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Status of the Integral/IBIS telescope modeling and of the response matrices generation

P. Laurent, O. Limousin, M. Cadolle-Bel, P. Goldoni, G. Malaguti, E. Caroli,
G. De Cesare, M. Del Santo, A. J. Bird, J. Grygorczuk, and J. M. Torrejon

DSM/DAPNIA/SAp, CEA-Saclay, 91191 Gif-sur-Yvette Cedex, France
IASF/CNR, via Gobetti 101, 40129 Bologne, Italy
IAS, Area di Ricerca di Tor Vergata, via del Fosso del Cavaliere, 00133 Rome, Italy
University of Southampton, Highfield, SO17 1BJ, UK
CBK, Bartycka 18A, 00-716 Warsaw, Poland
Universidad de Alicante, Alicante, Spain

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Abstract. The main objective of the IBIS modeling activities is the generation of the IBIS spectral response matrices. This generation has been done step by step by firstly constructing a "calibrated model" of each IBIS sub-system. A "calibrated model" is defined as a GEANT Monte-Carlo model, further checked by intensive corresponding calibration. These calibrated models have been in a second step integrated in the whole IBIS Mass Model. This Mass Model has been checked then using the data obtained during the IBIS telescope calibration, the Payload Ground Calibration at ESA/ESTEC, and will be refined using In-flight calibration data acquired during the whole INTEGRAL mission. The different IBIS response matrices have been generated using the IBIS Mass Model. Here we will present a status of the Mass Model and of the response matrices generation, and show with the Crab pulsar calibration data that, with the new release of the spectral extraction software by ISDC, we will have a good IBIS/ISGRI response from 20 to 600 keV.

Key words. modeling – coded mask instruments – response matrices

1. Introduction

The IBIS instrument (Ubertini et al. 2003) launched on board the ESA INTEGRAL observatory on October 17 2002, is a coded aperture telescope. It consists of a dual detection layer operating in the energy range between ~15 keV and 10 MeV. The open end pixelized detector plane, ISGRI (Lebrun et al. 2003), is composed of 128 by 128 cadmium–telluride, CdTe, semiconductor detectors covering the energy range ~15 keV to 1 MeV. Beneath this plane, is situated a second detector, PiCsIT (Di Cocco et al. 2003), comprising 64 by 64 caesium–iodide, CsI, scintillation pixels functioning in the energy interval ~175 keV to 10 MeV. The detection unit is actively shielded by being encased on all but the sky side by bismuth germanate (BGO) scintillator elements, eight underneath and eight lateral modules. At energies below 100 keV, the BGO acts as a passive shield. Above this threshold, the BGO behaves as an active element eliminating coincident events with the detection layers. Thus polluting background events are vetoed using the BGO shield. 3.2 m above the mean detector plane, is placed the coded mask.

Send offprint requests to: P. Laurent, e-mail: plaurent@cea.fr

2. IBIS modeling

The generation of the IBIS response matrices have been done step by step by constructing a "calibrated model" of the IBIS telescope. A "calibrated model" is defined as a GEANT Monte-Carlo model, further checked by intensive corresponding calibration. We will detail below the status of this activity.

2.1. IBIS QM modeling

In a first step, we have made a model of the IBIS Qualification Model (QM) by assembling the GEANT calibrated models of all the different IBIS sub-systems constituting the QM. This model has been used to plan the QM calibration, and check against the results of these calibration.

2.2. IBIS detector assembly and flight model modeling

In a second step, every IBIS sub-system teams (ISGRI, PiCsIT, Veto, and detector frame) have created a calibrated model of its system in the in-flight configuration. These models have been then "integrated" to form the virtual Detector Assembly system, which has been checked against the calibration made in Fall 2001. Then, we have added to the Detector Assembly model all the other IBIS sub-systems in order to create the model of the full IBIS Flight Model telescope (FM), and the results of the simulation have been compared to the IBIS FM calibration and Payload Calibration performed at ESA/ESTEC (December 2001 and January/February 2002).

3. Response matrices generation

3.1. Response matrices generation planning

A simplified model of the response matrix was available for testing interfaces with the ISDC system in 2001. The first IBIS FM calibrated Mass Model has been available soon after the IBIS FM calibration, that is at mid 2002. This has enabled the generation of the first issue of the response matrix in Fall 2002, which has been checked with the Cygnus X-1 Performance Verification phase data (see below). A second issue of the matrices will be available at ISDC with the next version of the ISDC software to be delivered on July 2003, resulting from the comparison of IBIS extracted spectra with the results of the Crab pulsar observations performed on February–March 2003.

3.2. Response matrices type and format

A response matrix has been generated for each IBIS main type of data: ISGRI, PiCsIT single, PiCsIT multiple, Compton single, and Compton multiple (see Ubertini et al. 2003 for a description of the IBIS modes). Three more matrices (not yet included into the ISDC system) can be constructed for the timing studies from ISGRI, Compton, and PiCsIT (Spectral Timing data). Up to now, these matrices have been constructed from the simulated IBIS response to an on-axis source.

The matrices format is adapted to have the maximal resolution for each detector in each peculiar mode. It is then up to the observer to decide which binning he/she wish for his/her scientific purpose. A standard binning is delivered by ISDC.

4. Tests of the response matrices

4.1. Test of the IBIS spectral extraction software and response matrices compatibility

As seen in Fig. 1, the results of the IBIS modeling may be transformed in XSPEC compatible formats, and used within this package. In the figure, we have also taken into account the following estimates for the IBIS background values:

ISGRI mode: 1000 cts/s
PiCsIT mode (single + multiple): 5000 cts/s
Compton mode: 100 cts/s

in order to compute the error bars. We have then fit these spectra with XSPEC, giving the model spectrum shown in Fig. 1. This fitted spectrum is composed by a power law with photon index $\alpha = -2.4$ and a line centered at an energy of 480 keV with a 22 keV width, parameters which are consistent within errors with the parameters we introduced as input in our Monte-Carlo simulations.

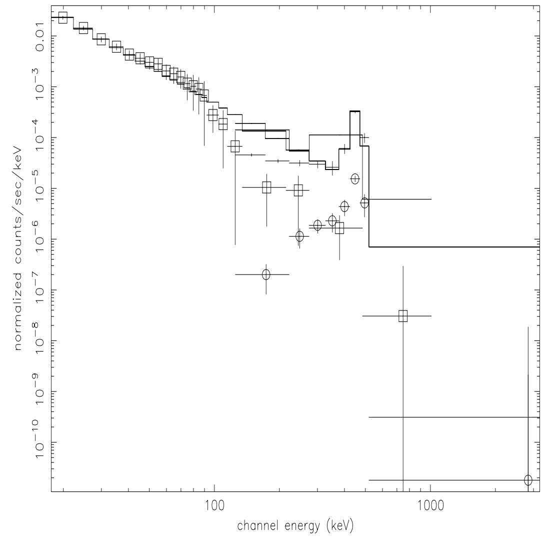

Fig. 1. Simulated IBIS raw spectra as introduced in XSPEC, shown with a powerlaw + 511 keV line fit. ISGRI points are indicated by squares, PICsIT points by crosses and Compton points by ellipses. The fitted model spectrum composed by a power law with photon index −2.4 and a line centered at an energy of 480 keV with a 22 keV width is also shown.

4.2. Data reduction

The celestial source spectra that we will show now in this paper are all derived using the ISGRI component of the standard OSA ("Offline Scientific Analysis") software, produced jointly by the Integral Science Data Center (ISDC), and the IBIS/ISGRI team at CEA/Saclay. This includes mainly software to build detector maps into different energy channels, and deconvolve them using standard techniques (Goldwurm et al. 2003; Gros et al. 2003). These software are the standard ones which are delivered to each INTEGRAL guest observers.

4.3. Tests of the matrices during PV phase

At the end of 2002, we have tested the first issue of IBIS response matrices officially delivered to ISDC using the Cygnus X-1 data obtained during the PV phase. For one science window, that is around 30 min of observation, the 20–200 keV ISGRI spectrum was reasonnably fitted with a Comptonised spectrum, with parameters in accordance to what was already observed from Cygnus X-1 (McConnell et al. 2002).

Also, the results are in accordance with what was obtained by SPI, and RXTE with simultaneous observations, which validates the ISGRI matrix in this energy range (Pottschmidt et al. 2003).

In order to test the response at higher energies, we have also computed ISGRI Cygnus X-1 mean spectra obtained by summing all the Cygnus X-1 on-axis observations during one given revolution. One of these spectra is shown in Fig. 2 for revolution 18, and indicates clearly a thermal comptonized shape. We thus fit these spectra up to 400 keV with a standard Sunyaev and Titarchuk thermal comptonization model (Sunyaev & Titarchuk 1980), obtaining a temperature of 41.2 ± 0.3 keV, and an optical depth of 3.09 ± 0.02, which is

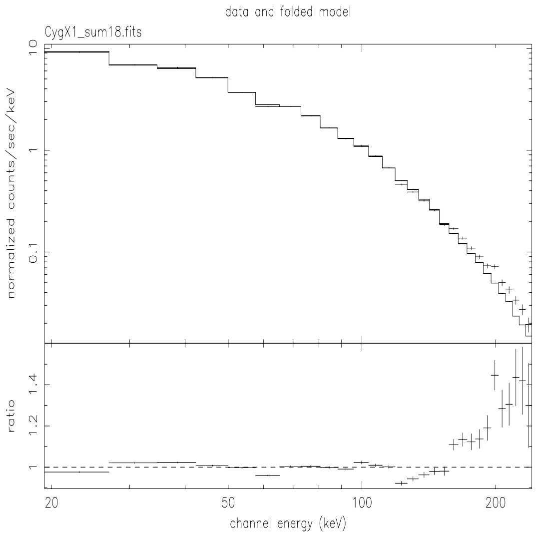

Fig. 2. ISGRI spectrum of Cygnus X-1 obtained summing all observations done during revolution 18. The line shows the fit with a Sunyaev Titarchuk model (see text). The bottom figure give the ratio between the difference fit-data and the data.

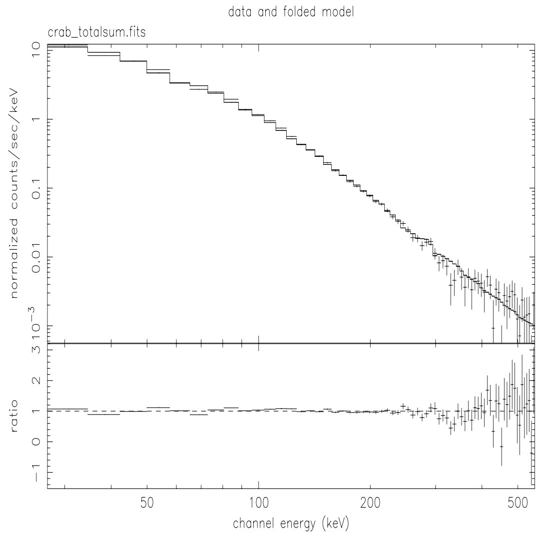

Fig. 3. ISGRI spectrum of the Crab obtained summing 90 ks of observations done during revolution 39. The line shows the fit with a power law model and the bottom figure give the ratio between the difference fit-data and the data (see text).

reminiscent of that already observed in the past from Cygnus X-1 (McConnell et al. 2002). The high reduced chi-square obtained (reduced chi-square = 18.7) could be partly due to a high energy excess above the model fit (see Fig. 2), similar to what reported by other instruments (McConnell et al. 2002). Besides the bad quality of the fit, which claims further verification of the origin of this excess, these results suggest that there are no strong deviations between the ISGRI results and previous spectral measurements of Cygnus X-1. This idea has then been further checked using the Crab observations.

4.4. Tests of the matrices with the Crab in-flight calibration data

We have tested the matrix available at ISDC with the Crab data acquired in February/March 2003 during the Integral In-Flight Calibrations. The fit with a power law give an energy index of −1.93 and a normalization at 1 keV of 7.7 photons/cm^2/s/keV between 20 and 500 keV. It is quite close to what is expected from the Crab nebula, but, at that time, some discrepancies were remaining. Indeed, large negative residuals below 20 keV were present, and a "snake" profile appeared for residuals below 150 keV. These features have been identified as due to three main factors:

1) the spectral extraction software had a bug at low energy which create this drop of counts around 20 keV;

2) the background correction of images was not perfect;

3) the sampling of the matrix at ISDC was not precise enough at low energy to correctly reproduce the variation of the ISGRI response. A new matrix with much more Monte Carlo points below 150 keV has been then computed and will be officially delivered with the new release of the ISDC software at the end of July 2003.

The example shown in Fig. 3 has been constructed using revolution 39, for a total acquisition time of 90 000 s, and using the new software and matrix. The fit with a power law give now an energy index of −2.12 ± 0.04, and a normalization at 1 keV of 8.2 ± 2 photons/cm^2/s/keV, close to the canonical value.

5. Actual status of the ISGRI spectral extraction

A few months after the launch, the standard analysis actually available at ISDC is obviously still not perfect as a lot of work have been done to derive the instrument in-flight characteristics from the calibration obtained during the Crab 2003, February and March observations and this has not been yet included into the ISDC system. The ISGRI energy-channel relation, the background correction and the response matrices have been improved and tested using the Crab observations. Thus, a correct spectral analysis, taking into account all we learnt with the Crab observations, will be available soon at ISDC, and we will have valuable results with ISGRI between 20 and 600 keV for fully coded sources. A few problems still remain anyway that we will briefly summarize here.

5.1. Problems at very low energy

As we have seen, spectral extraction is correct above 20 keV, but we have still some problems below, between 13 keV (the ISGRI lower threshold) and 20 keV. These problems are not clearly identified yet, but we presume that there are related to a wrong estimate of the mask transparency in the open elements. This transparency is quite complex, as it is not uniform over the whole mask, as it is supposed in the Mass Model, and also depend on the source direction with respect to the telescope axis. A study taking into account measures made by the Spanish group, building the mask, and low energy measures done during the Payload Ground Calibration is on-going.

5.2. Problems with the partially coded sources

All the studies we have shown up to now concern the fully coded field of view. The spectral extraction and spectral fitting for partially coded sources is not perfect at present, as we could see from the off-axis measures made with the Crab. Whereas the projection of these sources through the mask is well defined and modelized, the modelization of the passive materials around the mask is not consistent between a non standard off-axis matrix, made at Saclay for tests purposes, and what is done in the deconvolution software. This is also under study at that moment.

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