JEM–X Technical Note:

Background handling for JEM–X

by

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1 Introduction

The background in the detectors is partially caused by the Diffuse X-Ray Background (DXB), or in other words all sources not found and resolved by the subsequent analysis process. The DXB consists of a galactic and an extra-galactic term.

Charged particles come either directly from the charged energetic particles in the interplanetary space or from secondary radiation (including radioactivity) from interactions in the satellite material and give rise to the second background component termed particle background, particle induced background, or instrument background. This distribution is non-uniform and GEANT calculations on the basis of The Integral Mass Model (TIMM) have predicted a distribution a counts [7].

The fast image reconstruction by correlation is hampered by a non-uniform background — the noise level rises beyond the true background level and false sources appear.

The following section poses a number of questions and proposals for solving the problems from a non-uniform background.

In order to answer these questions, we should collect all relevant information. The ideas developed should also be tested as much as possible with reference to other coded mask experiments that have collected data in orbit, with numerical simulations, and theoretical analysis.

2 The Background Problem

The first step is to collect as much information as possible on the spatial distribution, the spectra, and the time variations of the background. It cannot be excluded that the background spectrum varies between the center of the detector and the edge. Also the presence of the satellite structure and the other experiments may also cause such variations.

Solving the background problem includes the following steps:

- Finding background models that can be produced from source-free JEM–X science windows and/or from numerical simulations.
- Binning these models into different data formats to produce background spectra and lightcurves for correcting non-imaging data.
- Using models and background event probabilities to correct the measured shadowgrams for background events before image generation processing.

2.1 Background Determination

An estimate of the background contribution in JEM–X observations must be produced as a function of position in the detector, energy, and time. The background is derived for a particular observing mode from the background estimate for a full imaging mode observation. The derivation can be made by proper averaging of the background in position and/or energy bins.

The background consists of two main components, the spatially slowly varying sky background and more inhomogeneous particle background. In many situations the (models of the) two components will be treated separately because the variations in time will be completely different.

The determination of background is a three step procedure as follows:

1. Select the method of modelling from the following alternatives:
   - Filtering of the current observation
   - Background simulation
   - Previous blank field observations
2. Modify the model scaling to correspond to a specific observation:
   - Find the best model
   - Define a scaling factor for the best model
3. Distribute the appropriate background for specific observing modes:
   - Spectra,
   - Lightcurves,
   - Images,

The filtering method is based on the assumption that the sources in the observed sky field will yield spatial variations in the shadowgram due to the mask and the collimator which have higher frequencies than those produced by the background components. The determination of the threshold frequency will will be based on tests with simulated observations including the predicted background contributions from the sky and from the instrument. The threshold frequency may be tunable on the basis of external parameter values for a specific observation. The original shadowgram subtracted by the filtered one is the background–corrected shadowgram. The filtering method determines only the spatial distribution of the background, and is therefore not suitable for generating background spectra.

The background model (both spatial and spectral) can be obtained by either computer simulations or blank field observations. There should be two catalogues for the background, one including the observed blank fields and the other the simulated models, to be used alternatively for further steps of the process. The first step assumes that the appropriate catalogues exist and makes a selection of the background which most closely matches with the selection parameter values. The selection parameters are not yet firmly specified.

The second step is to produce an estimate of the background for a particular observation from the generic background described above. It includes the determination of the scaling factor and applying it to the generic background, by that way generating a background estimate for a specific observation. If the filtering method is selected, the scaling comes automatically with applying the filter, and the only adjustable parameter affecting the result is the filtering frequency.

The third step is to deliver the specific background estimate in a format which is usable for a specific data format, which may be either a spectrum, lightcurve or a shadowgram.

The evaluation of the success of the procedure outlined above requires some other actions:

1. The actual prototyping of these tasks requires realistic simulations of observations including instrumental and sky background. The instrumental background estimates shall be acquired with the aid of the mass model of INTEGRAL.

2. The usage of the blank field observation alternative requires that a well determined background observing programme will be executed during the in-flight calibrations of INTEGRAL.

3. The acquisition of the radiation parameters required by the background scaling tasks assumes formal and practical arrangements to be made with with IBIS, SPI and IREM.

2.2 Background Handling for non–imaging modes

In this case it is not possible to subtract the background during the processing, instead for each generated JEM–X spectrum or lightcurve a corresponding model background spectrum or lightcurve is produced. These background data are then supposed to be used by the scientific analysis software.

To produce the background data, automatic tools extract a 'suitable' background shadowgram from an existing catalogue — based on various inputs like the spacecraft position and attitude — derive a scaling for this from simultaneous radiation measurements and finally bin the scaled shadowgram into a spectrum or lightcurve.

2.3 Background and Image Reconstruction

In its basic method the JEM–X image reconstruction will eliminate any uniformly distributed background — only the increased noise level will influence the results. Any deviation from uniformity will, however, introduce fake sources or lower the significance of other — real — sources.

The DXB consists of an extra–galactic part and a thermal galactic emission in the energy range where the detector is sensitive. The distribution of this type of background is isotropic on the sky and leads to a slightly peaked count distribution in the detector, see Fig. 1. The exception to this is the Galactic Ridge, the effect of which has to be further investigated.

3 Background Handling in the ISSW

The background handling is partly described in the ADD for the JEM–X ISSW. The following discussion leads up to an update of the ADD since several new ideas have been introduced. A diagram (made by Sami Maisala), Fig. 2, gives an overview of the process.

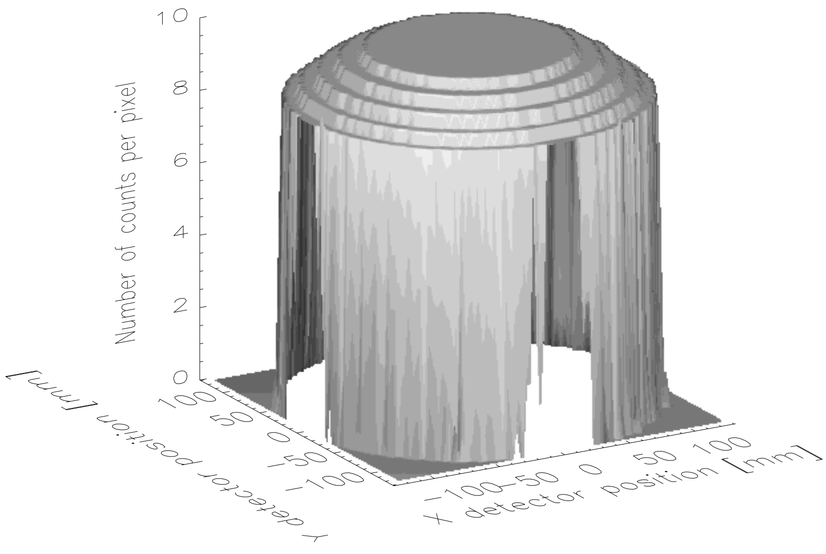

Figure 1: Distribution of the counts coming from the DXB as derived by raytracing. The shadowgram has been averaged in concentric annuli to bring out the general behaviour.

4 Format for background modelling (SL)

A detailed description of the background that is a function of position in the detector, energy, and time could in principle be done by setting up a 4-dimensional matrix of size 256×256×256 = 16.8×10^6 numbers per time step (which could be 8 s or even smaller). Considering that this information in any case will not be particularly precise a background modelling scheme is proposed to reduce the data storage as well as the number of I/O operations while still maintaining the proper level of precision.

First the spatial, spectral, and time dependencies are separated:

- The spatial part is described by a 256×256 array
- The spectral shape is given by a 256 element array with some spatial dependence
- A time dependence scaling factor

It is natural to divide both the spatial and spectral models into a DXB and a particle background.

The background count rate at detectory position (y,z) (referring to the satellite coordinate system), at energy channel E and at time T is then given by multiplying (separately for DXB and the particle background) the three factors:

Background count rate = spatial(y,z) × spectrum(E) × scale(T)

with

- spatial(y,z)$\sim$ 1
- spectrum(E) is the fraction of counts in channel E ($\sum_E \mathrm{spectrum}(E) = 1$)
- scale(T) is scaling to the predicted count rate at time T

The implicit assumption here is that the background spectral shape is invariable in the time period covered. In the best case this should be true for the duration of a science window, but including several background models during a single SciWin must be anticipated.

4.1 Spatial dependence of the spectral shape

4.1.1 The DXB

The DXB spectrum should not vary much over the detector. Variations in energy response could produce some positional dependence but presumably this should be small and neglible (TBC).

4.1.2 The particle background

The particle background spectrum is expected to vary across the detector. The actual dependence needs to be investigated. A first result has been derived by running the GEANT code with TIMM as input at the University of Southampton. The particle and photon flux arriving at the positions of the JEM–X detectors have been further analyzed by Marco Feroci ([7]) and the main results are shown in Fig. 3, the distribution of counts across the detector. Fig. 4 shows the same data, but binned so that the general features appear more clearly.

Two alternatives should be considered:

1. A number of spectral shapes are tabulated and a 256×256 array covering the detector area with indices specifying which spectral shape to select at a particular point.
2. Only two spectral shapes are stored and the spectrum at a specific point is obtained by interpolation between these two spectra: f1×spec1 + (1-f1)×spec2. As above the f1 values are stored in a 256×256 array.

5 Data structures

5.1 JMXi-BKDI-SPE

A 2D array (256 × 256) with indices (integer) for each detector pixel to represent the DXB. Such an index refers to a table of background spectra, JMXi-BKSP-CAT (see section 5.7, page 6).

5.2 JMXi-BKIN-SPE

A 2D array (256 × 256) with indices (integer) for each detector pixel to represent the instrument (particle) background. Such an index refers to a table of background spectra, JMXi-BKSP-CAT (see section 5.7, page 6).

5.3 JMXi-BKDI-SPA

A 2D array (256 × 256) giving the spatial distribution of background counts (or count rate) arising from the DXB.

5.4 JMXi-BKIN-SPA

A 2D array (256 × 256) giving the spatial distribution of background counts (or count rate) arising from the instrument (particle) background.

5.5 JMXi-BKDI-SCL

A table with the background scaling factor for the DXB as a function of time.

5.6 JMXi-BKIN-SCL

A table with the background scaling factor for the instrument (particle) background as a function of time.

5.7 JMXi-BKSP-CAT

A table of background spectra, both for DXB and particle background, representing all the variety that will appear in the JEM–X detector. In other words, for a given detector pixel and time, there should be a spectrum in this table that describes the background with reasonable precision.

6 References

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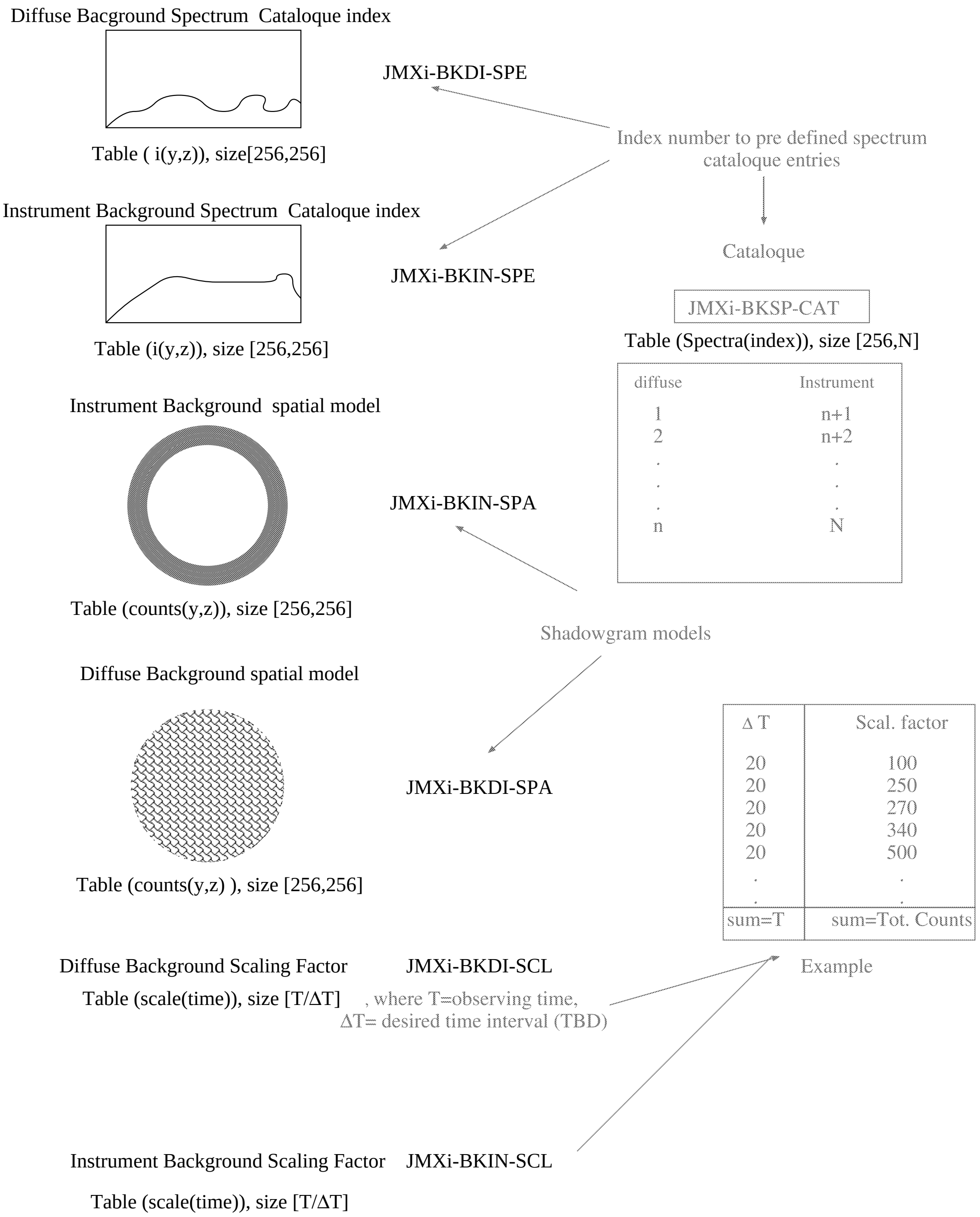

Figure 2: Background Handling Scheme (SM)

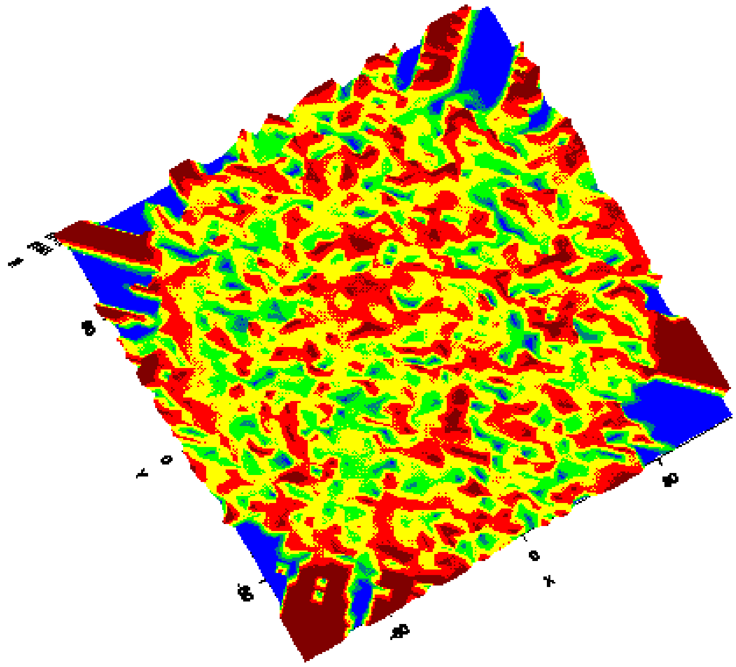

Figure 3: Distribution of the particle background counts as determined by the TIMM analyzed by GEANT and processed by Marco Feroci [7]

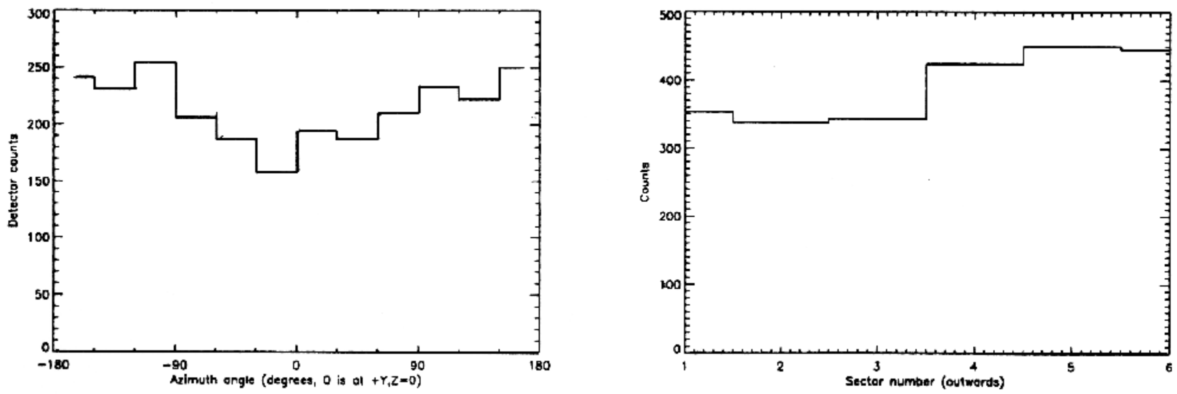

Figure 4: Distribution of the particle background counts as determined by the TIMM analyzed by GEANT and processed by Marco Feroci [7]