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Improved *JEM-X* imaging

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A new imaging method has been developed for *JEM-X*. The flux from each sky pixel is obtained from a fit to the observed shadowgram rather than from a back projected image. The fitting method is more direct than the standard back projection method used in the public *OSA* software and allows better possibilities for elimination of systematic image artifacts. An improvement of more than a factor two for the signal-to-noise of weak sources in mosaic images has been obtained at low energies near strong sources.

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1. Introduction

As the *INTEGRAL* mission [1] progresses more and more archieval data become available for systematic surveys and time variability studies. However, systematic noise features are present in the *JEM-X* [2] images and becomes increasingly visible as more data are combined into mosaic images. This noise is currently the limiting factor for the ultimate instrument sensitivity. The same problem has been recognized already for several years in the analysis of *ISGRI* data [3], and much effort has been invested by the *ISGRI* team in suppressing these effects. We are now addressing this issue in the *JEM-X* analysis.

2. *JEM-X* image reconstruction

The public analysis software for *JEM-X* data available through the *OSA* software [4] provides the *j_ima_iros*–tool for the generation of sky images based on data from single science windows. It also provides the *j_ima_mosaic*–tool [5] for combining multiple such sky images into a single image covering a larger sky field and/or increasing the effective observation time associated with a given sky field.

j_ima_iros uses a back projection technique to generate the sky image for each science window. The images constructed with this technique contains a number of known systematic noise features for which we have already developed correction algorithms. Statistical noise then dominates the resulting single science window images. However, when combining hundreds of such images into a mosaic image, additional systematic features emerge for which we did not find effective cures in the past.

All the analyses presented in this paper are based on data from 1800 science windows covering the sky field around the strong source *GRS 1915+105*. The peak effictive exposure time is about 700 ks. Figure 1 is a 13^{o} diameter mosaic centered on *GRS 1915+105* and analyzed with the current OSA software. The color scales used for this and the subsequent figures are individually normalized to half the peak level for the weak source *IGR J19140+0950* (For source identifications see Figure 5). With this choice for the color scales the noise levels in each figure are directly comparable relative to the weak sources in the field.

We expected that a better image reconstruction with less systematic noise could be obtained through the use of a fitting procedure for the flux from each sky pixel. The *j_ima_iros* tool already uses such a fitting procedure to determine source fluxes in the 'iterative removal of sources'–loop. The fitting functions used are 'pixel illumination functions' (*PIF*'s) for the sources found in the back projected images. Much more instrument description detail can be incorporated in the *PIF*'s than in the back projection algorithm. We have also found that the source fluxes obtained through fitting are more stable than those derived from an analysis of the images.

Calculating a *PIF* value for every sky pixel is much more time consuming than running a back projection. But with the new image generation process we can facilitate the subsequent mosaicking operations by using a fixed set of sky pixels for all science windows. Then the mosaicking step will be quite fast. The old back projected images are generated in coordinates fixed to the instrument and the mosaicking of many such images is a relatively slow process - and also causes some loss of

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resolution and consequently a reduction in the final sensitivity achievable with a given input data set.

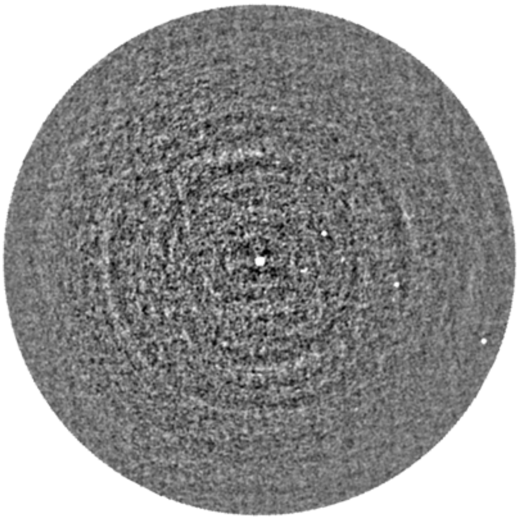

Figure 1: Back projection image mosaic
13° diameter mosaic centered on *GRS 1915*

Figure 2: Fitted image mosaic

3. Analysis of the new *JEM-X* images

Figure 2 shows a mosaic of the *GRS 1915* region based on the new, fitted images. The noise level is reduced relative to that of Figure 1, but not by a dramatic amount: the signal–to–noise (S/N) ratios for the weak sources in the field is improved by about 20%.

Some of the remaining noise is just the unavoidable Poisson noise caused by the high photon flux from *GRS 1915*. But there are also clear systematic noise features such as the circular ridges which are conspicuous in both figures.

4. Selective image generation

Close inspection of the noise features in Figure 2 convinced us that in addition to the obvious, but relatively harmless, ring structures there were other systematic artifacts which were more troublesome, because they could easily be mistaken for weak sources. These, apparently, are caused by remaining correlations between the strong source and the image point in question. Nominally the correct application of the *PIF*'s should eliminate such correlations, but obviously the reality does not conform to our models here.

We have therefore added a further condition to the image generation process: namely elimination of all shadowgram pixels where the total of contribution from all sources detected by *j_ima_iros* is predicted to be more than 50 % of the background signal in the pixel. The source and background contribution for the pixels are estimated based on the PIF values and the fitted source strengths as evaluated by *j_ima_iros*. In other words, we eliminate pixels which are well illuminated by known, strong sources. We call this imaging method "selective imaging". It is here an advantage that the *JEM-X* masks are only 25% transparent, meaning that at most a quarter of the shadowgram pixels are affected by any given source.

As shown in Figure 3 the selective imaging process turns out to be quite efficient for reducing noise. The weak source S/N-ratios in Figure 3 are improved by about 60% relative to those of Figure 2.

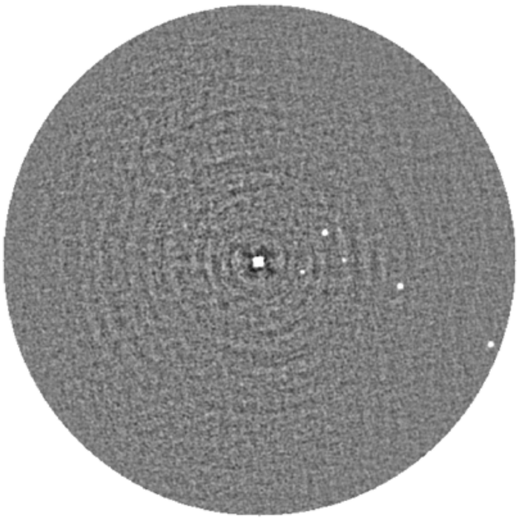

Figure 3: PIF selected image mosaic

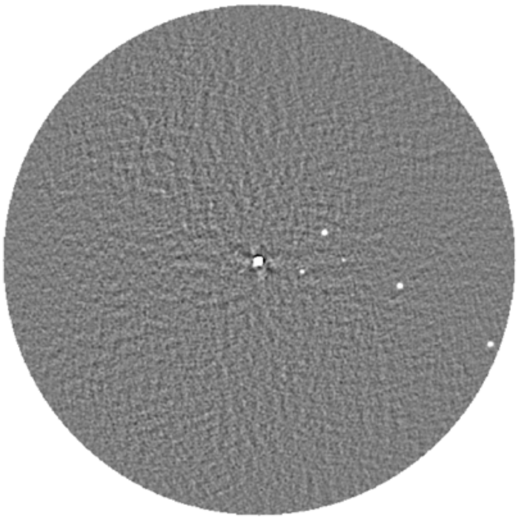

Figure 4: Ring cleaned mosaic

Finally we have implemented a smoothing of the ring features in the mosaic. This is done as a simple background subtraction along circular segments centered on *GRS 1915*. Figure 4 shows the final result. We see a further 15% improvement of the S/N ratios for the weak sources.

This last process can be said to be cosmetic only, since it is done on the image itself and not at the shadowgram level. Therefore it will not suppress point like artifacts in the mosaics, but it

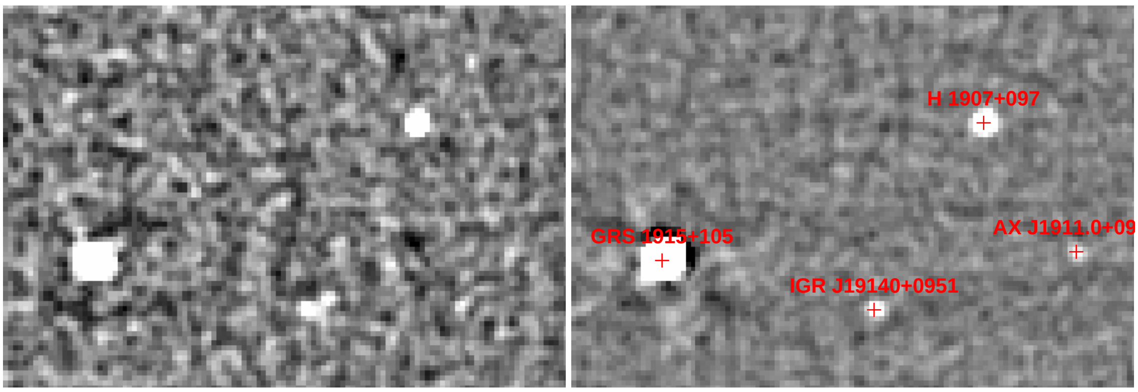

Figure 5: Elimination of shadowgram pixels with strong source illumination suppresses artifacts and and improves the visibility of real sources. Left: All pixel image, right: PIF selected and ring cleaned image

Signal-to-noise improvement relative to current *OSA* mosaics

Energy range (keV)	Back projection image mosaic	Fitted image mosaic	Selective imaging	Ring cleaning
3 to 7	1.00	1.20	1.85	2.10
7 to 11	1.00	1.08	1.52	1.63
11 to 20	1.00	1.10	1.34	1.40
20 to 35	1.00	1.01	1.09	1.04

Table 1: Analysis based on *JEM-X1* data from 1800 science windows (revolution 170-735). The improvement factors are calculated for the source *IGR J19140+0951* relative to the average image noise in a 13^{o} diameter region centered on *GRS 1915+105*.

does allow weak sources (and point like artifacts) to stand out more clearly. Figure 5 illustrates the improvement in the quality of the mosaic images by comparing a zoom of Figure 2 with the corresponding region in Figure 4.

5. Conclusions

New methods have been developed for noise reduction in mosaic images based on data from the *JEM-X* instruments. A significant reduction in the image noise has been achieved. The improvement is most significant for energies below 10 keV where the count rate from bright sources often dominates over the background count rate. Table 1 shows the S/N improvements achieved in four energy bands.

The improved methods will be used in the future for detection and spectral characterization of faint sources. As far as possible the new techniques will be implemented in future *OSA* releases.

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