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A new determination of the *INTEGRAL*/IBIS point source location accuracy *(Research Note)*

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ABSTRACT

Aims. We determine the point source location accuracy (PSLA) of 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 with the most accurate positions available, determined using focusing X-ray telescopes. Since the PSLA is a strong function of source detection significance, histograms of the offsets from true position were compiled to determine the 90% confidence limits 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 measurements were first made for 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 more than 50% in some cases.

Key words. instrumentation: miscellaneous – methods: data analysis

1. Introduction

The *INTEGRAL* satellite (Winkler et al. 2003), launched in October 2002, is an ESA space mission designed specifically to study the gamma-ray sky. 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. We discuss the point source location accuracy (PSLA) of the ISGRI low energy detector (15–1000 keV) of IBIS (Lebrun et al. 2003).

Because of the continuing necessity to follow-up the increasing unidentified *INTEGRAL* source population in other wavebands (particularly in the optical and infrared), the preciseness of the IBIS/ISGRI PSLA measurement is of great interest. In particular, it is hoped that with the release of new and updated Off-line Science Analysis (OSA 7.0) software the PSLA may 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 random or multiple source associations in other wavebands.

2. Refining the PSLA error radius

To empirically determine the PSLA of the IBIS/ISGRI telescope, we extract the positions of objects from the IBIS/ISGRI Science Windows[1] (ScWs) and compare these with their most accurately known positions. These can then be used to estimate the 90% error offset as a function of detected significance, allowing us to define the 90% PSLA. For the IBIS/ISGRI telescope, and coded mask telescopes in general, the PSLA depends strongly on detection significance, but also on the position of the source within the field of view. We therefore require a set of sources spanning a wide range of significances and off-axis positions for our analysis to be useful to all detected IBIS/ISGRI sources.

We complied a list of sources with accurately known positions. We decided to be conservative and only select sources whose nominal positions are accurately known rather than to bias our sample by also including sources with large nominal error radii, as for many newly discovered *INTEGRAL* sources. To do this we adopted the latest *INTEGRAL* General Reference Catalog (Version 30, Ebisawa et al. 2003[2]) and selected on the basis of the error radius, selecting those sources with an error less than 30″; at this level, the error on the true position should contribute negligibly to the measured offsets in 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 compared to the 721 sources detected in Bird et al. (2010), but we note that many

[1] An IBIS/ISGRI Science Window refers to one single *INTEGRAL* pointing of about 2000 s.
[2] http://isdc.unige.ch/Data/cat/latest/

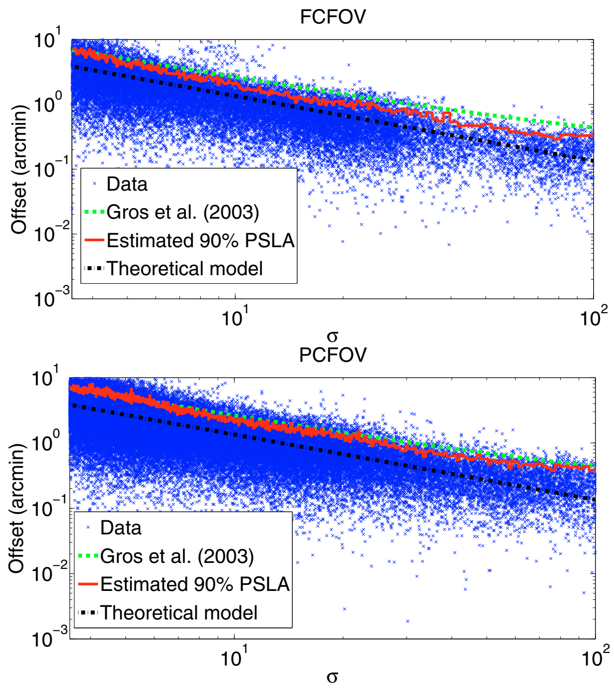

Fig. 1. Measured offset from true position (datapoints) as a function of detection significance for IBIS/ISGRI detected sources in the (*upper*) fully coded field of view and (*lower*) partially coded field of view. We also plot is the estimated 90% PSLA from Gros et al. (2003) (dashed line), our estimated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

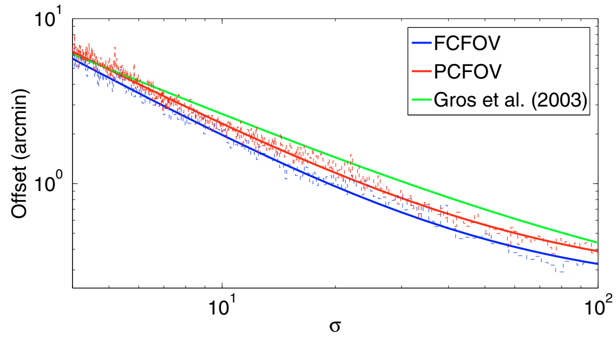

Fig. 2. Fits to the OSA 7.0 90% PSLA in FCFOV and PCFOV. In each case, the solid line represents the best fit. We also plot is the 90% PSLA estimate of Gros et al. (2003).

Table 1. Estimated PSLA fit parameters for the FCFOV and the PCFOV.

	FCFOV	PCFOV
65%	$a = 17.65$	$a = 18.78$
	$b = 0.14$	$b = 0.17$
	$c = -1.19$	$c = -1.16$
90%	$a = 31.1$	$a = 31.1$
	$b = 0.23$	$b = 0.25$
	$c = -1.25$	$c = -1.18$
95%	$a = 36.7$	$a = 34.8$
	$b = 0.25$	$b = 0.26$
	$c = -1.24$	$c = -1.14$
99%	$a = 36.4$	$a = 34.6$
	$b = 0.14$	$b = 0.19$
	$c = -1.04$	$c = -0.97$

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_FIN 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 (FCFOV) and partially coded field of view (PCFOV). The IBIS coded aperture mask has a field of view of 30°, the FCFOV being the central 9°×9° region; everything outside this region constitutes the PCFOV. We then determine the offset as a function of detection significance in both FCFOV and PCFOV, for all objects in question: this allows us to estimate the 90% PSL confidence by adaptively binning the measured offsets in significance to ensure the same statistics for all bins (100 measurements per bin). Around 25 000 and 75 000 individual offset measurements are used in the FCFOV and PCFOV analyses respectively. The results are shown in Fig. 1 where the solid line representing the 90% confidence limit, the dashed line indicates the result from Gros et al. (2003) and the dashed-dotted line shows the theoretical PSLA defined by Goldwurm et al. (2001). We note that the theoretical PSLA of Goldwurm et al. (2001) applies only to on-axis sources, whilst the estimated 90% PSLA of Gros et al. (2003) was derived for sources within 14 degrees of the telescope axis.

To fit the estimated 90% PSLA we used the form $y = ax^c + b$ (the same as used by Gros et al. 2003), and applied identical weights to all bins as they contain the same number of observations. For completeness we also estimated the 65%, 95% and 99% PSLA. The fit parameters for all estimated PSLA are shown in Table 1, whilst we display only the 90% PSLA in Fig. 2.

3. Comparison to previous results

These empirical fits can now be used 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, Fig. 2 once again shows 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 to highlight the error radius improvement. This is shown in Fig. 3, where it can be seen that the greatest reduction in radius occurs at approximately 10σ–15σ. The potential for reducing false matches when performing follow-up observations of these objects in other wavebands is however most clearly shown in Fig. 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 greatest reduction occurs in the range 20σ–25σ, where the area to inspect reduces by ≈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 ~250 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.

INTEGRAL/IBIS has also detected and classified a large number of persistent sources such as AGN, for which the peak significance is obtained 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 either in the FCFOV or the PCFOV, and so it is not trivial to establish which 90%

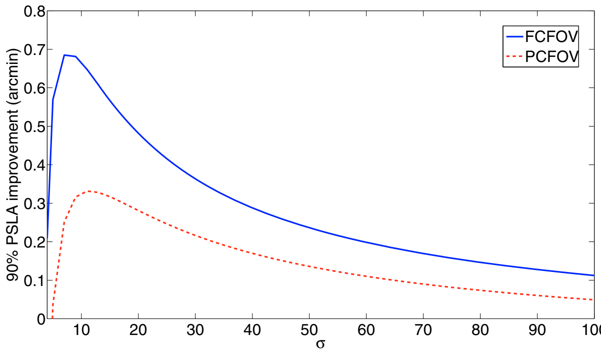

Fig. 3. 90% PSL error radius improvement between the old Gros et al. (2003) and the new (this work) estimates in arcminutes.

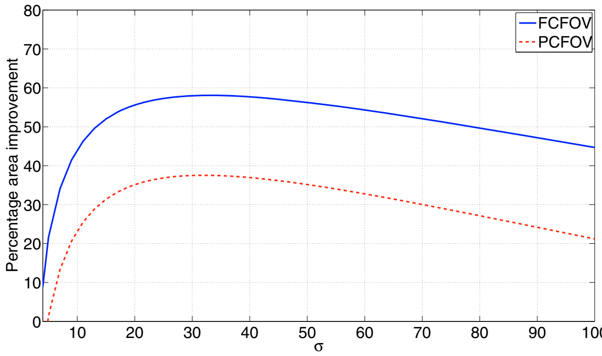

Fig. 4. Percentage sky search area improvement between the old Gros et al. (2003) and the new (this work) 90% error radii.

PSLA to use. In these cases we suggest a conservative approach and use the PCFOV PSLA estimate.

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

4. Conclusions

This work has shown that the IBIS/ISGRI PSLA (i.e., the size of the 90% error circle) has dramatically improved since the 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 *INTEGRAL* unidentified source population (≈30% of objects in the latest IBIS/ISGRI catalogue release by Bird et al. 2010). This improved error radius will greatly enhance the identification of *INTEGRAL* counterparts.

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