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The IBIS/ISGRI Survey of the Galactic Plane - Global Characteristics of the Gamma-Ray Sources

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Abstract. INTEGRAL is the first gamma-ray astronomy mission with a sufficient sensitivity and angular resolution combination appropriate to the detection and identification of considerable numbers of gamma-ray emitting sources. The large field of view enables INTEGRAL to survey the Galactic Plane on a regular (∼weekly) basis as part of the core programme. The first source catalogue, based on the 1st year of core programme data (∼5 Msec) has been completed and published (Bird *et al.* 2004). It contained 123 γ-ray sources (24 HMXB, 54 LMXB, 28 "unknown", plus 17 others) - sufficient numbers for a reasonable statistical analysis of their global properties. The detection of previously unknown γ-ray emitting sources generally exhibiting high intrinsic absorption, which do not have readily identifiable counterparts at other wavelengths, is intriguing. The substantial fraction of unclassified γ-ray sources suggests they must constitute a significant family of objects. In this paper we review the global characteristics of the known galactic sources as well as the unclassified objects.

Keywords. Gamma-rays: observations – X-rays: binaries – Galaxy: structure – Galaxy: stellar content.

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1. Introduction

INTEGRAL is the first gamma-ray astronomy mission with a sufficient sensitivity and angular resolution combination appropriate to the detection and identification of considerable numbers of gamma-ray emitting sources (Winkler *et al.* 2003). With an observation time of roughly 1000 seconds required to detect a $1M_{\odot}$ neutron star emitting at the Eddington limit from a distance of 10kpc it is clear that a meaningful survey of discrete galactic gamma-ray emitting objects is possible in the lifetime of INTEGRAL.

A significant fraction of the INTEGRAL core programme is devoted to regular scans of the Galactic Plane and a deep exposure of the Galactic Centre. This is facilitated by the large field of view of the on-board telescopes (9° × 9° fully coded and 29° × 29° zero response for IBIS, Ubertini *et al.* (2003)), which permits ∼100 ksec exposures of the Galactic Plane to be made ∼every 12 days). The 1st IBIS/ISGRI survey catalogue is constructed from ∼5 Msec of observations (all Core Programme observations between revolutions 46 and 120). The data is organised into short pointings (science windows) of ∼2 ksec. The ∼2500 individual science window images were then mosaiced using a custom tool to produce deep all-sky maps. An initial source list was obtained by searching all-sky mosaics using the *SExtractor* tool. It has since been discovered that the identification of IGR J17460-3047 was in fact a false detection. The typical point source location error range is 20″–3′, with a 1 arc minute error circle for a source >10σ (90% confidence) (Gros *et al.* 2003). The precision of the source locations allow for the clear association to sources seen by previous missions.

Of the 123 sources in the catalogue, 5 were unambiguously identified with AGN, 5 with white dwarfs, 4 with radio pulsars (free neutron stars), 3 supernova remnants and one cluster. Of the remainder, 54 were identified with known low mass X-ray binary (LMXB) systems, 24 with high mass X-ray binaries (HMXB) and the remaining 28 sources have no firm classification and are here after described as "unclassified". In this paper we have only considered the LMXBs, the HMXBs and the unclassified objects, discounting IGR J17460-3047 as a false detection.

2. The Log(N)-Log(S) Distributions

In this section we construct the number flux distribution for the various source types. We have assumed the usual power-law form of $N(>S) = KS^{-\alpha}$ for the relationship. As the sky coverage of the first survey is not complete, the Log(N)-Log(S) curves are only indicative of the true galactic distributions and must be corrected for both the area of sky covered and the depth of exposure (or the minimum detectable flux (MDF)) at each point. This is not straightforward due to the residual systematic structures in the sky maps, however it is possible by inspection of the error and exposure distributions to parameterise the variation in MDF as a function of exposure, thereby taking into account the effects of the residual systematic variations.

From this relationship and the general sky exposure map we can then correct the observed logN-logS resulting in the relationships shown in Figure 1.

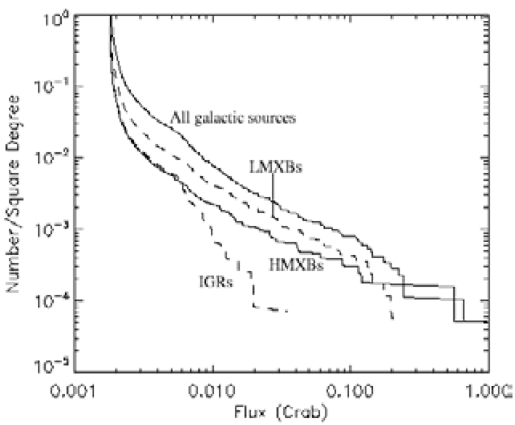

Figure 1. The Number-Flux relationships corrected for exposure and sky area observed.

The limiting detection threshold of 6 sigma is sufficiently high so that the maximum likelihood (ML) method (Murdoch et al. 1973) can be used to calculate the best-fit values of the slope of the number-flux relationship without the uncertainty in the correction factor for weaker sources dominating the correction itself. This has been performed for the corrected distributions and the value of the slope found in each case is shown below:

- All Galactic Sources, $\alpha = 0.91 \pm 0.09$
- LMXB, $\alpha = 0.95 \pm 0.13$
- HMXB, $\alpha = 0.81 \pm 0.15$
- Unclassified sources, $\alpha = 2.11 \pm 0.46$

It is of interest to consider and compare the Log(N)-Log(S) distributions of the various sub-groupings. The -0.91 slope of the power law for all the combined galactic sources is close to the -1 value expected for a uniform infinite plane distribution and lies between the value (-0.79 ± 0.07) measured for galactic sources by ASCA (Sugizaki *et al.* 2001) in the classic 2-10 keV X-ray band and the (-1.1) slope derived from the Einstein Galactic Plane survey (Hertz & Grindlay 1984). This all-source value is clearly dominated by the numerically superior LMXBs, which when detached provide a slope of -0.95 ± 0.13 as a sub-set. The value for LMXBs is thus consistent with -1, as qualitatively expected for a population with a larger scale height (Sugizaki *et al.* 2001). HMXBs are typically located within spiral arms and this would automatically lead to a value of α closer to 0.5. In this context, the -0.81 ± 0.13 slope measured for the HMXBs appears slightly flatter than the LMXBs and may reflect the likely location of these objects along the spiral arms. The steep slope of the unclassified sources may imply a different source

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population at low fluxes, this is far steeper than we may expect from even an extragalactic contamination. However, it must be remembered that there are relatively very few of these objects, and they are also amongst the weaker sources in the survey therefore care must be taken in any interpretation of this slope.

3. The Angular Distributions

The first year of INTEGRAL observations has been strongly biased towards the study of the Galactic Plane and in particular the Galactic Centre, hence the first IBIS/ISGRI catalogue is essentially a register of galactic sources. Figure 2 reveals the considerable differences in the longitudinal distribution of the HMXB and LMXB sources. Whereas the LMXB are concentrated in the Galactic Centre region, the HMXB are spread more extensively along the Galactic Plane, but in a non-uniform manner, with some evidence for bunching in the vicinity of the tangential points of the spiral arm structure. The locations of the spiral arm tangents were taken from Englmaier *et al.* (1999). Additionally, a number of HMXBs is seen at $l^{II} \sim \pm 90^o$, which is indicative of systems located within our particular spiral arm. This association had been previously noted through inspection of the Ginga data by Koyama *et al.* (1990) and in the RXTE/ASM data by Grimm *et al.* (2002).

The association with the spiral arms is entirely to be expected since the high mass binaries are young stellar systems and should be attached to regions where star formation has recently taken place, such as the spiral arms.

The unclassified sources appear to have a longitude distribution concentrated around the Galactic Centre, similar to that of the LMXBs. To some extent this is misleading as the Galactic Centre has had the most sky exposure and hence we are more likely to detect new systems in this region. However, upon closer examination, whilst some emulate the distribution of LMXB, it can be seen that the unclassified sources do not have a symmetrical distribution about the Galactic Centre and show some tendency to cluster around the locations of spiral arm tangents, specifically the Scutum, 3-kpc and Norma arms. Specifically the unclassified sources appear to concentrate in the 3-kpc and Norma spiral arms.

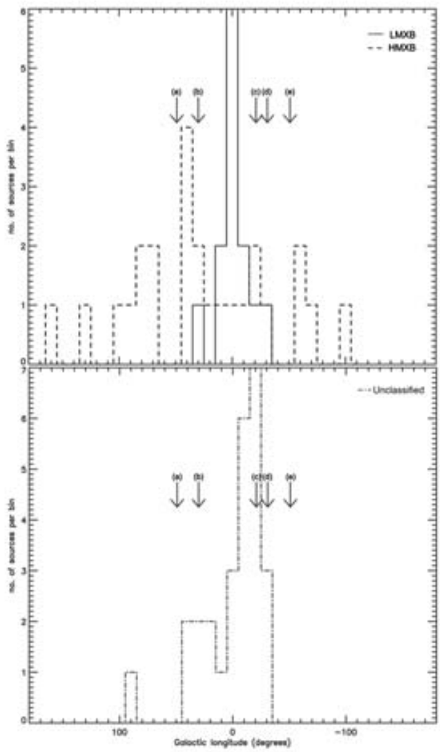

Figure 2. The Galactic longitude distribution of HMXBs, LMXBs and unclassified sources. Labelled are the locations of the spiral arm tangents: (a) - Sagittarius; (b) - Scutum; (c) - 3-kpc; (d) - Norma; (e) - Centaurus.

Examining the angular distribution off the Galactic Plane of the sources we find that the HMXBs exhibit a much narrower range of angular separations than the LMXBs, as expected if they are confined to the Galactic Disc. The much wider spread of the LMXBs is indicative of a population derived from the Galactic Bulge. The unclassified sources appear to have a sharp latitude cut-off similar to that of the HMXBs, this may indicate that they too are a primarily a population from the Galactic Disc. However, they do not precisely conform to either of the subgroups; this is not unexpected as they could consist of a mixture of both, or be a separated generic set.

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4. Summary and Discussion

The INTEGRAL Galactic Plane survey and ensuing first catalogue has offered for the first time the possibility to investigate the global γ-ray characteristics of galactic sources on a reasonable statistical basis. In this paper we have studied the generalised observational features of γ-ray selected previously unclassified objects, and compared them with the corresponding parameters of known HMXB and LMXB systems. Although the sample of sources has been γ-ray selected the Log(N)-Log(S) and angular distributions of the known classes, as expected, emulate those of X-ray selected sets e.g. Grimm *et al.* (2002), there appear to be subtle differences. Of great interest are the 27 "unidentified" objects, which naturally have overhanging questions such as what are they and how do they fit into mainstream stellar evolution?

Clearly a vigorous programme of follow-up studies on individual objects, using such missions as XMM-Newton, Chandra, and RXTE for timing studies, is one means to pursue the answers to these questions, and such activities are already underway: Matt & Guainazzi (2003); Walter *et al.* (2003); Hill *et al.* (2005); Stephen *et al.* (2005). The complementary statistical approach employed here essentially comes to the same conclusion i.e. that a large fraction of the unclassified objects are obscured high mass X-ray binary systems. Detailed studies of the main distributional characteristics of the unclassified sources when compared to the equivalent distributions of known X-ray binaries all point in this direction.

It is hardly surprising that INTEGRAL should discover a population of previously unnoticed sources. The catalogue is γ-ray selected, and INTEGRAL operates above the energy threshold for which significant photoabsorption takes place in universal abundance matter, so that a strong emitter above ∼30keV can be rendered insignificantly weak in the classical X-ray band. As discussed by Lutovinov *et al.* (2005), the HMXB systems constitute the most likely candidates. The stellar wind accretion mechanism that dominates in HMXB systems, as opposed to the Roche lobe overflow associated with LMXBs, naturally provides a suitable dense and strongly absorbing circumstellar wind to veil the X-ray emission.

Exactly how the γ-ray selected highly absorbed systems fit into the overall picture of binary star evolution is currently unclear. This is principally due to the requirement of a suitable companion able to generate a suitably dense gas surrounding the compact object to stifle the X-ray emission. We need to understand why they are different to "normal" HMXB. Do these highly absorbed systems relate to the mass/giant nature of the primary star, or to the orbit configuration, or are they experiencing a phase the binary systems routinely pass through, but have not been exposed at other wavelengths? Do they need to be HMXB? Clearly a series of dedicated observations is required to solve this problem.

References

Bird, A.J., Barlow, E.J., Bassani, L., *et al.*, 2004, ApJ, 607L, 33B
Englmaier, P. & Gerhard, O., 1999, MNRAS, 304, 512
Grimm, H.-J., Gilfanov, M. & Sunyaev, R., 2002, A&A, 391, 923
Gros, A., Goldwurm, A., Cadolle-Bell, M., *et al.*, 2003, A&A, 411, L179
Hertz, P. & Grindlay, J., 1984, ApJ, 278, 137
Hill, A.B., Walter, R., Knigge, C., *et al.*, 2005, A&A, 439, 255
Koyama, K., Kamada, M., Kunieda, H., *et al.*, 1990, Nature, 343, 148
Lutovinov, A., Revnivtsev, M., Molkov, S., *et al.*, 2005, A&A, 430, 997
Matt, G. & Guainazzi, M., 2003, MNRAS, 341, L13
Murdoch, H. S., Crawford, D. F. & Jauncey, D. L., 1973, ApJ, 183, 1
Stephen, J.B., Bassani, L., Molina, M., *et al.*, 2005, A&A, 432, L49
Sugizaki, M., Mitsuda, K., Kaneda, H., *et al.*, 2001, ApJS, 134, 77
Ubertini, P., Lebrun, F., Di Cocco, G., *et al.*, 2003, A&A, 411, L131
Walter, R., Rodriguez, J., Foschini, L., *et al.*, 2003, A&A, 411, L427
Winkler, C., Courvoisier, T. J.-L., Di Cocco, G., *et al.*, 2003 A&A, 411, L1