XMM–Newton observations of unidentified INTEGRAL/IBIS sources

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ABSTRACT
About 30 per cent of the sources in the fourth INTEGRAL/IBIS catalogue are unidentified in that they lack an optical counterpart. To be able to classify them, X-ray observations are of crucial importance as they can place tighter constraints on the high-energy error box, which is usually of the order of a few arcminutes, and allow their broad-band spectrum to be studied. To this aim we have cross-correlated the list of all unidentified IBIS sources in the fourth catalogue with the archive of all XMM–Newton pointings, finding a set of six objects with archival data. For one of them, IGR J17331–2406, no X-ray source is detected by XMM inside the IBIS error box, most likely due to the fact that it is a transient object. In the case of IGR J17445–2747 two possible X-ray counterparts are found inside the IBIS error box: one is very weak while the other is bright, but only detected once. In each of the remaining four cases: IGR J155359–5750, AX J1739.3–2923, AX J1740.2–2903 and IGR J18538–0102, we find instead a convincing association, for which we provide an improved X-ray position and information on the optical/infrared counterpart. We also performed a detailed analysis of their XMM/IBIS spectra, and on the basis of all information acquired we suggest that IGR J155359–5750 is an active galactic nucleus (AGN) of intermediate type, AX J1739.3–2923 and AX J1740.2–2903 are high-mass X-ray binary systems, IGR J17331–2406 and IGR J17445–2747 are Galactic transient sources and IGR J18538–0102 could be a background AGN.

Key words: catalogues – surveys – gamma-rays: general – X-rays: general.

1 INTRODUCTION
The fourth and most recent IBIS/INTEGRAL Soft Gamma-Ray Imager (ISGRI) survey (Bird et al. 2010) lists 723 hard X-ray sources of which 30 per cent are unidentified, i.e. lack an optical counterpart. Most of these sources are also poorly studied at energies below 10 keV, whereas X-ray observations can be of crucial importance to unveil their nature and class. Positional location with arcsecond accuracy, which can only be obtained using the capabilities of current X-ray telescopes, is necessary to pinpoint and classify the optical counterpart of these hard X-ray emitters. Furthermore, information in the X-ray band, which is often lacking, is necessary to characterize these sources in terms of spectral shape, flux, absorption and variability. Since the first IBIS survey, our group has conducted a comprehensive programme in the analysis of X-ray follow-up observations of unidentified IBIS sources, focusing recently on the fourth IBIS survey objects (Fiocchi et al. 2010; Landi et al. 2010). With this in mind, we have cross-correlated the list of the still unidentified IBIS sources included in the fourth catalogue with the archive of all XMM–Newton pointings, finding a set of six objects with archival data. For one of them no X-ray source is detected by XMM inside the IBIS error box, most likely due to the fact that it is a variable and/or transient object, while in another case two possible X-ray counterparts are found inside the IBIS error box: one is very weak and the other is bright, but only detected once. In the remaining four cases, we find instead a convincing association, for which we provide the improved X-ray position and information on the optical/infrared counterpart. We have also performed a detailed analysis of the XMM data, and in combination with IBIS spectra we have been able to study the broad-band properties of each source. Altogether, these data allow us to investigate the possible nature of these hard X-ray sources and to suggest that one is mostly likely an active galactic nucleus (AGN), two are probably Galactic binaries, two are Galactic transient objects and one could be associated either to a compact object in a supernova remnant or to a background AGN.

2 DATA REDUCTION AND ANALYSIS
For the sources in our sample, we use X-ray data acquired with the three X-ray CCD cameras (MOS1, MOS2 and pn) comprising the
European Photon Imaging Camera (EPIC) instrument on-board the XMM–Newton spacecraft (Strüder et al. 2001). The EPIC cameras offer the possibility to perform sensitive imaging observations over the telescope’s field of view (FOV) of 30 arcmin and in the energy range from 0.15 to 15 keV with moderate spectral ($E/\Delta E \sim 20–50$) and angular resolution [point spread function (PSF), 6 arcsec full width at half-maximum (FWHM)] and are therefore ideal for our objectives of improving the source position and studying broadband X-ray spectra.

XMM data were reprocessed using the Standard Analysis Software (SAS), version 9.0.0, employing the latest available calibration files. Only patterns corresponding to single and double events (PATTERN ≤ 4) were taken into account and the standard selection filter FLAG = 0 was applied. The observations were filtered for periods of high background, and the resulting net exposures for each source and each camera are reported in Table 1, which also lists the XMM observation date. For each observation, we analysed the XMM–Newton EPIC (MOS plus pn) images to search for X-ray sources which fall inside the IBIS error box and are therefore likely IBIS counterparts. Next we obtained X-ray spectra in the 0.5–12 keV band of the likely associated source. Source counts were extracted from circular regions of radius 20 arcsec centred on the source; background spectra were extracted from circular regions close to the source or from source-free regions of 80-arcsec radius. The ancillary response matrices (ARFs) and the detector response matrices (RMFs) were generated using the XMM SAS tasks ARFGEN and RMFGEN while the spectral channels were rebinned in order to achieve a minimum of 20 counts in each bin.

The INTEGRAL data reported here consist of all pointings performed (Winkler et al. 2003) during 5 yr of observations with typical exposures in the range 3000–8500 ks (see sixth column of Table 1); these are the same data used to obtain the fourth IBIS survey. ISGRI images for each available pointing were generated in various energy bands using the INTEGRAL Science Data Centre (ISDC) offline scientific analysis software (OSA; Goldwurm et al. 2003), version 7.0. Count rates at the position of the source were extracted from individual images in order to provide light curves in various energy bands; from these light curves, average fluxes were then extracted and combined to produce an average source spectrum (see Bird et al. 2010 for details). In the last column of Table 1 the variability indicator as defined by Bird et al. (2010) is also reported.

The XMM–Newton data were then fitted together with INTEGRAL average spectra using XSPEC, version 12.5.1 (Arnaud 1996), to cover the broad-band from 0.5 to 110 keV. A detailed description of the results obtained by this spectral analysis is given in a dedicated section for each source.

### 3 RESULTS

Altogether we analysed the XMM data of six IBIS sources (see Table 1). All sources discussed in this section appear in the fourth IBIS catalogue (Bird et al. 2010) either as new detections (AX J1740.2–2903 and IGR J18538–0102) or as already known hard X-ray emitters (IGR J15359–5750, IGR J17331–2406, AX J1739.3–2923 and IGR J17445–2747). Apart from the case of IGR J17331–2406 for which we could not find any XMM counterpart within the IBIS positional uncertainty, and that of IGR J17445–2747 where the only XMM detection inside the IBIS error box is possibly not the correct counterpart of the high-energy source, for the remaining four sources we were able to find a convincing counterpart in the X-ray band. For these sources it was also possible to extract the X-ray spectrum and to perform a broadband analysis. Table 2 lists the sources with X-ray detections together with their IBIS position and relative uncertainty as reported in Bird et al. (2010). For each of these gamma-ray emitters, we provide the position and relative uncertainties (at 90 per cent confidence level) of the sources detected by XMM within the 90 per cent IBIS error circle and considered to be the likely X-ray counterparts (see section on individual sources); we also report their count rate in the 0.2–12 keV energy band and optical/infrared identification obtained from various online archives such as NASA/IPAC Extragalactic Database (NED), High Energy Astrophysics Science Archive Research Center (HEASARC) and Set of Identifications, Measurements and Bibliography for Astronomical Data (SIMBAD).

The results of the broad-band spectral analysis relative to the four objects having good quality data are reported in Table 3, where we list the Galactic absorption, the column density in excess to the Galactic value, the power-law photon index, the reduced $\chi^2$ of the best-fitting model together with the 2–10 and the 20–100 keV fluxes. All quoted errors correspond to 90 per cent confidence level for a single parameter of interest ($\Delta \chi^2 = 2.71$). In the fitting procedure, a multiplicative constant, $C$, has been introduced to take into account possible cross-calibration mismatches between the X-ray and the soft gamma-ray data. When treating the INTEGRAL data, this constant $C$ was found to be close to one using various source typologies (e.g. Masetti et al. 2007; De Rosa et al. 2008; Panessa et al. 2008; Molina et al. 2009), so that any significant deviation from this value can be confidently ascribed to source flux variability between two non-simultaneous observations.

In the following, results on each individual source are presented.

### Table 1. Log of the XMM–Newton and IBIS observations used in this paper.

| IBIS source | XMM obs. date | Expo MOS1 (s) | Expo MOS2 (s) | Expo pn (s) | IBIS expo (ks) | Var* |
|-------------|---------------|---------------|---------------|-------------|---------------|------|
| IGR J15359–5750 | 2006 August 15 | 16 395 | | 11 470 | 2839 | |
| IGR J17331–2406 | 2006 April 02 | 10 566 | 10 809 | 8937 | 6962 | Y |
| AX J1739.3–2923 | 2005 August 29 | 16 899 | 17 299 | 14 035 | 8047 | |
| AX J1740.2–2903 | 2005 September 29 | 7568 | 7465 | 8488 | |
| IGR J17445–2747 | 2006 April 04 | 11 802 | 11 666 | 10 149 | 7295 | YY |
| IGR J18538–0102 | 2004 October 08 | 8058 | 8076 | 5586 | 2955 | |

*Variability indicator as in Bird et al. (2010).
Table 2. INTEGRAL/IBIS position of the sources and locations of the objects detected by XMM–Newton within the 90 per cent high-energy error circles, with relative counterparts. Also the XMM error radii are given at 90 per cent confidence level.

| XMM source | RA (J2000) | Dec. (J2000) | Error (arcsec) | Count rate (0.2–12 keV) (10^{-1} count s^{-2}) | Likely counterpart |
|------------|------------|-------------|---------------|-----------------------------------------------|-------------------|
| IGR J15359−5750 (RA = 15^{h}36^{m}00^{s}/l = 323.45, Dec. = −57^{\circ}49^{\prime}01^{\prime\prime}/b = −1.66, error radius = 2.2 arcmin) | 15^h36^m00^s | −57^\circ49^\prime52^\prime^2 | 3.2 | 1.37 ± 0.04 | 2MASS 15360282−5748529 MGPS J153602−574854 |
| #1 (in 90 per cent) | 15^h36^m02^s | −57^\circ48^\prime52^\prime^2 | 3.2 | 1.37 ± 0.04 | 2MASS 15360282−5748529 MGPS J153602−574854 |
| AX J739.3−2923 (RA = 17^h39^m21^s/l = 358.89, Dec. = −29^\circ23^\prime24^\prime0/b = 0.92, error radius = 4.5 arcmin) | 17^h39^m21^s | −29^\circ23^\prime48^\prime^7 | 3.3 | 0.63 ± 0.03 | 2MASS 17391792−2923478 |
| #1 (in 90 per cent) | 17^h39^m21^s | −29^\circ23^\prime48^\prime^7 | 3.3 | 0.63 ± 0.03 | 2MASS 17391792−2923478 |
| AXJ1740.2−2903 (RA = 17^h40^m11^s/l = 359.28, Dec. = −29^\circ02^\prime54^\prime0/b = 0.95, error radius = 2.7 arcmin) | 17^h40^m11^s | −29^\circ02^\prime54^\prime^0 | 3.2 | 1.54 ± 0.06 | 2MASS 17401814−2903381 |
| #1a | 17^h44^m29^s | −27^\circ46^\prime08^\prime.9 | 5.1 | 5.20 ± 1.84 | 2MASS 17442946−2746114 |
| IGR J18538−0102 (RA = 18^h53^m50^s/l = 21.28, Dec. = −01^\circ02^\prime40^\prime0/b = −1.00, error radius = 4.8 arcmin) | 18^h53^m50^s | −01^\circ02^\prime40^\prime^0 | 3.2 | 2.62 ± 0.08 | 2MASS 18534847−0102995 1RXHJ185348.2−010228 |

aXMM slew source, see text.

Table 3. XMM–Newton and INTEGRAL broad-band spectral analysis results: best-fitting results.

| Source | $N_{H}$ (Gal) (10^{22} cm^{-2}) | $N_{H}$ (10^{22} cm^{-2}) | $\Gamma$ | $\chi^2/\nu$ | $P_{\nu}(2−100\text{keV})$ (10^{-12}erg cm^{-2} s^{-1}) | $F_{\nu}(20−100\text{keV})$ (10^{-12} erg cm^{-2} s^{-1}) |
|--------|-----------------|-----------------|--------|--------|-----------------|-----------------|
| IGR J15359−5750 | 1.190 | 20.1^{+2.5}_{-2.9} (0.95^{+0.02}_{-0.01}) | 1.85^{+0.27}_{-0.25} | 223/207 | 4.97 | 23.28 |
| AX J1739.3−2923 | 0.980 | 1.88^{+0.35}_{-0.31} | 1.52^{+0.14}_{-0.14} | 155/165 | 1.27 | 6.4 |
| AX J1740.2−2903 | 0.968 | − | 0.36^{+0.21}_{-0.18} | 73/68 | 3.18 | 7.0 |
| IGR J18538−0102 | 0.993 | 0.41^{+0.1}_{-0.1} | 1.56^{+0.08}_{-0.08} | 255/259 | 4.00 | 7.83 |

aObserved fluxes.

bPartial covering absorption with its relative covering fraction.

3.1 IGR J15359−5750

IGR J15359−5750 is the oldest known source in our sample, in that it was reported as a new high-energy emitter in the second IBIS survey (Bird et al. 2006), but it remains unidentified. According to an archival search, a ROSAT faint X-ray source, 1RXS J153552.8−575055.0, is present within the ISGRI error circle with an associated positional error of 19 arcsec. The 0.2–12 keV EPIC image is shown in Fig. 1 together with the IBIS error circle (2.2 arcmin, as reported in the fourth survey) superimposed. It is clear that there is only one X-ray source consistent with the high-energy position (90 per cent error circle) which is not coincident with the ROSAT faint source. Instead within the XMM–Newton positional error of 3.2 arcsec we find an infrared source, 2MASS J15360282−5748529 which also coincides with the radio object MGPS J153602−574854 having a 36-cm flux of 29.4 ± 1.3 mJy. The Two Micron All Sky Survey (2MASS) object has the following magnitudes: $J = 14.75 ± 0.089$, $H = 13.243 ± 0.093$ and $K = 12.258 ± 0.067$ and no optical counterpart is reported in various archives queried. Despite its location on the Galactic plane, the presence of radio and X-ray emission strongly suggest that this source is a background AGN.

![Figure 1. EPIC 0.2–12keV image of the IGR J15359−5750, only one source is detected by XMM within the IBIS uncertainty (circle).](image-url)
the XMM/IBIS cross-calibration constant \(C\) much lower than one; this is probably an indication for the presence of more absorption, this time intrinsic to the source. The addition of intrinsic column density is strongly required by the data \(\Delta \chi^2 = 846\) for 1 d.o.f.; its value is found to be of \(N_{\text{H}} = 2 \times 10^{23}\) cm\(^{-2}\) and the photon index has in this case a more canonical value of \(\Gamma \sim 1.7\) and also \(C\) is \(\sim 0.95\). Despite the fit improvement, the data to model ratios show excess emission at soft X-ray energies and evidence for a line at around 6 keV. Another significant improvement \(\Delta \chi^2 = 32\) for 2 d.o.f.) is indeed obtained when we introduce the kσ iron fluorescence emission line at a fixed energy of 6.4 keV; the line is broad with a \(\sigma\) of 0.34\(^{+0.13}_{-0.11}\) keV and an equivalent width of 327\(^{+195}_{-125}\) keV. To account for the soft excess, we tried a more complex absorption model where besides the intrinsic column density, another absorber partially covering the source (model \textsc{pcfabs} in \textsc{xspec}) is also considered. The addition of this extra absorption component provides a good fit \(\chi^2 = 223/206\) and gives a photon index of \(\Gamma = 1.85\) and column densities of the order of \(N_{\text{H}} \sim 4 \times 10^{22}\) cm\(^{-2}\) fully covering the source and \(N_{\text{H}} \sim 2 \times 10^{23}\) cm\(^{-2}\) covering only 0.95 per cent of the object. In Fig. 2 and Table 3, the unfolded broad-band spectrum fitted with this model is shown and described, while in Fig. 3 the contours relative to the complex absorber \((N_{\text{H}}\text{ versus its covering fraction})\) are displayed. The cross-calibration constant between XMM and \textit{INTEGRAL} has a value of \(C = 1.1^{+0.51}_{-0.31}\), i.e. consistent with unity. Next we fixed the cross-calibration constant to one and substituted the simple power law with an exponentially cut-off power-law spectrum reflected by neutral material (model \textsc{pexrav} in \textsc{xspec}): in this way we were able to provide constraints on the reflection component \((R < 1.65)\) and cut-off energy \((E_C \geq 68\) keV).

The overall spectral characteristics are clearly compatible with the suggested extragalactic nature of the source and further indicates that IGR J15359−5750 could be an intermediate-type AGN like Mrk 6, 4U 1344−60 or IGR J21247+5058 (see Molina et al. 2009).

### 3.2 IGR J17331−2406

IGR J17331−2406, first reported as a high-energy emitter by Krivonos et al. (2007), is listed in the fourth IBIS survey catalogue as a transient source since to date it was detected by \textit{INTEGRAL} only once; it was discovered on 2004 September during outburst activity lasting \(\sim 30\) d and reaching a peak flux of \(\sim 30\) mCrab or \(4 \times 10^{-10}\) erg cm\(^{-2}\) s\(^{-1}\) (18–60 keV). The spectrum was quite hard, fitted with a power law having \(\Gamma \sim 1.8\) (Lutovinov et al. 2004). In the \textit{XMM–Newton} observation reported in this work we could not find any X-ray source within the ISGRI error circle; the X-ray upper limit to the flux is equal to \(\sim 2 \times 10^{-14}\) erg cm\(^{-2}\) s\(^{-1}\) (0.5–10 keV). It is worth noting that other 0.5–10 keV observations of the source have been reported in the literature from both \textit{Swift}/X-Ray Telescope (XRT) and \textit{Chandra} (Tomick et al. 2008; Landi et al. 2010), but no X-ray detections were obtained, providing upper limits very similar to that obtained with XMM. If we extrapolate the spectrum detected by IBIS during the outburst to low energies we obtain a flux of \(\sim 6 \times 10^{-14}\) erg cm\(^{-2}\) s\(^{-1}\) in the 0.5–10 keV band implying a dynamical range from quiescent to outburst of the order of 3000. It is clear that it will be extremely difficult to find the soft X-ray counterpart of IGR J17331−2406, unless a monitoring program is planned with the aim of promptly observing the source when in outburst.

### 3.3 AX J1739.3−2923

AX J1739.3−2923 was first reported as a high-energy emitter in the third IBIS survey (Bird et al. 2007) and soon associated to an ASCA object detected during observations of the Galactic Centre region (Sakano et al. 2002).

The ASCA and the most recent forth IBIS error circles (50 arcsec and 4.5 arcmin at 90 per cent, respectively) are shown in Fig. 4, superimposed on the 0.2−12 keV EPIC image.

It is evident from this figure that there are two bright X-ray sources and one weak source located inside the IBIS error circle: source N. 1 is also compatible with the ASCA positional uncertainty and is clearly AX J1739.3−2923 while the other two are much weaker X-ray emitters and are detected by XMM for the first time. Besides being the brightest of the two, the ASCA source is also the harder as it remains visible above 4.5 keV while the other disappears above a few keV. Thus the observational evidence suggests that AX J1739.3−2923 is the true counterpart of the \textit{INTEGRAL} object but it is now located with arcsecond precision thanks to XMM. Only marginally compatible with the XMM error circle, we find one possible counterpart in a 2MASS pointed source 2MASS 17391792−2923478 located at 4.8 arcsec.
from AXJ1739.3−2923 having magnitudes $J \sim 12.96$, $H = 12.17 \pm 0.053$ and $K = 11.65 \pm 0.052$; here too no optical counterpart was found.

Next we combined the XMM–Newton MOS and pn data together with the INTEGRAL/IBIS points in order to study the broadband (0.5–110 keV) spectrum of the source. As a first attempt, we tried a fit with a simple power law absorbed by the Galactic column density which in the direction of the source is quite high ($9.8 \times 10^{21}$ cm$^{-2}$; Dickey & Lockman 1990) due to its location on the Galactic plane. This simple model fits the data poorly ($\chi^2 = 305/166$) giving a very hard photon index ($\Gamma = 0.68$) which suggests the presence of extra absorption intrinsic to the source. Indeed the addition of this extra component is highly required by the data ($\Delta \chi^2 = 149$ for 1 d.o.f); this fit gives a column density of $N_H = 1.88 \times 10^{22}$ cm$^{-2}$, a photon index $\Gamma = 1.52$ and a 2–10 keV observed flux of $1.3 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$. The unfolded broad-band spectrum using this model is shown in Fig. 5 (see also Table 3). Our spectral parameters are in good agreement with the ASCA results (Sakano et al. 2002), in particular the very similar flux values suggest that the source is persistent and not remarkably variable; also the cross-calibration constant between XMM and INTEGRAL is $C = 1.59^{+0.72}_{-0.53}$, i.e. marginally compatible within uncertainties with unity. An inspection of the IBIS long-term light curve (18–60 keV), spanning about 4.5 yr, shows no sign of significant variability; this confirms the previous hypothesis of a persistent nature for the source. No radio counterpart, generally expected for an extragalactic object, has been found using all available radio catalogues in the HEASARC data base. On the other hand, the location of the source on the Galactic plane, the high intrinsic absorption, the hard photon index and the lack of timing signatures such as X-ray bursts in spite of the long monitoring, all favour the hypothesis that AX J1739.3−2923 is a weak, persistent and absorbed high-mass X-ray binary (HMXB) system.

3.4 AX J1740.2−2903

AX J1740.2−2903 is an X-ray source discovered by ASCA during the Galactic Centre region scans (Sakano et al. 2002). It is listed in the latest IBIS survey catalogue (Bird et al. 2010) with a 20–40 keV flux of 0.5 mCrab or $3.8 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ and it was not reported in the previous third IBIS catalogue because its detection ($5.5\sigma$) was just below the significance threshold considered in a region, the Galactic Centre, where large systematics errors are present. Investigation of the IBIS long-term light curve of AX J1740.2−2903, which spans about 4 yr, shows no sign of flaring or transient emission, instead the source seems to show a rather weak persistent emission.

The error circles of both ASCA (50 arcsec at 90 per cent) and IBIS (2.7 arcmin at 90 per cent solid circle) have been superimposed on the 0.2–12 keV EPIC image in Fig. 6 which reveals that AX J1740.2−2903 is just at the border of INTEGRAL positional uncertainty. Because of location of AX J1740.2−2923 being near the Galactic Centre where there are some systematic structures in the ISGRI sky maps, we have re-analysed the data and got an improved position at RA(J2000) = 17\textdegree40'11''1, Dec.(J2000) = −29\textdegree 02'54''00 and using these coordinates the X-ray source is found to be well inside the high-energy error circle (dashed circle in Fig. 6). Furthermore, considering that AX J1740.2−2923 is the only X-ray source in the XMM field detected above 4.5 keV, we conclude that the ASCA source is the natural IBIS counterpart, now located by XMM with higher precision.

We found only an infrared source, 2MASS 17401814−2903381, within the XMM positional uncertainty: it has $J$, $H$ and $K$ magnitudes of 13.34, 11.52 and 10.52, respectively, and no optical and radio counterpart.

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{AX J1739.3-2903}
\caption{XMM–Newton and INTEGRAL/ISGRI broad-band spectrum of AXJ1739.2−2923 modelled with a power law absorbed by the Galactic plus an intrinsic absorption.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{Figure 6. EPIC 0.2–12keV image of the region surrounding AX J1740.2−2903. Superimposed are the fourth IBIS catalogue (solid large), IBIS redefined (dashed large) and ASCA (small) error circles.}
\end{figure}
Despite the lack of EPIC pn data, we were nevertheless capable of performing the analysis of the broad-band spectrum of the source.

A fit with a power law absorbed by the Galactic column density does not provide a good fit ($\chi^2 = 156.71$) and gives a hard photon index of about one. Contrary to the previous cases, the addition of an extra absorption component is not required by the data, and furthermore, we found a very low value (0.43) for the cross-calibration constant between XMM and INTEGRAL. We note that the low (0.5–10 keV) and high (17–110 keV) energy data sets have completely different spectral shape; while the X-ray spectrum is well fitted with a power law of photon index $<1$, the IBIS spectrum is very soft being fitted with a power law having $\Gamma = 3.2$. Matching these two spectra clearly requires the presence of a low-energy cut-off if we assume no variability of the source, or a change in spectral shape if we suppose that the flux can vary. Fitting the source broad-band (0.5–110 keV) spectrum of AX J1740.2–2903 with an exponentially cut-off power law (model CUT-OFFPL in XSPEC) absorbed by the Galactic column density, provides an acceptable fit ($\chi^2 = 93.70$), a hard photon index $\Gamma = 0.6^{+0.20}_{-0.14}$ and a cut-off energy at $E_C = 11^{+3}_{-2}$ keV.

The XMM/IBIS constant is 2.72 $\pm$ 0.13, not consistent with unity which indicates some variability between the pointed XMM observation and the average IBIS measurement. However, we must note that extracting a spectrum without possible contamination from nearby sources in such a crowded area as the Galactic Centre is difficult so this might also explain the non-ideal cross-calibration constant. Inspection of the data to model ratio suggests the presence of residuals in the soft part of the spectrum around 6–7 keV. Therefore we first tried to fit the soft excess both with a blackbody and thermal plasma models, but the best fit only improves by adding to the cut-off power law a Raymond–Smith plasma ($\chi^2 = 73.68$). The temperature of the plasma is found to lie in the range 0.16–1.04 keV.

The addition of a line left free to vary in the 6–7 keV energy range, also improves the fit (but only at the 95 per cent confidence level) and provides our best-fitting model presented in Fig. 7 (see also Table 3). Fitting the data with this model gives a flatter photon index $\Gamma \sim 0.4$, a cut-off energy at around 10 keV, a line at $6.7^{+0.12}_{-0.04}$ keV with equivalent width of $400^{+400}_{-300}$ eV. In the light of all above findings, here too we suggest for this source a likely persistent HMXB nature.

3.5 IGR J17445–2747

IGR J17445–2747 represents an interesting case of a source with many X-ray follow-up observations but still without a convincing counterpart. Fig. 8 shows the XMM–Newton 0.2–12 keV image with superimposed all the possible X-ray counterparts proposed so far together with the INTEGRAL/IBIS error circles (dashed from the third catalogue and continuous from the fourth). IGR J17445–2747 first appeared in the third IBIS survey (Bird et al. 2007) and was subsequently associated to a relatively faint Swift/XRT source with a 2–10 keV flux of $1.5 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$, located however outside the INTEGRAL error box (Landi et al. 2007).

Then Chandra follow-up observations of the region detected three sources (Tomsick et al. 2008): the same source detected by XRT, a new one located inside the new ISGRI error circle (J174435.4–274453, diamond point) reported in the fourth IBIS catalogue and a third one just at its border (J174427.3–274324 box point).

Within the INTEGRAL/IBIS error circle XMM–Newton detects only one source at a position compatible with that of the Chandra source J174435.4–274453 indicating that this could be a possible counterpart. The source spectrum is poorly sampled by XMM as this is only a 4.6σ detection but we were able to estimate the 0.2–12 keV observed flux of $8 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ fully compatible with that of Chandra of $\sim 7 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$.

However, we note that within the IBIS error box there is also an XMM slew source: XMMSL1 J174429.4–274609 (circle point in the figure) whose coordinates are reported in Table 2. This source with a 0.2–12 keV flux of $1.64 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ is the brightest in the high-energy error circle and it is also extremely variable as it was seen only once out of four observations of the region made at different epochs. This source is associated only to an infrared object (2MASS J17442946–2746114) within the XMM slew (5.1 arcsec) positional uncertainty with $J$, $H$ and $K$ magnitudes of 15.13, 12.88 and 12.85, respectively.

The XMM upper limit on the source flux is $0.4 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ in the same waveband implying a dynamic range of around 40.

IGR J17445–2747 is reported in the fourth IBIS catalogue as a transient bursting source since it was significantly detected at

\footnote{Note that the source was wrongly put inside the IBIS error box in the Astron. Telegram.}
observations of unidentified IBIS sources

∼13 \sigma level (20–100\,keV) only during its outburst activity lasting for a total of ∼30\,d and reaching a peak flux of ∼30\,mCrab or $4.6 \times 10^{-10}\,\text{erg cm}^{-2}\,\text{s}^{-1}$ (20–100\,keV). On the contrary, the source was not detected in the total data set for an on-source exposure time of ∼7.3\,Ms, providing an upper limit to the flux of 0.1\,mCrab (20–40\,keV) and resulting in a dynamical range of ∼300.

Therefore, given the transient nature of both IGR J17445−2747 and XMMSL1 J174429.4−274609, we conclude that the two sources are very likely associated.

### 3.6 IGR J18538−0102

IGR J18538−0102 is a newly discovered INTEGRAL source listed in the fourth IBIS survey (Bird et al. 2010). Recently Stephen et al. (2010) provided an improved position for the source using the association with an XMM slew catalogue source (2XMM J185348.4−010229). These authors also noted that IGR J18538−0102 is spatially coincident with the supernova remnant candidate G32.1−0.9 detected in X-rays by ROSAT and ASCA (Folgheraiter et al. 1997): but it has a much harder spectrum and higher absorption than observed in the supernova remnant. This suggests the possibility that IGR J18538−0102 could be a more distant Galactic source or a background AGN and its alignment with G32.1−0.9 is only coincidental. Halpern & Gotthelf (2010) then reported on the XMM observation used here and further discussed a possible infrared/optical counterpart of the source. We re-analysed the XMM data in order to combine them with IBIS ones, performing for the first time a broad-band spectral analysis and discussing further the nature of this object.

The EPIC 0.2–12\,keV image shown in Fig. 9 with the INTEGRAL 90\,per cent error circle indicates that there is only one X-ray counterpart. Archival searches within the XMM–Newton positional uncertainty finds the infrared object (2MASS J18534847−0102295) discussed by Halpern and Gotthelf which has J, H and K magnitudes of 14.16, 14 and 12.50, respectively. It coincides with the USNO B10889−0406690 object ($R = 15.2\,\text{mag}$) and with the soft X-ray source 1RXS J185348.2−010228 detected by ROSAT–High Resolution Imager (HRI).

Next, we concentrated on broad-band spectral analysis. Folgheraiter et al. (1997) already provided indications on the source X-ray shape: they found that either a power law with a photon index of 1.8 or, alternatively, a thermal model with a $kT$ of about 2\,keV was appropriate to fit the 0.5–2\,keV low-energy X-ray (ROSAT and ASCA) data. Both models required absorption in excess to the Galactic value which in the source direction is $9.93 \times 10^{21}\,\text{cm}^{-2}$.

**Figure 9.** XMM EPIC 0.2–12\,keV image of IGR J18538−0102 with the high-energy error box superimposed.

**Figure 10.** XMM EPIC and INTEGRAL/IBIS (0.5–110\,keV) spectrum of IGR J18538−0102 fitted with an absorbed power law.

(Dickey & Lockman 1990). Our broad-band 0.5–110\,keV spectrum is poorly fitted with a simple power law absorbed by the Galactic absorption ($\chi^2 = 307/260$) but the addition of extra absorption, probably intrinsic to the source improves the fit significantly (at a confidence level >99.99\,per cent) and provides the best description of the source spectrum ($\chi^2 = 255/259$). The amount of extra column density is $N_H \sim 4 \times 10^{21}\,\text{cm}^{-2}$ while the value of photon index is $\Gamma = 1.56$; the cross-calibration is found to be $0.65^{+0.28}_{-0.22}$ indicating possible variability between the pointed XMM observation and the IBIS average measurement. The combined XMM–INTEGRAL unfolded spectrum fitted with this model is shown in Fig. 10 and described in Table 3. The spectral parameters are quite in agreement with what found by Halpern from the XMM data analysis alone but not fully compatible with the spectral parameters reported by Folgheraiter et al. (1997) although we get a similar flux in the 0.5–2\,keV energy band (∼$2 \times 10^{-12}\,\text{cm}^{-2}\,\text{s}^{-1}$). On the other hand, it is worth noting that a thermal model does not fit our broad-band data.

We conclude that IGR J18538−0102, as already argued by Halpern & Gotthelf (2010), is unlikely a compact object in the supernova remnant G32.1−0.9 but could be a background AGN that is coincidentally aligned with the supernova.

### 4 CONCLUSIONS

In this work we have cross-correlated the list of the still unidentified hard X-ray emitters listed in the fourth IBIS survey with the archive of all XMM–Newton pointings finding a set of six objects with archival data. First, we studied the EPIC images in order to find the IBIS error circle the X-ray counterpart(s). In the case where an associated source has been found, the XMM–Newton data have then been used together the INTEGRAL/IBIS spectra to study the broad-band slope and investigate the possible nature of the source.

In Table 4 a summary of our proposed identifications is reported. In a couple of cases no obvious X-ray counterpart has been found from the XMM–Newton observations, like IGR J173331−2406 and IGR J17445−2747. In the first case, no X-ray source has been detected. This is in perfect agreement with the IBIS survey data where this source has been found to be transient. Extrapolating to the low energies (0.5–10\,keV) the spectrum seen by IBIS during the source outburst and comparing it with the XMM upper limit,
we found a dynamical range of the order of 3000. Such a high value strongly suggests that IGR J17331−2406 could be either a transient black hole in the Galactic bulge or a Supergiant Fast X-ray Transient (SFXT); although this latter interpretation can be ruled out due to source location off the Galactic plane (≈5°) as well as its significantly longer outburst duration compared to classical SFXTs.

The other case where the XMM observation does not provide a secure X-ray counterpart is that of IGR J17445−2747. From the imaging analysis we found a faint XMM source at the border of the IBIS error circle which has also been detected by both Swift/XRT and Chandra. On the other hand, from archival searches we found an XMM slew source well inside the high-energy positional uncertainty which has been seen only once by XMM, and therefore is again in perfect agreement with the high-energy survey data which classified this source extremely variable; we therefore associate IGR J17445−2747 to XMMSL1 J174429.4−274609.

In the remaining four cases we have found a convincing X-ray counterpart in the IBIS error circle for which it has been possible to search for counterparts in other wavelength bands and also perform the spectral data analysis in the 0.5–10 keV band. The spectral parameters obtained together with the possible IR/optical/radio counterpart found allowed us to investigate on the nature of each source. We conclude that IGR J15359−5750 is an AGN of intermediate type for which we were able to estimate the amount of the complex absorption as well as to give constraints on the reflection and the broad-band spectral analysis performed in this work we can conclude that this object is unrelated compact object which happen to coincide with the supernova remnant, probably a background AGN that is coincidentally aligned even if no radio counterpart has been found in the more precise XMM error box.

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