Unveiling the nature of INTEGRAL objects through optical spectroscopy. II. The nature of four unidentified sources

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Abstract. We present the results of our optical spectrophotometric campaign ongoing at the Astronomical Observatory of Bologna in Loiano (Italy) on hard X-ray sources detected by INTEGRAL. We observed spectroscopically the putative optical counterparts of four more INTEGRAL sources, IGR J12391−1610, IGR J18406−0539, 2E 1853.7+1534 and IGR J19473+4452. These data have allowed us to determine their nature, finding that IGR J12391−1610 (=LEDA 170194) and IGR J19473+4452 are Seyfert 2 galaxies at redshifts $z = 0.036$ and $z = 0.053$, respectively, IGR J18406−0539 (=SS 406) is a Be massive X-ray binary located at $\sim 1.1$ kpc from Earth, and 2E 1853.7+1534 is a Type 1 Seyfert galaxy with $z = 0.084$. Physical parameters for these objects are also evaluated by collecting and discussing the available multiwavelength information. The determination of the extragalactic nature of a substantial fraction of sources inside the INTEGRAL surveys underlines the importance of hard X-ray observations for the study of background Active Galactic Nuclei located beyond the ‘Zone of Avoidance’ of the Galactic Plane.

Key words. X-rays: galaxies — Galaxies: Seyfert — X-rays: binaries — Techniques: spectroscopic — X-rays: individuals: IGR J12391−1610 (=LEDA 170194); IGR J18406−0539 (=SS 406); 2E 1853.7+1534; IGR J19473+4452

1. Introduction

One of the objectives of using satellites observing in the hard X-ray band (above 20 keV) is to obtain all-sky maps of celestial high-energy emission. This allows information on the sky distribution and characteristics of X-ray objects to be obtained, and opens an observational window on new populations of sources. Previously, several surveys have been performed by various spacecraft, such as HEAO-1 (13–180 keV; Levine et al. 1984), SIGMA onboard Granat (40–800 keV; Vargas et al. 1996) and BATSE onboard Compton-GRO (25–160 keV; Shaw et al. 2004). These surveys were mostly devoted to all-sky scannings, with particular attention to the Galactic Plane and to the Galactic Centre. However, the main drawbacks of these past hard X-ray surveys were the poor positional accuracy afforded by the available technology (typical error boxes were of the order of some degrees) and/or the low survey sensitivity ($>30$ mCrab).

In this sense, INTEGRAL (Winkler et al. 2003) produced a breakthrough in all-sky mapping of hard X-ray sources in terms of both sensitivity and positional accuracy. Indeed, thanks to the capabilities of the IBIS instrument (Ubertini et al. 2003), INTEGRAL is able to detect hard X-ray sources at the mCrab level with a typical localization accuracy of $\sim 2-3'$ (Gros et al. 2003). This has made it possible, for the first time, to resolve crowded regions such as the Galactic Centre and the spiral arms, and discover many new hard X-ray extragalactic objects beyond the Galactic Plane (the so-called ‘Zone of Avoidance’), where the massive presence of neutral hydrogen hampers observations in soft X-rays.
Since the launch of INTEGRAL, the ISGRI detector of IBIS has detected about 150 sources above 20 keV (Bird et al. 2004; Bassani et al. 2004; Molkov et al. 2004; Revnivtsev et al. 2004a; Krivonos et al. 2005; Revnivtsev et al. 2005; Sazonov et al. 2005) down to mCrab sensitivities. In the widest and densest of these surveys (i.e., that of Bird et al. 2004), most of the detected sources match already known Galactic Low-Mass and High-Mass X-ray Binaries (LMXBs and HMXBs; \( \sim 60\% \)), background Active Galactic Nuclei (AGNs; \( \sim 4\% \)) and Cataclysmic Variables (CVs; \( \sim 4\% \)). The remaining objects (about 23% of the sample) had no obvious counterpart at other wavelengths and therefore could not immediately be associated with any known class of high-energy emitting objects.

The majority of these unidentified sources are believed to be Galactic X-ray binary systems, although a few of them have turned out to be AGNs (e.g., Masetti et al. 2004, hereafter Paper I; Combi et al. 2005). However, since all these objects are hard X-ray selected and poorly known at other wavebands, there are serious possibilities that we might also be dealing with known types of sources but in peculiar evolutionary stages (e.g., Filiatre & Chaty 2004; Dean et al. 2005).

In order to reduce the INTEGRAL error box, correlations with catalogs at longer wavelengths (soft X-ray, optical, near- and far-infrared, and/or radio) are needed. Indeed, cross-correlation of the IBIS 20–100 keV catalogue with the ROSAT database (Voges et al. 1999) indicates a high degree of association (Stephen et al. 2005). Moreover, it increases the positional accuracy to few arcsecs, thus making the optical searches much easier. Similarly, the presence of a radio object within the IBIS error box can again be seen as an indication of an association between the radio emitter and the INTEGRAL source (e.g., Combi et al. 2005; Paper I). However, whereas the cross-correlation with catalogs at other wavebands is critical in pinpointing the putative optical candidates, only accurate optical spectroscopy can reveal the real nature of the X-ray emitting object.

For this reason, we started a program to perform optical spectroscopy of currently unidentified IBIS/INTEGRAL sources. Among these sources we have selected a sample of objects for which likely candidates could be pinpointed. In particular, we have selected our targets on the basis of their association with sources at other wavebands, mainly in the soft X-ray and radio. We have already been successful in providing the optical spectroscopic identification for 3 objects (Paper I).

Here we report results obtained at the Astronomical Observatory of Bologna in Loiano on a further group of four sources extracted from the forthcoming 2nd IBIS/INTEGRAL survey (Bassani et al. 2005; Bird et al. 2005), from the INTEGRAL Sagittarius Arm Tangent survey (Molkov et al. 2004), and from the INTEGRAL/Chandra minisurvey of Sazonov et al. (2005). In Sect. 2 we present the sample of objects selected for the observational campaign shown here, whereas in Sect. 3 a description of the observations is given; Sect. 4 reports the results for each source and a discusses them. 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, whereas for the INTEGRAL error box size a conservative 90% confidence level radius of 3′ will be considered.

2. The selected sample

**IGR J12391−1610**: listed in the 2nd IBIS survey (Bassani et al. 2005; Bird et al. 2005), as well as in the INTEGRAL/Chandra minisurvey of Sazonov et al. (2005), this object was detected by ISGRI at coordinates RA = 12h 39m 11.0, Dec = −16° 10′ 55″ (J2000), with fluxes (2.0±0.4)×10^{-11} erg cm^{-2} s^{-1} and (5.2±0.8)×10^{-11} erg cm^{-2} s^{-1} in the 20–40 and 40–100 keV bands, respectively. Within the INTEGRAL error box a soft X-ray source was detected by Chandra at a 0.5−8 keV flux of (2.0±0.3)×10^{-12} erg cm^{-2} s^{-1}; for details, see Sazonov et al. (2005) and Halpern (2005). We remark that these authors labeled the source as IGR J12391−1612. At the Chandra subarcsecond X-ray position (RA = 12h 39m 06.29, Dec = −16° 10′ 47.1″; equinox J2000; error radius: \( \sim 0′.6 \)), the apparently ‘normal’ and optically fairly bright (\( B \approx 15 \) mag) S0-type galaxy LEDA 170194 (Paturel et al. 2003) is present (Fig. 1, top left panel). Although a redshift (\( z = 0.0367±0.0001; \) da Costa et al. 1998) is reported, no classification is available in the literature for this galaxy. However, its characteristics, such as the detection at longer wavebands including near- (2MASX J12390630−1610472) and far-infrared (IRAS 12365−1554), as well as in the radio (NVSS J123906−161046; 39±1.6 mJy at 1.4 GHz; Condon et al. 1998), suggest that it might be an active galaxy. Its position well above the Galactic Plane (\( b = +46°6′ \)), together with the very accurate Chandra localization, excludes the possibility of a misidentification.

Searches in X-ray catalogues, and in the ROSAT all-sky survey (Voges et al. 1999) in particular, indicate that, despite its brightness in the 20−100 keV band, no higher-energy data exist for this source below 20 keV. However, Revnivtsev et al. (2004b) and Sazonov & Revnivtsev (2004) report the existence of the RXTE source XSS J12389−1614. Albeit with large (\( \sim 1° \)) positional uncertainty, its localization is consistent with the hard X-ray emission seen with INTEGRAL. It has 3–8 keV and 8–20 keV fluxes of (0.9±0.1)×10^{-11} erg cm^{-2} s^{-1} and (1.0±0.2)×10^{-11} erg cm^{-2} s^{-1}, respectively.

We moreover note that, in the INTEGRAL and IRAS error boxes of IGR J12391−1610, a further radio emitter (labeled as NVSS J123911−161041) is found with a flux of 3.8±0.5 mJy at 1.4 GHz (Condon et al. 1998). Just outside the 3-σ error circle of this radio source, the edge-on spiral galaxy (2MASX J12391039−1610432), located at \( \sim 1′ \) from LEDA 170194, is present. For this latter object, no information is available in the literature.

**IGR J18406−0539**: this source, with ISGRI coordinates RA = 18h 40m 55s, Dec = −05° 39′ 00″ (J2000),
was detected at a $(2.7\pm0.4)\times10^{-11}$ erg cm$^{-2}$ s$^{-1}$ flux in the 18–60 keV band (Molkov et al. 2004). Within the INTEGRAL error box no peculiar catalogued X-ray or radio object is reported. However, at the southwestern edge of the error box, the optical emission-line star SS 406 is found (see Fig. 1, top right panel). Stephenson & Sanduleak (1977) classified SS 406 as a probable OBe star with weak H$_\alpha$ emission. The possible identification of this hard X-ray object as an early-type emission-line star suggests that SS 406 could be the counterpart of IGR J18406–0539, in analogy with other HMXBs detected with INTEGRAL (e.g., Reig et al. 2005). This star is present in the Tycho catalogue (Høg et al. 2000) with magnitudes $B_T = 12.857 \pm 0.309$ mag and $V_T = 11.958 \pm 0.222$ mag. These, using appropriate conversion formulae (ESA 1997), correspond to a magnitude $V = 11.88 \pm 0.23$ mag and to a color index $B - V = 0.76 \pm 0.32$ mag in the Johnson system.

$2E$ 1853.7+1534: this object has also been detected in the forthcoming 2nd IBIS survey (Bassani et al. 2005; Bird et al. 2005) at coordinates RA = $18^h 56^m 01.9^s$, Dec = $+15^\circ 37' 16''$ (J2000), with fluxes $(2.1\pm0.2)\times10^{-11}$ erg cm$^{-2}$ s$^{-1}$ (20–40 keV) and $(1.9\pm0.4)\times10^{-11}$ erg cm$^{-2}$ s$^{-1}$ (40–100 keV). This IBIS source is positionally coincident with an old Einstein detection (McDowell 1994), at a flux of $\sim10^{-12}$ erg cm$^{-2}$ s$^{-1}$ in the 0.16–3.5 keV band. It is also consistent with a ROSAT HRI/BMW object, 1BMW J185600.5+153757 (Panzer et al. 2003), at a $0.1$–$2.0$ keV flux comparable to that of 2E 1853.7+1534. The coordinates (J2000) of this ROSAT object are RA = $18^h 56^m 00.4^s$, Dec = $+15^\circ 37' 56''$, with a total error radius of $8''$ once all systematic uncertainties are taken into account (Panzer et al. 2003). A radio source, NVSS J185600+153755, with a 1.4 GHz flux density of $3.4\pm0.4$ mJy (Condon et al. 1998) and total positional uncertainty of 0.3 arcmin is also found in coincidence with the ROSAT position. The arcsec-sized ROSAT and NVSS detections allowed us to identify 2E 1853.7+1534 with an USNO-A2.0 object (Fig. 1, bottom left panel) having optical magnitudes $R \sim 15.9$ and $B \sim 18.4$. These magnitudes indicate that this source is quite red ($B - R \sim 2.5$ mag), possibly as a consequence of its location projectionally close to the Galactic Plane ($b = +6^\circ1$). Its apparently extended shape, as seen on the DSS-II-Red Survey sources 3, points to an extragalactic origin for 2E 1853.7+1534.

IGR J19473+4452: it is one of the 8 objects included in the INTEGRAL/Chandra minisurvey of Sazonov et al. (2005), with ISGRI coordinates RA = $19^h 47^m 20.6^s$, Dec = $+44^\circ 51' 50''$ (J2000). These authors report that this source has 0.5–8 keV and 17–60 keV fluxes of $(3.0\pm1.0)\times10^{-12}$ erg cm$^{-2}$ s$^{-1}$ and $(2.5\pm0.4)\times10^{-11}$ erg cm$^{-2}$ s$^{-1}$, respectively; moreover, a large neutral hydrogen column density, $N_H = (11\pm1)\times10^{22}$ cm$^{-2}$, appears to be present along the line of sight of this object according to their X-ray spectral data fitting. At the subarcsecond Chandra position, RA = $19^h 47^m 19.37^s$, Dec = $+44^\circ 49' 42.4''$ (J2000; error radius: $\sim0''6$), a relatively bright optical and near-infrared object is detected (in Fig. 1, bottom right panel; see also Halpern 2005 and Sazonov et al. 2005) with USNO-A2.0 magnitudes $R \sim 15.2$ mag and $B \sim 15.7$. This, despite the large $N_H$ estimate above, indicates that the optical object is remarkably blue. Preliminary results from Sazonov et al. (2005) show that this is an extragalactic object, most likely an AGN, with redshift $z = 0.0539$. No clearer indication on the exact nature of this source is however reported by these authors.

3. Optical observations in Loiano

The Bologna Astronomical Observatory 1.52-metre “G.D. Cassini” telescope plus BFOSC was used to spectroscopically observe the galaxy LEDA 170194, the OBe star SS 406, and the putative optical counterparts to the INTEGRAL sources 2E 1853.7+1534 and IGR J19473+4452 (see Fig. 1). The BFOSC instrument is equipped with a 1300×1340 pixel EEV CCD. In all observations, Grism #4 and a slit width of 2′′ were used, providing a 3500–8500 Å nominal spectral coverage. The use of this setup secured a final dispersion of 4.0 Å/pix for all spectra. The spectrum of LEDA 170194 was acquired in such a way that the slit also included the closeby galaxy 2MASX J12391039–1610432. All observations were performed with the slit in the E-W direction: this, in particular for LEDA 170194 which was observed at large airmass ($\sim2$), may induce nonperfect flux calibration at the blue edge of the spectrum (that is, bluewards of 4000 Å) due to the fact that the slit was not oriented along the parallactic angle. The complete log of the observations is reported in Table 1.

The spectra, after cosmic-ray rejection, were reduced, background subtracted and optimally extracted (Horne 1986) using IRAF3. Wavelength calibration was performed using He-Ar lamps acquired soon after each spectroscopic exposure; all spectra were then flux-calibrated by applying a library response function built using the spectrophotometric standard BD+25°3941 (Stone 1977). When applicable, different spectra of the same object were stacked together to increase the S/N ratio. Wavelength calibration uncertainty was $\sim0.5$ Å for all cases; this was checked by using the positions of background night sky lines.

4. Results and discussion

Table 2 reports the (observer’s frame) emission-line wavelengths, fluxes and equivalent widths (EWs) of the five observed objects reported in Fig. 2. The line fluxes from

1 available at http://archive.eso.org/skycat/servers/usnoa
2 available at http://archive.eso.org/dss/dss/
3 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 U.S. National Science Foundation. It is available at http://iraf.noao.edu/
extragalactic objects were dereddened for Galactic absorption along the respective lines of sight following the prescription of Schlegel et al. (1998; see below). These same spectra were also not corrected for starlight contamination (see, e.g., Ho et al. 1993, 1997) given the limited S/N and resolution of the spectrum; however, we do not expect that this will affect any of our conclusions. Moreover, in the following we assume a cosmology with \( H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}, \Omega_\Lambda = 0.7 \) and \( \Omega_m = 0.3 \) (e.g., Koopmans & Fassnacht 1999).

4.1. IGR J12391−1610 (=LEDA 170194)

The spectra of the galaxy LEDA 170194 (Fig. 2, upper left) shows a number of narrow emission features that can be readily identified with redshifted optical nebular lines.
These include [O II] $\lambda 3727$, $H_\beta$, [O III] $\lambda \lambda 4958,5007$, $H_\alpha$, [N II] $\lambda \lambda 6548,6583$, and [S II] $\lambda \lambda 6716,6731$. All identified emission lines yield a redshift of $z = 0.036\pm0.001$, in perfect agreement with da Costa et al. (1998). The NaD doublet in absorption is also detected at the same redshift.

The presence of just narrow emission lines in the optical spectrum of LEDA 170194 indicates that they are due to the activity of an obscured AGN; this is also suggested by the NVSS radio detection and by the ROSAT non-detection in soft X-rays. We further confirm this by using the diagnostic line ratios $[\text{N II}]/H_\alpha = 0.95\pm0.04$, $[\text{S II}]/H_\alpha = 0.86\pm0.04$, and $[\text{O III}]/H_\beta = 8.7\pm0.7$, together with the detection of substantial [O I] $\lambda 6300$ emission: the values of these parameters place this source in the regime of Seyfert 2 AGNs (Ho et al. 1993, 1997).
Using the cosmology described above and the more accurate redshift of da Costa et al. (1998) we find that the luminosity distance to the galaxy LEDA 170194 is $d_L = 174$ Mpc, and that its X-ray luminosities are $7.4 \times 10^{42}$ erg s$^{-1}$ and $2.6 \times 10^{44}$ erg s$^{-1}$ in the 0.5–8 keV and 20–100 keV bands, respectively. These values place the source among the most luminous Type 2 Seyfert galaxies detected so far (e.g., Risaliti 2002; Sazonov & Revnivtsev 2004). The measured values for the X-ray luminosities of LEDA 170194 are thus comparable with that of "classical" AGNs.

The strength of the optical emission lines of LEDA 170194, after accounting for Galactic and intrinsic absorptions, can be used to estimate the star formation rate (SFR) and metallicity. First, a correction for Galactic reddening has been applied (we assumed a color excess $E(B-V) = 0.046$ mag following Schlegel et al. 1998). Next, considering an intrinsic Balmer decrement of Cardelli et al. (1989), the observed flux ratio $H_\beta/H_\alpha = 6.4$ implies an internal color excess $\alpha$ of Cardelli et al. (1989), the observed flux ratio $H_\beta/H_\alpha = 6.4$ implies an internal color excess $E(B-V) = 0.80$ mag (in the galaxy rest frame). Following Kennicutt (1998), we determine a SFR of $10^{\pm1} M_\odot$ yr$^{-1}$ from the reddening-corrected H$_\alpha$ luminosity of $(1.20 \pm 0.08) \times 10^{42}$ erg s$^{-1}$. The method (again in Kennicutt 1998) which instead uses the extinction-corrected [O III] luminosity, $(8.0 \pm 0.7) \times 10^{42}$ erg s$^{-1}$, yields a much larger SFR value, $110 \pm 30 M_\odot$ yr$^{-1}$. This high value, so different from that obtained using the H$_\alpha$ emission, may be produced by the abovementioned uncertainty in the flux calibration of the spectrum at its blue edge (see Sect. 3), so we should treat this latter SFR estimate very cautiously. Moreover, as stressed by Kennicutt (1998), the SFR determination from the [O III] line flux suffers from larger uncertainties with respect to that obtained from the H$_\alpha$ emission line.

The total reddening estimate along the line of sight inferred from the optical spectrum corresponds, using the empirical formula of Predel & Schmitt (1995), to a $N_H \approx 5 \times 10^{21}$ cm$^{-2}$, which is $\sim 4$ times less than that measured by Sazonov et al. (2005) from Chandra X-ray data.

Next, assuming for IGR J12391−1610 the best-fit X-ray spectrum as in Sazonov et al. (2005), we can determine the 2–10 keV flux of the source. This results in $2.2 \times 10^{42}$ 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 $\sim 2.5$, which indicates that this source is in the Compton-thick regime (see Bassani et al. 1999).

Although, as we said above, the [O II] emission line flux estimate is affected by large uncertainties, the detection of [O II], [O III], and H$_\beta$ also allows us to infer the gaseous oxygen abundance in this galaxy. Following Koubelnicky et al. (1999), the $R_{23}$ parameter, defined as the ratio between [O II] + [O III] and H$_\beta$ line fluxes, gives $12 + \log (O/H) \approx 8.5$. Considering the intrinsic luminosity of the source (it has rest-frame absolute $B$-band magnitude $M_B = -21.27$ mag; Prugniel 2005) and its [O III]/[N II] ratio ($\sim 3$), all of this information points to a basically solar oxygen abundance. A similar result is obtained if we use the [N II]/H$_\alpha$ flux ratio method (Kewley & Dopita 2002).

As mentioned in Sect. 3, we also acquired a spectrum of 2MASX J12391039−1610432, the edge-on galaxy located 1′ east of LEDA 170194. The spectrum, albeit noisy (see Fig. 2, upper right), shows the presence of prominent and narrow H$_\alpha$ and [N II] $\lambda\lambda 6548,6583$ emission lines at redshift $z = 0.071\pm0.001$. In this case also, the NaD doublet in absorption is detected at this same redshift. This implies a luminosity distance $d_L = 345$ Mpc for this galaxy, thus twice as far from Earth as LEDA 170194.

The detection of [N II] and H$_\alpha$ in the spectrum of 2MASX J12391039−1610432 also allows us to infer the gaseous oxygen abundance in this galaxy. The use of the [N II]/H$_\alpha$ ratio method (among those listed in Kewley & Dopita 2002) for the determination of the metallicity of this galaxy is indicated because it is the least sensitive to, and therefore not substantially influenced by, the lack of our knowledge of the absorption intrinsic to this galaxy. Indeed, the two emission lines are so close to each other that the differential intrinsic reddening is not significant. We thus find that the [N II]/H$_\alpha$ ratio observed here implies $12 + \log (O/H) \approx 9$. Therefore, in this case also we find an oxygen abundance which is consistent with the solar value.

The intensity of the H$_\alpha$ emission line of 2MASX J12391039−1610432, once corrected for the Galactic absorption, can also be used to estimate the SFR in this galaxy. Using Eq. (2) of Kennicutt (1998) we determine a SFR of $1.40\pm0.15 M_\odot$ yr$^{-1}$. This should conservatively be considered as a lower limit to the SFR because the effect of absorption intrinsic to 2MASX J12391039−1610432 was not accounted for.

The poor S/N of the spectrum of this source does not allow us to deduce much more about the nature of this narrow H$_\alpha$ emission-line galaxy. We of course can exclude that it is a Seyfert 1 type AGN due to the absence of broad emission lines. But, given its optical (and maybe radio) activity, we cannot a priori exclude that this object is co-responsible, together with LEDA 170194, for the X-ray emission detected by INTEGRAL as IGR J12391−1610. However, a quick look at a 3.3 ks Chandra observation (Seq. Num.: 701178, Obs. ID: 6276, PI: R.A. Sunyaev) acquired on July 25, 2005, does not show detectable X-ray emission either at the 2MASX J12391039−1610432 position or within the NVSS J123911−161041 radio error circle, whereas X-rays are clearly detected from LEDA 170194 (see also Halpern 2005 and Sazonov et al. 2005). This implies that either the soft (<10 keV) X-ray emission, if any, from the former sources is heavily absorbed or, more likely, that they are not X-ray emitting and that LEDA 170194 is solely responsible for the hard X-rays detected by INTEGRAL. In this latter case, the galaxy 2MASX J12391039−1610432 can be identified as a starburst/HII galaxy.

Regarding the association between this galaxy and the nearby NVSS radio source, we note that, given the relatively low S/N ratio of the radio detection, the NVSS...
position and the corresponding uncertainties may not be very accurate; so, they might actually be positionally consistent with each other. Thus, only detailed radio observations can give an answer to this open issue.

| Line          | λ_{Obs} (Å) | EW_{Obs} (Å) | Flux   |
|---------------|-------------|--------------|--------|
| IGR J12391−1610 (=LEDA 170194) |   |   |   |
| [O ii] λ5727  | 3858        | 85±10        | 64±4   |
| Hα           | 5039        | 8.6±0.6      | 7.9±0.6|
| [O iii] λλ4958,5007 | 5139,789 | 26.5±1.3,75±2 | 24.3±1.2,69±2 |
| [O i] λλ6300,6363 | 6526,6591 | 16.8±0.8,6.2±0.4 | 17.3±0.9,6.2±0.4 |
| [N ii] λ6583  | 46.5±1.4    | 47.7±1.4     |        |
| Hα           | 4919        | 15.0±1.5     | 50.2±1.5|
| [S ii] λλ6716,6731 | 6959,6973 | 22.6±1.1,19.0±1.0 | 23.6±1.2,19.8±1.0 |

| 2MASX J12391039−1610432 |   |   |   |
| [N ii] λ6583  | 7013        | 0.53±0.13    | 2.0±0.5 |
| Hα           | 7030        | 3.3±0.3      | 12.5±1.3|
| [S ii] λλ6716,6731 | 7052,6973 | 1.9±0.3,19.0±1.0 | 7.1±1.1,19.8±1.0 |

| IGR J18406−0539 (=SS 406) |
|---------------------------|
| Hα|5699 |10.6±0.2 |680±30 |

| IGR J19473+4452 |
|----------------|
| [O ii] λλ3727,4363 | 3920,5372 | 23.6±6,11±3 | 8±2,20±5 |
| Hα|5224 |6.6±1.3 |2.4±0.5 |
| [O iii] λλ4958,5007 | 5274,5274 | 25.3±9,76±44 | 9.0±0.9,75±11 |
| [O i] λλ6300,6363 | 6636,6936 | 3.5±0.9,7.3±0.7 | 1.1±0.3,2.3±0.2 |
| Hα|6913 |35±4 |11.2±0.8 |
| N ii] λ6583,6936 | 6936,7.3±0.7 | 2.3±0.2 |
| [S ii] λλ6716,6731 | 7077,7093 | 7.6±0.8,3.2±0.5 | 2.4±0.2,1.01±0.15 |

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

4.2. IGR J18406−0539 (=SS 406)

The optical spectrum of SS 406 is reported in the central left panel of Fig. 2. The absence of He II lines points to a B-star classification for this object. Moreover, the shape of the Balmer absorption lines, along with the detection of fainter absorption features produced by He i λλ4026,4471 and by light metals (such as Si II λλ4128, C II λλ4267 and Mg II λλ4481), points to a main-sequence, mid-type B star (most likely B5) identification. Finally, the presence of a strong Hα line in emission (possibly showing a P-Cyg profile) allows us conclusively to classify SS 406 as a Be star.

Assuming no absorption along the line of sight, a spectral type B5V for SS 406 (which implies an absolute magnitude M_V = −1.2 mag; Jaschek & Jaschek 1987) and using the observed V-band magnitude V = 11.88±0.23 mag (See Sect. 1.2), one obtains that the distance to the source is d ∼ 4 kpc. This should be considered as an upper limit, as no correction for Galactic absorption was taken into account. However, we expect that significant reddening is present towards SS 406, given its Galactic latitude (b = −0.0°), the shape of its observed spectral continuum, the total EW (4.5±0.2 Å) of the Na Doublet at 5890 Å, and the presence of other absorption features which are due to interstellar matter (see Fig. 2, central left panel).

A more accurate estimate for the distance can be obtained by considering the intrinsic and observed B − V color indices of the star, i.e. (B − V)_0 = −0.15 mag (Wegner 1994) and B − V = 0.76±0.32 mag, respectively. Their difference implies a color excess E(B − V) = 0.91±0.32 for SS 406 in the hypothesis that no further emission from the accreting object contributes to the total optical light. By correcting for this color excess using the reddening law of Cardelli et al. (1989), we get an apparent unabsorbed V-band magnitude V_0 = 9.0±1.0 mag, which in turn gives a distance d = 1.1±0.6 kpc assuming the absolute V magnitude reported above. This distance is marginally compatible with SS 406 being located in the Sagittarius Arm (which lies at ~2 kpc; see, e.g., Molkov et al., 2004), and implies an 18–60 keV luminosity of ~4×10^{33} erg s^{-1}. This, together with the EW of the Hα emission line, is typical of low-luminosity, persistently-emitting Galactic HMXBs (see e.g. White et al. 1995).

We note that IGR J18406−0539 is located ~4′ away (and not 7′ as reported in Rodriguez et al. 2004) with respect to the other INTEGRAL/ASCA transient source IGR J18410−0535/AX J1841.0−0536, thus marginally consistent with it (Halpern et al., 2004; Bamba et al., 2001; Rodriguez et al., 2004). However, the fact that the refined Chandra position and the optical counterpart to IGR J18410−0535 (Halpern & Gotthelf 2004) lie 3′5 from the IGR J18406−0539 position, thus formally outside its error box (and moreover are 6′1 away from SS 406), suggests that these two INTEGRAL sources are not the same.

Besides, assuming an average number of ~0.05 Be stars per arcmin^2 along the Galactic Plane (see Reig et al., 2005), we find that the chance probability of observing two Be stars within a radius of ~3′ is around 7%. Thus,
although we cannot exclude that IGR J18460–0539 and IGR J18410–0535 are the same source (in this case, the detection of the former actually corresponds to the quiescent state of the latter) we put forward that, if the two INTEGRAL sources are independent, we regard the association between IGR J18406–0539 and SS 406 as likely.

4.3. 2E 1853.7+1534

In the spectrum of 2E 1853.7+1534 (in Fig. 2, centre right) the most striking spectral feature is a prominent and broad redshifted H$_\alpha$+[N II] emission blend. A broad H$_\beta$ emission line, as well as [O III] $\lambda$5007 narrow forbidden lines and possibly a broad He I $\lambda$5875 emission are also detected. All of these features have a redshift $z = 0.084 \pm 0.001$. The presence of these emissions imply that this source is a Type I Seyfert galaxy according to, e.g., the classification of Osterbrock (1989).

Assuming the cosmology described above, this redshift means a luminosity distance of 412 Mpc for 2E 1853.7+1534 and X-ray luminosities of $2.0 \times 10^{43}$ erg s$^{-1}$ and $8.1 \times 10^{44}$ erg s$^{-1}$ in the 0.1–2 keV and 20–100 keV bands, respectively. Analogously, this distance implies an absolute optical B-band magnitude $M_B \sim -23.5$ mag. This is, strictly speaking, an actual lower limit to the B-band luminosity of 2E 1853.7+1534, as no absorption internal to the AGN host galaxy was considered. However, substantial intrinsic reddening is not expected in Seyfert 1 galaxies, so we can confidently consider this value for $M_B$ as close to the real one. All of these luminosity estimates place 2E 1853.7+1534 at the bright end of the Seyfert 1 galaxies distribution (Perola et al. 2002).

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 flux of the H$_\beta$ emission (in Table 2), corrected considering a foreground Galactic color excess $E(B-V) = 0.94$ (Schlegel et al. 1998) and (ii) a broad-line region gas velocity $v_{\text{BLR}} \sim (\sqrt{3}/2) v_{\text{FWHM}} \sim 4200$ km s$^{-1}$ (where $v_{\text{FWHM}} \sim 4800$ km s$^{-1}$ is the velocity measured from the FWHM of the H$_\beta$ emission line). From Eq. (2) of Wu et al. (2004) we find that the BLR size is $R_{\text{BLR}} \sim 54$ light-days. Furthermore, using Eq. (5) of Kaspi et al. (2000), the AGN black hole mass in 2E 1853.7+1534 is $M_{\text{BH}} \sim 1.4 \times 10^8 M_\odot$. Again, this is a lower limit (but likely close to the real value for the reasons explained above) as no absorption intrinsic to the AGN was accounted for.

4.4. IGR J19473+4452

Analogously to the case of the LEDA 170194 (Sect. 4.1), the spectrum of the putative counterpart to IGR J19473+4452 (Fig. 2, lower left) shows several narrow emission lines, which we identified as [O II] $\lambda\lambda$727, H$_\beta$, [O III] $\lambda\lambda$4958,5007, H$_\alpha$, [N II] $\lambda\lambda$6583, and [S II] $\lambda\lambda$6716,6731. All of these emission features lie at a redshift $z = 0.053 \pm 0.001$, consistent with Sazonov et al. (2005).

In this case also, the exclusive presence of narrow emission lines in the spectrum of the optical counterpart to IGR J19473+4452 points to the fact that they originate within a Narrow-Line Region of an AGN. A confirmation of this comes by examining the diagnostic line ratios of Ho et al. (1993, 1997). These, [N II]/H$_\alpha = 0.21 \pm 0.03$, [S II]/H$_\alpha = 0.30 \pm 0.06$ and [O III]/H$_\alpha = 11.2 \pm 2.3$, place IGR J19473+4452 among Seyfert 2 AGNs.

To compute the internal reddening of this AGN, we again use the procedure described in Sect. 3.1. We find that the $H_\alpha/H_\beta$ flux ratio, once corrected for the Galactic absorption $E(B-V) = 0.20$ mag (according to Schlegel et al. 1998), is 4.59; this indicates a rest-frame internal color excess $E(B-V) = 0.48$ mag for IGR J19473+4452. We note that the total reddening estimate along the line of sight corresponds, using the empirical formula of Predehl & Schmitt (1995), to a neutral hydrogen column density $N_H \approx 4 \times 10^{21}$ cm$^{-2}$, that is $\sim 30$ times less than the $N_H$ measure obtained by Sazonov et al. (2005) from Chandra X-ray data.

The measured redshift implies a luminosity distance to this source of 254 Mpc, and thus X-ray luminosities of $2.3 \times 10^{43}$ erg s$^{-1}$ and $1.9 \times 10^{44}$ erg s$^{-1}$ in the 0.5–8 keV and 17–60 keV bands, respectively. Using the $B$-band optical magnitude of this object, the above distance points to an absolute $B$ magnitude $M_B \sim -23.4$ mag. These values place this source in the bright side of the Type 2 Seyfert galaxies luminosity distribution (Risaliti 2002; Sazonov & Revnivtsev 2004).

In the same way as performed for IGR J12391–1610, we can determine the Compton regime for IGR J19473+4452. Using the X-ray spectral information of Sazonov et al. (2005), we obtain a 2–10 keV flux of $4.0 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$. This implies an $X$-[O III]$_{5007}$ ratio of $\sim 30$, indicating that this source is well in the Compton-thin regime for Seyfert 2 galaxies (Bassani et al. 1999).

For IGR J19473+4452 we can calculate, after having taken into account the Galactic and intrinsic absorptions, the SFR and metallicity of this galaxy. Again following Kennicutt (1998), we determine a SFR of $2.1 \pm 0.2$ $M_\odot$ yr$^{-1}$ from the reddening-corrected $H_\alpha$ luminosity of $(2.64 \pm 0.18) \times 10^{41}$ erg s$^{-1}$. The method (again in Kennicutt 1998) which instead uses the extinction-corrected [O II] luminosity, $(5.3 \pm 1.3) \times 10^{42}$ erg s$^{-1}$, gives a SFR of $7 \pm 3$ $M_\odot$ yr$^{-1}$, which is larger than, but still consistent with (at the 90% confidence level) that derived using the $H_\alpha$ emission line flux.

Moreover, the detection of [O II], [O III] and $H_\beta$ also allows us to infer the gaseous oxygen abundance of this galaxy. In this occurrence also, the application of the Kobulnicky et al.’s (1999) method implies a basically solar oxygen abundance. Similar results are obtained using the [N II]/H$_\alpha$ flux ratio method (Kewley & Dopita 2002).
4.5. The nature of optically identified INTEGRAL sources

Summing up all the knowledge available in the literature, at present (November 2005) 16 unknown or newly-discovered INTEGRAL sources were identified by means of optical spectroscopy. These are 2 LMXBs (Paper I; Roelofs et al. 2004), 7 HMXBs (this work; Reig et al. 2005; Halpern & Gotthelf 2004; Torrejón & Negueruela 2004; Negueruela et al. 2005 and references therein), 1 CV (Cieslinski et al. 1994; Masetti et al. 2005) and 6 AGNs (this work; Paper I; Torres et al. 2004). In percentages, these numbers translate into 56% of XRBs (with 78% of them being HMXBs and 22% being LMXBs), 38% of AGNs and 6% of CVs.

If we compare these numbers with those coming out of the group of the 95 identified objects belonging to the 1st IBIS/INTEGRAL survey (Bird et al. 2004), that is, 80% of XRBs (with only 30% of them being HMXBs in this sample), 5% of AGNs and 5% of CVs, we see that a substantial fraction of the INTEGRAL sources identified a posteriori through optical spectroscopy and lying in the Galactic Plane is made of background AGNs. Albeit these small numbers do not allow us to perform an in-depth statistical analysis of the sample, we put forward the idea that INTEGRAL is a fundamental instrument with which to explore the Zone of Avoidance of the Galaxy not only for Galactic sources but also, and apparently mainly, for objects lying beyond the Galaxy. Besides, within the class of XRBs, a larger number of HMXBs, with respect to that of LMXBs, is detected among the unknown INTEGRAL sources.

Walter et al. (2004) already noted that INTEGRAL allowed the discovery of a new population of absorbed transient supergiant HMXBs; moreover, INTEGRAL doubled the number of known Galactic HMXBs with supergiant companion (Walter et al. 2005). We stress here that, equivalently, this hard X-ray telescope is also allowing us to pin down new AGNs lying in a strip of the sky which up to now has been poorly, or at least not carefully, explored in a systematic way.

5. Conclusions

In a sequel of the work started in Paper I, we have identified four more INTEGRAL sources by means of optical spectroscopy acquired at the Astronomical Observatory of Bologna in Loiano (Italy).

We determined their nature as follows: (i) IGR J12391−1610 is an X-ray luminous Type 2 Seyfert galaxy in the Compton-thick regime, located at $z = 0.036$, with solar metallicity and SFR $\sim 10 M_\odot$ yr$^{-1}$; (ii) IGR J18406−0539 is a Be/X HMXB at a distance of $\sim 1.1$ kpc from Earth and marginally consistent with being located in the Sagittarius Arm of the Galactic Disk; (iii) 2E 1853.7+1534 is a luminous Type 1 Seyfert galaxy at $z = 0.084$ with a central black hole of mass $\sim 1.4 \times 10^8 M_\odot$; (iv) IGR J19473+4452 is a bright, Compton-thin regime, Seyfert 2 galaxy at $z = 0.053$ with solar metallicity and SFR $\sim 2 M_\odot$ yr$^{-1}$.

We have also determined the nature and redshift ($z = 0.071$) of a starburst/H II galaxy located 1$'$ east of LEDA 170194, the optical counterpart to IGR J12391−1610; we moreover regard as unlikely any contribution of that field galaxy to the total X-ray emission detected as IGR J12391−1610.

The statistical analysis of the (admittedly small, but growing) number of INTEGRAL unknown or newly-discovered sources, the nature of which is being pinpointed through optical spectroscopy, shows that a substantial fraction of them is of extragalactic origin. This underscores the importance of hard X-ray observations for the study of background AGNs located beyond the Zone of Avoidance of the Galaxy.

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