A new determination of the **INTEGRAL/IBIS**
point source location accuracy

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**ABSTRACT**

**Aims.** To determine the Point Source Location Accuracy (PSLA) for the INTEGRAL/IBIS telescope based on analysis of archival in-flight data.

**Methods.** Over 40 000 individual pointings (science windows) of INTEGRAL/IBIS data were analysed using the latest Off-line Science Analysis software, version 7.0. Reconstructed source positions were then compared against the most accurate positions available, determined from focusing X-ray telescopes. Since the PSLA is a strong function of source detection significance, the offsets from true position were histogrammed against significance, so that the 90% confidence limits could be determined. This has been done for both sources in the fully coded field of view (FCFOV) and partially coded field of view (PCFOV).

**Results.** The PSLA is found to have improved significantly since values derived from early mission data and software for both FCFOV and PCFOV.

**Conclusions.** This result has implications for observers executing follow-up programs on IBIS sources since the sky area to be searched is reduced by >50% in some cases.

**Key words.** Instrumentation: detectors. Methods: data analysis

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1. Introduction

The **INTEGRAL** satellite (Winkler et al. 2003), launched in October 2002, is an ESA space mission specifically designed to study the gamma-ray sky. In particular the IBIS (Imager on Board of the **INTEGRAL** Satellite) telescope (Ubertini et al. 2003) is the main hard X-ray/soft gamma-ray coded aperture imaging instrument (Goldwurm et al. 2003), and is responsible for surveying and cataloguing the sky above 17 keV. Here we discuss the point source location accuracy (PSLA) of the ISGRI low energy detector (15-1000 keV) of IBIS (Lebrun et al. 2003).

Due to the continuing necessity to follow-up the growing unidentified **INTEGRAL** source population in other wavebands (particularly optical and infrared), it is of great interest to ensure the correctness of the IBIS/ISGRI PSLA. In particular, it is hoped that with the release of new and updated Off-line Science Analysis (OSA 7.0) software the PSLA could have improved substantially compared to the already published estimates based on early mission data and software releases (Gros et al. 2003, constructed the PSLA based upon OSA 3.0). Any improvement in the PSLA is important in reducing the chance of random or multiple source associations in other wavebands.

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2. Refining the PSLA error radius

In order to empirically determine the PSLA of the IBIS/ISGRI telescope, we can extract the positions of objects from the IBIS/ISGRI Science Windows (ScWs) and compare these with their best known positions. This can then be used to estimate the 90% error offset as a function of detected significance, allowing us to define the 90% PSLA. In particular, the IBIS/ISGRI telescope (and coded mask telescopes in general) PSLA depends strongly on detection significance, but also on the position of the source within the field of view. We therefore require for our analysis a set of sources spanning a wide range of significances and off-axis positions in order to allow our analysis to be useful for all detected IBIS/ISGRI sources.

We begin by compiling a list of sources with good positions. It is best at this stage to be conservative and only select sources where accurate nominal positions are known rather than to bias our sample by also including sources with large nominal error radii. Since the **INTEGRAL** General Reference Catalog (Version 30, Ebisawa et al. 2003, http://isdc.unige.ch/Data/cat/latest/) and make a

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selection on the error radius, selecting those sources with an error less than 30”; at this level, the error on the true position should give a negligible contribution to the measured offsets to the IBIS position. Thus the total number of objects used in our sample is 332, spanning a wide range of detection significances and off-axis angles. This number might seem small when compared to the 721 sources detected in Bird et al. (2010), however we note that many objects in that catalog are newly discovered INTEGRAL sources for which X-ray follow-up is not yet available, and that therefore have relatively large nominal error radii.

After performing an imaging analysis with the OSA 7.0 pipeline, we inspected all available ScW images and extracted the fitted positions which resulted from the image deconvolution: these are the columns RA_FIN and DEC_JFIN from the isgri_sky_res file for all pointings where any of the 332 objects was present. The dataset was divided into fully coded field of view and (lower) partially coded field of view. Also plotted is the estimated 90% PSLA from Gros et al. (2003) (dashed line), our estimated 90% PSLA (solid line) and the telescope theoretical PSLA from Goldwurm et al. (2001) (dashed-dotted line).

Fig. 1. Measured offset from true position (datapoints) as a function of detection significance for IBIS/ISGRI detected sources in the (upper) fully coded field of view and (lower) partially coded field of view. Also plotted is the estimated 90% PSLA from Gros et al. (2003) (dashed line), our estimated 90% PSLA (solid line) and the telescope theoretical PSLA from Goldwurm et al. (2001) (dashed-dotted line).

In each case, the solid line represents the best fit. Also plotted is the 90% PSLA estimate of Gros et al. (2003).

3. Comparison to previous results
These empirical fits can now be used in order to estimate the improvement in radius and area between the previously published fit of Gros et al. (2003) and our own estimates. To this end, Figure 2 shows once again our fits for the 90% PSLA for the FCFOV and PCFOV and the Gros et al. (2003) result. To demonstrate the decrease in error radius between the Gros et al. (2003) result and our new updated PSLA we simply subtract the two fits in order to display the error radius improvement. This is shown in Figure 3, where it can be seen that the biggest reduction in radius occurs at approximately 10σ – 15σ. The potential

<table>
<thead>
<tr>
<th></th>
<th>FCFOV</th>
<th>PCFOV</th>
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<tr>
<td>65%</td>
<td>a = 17.65</td>
<td>a = 18.78</td>
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<tr>
<td></td>
<td>b = 0.14</td>
<td>b = 0.17</td>
</tr>
<tr>
<td></td>
<td>c = -1.19</td>
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<td>90%</td>
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<td></td>
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<td></td>
<td>c = -1.25</td>
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<td>a = 36.7</td>
<td>a = 34.8</td>
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<td>c = -0.97</td>
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Fig. 2. Fits to the OSA 7.0 90% PSLA in FCFOV and PCFOV. In each case, the solid line represents the best fit. Also plotted is the 90% PSLA estimate of Gros et al. (2003).
for reducing false matches when performing follow-up observations of such objects in other wavebands is however best shown in Figure 4, where the percentage area improvement of the 90% error circle is shown. This is defined to be the area subtended by our 90% PSLA as a function of significance divided by the area subtended by the 90% PSLA estimate of Gros et al. (2003). Here the biggest reduction occurs in the range $20\sigma - 25\sigma$, where the area to inspect reduces by $\approx 50\%$ from the previous Gros et al. (2003) result. This would be a typical significance for a transient detection in a single ScW of a source of $\approx 250\text{mCrab}$. We therefore predict that these transient detections will benefit the most from this improved 90% PSLA, where the probability of false matches for follow-up observations will be drastically reduced.

\textit{INTEGRAL}/IBIS has also detected and classified a large number of persistent sources such as AGN, which obtain their peak significance after mosaicking many individual ScWs. In this case it is not always easy to establish how many pointings were used where the source candidate was in the FCFOV or the PCFOV, and so it is not trivial to establish which 90% PSLA to use. In these cases we suggest a conservative approach and use the PCFOV PSLA estimate.

We have also carried out the same analysis for data reduced with and older version of the analysis software, OSA 5.0, and find after fitting the 90% PSLA, that an improvement on the estimated error circle size had already been achieved with OSA 5.0 compared to the Gros et al. (2003) result based on OSA 3.0; however with the latest version of the software release, OSA 7.0, the improvement is even more evident. This result also indicates that a re-analysis of archival data with the latest software will often yield far better source positions, and may allow observers to distinguish between multiple candidate counterparts far better than previously.

\section*{4. Conclusions}

This work has shown that the IBIS/ISGRI PSLA (ie the size of the 90\% error circle) has dramatically improved since the last study of Gros et al. (2003) and this can be attributed to improvements in the OSA software. The main implications of this result will be for follow-up observations, particularly in the optical and infrared wavebands, of the \textit{INTEGRAL} unidentified source population ($\approx 30\%$ of objects present in the latest IBIS/ISGRI catalogue release by Bird et al. 2010). This improved error radius will greatly enhance the identification of \textit{INTEGRAL} counterparts.

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\textbf{References}


