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Unveiling the nature of *INTEGRAL* objects through optical spectroscopy

II. The nature of four unidentified sources⋆

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ABSTRACT

We present new results from our optical spectrophotometric campaign ongoing at the Astronomical Observatory of Bologna in Loiano (Italy) on hard X-ray sources detected by *INTEGRAL*. We have 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 ∼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 – X-rays: binaries – 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 operating 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 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 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.

⋆ Based on observations collected at the Astronomical Observatory of Bologna in Loiano, Italy.

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; Revnivstev et al. 2004a; Krivonos et al. 2005; Revnivstev et al. 2005; Sazonov et al. 2005) down to mCrab sensitivities. In the widest and deepest survey (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; ~60%), background Active Galactic Nuclei (AGNs; ~4%) and Cataclysmic Variables (CVs; ~4%). Several remaining sources (about 23% of the sample) had instead 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 objects 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., Filliatre & Chaty 2004; Dean et al. 2005).

In order to reduce the *INTEGRAL* error box, correlations with catalogues 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 catalogues 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 programme to perform optical spectroscopy of currently unidentified IBIS/*INTEGRAL* sources. From 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 2$^{\rm nd}$ 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; in Sect. 4 we report the results for each source and discuss 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, while for the *INTEGRAL* error box a conservative 90% confidence level radius of 3′ will be used.

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 = $12^{\rm h}39^{\rm m}11\overset{\rm s}{.}0$, 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 = $12^{\rm h}39^{\rm m}06\overset{\rm s}{.}29$, Dec = $-16°10'47\overset{''}{.}1$; equinox J2000; error radius: ~$0\overset{''}{.}6$), the apparently "normal" and optically fairly bright (B ~ 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: 39.4 ± 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 = $+46\overset{\circ}{.}6$), 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 high-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 (~1°) positional uncertainty, its position 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 ~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 = $18^{\rm h}40^{\rm m}55\overset{\rm s}{.}2$, Dec = $-05°39'00''$ (J2000), was detected at a (2.7 ± 0.4) × 10^{-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

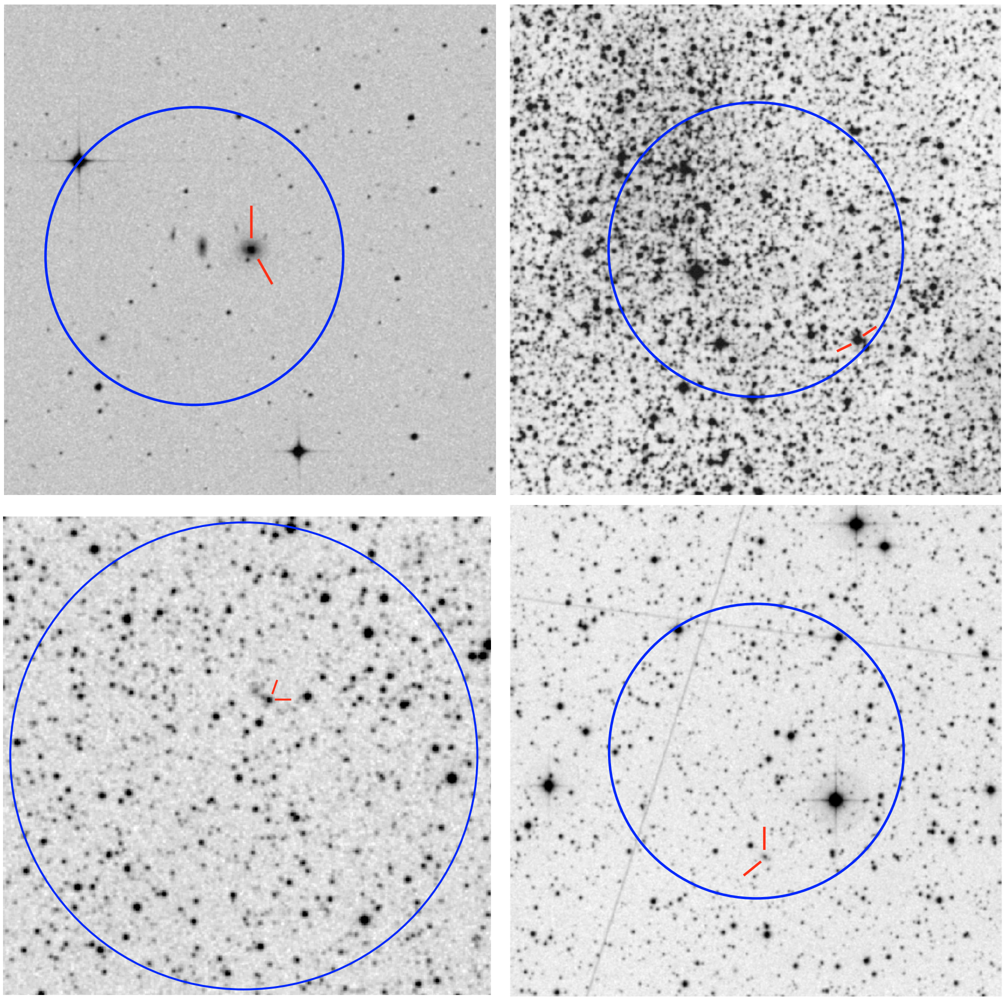

Fig. 1. DSS-II-Red optical images of the fields of IGR J12391−1610 (*top left panel*), IGR J18406−0539 (*top right panel*), 2E 1853.7+1534 (*bottom left panel*) and IGR J19473+4452 (*bottom right panel*). The putative optical counterparts are indicated with tick marks, while the circle mark the 3′ radius conservative ISGRI/*INTEGRAL* error boxes of the hard X-ray sources. Field sizes are 10′ × 10′ for IGR J12391−1610, IGR J18406−0539 and IGR J19473+4452, and 6′ × 6′ for 2E 1853.7+1534. In all cases, North is up and East to the left. In the top left panel, the object 2MASX J12391039−1610432 is the edge-on galaxy located ~1′ East of the galaxy LEDA 170194.

a probable OBe star with weak H_α 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 ± 0.309 mag and V_T = 11.958 ± 0.222 mag. These, using appropriate conversion formulae (ESA 1997), correspond to a magnitude V = 11.88 ± 0.23 mag and to a color index $B - V$ = 0.76 ± 0.32 mag in the Johnson system.

2E 1853.7+1534: this object also has been detected in the forthcoming 2nd IBIS survey (Bassani et al. 2005; Bird et al. 2005) at coordinates RA = $18^h56^m01\overset{s}{.}9$, Dec = +15°37′16″ (J2000), with fluxes (2.1 ± 0.2) × 10^{-11} erg cm^{-2} s^{-1} (20–40 keV) and (1.9 ± 0.4) × 10^{-11} erg cm^{-2} s^{-1} (40–100 keV). This IBIS source is positionally coincident with an *Einstein* detection (McDowell 1994), at a flux of ~10^{-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 (Panzera 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 = $18^h56^m00\overset{s}{.}48$, Dec = +15°37′56.″6, with a total error radius of 8″ once all systematic uncertainties are taken into account (Panzera et al. 2003). A radio source, NVSS J185600+153755, with 1.4 GHz flux density of 3.4 ± 0.4 mJy (Condon et al. 1998) and total positional uncertainty of 6.″3 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[1] object (Fig. 1, bottom left panel) having optical magnitudes R ~ 15.9 and B ~ 18.4. These magnitudes indicate that this source is quite red ($B - R$ ~ 2.5 mag), possibly as a consequence of its location projectionally close to the Galactic Plane (b = +6.°1). Its apparently extended shape, as seen on the DSS-II-Red Survey[2], 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),

[1] available at
http://archive.eso.org/skycat/servers/usnoa

[2] available at http://archive.eso.org/dss/dss/

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

Object	Date	Mid-exposure time (UT)	Grism number	Slit (arcsec)	Exposure time (s)
IGR J12391−1610 (=LEDA 170194)	01 Apr. 2005	22:45:46	#4	2.0	2400
IGR J18406−0539 (=SS 406)	06 Jun. 2005	23:51:25	#4	2.0	2 × 600
2E 1853.7+1534	06 Jun. 2005	22:43:47	#4	2.0	1800
IGR J19473+4452	01 Sep. 2005	21:45:59	#4	2.0	1800

with ISGRI coordinates RA = $19^h47^m20^s.6$, Dec = +44°51′50″ (J2000). These authors report that this source has 0.5–8 keV and 17–60 keV fluxes of $(3.0 \pm 1.0) \times 10^{-12}$ erg cm^{-2} s^{-1} and $(2.5 \pm 0.4) \times 10^{-11}$ erg cm^{-2} s^{-1}, respectively; moreover, a large neutral hydrogen column density, $N_{\rm H} = (11 \pm 1) \times 10^{22}$ 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 = $19^h47^m19^s.37$, Dec = +44°49′42″.4 (J2000; error radius: ~0″.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 $N_{\rm H}$ 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-m "G.D. Cassini" telescope plus BFOSC was used to observe spectroscopically 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 (~2), 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 IRAF[3]. 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 ~0.5 Å for all cases; this was checked by using the positions of background night sky lines.

[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 US National Science Foundation. It is available at `http://iraf.noao.edu/`

4. Results and discussion

Table 2 reports the (observer's frame) emission-line wavelengths, fluxes and equivalent widths (*EW*s) of the five observed objects, the spectra of which are shown 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; see below). 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; however, we do not expect that this will affect any of our conclusions. In the following we assume a cosmology with $H_0 = 65$ km s^{-1} Mpc^{-1}, $\Omega_\Lambda = 0.7$ and $\Omega_{\rm m} = 0.3$ (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] λ3727, H_β, [O III] $\lambda\lambda$4958, 5007, H_α, [N II] $\lambda\lambda$6548, 6583, and [S II] $\lambda\lambda$6716, 6731. All identified emission lines yield a redshift of $z = 0.036 \pm 0.001$, in perfect agreement with da Costa et al. (1998). The NaD doublet in absorption is also detected at the same redshift.

The presence of only 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* nondetection in soft X-rays. We further confirm this by using the diagnostic line ratios [N II]/H_α (=0.95 ± 0.04), [S II]/H_α (=0.86 ± 0.04), and [O III]/H_β (=8.7 ± 0.7), together with the detection of substantial [O I] λ6300 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

Table 2. Observer's frame wavelengths, *EW*s (both in Ångstroms) and fluxes (in units of 10^{-15} erg s^{-1} cm^{-2}) of the emission lines detected in the spectra of the five objects reported in Fig. 2. For the extragalactic objects the values are corrected for Galactic reddening assuming (from Schlegel et al. 1998) $E(B-V) = 0.046$ mag along the LEDA 170194 and 2MASX J12391039−1610432 line of sight, $E(B-V) = 0.94$ mag along the 2E 1853.7+1534 line of sight and $E(B-V) = 0.20$ mag along the IGR J19473+4452 line of sight. The error on the line positions is conservatively assumed to be ±4 Å, i.e., comparable with the spectral dispersion (see text).

Line	$\lambda_{\rm obs}$ (Å)	$EW_{\rm obs}$ (Å)	Flux
IGR J12391−1610 (=LEDA 170194)			
[O II] λ3727	3858	85 ± 10	64 ± 4
H_β	5039	8.6 ± 0.6	7.9 ± 0.6
[O III] λ4958	5139	26.5 ± 1.3	24.3 ± 1.2
[O III] λ5007	5189	75 ± 2	69 ± 2
[O I] λ6300	6526	16.8 ± 0.8	17.3 ± 0.9
[O I] λ6363	6591	6.2 ± 0.4	6.2 ± 0.4
[N II] λ6548	6783	20.4 ± 1.4	20.7 ± 1.4
H_α	6798	49.1 ± 1.5	50.2 ± 1.5
[N II] λ6583	6822	46.5 ± 1.4	47.7 ± 1.4
[S II] λ6716	6959	22.6 ± 1.1	23.6 ± 1.2
[S II] λ6731	6973	19.0 ± 1.0	19.8 ± 1.0
2MASX J12391039−1610432			
[N II] λ6548	7013	0.53 ± 0.13	2.0 ± 0.5
H_α	7030	3.3 ± 0.3	12.5 ± 1.3
[N II] λ6583	7052	1.9 ± 0.3	7.1 ± 1.1
IGR J18406−0539 (=SS 406)			
H_α	6559	10.6 ± 0.2	680 ± 30
2E 1853.7+1534			
H_β	5268	89 ± 9	161 ± 17
[O III] λ4958	5372	11 ± 3	20 ± 5
[O III] λ5007	5425	44 ± 7	75 ± 11
He I λ5875	6368	26 ± 5	41 ± 8
H_α + [N II]*	7113	470 ± 20	790 ± 40
IGR J19473+4452			
[O II] λ3727	3920	23 ± 6	8 ± 2
H_β	5121	6.6 ± 1.3	2.4 ± 0.5
[O III] λ4958	5224	25 ± 3	9.0 ± 0.9
[O III] λ5007	5274	76 ± 4	26.8 ± 1.4
[O I] λ6300	6636	3.5 ± 0.9	1.1 ± 0.3
H_α	6913	35 ± 4	11.2 ± 0.8
[N II] λ6583	6936	7.3 ± 0.7	2.3 ± 0.2
[S II] λ6716	7077	7.6 ± 0.8	2.4 ± 0.2
[S II] λ6731	7093	3.2 ± 0.5	1.01 ± 0.15

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

that its X-ray luminosities are 7.4×10^{42} erg s^{-1} and 2.6×10^{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 $H_\alpha/H_\beta = 2.86$ (Osterbrock 1989) and the extinction law of Cardelli et al. (1989), the observed flux ratio $H_\alpha/H_\beta = 6.4$ 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 ± 1 $M_\odot$ yr^{-1} from the reddening-corrected H_α 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 II] luminosity, $(8.0 \pm 0.7) \times 10^{42}$ erg s^{-1}, yields a much larger SFR value, 110 ± 30 $M_\odot$ yr^{-1}. This high value, so different from that obtained using the H_α emission, may be produced by the above-mentioned 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 II] line flux suffers from larger uncertainties with respect to that obtained from the H_α emission line.

The total reddening estimate along the line of sight inferred from the optical spectrum corresponds, using the empirical formula of Predehl & Schmitt (1995), to a $N_{\rm H} \approx 5 \times 10^{21}$ cm^{-2}, which is ~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 2.2×10^{-12} erg cm^{-2} s^{-1}. The comparison between the reddening-corrected [O III] λ5007 emission flux and the 2–10 keV X-ray flux estimated above implies an X-ray/[O III]$_{5007}$ ratio of ~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_β also allows us to infer the gaseous oxygen abundance in this galaxy. Following Kobulnicky et al. (1999), the R_{23} parameter, defined as the ratio between [O II] + [O III] and H_β line fluxes, gives 12 + log (O/H) ≈ 8.5. 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 (~3) point to a basically solar oxygen abundance. A similar result is obtained if we use the [N II]/H_α flux ratio method (Kewley & Dopita 2002).

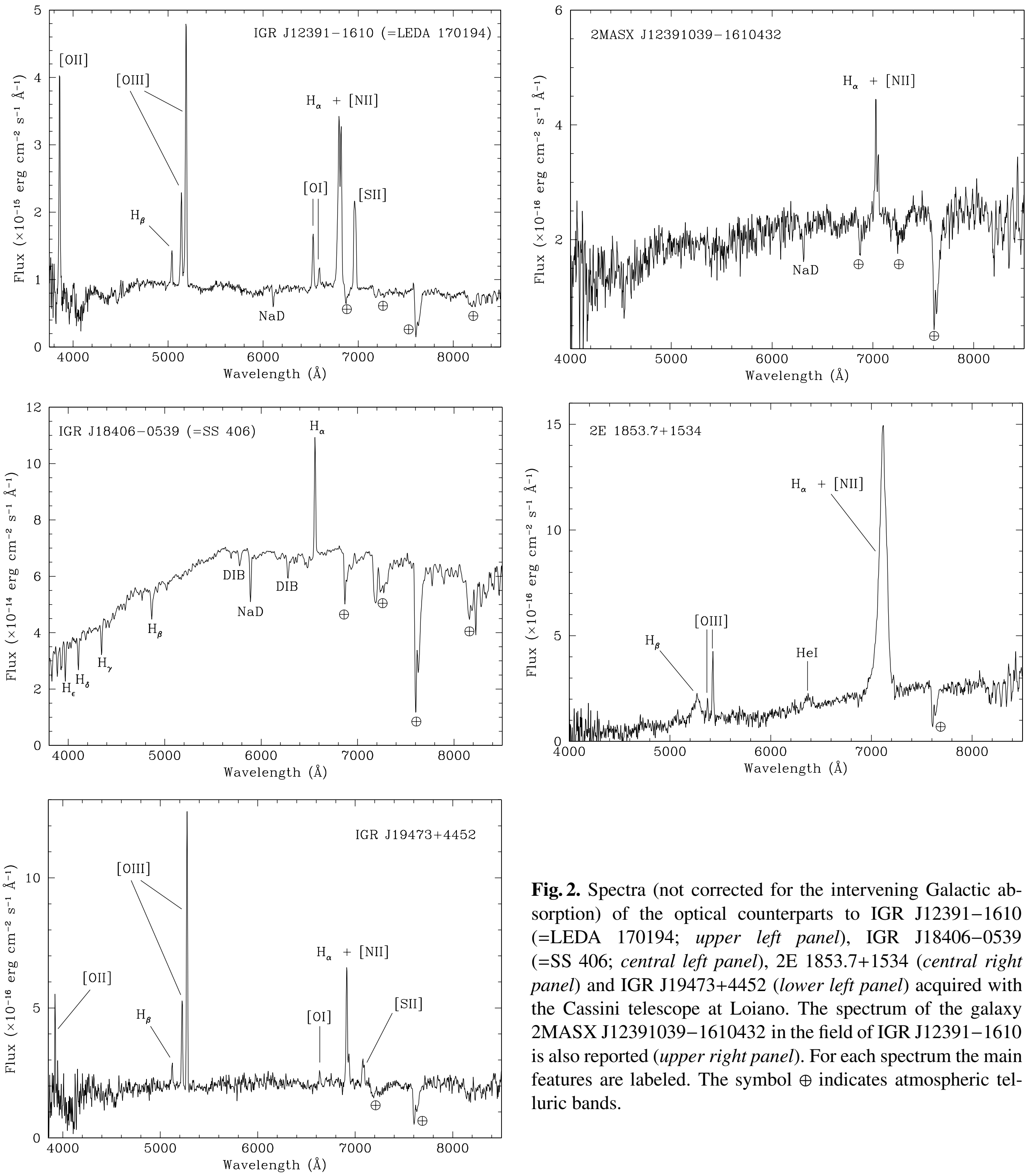

Fig. 2. Spectra (not corrected for the intervening Galactic absorption) of the optical counterparts to IGR J12391−1610 (=LEDA 170194; *upper left panel*), IGR J18406−0539 (=SS 406; *central left panel*), 2E 1853.7+1534 (*central right panel*) and IGR J19473+4452 (*lower left panel*) acquired with the Cassini telescope at Loiano. The spectrum of the galaxy 2MASX J12391039−1610432 in the field of IGR J12391−1610 is also reported (*upper right panel*). For each spectrum the main features are labeled. The symbol ⊕ indicates atmospheric telluric bands.

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_α and [N II] $\lambda\lambda$6548, 6583 emission lines at redshift z = 0.071 ± 0.001. 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, twice as far from Earth as LEDA 170194.

The detection of [N II] and H_α 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_α 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_α ratio observed here implies 12 + log (O/H) ≈ 9. Therefore, in this case also we find an oxygen abundance which is consistent with the solar value.

The intensity of the H_α 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 ± 0.15 $M_\odot$ 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_α emission-line galaxy. We 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 error box may not be very accurate; so, the two positions may be consistent with each other. Thus, only detailed radio observations can give an answer to this open issue.

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 $\lambda\lambda$4026, 4471 and by light metals (such as Si II λ4128, C II λ4267 and Mg II λ4481), points to a main-sequence, mid-type B star (most likely B5) identification. Finally, the presence of a strong H_α 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 $V = 11.88 \pm 0.23$ mag (See Sect. 1.2), one obtains that the distance to the source is $d \sim 4$ kpc. This should be considered as an upper limit, as no correction for Galactic absorption is taken into account. However, we expect that significant reddening is present towards SS 406, given its Galactic latitude ($b = -0\overset{\circ}{.}2$), 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 $B - V = 0.76 \pm 0.32$ mag, respectively. Their difference implies a color excess $E(B - V) = 0.91 \pm 0.32$ 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 $V_0 = 9.0 \pm 1.0$ mag, which in turn gives a distance $d = 1.1^{+0.6}_{-0.4}$ 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 $\sim 4 \times 10^{33}$ erg s^{-1}. This, together with the *EW* of the H_α 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$\overset{\prime}{.}$5 from the IGR J18406−0539 position, thus formally outside its error box (and moreover 6$\overset{\prime}{.}$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 J18406−0539 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 suggest 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_α+[N II] emission blend. A broad H_β emission line, as well as [O III] λ5007 narrow forbidden lines and possibly a broad He I λ5875 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 1 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 × 10^{43} erg s^{-1} and 8.1 × 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, a 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_β 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 $v_{\rm BLR} \sim (\sqrt{3}/2) \cdot v_{\rm FWHM} \sim 4200$ km s^{-1} (where $v_{\rm FWHM} \sim 4800$ km s^{-1} is the velocity measured from the FWHM of the H_β emission line). From Eq. (2) of Wu et al. (2004) we find that the BLR size is $R_{\rm BLR} \sim 54$ light-days. Furthermore, using Eq. (5) of Kaspi et al. (2000), the AGN black hole mass in 2E 1853.7+1534 is $M_{\rm BH} \sim 1.4 \times 10^8$ $M_\odot$. 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] λ3727, H_β, [O III] $\lambda\lambda$4958, 5007, H_α, [N II] λ6583, 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_α = 0.21 ± 0.03, [S II]/H_α = 0.30 ± 0.06 and [O III]/H_β = 11.2 ± 2.3, place IGR J19473+4452 among Seyfert 2 AGNs.

To compute the internal reddening of this galaxy, we again use the procedure described in Sect. 3.1. We find that the H_α/H_β 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 $N_{\rm H} \approx 4 \times 10^{21}$ cm^{-2}, that is ~30 times less than the $N_{\rm H}$ 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 × 10^{43} erg s^{-1} and 1.9 × 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 × 10^{-12} erg cm^{-2} s^{-1}. This implies an X-ray/[O III]$_{5007}$ ratio of ~30, indicating that this source is well within 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 ± 0.2 $M_\odot$ yr^{-1} from the reddening-corrected H_α luminosity of (2.64 ± 0.18) × 10^{41} erg s^{-1}. The method (again in Kennicutt 1998) which instead uses the extinction-corrected [O II] luminosity, (5.3 ± 1.3) × 10^{42} erg s^{-1}, gives a SRF of 7 ± 3 $M_\odot$ yr^{-1}, which is larger than, but still consistent with (at the 90% confidence level) that derived using the H_α emission line flux.

Moreover, the detection of [O II], [O III] and H_β also allows us to infer the gaseous oxygen abundance of this galaxy. Also in this case, 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_α flux ratio method (Kewley & Dopita 2002).

4.5. The nature of optically identified INTEGRAL sources

Summing 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 for 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 composed of background AGNs. Albeit that these small numbers do not allow us to perform an in-depth statistical analysis of the sample, we put suggest 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* has allowed the discovery of a new population of absorbed transient supergiant HMXBs; moreover, *INTEGRAL* doubled the number of known Galactic HMXBs with a 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 ∼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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