SEARCH FOR WEAK AND TRANSIENT SOURCES IN INTEGRAL ARCHIVE

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ABSTRACT

Large field of view of INTEGRAL imaging instruments allows us to study many sources besides the nominal target. Many variable objects could be below the detection level for most of the time but aimed search in the archive can bring them out of the blur with properly chosen observation periods. We develop specific tools trying to reach the weakest sources while extracting the fluxes in a consistent way.

Key words: INTEGRAL; stars: cataclysmic variables; galaxies: active nuclei.

1. INTRODUCTION

Current strategy for search of gamma-ray sources in images from INTEGRAL relies on monitoring of individual science windows and mosaics created per observation groups as a part of standard archive processing, and finally in checking of excesses in the overall mosaics as those produced in IBIS survey program. Variable nature of many sources would cause their emission to be smeared out below the detection level in the latter mosaics, while they could be in general too weak (esp. if their emission lies mainly outside the keV range of INTEGRAL instruments) to be detected on the scale of hours or days.

Among the basic classes of high-energy objects we have two examples that correspond to this description:

cataclysmic variables together with wider spaced **symbiotic binaries** are rather soft X-ray sources, however besides those detected in IBIS survey program (e.g. V1223 Sgr, V2400 Oph, V709 Cas, SS Cyg, V1432 Aql) there is a number of CV candidates among new IGR sources. In the most promising category of Intermediate Polars, flares have been reported (for V1223 Sgr by Barlow [1]) on the timescale of 3 hours.

blazars the choice based on X-ray detection from different satellites (Donato [3]), however in hard X-ray band (corresponding to IBIS domain) the emission is weak with onset of the second (Inverse Compton) peak in MeV range. There is a ToO program for blazars based on optical or X-ray trigger, however, number of blazars detected so far is quite low due to poor coverage of high Gal. latitudes.

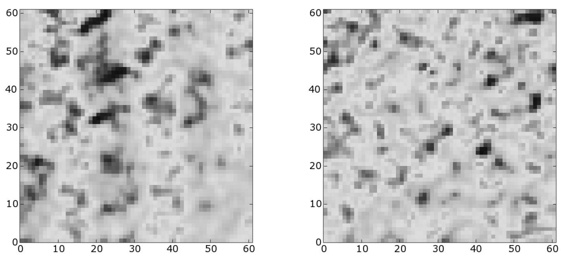

Figure 1. The pictures correspond to Carina and Vela regions (mosaics from ISDC archive made on per-revolution basis), where in the center of the box (coordinates in pixels) should be located GQ Mus (rev. 198) and IX Vel (rev. 88) respectively. These examples show the level and structure of deconvolution noise – darker means higher flux – in the second case there seems to be some excess at the expected position, however, it should be compared to "false" sources around.

Both classes of sources show also an important optical variability, typically correlated (sometimes anti-correlated) with high-energy activity. In the choice of a proper time interval we can recourse to the optical monitoring provided by several ground telescopes (since the on-board OMC has – compared to HE instruments – smaller field of view), more details on related observation campaigns in Kubanek [6].

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2. MOSAIC PREPARATION

The aim of this step is to obtain maximum exposure possible for a given class of sources while reducing the **number of mosaics** to be computed, i.e. combining mosaics for nearby sources (esp. important for CVs concentrated along Gal. plane). Some limit is set (10 degrees for IBIS images) for the distance of a source from the center of the FoV, beyond which the background contributes more to the final mosaic than the source.

For a principal target all science windows within a chosen distance are marked; then for the sources of interest contained in this first order mosaic we check how many of the SCWs relevant to a given source are already included – if the fraction of "missing" windows is small enough, they are attached to the mosaic. The procedure can be repeated several time: wit the requirement of 80% SCWs already included the process converges even for quite dense regions.

For example from the total number of 1550 cataclysmics in the final Downes [4] catalogue, we have selected 111 best candidates (based on their strong flux in highest ROSAT band or their detection with ASCA). In the end 76 mosaics were formed, after selecting only those containing public data with reasonable ISGRI good-time coverage, the number of mosaics was reduced to 45. These mosaics were then split into up-to 7 time intervals (following several criteria as minimal gap between and maximal spread of a SCW group), so the total of **176** mosaics was reached, containing about **16000** SCWs.

These mosaics contain **75** of our primary targets, and in addition **560** other CV sources. The total exposure goes as high as 3.6 Msec (for V2400 Oph), the average value being about 600 ksec (even for non-primary targets the exposure can even exceed 6 Msec when they are close enough to galactic center).

Similar task, with slightly larger set of targets, was performed for smaller field of view of JEM-X; some of the mosaics were split in several pieces, counterweighting smaller coverage of these instruments, so the total number of 40 mosaics was similar to the previous case (after splitting in time intervals it has risen to 79). We covered 95 sources, almost half of them our primary targets. The average exposure was above 100 ksec.

2.1. Search in archived mosaics

Since the complete standard analysis of such huge number of SCWs would be extremely time-demanding, we profit of the processed data stored in ISDC archive (for IBIS now in second revision up to about rev. 300), so the only task left is combining the SCWs available in mosaics. For ISGRI, this is the task performed by **ii_skyimage** (with param. DoPart2=2), in the case of JEM-X one has to rely on **varmosaic** tool of HEATOOLS. Because of rather fine energy binning

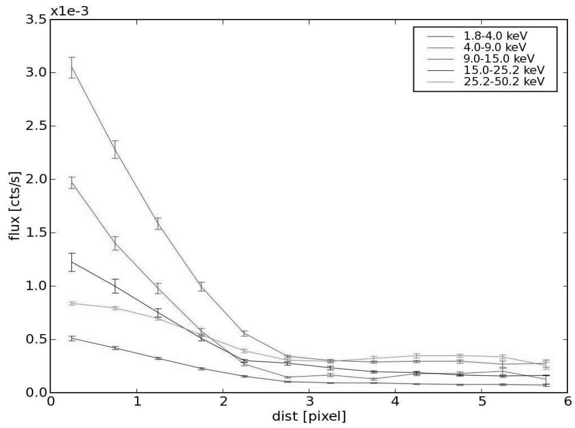

Figure 2. Radial profiles of a strong source in ISGRI mosaics – the lines are ordered from top to bottom (on the right side) with increasing energy, except for the lowest line, which corresponds to the first band. The central part of the profile seems to decrease almost linearly with distance.

in standard data processing the resulting mosaics are too large to be transfered easily. Special function of **mosaic_spec** tool allows to extract a rectangular cutout (across the energy bins) around the target position, typically with side of 30 or 40 pixels (i.e. 1 degree). In the example of CV analysis there are almost 3500 of these positions (350 of primary targets), however, their total size is only a fraction of that of the mosaics.

Prior to the procedure described above we looked at positions of most promising CVs in mosaics constructed on per-revolution basis during archiving at ISDC. Two cutouts at positions of known cataclysmic variables from the per-revolution mosaics of ISGRI images are shown on fig. 1. No significant excess being detected, these images serve as an example of the level of fluctuations (together with some periodic structure in the first picture) we have to deal with.

3. SIGNAL MEASUREMENT

The most delicate task is the localization and measurement of a signal, especially for weak sources close to background fluctuations. Since the noise pattern of deconvolved images is quite different from that of normal CCD images, instead of standard tools of optical astronomy we developed a small analysis package written in python (extended with *numarray* and *pyfits* modules).

First step is a localization of all excesses in the cut-out region and then, after masking all adjacent pixels, the remaining background is fitted with 2-D paraboloid and subtracted. The peaks reasonable above the background variance are then barycentered and the central part is fitted with a PSF of choice – in the case of Gaussian profile

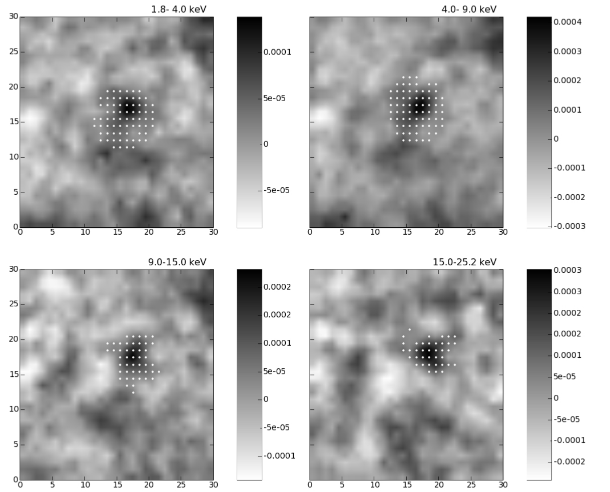

Figure 3. JEM-X images of IC 4329A in standard bands of 1.8−4−9−15−25 keV (flux in ct/s). The dots indicate the pixels used in the peak measurement (barycentring, fitting etc.). One of the tests checks the dependence of the result on the choice of these points (that becomes more complicated in crowded regions).

the central part of the peak can be adjusted analytically using regression.

The program is able to take into account the asymmetry of the peak, that is roughly estimated already from second moments and then refined as a parameter to χ^2 fitting. Having estimated correctly the peak position and its eventual asymmetry, the radial profile can be constructed and compared with the PSF used. In the figure 2 these profiles are shown for a rather strong source NGC 4151 in 5 energy bands of JEM-X measurements.

In principle the value of the flux from a given source should be extracted from the pixel of the deconvolved image corresponding to a given direction. However, due to large pixel size the source position falls somewhere in between neighbor pixels and the expected peak value should be calculated as some smooth interpolation of pixels influenced by the source. We tried both 2-D PSF fitting and extrapolation of the radial profile summarized in the table 1. The variation of the background in the image was (related to the mean variance in the cut-out) of the order of $2 \sim 3\sigma$, so the differences between various methods are (in certain bands) significant.

4. STATUS

So far we are testing the method's stability on AGNs identified in second IBIS survey catalogue, for corresponding data from JEM-X, as is the case of IC 4329A shown on fig. 3.

We also check the amplitudes of peaks before and after summing of multiple energy bands. At this phase of development, we do not consider the extracted intensities to be reliable enough for publication; we probably have to use Monte-Carlo tests to check the absence of any systematic biases.

5. SENSITIVITY LIMITS

Our aim is to extend this bias-free flux estimation to as low flux as possible. This would give us statistics-determined upper limits of fluxes of non-detected sources in constructed mosaics that improve current sensitivity reached by standard analysis methods. An essential point is a reliable distinction between real sources and image artifacts, so common in deconvolved images of coded-mask instruments (especially beyond the half-covered FoV).

As an illustration we can mention the search for CVs in JEM-X mosaics described above. Using images from ISDC archive processed with *j_ima_iros* ver. 1.4.0, we have found 658 peaks with signif. greater than 2 sigma in 102 cut-outs (out of all 181 cut-outs); 288 peak has risen above 5σ and 24 above 10σ. However, the only coincidence closer than 2 arcmin to the theoretical CV position was found for V442 Oph with sign. 5.3σ.

The survey is clearly not complete as far as CVs are concerned. We have not included all those already detected in IBIS survey, namely not those of new IGR sources, that were classified as cataclysmic variables (e.g. in Masetti [7]) because of some typical properties in their optical spectra. In the present dataset we were aiming principally at new detections in the JEM-X domain, excluding those known from previous surveys.

6. CONCLUSIONS

The poster presentation described current status of our development of tools and algorithms for search of sources in IBIS and JEM-X mosaics. The up-to-date results of this ongoing work can be found in detail on our web page `http://altamira.asu.cas.cz/icvwg`.

More care should be taken in future of SCW quality checking – besides the cut on background fluctuation applied for example in the construction of IBIS survey mosaics [2] one can also suggest rejecting all SCWs where ghost positions of strong sources coincide with one of the searched objects. These side effects are not always perfectly removed during the cleaning of deconvolved images and these extra precautions might be advisable when trying to touch the sensitivity limits.

Table 1. The table here compares the fluxes (in 10^{-3} ct/s) from the peak amplitude estimated with different methods for rather strong source NGC 4151. First line shows the results obtained with analytic 2-D regression (that assumes the background was correctly subtracted – then the central part of the peak is approximated with a paraboloid in logarithmic scale). Second and third rows are fits to the profile function extrapolated to point 0 using linear and cubic shape. The next 2 rows are the amplitudes of a real 2-D fit with MPFIT package (using Levenberg-Marquardt least-squares minimization), first with Gaussian, then with Moffat PSF. If we believe most the radial profile fits, then the Gaussian shape correspond better in the value of peak amplitude than Moffat. Last lines gives significance of the central point in different energy bands.

	1.8-4.0 keV	4.0-9.0 keV	9.0-15.0 keV	15.0-25.2 keV	25.2-50.2 keV
regression	0.45	2.46	1.80	1.14	0.90
lin. radial	0.55	3.30	2.10	1.34	0.94
cub. radial	0.55	3.45	2.29	1.32	0.82
mpfit gaussian	0.56	3.35	2.32	1.52	0.90
mpfit moffat	0.61	3.68	2.51	1.86	0.93
signif.	28	88	67	36	16

ACKNOWLEDGMENTS

We gladly acknowledge the extensive use of INTEGRAL Science Data Center archive. Our work was supported by the project ESA PECS project 98023 and by the Grant Agency of the Czech Republic, grant A3003206.

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