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Letter to the Editor

Using the ROSAT Bright Source Catalogue to find counterparts for IBIS/ISGRI survey sources

J. B. Stephen[1], L. Bassani[1], M. Molina[2], A. Malizia[1], A. Bazzano[3], P. Ubertini[3], A. J. Dean[4], A. J. Bird[4], F. Lebrun[5], R. Much[6], and R. Walter[7]

[1] IASF/CNR, Via Piero Gobetti 101, 40129 Bologna, Italy
e-mail: stephen@bo.iasf.cnr.it
[2] Dipartimento di Astronomia, Università di Bologna, via Ranzani 1, 40127 Bologna, Italy
[3] IASF/CNR, Via del Fosso del Cavaliere, 00133 Roma, Italy
[4] University of Southampton, Southampton, UK
[5] CEA-Saclay, DSM/DAPNIA/Service d'Astrophysique, 91191 Gif-sur-Yvette Cedex, France
[6] ESA-ESTEC, Research and Scientific Support Department, Keplerlaan 1, 2201 AZ, Noordwijk, The Netherlands
[7] INTEGRAL Science Data Centre, Chemin d'Ecogia 16, 1291 Versoix, Switzerland

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Abstract. The IBIS/ISGRI first year galactic plane survey has produced a catalogue containing 123 hard X-ray sources visible down to a flux limit of a few milliCrabs. The point source location accuracy of typically 1–3 arcmin has allowed the counterparts for 95 of these sources to be found at other wavelengths. In order to identify the remaining 28 objects, we have cross-correlated the ISGRI catalogue with the ROSAT All Sky Survey Bright Source Catalogue. In this way, for ISGRI sources which have a counterpart in soft X-rays, we can use the, much smaller, ROSAT error box to search for identifications. As expected, we find a strong correlation between the two catalogues and calculate that there are 75 associations with the number expected by chance to be almost zero. Of these 75 sources, ten are in the list of unidentified objects. Using the ROSAT error boxes we provide tentative associations for 8 of these.

Key words. catalogues – surveys – gamma-rays: observations

1. Introduction

A key strategic objective of the INTEGRAL mission is a regular survey of the galactic plane complemented by a deep exposure of the Galactic Centre (Winkler et al. 2003). This makes use of the unique imaging capability of IBIS (Ubertini et al. 2003) which allows the detection of sources at the mCrab level with an angular resolution of 12 arcminutes and a point source location accuracy (PSLA) of typically 1–3 arcmin within a large ($29° \times 29°$) field of view. In its first year, there have been several surveys produced from the IBIS/ISGRI data (Revnivtsev et al. 2004a; Molkov et al. 2004; Bird et al. 2004). The most complete is that of Bird et al which has detected 123 sources down to a flux level of a few mCrab between 20−100 keV. Within this sample of hard X-ray emitting objects, there are 53 low mass and 23 high mass X-ray binaries, 5 AGN and various other objects such as pulsars, cataclysmic variables and a dwarf nova. The remaining objects (~30 or about 24% of the sample) have no obvious counterparts at other wavelengths and therefore cannot yet be associated with any known class of high energy emitting objects. Searching for counterparts of these new high energy sources is of course a primary objective of the survey work but it is made very difficult by the good, but still too large, INTEGRAL error boxes. Cross correlations with catalogues in other wavebands can be used as a useful tool with which to restrict the positional uncertainty of the objects detected by IBIS and so to facilitate the identification process. Herein, we report on the very strong level of correlation between the ISGRI first year catalogue and the ROSAT All Sky Survey Bright Source Catalogue (RASSBSC). As a result of this work, we estimate the current uncertainty in the ISGRI positions and obtain a number of possible identifications with objects at other frequencies. Obviously this result provides a useful tool with which to validate our source detection procedure in future IBIS survey work. Furthermore, the information provided by ROSAT, in combination with the IBIS data can be used in population studies as well as for diagnostic analysis.

2. Cross correlating the IBIS/ISGRI survey and ROSAT Galactic plane survey

The ROSAT all-sky survey (RASS; Voges 1992), performed in the period July 1990 to February 1991, was carried out with the X-ray telescope (XRT) and the Position Sensitive Proportional Counter (PSPC, Pfeffermann et al. 1986). The survey mapped about 60 000 sources in the soft X-ray band

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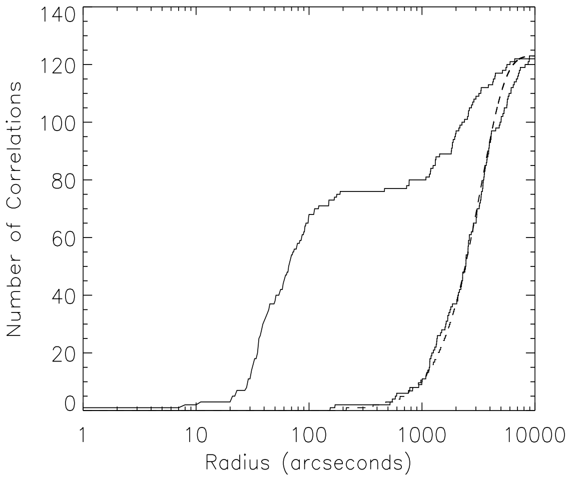

Fig. 1. The Number of ISGRI/ROSAT (upper solid) and "Anti-ISGRI"/ROSAT (lower solid) associations as a function of distance. The dashed line shows the number of correlations expected by chance.

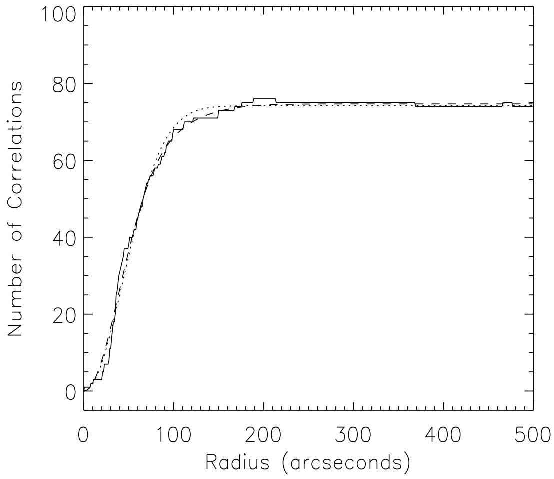

Fig. 2. A close-up of the ISGRI-ROSAT Correlation distribution. The one-Gaussian (dotted) and two-Gaussian (dashed) fits to the data are also shown.

(0.1–2.4 keV) down to a limiting flux of the order of a few 10^{-13} erg cm^{-2} s^{-1}. From this source list the Bright Source Catalogue (RASSBSC-1.4.2RXS), containing 18806 RASS sources having a PSPC count rate larger than 0.05 cts/s in the 0.1–2.4 keV band and at least 15 source counts, was extracted providing the positions of the brightest objects at soft X-ray energies (Voges et al. 1999). Many of these sources have been identified as stars, AGN, cataclysmic variables and accreting binaries, most of which are expected to emit above 10–20 keV, i.e. in the IBIS/ISGRI regime. In order to investigate this, we have cross-correlated the ISGRI first year survey (Bird et al. 2004) with the RASSBSC.

We took both catalogues and calculated the number of ISGRI sources for which at least one ROSAT counterpart was within a specified distance, out to a maximum of around 3 degrees. To have a control group we then created a list of "anti-ISGRI sources", mirrored in Galactic longitude and latitude, and the same correlation algorithm applied. Figure 1 shows the results of this process. The lower solid curve is the "anti-source" correlation, while the dashed line is that expected from chance correlations given the number of ISGRI objects, the number of ROSAT sources and assuming that the latter are evenly distributed across the sky. It is clear that, in this case, the number of correlations can be completely explained by chance. The upper solid curve, however, shows the number of associations for the ISGRI catalogue, and demonstrates that a strong correlation exists, out to a few hundreds of arcseconds before chance coincidences begin to dominate at about 10 arcmin. In particular, we see that at an error radius of about 3 arcmin, the statistical number of chance coincidences expected is 0 (0.35).

The shape of the figure, shown in more detail in Fig. 2, reveals two aspects about the ISGRI sources – the curve should be consistent with the point spread location accuracy (PSLA), as the ISGRI uncertainty in position dominates the ROSAT error, while the total number of correlations is given by where it flattens off. By fitting a Gaussian function to the curve we obtain an average PSLA over all sources of about 1.25 arcmin (90% confidence) and a total number of 75 correlations. In reality, the PSLA of ISGRI sources is dependent on the source significance, and so the shape of the curve would be the sum of many Gaussians of varying widths. By fitting two Gaussians we obtain a significantly better fit to the data with an average PSLA of 1 arcmin for sources stronger than about 20σ and 2.5 arcmin for weaker detections. These values are consostent with those reported by the ISGRI team (Gros et al. 2003) and indicate that the mosaicing procedure used for summing together such large amounts of data does not significantly alter the image quality.

Despite the strong correlation found between the two catalogues, a significant fraction (~40%) of the ISGRI sources have no association with a ROSAT object. This may be due to strong absorption preventing detection in soft X-rays. Of the overall sample of 75 ROSAT sources associated with ISGRI detections, 38 are low mass X-ray binaries, 13 high mass X-ray binaries, 4 AGN/Clusters, 5 pulsars, 3 Cataclysmic variables and 2 other sources, giving a total of 65 identifications. This leaves a total of 10 ISGRI objects not yet optically identified which statistically should be in the RASSBSC. Therefore we can now take the ROSAT positional uncertainty and reduce the ISGRI error box in the search for possible counterparts; in some cases ROSAT error box is of the order of 6–10 arcsec which is sufficiently small to highlight one or two likely counterparts.

3. Searching for counterparts of unidentified IBIS/ISGRI sources

For the 10 IBIS survey sources which are unidentified and have a possible counterpart in the RASSBSC, Table 1 reports the ISGRI name, ROSAT coordinates and error box radius as well as the distance of the ROSAT position from that of the IBIS/ISGRI best fit source location. The ROSAT uncertainty provides a smaller error box than ISGRI and so allows an easier search for counterparts. In the following, we provide details on this search and indicate a number of optical counterparts. In some cases, follow up spectroscopic observations of these counterparts have already permitted secure identifications.

Table 1. Unidentified ISGRI sources with a RASSBSC counterpart.

Name	ROSAT coord.	Positional error (″)	Distance (′)
IGR J15479−4529	15 48 14.50−45 28 45.0	9	0.54
IGR J16167−4957	16 16 37.20−49 58 47.5	16	1.35
IGR J16558−5203	16 56 05.60−52 03 45.5	8	0.97
4U1705−32	17 08 54.40−32 18 57.5	8	1.19
IGR J17303−0601	17 30 21.50−05 59 33.5	7	0.44
IGR J17195−4100	17 19 35.60−41 00 54.5	8	0.89
IGR J17200−3116	17 20 06.10−31 17 02.0	9	1.15
IGR J17254−3257	17 25 25.50−32 57 17.5	14	1.23
IGR J17488−3253	17 48 54.71−32 54 44.0	11	1.61
XTE J1901+014	19 01 41.00+01 26 18.5	12	2.80

IGR J15479−4529: The identification of IGR J15479−4529 can be taken as a case study: this source was discovered during an observation of the X-ray transient 4U 1630−47 (Tomsick et al. 2004) and localized at RA(J2000) = 15 47 0.9 and Dec (J2000) = −45 29 00 (2′ uncertainty); this position is 3.6′ from the location of 1RXS J154814.5−452845, a bright ROSAT all sky survey source recently identified with an intermediate polar cataclysmic variable (Haberl et al. 2002). Although the ROSAT source was outside the ISGRI error box, observations by XMM-Newton indicate that the object is a strong X-ray emitter up to 10 keV, suggesting the possibility of an association between the X and gamma-ray emissions. The IBIS/ISGRI first year survey has been able to provide a more refined position, locating the gamma-ray source only 0.7′ away from 1RXS J154814.5−452845 thus confirming the association and therefore providing a secure identification for this IBIS object.

IGR J16167−4957: This is one of the only two survey sources located in the Norma region and associated with a bright ROSAT object (the other being IGR J16558−5203); this is possibly due to a combination of higher flux and lower extinction which prevents soft X-rays being totally absorbed in these two cases. Within the ROSAT error box of IGR J16167−4957 there are too many optical and/or near-infrared counterparts in the USNO-B1/2-MASS catalogues (Monet et al. 2003; Cutri et al. 2003) for a fruitful identification search; clearly an error box larger than 10 arcsec is of no use in crowded regions of the galactic plane/centre.

IGR J16558−5203: This is the other survey source located in the Norma Region and associated with a bright ROSAT source; by itself the X-ray error box, although small, is insufficient to pinpoint a single candidate. Luckily the soft X-ray source has also been observed with the ROSAT/HRI instrument and detected as RXH J165605.6−520339; in this case the uncertainty associated with the position is of the order of a few arcseconds, which is sufficient to pinpoint a likely optical/infrared candidate: a USNO-B1 source located at RA = 16 56 05.6 and Dec = −52 03 40.4. This, possibly extended, source is quite bright in both B and R optical bands ($B \sim 14.5$, $R \sim 13.5$) and is also visible in the near infrared (2-MASS). Follow up optical spectroscopic observations of this likely counterpart can prove its association with the IBIS source and define its nature.

4U1705−32: Although previously detected both by the Uhuru and HEAO satellites in the 2–6 keV band ($2{-}45 \times 10^{-11}$ erg cm^{-2} s^{-1}, Forman et al. 1978; Wood et al. 1984) and despite its X-ray brightness, this source is still unidentified. The ROSAT PCPC error box provides two optical counterparts, of which only one is also a near infrared source (2-MASS and DENIS). Here too the source error box has been observed with the HRI instrument on various occasions: the source was found to be variable by at least a factor of 6 over a six month period. Inspection of the small HRI error circle (at RA = 17 08 54.23 Dec = −32 18 55.8 with a 2″ radius) indicates the lack of any optical and/or infrared conterpart suggesting that the source is extremely weak (or highly absorbed) in optical with an upper limit on B of ∼20 magnitudes. Within 5″ from the ROSAT/HRI position lies an USNO $B-1$ source at RA = 17 08 53.85 Dec = −32 18 55.4 having $B \sim 18$ and $I \sim 16$; no source is listed at this position in the 2-MASS catalogue. Follow-up work on this nearby object and a deep search of the HRI error could shed light on this bright X-ray emitter.

IGR J17303−0601: This source coincides with the HEAO A1 object 1H1726−058 having a 2–10 keV flux of 1.5×10^{-11} erg cm^{-2} s^{-1} (Wood et al. 1984). An object close to the ISGRI position is also listed in the recent RXTE all sky survey (XSS17309−0552, see Revnivtsev et al. 2004b). Sazanov and Revnivtsev (2004) suggested an extragalactic origin on the basis of its similarity with the spectral slope of this class of sources as detected by RXTE. Inspection of the ROSAT error box indicates the presence of two likely counterparts both with detection at near-infrared (2-MASS survey) and optical frequencies (USNO-B1 catalogue). The furthest to the ROSAT position is also the brightest of the two sources ($R \sim 15.5$). Recent optical spectroscopy of both candidates has allowed us to identify the true counterpart and also to identify it with a low mass-X-ray binary system (Masetti et al. 2004 and details therein).

IGR J17195−4100: The ROSAT error box of this ISGRI source contains only one bright ($B \sim 15$) optical source according to the USNO-B1 catalogue (RA = 17 19 35.94 Dec = −41 00 53.5). Within 2.2″ from this source lies a bright near-infrared source which is possibly extended or unresolved in the direction of the USNO-B1 object. Two more optical sources are located just outside the ROSAT error circle. Clearly follow up optical work on the most likely counterpart (and possibly of the nearby objects too) can determine if the source has the characteristics of a high energy emitting source and further determine its association to the near-infrared object.

IGR J17200–3116: Within the ROSAT error box there is only one USNO B1 source at RA = 17 20 06.1 Dec = −31 17 02.0 (∼19 mag in *B*) : this source is also near-infrared detected. However, inspection of the 2-MASS survey indicates the presence of two extra near-infrared objects. Although these two objects are brighter than the USNO-B1 source in *JHK* band photometry, they must be extremly reddened in optical as they are below the USNO-B1 catalogue threshold.

IGR J17254–3257: Inspection of the ROSAT error box indicates the presence of only one optical source in USNO-B1 at RA = 17 25 26.03 Dec = −32 57 06.1; this source has a *B* magnitude in the range 18–19 and is also near-infrared detected. However, the 2-MASS catalogue reports 5 more sources within the X-ray error box, again a clear indication that an error radius greater than 10 arcsec makes the identification procedure highly difficult.

IGR J17488–3253: The positional uncertainty on this ROSAT source is too large for a fruitful identification process; luckily this source was also observed by the HRI instrument (1RXH J174854.9–325448) and localized at RA = 17 48 54.9 Dec = −32 54 48.2 with an uncertainty of a few arcseconds. Within this error box no optical, radio and/or infrared counterpart is found, implying a very weak source at all these frequencies, however at the edge of the ROSAT error circle a (possibly extended) source with $R \sim 16$ is clearly seen on DSS2. Optical photometry can disintangle whether this object is extended or made of a group of point like sources and spectroscopy will be able to pinpoint the nature of the source(s) responsible for the high energy emission.

XTE J1901 + 014: This source has often been detected at soft X-ray energies by Einstein (2E1859.1+0122, Hertz & Grindlay 1988), EXOSAT (GPS1858+015, Warwick et al. 1988) and most recently by ROSAT. Apart from the survey detection, the source was also seen during a pointed ROSAT/HRI measurement performed on 1994 October 3, however, its position appears to be slightly offset from the RASSBSC coordinates (the HRI position is RA = 19 01 40.1 Dec = +01 26 30.6 with an error radius of 10′′, Wijnands 2002). Although these locations are compatible within the errors, each contains various possible counterparts: within the RASSBSC error box (see Table 1) lies a single object in the USNO-B1/2-MASS catalogue at RA = 19 01 41.11 and Dec = 01 26 28.3 having *B*, *R* and *K* magnitudes of 17 and 14.5 and 13.7 respectively. Instead within the *HRI* error box we only find a 2-MASS object at RA = 19 01 39.84 and Dec = +01 26 32.6 with $K = 10.4$ and no optical counterpart.

4. Conclusions

We have shown that, as expected, there is a strong correlation between the ISGRI survey source list and the ROSAT All Sky Survey Bright Source Catalogue. By analysing this correlation, we have further shown that the ISGRI positional uncertainty is similar for the mosaiced images as for the individual observations at around 1–3 arcmin. Furthermore the correlation function allows us to calculate that there should be 75 clear ISGRI-ROSAT source correlations (with the number due to chance being almost zero), and as only 65 have already been identified, we can use this information to help find optical counterparts for the other 10 sources by using the associated ROSAT positional uncertainty. In eight cases the ROSAT error box is sufficiently small to pinpoint 1–3 likely counterparts. We can also use the ROSAT associations to validate source detections in future survey work when, working at lower significance levels, we expect to introduce spurious sources due to imperfect image cleaning: a likely ROSAT counterpart would increase the probability that any excess found is a real IBIS/ISGRI source. Population studies, as well as diagnostic analysis of the ROSAT/IBIS-ISGRI associations is in progress and will be presented in a future work.

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