PERFORMANCE MODELLING OF THE INTEGRAL PAYLOAD

A. R. Green, F. Lei, A. J. Bird, A. J. Dean
Physics Department, Highfield, Southampton, SO17 1BJ, U.K.

ABSTRACT

The INTEGRAL mission comprises four independent co-aligned instruments and a spacecraft. Whilst the instruments are designed for independent operation their detailed performances will be dependent upon each other and the spacecraft subsystems. This is because their background noise counting rates and hence sensitivities are strongly influenced by local particle fluxes which in themselves are dependent upon a combination of the external particle environment and their precise position with respect to the surrounding material. The latter is clearly dominated by the other instruments. Likewise the imaging performances are influenced by unwanted shadows cast by strong off-axis celestial sources which are partially occulted by the surrounding material of other instruments and the spacecraft. Performance modelling which takes into account all of the on-board material, its isotopic composition and its precise geometrical layout can play a vital role in the context of extracting the maximum science from the INTEGRAL mission. Apart from understanding and quantifying the expected it is also important to be able to unravel and quantify any unexpected phenomena which may occur after launch. In the past this has been possible to achieve by performing tests on the flight spares. For the case of INTEGRAL there will be no complete flight spare, so a computer based mass model will represent the only means of testing any perplexing post launch scenarios. The benefits of a realistic mass model and Monte-Carlo simulations are discussed in the context of the INTEGRAL project.

Keywords: $\gamma-$ray Astronomy ; Instrument Simulation ; Monte Carlo modelling

1. INTRODUCTION

The INTEGRAL mission (Winkler 1996) is the next $\gamma-$ray Observatory mission and has two main instruments, and imager and a spectrometer, and two monitor instruments, an X-ray monitor and an optical monitor. Three of these instruments have overlapping energy ranges. Although these instruments are designed to work independently undoubtedly some of the best science will result from a combination of data from all of the instruments.

The individual instrument teams will model their own instruments and may include a crude model of the other instruments however, the role of the INTEGRAL Mass Model (TIMM) is to provide an overall uniform modelling programme, which will have numerous benefits to the project as a whole.

2. THE NEED FOR AN INTEGRAL MASS MODEL

An integrated, uniform simulation program can have huge benefits to a project such as INTEGRAL. Some of the important benefits the mass model will provide to the project are listed below :

- Uniform modelling of the background counting rates in active components
- Complete modelling of the effects of the local mass distribution, i.e. the effect of the spacecraft and other instruments
- Assessment of the relative performance of each instrument
- Assessment of problems caused by off-axis shadows
- Independent assessment of event rates and processing requirements

The mass model can also provide simulation assistance to the ISDC and the ISOC.

Although many of the tasks can, and will, be carried out by the instrument teams, the mass model will provide an independent assessment of the problems/findings. However, when evaluating the effect of payload and spacecraft mass distribution on the spatial uniformity of the background for instance, the mass model will be superior as the mass model describes each instrument fully. Similarly the mass model will have detailed geometrical information about all the instruments and the spacecraft structure and hence will be able to assess any possible shadowing problems which may occur.

A further important role for the mass model will be in the analysis of scientific data post-launch. Unlike many other space telescopes there will be no INTEGRAL flight spare. It is anticipated that there will be a detailed mass model which can be used to help explain unexpected results, and may also prove useful in the development of new algorithms in the event of partial instrument failure.

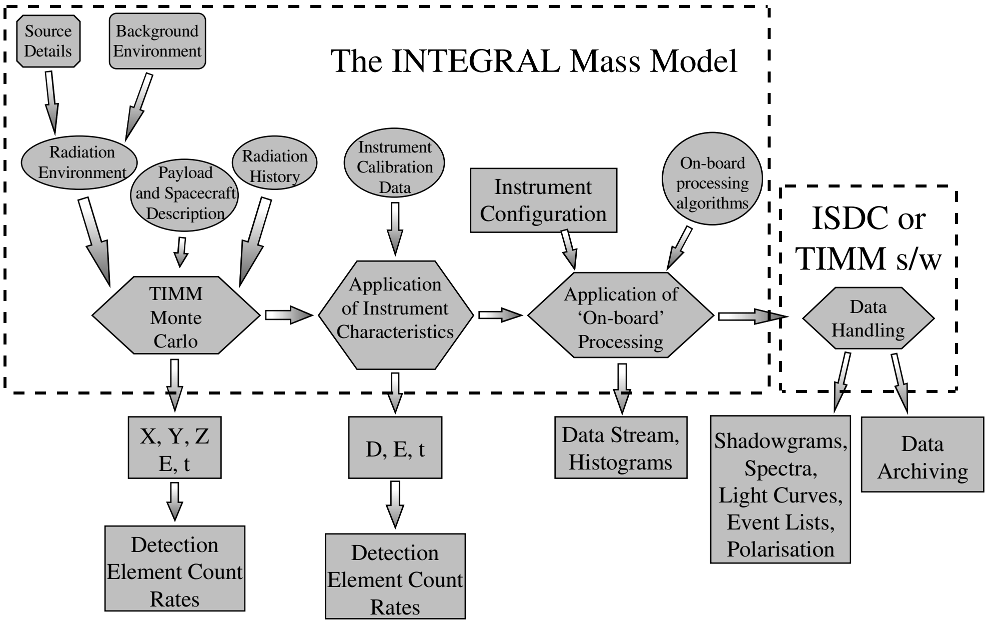

Figure 1: The Data Flow Diagram for the INTEGRAL Mass Model.

3. THE INTEGRAL MASS MODEL - TIMM

The INTEGRAL Mass Model (TIMM) consists of three main packages, each with individual inputs and outputs. Figure 1 summarise these packages and shows the relevant inputs and outputs.

The TIMM Monte-Carlo

The TIMM Monte-Carlo is the backbone of the INTEGRAL mass model project. The Monte-Carlo is written using the GGOD package (Lei et al. 1996). The GGOD Monte-Carlo package takes as input the detailed geometry and mass composition of the spacecraft and payload, the radiation environment and the radiation history. It the tracks all the interactions and records all energy deposits. In practice we only record the energy deposits which occur in active components thus reducing the size of the data set considerably. However, it is possible to keep track of energy deposits in any component. The energy deposition is described by five parameters, the position (X,Y,Z) the energy, and the time of the energy deposit (if required).

The GGOD suite of software is a combination of the GEANT/GCALOR code, and the ORIHET and DECAY packages. Figure 2 shows the basic data flow within the GGOD package. GGOD tracks photons (E $>$ 10 keV), electrons, energetic hadrons and low energy neutrons (10^{-5} eV – 20 MeV). It also logs isotope production rates in the mass model material which then enables the tracking of decays of radioactive isotopes which happen in the future. The complete GGOD software enables the tracking of both the prompt and the delayed component.

The data which comes out of the TIMM Monte-Carlo can be binned to obtain raw interaction rates and doses for any component within the model. However, to make the data more realistic we need to apply the detector characteristics.

Application of the Instrument Characteristics

The TIMM Monte-Carlo describes the interactions in terms of X, Y, Z and exact energy. To make the data resemble the actual measured data more closely the instrument characteristics need to be applied. Primarily the measured energy needs to be given a more random distribution governed by the expected spectral resolution of the detectors, and any energy thresholds need to be applied. Also the data is rebinned from X, Y, Z to a detector element taking into account any spatial non-uniformity in the response of the detectors.

The values for the spectral resolution etc., will ultimately come from the ground calibration of the detectors, and can be updated throughout the model's lifetime.

The data at this stage can be used to determine event rates, veto dead times etc as well as event rates in the electronic processing units.

Application of On-board Processing Algorithms

Clearly the on-board processing algorithms will affect the sensitivity of the instruments and so must also be simulated. Data received from the previous stage will be binned up or rejected using the algorithms as supplied by the instrument teams. The output from this stage should closely resemble the data which the observer will receive.

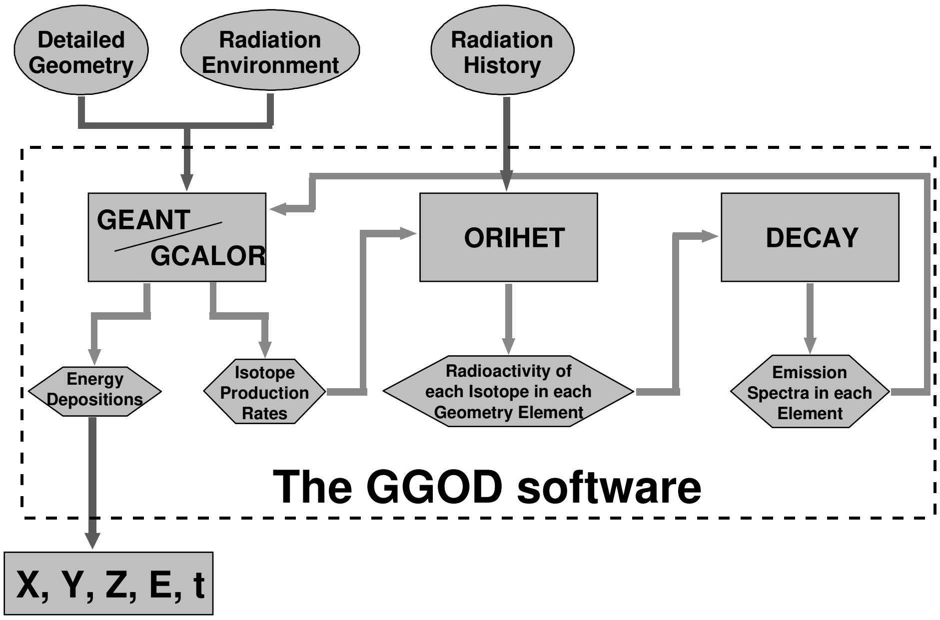

Figure 2: The GGOD Package. The GGOD package is made up of three separate pieces of software, GEANT/GCALOR, ORIHET and DECAY and can track most types of particles/photons over the relevant energy range for INTEGRAL.

Data Processing
To get a true measure of the sensitivity of the instruments the data must be processed into final images. It is anticipated that this will be carried out using the software provided by the INTEGRAL Science Data Center, although if the software does not yet exist, locally produced TIMM software will be used.

Data Archiving
The data will also be archived throughout the process. At the initial stage the output from the TIMM Monte-Carlo will be archived (probably in GEANT hbook format). The data produced after the application of the instrument characteristics and on-board processing algorithms will be archived in an ISDC compatible format. This data may either be made available to all users of INTEGRAL, or a subset of users at the ISDC.

4. DATA INPUTS

There are two main inputs to TIMM, a detailed mass model of the entire payload and spacecraft, and the radiation environment. In addition to these two main inputs there are also a number of auxiliary inputs.

The Detailed Mass Model
The spacecraft and payload model needs to be an accurate representation of the mass distribution, isotopic composition and geometry. Clearly different levels of detail are required for different tasks, i.e. to model the possible shadowing effects a detailed geometrical model of all components 'above' the detection planes are required. However, for background calculations very detailed geometry is not required only the correct mass distribution.

We have defined three different models based on the level of geometrical detail required :

- The **Major Component Model** involves detailed modelling of the active detector components and crude modelling of the support structure and non-active components.
- The **Minor Component Model** is similar to the Major Component Model except that material around the detection plane and the spacecraft is modelled in more detail
- The **Fine Detail Model** contains extra detail about structure which may shadow the detector, e.g. mask support structures, PLM walls, etc.

Clearly the construction of a fine detail model will be a difficult and time consuming task and it is not expected that a fine detail model will be available until June 2000. As the problem of shadowing needs to be considered before then, we intend to add some fine detail, such as mask support structures, into the early versions of the major component model to test for the effects of shadowing.

The models are to be updated after each of the major ESA reviews with the exception of the fine detail model which will not be started until January 2000. As the project progresses there will be less updates to the major and minor component models allowing more time for the updating of the fine detail model.

The Radiation Model
The radiation model consists primarily of the background photons and particles, although it can of

course contain information about the distribution of sources in the sky. The main components of the model are the cosmic diffuse $\gamma-$rays and the cosmic rays, the flux of which varies as a function of orbit position and time. Other sources of background are the trapped radiation and solar flares. The radiation model will also contain information about the radiation history so that induced radioactivity can be tracked.

It is anticipated that the radiation model will be constructed with the aid of the ESTEC space modelling division, and will improve throughout the course of the mass model project.

The Auxiliary Inputs

As illustrated in Figure 1 there are three other important auxiliary inputs. These are the instrument calibration data, which is required so that the 'perfect' events can be turned into more realistic events. The instrument configuration and on-board algorithms are required to process the individual events to the data types which will be transmitted to the ground.

5. DATA OUTPUTS

The detailed outputs of the mass model have yet to be determined however listed below are some of the possible outputs and uses of TIMM.

- Assessment of instrument performance - e.g. detection efficiency, etc
- Assessment of instrument background
- Instrument response modelling - generation of an instrument response matrix
- Background modelling for scientific analysis - Generation of an instrumental background for a specific observation
- Source field modelling - Aid in explaining unexpected features in an image.
- Verification of instrument configuration changes
- ISDC software testing
- Post Launch diagnostics - see above

The main users of TIMM will be the INTEGRAL Science Data Center (ISDC), the INTEGRAL Science working Team (ISWT) and the INTEGRAL Science Operations Center (ISOC).

TIMM will generally work on a request basis, i.e. one of the above users will request information from the TIMM team and then they will return the information in the form of data files or a report.

The results of the modelling process will be archived and will be accessible to all INTEGRAL Instrument Teams and a subset of data will be available to the general user community as required.

6. SUMMARY

The INTEGRAL mass model will provide an important tool to aid the understanding of the scientific output from INTEGRAL. The mass model is clearly a flexible tool with many applications within the project. TIMM will provide probably the best test bed for fault diagnosis post-launch and it is desirable that the detailed mass model is as complete as possible at the time of launch.

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[1]More information about the TIMM project can be found on the INTEGRAL Mass Model world wide web site which has the following URL :
`http://www.astro.soton.ac.uk/~integral/MassModel.html`