

Unveiling the nature of *INTEGRAL* objects through optical spectroscopy

III. Observations of seven southern sources[★]

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ABSTRACT

Context. The detection, thanks to the *INTEGRAL* satellite, of a number of new hard X-ray sources calls for the identification of their nature by means of observations at longer wavelengths.

Aims. In our continuing campaign to identify longer-wavelength counterparts of these newly-discovered hard X-ray sources detected by *INTEGRAL*, we observed the putative optical counterparts of seven southern sources at the South African Astronomical Observatory and at the European Southern Observatory.

Methods. Optical spectroscopy was performed on all candidates of these X-ray sources. For two of these objects, optical photometry was also acquired.

Results. These observations firmly established the nature of four of these sources: we found that IGR J10404–4625 (=LEDA 93974), 4U 1344–60 and IGR J16482–3036 are Active Galactic Nuclei (AGNs) at redshifts $z = 0.0237$, 0.013 and 0.0313, respectively, and that 2RXP J130159.6–635806 is a Galactic High-Mass X-ray Binary (HMXB). We also give possible optical identifications for three further objects, namely IGR J11215–5952, IGR J11305–6256 and IGR J16207–5129, which are consistent with being Galactic HMXBs. Physical parameters for these objects are also evaluated by collecting and discussing the available multiwavelength information.

Conclusions. The detection of four definite or likely HMXBs out of seven objects in our sample further stresses *INTEGRAL*'s crucial contribution in hunting this class of object. Also, the determination of the extragalactic nature of a substantial fraction of the *INTEGRAL* survey sources underlines the importance of hard X-ray observations for the study of background AGNs located beyond the “Zone of Avoidance” of the Galactic Plane.

Key words. X-rays: binaries – X-rays: galaxies – galaxies: Seyfert – techniques: spectroscopic

1. Introduction

One of the objectives of the *INTEGRAL* mission (Winkler et al. 2003) is to survey the hard (20–100 keV) X-ray sky, with particular attention to the Galactic Plane. The capabilities of the IBIS instrument (Ubertini et al. 2003) allow *INTEGRAL* to detect hard X-ray sources at the mCrab level with a typical

localization accuracy of 2–3' (Gros et al. 2003). This combination of sensitivity and positional accuracy is unprecedented for surveys in the hard X-ray band above 20 keV and make it possible, for the first time, to resolve crowded regions of the hard X-ray sky such as the Galactic Centre and the spiral arms. These capabilities have also allowed the discovery of many new hard X-ray extragalactic objects beyond the Galactic Plane (the so-called “Zone of Avoidance”), where interstellar obscuration hampers observations in soft X-rays.

Since the launch of *INTEGRAL* in October 2002, IBIS has already scanned large portions of the sky, and allowed the

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production of two deep (down to mCrab sensitivities) Galactic Plane Surveys (Bird et al. 2004, 2005; Bassani et al. 2004, 2005) as well as surveys of the Galactic Centre (Revnivtsev et al. 2004), of spiral arms of the Galaxy, such as the Sagittarius (Molkov et al. 2004) and Crux (Revnivtsev et al. 2005) arms, and of the Coma cluster of galaxies (Krivonos et al. 2005).

Within these surveys, the ISGRI detector of IBIS has revealed more than 200 sources between 20 and 100 keV, the relative majority of them ($\sim 50\%$) being Galactic X-ray binaries, with a smaller percentage ($\sim 10\%$) of Active Galactic Nuclei (AGNs). However, about one fourth of the sample has no secure counterpart at longer wavelengths and therefore cannot yet be associated with any known class of objects. The majority of these unidentified sources are believed to be X-ray binaries, although some of them have been identified as AGNs (e.g., Masetti et al. 2004, 2006, hereafter Papers I and II; Bikmaev et al. 2005).

In order to reduce the *INTEGRAL* error circle, correlations with catalogues at longer wavelengths (soft X-ray, optical, near- and far-infrared, and/or radio) are employed. In particular, Stephen et al. (2005,b) found a strong positional correlation between the ISGRI objects and the softer X-ray sources in the *ROSAT* catalogue of bright sources (Voges et al. 1999), showing that a bright *ROSAT* source, if present within an ISGRI error circle, is very likely the soft X-ray counterpart of the corresponding *INTEGRAL* object. Similarly, Sazonov et al. (2005) accurately determined the positions of the soft X-ray counterparts of 6 *INTEGRAL* sources by using *Chandra* data. The use of the positional information coming from soft X-ray satellites therefore increases the positional accuracy to a few arcsecs, thus making the optical searches much easier.

Also, the presence of a radio object within the IBIS error box can be seen as an indication of an association between the radio emitter and the *INTEGRAL* source (e.g., Paper I; Paper II). However, whereas the cross-correlation with catalogues at other wavebands is fundamental in pinpointing the putative optical candidates, only optical spectroscopy can reveal the exact nature of the X-ray emitting object. Additionally, broadband optical photometry can help to determine other characteristics, such as the overall spectral energy distribution and absolute magnitude.

Thus, in our continuing effort to identify the unknown *INTEGRAL* sources, here we concentrate on a sample of 7 southern objects for which likely bright candidates could be pinpointed on the basis of their association with sources in other wavebands. These are mainly in soft X-rays and radio, or where a bright emission-line star could be detected within the ISGRI error circle.

Admittedly, the latter cases are the weaker ones among our selection of putative counterparts, due to the relatively large *INTEGRAL* error boxes and the lack of more accurate catalogued localizations at shorter wavelengths (other than optical). However, in several instances a bright emission-line star in an *INTEGRAL* error circle has been found to be the actual optical counterpart of the source responsible for the detected hard X-ray emission (e.g., Reig et al. 2005), so we consider these stars as important and viable candidates. We refer the reader to

Reig et al. (2005) for a detailed discussion of the possibilities and caveats that these putative associations imply.

We moreover remark the following: using the spectral information of the stars in the Hipparcos catalogue (Perryman et al. 1997), together with (i) the known number densities of bright stars, (ii) the proportion of early-type stars showing emission lines and (iii) the percentage of stars in each spectral class (as in Allen 1973), we find that, in our cases, the chance probability of finding a bright blue emission-line star within the *INTEGRAL* error box is less than 0.05% along the Galactic Plane. This makes us confident that our choice of putative optical bright candidates of early spectral type and with emission lines is fully justified.

We present here the spectroscopic results on these 7 sources obtained at the South African Astrophysical Observatory (SAAO) and at the European Southern Observatory (ESO). For two of them, optical photometry was also obtained, and is reported here. In Sect. 2 we present the sample of objects selected for this observational campaign, whereas in Sect. 3 a description of the observations is given; Sect. 4 reports the results for each source and discusses their nature. Conclusions are drawn in Sect. 5.

In the following, when not explicitly stated otherwise, for our X-ray flux estimates we will assume a Crab-like spectrum.

2. The selected sample

IGR J10404–4625: this source is present in the 2nd IBIS survey (Bassani et al. 2005; Bird et al. 2005) and is detected with fluxes of 2.9 ± 0.7 mCrab and 5.9 ± 1.1 mCrab in the 20–40 and 40–100 keV bands, respectively. Inside the *INTEGRAL* error box no bright soft X-ray sources are found; however, a single radio source, SUMSS¹ J104022–462525, with flux density 61.3 ± 2.0 mJy at 843 MHz, is present. This is in turn positionally coincident with a far-infrared *IRAS* source and with the optical S0-a type galaxy LEDA 93974 (Paturel et al. 2003; Fig. 1, upper left panel). This latter object is classified as an emission-line spiral galaxy at redshift $z = 0.024$ (Wamsteker et al. 1985; Stein 1996), but no optical spectral classification is available at present, nor has any spectrum been published. Nevertheless, the reported results suggest that LEDA 93974 is an active galaxy.

IGR J11215–5952: this variable, possibly transient, source was detected in the 20–60 keV band on 2005 April 22, during an *INTEGRAL* Galactic Plane scan, at a flux of 75 mCrab which halved ~ 40 min later (Lubinski et al. 2005). The source was not detected in the 60–200 keV band; this, according to those authors suggests a soft spectrum for the object. As noted by Negueruela et al. (2005), the B1 Ia-type supergiant HD 306414 (Vijapurkar & Drilling 1993) lies well inside the *INTEGRAL* error circle of IGR J11215–5952 (Fig. 1, upper middle panel). On the basis of the photometric properties of this source, Negueruela et al. (2005) suggested this star as the optical counterpart of the *INTEGRAL* hard X-ray source and that its distance is around 8 kpc.

¹ The SUMSS catalogue is available at <http://www.astrop.physics.usyd.edu.au/SUMSS/>

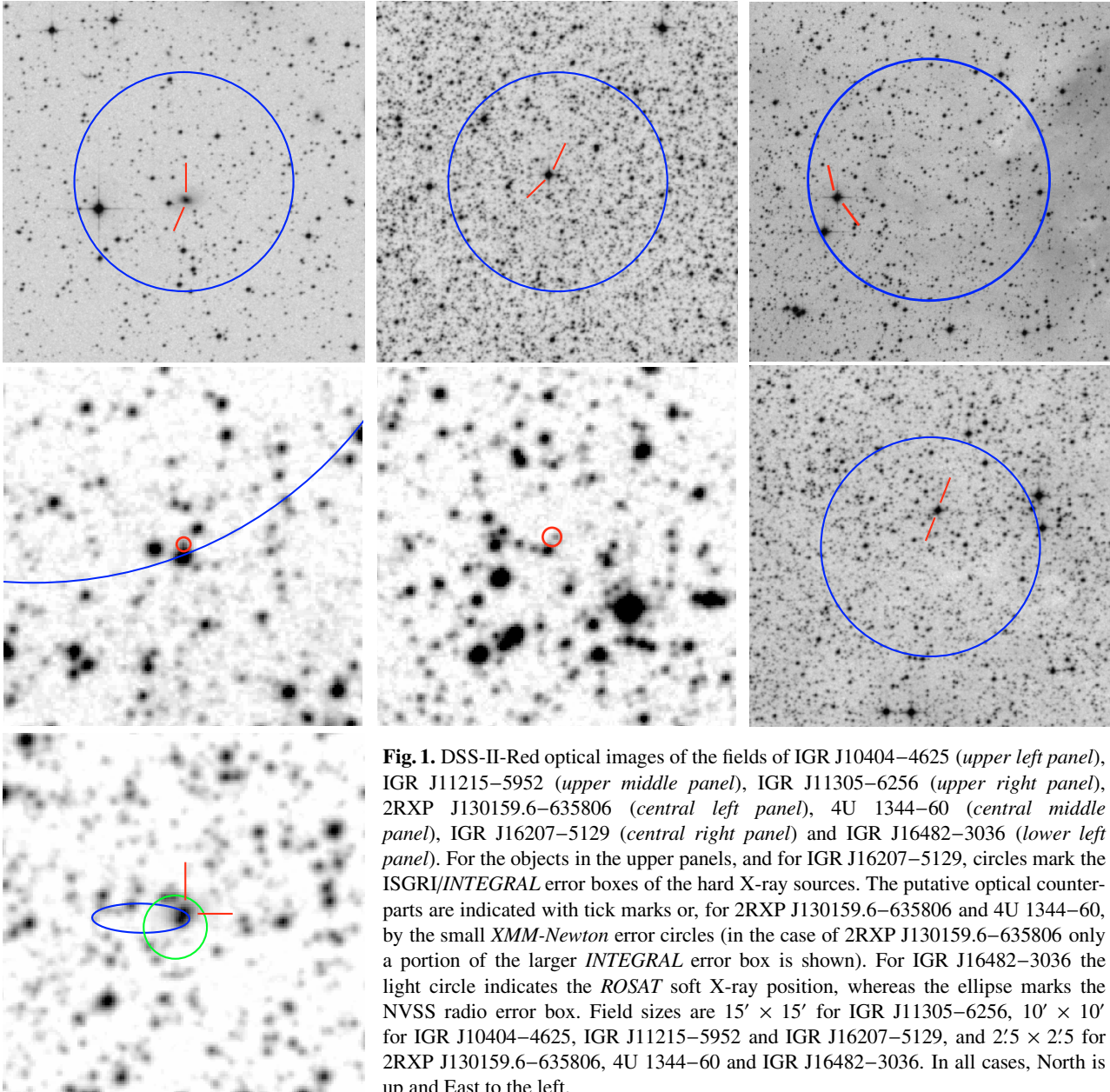


Fig. 1. DSS-II-Red optical images of the fields of IGR J10404–4625 (*upper left panel*), IGR J11215–5952 (*upper middle panel*), IGR J11305–6256 (*upper right panel*), 2RXP J130159.6–635806 (*central left panel*), 4U 1344–60 (*central middle panel*), IGR J16207–5129 (*central right panel*) and IGR J16482–3036 (*lower left panel*). For the objects in the upper panels, and for IGR J16207–5129, circles mark the ISGRI/*INTEGRAL* error boxes of the hard X-ray sources. The putative optical counterparts are indicated with tick marks or, for 2RXP J130159.6–635806 and 4U 1344–60, by the small *XMM-Newton* error circles (in the case of 2RXP J130159.6–635806 only a portion of the larger *INTEGRAL* error box is shown). For IGR J16482–3036 the light circle indicates the *ROSAT* soft X-ray position, whereas the ellipse marks the NVSS radio error box. Field sizes are $15' \times 15'$ for IGR J11305–6256, $10' \times 10'$ for IGR J10404–4625, IGR J11215–5952 and IGR J16207–5129, and $2.5' \times 2.5'$ for 2RXP J130159.6–635806, 4U 1344–60 and IGR J16482–3036. In all cases, North is up and East to the left.

IGR J11305–6256: this previously unknown hard X-ray transient (Produit et al. 2004) was discovered by IBIS/ISGRI on May 12, 2004 during an *INTEGRAL* observation of the Carina region. Produit et al. (2004) report a detection at an average flux of 8 mCrab in the 20–60 keV band, while there was no detection in the 3–10 keV band (no value for the upper limit to the X-ray flux in this band is however available). The only conspicuous catalogued object within the *INTEGRAL* error box of IGR J11305–6256 is the emission-line star HD 100199 (Fig. 1, upper right panel), which has $V = 8.23$ and $B - V = +0.01$ (Ferne 1983). This is classified as a blue giant of spectral type B0 IIIe (Garrison et al. 1977), but no spectrum has been published, and no further information is available on this star. However, its identification as an early-type emission-line star suggests HD 100199 as a strong

candidate for IGR J11305–6256, by analogy with other High-Mass X-ray Binaries (HMXBs) detected with *INTEGRAL* (e.g., Reig et al. 2005; Paper II), even if the relatively large error circle ($5'$) makes this identification less secure.

2RXP J130159.6–635806: known also as IGR J13020–6359, this source was detected in both the Crux arm survey (Revnitsev et al. 2005) and in the 2nd IBIS survey (Bird et al. 2005). In the latter survey it appears with fluxes of 2.1 ± 0.2 mCrab and 1.3 ± 0.4 mCrab in the 20–40 keV and 40–100 keV bands, respectively. At the edge of the ISGRI error circle, a *ROSAT* and *XMM-Newton* source was found (Chernyakova et al. 2005) to be an accreting X-ray pulsar with spin period ~ 700 s and spectral characteristics of a HMXB. The smaller *XMM-Newton* error box ($3''$ radius; Chernyakova et al. 2005) encompasses two optical objects (Fig. 1, central

left panel), a brighter one with USNO-A2.0² magnitude $R \sim 13.9$ and a fainter one of unknown magnitude; for the latter object, a rough magnitude estimate using the relevant DSS-II-Red Optical Survey³ image gives $R \approx 17$. Optical spectroscopy is therefore needed to clarify which of the two is the actual counterpart to 2RXP J130159.6–635806, and to independently confirm the HMXB nature of this source.

4U 1344–60: this Ariel and Uhuru source (Seward et al. 1976; Forman et al. 1978) was detected, for the first time above 10 keV, in the 2nd IBIS survey (Bird et al. 2005), at 20–40 and 40–100 keV fluxes of 3.9 ± 0.2 mCrab and 4.7 ± 0.4 mCrab, respectively. It is also associated with a source seen by *Einstein*, *EXOSAT*, *ASCA* and *XMM-Newton*. The data from *Einstein* (McDowell 1994) and *EXOSAT* (Warwick et al. 1988) indicate that this source has fluxes of $\sim 2 \times 10^{-12}$ erg cm⁻² s⁻¹ and $\sim 2.3 \times 10^{-11}$ erg cm⁻² s⁻¹ in the 0.16–3.5 keV and 2–6 keV bands, respectively. According to Michel et al. (2004) and Bassani et al. (2005), this source has the X-ray spectral characteristics of an AGN. But, despite this long history of observations, the object is still optically unidentified. However, the smaller *XMM-Newton* error box (4'' radius) with coordinates RA = 13^h47^m36^s.43, Dec = –60°37'02".4 (J2000) available in a serendipitous archival observation of this field⁴ allowed us to pinpoint two optical objects consistent with the *XMM-Newton* position (see Fig. 1, central middle panel), the brighter one at $R \sim 16.4$ according to the USNO-A2.0 catalogue, and the fainter one of unknown magnitude; in this case also, we roughly estimate its magnitude as $R \approx 19$ from the corresponding DSS-II-Red Survey image. As for IGR J13020-6359, optical spectroscopy of both objects is now required to complete this identification.

IGR J16207–5129: this hard X-ray source was detected for the first time by IBIS/ISGRI in the 1st Galactic Plane Survey performed with *INTEGRAL* (Bird et al. 2004), with a flux of 3.8 ± 0.3 mCrab in the 20–40 keV band; only an upper limit of <4 mCrab was instead obtained in the 40–100 keV band. Again, an emission-line star, HD 146803, is the only interesting catalogued object present inside the *INTEGRAL* error box (Fig. 1, central right panel). This star shows H α in emission (MacConnell 1981) and is of spectral type A1 IV (Houk 1978). According to the information catalogued in SIMBAD⁵, HD 146803 has $B = 10.41$ and $V = 10.45$. The spectral characteristics of this star again, as for the cases above, strongly suggest it to be the optical counterpart of the hard X-ray source detected by *INTEGRAL*.

IGR J16482–3036: this object also has been detected in the 2nd IBIS survey (Bassani et al. 2005; Bird et al. 2005), with fluxes of 1.6 ± 0.2 mCrab (20–40 keV) and 1.6 ± 0.3 mCrab (40–100 keV). Inside the *INTEGRAL* error box the soft X-ray source 1RXS J164815.5–303511, belonging to the *ROSAT* Bright Source Catalogue (Voges et al. 1999), is found

at a 0.1–2.4 keV flux of $(8.3 \pm 1.3) \times 10^{-13}$ erg cm⁻² s⁻¹. This, according to Stephen et al. (2005, 2006), strongly suggests that this source is the soft X-ray counterpart of IGR J16482–3036. Consistent with the *ROSAT* position, a NVSS radio source, with flux of 3.5 ± 0.6 mJy at 1.4 GHz (Condon et al. 1998), is present. The intersection of the smaller NVSS and *ROSAT* error boxes allows us to pinpoint an extended optical object on the DSS-II-Red Survey image (Fig. 1, lower left panel), which has $R \sim 13.4$ and $B \sim 15.8$ according to the USNO-B1.0 catalogue (Monet et al. 2003). Optical spectroscopy would thus conclusively determine the nature of this source.

3. Observations at SAAO and at ESO

3.1. Spectroscopy

We observed five southern optical objects of our sample with the SAAO 1.9-m “Radcliffe” telescope located near Sutherland, South Africa. The Radcliffe telescope carried a CCD spectrograph mounted at the Cassegrain focus; the instrument was equipped with a 1798 × 266 pixel SITe CCD. In all observations, Grating #7 and a slit of 1''.8 were used, providing a 3850–7200 Å nominal spectral coverage. This setup gave a dispersion of 2.3 Å/pix for all spectra acquired at SAAO.

We also retrieved from the ESO archive⁶ spectroscopic observations of the optical candidates of both 4U1344–60 (ESO Program ID: 70.D-0227) and 2RXP J130159.6–635806 (ESO Program ID: 71.D-0296). These were obtained with the 3.6 m ESO telescope located in La Silla (Chile); this telescope was equipped with EFOSC2 and a 2048 × 2048 pixel Loral/Lesser CCD with 2 × 2 binning. For both pointings Grism #6 and a slit of 1''.5 were used, giving a 3850–8100 Å nominal spectral coverage, at a dispersion of 4.1 Å/pix. In these two cases the slit was oriented in such a way as to include both candidates. The complete spectroscopy observation log for both SAAO and ESO is contained in Table 1.

The spectra, after cosmic-ray rejection and correction for bias and flat field, were reduced, background subtracted and optimally extracted (Horne 1986) using IRAF⁷. Wavelength calibration was performed using Cu-Ar lamps for the SAAO spectra and He-Ar lamps for the ESO spectra. SAAO spectra were then flux-calibrated by using the spectrophotometric standards CD-32°9927 and LTT 377, whereas those secured at ESO were calibrated in flux using the standard LTT9239; these three standards are extracted from the catalogues of Hamuy et al. (1992, 1994). In the case of 2RXP J130159.6–635806, we stacked together the two spectra to increase the signal-to-noise ratio (S/N). The wavelength calibration uncertainty was ~ 0.5 Å for all cases, and was checked by using the positions of background night sky lines.

² Available at

<http://archive.eso.org/skycat/servers/usnoa/>

³ Available at <http://archive.eso.org/dss/dss/>

⁴ Available at

<http://heasarc.gsfc.nasa.gov/docs/archive.html>

⁵ see <http://simbad.u-strasbg.fr/>

⁶ Available at <http://archive.eso.org/>

⁷ IRAF is the Image Analysis and Reduction Facility made available to the astronomical community by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under contract with the US National Science Foundation. It is available at <http://iraf.noao.edu/>

Table 1. Log of the observations presented in this paper.

Object	Date	Mid-exposure time (UT)	Telescope	Grism or filter	Slit or seeing (")	Exposure time (s)
Spectroscopy						
LEDA 93974	23 Jul. 2005	17:25:24	SAAO 1.9 m	#7	1.8	1000
2RXP J130159.6–635806	28 Jun. 2003	02:34:04	ESO 3.6 m	#6	1.5	2 × 600
4U 1344–60	01 Mar. 2003	08:09:36	ESO 3.6 m	#6	1.5	1000
HD100199	23 Jul. 2005	17:58:28	SAAO 1.9 m	#7	1.8	90
HD306414	23 Jul. 2005	17:45:05	SAAO 1.9 m	#7	1.8	300
HD146803	22 Jul. 2005	19:22:10	SAAO 1.9 m	#7	1.8	200
IGR J16482–3036	22 Jul. 2005	19:44:10	SAAO 1.9 m	#7	1.8	1000
Imaging						
2RXP J130159.6–635806	28 Jun. 2003	02:19:26	ESO 3.6 m	<i>R</i>	1.6	20
2RXP J130159.6–635806	28 Jun. 2003	02:47:45	ESO 3.6 m	<i>i</i>	1.9	300
2RXP J130159.6–635806	28 Jun. 2003	02:53:27	ESO 3.6 m	<i>V</i>	2.1	300
4U 1344–60	01 Mar. 2003	07:51:40	ESO 3.6 m	<i>R</i>	1.0	20

3.2. Photometry

Through the ESO archive we also retrieved optical imaging frames of the fields of 2RXP J130159.6–635806 and of 4U 1344–60, acquired again with EFOSC2 at the ESO 3.6 m under the same programs and on the same nights in which spectroscopy was performed. In detail, a single *R*-band frame was available for the 4U 1344–60 field, and *VRi* images for the field of 2RXP J130159.6–635806. Table 1 also contains information on these imaging observations.

The 2×2-rebinned CCD of EFOSC2 secured a plate scale of 0".31/pix, and a useful field of 5'.2 × 5'.2. Images were corrected for bias and flat-field in the usual fashion and calibrated using the EFOSC2 zero-points⁸. The putative counterparts of these two *INTEGRAL* sources were clearly detected in all images, and their magnitudes were determined with MIDAS⁹. Because of (i) the pointlike appearance of all candidates and (ii) the fairly crowded fields, we applied the *DAOPHOT* PSF-fitting routine (Stetson 1987).

4. Results and discussion

Table 2 contains the (observer's frame) emission-line wavelengths, fluxes and equivalent widths (*EWs*) for the seven spectra displayed in Fig. 2. The line fluxes from extragalactic objects were dereddened for Galactic absorption along the respective lines of sight following the prescription of Schlegel et al. (1998) and assuming the Galactic extinction law of Cardelli et al. (1989). These same spectra were not corrected for starlight contamination (see, e.g., Ho et al. 1993, 1997) given the limited S/N and resolution of the spectrum. We do not believe that this affects any of our conclusions. In the

following we assume a cosmology with $H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_\Lambda = 0.7$ and $\Omega_m = 0.3$.

4.1. IGR J10404–4625 (=LEDA 93974)

The spectrum of the galaxy LEDA 93974 shows a number of narrow emission features that can readily be identified with redshifted optical nebular lines. These lines include [O III] $\lambda\lambda 4959, 5007$, [O I] $\lambda 6300$, H_α , [N II] $\lambda\lambda 6548, 6583$, and [S II] $\lambda\lambda 6716, 6731$. All identified emission lines yield a redshift $z = 0.0237 \pm 0.0006$, in perfect agreement with the value of Paturel et al. (2003). The NaD doublet and the Mg b band, both in absorption, are also detected at the same redshift. The H_β emission line is not detected down to a 3σ flux limit of $1.4 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$.

The presence of only narrow emission lines in the optical spectrum of LEDA 93974 suggests activity typical of a Narrow-Line Region (NLR) surrounding an obscured AGN (see, e.g., the classification of Veilleux & Osterbrock 1987); this is also supported by the SUMSS radio detection and by the nondetection in the soft X-ray band. We further confirm this by using the diagnostic line ratios [N II]/ H_α , [S II]/ H_α , and [O III]/ H_β , together with the detection of substantial [O I] $\lambda 6300$ emission: the values of these quantities place this source in the regime of Seyfert 2 AGNs (Ho et al. 1993, 1997).

The lower limit on the H_α/H_β line ratio can be used to give an estimate of the lower limit to the extinction within the NLR itself. This line ratio, once corrected for Galactic absorption assuming (from Schlegel et al. 1998) $E(B - V) = 0.16$ along the LEDA 93974 line of sight, is >16 . Considering an intrinsic Balmer decrement $H_\alpha/H_\beta = 2.86$ (Osterbrock 1989) and the extinction law by Cardelli et al. (1989) for the reddening within the NLR of LEDA 93974, the observed lower limit for the H_α/H_β flux ratio implies an internal $E(B - V) > 1.8$ and an extinction $A_V > 5.6$ (in the galaxy rest frame). Substantial absorption within the NLR is also suggested by the presence of

⁸ Available at:

<http://www.ls.eso.org/lasilla/sciops/3p6/efosc/zp/>

⁹ <http://www.eso.org/projects/esomidat>

Table 2. Observer’s frame wavelengths, *EW*s and fluxes (in units of 10^{-15} erg s $^{-1}$ cm $^{-2}$) of the emission lines detected in the spectra of the seven objects shown in Fig. 2. For the extragalactic sources the values are corrected for Galactic extinction assuming, from Schlegel et al. (1998), $E(B - V) = 0.16$ (for LEDA 93974), 2.90 (for 4U 1344–60) and 0.34 (for IGR J16482–3036). The error on the line positions is conservatively assumed to be ± 2 Å and ± 4 Å for the SAAO and ESO spectra, respectively, i.e. comparable to the corresponding spectral dispersions (see text).

Line	λ_{obs} (Å)	EW_{obs} (Å)	Flux
IGR J10404–4625 (=LEDA 93974)			
[O III] $\lambda 4958$	5076	7.3 ± 0.7	23 ± 2
[O III] $\lambda 5007$	5125	8.6 ± 0.9	27 ± 3
[O I] $\lambda 6300$	6450	2.4 ± 0.4	7.9 ± 1.2
[N II] $\lambda 6548$	6705	8.6 ± 0.9	29 ± 3
H $_{\alpha}$	6720	7.1 ± 0.7	24 ± 2
[N II] $\lambda 6583$	6740	16.6 ± 1.7	56 ± 6
[S II] $\lambda 6716$	6880	2.1 ± 0.4	6.8 ± 1.4
[S II] $\lambda 6731$	6890	2.9 ± 0.6	9.2 ± 1.8
HD 306414			
H $_{\alpha}$	6566	1.9 ± 0.1	530 ± 30
HD 100199			
H $_{\beta}$	4862	0.38 ± 0.06	970 ± 150
He I $\lambda 5015^a$	5012	0.09 ± 0.02	220 ± 60
	5020	0.13 ± 0.03	310 ± 80
He I $\lambda 5875^a$	5871	0.42 ± 0.04	670 ± 70
	5881	0.53 ± 0.05	840 ± 80
H $_{\alpha}$	6563	7.9 ± 0.2	9300 ± 300
He I $\lambda 6678^a$	6672	0.17 ± 0.03	190 ± 40
	6684	0.24 ± 0.05	270 ± 50
He I $\lambda 7065^a$	7060	0.50 ± 0.05	490 ± 70
	7070	0.53 ± 0.05	520 ± 50
2RXP J130159.6–635806			
H $_{\alpha}$	6562	21.7 ± 1.1	2.37 ± 0.12
4U 1344–60			
H $_{\alpha}$ + [N II]*	6650	259 ± 13	3040 ± 150
[S II] $\lambda 6731$	6821	3 ± 1	32 ± 10
HD 146803			
H $_{\alpha}$	6563	8.7 ± 0.4	1900 ± 100
IGR J16482–3036			
H $_{\gamma}$ (broad comp.)	4493	50 ± 10	170 ± 30
H $_{\beta}$ (narrow comp.)	5011	27 ± 4	91 ± 14
H $_{\beta}$ (broad comp.)	5042	98 ± 10	340 ± 30
[O III] $\lambda 4958$	5114	7.8 ± 0.8	27 ± 3
[O III] $\lambda 5007$	5165	18.7 ± 1.3	65 ± 5
[O I] $\lambda 6300$	6501	6.7 ± 0.7	23 ± 2
[O I] $\lambda 6363$	6562	1.7 ± 0.3	5.8 ± 1.2
H $_{\alpha}$ + [N II]*	6769	366 ± 18	1300 ± 70
[S II] $\lambda 6716$	6930	3.5 ± 0.5	12.9 ± 1.9
[S II] $\lambda 6731$	6944	3.7 ± 0.6	13.4 ± 2.0

^a Double-peaked line.

* These lines are heavily blended. The wavelength of the emission peak is reported.

a prominent interstellar NaD absorption doublet (with $EW_{\text{NaD}} = 3.1 \pm 0.3$ Å) at the redshift of the galaxy.

The lower limit on A_V implies, using the empirical formula of Predehl & Schmitt (1995), a lower limit to the hydrogen column density within the LEDA 93974 NLR of $N_{\text{H}} > 1 \times 10^{22}$ cm $^{-2}$. Given that this is just a lower limit, and considering the uncertainties involved in the above treatment, we chose not to apply this correction to the following.

Using the cosmology described above we find that the luminosity distance to LEDA 93974 is $d_L = 111$ Mpc, and that its X-ray luminosity is 1.1×10^{44} erg s $^{-1}$ in the 20–100 keV band. This value places the source among the most luminous Type 2 Seyfert galaxies detected so far (cf. Malizia et al. 1999). The measured value for the X-ray luminosity of LEDA 93974 is thus comparable to that of “classical” AGNs.

The optical Gunn *g*- and *r*-band magnitudes of this galaxy, reported by Jørgensen et al. (1995) as $g = 13.55$ and $r = 13.60$, together with the conversion equations from these authors, allowed us to estimate the Johnson-Cousins *BVR* magnitudes of LEDA 93974 as $B = 14.11$, $V = 13.55$ and $R = 13.23$. In particular, the *B*-band magnitude implies that the absolute optical *B* magnitude of this galaxy is $M_B = -21.1$. This is, strictly speaking, a lower limit to the *B*-band luminosity of LEDA 93974, as no internal reddening was considered.

Next, assuming for IGR J10404–4625 an X-ray spectrum typical of a Seyfert 2 galaxy, with a power law of photon index $\Gamma = 1.9$ (see Bassani et al. 1999, and references therein) we can extrapolate the information obtained with *INTEGRAL* to determine the unabsorbed 2–10 keV flux of the source to be 6.1×10^{-11} erg cm $^{-2}$ s $^{-1}$. The comparison between the reddening-corrected [O III] $\lambda 5007$ emission flux and the 2–10 keV X-ray flux estimated above implies an X-ray/[O III] $_{5007}$ ratio of ~ 2000 , indicating that the source is well within the Compton-thin regime for Seyfert 2 galaxies (see Bassani et al. 1999). We however caution the reader that this is an upper limit to the ratio, as no correction due to the absorption intrinsic to the NLR of the galaxy was applied to the [O III] $\lambda 5007$ line flux.

The strength of the optical emission lines of LEDA 93974, after accounting for Galactic reddening, can be used to estimate the star formation rate (SFR) and metallicity. From the unabsorbed H $_{\alpha}$ flux in Table 2, and following Kennicutt (1998), we determine a *SFR* of $0.28 \pm 0.02 M_{\odot}$ yr $^{-1}$ from the reddening-corrected H $_{\alpha}$ luminosity of $(3.6 \pm 0.3) \times 10^{40}$ erg s $^{-1}$. We again stress that this is a strict lower limit to the SFR as the effect of absorption intrinsic to LEDA 93974 was not accounted for.

4.2. HD 306414

The spectrum of HD 306414 (see Fig. 2) is characterized by H $_{\alpha}$ emission. Its presence and its *EW* are often found in early B supergiants (e.g., Leitherer 1988). Besides this, and following the spectral type classification criteria of Jaschek & Jaschek (1987), the narrowness of the other detected Balmer lines in absorption, the absence of He II lines, and the presence of He I and light metal (such as C III) absorption lines suggest that the star is an early B-type supergiant, in agreement with the B1 Ia classification of Vijapurkar & Drilling (1993).

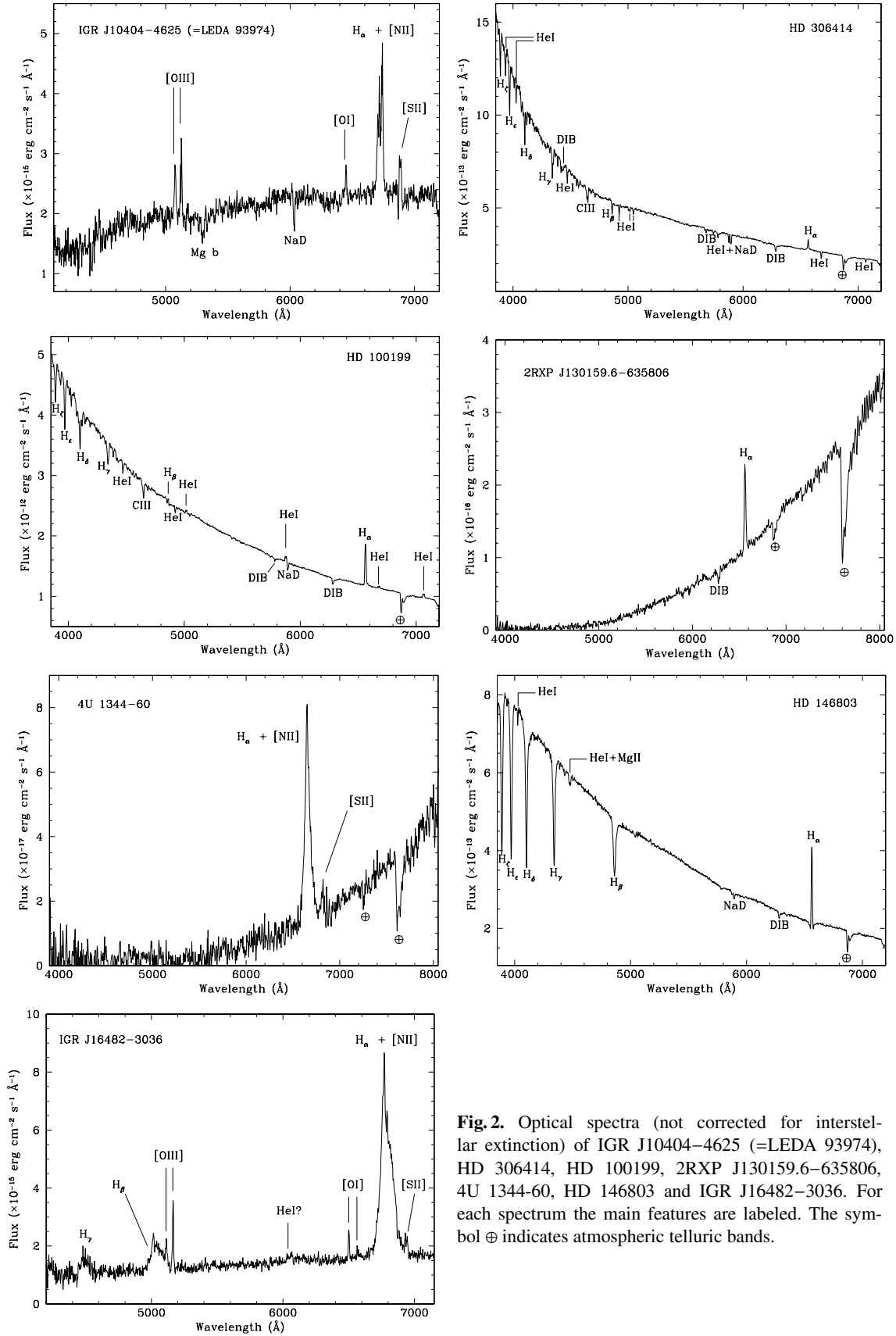


Fig. 2. Optical spectra (not corrected for interstellar extinction) of IGR J10404-4625 (=LEDA 93974), HD 306414, HD 100199, 2RXP J130159.6-635806, 4U 1344-60, HD 146803 and IGR J16482-3036. For each spectrum the main features are labeled. The symbol \oplus indicates atmospheric telluric bands.

Although this is not sufficient to firmly identify HD 306414 as a HMXB optical counterpart of IGR J11215-5952, it is

intriguing that this hard X-ray transient source contains in its error circle such an unusual emission-line object. This would

be similar to the cases of other supergiant fast X-ray transient (SFXT) HMXBs described by Sguera et al. (2005) and which *INTEGRAL* is discovering during its Galactic Plane scans.

Assuming that HD 306414 is of spectral type B1 Ia implies $M_V = -6.4$ and $(B - V)_0 = -0.19$ (Lang 1992). Using the observed $B = 10.57$ and $V = 9.98$ for this star (Klare & Neckel 1977), gives a color excess of $E(B - V) = 0.78$ and a distance of $d \sim 6.2$ kpc. This distance estimate is in general agreement with that given by Negueruela (2005), whereas the color excess is slightly less than, but broadly consistent with, the value of $E(B - V) = 0.83$ obtained from the infrared maps of Schlegel et al. (1998), thereby supporting the large distance.

This distance is compatible with HD 306414 being located in the far end of the Carina arm (see, e.g., Leitch & Vasisht 1998) and implies, if this star is indeed the optical counterpart of IGR J11215–5952, a 20–60 keV peak luminosity of $\sim 4 \times 10^{36}$ erg s⁻¹. This again compares well with the outburst peak luminosities of SFXTs (Sguera et al. 2005; Smith et al. 2005).

Thus, there is strong circumstantial evidence that IGR J11215–5952 and HD 306414 may be the same object, and that this system is a fast transient HMXB. Clearly, pointed soft X-ray observations obtainable with satellites affording arcsecond localizations (such as *Chandra*, *XMM-Newton* or *Swift*) will allow a confirmation (or denial) of the above association.

4.3. HD 100199

Our observation confirms the emission-line nature of HD 100199 by the detection of H α , H β and several He I lines in emission (see Fig. 2 and Table 2). Again using the criteria of Jaschek & Jaschek (1987), the width of the Balmer lines in absorption and the detection of He I and light metal absorption lines are consistent with the most recent spectral type classification for HD 100199 of B0 IIIe (Garrison et al. 1977).

From a closer inspection of the optical spectrum, we found that, whereas the Balmer emission lines are single-peaked, the He I emission lines are double-peaked. These emission line properties are typical of early Be stars. Such objects frequently display double peaked emission lines in optically thin transitions, such as He I, and single-peaked Balmer lines, which are optically thick. This effect is related to electron scattering of photons in the Be star disk-like circumstellar envelope and to the geometry of the envelope itself; see, e.g., Hanuschik et al. (1996) for an extensive atlas of line profiles, and references therein for details on line formation mechanisms.

We can estimate the distance to HD 100199 in the same way as performed above for HD 306414. The B0 III spectral type implies $M_V = -5.1$ and $(B - V)_0 = -0.295$ (Lang 1992). From the observed $B = 8.24$ and $V = 8.23$ of Fernie (1983) we determine a distance of $d \sim 3$ kpc and $E(B - V) = 0.31$ along the HD 100199 line of sight. This color excess is substantially lower than the Galactic value of $E(B - V) = 3.87$ (Schlegel et al. 1998). This supports a location for HD 100199 in the near side of the Carina arm (see, e.g., Leitch & Vasisht 1998).

If HD 100199 is the actual optical counterpart of IGR J11305–6256, then this distance implies a 20–60 keV

luminosity of $\sim 1 \times 10^{35}$ erg s⁻¹. This luminosity is comparable to that of the persistent Be/X HMXB system X Per/4U 0352+309, which moreover has a similar optical companion (e.g., Haberl et al. 1998). However, the lack of further information on the X-ray spectrum of IGR J11305–6256 prevents us from a deeper comparison between these two X-ray sources.

As for the case of HD 306414 (see Sect. 4.2), the current evidence is insufficient to firmly identify HD 100199 as the true optical counterpart of IGR J11215–5952, and that this X-ray source is a HMXB. We therefore regard the association between these two objects as possible, but not firm due to the lack of more multiwavelength information.

4.4. 2RXP J130159.6–635806

The brighter of the two possible counterparts within the 2RXP J130159.6–635806 *XMM-Newton* error circle has the spectrum of a normal M-type star, and can thus be discarded as a candidate for the X-ray emission. However, the spectrum of the fainter of the two shows a prominent narrow H α line at redshift zero superimposed on a very reddened continuum (see Fig. 2). This demonstrates that this object is the optical counterpart of this *INTEGRAL* hard X-ray source, and that it is a Galactic object, most probably an accreting X-ray binary embedded in the Galactic Plane. This explains the very reddened optical spectrum of this source, which shows no signal below ~ 5000 Å.

The low S/N of this spectrum does not allow us to determine the presence of any other feature, and we are thus not able to define the spectral type of the mass donor star, and in turn its distance. Optical photometry can nevertheless help us in this task. Our *VRi* data show that this object has $V = 19.67 \pm 0.02$, $R = 17.70 \pm 0.02$ and $i = 16.08 \pm 0.03$. These values, together with the near-infrared *JHK* magnitudes reported by Chernyakova et al. (2005), are consistent with those of a heavily reddened X-ray binary.

The possibility that this object is an LMXB or a CV is, however, unlikely. For it to be an LMXB, assuming $M_V \sim 0$ and $(V - R)_0 \sim 0$ (van Paradijs & McClintock 1995), would require $A_V \sim 11$ and a distance $d \sim 560$ pc, too close to explain the large reddening observed. An even more extreme situation applies for a CV interpretation: given $M_V \sim 9$ and $(V - R)_0 \sim 0$ (Warner 1995), we obtain a distance $d \sim 9$ pc. Thus we discard both the CV and LMXB interpretations for this source.

If instead an early-type star is considered as the mass donor in this X-ray binary, we find, assuming the Galactic absorption law of Cardelli et al. (1989) and using the dereddened color indices of Wegner (1994) for early-type stars, that the reddening towards 2RXP J130159.6–635806 is $A_V \sim 10.5$ or 9.5 for the cases of an O5 Ia or B9 V star respectively. These two extremes imply the following distance estimates: given M_V of -6.6 and $+0.2$, respectively (Lang 1992), we find $d \sim 14$ kpc and $d \sim 1$ kpc for O5 Ia and B9 V stars, respectively.

Neither of these extremes is, however, likely, because they are either too far to belong to the Galactic disk (see Fig. 1 of Leitch & Vasisht 1998) or (again) too close to explain the

large reddening observed. Moreover, the H_α EW appears too large if the secondary star is a supergiant (see Leitherer 1988). Thus, 2RXP J130159.6–635806 is likely to be a HMXB hosting a late O-/early B-type star of intermediate luminosity class.

All of the above is fully consistent with the X-ray picture of this source reported by Chernyakova et al. (2005), who have shown that this system hosts a slow X-ray pulsar (with spin period of ~ 700 s) and that it has the characteristics of a persistent Be/X-ray binary, similar to the X Per/4U 0352+309 system (e.g., Haberl et al. 1998).

The following considerations can help us to better constrain the companion spectral type. The observed optical extinction is fully consistent with the column density of $N_H = 1.7\text{--}1.9 \times 10^{22} \text{ cm}^{-2}$ along this line of sight (Dickey & Lockman 1990; Chernyakova et al. 2005): using the empirical formula of Predehl & Schmitt (1995), an $A_V \approx 10$ implies that $N_H \approx 1.8 \times 10^{22} \text{ cm}^{-2}$. This suggests that 2RXP J130159.6–635806 is at a large distance, and that it lies within the Crux arm, as hypothesized by Chernyakova et al. (2005). In this case, at a distance $d \sim 7$ kpc, we find $M_V \sim -4.5$, corresponding to either a B1 III or a O9 V spectral type companion (Lang 1992), with a slight preference for the latter in terms of dereddened color indices. This distance also implies a 20–100 keV luminosity of $1.6 \times 10^{35} \text{ erg s}^{-1}$, which is compatible with 2RXP J130159.6–635806 being a persistent HMXB similar to X Per.

Independent support for the above reddening estimates comes from the application of the $H\alpha/H\beta$ flux ratio criterion (Osterbrock 1989) used in Sect. 4.1. The 3σ upper limit of $6 \times 10^{-17} \text{ erg cm}^{-2} \text{ s}^{-1}$ for the $H\beta$ flux implies a line ratio >40 ; this converts into a lower limit of $A_V > 8.4$.

4.5. 4U 1344-60

Inspection of the spectrum (in Fig. 2) of the fainter of the two candidates shows that the only outstanding feature present is a large and broad emission line superimposed on a low S/N continuum. We readily identify this feature as the $H_\alpha + [\text{N II}]$ complex at a redshift $z = 0.013 \pm 0.001$. A lower significance emission line is also detected and identified as $[\text{S II}] \lambda 6731$ at the same redshift. This allows us to identify this source as a type 1 Seyfert galaxy (according to the classification of Veilleux & Osterbrock 1987). No continuum emission is detected below $\sim 5500 \text{ \AA}$ due to the strong Galactic reddening along this line of sight: the Galactic color excess along this direction is indeed $E(B - V) = 2.90$ (Schlegel et al. 1998).

The spectrum of the other putative counterpart is instead basically featureless, with a hint of H_α and H_β absorption lines at $z = 0$. We thus identify this object as a probable normal galactic star, and we regard the fainter of the two objects (with $R = 18.73 \pm 0.03$, from photometry on the ESO image) as the actual optical counterpart of 4U 1344–60.

The identification of 4U 1344–60 as a type 1 Seyfert galaxy is also supported by ASCA results (Tashiro et al. 1998), which indicate an X-ray spectrum typical of this class of objects (cf. Mushotzky et al. 1993). The redshift measured above corresponds to a luminosity distance $d_L = 60.6$ Mpc; this in turn

implies for 4U 1344–60 X-ray luminosities of $1.0 \times 10^{43} \text{ erg s}^{-1}$ and $3.2 \times 10^{43} \text{ erg s}^{-1}$ in the 2–6 keV and 20–100 keV bands, respectively. This distance also implies $M_R = -22.5$, although strictly speaking this is a lower limit, as no absorption internal to the AGN host galaxy was considered. These X-ray and optical luminosity estimates place 4U 1344–60 amongst the average of typical Seyfert 1 AGNs (e.g., Malizia et al. 1999).

4.6. HD 146803

The most relevant feature in the optical spectrum of HD 146803 (see Fig. 2) is the H_α profile, with a prominent emission core and absorption wings. The other Balmer lines, in absorption, appear to be much wider than those of supergiant stars such as HD 306414: this suggests that the luminosity class of this star is indeed between III and V. Moreover, the detection of He I absorption and the nondetection of light metal lines, apart from Mg II $\lambda 4481$, suggests that this is a fairly luminous late B-type star, rather than an early A-type. Thus, again using the criteria of Jaschek & Jaschek (1987), we suggest that HD 146803 is more likely a late-type B star of luminosity class III.

Assuming a spectral type of B8 III, we can again compute its distance with the same method applied in Sects. 4.2 and 4.3: such stars have $M_V = -1.2$ and $(B - V)_0 = -0.11$ (Lang 1992). From the observed magnitudes of $B = 10.41$ and $V = 10.45$ (see Sect. 2) we obtain a distance of $d \sim 1.9$ kpc, and a color excess of $E(B - V) = 0.07$ along the HD 146803 line of sight. This color excess is, as for HD 100199 (Sect. 4.3), substantially less than that, $E(B - V) = 5.63$, obtained from the maps of Schlegel et al. (1998), which supports the lower distance.

This places HD 146803 in the Sagittarius arm of the Galaxy (see, e.g., Leitch & Vasisht 1998). On the assumption that this star is the optical counterpart of IGR J16207–5129, the above distance estimate implies a 20–40 keV band luminosity of $\sim 1.3 \times 10^{34} \text{ erg s}^{-1}$.

If HD 146803 and IGR J16207–5129 are the same source, the aforementioned spectral type identification and X-ray luminosity determination suggest that this object may be a low-luminosity, persistently-emitting HMXB with late-type B companion, similar to 1H 0739–529 (Liu et al. 2000, and references therein). However, the nondetection of this source in the 0.16–4.0 keV band (Grillo et al. 1992) suggests that it may be transient. In summary, the association between HD 146803 and IGR J16207–5129 is still tentative and further multiwavelength investigations are needed to confirm the identification.

4.7. IGR J16482–3036

In the spectrum of this object the most striking spectral feature is a prominent and broad, redshifted $H_\alpha + [\text{N II}]$ emission blend topped by a narrow H_α emission component. A broad plus narrow H_β and broad H_γ emissions, the former flanked by narrow $[\text{O III}]$ emission, are also detected. Possibly, He I $\lambda 5875$ is also present in emission. All of the narrow features have a redshift $z = 0.0313 \pm 0.0006$, whereas that of the broad lines is $z = 0.036 \pm 0.001$; this kind of velocity shift between broad

and narrow line components is not uncommon in type 1 AGNs (e.g., Sulentic et al. 2000). All of the above information implies that this source is a type 1 Seyfert galaxy (see Veilleux & Osterbrock 1987).

Assuming the redshift obtained from the narrow lines and the cosmology described above, we obtain for IGR J16482–3036 a luminosity distance of 146 Mpc and X-ray luminosities of 2.1×10^{42} erg s⁻¹ and 6.9×10^{43} erg s⁻¹ in the 0.1–2.4 keV and 20–100 keV bands, respectively. These X-ray luminosity estimates place IGR J16482–3036 on the bright side of the Seyfert 1 galaxies distribution (Malizia et al. 1999). Analogously, this distance implies $M_B = -20.0$, again a lower limit to the *B*-band luminosity of IGR J16482–3036, as no absorption internal to the AGN host galaxy was accounted for.

Concerning this issue, the complex structure of the H α plus [N II] emissions does not allow us to obtain a reliable measure of the H α narrow component flux. Thus, in principle, we are not able to correct the optical spectrum of IGR J16482–3036 for any absorption that is intrinsic to the galaxy. However, assuming the same gaussian shape for the narrow Balmer components, we obtain an H α /H β flux ratio equal to the line peak ratio. Therefore, given that the latter ratio is ~ 2.7 , we can assume that no substantial further absorption is present within the galaxy, in agreement with its Seyfert 1 nature.

For this hypothesis of negligible internal absorption, and assuming an H α narrow-component flux of 2.6×10^{-13} erg cm⁻² s⁻¹, we can estimate the SFR in this galaxy. Again using Eq. (1) of Kennicutt (1998) and the luminosity distance derived above, we find a *SFR* of $\sim 5 M_{\odot}$ yr⁻¹.

The complexity of the H α plus [N III] emission region, together with the absence of [O II] within our spectral range, does not allow us to compute the metallicity of this galaxy. With the available spectral data only an approximate lower limit of ≈ 7.0 for the $12 + [\text{O}/\text{H}]$ parameter, corresponding to a metal abundance of $\approx 0.01 Z_{\odot}$, can be obtained using the R₂₃ parameter as described in Kobulnicky et al. (1999).

Next, following Kaspi et al. (2000) and Wu et al. (2004), we can compute an estimate of the mass of the central black hole in this active galaxy. This can be achieved using (i) the H β emission flux, corrected for a foreground Galactic color excess of $E(B - V) = 0.34$ (Schlegel et al. 1998) and (ii) a broad-line region (BLR) gas velocity $v_{\text{BLR}} \sim (\sqrt{3}/2) \cdot v_{\text{FWHM}} \sim 6600$ km s⁻¹ (where $v_{\text{FWHM}} \sim 7700$ km s⁻¹ is the rest-frame velocity measured from the H β emission FWHM). Using the above information, from Eq. (2) of Wu et al. (2004) we find that the BLR size is $R_{\text{BLR}} \sim 22$ light-days. Furthermore, using Eq. (5) of Kaspi et al. (2000), the AGN black hole mass in IGR J16482–3036 is $M_{\text{BH}} \sim 1.4 \times 10^8 M_{\odot}$.

5. Conclusions

We have presented the results of the third stage (the first one dealing with southern objects), this time accomplished at SAAO and at ESO, of our ongoing observational campaign aimed at the identification of newly-discovered *INTEGRAL* objects of unknown nature. We spectroscopically observed the putative optical counterparts of seven southern *INTEGRAL*

sources. For two cases, optical photometry was also obtained. This approach, already very successful as demonstrated in Papers I and II, allowed us to firmly determine the nature of at least four of these objects.

We found that: (i) IGR J10404–4625 (=LEDA 93974) is a Seyfert 2 galaxy in the Compton-thin regime at $z = 0.0237$; (ii) 2RXP J130159.6–635806 is a non-supergiant HMXB in the Crux Arm, at a distance ≈ 7 kpc; (iii) 4U 1344–60 is a Seyfert 1 galaxy at $z = 0.013$; and (iv) IGR J16482–3036 is a Seyfert 1 galaxy at $z = 0.0313$ with a central black hole of mass $\sim 1.4 \times 10^8 M_{\odot}$.

We also give possible identifications for three further cases, namely: (i) HD 306414 is the likely counterpart of IGR J11215–5952 and thus probably a SFXT HMXB located at a distance $d \sim 6.2$ kpc; (ii) HD 100199 is possibly associated with the hard X-ray source IGR J11305–6256, which, if correct, would then resemble the persistent HMXB X Per, but at a distance ~ 3 kpc; (iii) HD 146803 is tentatively associated with IGR J16207–5129; which would identify it as a HMXB, possibly similar to 1H 0739–529, and located at a distance of ~ 1.9 kpc. However, more extensive multiwavelength studies of the error boxes of these sources, especially through pointed soft X-ray observations (obtainable with satellites such as *Chandra*, *XMM-Newton* or *Swift*), will allow a conclusive test of these three possible associations.

Moreover, all of the above once again demonstrates, as already remarked in Papers I and II, that *INTEGRAL* is making a fundamental contribution to the detection and study of a substantial fraction of persistent and transient HMXBs along the Galactic Plane, and of background AGNs located beyond the Zone of Avoidance of the Galactic Plane.

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Note added in proof. Recent (24 December 2005) publicly-available observations of the field of IGR J11305–6256, performed with the XRT instrument onboard the *Swift* satellite, showed that the only X-ray source detected within the ISGRI error box is positionally fully consistent with star HD 100199. The accurate X-ray localization (J2000; RA = 11 31 06.5, Dec = $-62^{\circ}56'46''.6$, error radius: $6''$) afforded with XRT lies $3''.5$ from HD 100199 and thus proves beyond any reasonable doubt that, indeed, this star is the optical counterpart of IGR J11305–6256.

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