gaussian emission line at $E = 6.5 \pm 0.1$ keV and width $\sigma = 0.3^{+0.2}_{-0.1}$ keV is required at 99.67%. Further observations are required to better constrain the nature of this excess.

4. OPTICAL/INFRARED COUNTERPARTS

With the improved position given by XMM-Newton, it became possible to look for the counterparts at other wavelengths, specifically in the optical/infrared bands (Tom-sick et al. 2003b). Two sources have been found in the Two Microns All–Sky Survey (2MASS): the first, labelled 1 in Fig. 5, could also be the most probable counterpart. The infrared colours along the line of sight ($E(J-H) = 1.0, E(H-K) = 0.8$, for the extinction due to the Galactic absorption $A_V = 11.1$) suggesting an excess perhaps due to the presence of hot plasma or circumstellar dust, consistent with the findings of the X–ray analysis. Specifically, the source 1 is not detected in the $J$ band, with an upper limit of $J > 14$. Concerning the source 2, there are detections in other catalogs: a summary of the optical/infrared detections is shown in Table 1. It is worth noting that the source 2 is classified as a non-star object, that may be either galaxies or blended objects, in the Guide Star Catalog 2.2\textsuperscript{2}. Indeed, it appears slightly elongated with an eccentricity of 0.07 and a semimajor axis of 3.12 pixels.

Figure 6. Broad band unfolded spectrum of IGR J16320 – 4751 obtained with a simultaneous fit of XMM-Newton (EPIC–PN) and INTEGRAL (IBIS/ISGRI) data. The energy ranges are 3 – 12 keV for XMM-Newton and 30 – 60 keV for INTEGRAL.

5. DISCUSSION AND CONCLUSIONS

In the present work we confirmed and extended the results obtained by Rodriguez et al. (2003b). The nature of IGR J16320 – 4751 is not clear yet and, even though the most probable hypothesis is a Galactic X–ray binary, the possibility of an extragalactic object cannot be com-

\textsuperscript{2}http://www-gass.stsci.edu/gsc/GSChome.htm
The nature of the accreting object is not clear as well: the strong differences in the photon index in the energy bands J, H, and K suggest a hot plasma solution, typical of accreting neutron stars (see, e.g., White et al. 1983). The photon index is $\Gamma = 0.7^{+0.2}_{-0.3}$, the column density $N_H = (2.0 \pm 0.2) \times 10^{25}$ cm$^{-2}$, and the cutoff energy $10 \pm 3$ keV. The scaling constant applied to the ISGRI spectrum is $5^{+3}_{-2}$. We stress that the observations were not simultaneous and the source is strongly variable. Therefore, this fit should be taken with extreme care.

Another possibility, given the low luminosity in both bands ($8 \times 10^{34}$ erg/s in the 0.2 – 12 keV energy band, and $3 \times 10^{35}$ erg/s in the 20 – 60 keV band) if the source is located in the Norma Arm (5 kpc), is that we are observing the emission from a jet. In this case, we could make the hypothesis that the change in the photon index could be due to a break, because of a change in the mechanism of cooling of electrons.

The key question in the study of this source is therefore the spectral variability. An approved coordinated INTEGRAL and XMM-Newton observation to be performed by next August should give us sufficient data to disentangle these hypotheses.

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### Table 1. Optical/Infrared counterparts of IGR J16320 – 4751.

| Source 1 | Catalog | Magnitude |
|----------|---------|-----------|
|          | 2MASS\(^a\) | \(J < 14.08\) |
|          | 2MASS\(^a\) | \(H = 13.03 \pm 0.04\) |
|          | 2MASS\(^a\) | \(K = 10.99 \pm 0.04\) |

| Source 2 | Catalog | Magnitude |
|----------|---------|-----------|
|          | USNO B1\(^b\) | \(B_1 \text{ n.a.}\) |
|          | USNO A2\(^b\) | \(B = 17.3 \pm 0.3\) |
|          | GSC 2.2\(^c\) | \(B = 18.0 \pm 0.4\) |
|          | USNO CCD AC\(^d\) | \(UCAC = 16.0 \pm 0.3\) |
|          | USNO B1\(^b\) | \(R_1 = 14.6 \pm 0.3\) |
|          | USNO B1\(^b\) | \(R_2 = 15.4 \pm 0.3\) |
|          | USNO A2\(^b\) | \(R = 15.0 \pm 0.3\) |
|          | GSC 2.2\(^c\) | \(R = 15.4 \pm 0.4\) |
|          | USNO B1\(^b\) | \(I = 14.2 \pm 0.3\) |
|          | DENIS\(^e\) | \(I = 14.00 \pm 0.03\) |
|          | 2MASS\(^a\) | \(J = 12.13 \pm 0.02\) |
|          | DENIS\(^e\) | \(J = 12.22 \pm 0.09\) |
|          | 2MASS\(^a\) | \(H = 11.24 \pm 0.03\) |
|          | 2MASS\(^a\) | \(K = 10.82 \pm 0.04\) |
|          | DENIS\(^e\) | \(K = 10.75 \pm 0.07\) |

\(^a\) Two Microns All Sky Survey (2MASS) Point Source catalog, Cutri et al. (2003).

\(^b\) US Naval Observatory Catalog A2, Monet et al. (1998). US Naval Observatory Catalog B1, Monet et al. (2003). For the latter, B and R magnitudes are taken from two types of plates and referenced with subscripts 1 and 2: (1) Palomar Observatory Sky Survey (POSS) I, (1949 – 1965), with emulsion sensible at the wavelengths 620 – 670 nm; (2) POSS II (1985 – 2000), sensible at 385 – 540 nm.

\(^c\) Guide Star Catalog 2.2.

\(^d\) US Naval Observatory CCD Astrograph Catalog (UCAC, [http://ad.usno.navy.nrl/ucac/](http://ad.usno.navy.nrl/ucac/)). UCAC magnitude is in the wavelength band 579 – 642 nm, between V and R bands.

\(^e\) DEep Near Infrared Survey (DENIS) of the southern sky (DENIS Consortium 2003, [http://cdsweb.u-strasbg.fr/denis.html](http://cdsweb.u-strasbg.fr/denis.html)).