Background matters for JEM–X

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1 Introduction

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

The 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. This distribution is non-uniform and TIMM (The Integral Mass Model) coupled with the GEANT calculations has predicted a distribution a counts (ref. Feroci, Dean, Lei, and others).

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 resolve 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. The last section is devoted to this, although rather sparse at the moment.

2 The Background Problem

In this section *(extracted from the JEM–X ADD section 2.5)* we discuss how the background problem can be solved:

- By finding background models that can be produced from source-free JEM-X science windows or from computational simulations.
- By finding the probability that a given event is a background event.
- By binning these models into different data formats to produce background spectra and lightcurves for correcting non-imaging data.
- By 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. The estimate is the fraction of background counts for each specific position and energy channel of

JEM-X. An estimate of background is derived for each desired observing mode from the background estimate for a full imaging mode observation. The derivation can be made by proper averaging of background estimates in position and/or energy bins.

The background consists of two main components, the spatially homogeneous sky background and inhomogeneous instrument background. Major part of the inhomogeneous instrument background does not come via the mask. It arises when photons and particles interact with the bulk material near the detector.

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

1. Select the method of modelling from the following alternatives:
   - Filtering
   - Background simulation
   - Blank field observation
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 which have higher frequencies than those produced by the background components. The threshold frequency will have some initial, approximately suitable value, which 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 resulting shadowgram after filtering is considered free of background, and thus the original shadowgram subtracted by the filtered one is the background shadowgram. The filtering method determines only 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 with no Imaging

In this case there is no attempt at subtracting the background during the processing, instead for each generated JEM-X spectrum or lightcurve a corresponding 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 contemporaneous radiation measurements and finally bin the scaled shadowgram into a spectrum or lightcurve.

2.3 Background and Image Reconstruction

There are two sources of background in the JEM–X detectors. The particle and high energy photon flux interact with the matter in the satellite and produces a background in the detector. In spite of the attempts to reject this background a fraction ($\sim$1% or less) will be accepted as X–ray photons. The intensity of this background will be highly variable at times when solar flares raise the density of high energy particles. Due to the uneven distribution of mass in the satellite as seen from the position of either one of the JEM–X detector the distribution of these background counts will be non-uniform over the surface of the detector.

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 sources.

The other source of background is the diffuse X–ray background (DXB) due to unresolved sources (mainly extra-galactic) and thermal galactic emission in the energy range where the detector is sensitive. The distribution of this type of background is uniform on the sky and leads to a slightly centrally peaked count distribution in the detector.

The correction for the background should ideally remove the background counts and leave the source counts, which is clearly not possible. The (currently) best approach is to somehow deduce the background (size and shape) from the actual observation or model it by applying earlier observations, the INTEGRAL radiation monitor, and possibly model calculations. A recorded count can then be assigned a probability that it is a background count based on its position in the detector.

The image reconstruction must then take this probability into account in the algorithm.

3 Questions that should be answered and discussed

3.1 How serious is the background problem?

What degree of error in the observed results would be introduced we don't do anything to determine/reduce the instrument background ? Can we regard the background handling as a "secondary" task ?

3.2 How to identify variations in the background level?

The term non-uniformity of the background counts applies to averaging over a finite region in the detector. Some granularity will always be present in any image representation of the detector surface due to counting statistics. A second source to this granularity is the coded mask pattern and the collimator when there are a few not too weak sources in the FOV.

A smoothing algorithm must take this into account.

If the background count distribution can be modelled (such as the shape due to the DXB) with appropriate 2D functions such an approach might be chosen using fitting (adaption) for each exposure.

3.3 Can We Use Weights for Each Count

If the shadowgram is to be used for source finding etc. by the correlation method it can be levelled out by applying factors for each pixel found be one of the above methods. Subtraction should be avoided since information on sources might be lost. When determining the source intensities the factors (weights) used must be taken into account.

3.4 How is a non-uniform bkg handled in the photon tagging method?

In the photon tagging each event is related to the set of known sources i.e. determining if the path to the source is open or closed seen through the coded mask (and other parts of the instrument). The event weights are then the amounts with which the event contributes to the light curve of a particular source.

The photon tagging method is mathematically very similar to cross correlation. The effects of a non-uniform background should therefore be the same as in cross correlation. The effect can probably be taken into account in the analysis. Maybe this have already been done? (Skinner & Nottingham 1992?) (Nucl. Instr. Methods Phys. Res. A333, 540)

3.5 Treat Background as two Components?

If there are time variations in background it is good if the components can be handled separately when building a light curve. The two components will scale differently and have different spectral distribution. Can we use the difference in energy distribution between the two components to help distinguish between them?

3.6 What is the degree of nonuniformity of the diffuse background in the shadowgram?

Can we neglect it, and assume that the reconstruction will "take care" of removing it? If not, is it then possible to reliably determine the shape of the 2D-distribution produced by the diffuse sky background on the shadowgram?

3.7 What is the proper mathematical filter for the filtering method?

(there must be experience on that).

3.8 Filtering spatial scales?

We understand that the filtering frequency depends on the shape of the 2D-distribution of the instrument background, and we need, at this stage, a simulated model of the spatial distribution to test the method. Without having this information available, and wanting to make some progress in the SW development, we ask: How much does the spatial shape actually depend on the specific instrument configuration and mass model ? Can we assume that the shape is an 8th degree polynomial, with polar symmetry around the optical axis, and minimum in the centre of the detector (resulting from Compton scattering in the detector environment) ?

3.9 Empty sky regions?

Are there sky regions empty enough for "blank sky" observations with JEM-X ?

3.10 How do we derive the instrument background?

How do we derive the instrument background if we:

1. make image reconstruction of the shadowgram with all background included,
2. find an "empty background region" in the image, and
3. try to utilize this background estimate for the whole image ? Does this idea work at all for coded aperture imaging ?

3.11 How to make background models?

Can we expect to be able to make a set of useful (instrument) background models as a function of the 3 following parameters together:

1. orbital parameters
2. independent radiation level information
3. Spatial background distribution on the basis of Integral Mass Model simulation ?

3.12 How much should we rely on bkg estimates?

How much should we rely on the background estimates as we proceed to the later stages of the data analysis, refined image analysis, and source data extraction?

Maybe the background estimates should only be applied to the basic imaging processing and to the non-imaging data where the non-uniformity is less important. In the refined image analysis a self consistent background modelling could (or should?) be part of the analysis.

3.13 How is bkg handled in refined image analysis?

Do we

1. keep it fixed?
2. handle it internally in the analysis?
3. or update it iteratively by calling the background estimation routines?

3.14 How to get background during flight?

What is the best way of determining the instrument background during flight ? should we point to the moon ?

4 Answers emerging

4.1 The distribution of the DXB in the detector

Fig. 1 is a plot of the smoothed distribution in the detector derived by raytracing. Contrary to expectation there is rather a deficiency in the center than a peak.

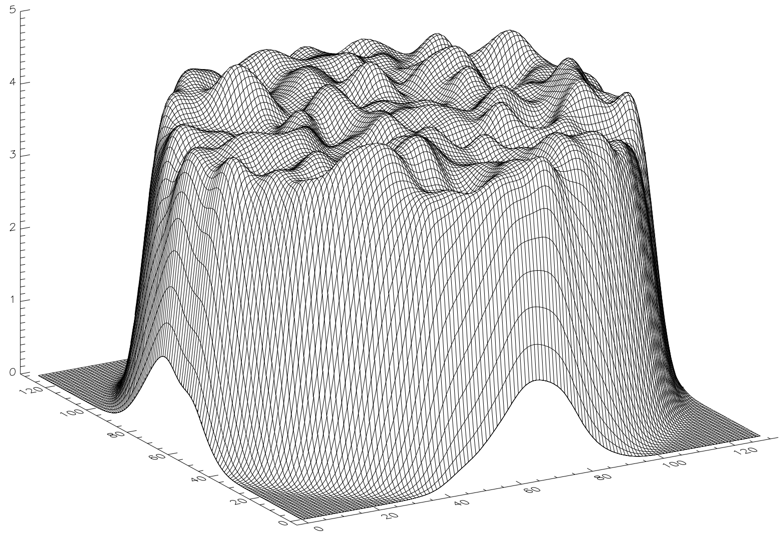

Figure 1: *The distribution of DXB counts in the detector for a 2500 s exposure in the energy range 3 – 20 keV. The image has been convolved with a gaussian with a FWHM of 16 mm. The diameter of the detector is 250 mm.*

5 References

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