

## Unveiling the nature of three *INTEGRAL* sources through optical spectroscopy<sup>\*</sup>

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**Abstract.** The results of an optical spectroscopy campaign performed at the Astronomical Observatory of Bologna in Loiano (Italy) on three hard X-ray sources detected by *INTEGRAL* (IGR J17303–0601, IGR J18027–1455 and IGR J21247+5058) are presented. These data have allowed a determination of the nature for two of them, with IGR J17303–0601 being a low mass X-ray binary in the Galaxy and IGR J18027–1455 a background type 1 Seyfert galaxy at redshift  $z = 0.035$ . IGR J21247+5058, instead, has a quite puzzling spectroscopic appearance, with a broad, redshifted  $H_\alpha$  complex superimposed onto a “normal” F/G-type Galactic star continuum: these features, together with the spatially coincident extended radio emission, might suggest a chance alignment between a relatively nearby star and a background radio galaxy. These results underline the still non-negligible importance of smaller telescopes in modern astrophysics.

**Key words.** X-rays: binaries – X-rays: galaxies – techniques: spectroscopic – X-rays: individuals: IGR J17303–0601, IGR J18027–1455, IGR J21247+5058

### 1. Introduction

One main objective of the *INTEGRAL* mission is a regular survey of the Galactic Plane complemented by a deep exposure of the Galactic Centre. This makes use of the unique imaging capability of IBIS (Ubertini et al. 2003) which allows the detection of sources at the mCrab level with an angular resolution of 12' and a typical point source localization accuracy of 2–3': this has made it possible, for the first time, to resolve crowded regions such as the Galactic Centre and the spiral arms, and to discover many new hard X-ray objects.

In its first year, IBIS has detected 123 sources between 20 and 100 keV (Bird et al. 2004): within this sample of hard X-ray emitting objects, 53 low mass and 23 high mass X-ray binaries, 5 Active Galactic Nuclei (AGN) and a handful of other objects such as pulsars, cataclysmic variables and a dwarf nova are found. The remaining objects (28, or about 23% of the sample) have no obvious counterparts at other wavelengths and therefore cannot yet be associated with any known class of high-energy emitting objects. Only for a tiny fraction of these sources have follow-up observations at X-ray energies as well as in the optical/near-infrared wavebands been carried out so far (Rodríguez 2004). Although the cross-correlation with catalogues or surveys at other wavelengths (especially soft X-rays, optical and radio) is of invaluable help in pinpointing the putative optical candidates, only accurate optical spectroscopy can confirm the association and reveal the nature of the object.

Most of these unidentified sources are believed to be X-ray binary systems, where one of the two members is either a black hole or a neutron star. There is however the possibility that some of them could be AGN similar to those already detected (Bassani et al. 2004). With the aim of pursuing secure identifications for some of the IBIS unidentified sources, we have extracted a small sample of three objects with relatively bright putative optical counterparts in order to assess their nature. These are IGR J17303–0601, IGR J18027–1455 and IGR J21247+5058.

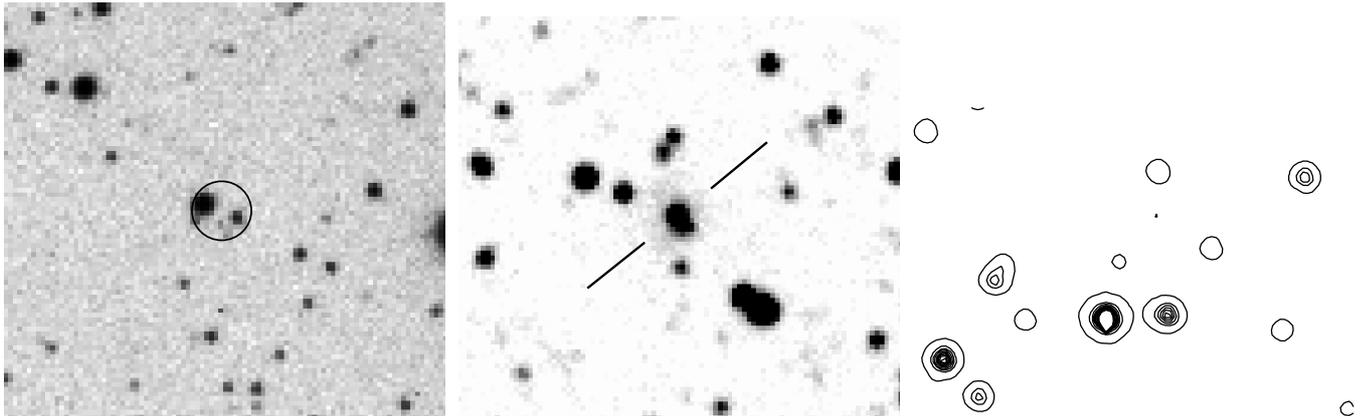
IGR J17303–0601 positionally coincides with 1RXS J173021.5–055933 (Voges et al. 1999), an X-ray object detected from 0.1 to 30 keV (by *ROSAT*, *HEAO-A1* and *RXTE*). Within the small *ROSAT* error box (7'') two optical objects, one with  $R \sim 15.5$  and the other with  $R \sim 18$  according to the USNO catalogues (Monet et al. 2003), are found on the Digitized Sky Survey<sup>1</sup> (DSS). This X-ray source was suggested to be an AGN by Sazonov & Revnivtsev (2004) on the basis of its similarity with the spectral slope of this class of sources as detected by *RXTE*.

IGR J18027–1455 (Walter et al. 2004) is another likely AGN candidate: inside the 2' ISGRI error box of this source a *ROSAT* object (1RXS J180245.5–145432; Voges et al. 1999) and a NVSS<sup>2</sup> radio object (NVSS 180247–145451), positionally consistent with each other, are found (as first noted by Combi et al. 2004a,b). At the radio coordinates, an

<sup>\*</sup> Based on observations collected at the Bologna Astronomical Observatory in Loiano (Italy).

<sup>1</sup> <http://archive.eso.org/dss/dss/>

<sup>2</sup> <http://www.cv.nrao.edu/nvss/>



**Fig. 1.** *Left panel:* section of an *R*-band image showing the *ROSAT* error circle ( $7''$  radius) of the source 1RXS J173021.5–055933, positionally consistent with IGR J17303–0601. The field size is about  $50'' \times 50''$ . *Central panel:* section of an *R*-band image showing the optical counterpart of IGR J18027–1455 (indicated by the tick marks). The field size is about  $50'' \times 50''$ . *Right panel:* contour plot from the *I*-band image of the field around the counterpart of IGR J21247+5058, which is the rightmost of the two objects at the centre. The field size is about  $40'' \times 30''$ ; the field is rotated of about  $12^\circ$  clockwise. All images have North up and East to the left and were acquired in Loiano on 14–15 July 2004.

extended 2MASS<sup>3</sup> infrared source (2MASX J1802473–145454) is present. The DSS also shows an extended optical object, with USNO-A2.0 magnitude  $R \sim 15$ , at this position. A preliminary analysis of the data which will be presented here, and indicating that this object is indeed a type 1 AGN, was reported by Masetti et al. (2004a).

IGR J21247+5058 (Walter et al. 2004) has recently been associated by Ribó et al. (2004) and Combi et al. (2004b) with the radio source 4C50.55, which shows a morphology typical of a radio galaxy (Mantovani et al. 1982). The optical counterpart is clearly detected on the DSS and is present on the USNO-A2.0 catalogue with magnitude  $R \sim 15.5$ .

To firmly establish the nature of these sources, we thus performed a spectroscopic campaign on their optical candidates listed above with the 1.5 m “G.D. Cassini” telescope of the Astronomical Observatory of Bologna located at Loiano (Italy), in order to study the continuum and to reveal the possible presence of Balmer lines or other features that will pinpoint the redshift and nature of these objects.

## 2. Optical observations at Loiano

Medium-resolution optical spectra of the optical candidates of the sources IGR J17303–0601, IGR J18027–1455 and IGR J21247+5058 were acquired on 14–15 July 2004 and 2–3 August 2004 in Loiano (Italy) with the Bologna Astronomical Observatory 1.52 m “G.D. Cassini” telescope plus BFOSC, equipped with a  $1300 \times 1340$  pixels EEV CCD. In all cases Grism #4 was used, providing a  $3500\text{--}8700 \text{ \AA}$  nominal spectral coverage; slit widths of  $2''$  and  $2''.5$  during the July and August runs, respectively, were used in order to match the night’s seeing. The use of these setups secured a final dispersion of  $4.0 \text{ \AA}/\text{pix}$  for all spectra.

Besides all the above, in the case of IGR J17303–0601 we put the slit at position angle  $\text{PA} = +65^\circ$  in order to include both candidate optical counterparts (see Sect. 1); similarly, when we

observed IGR J21247+5058 we rotated the slit by  $12^\circ$  to get the spectrum of a pointlike object lying  $\sim 8''$  southeast of the optical source coincident with the NVSS radio emission.

Spectra, after correction for flat-field, bias and cosmic-ray rejection, were background subtracted and optimally extracted (Horne 1986) using IRAF<sup>4</sup>. Wavelength calibration of the spectra was performed using He-Ar lamps, while the flux calibration was applied through the spectrophotometric standard BD+25°3941; finally all spectra from each source were stacked together to increase the S/N ratio. Wavelength calibration was checked by using the positions of background night sky lines; the error was  $\sim 0.5 \text{ \AA}$  for all spectra.

On the night between 14 and 15 July 2004 we also acquired *R*-band imaging of IGR J17303–0601 and IGR J18027–1455, and *BVRI* imaging of IGR J21247+5058, again in Loiano with BFOSC under an average seeing of  $1''.6$ . The EEV CCD, with a scale of  $0''.58/\text{pix}$ , secured a field of  $12'.6 \times 12'.6$ . Images were corrected for bias and flat-field in the usual fashion and calibrated using the PG 2213-006 field (Landolt 1992); the calibration accuracy is better than 2% in all bands. All of the putative counterparts of IGR sources (in Fig. 1) were well detected in all images. Magnitudes were measured within MIDAS<sup>5</sup> through PSF-fitting (Stetson 1987) or aperture photometry depending on whether the object was point-like or extended.

## 3. Results

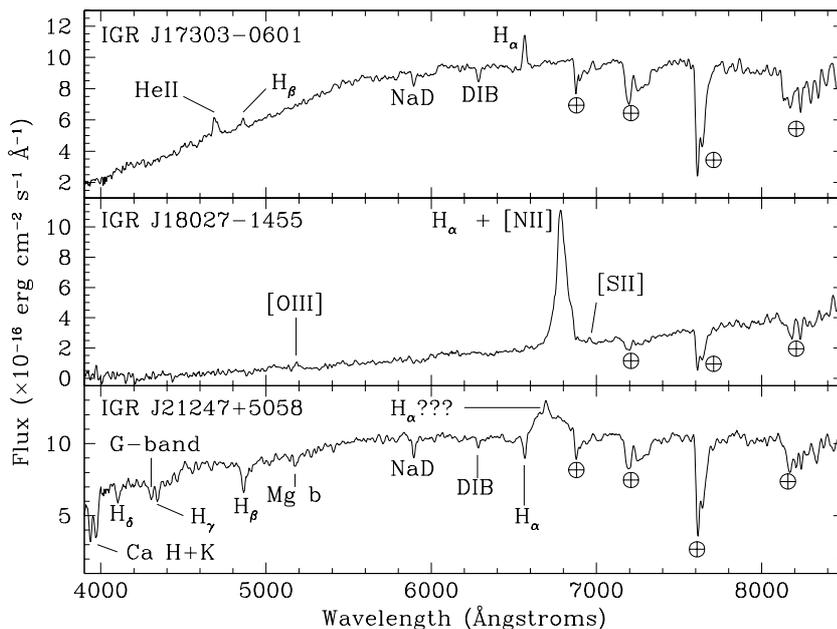
In all three cases, the spectra acquired in Loiano show emission features which are typical of X-ray emitting objects. We therefore conclude that we have clearly identified the optical counterparts to these three IGR sources. We discuss in detail the characteristics and the nature of each case in the following.

**IGR J17303–0601:** *R*-band imaging acquired in Loiano (Fig. 1, left panel) shows that the *ROSAT* error box, although small, is quite crowded, with at least 5 objects inside. The spectrum of the brighter object in the error box (shown in Fig. 2,

<sup>3</sup> <http://www.ipac.caltech.edu/2mass/>

<sup>4</sup> <http://iraf.noao.edu/>

<sup>5</sup> <http://www.eso.org/projects/esomidas>



**Fig. 2.** Average optical spectra of the optical counterparts to IGR J17303–0601 (*upper panel*), IGR J18027–1455 (*central panel*) and IGR J21247+5058 (*lower panel*) acquired with the Cassini telescope at Loiano. The spectra, in the 3900–8500 Å range, are smoothed with a Gaussian filter with  $\sigma = 4$  Å (i.e. comparable with the spectral dispersion). The main spectral features are labeled. The symbol  $\oplus$  indicates atmospheric telluric features.

top panel) reveals the presence of the Balmer  $H_\alpha$  and  $H_\beta$  lines in emission, as well as the He II  $\lambda 4686$  Å emission, superimposed onto a reddened continuum. Absorption lines produced by the Diffuse Interstellar Band (DIB) at  $\lambda 6280$  Å and by the Na Doublet (NaD) at  $\lambda 5890$  Å are also detected. The spectrum of the fainter of the two proposed optical counterparts shows instead a lower S/N continuum on which we identified metallic absorption bands typical of a late-type star and no emission features. We therefore regard the identification of the brighter source within the *ROSAT* error circle as the optical counterpart to IGR J17303–0601 as secure.

All the optical emission lines of this object are at redshift zero, indicating that this object belongs to the Galaxy. Besides, the presence of the He II strongly indicates that this object is undergoing mass accretion onto a compact star (e.g. van Paradijs & McClintock 1995). We thus conclude that this source is very likely an X-ray binary system.

The strength of the optical Balmer emission lines can be used to estimate the Galactic reddening toward IGR J17303–0601. For  $H_\alpha$  and  $H_\beta$  we measure a flux of  $4.4 \times 10^{-15}$  erg cm $^{-2}$  s $^{-1}$  and  $9.8 \times 10^{-16}$  erg cm $^{-2}$  s $^{-1}$ , respectively. Assuming an intrinsic Balmer decrement of  $H_\alpha/H_\beta = 2.86$  (Osterbrock 1989) and the extinction law of Cardelli et al. (1989), the observed  $H_\alpha/H_\beta$  flux ratio (i.e. 4.5) implies a line-of-sight reddening of  $E(B - V) = 0.45$  mag. According to Schlegel et al. (1998), the total Galactic color excess along the IGR J17303–0601 line of sight is  $E(B - V) = 0.61$  mag: this also suggests that this source is within the Galaxy. We remark that this value of  $E(B - V)$  is reliable as the source has Galactic latitude  $b = +15^\circ 01'$  (see Schlegel et al. 1998, for details).

R-band photometry returns a magnitude value  $R = 15.78 \pm 0.01$  for the object, which transforms into

$R_0 = 14.6 \pm 0.1$  once corrected for interstellar extinction (we assume a 0.1 mag total error to account for all of the uncertainties in the color excess determination). This value is that expected from a persistent low-mass X-ray binary (LMXB) located in the Galactic bulge: indeed, assuming a distance  $d \sim 8$  kpc, we obtain an absolute magnitude  $M_R \sim 0$ , typical of persistent LMXBs (van Paradijs & McClintock 1995). The *INTEGRAL* X-ray data (Bird et al. 2004) also support this interpretation: assuming a Crab-like spectrum, we obtain a 20–40 keV luminosity of  $1.8 \times 10^{35}$  erg s $^{-1}$  for a distance of 8 kpc. This value is quite typical of persistent neutron-star LMXBs in the soft state (Barret et al. 2000; Masetti et al. 2004b).

**IGR J18027–1455:** the non-pointlike appearance of the optical source coincident with the radio position, along with the diffuse nebulosity around it (see Fig. 1, central panel) is strongly suggestive of an AGN as the optical counterpart to this IGR source. Indeed, the average optical spectrum of the source (Fig. 2, central panel) shows a faint and reddened continuum dominated by a strong emission around 6800 Å which we readily identify with the line complex composed of  $H_\alpha$  and [N II]  $\lambda\lambda 6548, 6583$  at redshift  $z = 0.035 \pm 0.001$ . Fainter and narrower emissions which we identify with nebular lines, that is, [O III]  $\lambda 5007$  and [S II]  $\lambda 6716$ , are also found at wavelengths consistent with this redshift. Our photometry gives  $R = 16.55 \pm 0.01$  for the object.

The rest-frame width of the  $H_\alpha$  emission,  $\sim 2700$  km s $^{-1}$ , allows us to classify it as a broad-line AGN, and very likely as a type 1 Seyfert galaxy. Assuming a cosmology with  $H_0 = 65$  km s $^{-1}$  Mpc $^{-1}$ ,  $\Omega_\Lambda = 0.7$  and  $\Omega_m = 0.3$ , this corresponds to a distance of 166 Mpc. At this distance, the source X-ray luminosity is  $3 \times 10^{42}$  erg s $^{-1}$  and  $1.7 \times 10^{44}$  erg s $^{-1}$  in the 0.1–2.4 keV and in the 20–100 keV bands assuming again a

Crab-like spectrum. The absolute  $B$ -band magnitude of the object, computed assuming that  $B = 19.3$  (Monet et al. 2003) and considering a Galactic color excess  $E(B - V) = 1.26$  along the object's line of sight (Schlegel et al. 1998), is  $M_B \sim -22$ . These values place this source among the brightest type 1 Seyfert galaxies detected so far (Ho et al. 1997; Malizia et al. 1999). However, differently from the case of IGR J17303-0601, here the  $E(B - V)$  value may not be fully reliable due to the low Galactic latitude ( $b = +3^\circ.66$ ) of the object.

**IGR J21247+5058:** the spectrum of this source (Fig. 2, bottom panel) has a puzzling appearance. It shows a smooth continuum, typical of a late F- or early G-type star (e.g., Jaschek & Jaschek 1987), with narrow Balmer absorptions along with NaD, DIB, the Ca H+K doublet and the  $G$ -band and Mg b complexes again in absorption, all at redshift 0. However, superimposed to this stellar-like continuum, a broad emission bump around  $6700 \text{ \AA}$  is apparent, topped by a narrow emission. If we identify the latter as  $H_\alpha$ , we obtain a redshift  $z = 0.020 \pm 0.001$ .

We are confident that this feature is real as it is independent of the position of the object along the slit, and is not detected in the spectrum of the (late-type, possibly K) star located  $8''$  east of the putative counterpart of IGR J21247+5058.

Photometry also suggest that this object is quite peculiar: the magnitude data collected in Loiano indicate that it has  $B = 16.59 \pm 0.02$ ,  $V = 16.05 \pm 0.01$ ,  $R = 15.46 \pm 0.01$ ,  $I = 14.42 \pm 0.02$ ; that is, the source seems to become substantially redded as one moves from the  $R$  to the near-infrared. Indeed, the  $BVR$  magnitudes are consistent with those of a late F main-sequence star located  $\sim 2.5$  kpc from Earth, while the  $R - I$  color is more typical of an M-type star (Cox 2000).

$I$ -band imaging, in contrast to what is seen in other bands, seems to suggest that the object is slightly elongated in the east-west direction and with its intensity centre displaced from its PSF centroid (Fig. 1, left panel). We therefore put forward the hypothesis of a chance alignment between a Galactic F-type star and a background radio galaxy at  $z = 0.02$  which is responsible for both the radio morphology and the optical spectral bump around  $6700 \text{ \AA}$ . In this hypothesis, assuming the same cosmology as for IGR J18027-1455, the distance to this galaxy is 94 Mpc, and the extension of the radio lobes is  $\sim 200$  kpc; the 20–100 keV luminosity would be  $1.4 \times 10^{44} \text{ erg s}^{-1}$  for a Crab-like spectrum, locating this source also at the high end of the AGN luminosity distribution.

Optical and/or near-infrared imaging with sub-arcsec seeing would be highly desirable to confirm the alignment hypothesis presented here. We conclude by noting that, although Mantovani et al. (1982) suggested that optical spectroscopy would be able to disentangle the nature of this object, no observations of this kind have been reported in more than 20 years.

#### 4. Conclusions

Thanks to the cross-correlation among catalogues at different wavelength, and by using optical spectroscopy, we established the nature of three *INTEGRAL* sources detected along the Galactic Plane: IGR J17303-0601 is a LMXB located in the Galactic Bulge, IGR J18027-1455 is a background

type 1 Seyfert galaxy at  $z = 0.035$ , and IGR J21247+5058 is quite likely a background radio galaxy at  $z = 0.020$  with its spectrum contaminated by the chance superposition of a Galactic star.

To conclude, we stress the fact that, in the era of large observatories, high-quality science on up-to-date astrophysical topics, such as the hunt for the nature of IGR sources, can still be achieved with the use of small- and medium-sized telescopes.

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