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Constructing an IBIS/ISGRI slew survey

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Abstract. INTEGRAL/IBIS has two operation modes: pointing and slew. The telescope collects data while operated in both modes, but only pointing data are currently processed with the INTEGRAL Off-line Scientific Analysis software. This work aims at giving access to INTEGRAL/IBIS slew data ($\approx$ 30Ms of data, corresponding to about 7% of the total observing time) for scientific analysis. Slew data will extend the coverage of regions of the sky that aren't regularly observed and provide additional data points for long-term light curves. This will significantly contribute to the study of hard X-ray transient sources and the long-term monitoring of transient activity of persistent sources.

Key words. Instruments: INTEGRAL – Instruments: IBIS/ISGRI – Instruments: coded apertures – Instruments: coded masks – gamma - rays: surveys – X - rays: surves

1. Introduction

The INTEGRAL Off-line Scientific Analysis (OSA) software reconstructs the position of sources from the detector image by means of a cross-correlation Goldwurm et al. (2003). This is possible because the image formed in pointing operation mode represents the shadow of the coded mask on the detector plane. The telescope also collects data while being maneuvered from one stable position to another (slew mode). During slews the cross-correlation analysis is not possible, since the image on the detector plane is not correlated to the presence of a source in a fixed position in the field of view (FOV). This work makes use of a back-projection approach to analyse slew data collected by IBIS/ISGRI instrument. A sensitivity limit of $50 - 70$ mCrabs is estimated for a single data acquisition period (science window or ScW) in slew mode, depending on the speed of the pointing axis (slew rate).

2. Data analysis

During slews, the detector image is not the result of the mask blocking part of the radiation from a source in fixed position of the FOV and therefore a cross correlation with the correlation inverse array G Goldwurm et al. (2003) does not have peaks at the source position. Nevertheless, each detected photon must have passed through one of the apertures in the mask. This allows IBIS/ISGRI slew data analysis with an alternative approach based on a back-projection technique. The knowledge of the instrument geometry is used to trace back each detection (event) to all the regions of the sky that the corresponding photon could have come from. The position of astronomical sources is then reconstructed by tracing a great number of photons from different positions in the detector.

A diagram of the algorithm applied to INTEGRAL/IBIS data is shown in figure 1. It makes use of the outputs of some stages of

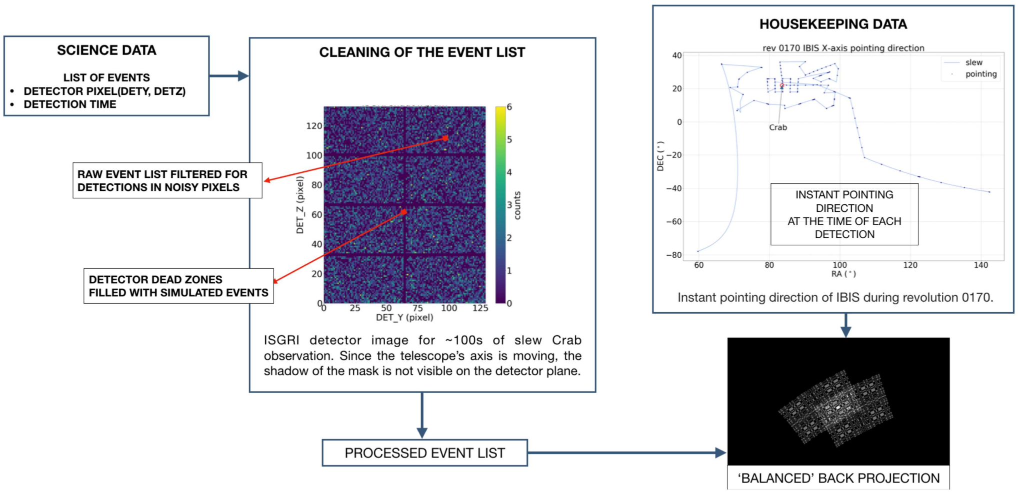

Fig. 1. Representation of the stages of the back-projection algorithm for IBIS/ISGRI data.

OSA analyisis to reduce the detector noise before the back-projection of every single event[1]. The program takes the pre-processed list of events (ISGR-EVTS-ALL) as input. The good time intervals indicated in the table IBIS-GNRL-GTI are first applied. Then, all events flagged as noisy by the OSA *ibis_isgr_evts_tag* script are removed. These include events from pixels that had a switch off during the ScW and from pixels with an abnormal distribution in time between events.

The event list is then filtered according to the standard selection criteria applied in the OSA script *ii_shadow_build*, which removes events below the characteristic low threshold value, events with rise time outside the default values and events from pixels which show a deviation from the average ISGRI spectrum[2]. The next stage consists of filling the inactive areas of the detector (i.e. the gaps between the modules and the pixel previously flagged as noisy). A 2D histogram of the number of events in the detector plane is made (figure 1) and a number of events is assigned to each of the dead pixels. This number is drawn from a Poisson distribution around the average number of events in all active pixels in a 20×20 area around the dead pixel. A random time of detection is also assigned to these fake events.

In order to reconstruct all the possible directions of all incoming photons, the IBIS pointing direction is calculated at the time of each detection by interpolating the values stored in the housekeeping packets data (INTL-ORBI-SCP). For each detection, every pixel in the sky map is filled with a different value depending on whether it can be seen by the detector pixel through an opening in the mask at the time of detection or not. This value is:

1. 1 if the position of the sky pixel can be seen by the detector pixel through an opening in the mask
2. $-1 \times B$ 1 if the position of the sky pixel is obscured from the detector pixel by one of the closed mask pixels.
3. 0 if the position of the sky pixel is not in the field of view.

The weighting factor B is needed to obtain a flat image in absence of sources. To achieve this, OSA scripts use a balanced deconvolution

[1] Introduction to the INTEGRAL Data Analysis, August 2015, INTEGRAL Science Data Centre, `https://www.isdc.unige.ch`

[2] IBIS Analysis User Manual, August 2018, INTEGRAL Science Data Centre, `https://www.isdc.unige.ch`

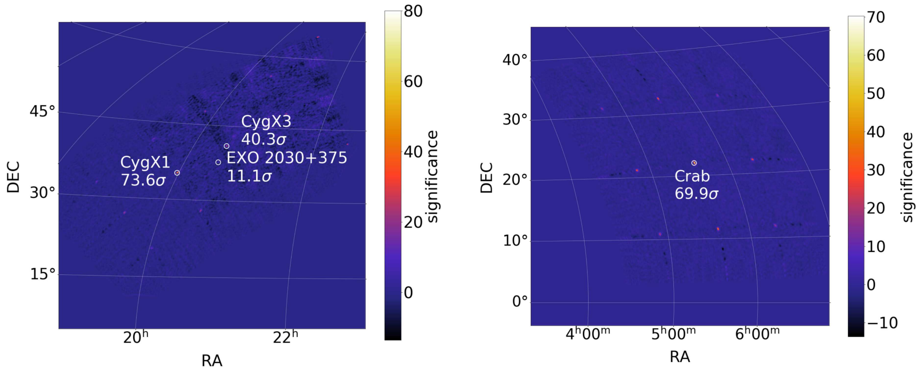

Fig. 2. (Left) Significance map for ≈ 13ks of slew observation of the Cygnus region in revolution 80. (Right) Significance map for ≈ 1ks of Crab slew observationin revolution 170.

with a normalization array B. In order to apply the same normalization to a back-projection approach, the pixels of the sky map corresponding to opaque elements of the mask are weighed by a balancing factor B given by the ratio of the number of detector pixels seen by that sky position through an open mask pixel and the number of detector pixels obscured by the closed elements of the mask. B is only constant (and equal to 1) in the fully coded field of view (FCFOV), due to the transmission of the mask not being 50% in the partially coded field of view (PCFOV). Variance and significance maps are also computed with a similar technique Goldwurm et al. (2003).

3. Results

The back projection approach has been applied to two sets of slew ScWs to produce intensity, variance and significance maps.

The first data set 2 includes ≈ 1ks of exposure of the Crab from orbit 170. The ScWs used for this analysis are between a set of calibration pointings forming a dithering pattern around the position of the target. The average slew rate is ≈ 0.2 deg/s. A point source at the position of the Crab is clearly visible, as well as eight ghost images at symmetrical positions around the target. The second data sets data set consists of slews accumulated between pointings of the Cygnus region of orbit 80 for a total exposure of ≈ 13ks and an average slew rate of again ≈ 0.2 deg/s. Three sources are visible in the field of view (fig 2): the black-hole high-mass X-ray binary Cyg X-1(73.6σ), and the two X-ray binaries Cyg X-3 and EXO 2030+375 (respectively 40.3σ and 11.1σ). Ghost images of Cyg X-1 and Cyg X-3 are also visible in this map.

4. Conclusions

The application of a back projection approach to two test data sets has proved that this technique is able to reconstruct the position of sources using data from slew observations. This method needs further developments in order to make scientific products (e.g. spectra and light curves) available for slew observations. These include a full calibration of the technique to obtain fluxes and the creation of event lists in different energy bands to obtain spectra. The use of the detector efficiency shadowgrams to weight the back-projected events will also be implemented. Techniques for recognition and removal of ghost images in IBIS slews also needs to be developed and added to the analysis. This analysis will then tested on longer and faster slews, in order to evaluate its sensitivity and accuracy in these conditions.

References

Goldwurm, A., et al. 2003, A&A, 411, L223