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Letter to the Editor

The INTEGRAL Mass Model – TIMM*

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Abstract. The INTEGRAL Mass Model (TIMM) was started in 1995 and aimed to create a detailed geometrical model of the whole INTEGRAL satellite on computer. In parallel, a comprehensive Monte Carlo simulation code (called GGOD) has been developed. The mass model and the Monte Carlo code together enable the in-flight operation of INTEGRAL to be simulated at the individual event level. Thus TIMM can be used to provide an independent evaluation of the performance of the individual instruments, to study the interference and complementarity between instruments, to generate test data for software development, and as a powerful tool for post-launch diagnosis. In this paper TIMM is briefly reviewed, some examples from ground calibration are presented, and preliminary comparison to flight data is shown. The future use of TIMM to flat field flight data is also briefly discussed.

Key words. γ-ray astronomy – instrument simulation

1. Introduction

INTEGRAL is very complex and, due to the penetrative nature of γ-rays, the individual instruments can affect each other's performance. Although the instrument teams are responsible for the design and modelling of their own instruments, experience from past missions tells us that it is necessary to have an independent system-wide modelling programme to assess or provide support to the following aspects of INTEGRAL:

– Overall background modelling – including the effects of the local environment;
– Instrument design issues including internal event rates and telemetry requirements;
– Possible shadowing of one instrument by another or spacecraft structure;
– Independent assessment of instrument sensitivities;
– Analysis software development;
– Payload Ground Calibration (PLGC) activities;
– Post-launch problem solving and system configuration validation.

The main tasks of TIMM are to build an independent geometrical and chemical model of the entire INTEGRAL payload and spacecraft, and to perform intensive Monte Carlo simulations, thus providing a unified background and performance evaluation of all instruments. In this paper results are presented for IBIS and SPI only. The model is constructed using information supplied by the instrument teams about the geometrical distribution, and chemical composition, of material in the instruments. Apart from understanding and quantifying the background, it is also important to be able to unravel any unexpected phenomena which may occur after launch. In the past this has been possible to achieve by performing tests on the flight spare. For the case of INTEGRAL there will be no complete flight spare and TIMM will represent the only means of testing any perplexing post launch scenarios.

2. GGOD and The INTEGRAL Mass Model

As previously discussed (Lei et al. 1999; Ferguson et al. 2001) TIMM consists of three main parts: the payload and spacecraft model; the GGOD software suite; and the simulation of instrument characteristics and on-board signal/data processing.

The model of the payload and spacecraft has been constructed using detailed technical drawings of INTEGRAL. The GGOD software suite has been developed locally at Southampton to allow all of the background components of INTEGRAL to be fully modelled. GGOD (Fig. 1) uses the

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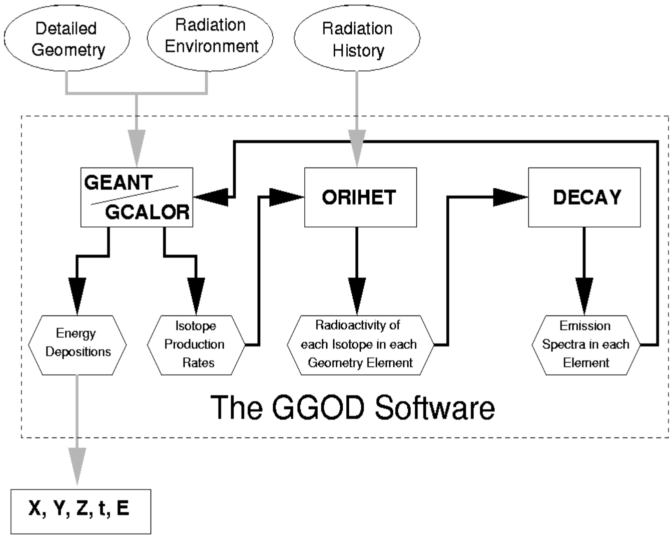

Fig. 1. Overview of the data flow within the GGOD software suite. Light coloured arrows refer to data input and output, to and from, the GGOD software. Dark arrows represent the flow of data between the components of the software. The ellipses represent the input data required by GGOD while the output data is represented by the rectangle. Internal data files are represented by hexagons.

GEANT, GCALOR, ORIHET and DECAY codes to allow simulation of cosmic diffuse γ-rays, cosmic rays, and induced radioactivity. Within the overall GGOD structure, GEANT and GCALOR are used to track photons and particles through the spacecraft geometries and process their prompt interactions. Using the rate of isotope production, ORIHET calculates the radioactivity within each geometry element, and from this DECAY generates the photons and particles produced, and these are then tracked through the geometries by GEANT/GCALOR. For an extensive review of the development and applications of mass modelling see Dean et al. (2003).

3. Payload Ground Calibration (PLGC)

Limited validation of TIMM has been carried out using PLGC data. A selection of runs have been simulated and the shadowgrams recorded within PICsIT have been qualitatively compared with the real data. Four runs are presented here: shining the source through the SPI mask onto the IBIS detector planes (Fig. 2); shining the source through the JEM-X masks onto the IBIS detector planes (Fig. 3); IBIS on-axis (Fig. 4); and shining the source through the edge of the SPI mask onto the IBIS detector planes (Fig. 5).

In all four cases the qualitative agreement is readily apparent, however there is a clear offset in all cases due to inaccuracy in the supplied source position. There are some features present in the real data that have not been reproduced by the simulations. It is clear TIMM currently has an outdated design for the JEM-X mask structures (Fig. 3). There are also some successes for the modelling approach; note how well the slats around the SPI mask are reproduced (Fig. 5).

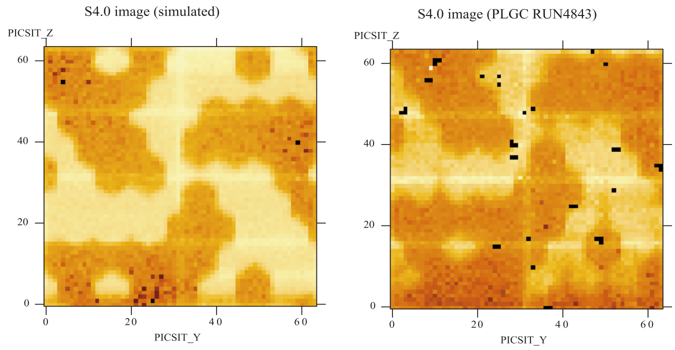

Fig. 2. Comparison of PICsIT shadowgrams for the PLGC position 2 (source shining through the SPI mask onto the IBIS detector plane). Simulation is on the left and real data (Calibration Run 4843) is on the right. The images are slightly offset due to inaccuracy in the supplied source position.

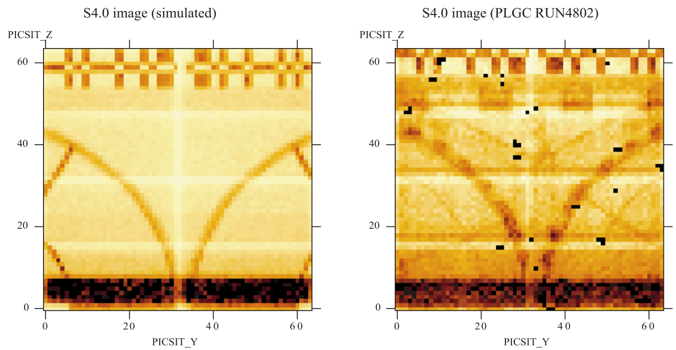

Fig. 3. Comparison of PICsIT shadowgrams for the PLGC position 3 (source shining through the JEM-X mask onto the IBIS detectors). Simulated data is on the left and the real data (Calibration Run 4802) is on the right.

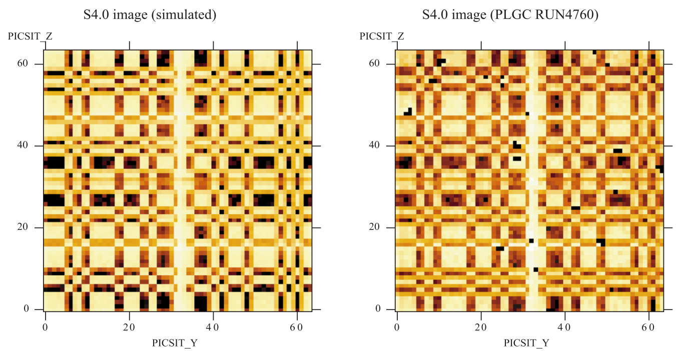

Fig. 4. Comparison of PICsIT shadowgrams for the PLGC position 5 (on-axis illumination of IBIS). Simulated data on the left and real data (Calibration Run 4760) is on the right.

4. Comparison with flight data

In this paper a preliminary comparison of in-flight data and pre-launch simulations is presented. TIMM underestimates by a factor of ~2 the PICsIT single pixel spectrum (Fig. 6), however some features within the spectrum are clearly reproduced (i.e. at ~500 and 660 keV). Further features, at 1–2 MeV and ~3 MeV, appear to be visible in both the simulated and real data. Within the real PICsIT data there is a noticeable increase in counts below ~300 keV, which is not reproduced by the

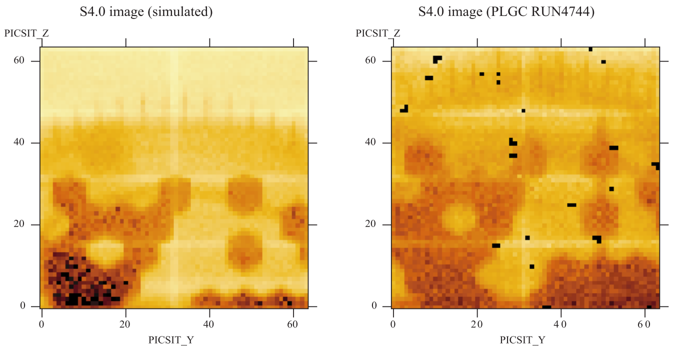

Fig. 5. Comparison of PICsIT shadowgrams for the PLGC position 8 (source shining through the edge of the SPI mask onto the IBIS detectors). Simulated data on the left and real data (Calibration Run 4744) on the right.

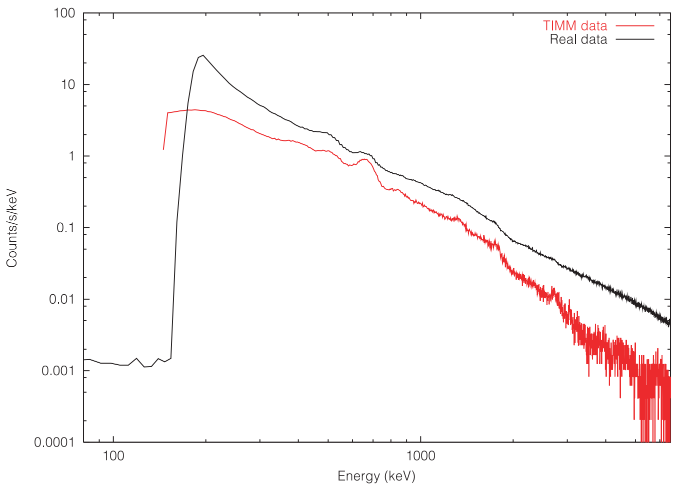

Fig. 6. Comparison of in-flight PICsIT single site spectrum (taken from empty field at the end of rev 38) with the pre-launch TIMM simulation.

simulation. This is probably caused by spurious events generated within pixels as they recover after a high-energy cosmic ray event (see Segreto et al. 2003 for a detailed explanation).

The simulated and real SPI spectra show many lines produced by the decay of radioactive elements within the instrument (Fig. 7). Since no energy resolution has been applied to the simulation it is difficult to judge whether the line intensities are correct. Considering just the continuum, it is clear that the simulations underestimate the real data by a factor of 2–3. Above 1 MeV the statistics in the simulation are not good enough to allow a proper comparison. A similar comparison, using software suite entitled MGGPOD, plus a more detailed investigation of the lines present is given in Weidenspointner et al. (2003).

The current TIMM simulations were undertaken using the cosmic ray intensity expected at solar maximum. This is likely to be an underestimation of the current cosmic ray intensity, and this may contribute to the factor ~2 difference between the real and simulated data.

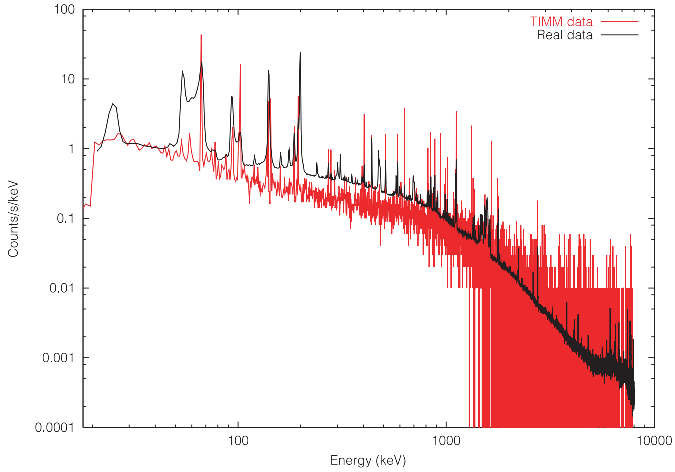

Fig. 7. Comparison of in-flight SPI single detector spectrum (taken from rev 13) and the pre-launch TIMM simulation (interactions within 8 μsec are combined into one event). The broad spikes in the data in the 1.4–1.6 MeV band are electronic noise (see Roques et al. 2003 for a fuller explanation).

5. Future uses of TIMM – flat fielding

It is intended to use TIMM to subtract off the systematic background from INTEGRAL observations and thus achieve the statistical sensitivity (so called flat fielding; see Dean et al. 2003 for a comprehensive review). The count rate over the IBIS detector planes predicted by TIMM, even with no source, is far from uniform. The sources of non-uniformity are the geometrical structure of the detector planes and shadows cast onto the detector planes by structures within the spacecraft and/or payload (Ferguson 2000).

Figure 8 shows projections of the single site event count distributions along the *PICSIT_Y* and *PICSIT_Z* axes. The four sets of pictures (top to bottom) show the simulation with veto on, the real data with veto on, the simulation with veto off and the real data with veto off. Within the plots the effect of detector module gaps can be seen (at *PICSIT_Y* = 32 and at *PICSIT_Z* = 16, 32 and 48). Pixels adjacent to a module gap have a significantly higher background than those in the middle of a module. This is due to scatter into, and out of, the passive material between modules and due to the increase in effective area of pixels next to module gaps. It is also clear to see that the edge pixels have an enhanced count rate. The general shape of this enhancement is closely reproduced in the simulations. However, when the veto is applied there is still some enhancement in the very edge pixels within the simulation which is not seen in the real data. This may be due to excess passive material around the detector plane in the mass model.

One set of features is not reproduced by simulations at all. In the *PICSIT_Y* projection with veto off pictures the real data clearly shows the effect of the semi-modules (*PICSIT_Y* = 16 and 48). The analysis code currently being used does not include the effects of semi-module electronics and logic. This demonstrates why TIMM must include both physical and electronic effects to simulate realistically the data.

In the *PICSIT_Z* projections it is possible to see a small increase in the background level towards SPI and JEM-X.

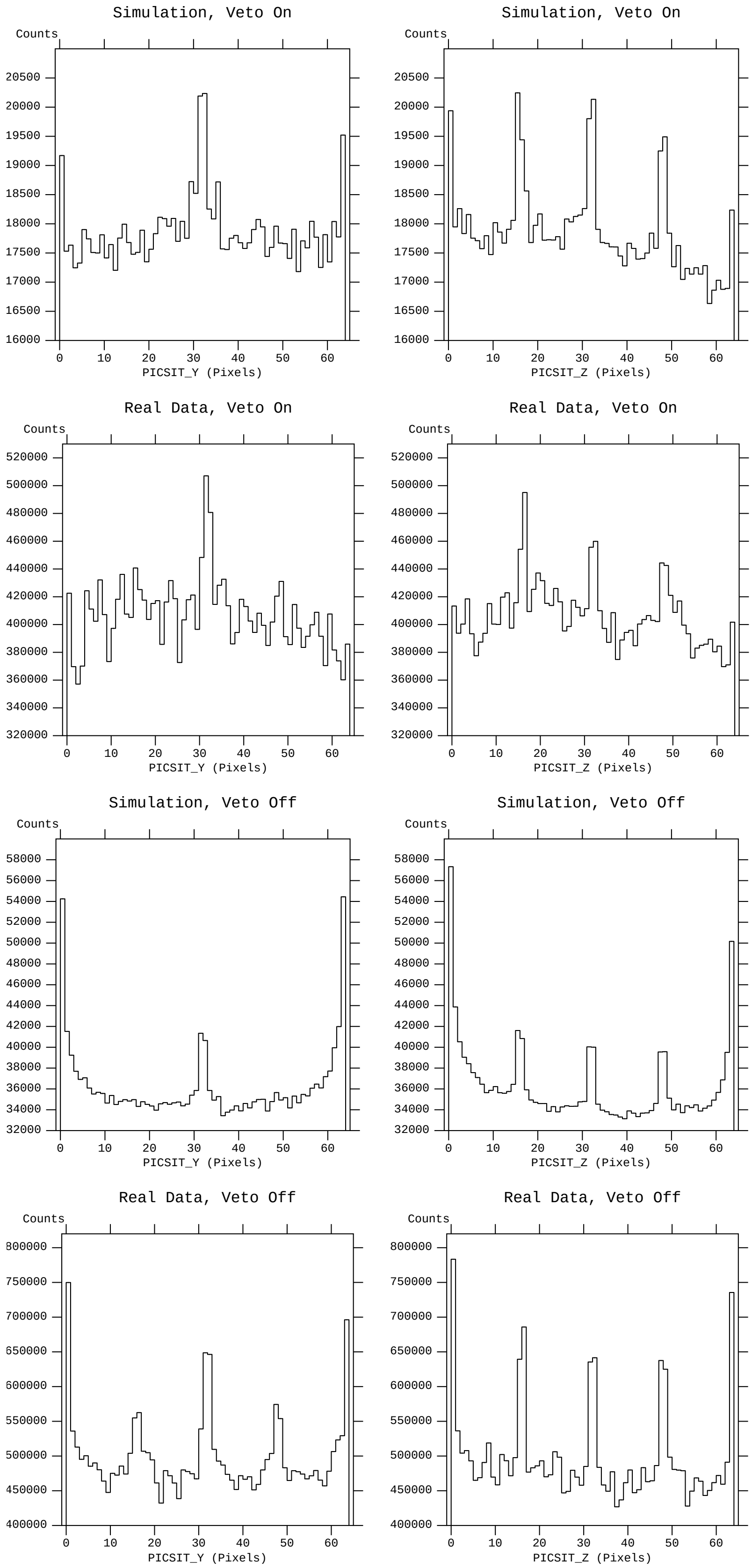

Fig. 8. Projection of the *PICSIT_Y* and *PICSIT_Z* axes of the PICsIT single pixel background events. Top to bottom are the simulation with veto on, real data wth veto on, simulation with veto off and the real data with veto off. In this co-ordinate system SPI and JEM-X are at negative *PICSIT_Z*. The real data, veto on and off, projections were not produced using equal exposures.

This is probably due to either scatter off of SPI and JEM-X or to their radioactivity.

The second cause of non-uniformity in the simulations is shadowing by parts of the spacecraft or payload structure. Examples of this were seen during the PLGC. From the selected runs simulated it is clear that many parts of the spacecraft structure can produce features within the shadowgrams recorded by IBIS (i.e. the slats in the SPI mask support structure; Fig. 5).

6. Conclusions

INTEGRAL was the first mission to use mass modelling from the early phases to aid in design, optimisation and background estimation. A geometrical and chemical model of INTEGRAL has been developed along with a Monte Carlo based software suite. This combination has been shown to produce results which qualitatively agree well with the real instruments.

A small subset of PLGC runs have been modelled. Many of the features present in the real data are reproduced by the simulations. The biggest difference is due to inaccuracy in the supplied source position. Features observed but not predicted by the simulations are being used to update the model.

Pre-launch simulations are within an absolute factor of 2–3 of the flight data and agree well in shape, the differences probably being explained by an underestimation of the current cosmic ray component. Work is currently on-going to improve the agreement between simulation and flight data, and to understand both.

The predicted non-uniform nature of the IBIS background will introduce systematic effects which will limit the sensitivity if not accounted for. TIMM will be used to model these features, subtract them from the data, and thus reduce systematic errors and recover the statistical sensitivity of INTEGRAL. This allows one to normalise data taken at different epochs and is therefore important for surveys.

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References

Dean, A. J., Bird, A. J., Diallo, N., et al. 2003, Space Sci. Rev., 105, 285
Ferguson, C., Lei, F., Dean, A. J., et al. 2001, Exploring the gamma-ray universe, Proc. Fourth INTEGRAL workshop, 4−8 Sep. 2000, Alicante, Spain, ed. B. Battrich, Scient. ed. A. Gimenez, V. Reglero, & C. Winkler, ESA SP-459, 565 (Noordwijk: ESA Publications Division), ISBN 92-9092-677-5
Ferguson, C. 2000, Ph.D. Thesis, University of Southampton
Lei, F., Ferguson, C., Bird, A. J., Lockley, J. J., & Dean, A. J. 1999, Astrophys. Lett. Comm., 39, 373
Roques, J.-P., Schanne, S., von Kienlin, A., et al. 2003, 411, L91
Segreto, A., Labanti, C., Bazzano, A., et al. 2003, 411, L215
Weidenspointner, G., Kiener, J., Gros, M., et al. 2003, 411, L113