INTEGRAL Science Data Centre

JEM-X Analysis User Manual

Authors and Approvals

ISDC	JEM-X Analysis User Manual	
September 2012	10.0	

Prepared by :   M. Chernyakova
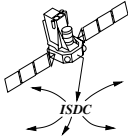   P. Kretschmar
                         JEM-X team
                         A. Neronov
                         V. Beckmann
                         L. Pavan

Agreed by :   C. Ferrigno ....

Approved by :   T. J.-L. Courvoisier ....

Document Status Sheet

ISDC	JEM-X Analysis User Manual	
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18 July 2003	2.0	Second Release. Sections 5, 6, 9, 8.1, Appendix C and bibliography were updated. Section 8.11 was added.
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19 SEP 2012	Printed	

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Acronyms and Abbreviations

ADC	Analog to Digital Converter
CR	Cosmic Rays
DFEE	Digital Front End Electronics
DPE	Data Processing Electronics
DSRI	Danish Space Research Institute
DXB	Diffuse X-ray Background
FRSS	Fixed Radiation Source System
FCFOV	Fully Coded Field of View
FOV	Field of View
FULL	Full Imaging Format
GTI	Good Time Interval
IC	Instrument Characteristics
IJD	Integral Julian Day
ISOC	Integral Science Operations Centre
ISDC	Integral Science Data Center
ISSW	Instrument Specific Software
JEM-X	Joint European Monitor for X-rays
HURA	Hexagonal Uniformly Redundant Array
IROS	Iterative Removal of Sources

MSP	Microstrip Plate
OBT	On Board Time
OCL	Off-line Calibration
OG	Observation Group
PCFOV	Partially Coded Field of View
PHA	Pulse Height Amplitude
PI	Pulse Invariant
RATE	Countrate Format
REST	Restricted Imaging Format
S/C	Spacecraft
SPTI	Spectral-Timing Format
SPEC	Spectral Format
SDAST	Science Data Analysis Team
TBW	To be written
TIME	Timing Format
TM	Telemetry
ZRFOV	Zero Response Field of View
SPAG	Spatial gain variation (of the microstrip plate)

Glossary of Terms

- *ISDC system:* the complete ground software system devoted to the processing of the *INTEGRAL* data and running at the ISDC. It includes contributions from the ISDC and from the *INTEGRAL* instrument teams.

- *Science Window (ScW):* For the operations, ISDC defines atomic bits of *INTEGRAL* operations as either a pointing or a slew, and calls them ScWs. A set of data produced during a ScW is a basic piece of *INTEGRAL* data in the ISDC system.

- *Observation:* Any group of ScW used in the data analysis. The *observation* defined from ISOC in relation with the proposal is only one example of possible *ISDC observations*. Other combinations of Science Windows, *i.e.,* of observations, are used for example for the Quick-Look Analysis, or for Off-Line Scientific Analysis.

- *Pointing:* Period during which the spacecraft axis pointing direction remains stable. Because of the *INTEGRAL* dithering strategy, the nominal pointing duration is of order of 20 minutes.

- *Slew:* Period during which the spacecraft is manoeuvred from one stable position to another, i.e., from one pointing to another.

- *Shadowgram:* The pattern of detected events on the microstrip plate produced when particles and xrays pass through the coded mask and hit the plate

- *Sky image:* Image of the sky above the telescope produced when a shadowgram integrated over a given period of time is deconvolved by the image construction software

- *Mosaic:* A sky image produced by merging two or more separate sky images so as to cover a greater area of sky, or to enhance the signal from a particular area of the sky.

Introduction

This document, 'JEM-X Analysis User Manual', has been written to help you with the JEM-X specific part of the *INTEGRAL* Data Analysis.

You will find some text in blue along this manual: it is used to notify a difference with respect to the previous version of this document, or the introduction of a new section (in this case only the title is marked in blue).

A more general overview on the *INTEGRAL* Data Analysis can be found in the 'Introduction to the *INTEGRAL* Data Analysis' [1]. For the JEM-X analysis scientific validation report see [3]

The 'JEM-X Analysis User Manual' is divided into two major parts:

- Description of the Instrument
  This part, based to some extent on the JEM-X User Manual [2], introduces the *INTEGRAL* on-board X-Ray Monitor (JEM-X).

- Description of the Data Analysis
  This part starts with an overview describing the different steps of the analysis. Then, in the Cookbook Section, several examples of analysis and their results and the description of the parameters are given.

  Finally, the used algorithms are described. A list of the known limitations of the current release is also provided.

In the Appendix of this document you find the description of the Raw and Prepared Data and also the description of the Scientific Products.

Part I

Instrument Definition

1 Scientific Performance Summary

The Joint European Monitor for X-rays (JEM-X) on-board *INTEGRAL* fulfills three roles:

- It provides complementary data at lower energies for the studies of the gamma-ray sources observed by the two main instruments, IBIS and SPI. Flux changes or spectral variability at the lower energies may provide important elements for the interpretation of the gamma-ray data. In addition, JEM-X has a higher spatial resolution than the gamma-ray instruments. This aids with the identification of sources in crowded fields.

- During the recurrent scans along the galactic plane JEM-X provides rapid alerts for the emergence of new transients or unusual activity in known sources. These sources may be unobservable by the other instruments on *INTEGRAL* .

- Finally, JEM-X may deliver independent scientific results concerning sources with soft spectra, serendipitously detected in the field of view (FOV) during the normal observations.

JEM-X operates simultaneously with the main gamma-ray instruments IBIS and SPI. It is based on the same principle as the two gamma-ray instruments on *INTEGRAL* : sky imaging using a coded aperture mask. The performance of JEM-X is summarized in Table 1.

Table 1: JEM-X parameters and performance.

Energy range	$3 - 35$ keV
Energy resolution†	$\Delta E / E = 0.40 \times \left[(1/E \text{ keV}) + (1/120 \text{ keV}) \right]^{1/2}$
Field of view (diameter)†	$4.8°$ Fully illuminated
	$7.5°$ Half response
	$13.2°$ Zero response
Angular resolution (FWHM)	$3'$
Relative point source location error	$1'$ (90% confidence radius for a 5σ isolated source)
Continuum sensitivity	1.2×10^{-4} ph cm^{-2}s^{-1}keV^{-1} @ 6 keV
for a single JEM-X unit	1.0×10^{-4} ph cm^{-2}s^{-1}keV^{-1} @ 30 keV
(isolated source on-axis)	for a 3 σ cont. detection in 10^5s, $\Delta E = 0.5E$
Narrow-line sensitivity	1.6×10^{-4} ph cm^{-2}s^{-1} @ 6 keV
(isolated source on-axis)	1.3×10^{-4} ph cm^{-2}s^{-1} @ 20 keV
	for a 3σ line detection in 10^5s
Timing resolution	122 μs (relative timing)
	~ 1 ms (absolute timing)

† The energy resolution is slowly changing (degrading) over time.
‡ At the half response angle the sensitivity is reduced by a factor 2 relative to the on-axis sensitivity.
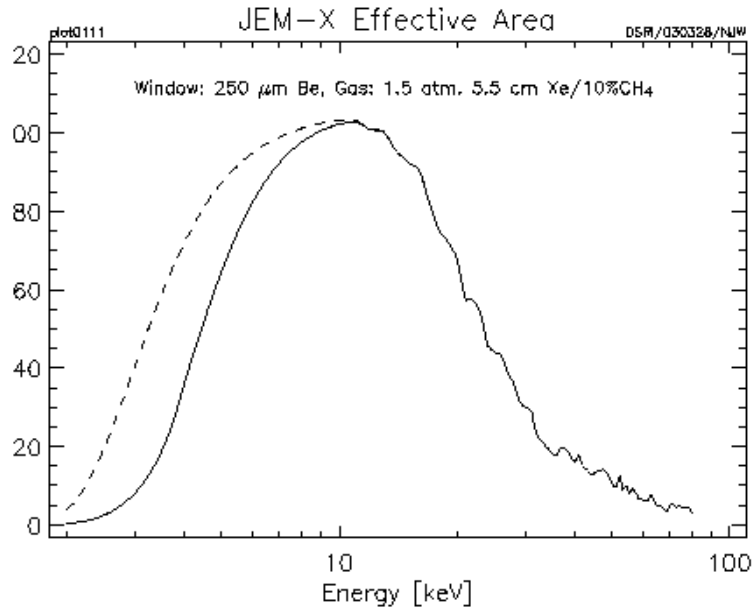
Figure 1: JEM-X effective area with the mask taken into account. The dashed line shows the effective area before the high voltage reduction and the full curve shows efficiency when taking into account the effect of the electronic low-signal cutoff (approximately).

2 Instrument Description

2.1 The Overall Design

JEM-X consists of two identical coded-aperture mask telescopes co-aligned with the other instruments on *INTEGRAL* . The photon detection system consists of high-pressure imaging Microstrip Gas Chambers (MSGC) located at a distance of 3.4 m from each coded mask. Figure 2 shows a schematic diagram of one JEM-X unit. A single JEM-X unit comprises 3 major subsystems: the detector, the associated electronics and the coded mask.

The two JEM-X units have been used alternatively in the past, and are currently operated simultaneously. The decision to use only one instrument at a time was made about three months after launch when a gradual loss in sensitivity had been observed in both JEM-X units, due to the erosion of the microstrip anodes inside the detector. By lowering the operating voltage, and thereby the gain of the detectors, the anode damage rate has now been reduced to a level where the survival time of the detectors seems to be assured for a further five year period. Only 6 anodes have been lost on JEM-X1 in all of 2006. Another 7 anode strips have been lost on JEM-X1 in the first 8 months of 2007. For the complete, updated list of dead anodes see http://www.spacecenter.dk/∼oxborrow/sdast/InstrConfig/JC.BadAnodes.txt

2.2 The Detector

Each JEM-X detector is a microstrip gas chamber with a sensitive geometric area of 500 cm^2 per unit. The gas inside the steel pan-shaped detector vessel is a mixture of xenon (90%) and methane (10%) at 1.5 bar pressure. The incoming photons are absorbed in the xenon gas by photo-electric absorption and the resulting ionization cloud is then amplified in an avalanche of ionizations by the strong electric field near the microstrip anodes. Significant electric charge is picked up on the strip as an electric impulse. The position of the electron avalanche in the direction perpendicular to the strip pattern is measured from the centroid of
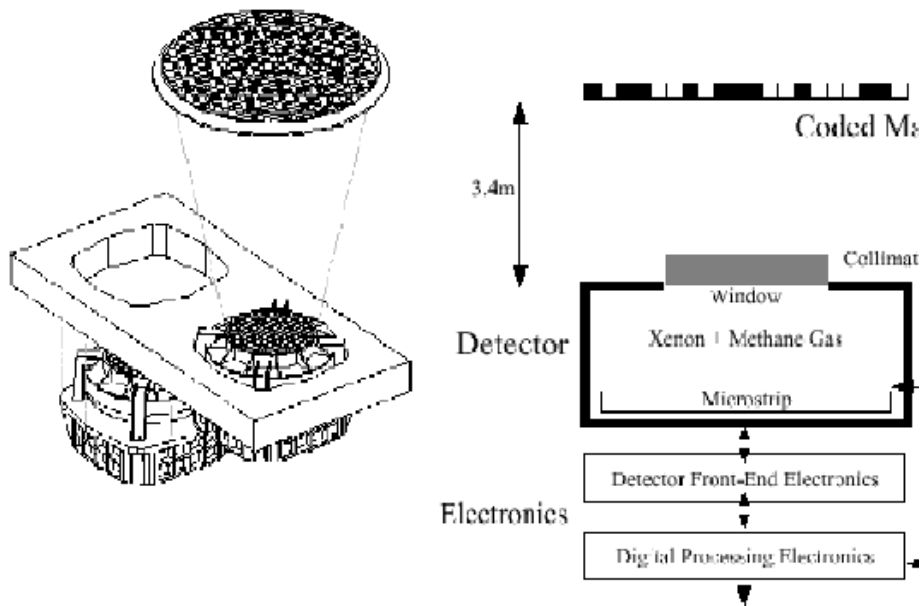
Figure 2: Left:Overall design of JEM-X, showing the two units, with only one of the two coded masks. Right: functional diagram of one unit.

the avalanche charge. The orthogonal coordinate of an event is obtained from a set of electrodes deposited on the rear surface of the microstrip plate (MSP).

The X-ray window of the detector is composed of a thin (250 μm) beryllium foil which is impermeable to the detector gas but allows a good transmission of low-energy X-rays (see dashed curve in Fig. 1). the Be window imposes an absolute lower limit of $\simeq 3$ keV on the energy of X-rays coming into the detector, and hence it is meaningless to try to push the data analysis below this limit.

A collimator structure with square-shaped cells is placed on top of the detector entrance window. It gives support to the window against the internal pressure and, at the same time, limits and defines the field of view of the detector. The collimator is important for reducing the count rate caused by the cosmic diffuse X-ray background. However, the presence of the collimator also means that sources near the edge of the field of view are attenuated with respect to on-axis sources (see Fig.3). The materials for the collimator (molybdenum, copper, aluminium) have been selected in order to minimize the detector background caused by K fluorescence. Four radioactive sources are embedded in each detector collimator in order to calibrate the energy response of the JEM-X detectors in orbit. For JEM-X1 two ^{55}Fe and two ^{109}Cd sources were used. For JEM-X2 all four radioactive sources are ^{109}Cd. Each source illuminates a well defined spot on the microstrip plate. ^{109}Cd emits 22 keV and 88 keV photons. ^{55}Fe produces one unresolved doublet at 6 keV. The gain of the detector gas is monitored continuously with the help of these sources. Figure 4 shows the collimator layout and the locations of the calibration sources. There is one calibration source for each anode segment on the MSP. The 29.6 keV photons produced by Xe fluorescence can be detected all over the MSP and are used for offline monitoring of the gain correction by the software, and also to produce instrument model tables of the spatial gain (SPAG) variation across the detector plate. For the complete archive of these offline analyses see: http://www.spacecenter.dk/∼oxborrow/sdast/GAINresults.html.
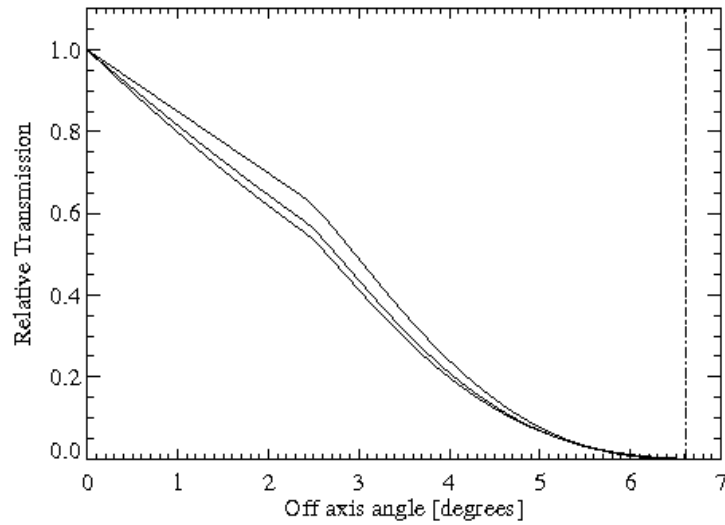
Figure 3: Off axis response of JEM-X below 50 keV where the collimator walls are opaque. The thick line shows the average transmission through the collimator considering all azimuth angles. The square pattern of the collimator introduces an azimuthal dependence of the throughput with a minimum and a maximum as indicated by the two thin curves (no response at ZRFOV indicated by dash-dot line).
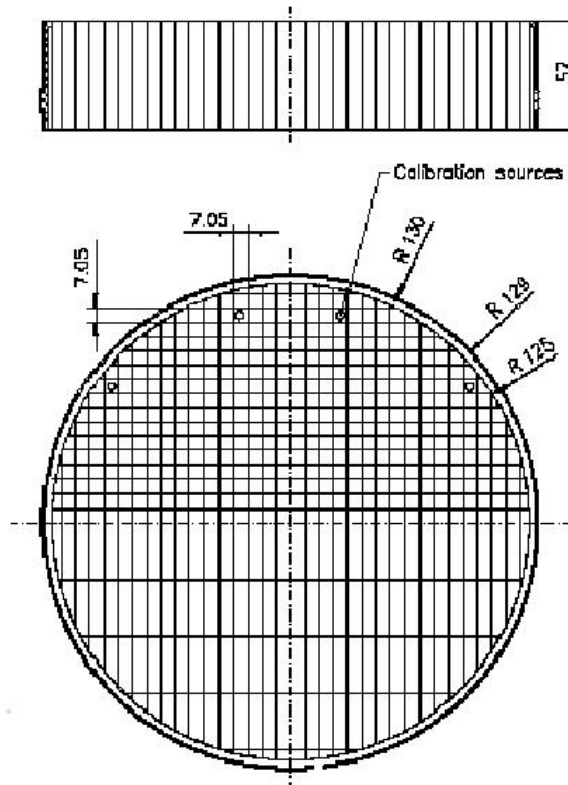
Figure 4: Collimator layout. In this diagram the 4 calibration sources are situated on the upper side. The dimensions are in mm, i.e. collimator length = 57 mm, radius = 130 mm
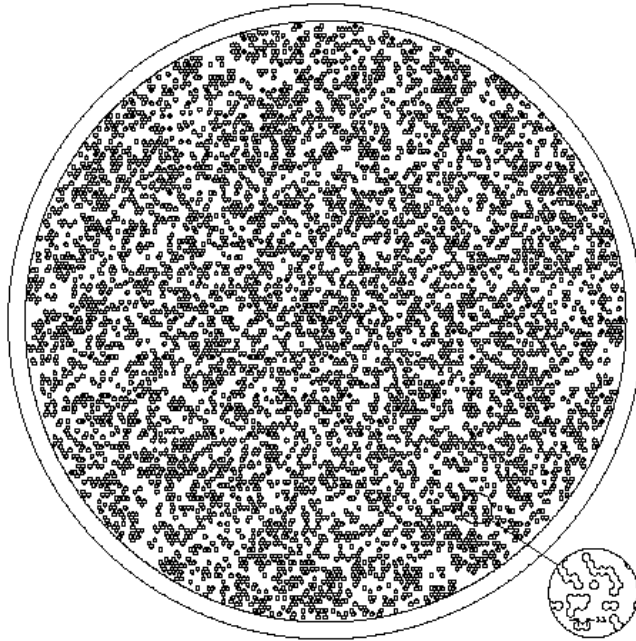
Figure 5: Illustration of the JEM-X coded mask pattern layout without the mechanical interface. The diameter of the coded mask is 535 mm. The mask has a transparency of 25%.

2.3   Coded Mask

The mask is based on a Hexagonal Uniformly Redundant Array (HURA). For JEM-X a pattern composed of 22501 elements with only 25% open area has been chosen. The 25% transparency mask actually achieves better sensitivity than a 50% mask, particularly in complex fields with many sources, or in fields where weak sources should be studied in the presence of a strong source. A mask with lower transparency also has the advantage of reducing the number of events to be transmitted, while at the same time increasing the information content of the remaining events. Considering the telemetry allocation to JEM-X, this means an improved overall performance for the instrument, particularly for observations in the plane of the Galaxy. The mask height above the detector (3.4 m) and the mask element dimension (3.3 mm) define together the angular resolution of the instrument, in this case 3'. Figure 5 illustrates the JEM-X coded mask pattern.

3 Instrument Operations

3.1 Telemetry Formats and Data Compression

JEM-X data can be transmitted in several different telemetry formats which vary in their information content for position, energy or time and the required bandwidth per event. In addition, a "grey filter" mechanism exists eliminating a fraction of the incoming events in a randomized way. The possible transmission settings range from 32/32 to 1/32 of the incoming events. These mechanisms allow the instrument to cope with sources of very different brightness despite its limited telemetry allocation.

For formats with poor time resolution (REST, SPEC) countrate data packets are also transmitted to provide some data for timing analysis. However countrate data is not an independent data format.

For a given observation a primary and a secondary telemetry format are defined and they can be identical. If the observed data rate is too high to be transmitted completely, first the grey filtering will be increased to reduce the number of processed events. Should this not be sufficient the instrument will autonomously switch to the secondary telemetry format, continuing to adapt the grey filter as necessary. For decreasing input rates the instrument will reduce the filtering and possibly switch back to the primary format. All these changes are driven by the filling status of an on-board buffer, the mechanism includes a certain hysteresis in order to avoid rapid switching between formats.

The characteristics of primary and secondary telemetry formats are listed in Table 2. The default primary format is Full Imaging and the default secondary format is Restricted Imaging. Note that in the Spectral Timing format the actual spectral resolution will be slightly lower than that of the Full Imaging mode due to spatial gain variations in the detector. It is recommended, however, that the full imaging format is used both as primary and secondary format.

Table 2: Characteristics of the JEM-X Telemetry Packet Formats.

Format Name		Detector Image Resolution (pixels)	Timing Resolution	Spectral Resolution (channels)	Events per packet
Full Imaging	(FULL)	256 x 256	$1/8192\mathrm{s} = 122\mu\mathrm{s}$	256	≤ 105
Restricted Imaging	(REST)	256 x 256	≤ 32 s	8	≤ 320
Countrate	( )	None	$1/8$ s = 125 ms	1	n/a
Spectral Timing	(SPTI)	None	$1/8192\mathrm{s} = 122\mu\mathrm{s}$	256	≤ 210
Timing	(TIME)	None	$1/8192\mathrm{s} = 122\mu\mathrm{s}$	None	≤ 550
Spectrum	(SPEC)	None	$1/8\mathrm{s}$ = 125 ms	64	n/a

3.2 Energy Binning

3.2.1 PHA Binning

The energy values of the events provided in the telemetry are given as a bin number from 0 to 255. These are non-linear groupings of the original 4096 bins of the on-board Analog to Digital Converter (ADC). While the ADC channels are highly linear, the PHA bins are designed to be logarithmic so that the energy resolution of the bins parallels that of the detector. The actual grouping of the ADC channels into PHA telemetry bins is determined by a lookup table used by the Data Processing Electronics (DPE) to pack the telemetry. After the high voltage reductions this table has been updated to match the changed ADC signal strengths.

See also Appendix B.3 for more details.

3.2.2 PI Binning

The PI bin limits in keV have been defined so that the entire energy range (nominally 3–100 keV) is covered and the binsize is a more or less constant fraction of the detector resolution. The PI binning table for the Full Imaging mode with the highest number of bins (256) is shown in Table 3. See Appendix B.3 for more details.

Table 3: Energy boundaries of the PI channels

PI	E_{min}	E_{max}	PI	E_{min}	E_{max}	PI	E_{min}	E_{max}
0	0.00	0.06	86	6.24	6.32	171	17.90	18.16
1	0.06	0.12	87	6.32	6.40	172	18.16	18.42
2	0.12	0.18	88	6.40	6.48	173	18.42	18.68
3	0.18	0.24	89	6.48	6.56	174	18.68	18.94
4	0.24	0.30	90	6.56	6.64	175	18.94	19.20
5	0.30	0.36	91	6.64	6.72	176	19.20	19.46
6	0.36	0.42	92	6.72	6.80	177	19.46	19.72
7	0.42	0.48	93	6.80	6.88	178	19.72	19.98
8	0.48	0.54	94	6.88	6.96	179	19.98	20.24
9	0.54	0.60	95	6.96	7.04	180	20.24	20.50
10	0.60	0.66	96	7.04	7.12	181	20.50	20.76
11	0.66	0.72	97	7.12	7.20	182	20.76	21.02
12	0.72	0.78	98	7.20	7.28	183	21.02	21.28
13	0.78	0.84	99	7.28	7.36	184	21.28	21.54
14	0.84	0.90	100	7.36	7.44	185	21.54	21.80
15	0.90	0.96	101	7.44	7.52	186	21.80	22.06
16	0.96	1.02	102	7.52	7.60	187	22.06	22.32
17	1.02	1.08	103	7.60	7.68	188	22.32	22.58
18	1.08	1.14	104	7.68	7.76	189	22.58	22.84
19	1.14	1.20	105	7.76	7.84	190	22.84	23.10
20	1.20	1.26	106	7.84	7.92	191	23.10	23.36
21	1.26	1.32	107	7.92	8.00	192	23.36	23.72
22	1.32	1.38	108	8.00	8.08	193	23.72	24.08
23	1.38	1.44	109	8.08	8.16	194	24.08	24.44
24	1.44	1.50	110	8.16	8.24	195	24.44	24.80
25	1.50	1.56	111	8.24	8.32	196	24.80	25.16
26	1.56	1.62	112	8.32	8.42	197	25.16	25.52
27	1.62	1.68	113	8.42	8.52	198	25.52	25.88
28	1.68	1.74	114	8.52	8.62	199	25.88	26.24
29	1.74	1.80	115	8.62	8.72	200	26.24	26.60
30	1.80	1.86	116	8.72	8.82	201	26.60	26.96
31	1.86	1.92	117	8.82	8.92	202	26.96	27.32
32	1.92	2.00	118	8.92	9.02	203	27.32	27.68
33	2.00	2.08	119	9.02	9.12	204	27.68	28.04
34	2.08	2.16	120	9.12	9.22	205	28.04	28.40
35	2.16	2.24	121	9.22	9.32	206	28.40	28.76
36	2.24	2.32	122	9.32	9.42	207	28.76	29.12
37	2.32	2.40	123	9.42	9.52	208	29.12	29.48
38	2.40	2.48	124	9.52	9.62	209	29.48	29.84
39	2.48	2.56	125	9.62	9.72	210	29.84	30.20
40	2.56	2.64	126	9.72	9.82	211	30.20	30.56
41	2.64	2.72	127	9.82	9.92	212	30.56	30.92
42	2.72	2.80	128	9.92	10.08	213	30.92	31.28
43	2.80	2.88	129	10.08	10.24	214	31.28	31.64
44	2.88	2.96	130	10.24	10.40	215	31.64	32.00
45	2.96	3.04	131	10.40	10.56	216	32.00	32.36
46	3.04	3.12	132	10.56	10.72	217	32.36	32.72

47	3.12	3.20	133	10.72	10.88	218	32.72	33.08
48	3.20	3.28	134	10.88	11.04	219	33.08	33.44
49	3.28	3.36	135	11.04	11.20	220	33.44	33.80
50	3.36	3.44	136	11.20	11.36	221	33.80	34.16
51	3.44	3.52	137	11.36	11.52	222	34.16	34.52
52	3.52	3.60	138	11.52	11.68	223	34.52	34.88
53	3.60	3.68	139	11.68	11.84	224	34.88	36.16
54	3.68	3.76	140	11.84	12.00	225	36.16	37.44
55	3.76	3.84	141	12.00	12.16	226	37.44	38.72
56	3.84	3.92	142	12.16	12.32	227	38.72	40.00
57	3.92	4.00	143	12.32	12.48	228	40.00	41.28
58	4.00	4.08	144	12.48	12.64	229	41.28	42.56
59	4.08	4.16	145	12.64	12.80	230	42.56	43.84
60	4.16	4.24	146	12.80	12.96	231	43.84	45.12
61	4.24	4.32	147	12.96	13.12	232	45.12	46.40
62	4.32	4.40	148	13.12	13.28	233	46.40	47.68
63	4.40	4.48	149	13.28	13.44	234	47.68	48.96
64	4.48	4.56	150	13.44	13.60	235	48.96	50.24
65	4.56	4.64	151	13.60	13.76	236	50.24	51.52
66	4.64	4.72	152	13.76	13.92	237	51.52	52.80
67	4.72	4.80	153	13.92	14.08	238	52.80	54.08
68	4.80	4.88	154	14.08	14.24	239	54.08	55.36
69	4.88	4.96	155	14.24	14.40	240	55.36	56.64
70	4.96	5.04	156	14.40	14.56	241	56.64	57.92
71	5.04	5.12	157	14.56	14.72	242	57.92	59.20
72	5.12	5.20	158	14.72	14.88	243	59.20	60.48
73	5.20	5.28	159	14.88	15.04	244	60.48	61.76
74	5.28	5.36	160	15.04	15.30	245	61.76	63.04
75	5.36	5.44	161	15.30	15.56	246	63.04	64.32
76	5.44	5.52	162	15.56	15.82	247	64.32	65.60
77	5.52	5.60	163	15.82	16.08	248	65.60	66.88
78	5.60	5.68	164	16.08	16.34	249	66.88	68.16
79	5.68	5.76	165	16.34	16.60	250	68.16	69.44
80	5.76	5.84	166	16.60	16.86	251	69.44	70.72
81	5.84	5.92	167	16.86	17.12	252	70.72	72.00
82	5.92	6.00	168	17.12	17.38	253	72.00	73.28
83	6.00	6.08	169	17.38	17.64	254	73.28	74.56
84	6.08	6.16	170	17.64	17.90	255	74.56	81.92
85	6.16	6.24						

The complete table can also be found in JMXi-IMOD-GRP structure, in extension JMXi-FBDS-MOD. The Xe instrumental background line which is used to verify the gain calibration of the instrument should appear in the channel 209.

4 Performance of the Instrument

The properties described in the following have been derived in part from pre-flight calibration measurements and modeling and in part from calibration observations in orbit. JEM-X has had major changes of its configuration since launch, the most important being a reduction of the high voltages reducing the gas gain from 1500 down to 500 for JEM-X 1 and to 750 for JEM-X 2. These changes also affect the instrument performance.

4.1 Position Resolution

The position determination accuracy depends on the number of source and background counts and on the position in the Field of View (FOV). Off-axis the collimator blocks some of the source photons and beyond the fully coded FOV (FCFOV) the coding is incomplete.

Figure 6 shows the position resolution for a source on axis as function of energy. The cause of the degradation below 10 keV is the signal-to-noise ratio of the front-end electronics. The energy dependence of the position resolution above 10 keV is determined by the increase of the primary photoelectron range with energy. The position resolution is slightly degraded compared to the ground calibrations.
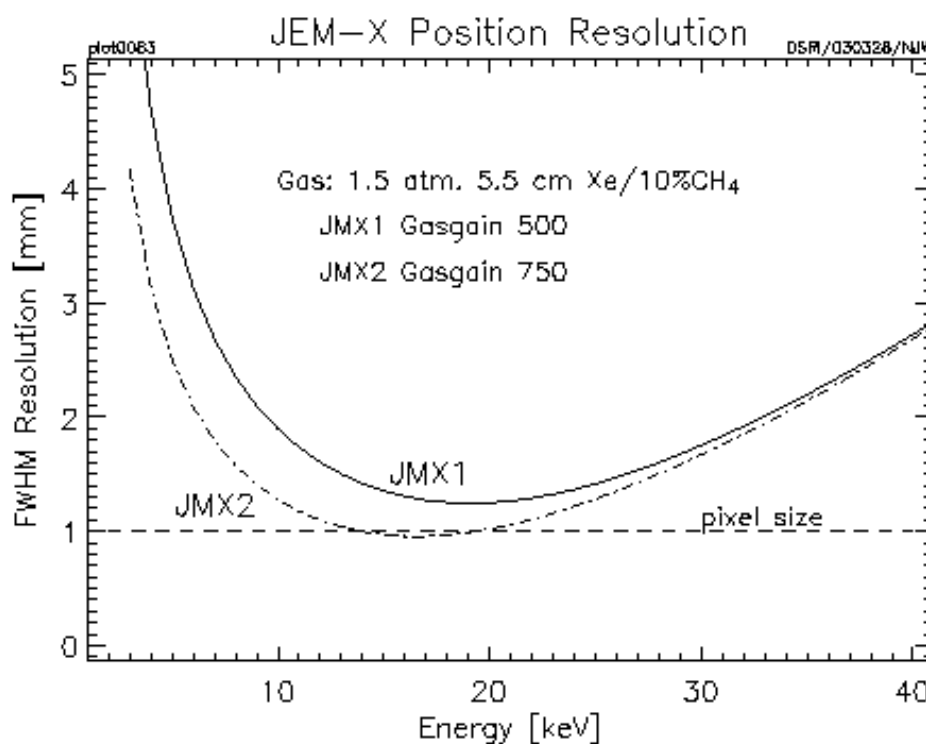
Figure 6: The calculated position resolution in the JEM-X 1 and JEM-X 2 detectors as a function of energy valid after 2002-11-09 (JEM-X 1) and after 2002-11-12 (JEM-X 2).

4.2 Energy Resolution

The energy resolution has been determined in the laboratory as

$$\Delta E/E(FWHM) = 0.40 \cdot \sqrt{1/E[\text{keV}] + 1/120 \text{ keV}}.$$

This value has not been significantly affected by the gain change and the corresponding slight rise in importance of the electronic noise.

4.3 Background

The local radiation environment is mainly produced by two components: the diffuse X-ray background (DXB) and cosmic rays (CR). Most of the latter are rejected on-board with a combination of pulse height, pulse shape, anti-coincidence and "footprint" evaluation techniques. These techniques allow a particle rejection efficiency of >99.9% with carefully tuned selection parameters. This high rate of background rejection has ensured that there has been no significant increase in background events in the telemetry despite the steady increase in the CR rate at Solar minimum.

Figure 7 shows an actual background spectrum which is composed of the diffuse X-ray background, instrumental background due to the interactions with cosmic rays and three strong instrumental lines due to the cooper and molybdenum in the collimator (8.04 keV and 17.4 keV) and Xe fluorescence from the detector gas at 29.6 keV.
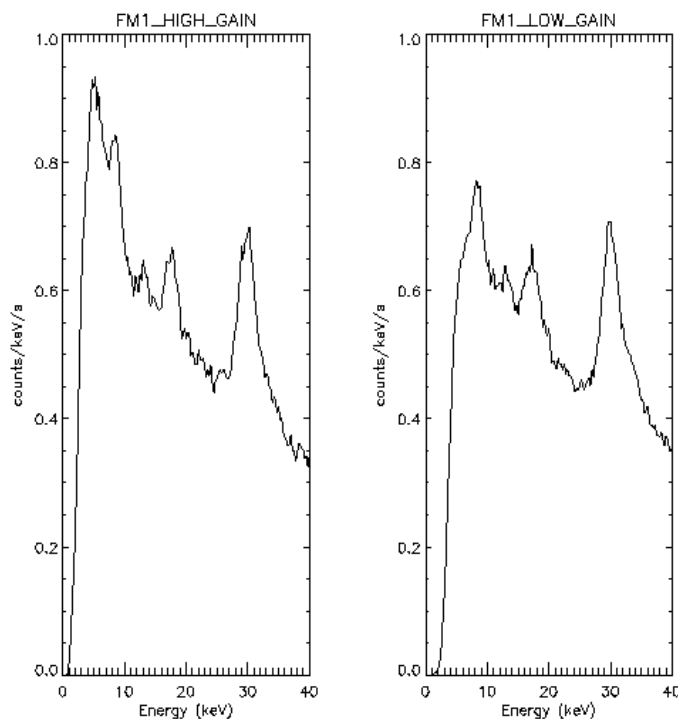
Figure 7: Empty field background spectrum measured with the nominal detector gain of 1500 (left) compared to the background spectrum with the reduced gain of 500 (right). After these measurements the rejection criteria have been adjusted (2003-02-25), but no blank fields have been observed for a longer period since then. The background has increased with about 10-15% at higher energies and with 20-30% below 10 keV after the adjustment.

4.4 Sensitivity

The sensitivity achieved for source detection and flux determination also depends on the performance of the deconvolution software. Figure 8 shows the 3σ detection limit as a function of observation time.

The changes in gas gain and corresponding changes in signal patterns led to a large fraction of events being classified as background and rejected on-board until new selection criteria could be determined and uploaded (2003-03-25, revision 45). Even with the new optimized selection criteria the detector sensitivity below 5 keV is reduced.
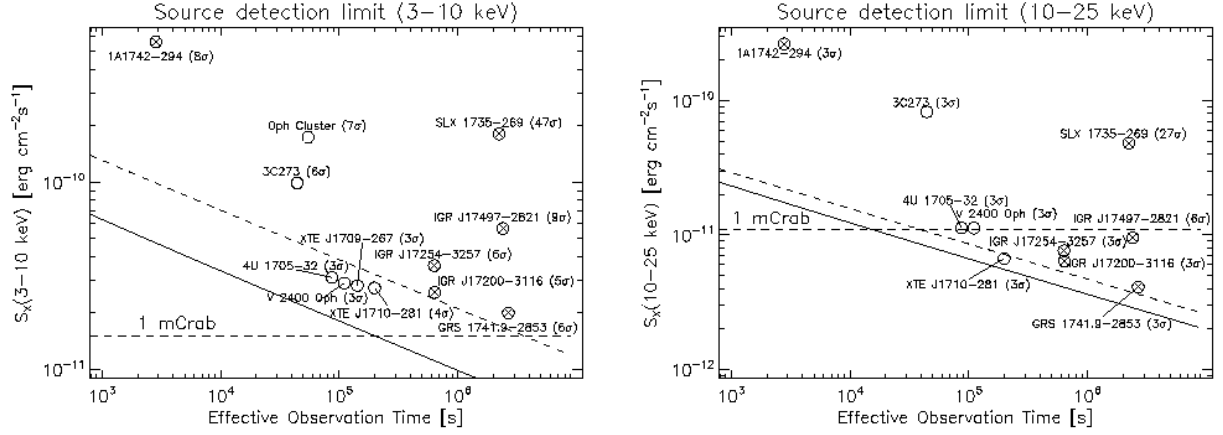
Figure 8: Source detection capabilities in the 3 to 10 keV (resp. 10 to 25 keV) band as function of effective accumulated observation (exposure) time in JEM-X mosaic images corrected for dead time, grey filter and vignetting effects. The thick solid curve is obtained from simulations where an isolated source must be detected at 3σ in the deconvolved image. The dashed line represents the case where there are additional sources in the field of view giving a background corresponding to a total of 1 Crab. Examples of actual observations are given: the source 3C 273 and the other empty circles are instances of isolated sources, while the crossed circles represent sources observed in the crowded Galactic Centre region. The σ-values given in parentheses are obtained from a measure of the highest source pixel in significance mosaic maps with default pixel size (1.5 arcmin).

Part II

Data Analysis

5 Overview

The scientific analysis performed by the user on the data collected by the three high-energy instruments on-board *INTEGRAL* has a lot of commonality, despite the various differences in detail. In a certain step, for example, events are corrected for instrumental fingerprints, in another one events are binned into detector maps, and in yet another step sky images are derived by image deconvolution.

In order to make this more transparent for scientists working with data from several instruments, so-called *Analysis Levels* were identified by the ISDC and designated with unique labels. The order of these levels, the detailed processing and the details of the outputs may differ across instruments, but in general, a given level will mean similar tasks and similar outputs for JEM-X, IBIS, and SPI. The list of all levels is given in the Introduction to the *INTEGRAL* Data Analysis [1]. For JEM-X the following levels have been defined:

Table 4: Overview of the JEM-X Scientific Analysis Levels.

Tasks	Description
COR	Data Correction
GTI	Good Time definition and handling
DEAD	Dead Time derivation
CAT_I	Catalogue source selection for Imaging
BIN_I	Event binning for Imaging
IMA	Image reconstruction, source flux determination
SPE	Source spectra and response extraction (for XSPEC)
LCR	Source light curves extraction
BIN_S	Event binning for Spectral Analysis
BIN_T	Event binning for Timing Analysis
IMA2	Creation of mosaic images and summary on sources found

Figure 9 shows the Scientific Analysis overview. The details of each step are briefly discussed below.

COR – Data Correction (j_correction)

Corrects science data for instrumental fingerprints such as energy and position corrections, as well as flagging events of dubious quality. Look up tables of pre-flight corrections are used, as well as tables of in-flight calibrations determined by offline analysis of science data, calibration spectra, and instrumental background lines. Dynamic determination of known transient problems (e.g. hotspots on the detector) is also done in this level. The majority of calibration tables are stored in the Instrument Model group, JMXi-IMOD-GRP (with i = 1 and 2 for JEM-X1 and JEM-X2, respectively), but the offline gain history Instrument Characteristics tables are stored separately in JMXi-GAIN-OCL data structures. The latter are also located automatically by the OSA software just like the IMOD group.

GTI – Good Time Handling (j_gti)

Good Time Intervals (GTIs) are used in the analysis to select only those data taken while the detector was considered to work correctly. The corresponding data structures consist simply of a list of start and stop times of those intervals considered "good". Usually, these intervals are generated based on the following data:

1. Housekeeping parameters which are compared with pre-set limits.
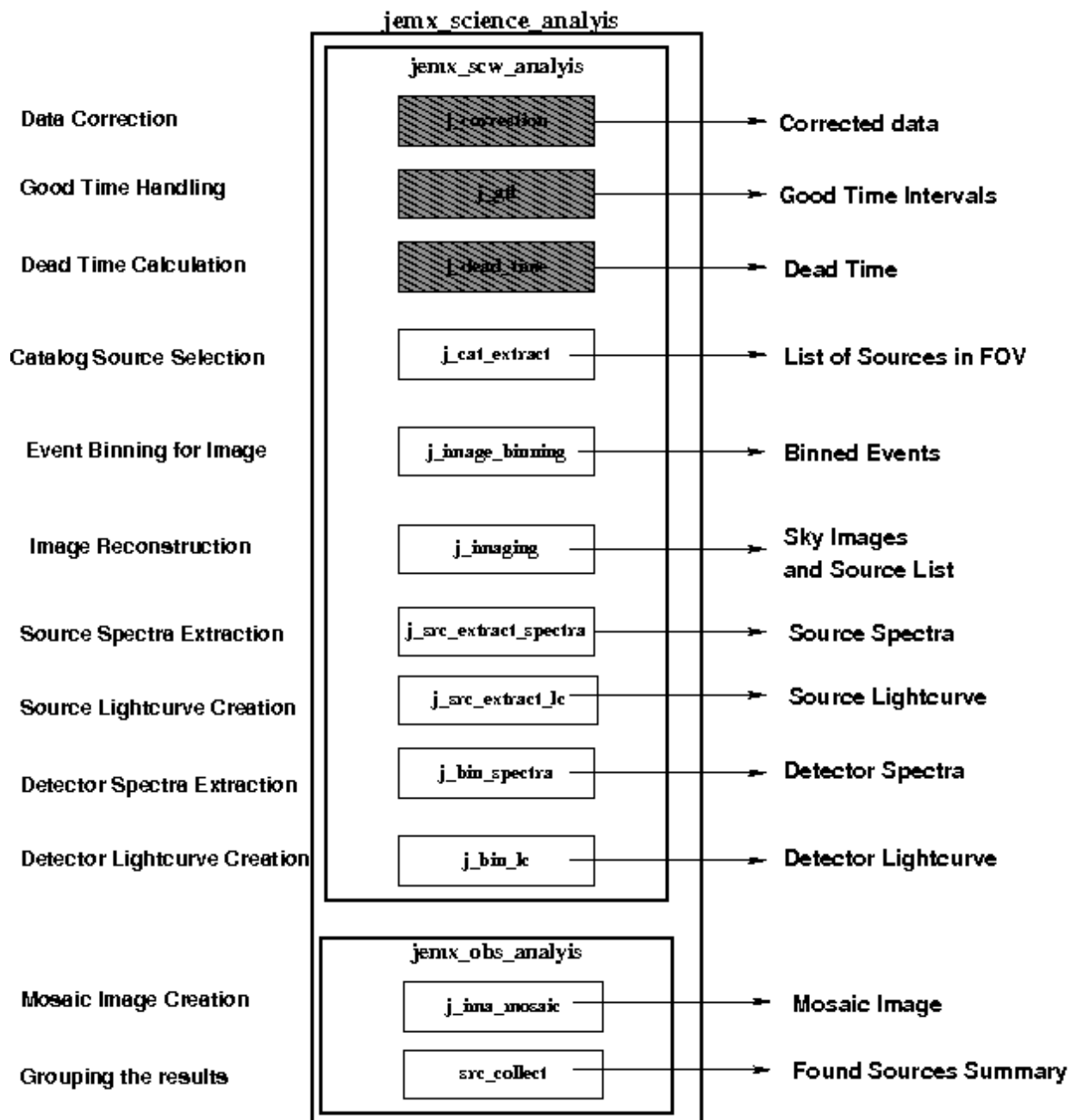
Figure 9: Decomposition of the *jemx_science_analysis* script.

2. The satellite stability as recorded in the attitude data.

3. Gaps (lost packets) in the telemetry flow.

In addition, this step excludes by default periods when the instrument configuration is not adapted to the production of scientific works, either because of hardware problems or because of intentional modifications of the instrument configurations for the purpose of testing and calibrations. These periods are marked as "bad time intervals" in the Instrument Characteristics data.

DEAD – Dead and Live Times (j_dead_time)

For each 8 second onboard polling cycle, this level calculates the dead time during which photons are lost due to finite read in time of registers, event processing time, grey filter losses, buffer losses and double event triggers.

CAT_I – Catalogue Source Selection (j_cat_extract)

Selects a list of known sources from the given catalogue. Creates a source data structure, containing source location and expected flux values.

BIN_I – Event Binning for Imaging (j_image_binning)

Defines the energy bins to be used for imaging, selects good events within the GTI, and creates shadowgrams. Works only on FULL and REST data (see Table 2).

IMA – Image Reconstruction (j_imaging)

Generates sky images and performs search for significant sources. If sources are detected, a new source data structure is created, including part of the information from the input catalogue concerning the identified sources. Works only on FULL and REST data (see Table 2)

SPE – Spectra Extraction (j_src_extract_spectra)

Extracts spectra for individual sources found at IMA step, and produces the specific response files (ARFs) needed for spectral fitting with the XSPEC package. Works only on FULL data (see Table 2).

LCR – Extract Source Light Curves (j_src_extract_lc)

Produces light curves for individual sources. Works only on FULL data (see Table 2)

BIN_S – Event Binning for Spectral Analysis (j_bin_spectra)

Creates detector spectra, i.e spectra of all events recorded within the GTI are corrected for greyfilter, ontime and deadtime. A series of spectra resolved in time or phase over a given period can be produced.

BIN_T – Creates Detector Light Curves (j_bin_lc)

Creates binned lightcurves for entire detector area.

IMA2 – Mosaic Image Creation (j_ima_mosaic, src_collect)

Generates mosaic sky images and creates the list of all found sources. Works only on FULL and REST data (see Table 2)

Since October 18, 2004, all public *INTEGRAL* data are available including already the correction step, and also the instrumental GTI and deadtime handling have been already performed at the science window level. This allows to speed up the scientific analysis of JEM-X data as there is no need to redo the COR, GTI and DEAD levels, but you can directly start JEM-X analysis from the CAT_I level.

It is however recommended that users run the science analysis from the COR level onwards, especially after downloading new software, and IMOD/IC files. This will undoubtedly give better results than the archived data. Archived data necessarily fossilize our understanding of the instruments as it was at the time of the archival processing and can therefore be several years out of date since our knowledge of the instruments, and the software to process the data is still improving.

6 Cookbook for JEM-X analysis

The Cookbook describes how to use the OSA JEM-X software. It covers the following steps:

- Setting up the analysis data
- Setting the environment
- Launching the analysis
- Interpreting the results

We assume that you have already successfully installed the ISDC Off-line Scientific Analysis (OSA) Software version 10.0 (The directory in which OSA is installed is referred later as the ISDC_ENV directory). If this is not the case, look at the "Installation Guide for the *INTEGRAL* Off-line Scientific Analysis" [4] for detailed help.

6.1 Setting Up the Analysis Data

In order to set up a proper environment, you first have to create an analysis directory (e.g `jmx_data_rep`) and "cd" into it:

```
mkdir jmx_data_rep
cd jmx_data_rep
setenv REP_BASE_PROD $PWD
```

This working directory will be referred to as the `REP_BASE_PROD` directory in the following. All the data required in your analysis should then be available from this "top" directory, and they should be organized as follows:

- **scw/** : data produced by the instruments (e.g., event tables) cut and stored by ScWs
- **aux/** : auxiliary data provided by the ground segment (e.g., time correlations)
- **cat/** : ISDC reference catalogue
- **ic/** : Instrument Characteristics (IC), such as calibration data and instrument responses
- **idx/** : set of indices used by the software to select appropriate IC data

The JEM-X example presented below is based on observations of the Crab from Revolution 102.

Part of the required data may already be available on your system[1]. In that case, you can either copy these data to the relevant working directory, or better, create soft links as follows

```
ln -s directory_of_ic_files_installation__/ic ic
ln -s directory_of_idx_files_installation__/idx idx
ln -s directory_of_cat_installation__/cat cat
ln -s directory_of_local_archive__/scw scw
ln -s directory_of_local_archive__/aux aux
```

---

[1]For installation of the Instrument Characteristics files (OSA_IC package) and the Reference Catalogues (OSA_CAT package), follow the instructions given in "Installation Guide for the *INTEGRAL* Data Analysis System" [4].

JEM-X calibration files are continuously produced by the JEM-X Team for new revolutions. To be sure to have all the latest calibrations, update your copy of the Instrument Characteristics each time you want to analyse new data, using the rsync command:

```
rsync -Lzrtv isdcarc.unige.ch::arc/FTP/arc_distr/ic_tree/prod/  directory_of_ic_files_installation__
```

This command will download the Instrument Characteristics files (`ic` and `idx` directories) to your `directory_of_ic_files_installation__`.

Then, just create a file 'jmx.lst' containing the 2 lines:

```
scw/0102/010200210010.001/swg.fits[1]
scw/0102/010200220010.001/swg.fits[1]
```

which is the list of ScWs you want to analyse (technically, we call them DOLs - *Data Object Locators* -, i.e. a specified extension in a given FITS file). [2]

This file name 'jmx.lst' will be used later as an argument for the og_create program (see section 6.5).

Alternatively, if you do not have any of the above data on your local system, or if you do not have a local archive with the scw/ and the aux/ branch available, follow the next section instructions to download data from the ISDC WWW site.

6.2 Downloading Your Data

To retrieve the required analysis data from the archive, go to the following URL:
http://www.isdc.unige.ch/integral/archive.

You will reach the W3Browse web page which will allow you to build a list of Science Windows (ScWs) needed to create your observation group for OSA.

- Type the name of the object (Crab) in the 'Object Name Or Coordinates:' field.

- Click on the 'More Options' button at the top or at the bottom of the web page.

- Deselect the 'All' checkbox at the top of the Catalog table, and select the 'SCW - Science Window Data' one.

- Press the 'Specify Additional Parameters' button at the bottom of the web page.

- Deselect the 'View All' checkbox (press twice on it) at the top of the Query table.

- Select 'scw_id' and put the value '0102*' (without the quotes) to specify all Scws from Revolution 102.

- Select 'scw_type' and put the value 'pointing' (without the quotes), or simply 'po*' to get only pointings.

- Press the 'Start Search' button at the bottom of the web page. At this point, you should be at the Query Results page with all the Scws available for revolution 102.

- Sort the 'Scw_id' column by clicking on the left arrow below the column name. You can then select the two Scws we are interested in, i.e 010200210010 and 010200220010.

Press the '**Save SCW list** for the creation of Observation Groups' button at the bottom of that table and save the file with the name 'jmx.lst'. The file name 'jmx.lst' will be used later as an argument for the `og_create` program (see section 6.5). In this file, you should find the 2 lines:

---

[2]When an analysis script asks you to specify the DOL, you should specify the path of the corresponding FITS file, and the corresponding name or number of the data structure in square brackets(do not forget that numbering starts with 0!). See more details in the Introduction to the INTEGRAL Data Analysis [1].

```
scw/0102/010200210010.001/swg.fits[1]
scw/0102/010200220010.001/swg.fits[1]
```

You should then download the data pressing the 'Request data products for selected rows' button. In the 'Public Data Distribution Form', provide your e-mail address and press the 'Submit Request' button. You will be e-mailed the required script to get your data and the instructions for the settings of the IC files and the reference catalogue. Just follow these instructions.

6.3 Setting the environment

Before you run any OSA software, you must also set your environment correctly.

The commands below apply to the `csh` family of shells (i.e `csh` and `tcsh`) and should be adapted for other families of shells[3].

In all cases, you have to set the `REP_BASE_PROD` variable to the location where you perform your analysis (e.g the directory `jmx_data_rep`). Thus, type:

```
setenv REP_BASE_PROD $PWD
```

Then, if not already set by default by your system administrator, you should set some environment variables and type:

```
setenv ISDC_ENV directory_of_OSA_sw_installation
setenv ISDC_REF_CAT $REP_BASE_PROD/cat/hec/gnrl_refr_cat_0031.fits\[1]
source $ISDC_ENV/bin/isdc_init_env.csh
```

The idea is to:

- set `ISDC_ENV` to the location where OSA is installed

- set `ISDC_REF_CAT` to the DOL of the ISDC Reference Catalog

- run the OSA set-up script (`isdc_init_env.csh`) which initializes further environment variables relative to `ISDC_ENV`.

Besides these mandatory settings, there are two optional environment variables (COMMONLOGFILE and COMMONSCRIPT) which are useful.

- By default, the software logs messages to the screen (STDOUT). To have also these messages in a file (i.e common_log.txt) and make the output chattier[4], use the command:

  ```
  setenv COMMONLOGFILE +common_log.txt
  ```

- When you launch the analysis, the Graphical User Interface (GUI) is launched. As your level of expertise with the software increases, you may wish to not have the GUIs pop up when you launch your analysis. In this case, the variable COMMONSCRIPT must be defined:

  ```
  setenv COMMONSCRIPT 1
  ```

---

[3]If the setenv command fails with a message like:'setenv: command not found' or 'setenv: not found', then you are probably using the sh family. In that case, please replace the command 'setenv my_variable my_value' by the following command sequence 'my_variable=my_value ; export my_variable'
In the same manner, replace the command 'source my_script' by the following command '. my_script' (the '.' is not a typo!).

[4]For example, the exit status of the program will now appear.

When the GUI is disabled, parameters can be specified on the command line typing `'name = value'` after the script name.

To revert and have the GUI again, unset the variable:

```
unsetenv COMMONSCRIPT
```

6.4   Useful to know!

In this section we report some general information that might be useful when running OSA software. Most of these information can be found also in the IBIS Cookbook[5].

- How do I get some help with the executables?
  All the available help files are stored under $ISDC_ENV/help. To visualize a help file interactively type `tool_name --h` once your environment is set (i.e. the command *which tool_name* should return the path to it).

- Where are the parameter files and how can I modify them?
  All the available executables for the analysis of *INTEGRAL* data are under $ISDC_ENV/bin. The corresponding parameter files are stored under $ISDC_ENV/pfiles/*.par. The first time you launch a script, the system will copy the specific `tool.par` from $ISDC_ENV/pfiles/ to a local directory (/user_name/pfiles/). The parameter file in the local directory is the one used for the analysis and is the one you can modify. If this parameter file is missing (e.g. you have deleted it), the system will just re-copy it from $ISDC_ENV/pfiles/ as soon as you launch the script again. The system knows what to copy from where thanks to the $PFILES environment variable that is also used in FTOOLS (http://heasarc.gsfc.nasa.gov/ftools/). Each parameter is characterized with a letter that specifies the parameter type, i.e:
  "q" (query) parameters are always asked to the user
  "h" (hidden) parameters are not asked to the user and the indicated value is used
  "l" (learned) parameters are updated with the user's value during the use of the program.
  The GUI is a fast and easy way to change the parameters, see also the explanation at the end of this section.

- What are groups and indices?
  The ISDC software makes extensive use of groups and indices. While it is not necessary to grasp all the details of these concepts, a basic understanding is certainly quite useful.

  As implied by their names, "groups" make possible the grouping of data that are logically connected. Groups can be seen as a kind of data container, not completely unlike standard directories. At ISDC, we create separate groups for each pointing, in which we store the many different data types produced by INTEGRAL and its instruments. The user then only has to care about one file, the group, many tens of files being silently included. Several pointings (the "Science Window Groups") can be arbitrarily grouped into bigger groups (the "Observation Group") to select data very efficiently according to the user's needs.

  Indices are a special kind of groups, which differ only in the fact that all the the data sets they contain are similar and that the indices know the properties of the data sets they contain. Indices are a kind of poor man's database. For example, an imaging program creates several images of different types (flux map, significance map,...) in different energy bands. These images are stored in an index, in which the image type and energy band information is replicated. ISDC software is then able to select very efficiently the needed images. The user can also make use of the indices; just by looking at the index (for instance using "fv"), the user can identify immediately the content of each image.

- Why do I need "[1]" after a FITS file name?
  A FITS file can have many extensions and sometimes it is necessary to specify as input to a given parameter not the file name alone (`file.fits`) but the extension too (`file.fits[1]`, or `file.fits[2]`,

---

[5]The IBIS Cookbook is available at the URL http://www.isdc.unige.ch/integral/analysis

etc). The file name with a specified data structure (extension) is called DOL (Data Object Locator). When you modify the parameter file itself (see above) or use the GUI, the extension will be correctly interpreted in the `file.fits[1]` case. On the command line though, the normal CFITSIO and FTOOLS rules apply, i.e. you have to specify it as one of the following
`file.fits\[1]`
`file.fits+1`
`"file.fits[1]"`.
Note that if no extension is specified explicitly then the first one ([1]) will be used by default.

- What are the general functionalities of the GUI?
  When you launch the analysis, by default the GUI is launched, providing an opportunity to set the values of all desired parameters, see Figure 10. On the right side of the panel you see the following buttons:

  - `Save as` – With the "Save As" - button a file is created. This file stores all parameters as they are currently defined in the GUI as a command line script. This file is an executable one and calling it from the command line will launch the instrument analysis program with the parameters as they were defined in the GUI.
  - `Load` With the "Load" - button a previously saved file (see "Save As") can be read and the GUI will update all parameters with the values as they are defined in the loaded file.
  - `Reset` With the "Reset" - button the parameters in the GUI will be reset to the default values as they are defined in the parameter file of the instrument analysis program and stored in the $ISDC_ENV/pfiles directory.
  - `Run` With "Run" - button the analysis is launched.
  - `Quit` With "Quit" - button you quit the program without analysis launch.
  - `Help` With "Help" - button the help file of the main script is opened in a separate window.
  - `hidden` With the "hidden" - button you have an access to the hidden parameters with values defined by the instrumental teams. Change them with care!

  The environment variable `COMMONSCRIPT` is used to disable/enable the GUI (see section 6.3).

6.5 A Walk Through the JEM-X Analysis

After setting up the data and the environment, you are ready to call the analysis script on the Crab region observations defined above and stored in the jmx.lst file.

Firstly, create an Observation Group (see the description of the executable *og_create* in the "Toolbox" and "Data Analysis" sections of the Introduction to the *INTEGRAL* Data Analysis [1]):

```
og_create idxSwg=jmx.lst ogid=crab baseDir="./" instrument=JMX2
```

As a result, the directory `$REP_BASE_PROD/obs/crab` will be created[6]. It contains the files `og_jmx2.fits` and `swg_idx_jmx2.fits` as well as the subdirectory `scw` necessary for the analysis. In the latest version of og_create, the file indicated in idxSwg is automatically interpreted as a fits file when the name includes a "+" or "[" sign.

6.6 Examples of Image Creation

Now you can go to the directory created with *og_create* and start the analysis

---

[6]To create the structure for both JemX units at the same time, it is possible to call og_create only once, with the parameter `instrument=JMX1,JMX2`.

```
cd obs/crab
jemx_science_analysis startLevel="COR" endLevel="IMA" nChanBins=-4 jemxNum=2
```

The above command launches the analysis which will run from the Correction step (`startLevel="COR"`) up to the image creation level (`endLevel="IMA"`). It is important to specify that we are interested in the second of JEM-X instruments: `jemxNum=2`. `nChanBins` parameter specifies the energy binning (see section 6.7.2 for details).

At the beginning the script launches the GUI (Fig. 10) and you can check the parameter settings (the full
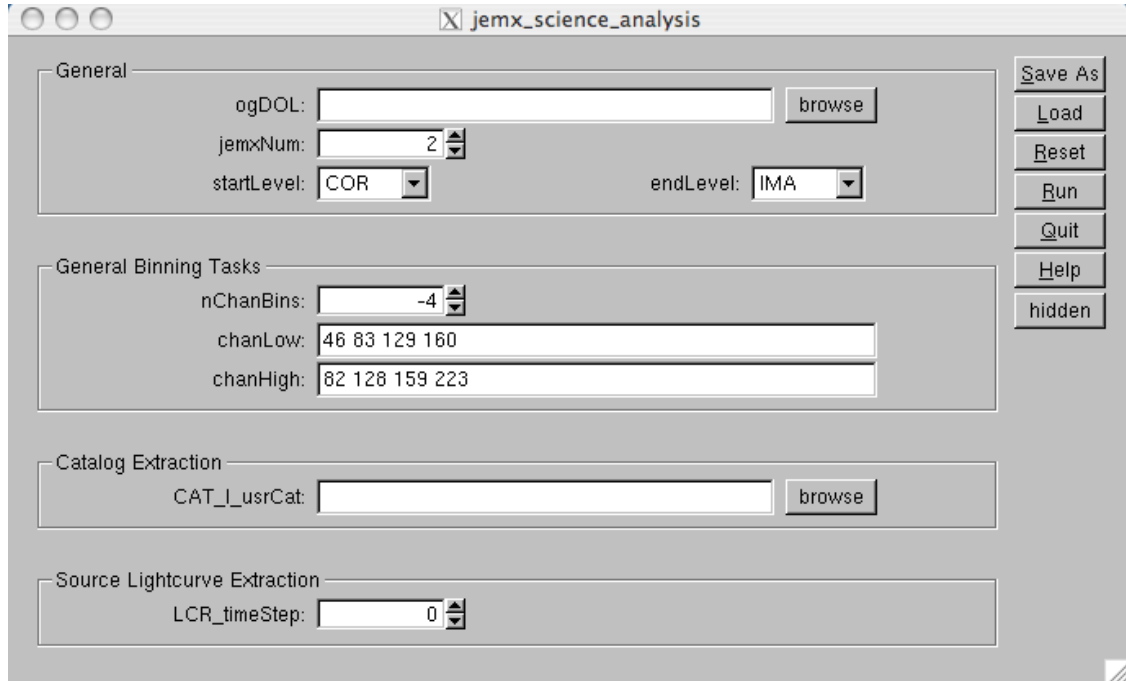
Figure 10: GUI for JEM-X science analysis.

list of the parameters is given in Table 60). Only the most important parameters (shown in bold in Table 60) appear within the main panel of GUI. To access the other "hidden" parameters click on the button "hidden" on the right side of the panel.

The behaviour of the IMA step has changed between OSA 7 and OSA 8. This is because fluxes have now to be extracted using the IMA step, in order to profit from the vast improvement in the modelling of the JEM-X instruments in OSA 8. Therefore, the normal behaviour is that IMA does not produce images for the binning specified under "General Binning Tasks".

By default, *jemx_science_analysis* creates images in the 3 energy ranges: 3-7 keV, 7-11 keV and 11-20 keV, which corresponds to the images used for optimal source detection. While this can be changed by the user, this should not be modified in normal analyses. To generate images in arbitrary energy bands, see section 6.6.7.

In the upper frame of the front panel called "General" you can choose at which level you want to start and stop the script execution. In the Overview chapter you have seen that there are different processing levels of the analysis. You can choose to run only some of them. The default settings of the *jemx_science_analysis* script are
  `startLevel="COR"`   start the script at COR level,
  `endLevel="IMA2"`   stop the script at IMA2 level.
It is advisable always to start with level `COR`. This will allow the processing of the data using the latest knowledge of the calibration of the instrument.

If you want to skip some levels, click on the "hidden" button on the right of the GUI panel to access the whole set of *jemx_science_analysis* parameters. In the frame "General" you find the `skipLevels` parameter. However, be always careful while setting this parameter – levels often depend on the previous ones, so make sure that your selection makes sense. Another useful hidden parameter `IMA_skyImagesOut` in the `IMA` section enables you to choose the types of images which you want to output[7]. The checkbox `IMA_detImagesOut` enables you to output also the images in the pre-defined energy bands used by the *j_ima_iros* for the source search. This option is not recommended if you want to extract a spectrum from the mosaic image later.

In the middle of the GUI front panel you have a possibility to choose a "user input catalog" (the parameter `CAT_I_usrCat`). At the moment you can leave it empty (the software will use the general *INTEGRAL* source catalog for the analysis). However, for the correct extraction of spectra and lightcurves of the sources it is recommended to create a "user catalog" with the positions of the sources for which you plan to extract the spectra and/or the lightcurves. We will come back to this in the following sections (and sect. 7.5).

Once you are satisfied with the settings, save them by pressing the "Save As" button at the front panel of GUI and then press "Run" to start the data reduction.

6.6.1 Results from the Image Step

After *jemx_science_analysis* finishes its operation, the results are stored separately for each ScW of the observation group. They are located in the subdirectories named `scw/RRRRPPPPSSSF.001/` (where `RRRRPPPPSSSF` is the number of the ScW).

Go to one of these directories and have a look at the files

```
cd scw/010200210010.001/
ls
```

This is the output from all the processing steps done by the script.

The output image is `jmx2_sky_ima.fits`. You can check it using e.g. *fv*:

```
fv jmx2_sky_ima.fits
```

You will find that this file contains 7 extensions: the index of all images, 3 cleaned sky images (`RECONSTRUCTED` type), and 3 variance maps, one for each of the 3 selected energy bands (see Fig. 11).

In the file `jmx2_srcl_res.fits` you find a list of all found sources, the energy bands, and the derived flux values, and in the file `jmx2_srcl_cat.fits` the list of the sources in the input catalog. You can see that most of the catalog sources were not found, as they are too weak. When you run the lightcurve and spectra extraction steps the results would be produced for all sources listed in `jmx2_srcl_res.fits`.

Please note that with OSA10 the count rates are scaled to one cm^2, while until OSA9 the count rates were scaled to one dm^2.

There is a nice way to locate the found sources as well as the catalog sources on the sky image. To do it use the utility *cat2ds9*:

```
cat2ds9 jmx2_srcl_res.fits\[1] found.reg symbol=box color=red
cat2ds9 jmx2_srcl_cat.fits\[1] cat.reg symbol=circle color=white
```

(to find out more about this program type `cat2ds9 --h` in the command line). With the help of the above two commands the two files `found.reg` and `cat.reg` are created. They contain the lists of all the found sources and all the catalog sources, respectively.

---

[7]Several types of images may be produced: the vignetting-corrected intensity image, called `RECONSTRUCTED`, the variance image `VARIANCE`, `RECTIFIED` (raw intensity image), `RESIDUAL` (residuals left after removing all found sources) and `EXPOSURE` (the exposure map).
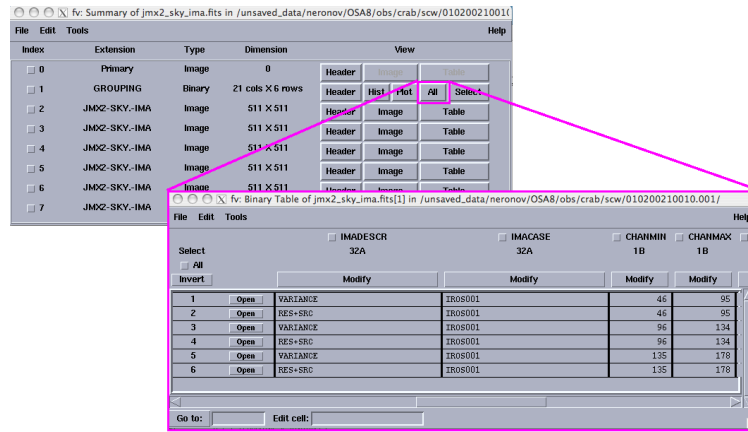
Figure 11: The content of `jmx2_sky_ima.fits` file.
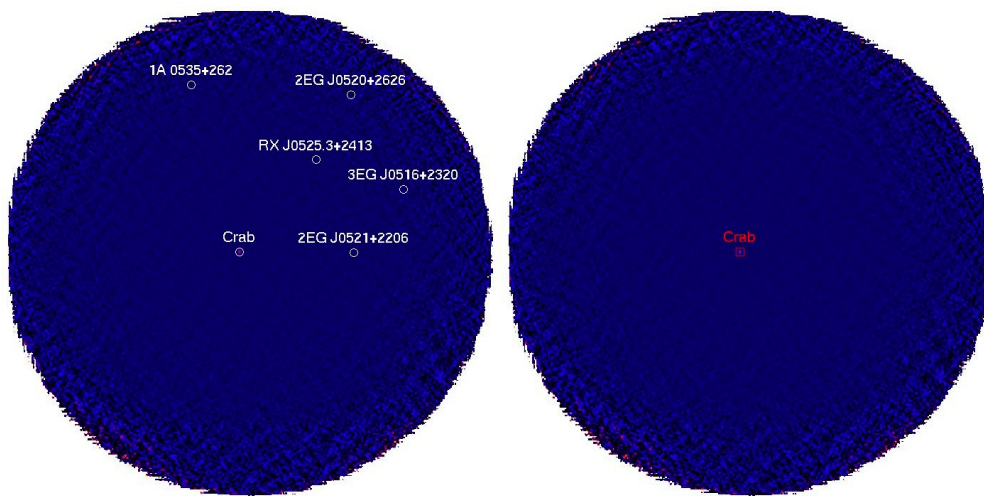
Figure 12: The image of Crab region. Catalog sources in the FOV are shown with white circles. The only found source (Crab) is shown with a red box.

With the help of *ds9* viewer you can display the sky images in any of the three energy bands. For example, to look at the 7–11 keV image which is contained in the 5th extension of the `jmx2_sky_ima.fits` file you can type

```
ds9 jmx2_sky_ima.fits\[5]
```

You can load the region files `cat.reg` and `found.reg` created with *cat2ds9* by using the "Region" menu of *ds9* or directly from the command line:

```
ds9 jmx2_sky_ima.fits\[5] -region cat.reg
```

In Fig. 12, the left panel shows the Crab region in the second energy band (7–11 keV) with the catalog sources, and the right one – the same region with the found sources (Science Window 010200210010).

6.6.2   Weak Sources and Sources at the Edge of the FOV

The source acceptance is based on a positive detection in at least two energy bands. However, a strong source that only appears in a single energy band may also be accepted. Such an acceptance is based on the parameter 'IMA_detSigSingle' (Note, however, that it is NOT a statistical sigma). The default value is 12 which prevents most of the spurious detections to be accepted. However, if the aim is to find the weak sources the value can be reduced to e.g. 10. Still lower values will probably cause too many spurious sources. The number of detector pixels that contribute to the sky image decreases towards the edge of the FOV. That implies on one hand that spurious sources are more likely to occur at the edge and on the other hand that sources located there will be less reliable as is reflected in the relative error of the flux determination.

6.6.3   PIF-cleaning of images around strong sources

The image generating algorithm used by default in the JEM-X Scientific Analysis assigns equal weights to all active detector pixels. This allows to assign errors to the source fluxes with reasonable accuracy. For observations where the diffuse background is dominating the count rate this imaging technique appear as the best approach.

However, when bright sources are in the field of view and significantly increases the global count rate the situation changes. Due to the presence of the 25% open mask, the counts from a source will affect strongly at most a quarter of the detector pixels, but in those it may strongly dominate the pixel counts. Consequently, it could be advantageous to reduce the weight of pixels illuminated by a bright source when generating images intended for detection of weak sources. Since we are always operating with very few counts in the individual detector pixels the pixel counts cannot be used to determine the relevant weights, instead the weights are derived from the pixel illumination functions (PIF) used in the source fitting procedure. A new "PIF-weighted" image generation algorithm based on the above considerations have been implemented and is available in the new JEM-X Scientific Analysis package.

PIF imaging can be activated by including the string "PIF" in the IMA_skyImagesOut string accessible from the jemx_science_analysis GUI as one of the "hidden" parameters.
(Example: `IMA_skyImagesOut="PIF,RECONSTRUCTED,VARIANCE"`. Abbreviations as e.g. `"PIF,RECON,VARIA"` can also be used) .

The PIF-imaging technique improves the visibility of weak sources in crowded fields like the Galactic Centre or in the neighborhood of strong sources like the Crab or GRS 1915+105 (Figure 13).

NOTE HOWEVER, THAT PIF-IMAGES SHOULD NOT BE USED WITH "mosaic_spec"! FOR THE TIME BEING IT IS NOT RELIABLE TO EXTRACT SPECTRA WITH "mosaic_spec" (6.7.7) FOR STRONG SOURCES (SOURCES STRONG ENOUGH TO BE DETECTED IN SINGLE SCIENCE WINDOWS) FROM PIF IMAGES - OR FROM MOSAICS BASED ON PIF IMAGES.
THE FITTED FLUXES in "src_ls_res" SHOULD BE USED TO EXTRACT SPECTRA FOR STRONG SOURCES, THESE FLUXES ARE NOT AFFECTED BY THE PIF-IMAGING OPTION.

6.6.4   The Mosaic Image

The IMA2 level produces JEM-X mosaic images by combining all the individual *j_ima_iros* images from the different science windows gathered in the observation group. The combined images have longer exposure time. As a consequence, weaker sources which are not visible in single ScW may appear in the mosaic images.

In what follows we consider an example of a JEM-X mosaic of the Galactic Center region for the revolution 0053 in March 2003. You can browse through the *INTEGRAL* data archive and check that within this revolution the pointings which have the Galactic Center within the JEM-X2 FOV are

```
scw/0053/005300410010.001/swg.fits[1]
scw/0053/005300420010.001/swg.fits[1]
```
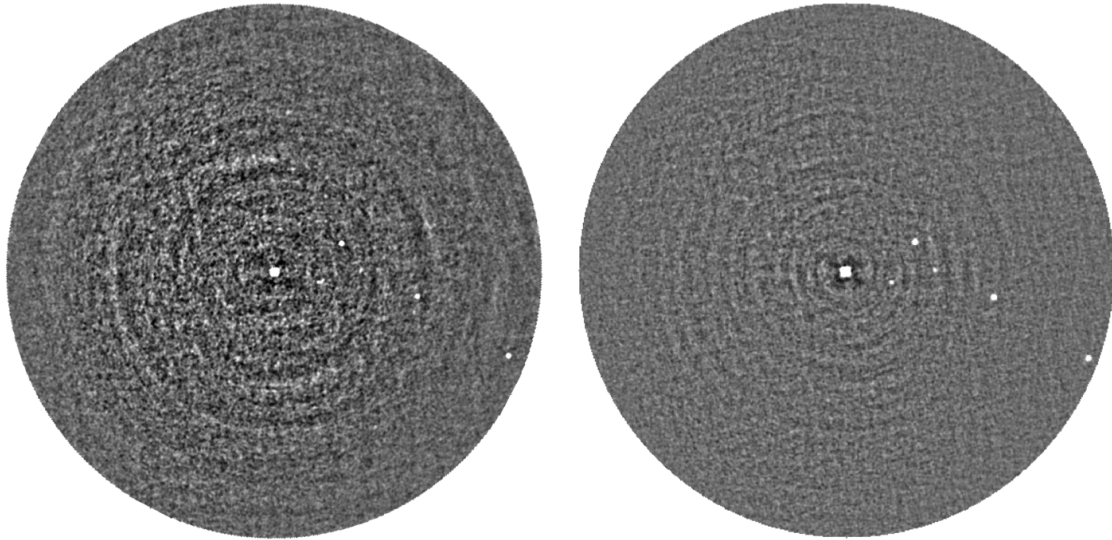
Figure 13: *Left*: Mosaic from conventional images centered on the strong source GRS 1915+105. *Right*: Mosaic from PIF images in the same region of the sky.

```
scw/0053/005300490010.001/swg.fits[1]
scw/0053/005300510010.001/swg.fits[1]
scw/0053/005300580010.001/swg.fits[1]
scw/0053/005300590010.001/swg.fits[1]
scw/0053/005300650010.001/swg.fits[1]
scw/0053/005300660010.001/swg.fits[1]
scw/0053/005300670010.001/swg.fits[1]
scw/0053/005300680010.001/swg.fits[1]
scw/0053/005300740010.001/swg.fits[1]
scw/0053/005300750010.001/swg.fits[1]
scw/0053/005300760010.001/swg.fits[1]
scw/0053/005300820010.001/swg.fits[1]
```

Save the above list to the file `mos.lst`. To produce the mosaic image of these pointings you have first to create the corresponding observation group `mos` using the *og_create* tool, as has been explained above, and run the *jemx_science_analysis* up to the `IMA` level.

```
cd $REP_BASE_PROD
og_create idxSwg=mos.lst ogid=mos baseDir="./" instrument=JMX2
cd obs/mos
jemx_science_analysis startLevel="COR" \
   endLevel="IMA" jemxNum=2
```

Next, to produce the mosaic from the intensity images for each energy band as obtained at the IMA level, you have to run the *jemx_science_analysis* script at `IMA2` level only:

```
jemx_science_analysis startLevel="IMA2" endLevel="IMA2" jemxNum=2
```

Again, do not forget to specify which of the JEM-X instruments you are interested in (`jemxNum=2` in our case). By default, "intensity" (RECONSTRUCTED), "variance", "significance" and "exposure" mosaic images will be produced.

The same result can be obtained calling `jemx_science_analysis` only once, from `startLevel="COR"` to

Figure 14: The content of `jmx2_obs_res.fits` file.

`endLevel="IMA2"`, eventually skipping the intermediate levels with the command `skipLevels="LCR, SPE, BIN_S, BIN_T"`.

Apart from the mosaic images, the output of the IMA2 level contains a collection of the results from the individual science windows which is contained in the file `jmx2_obs_res.fits`. Its content is shown in Fig. 14. With the help of *cat2ds9* command you can produce a region file `found.reg` to locate these sources at the mosaic image:

```
cat2ds9 jmx2_obs_res.fits\[1] found.reg symbol=circle color=white
```

Note that since the same sources can be found in many ScWs you can have one and the same source repeated several times in the resulting region file.

You can look at the content of the resulting mosaic images contained in the file `jmx2_mosa_ima.fits` with *fv* and display them with *ds9* exactly as you did with the images from individual ScWs (see Fig. 15 for the example of image in 7–11 keV energy band). In this figure you can see the sources found in single ScW analysis shown with white circles. One can see that two additional sources, which were not detected in the single ScWs, appear in the mosaic image (the sources shown by the green crosses).

If you are interested only in a particular region of the mosaic you can "zoom" on a given position in the sky running *jemx_science_analysis* with additional parameters `IMA2_RAcenter, IMA2_DECcenter` and `IMA2_diameter` which will specify the position of the center and the diameter (in degrees) of the resulting mosaic image. To do so, first move the existing images[8]:

```
mv jmx2_mosa_ima.fits jmx2_mosa_ima_original.fits
mv jmx2_obs_res.fits jmx2_obs_res_original.fits
```

Remember that the images have to be also removed from the observation group. This can be done by the following command:

---

[8]For more details on how to re-run the analysis see sections 7.3
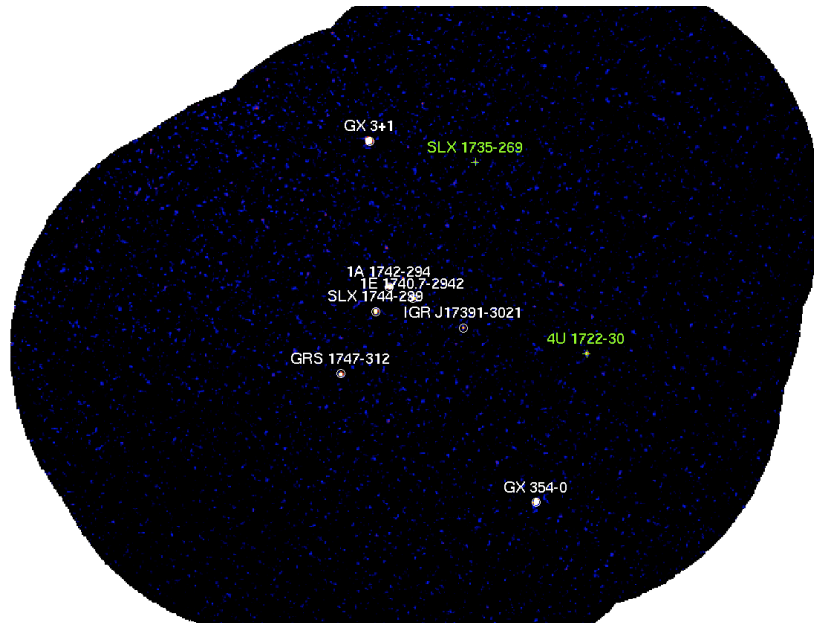
Figure 15: The mosaic image of the Galactic Center region for revolution 0053 in the 7–11 keV energy band (signifcance map).

```
dal_clean og_jmx2.fits+1
```

Now re-run the analysis script:

```
jemx_science_analysis startLevel="IMA2" endLevel="IMA2" jemxNum=2 \
    IMA2_diameter=5.0 IMA2_RAcenter=266.4 IMA2_DECcenter=-29.0
```

(we have chosen to center the image on the Galactic Center position here).

If you want to produce a mosaic image only for a specific energy band you can pass the minimal and maximal energies of the selected energy band to the *jemx_science_analysis* through the parameters `IMA2_eminSelect` and `IMA2_emaxSelect`. Note that the energies have to be the same as defined previously in `chanLow` and `chanHigh`.

To get the largest possible output mosaic in equatorial coordinates the parameters "radiusSelect" and "diameter" must both be set to -1. A better way, available with OSA v.10.0, is to use the Aitoff-Hammer projection (in galactic coordinates) by setting the option AITproj. The latter enables the mosaicking of large parts of the sky, such as for the Galactic Plane Scans, without distortion of the map (an example is in Fig. 16). This new feature can be activated setting the parameter `IMA2_AITproj="yes"`. The command should be therefore as follows:

```
jemx_science_analysis startLevel="IMA2" endLevel="IMA2" jemxNum=2 IMA2_AITproj="yes"
```

The resulting AIToff mosaics are expected to be mapped in the Galactic plane, and are therefore oriented in galactic, rather than equatorial, coordinates. To produce a mosaic over the whole sky you will need to decrease the resolution of the image by increasing the pixel size (cdelt) at least to 0.075 degree. The computation in AIToff-Hammer projection can take approximately 10% more CPU-time; and the resulting file can have a rather large dimension (for example ∼1G). In this case a simple solution can be to compress the file (e.g. with gzip) and to work directly with the compressed file (ds9 as well as other HEASOFT tools are able to work directly with the compressed file).
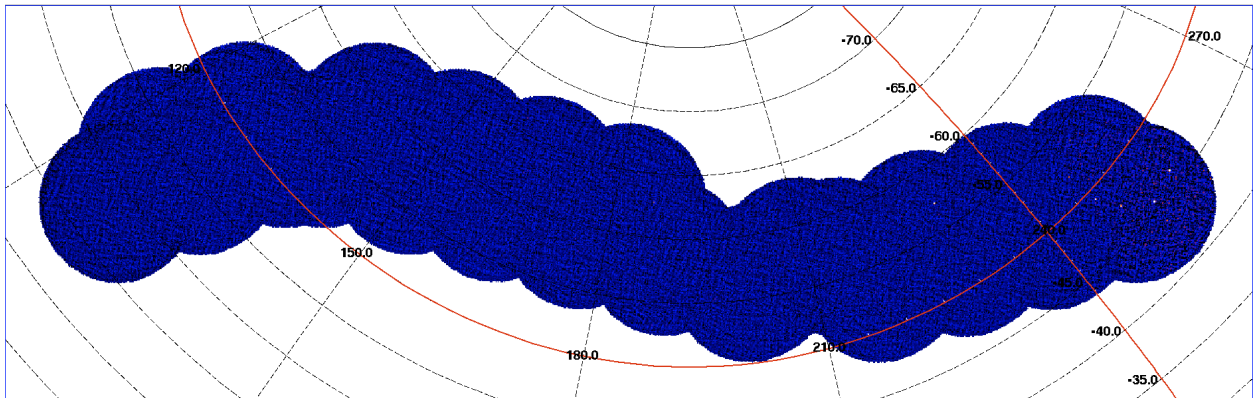
Figure 16: The mosaic image of the Galactic Plane Scan observation of revolution 399 in the 3–10 keV energy band, obtained in AIToff-Hammer projection.

6.6.5 Combining JEMX-1 and JEMX-2 mosaic images

j_ima_mosaic can combine JEM-X mosaics, provided that they have been obtained in the same energy bands, for the same sky area and in the same projection. As for the simple mosaic image the user may specify the coordinates of the center of the image (`RAcenter` and `DECcenter` parameters), as well as its size and resolution (`diameter` and `cdelt` parameters[9]), when creating the mosaics. Any mix, however, of JEMX-1 and JEMX-2 mosaics is allowed.

As an example, let us create a mosaic image of the Galactic Center region, which combines the JEMX-2 mosaic (see previous sub-section) with the JEMX-1.

To combine mosaics, these must be attached in a group, so the first step is to create an empty group:

```
dal_create obj_name=jemx_mosaics.fits template=""
```

This uses the default template, which is a standard group. Next, we need to attach the mosaics:

```
dal_attach jemx_mosaics.fits obs1/jmx1_mosa_ima.fits\
    obs2/jmx1_mosa_ima.fits obs3/jmx2_mosa_ima.fits ""
```

The final `""` is necessary to signal to *dal_attach* that there are no more data structures to attach. Up to five data structures can be attached with a single *dal_attach* commands. Additional extensions can be added by issuing another *dal_attach* command.

The combination of the mosaic is then very easily performed using the command:

```
j_ima_mosaic inObsGrp=jemx_mosaics.fits outfile=combined_mosaic.fits moscomb=y radiusSelect=-1
```

Combined JEMX-1 and JEMX-2 mosaics have the same structure as JEMX-1 ones, with EXTNAME="JMX1-MOSA-IMA".

6.6.6 Finding Sources in the Mosaic Image

j_ima_src_locator is a tool to locate point sources in an image. Since OSA-7 it is included in the OSA distribution but is not part of the pipeline. This tool can be used to search for the gaussian excesses in the mosaic image (but not to identify the detected sources at the moment).

---

[9]For details on j_ima_mosaic parameters see sections 8.11.1 and Appendix D

Figure 17: The content of the `jmx2_sloc_res.fits` file.

As an example, let us find all the significant excesses in the 7-11 keV mosaic image of the Galactic Center region. We assume that in the mosaic image `jmx2_mosa_ima.fits` the intensity map is in the extension 2 and the significance is in the extension 4 (which is the case if the default value of `IMA_skyImagesOut` parameter is used). The command

```
j_ima_src_locator inDOL=jmx2_mosa_ima.fits\[2] \
    sigDOL=jmx2_mosa_ima.fits\[4] outFile=jmx2_sloc_res
```

produces the list of the detected sources `jmx2_sloc_res.fits`. In this file all the significant sources in the mosaic image are listed. However, they are not identified with the known sources. To do the source identification, you can use the *q_identify_srcs* script:

```
q_identify_srcs srcl_cat_dol="$ISDC_REF_CAT"\
    srcl_res_dol=jmx2_sloc_res.fits instrument=5
```

(use `instrument=4` for JEMX-1 and `instrument=5` for JEMX-2) . As a result, the list of sources in the file `jmx2_sloc_res.fits` looks like it is shown in Fig. 17.

When inspecting the result the user might want to get rid of (too many) spurious sources or include more sources that seem to be present. To achieve the latter the parameter 'maxNumSrcs' must have an adequate value and the 'detsigMin' parameter might be lowered.

Analogously 'detsigMin' can be increased to avoid false sources and there is some help in the log file to find a reasonable value. Giving a negative 'detsigMin' will cause *j_ima_src_locator* to apply a limit of the first found histogram value exceeding one plus the absolute value of the given 'detsigMin'.

The JEM-X coded mask has an almost non-cyclic pattern, which ensures imaging artifacts (ghost sources) are particularly rare. Nevertheless in some peculiar cases, a bright source inside the FOV might cause the presence of ghosts in the mosaic. These artifacts appear at 8.32 degrees from the bright source. To verify that a 'New Source' in the sloc_res file is not instead a ghost, a simple test consists in checking whether there are bright sources at 8.3 deg from it in the FOV[10].

---

[10]If you encounter a doubtful case, you can contact the help desk at http://www.isdc.unige.ch/integral/support/helpdesk

6.6.7 Making images in arbitrary energy bands

IMA can use the general energy binning parameters `nChanBins`, `chanLow` and `chanHigh` to generate images (note however that these parameters always determine the energy binning in the spectral extraction step, SPE). To use these parameters at the IMA step, click on the "hidden" button and choose the "IMA" tab. Put the `IMA_detImagesOut` to `No` and `IMA_userImagesOut` to `Yes`. If you run the IMA step with such parameter settings, jmx$i$_sky_ima.fits will contain sky images for all bins specified by "General Binning Parameters". The mosaic image produced at the IMA2 level will also use these energy bins.

6.7 Source Spectra Extraction

Two spectral extraction algorithms can be used to extract the spectrum of a JEM-X source: the "standard" spectral extraction carried out at the `SPE` level (discussed in section 6.7.1), and the spectral extraction from mosaic images (discussed in section 6.7.7). Both of them originate from the imaging step.

WARNING: with OSA10, the count rates are scaled to one cm^2, while until OSA9, the count rate was scaled to one dm^2.

6.7.1 Spectral Extraction at SPE level

The "standard" spectral extraction procedure is carried out at the `SPE` level of the *jemx_science_analysis* script by re-formatting the source fluxes found at the IMA step. The file `jmx2_srcl_res.fits` serves as input for the spectral extraction in each ScW. It is important to note, however, that *j_ima_iros* will always find a little bit different source positions in different ScWs. The deviation of the found source position from the true one may lead to an error in determination of the source spectrum. To avoid this difficulty it is recommended to create a "user catalog" with the names and positions of the sources for which you want to extract the spectra[11].

For example, in the considered case, the source of interest is the Crab and one can just copy the corresponding line from the general reference catalog:

```
fcopy "${ISDC_REF_CAT}[NAME=='Crab']" user_cat.fits
```

In the new `user_cat.fits` file you have to change the `FLAG` column to `1`: in this case *jemx_science_analysis* would directly copy the source position information to the `jmx2_srcl_res.fits` after IMA step (see Sections 6.7.6 and 8.6.1 for an explanation on the possible FLAG values).

6.7.2 Energy binning definition

The user must now specify all the bins (s)he wants in the spectra, using `nChanBins`, `chanMin` and `chanMax` parameters. As this can be tedious, standard binnings are provided by setting `nChanBins` to be < 1. In this case IMA extracts fluxes in $2^{-\text{nChanBins}}$ bins, i.e. a value `nChanBins=0` results in a single wide energy bin, while a value of `-4` results in production of 16-channel spectra. The smallest allowed value is `-6`, corresponding to the 64-channel spectra. Table 5 shows the standard energy bins up to 16 channels.

6.7.3 Spectral response generation

For spectral analysis, a response redistribution function (RMF) should be generated according to the spectral binning specified by the user. The *j_rebin_rmf* script allows to do this very easily. There are several ways to

---

[11]To force the use of the catalogue positions the JMXi-SRCL-RES table must be manipulated by e.g an ftool to update columns RA_OBJ, DEC_OBJ. For more details see section 9.

nChanBins	chanLow	chanHigh
0	46	223
-1	46 130	129 223
-2	46 77 130 175	76 129 174 223
-3	46 59 77 102 130 153 175 199	58 76 101 129 152 174 198 223
-4	46 52 59 68 77 89 102 117 130	51 58 67 76 88 101 116 129
	141 153 165 175 187 199 211	140 152 164 174 186 198 210 223

Table 5: Standard energy binning.

run this script. The user can specify the bins individually, generate a bin list in a text file (see FTOOLS *rbnrmf* explanations). For example,

```
j_rebin_rmf chanMin="46 77 130 175" chanMax="76 129 174 233" jemx_num=2
```

or

```
j_rebin_rmf binlist=mybins.txt outfile="jmx1_rmf_mybins.fits"
```

Otherwise, it is possible to use pre-defined standard binnings matching those set with **nChanBins**< 1:

```
j_rebin_rmf binlist=STD_016
```

(matches **nChanBins=-4**). As a result, a file `jemx_rebinned_rmf.fits` (unless a different file name has been specified through *outfile*), which contains the rebinned RMF will be produced.

Note that *jemx_num=1* is the default value. The output file name (default jemx_rebinned_rmf.fits) can be set through the *outfile* parameter. It is convenient to create an RMF before the spectral analysis so that one can just pass the rebinned RMF to the analysis scripts. In this way, the fits files with the spectra will automatically contain a link to the correct RMF.

6.7.4 Individual Science Windows Spectra

Let us first proceed with the spectral extraction using the source positions found at the `IMA` step. In our example only the Crab was found by the imaging analysis, so the spectral analysis will generate only the spectrum of the Crab if you run the script with default values (assuming you run j_rebin_rmf in your $REP_BASE_PROD directory):

```
cd $REP_BASE_PROD/obs/crab

jemx_science_analysis startLevel="SPE" endLevel="SPE" jemxNum=2\
    response="$REP_BASE_PROD/jemx_rebinned_rmf.fits"
```

The results of the spectral analysis data are in the file

```
scw/RRRRPPPPSSSF.001/jmx2_srcl_spe.fits
```

Look on the result of the spectral analysis of the Science Window 010200210010

```
cd scw/010200210010.001/
fv jmx2_srcl_spe.fits
```

In this file you find the spectra for all sources that were found at the **IMA** level. Note that the correspondence between source name and source ID can be found in the file `jmx2_srcl_res.fits`.
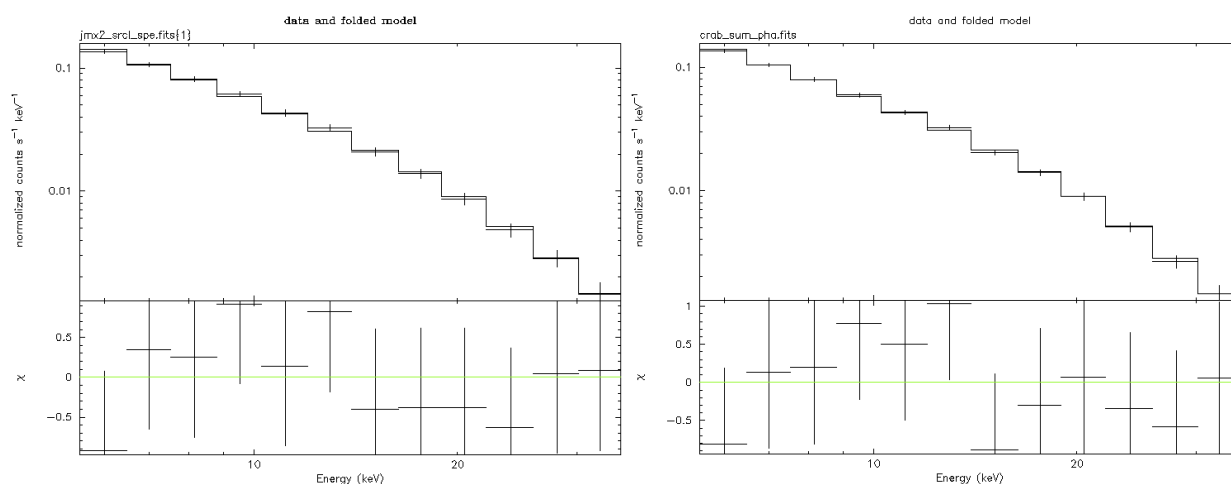
Figure 18: Left panel: Crab spectrum in ScW 010200210010. Right panel: Combined Crab spectrum of ScW 010200210010 and ScW 010200220010.

The JEM-X systematics are of the order of a few percents, typically 3%. We add this explicitly to jmx2_srcl_spe.fits file with the command below:

```
fparkey 0.03 jmx2_srcl_spe.fits SYS_ERR add=yes
```

The obtained spectrum can be analysed e.g. within *XSPEC* program:

```
xspec
XSPEC>cpd /xw
XSPEC>data jmx2_srcl_spe.fits{1}
XSPEC>ign **-5.0
XSPEC>setplot energy
XSPEC>model po
XSPEC>fit
XSPEC>plot ldat del
```

The above set of *XSPEC* commands reads the data file and fits the data with "power-law" model[12]. The result is shown in the left panel of Fig. 18. The fit results in a photon index of $\Gamma = 2.08 \pm 0.11$, and a normalisation at 1 keV of 9 ± 1.

To understand the importance of the "user catalog" let us extract the Crab spectrum using the catalog position of the source, not the one found at the **IMA** level. For this you have to re-run the analysis starting from the very beginning, but specifying that you want to use your own catalog for the spectral and lightcurve extraction. Create a new observation group `crab_usrcat`

```
cd $REP_BASE_PROD
og_create idxSwg=jmx.lst ogid=crab_usrcat baseDir="./" instrument=JMX2
```

copy the user catalog created as explained above into the observation group

```
cp user_cat.fits obs/crab_usrcat
```

---

[12]Please note that if your analysis ends with a really weird looking spectrum it can be related to the problem of gain coefficients modelling. See section 8.1.1 for a discussion.

and run the analysis till `SPE` level in this group:

```
cd obs/crab_usrcat
jemx_science_analysis startLevel="COR" \
   endLevel="SPE" jemxNum=2 CAT_I_usrCat="user_cat.fits" \
   nChanBins=-4 response="$REP_BASE_PROD/jemx_rebinned_rmf.fits"
```

The obtained spectra can be analysed with *XSPEC* as it was done above. To convince yourself that the spectral extraction with and without fixing the source position gives slightly different results, you can compare the two spectra, $REP_BASE_PROD/obs/crab/scw/010200210010.001/jmx2_srcl_spe.fits and $REP_BASE_PROD/obs/crab_usrcat/scw/010200210010.001/jmx2_srcl_spe.fits by entering them simultaneously in *XSPEC*.

With this OSA release, and until the flux determination algorithm in *j_ima_iros* is duplicated in a dedicated spectral extraction tool, it is not possible anymore to generate several spectra in a single analysis with a given time step. The user must define her/his own GTIs for the specific time period.

6.7.5 Combining Spectra of different Science Windows

With the help of the *spe_pick* program, described in the Introduction to the *INTEGRAL* Data Analysis [1], it is possible to combine the spectra from the different Science Windows. To define the source for which you want to combine the spectra you should either input its Source ID, or the source coordinates. In our case, to combine all the spectra belonging to the given Observation Group of the Crab give the following command

```
spe_pick group="og_jmx2.fits[1]" instrument="JMX2"\
   source="J053432.0+220052" rootname="crab"
```

The `rootname` argument allows to choose the name of the resulting spectral data files. For example, the above command produces the files

`crab_single_pha2.fits`	with all individual spectra of the source,
`crab_single_arf2.fits`	with corresponding individual ARFs,
`crab_sum_pha.fits`	with the combined spectrum,
`crab_sum_arf.fits`	with the ARF for the combined spectrum.

The resulting spectrum `crab_sum_pha.fits` can be analysed with *XSPEC* exactly in the same way as in the case of the individual ScW spectra (see above). The result of such analysis is shown in the right panel of Fig 18. You can check that combining the spectra obtained with/without fixing the source positions results in slightly different spectral fits in *XSPEC*.

It is also possible to combine the spectra of the Science Windows which belong to different observation groups. This is explained in section 7.4.2.

6.7.6 Extracting Spectra from a given Position in the Sky

It can happen that after the `IMA` level is done, you find that there is one more source from which you would like to extract a spectrum (e.g. you find a weak source which appears only in the mosaic image or you want to "fix" the position of a strong source with user catalog). In this case you can "force" the script to extract the spectrum from a given position on the sky. For this, you need to redo the analysis from the CAT_I step, after inserting your source in the user catalog with `FLAG=1`.

As an example, let us extract the spectrum of the source 4U 1722-30, which is clearly visible in the mosaic image of the Galactic Center region (Fig. 15) but which was not detected the imaging step (you can check that this source does not appear in any of the `jmx2_srcl_res.fits` files in the observation group `obs/mos`). For this case, the `SOURCE_ID, NAME, RA_OBJ, DEC_OBJ` are J172733.2-304807, 4U 1722-30, 261.8883

and `-30.80194` , respectively. Fill the corresponding line in the file `user_cat.fits`, update column FLAG (FLAG=1), and run the *jemx_science_analysis* with the user-defined catalog, as explained above.

The resulting files `scw/RRRRPPPPSSSF.001/jmx2_srcl_spe.fits` will contain a row with the spectrum of 4U 1722-30. The quality of the single ScW spectra is not very high, because of the short integration time (see Fig. 19). However, with the help of the *spe_pick* command (see previous sub-section) you can sum up the spectra of individual ScWs and obtain a better spectrum based on longer integration time (Fig. 19).

Sources marked with FLAG=1 in the user catalog will be included in the flux fitting procedure, and their derived fluxes will appear in the srcl_res file. You can introduce many FLAG=1 sources simultaneously, and you will get fluxes estimates for all of them in srcl_res. The flux values for the FLAG=1 sources are not derived from a fit including all these sources simultaneously. Such a fit might easily be highly unstable. Instead the flux estimate for each of the FLAG=1 sources will be extracted from a separate fit for this specific source together with the "basic source set" i.e. the strong sources found by j_ima_iros.

The maximum number of FLAG=1 sources which will be accepted by j_ima_iros in the analysis of a specific science window is 75. However this does not mean that you cannot work with a 'user catalog' with 200 FLAG=1 sources. What counts for j_ima_iros is the number of FLAG=1 sources which falls inside the 10 degree diameter field-of-view for the current science window. The program will not fall over if there are more than 75 FLAG=1 sources visible, it will simply only accept the first 75 visible FLAG=1 sources in the user catalog.

Under special circumstances you may want to force a specific source into all the fits (for all the FLAG=1 sources). This can be done (but is not recommended for general use) by setting FLAG=3. A maximum of three FLAG=3 sources will be extracted from your user catalog - additional FLAG=3 sources will not be neglected.
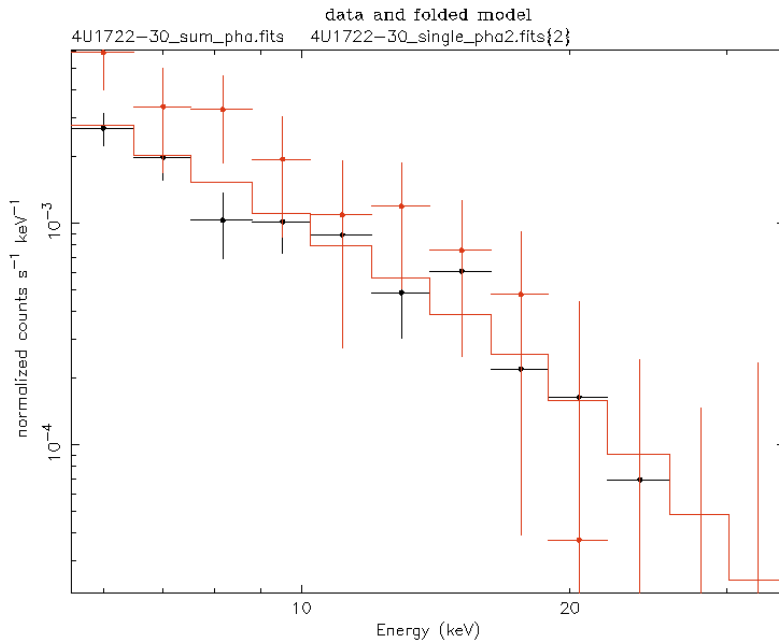
Figure 19: The spectrum of 4U 1722-30 in ScW 0053004200 (red) and in the whole revolution 0053 (black).

6.7.7 Spectral Extraction from Mosaic Images

Using the *mosaic_spec* script one can extract the source spectra from mosaic images and from individual ScW images. To extract spectra from a mosaic one needs first to produce images in narrow energy bands

(to get a reasonable number of energy bins in the resulting spectrum).

As an example, let us extract the spectrum of 4U 1722-30 from the mosaic images. First, one needs to create a new observation group using the list of ScWs considered for the mosaic of the Galactic Center region:

```
cd $REP_BASE_PROD
og_create idxSwg=mos.lst ogid=mosspec baseDir="./" instrument=JMX2
cd obs/mosspec
```

Next, one needs to produce the sky images in the 16 chosen energy bins.

```
jemx_science_analysis startLevel="COR" endLevel="IMA2" nChanBins=-4\
    IMA_detImagesOut=no IMA_userImagesOut=yes \
    skipLevels="LCR,SPE,BIN_S,BIN_T" jemxNum=2
```

The above command will produce JEM-X sky images and the mosaic in the 16 standard energy bands. You have to explicitly specify that you want to keep the VARIANCE extension in the output of mosaic step (`IMA2_viewVar=Y`, which is set to "yes" by default.), since the variance value at the source location is the error of the flux determination in a given energy band.

Now you can find the spectrum of any of the sources (and even extract a spectrum or energy-dependent upper limit of the flux from any position on the sky) from the sky images in each ScW, using the *mosaic_spec* script. E.g. the command

```
cd scw/005300410010.001
mosaic_spec "" "" DOL_idx="jmx2_sky_ima.fits"\
    DOL_spec="spectrum_scw.fits(JMX2-PHA1-SPE.tpl)"\
    EXTNAME="JMX2-SKY.-IMA" ra=261.89 dec=-30.80 \
    posmode=0 widthmode=-2 Intensity="RECONSTRUCTED"
```

will extract the spectrum from the position on the sky RA=261.89 , DEC=-30.80 corresponding to the position of 4U 1722-30. The spectrum will be written in the file spectrum scw.fits (using the template specified in the template file `JMX2-PHA1-SPE.tpl`). A number of parameters of the mosaic spec script specify the way in which the source flux and error are extracted from the sky image. In general, the script attempts to fit a Gaussian to the excess of intensity at the position of the source. The parameter `posmode=0` specifies that the source position always should be left free (`-1` would freeze the source coordinates, as the user may prefer to do with relatively weak sources). The parameter `widthmode=-2` specifies that the width of the fitted Gaussian should be read from the JEM-X image. The parameter Intensity specifies which of the possible intensity images will be used for the spectral extraction (only `RECONSTRUCTED` or `RECTIFIED` can be meaningfully used; `RECONSTRUCTED` is recommended). For JEM-X, the use of the `size` parameter (that in the past was set to `size=7`) is now obsolete.

To extract the spectrum from the mosaic image, go to the directory which contains `jmx2_mosa_ima.fits` and run *mosaic_spec* in the following way

```
cd ../../
mosaic_spec "" "" DOL_idx="jmx2_mosa_ima.fits"\
    DOL_spec="spectrum_mosa.fits(JMX2-PHA1-SPE.tpl)"\
    EXTNAME="JMX2-MOSA-IMA" ximg=0 yimg=0\
    ra=261.89 dec=-30.80 posmode=0 widthmode=-1 psf=2.0 Intensity="RECONSTRUCTED"
```

As a result, a spectrum `spectrum_mosa.fits` will be extracted from the sky position of 4U 1722-30.In this second case we used the combination of parameters `widthmode=-1 psf=2.0`, as the PSF of mosaic images is slightly larger than the PSF of single pointing images.

To analyse the spectra, you need to rebin the response matrix with the help of ftool *j_rebin_rmf*, as it is explained above.

The ancillary response function (ARF) for JEM-X2 spectra, can be automatically extracted from the IC tree using the script *j_image_arf*:

```
j_image_arf jemx_num=2 outfile=jmx2_image_arf.fits
```

Note that this ARF can only be used with spectra extracted with *mosaic_spec*, either for ScW images or from mosaics. The ARFs to be used when running the SPE step and *spe_pick* are different, and are automatically found and attached to the spectra by the *jemx_science_analysis* script.

Now you can enter the spectra extracted from the images in the individual ScWs and from the mosaic image into XSPEC and analyse them in a way similar to the one described in the previous sections.

```
xspec
data spectrum_mosa.fits
resp jemx_rebinned_rmf.fits
arf jmx2_image_arf.fits
cpd /xw
setplot energy
plot ldata
.......
```

The resulting spectrum is shown in Fig. 20.
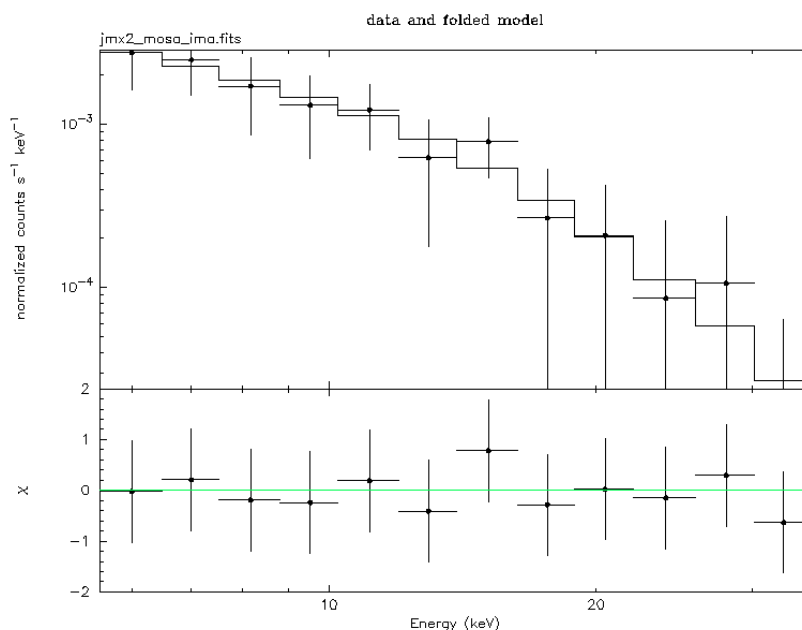
Figure 20: The spectrum of 4U 1722-30 extracted from mosaic image.

6.8 Source Lightcurve Extraction

6.8.1 Lightcurve extraction at LCR level

The lightcurves of sources found at the `IMA` step are created at the `LCR` level of the *jemx_science_analysis* script. However, this step is omitted by default. LCR step should be used only for the cases where time bins shorter than the duration of one ScW are necessary. If the ScW time scales are sufficient, better fluxes are obtained from the IMA step (see section 6.8.5). The file `jmx2_srcl_res.fits` serves as an input catalog for the lightcurves extraction in each ScW. It is important to note, however, that source positions found by *j_ima_iros* will differ slightly from ScW to ScW. The deviation of the found source position from the true one will lead to an error in the determination of the source lightcurve. To avoid this difficulty it is recommended to create a "user catalog" (in the same way as you did for the spectral extraction) with the names and positions of the sources for which you want to extract the lightcurves (see section 9 to force usage of the catalogue coordinates).

6.8.2 Individual Science Windows Lightcurves

To produce the Crab lightcurve, we have to run the lightcurve analysis in directory
`$REP_BASE_PROD/obs/crab_usrcat`.
The `LCR` level of the *jemx_science_analysis* script produces the lightcurves of the sources from the catalog of sources found in the imaging analysis, `jmx2_srcl_res.fits`. To obtain the lightcurve of the only found source (Crab) you can give the command

```
jemx_science_analysis startLevel="LCR" endLevel="LCR" skipLevels=""\
   nChanBins=2 chanLow="46 129" chanHigh="128 223" \
   CAT_I_usrCat=user_cat.fits jemxNum=2 LCR_timeStep=100.0
```

The parameter `LCR_timeStep` sets the binning time of the light curve in seconds. Selecting `nChanBins=2, chanLow="46 129" chanHigh="128 223"` we choose to produce the lightcurve in two energy bins: 3-10 keV and 10-35 keV.

Notice that the hidden parameter LCR_fluxScaling controls the unity in which the count rate is displayed. Until OSA9, the count rate was scaled to one dm^2 (this can be set with LCR_fluxScaling=2), with OSA10, we decided to scale it to one cm^2 (default value LCR_fluxScaling=3).

As a result for each found source a lightcurve is produced in each energy band. The results are written into the file

```
scw/RRRRPPPPSSSF.001/jmx2_src_lc.fits
```

6.8.3 Combining Lightcurves from Different Science Windows

Similar to the spectral case there is the tool *lc_pick* (see [1] for details) to combine the lightcurves from the single Science Windows.

```
lc_pick group="og_jmx2.fits[1]" source="J053432.0+220052"\
   lc="crab_lc.fits"
```

The resulting file contains two lightcurves, one for each energy band. One of the obtained lightcurves is shown in Figure 21.

It is also possible to sum up lightcurves from different observation groups. The method to do this is the same as in the spectral case, and is explained in section 7.4.2.

Bin time: 100.0   s

Start Time 12866 15:58:21:925   Stop Time 12866 17:06:41:925
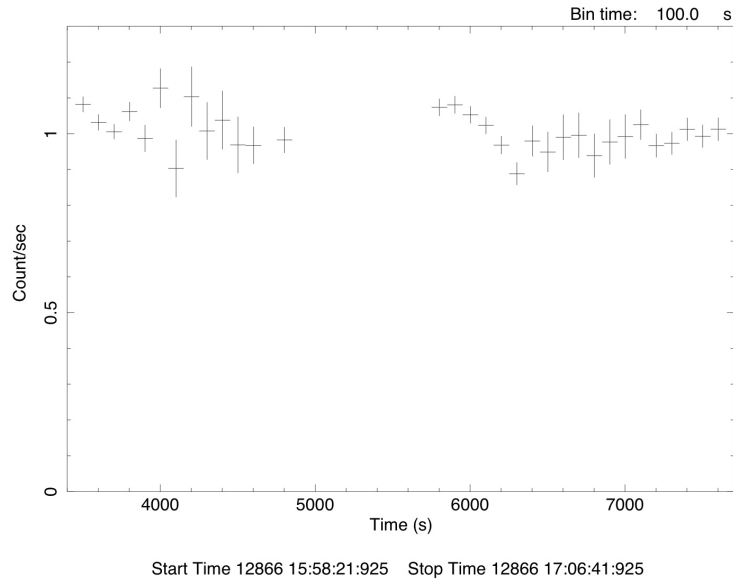
Figure 21: Crab lightcurve, first energy band.

The vignetting by the collimator and mask support structure of JEM-X has a more complex structure than originally thought. Therefore, source fluxes can vary significantly, of the order of 10%, from one Science Window to the next. At off-axis angles of 5 degrees this can even reach 30% in bad cases. The modeling of vignetting at the IMA and SPE steps is at the moment much better than this.

6.8.4   Displaying the Results of the Lightcurve Extraction

To see the source lightcurve, you should plot the column RATE with error ERROR versus column TIME, whereas to see the background lightcurve, you should plot column BACKV with error BACKE versus TIME. To display the resulting lightcurve it is convenient to use the *lcurve* program from the FTOOLS package:

```
lcurve
Number of time series for this task[] 1
Ser. 1 filename +options (or @file of filenames +options)[] crab_lc.fits[2]
Name of the window file ('-' for default window)[] -
Newbin Time or negative rebinning[] 100
Number of Newbins/Interval[] 46     (take this number from the line above:
                                      Maximum Newbin No. 46)
Name of output file[default]
Do you want to plot your results?[] yes
Enter PGPLOT device[] /XW
hardcopy crab_lc.ps/PS
quit
```

As a result, the crab_lc.ps file was produced and is shown in Figure 21.

6.8.5   Lightcurve extraction from the IMA step

IMA step of *jemx_science_analysis* script outputs the fluxes of all detected sources in jmxi_srcl_res.fits files. A Scw-by-Scw lightcurve of all these sources could be obtained with the help of *src_collect* script.

As an example, let us produce the Scw-by-Scw lightcurve of GX 354-0 in two energy bands, 3-10 keV and 10-35 keV. For this we will need first to extract fluxes from the images in these energy band in each ScW:

```
cd $REP_BASE_PROD
og_create idxSwg=mos.lst ogid=ima_lc baseDir="./" instrument=JMX2
cd obs/ima_lc
jemx_science_analysis startLevel="COR" endLevel="IMA" jemxNum=2\
    nChanBins=2 chanLow="46 129" chanHigh="128 223"
```

For each source, IMA step output contains fluxes in 3 "standard" IMA energy bands, plus the fluxes in the energy bins specified by `nChanBins`, `chanMin` and `chanMax` parameters.

To extract the ScW-by-ScW lightcurve from the images one has to run the script

```
src_collect group=og_jmx2.fits+1 results=GX354_scw_lc.fits\
    instName=JMX2 select="NAME == 'GX 354-0' "
```

As a result, the file GX354_scw_lc.fits will contain the source lightcurves in the 3 standard and the user-defined energy bands. To display the lightcurve e.g. in the 1st user defined energy band (3-10 keV) in our example you can use the *fv* program to plot the `FLUX[4]`, `FLUXERR[4]` vs. `TSTART`. The `[4]` in the square brackets signifies that one wants to plot the 4-th energy band (remember that the first three bins always contains the fluxes in the detection images, so the first user bin is the 4th one). One can extract the light curve in a single energy bin usuing the following command:

```
fcopy "GX354_scw_lc.fits [col TIME=(TSTART+TSTOP)/2; RATE = FLUX[4];\
    ERROR = FLUX_ERR[4]]" light_curve.fits.
```

This file can be visualized with `lcurve` as explained above.

Note, that the source GX 354-0 is a bright X-ray binary which is detected in each ScW, so that information about the source flux in each ScW is always available in the jmx2_srcl_res.fits files. For a weaker source, like 1E 1740.7-2942, which is not always detected in single ScWs, one has to "force" *jemx_science_analysis* to output information about the flux (or an upper limit on the flux) of the source into jmx2_srcl_res.fits files in each ScW by running the analysis with the user-defined input source catalog, as it is explained in section 7.5.

7   Useful recipes for JEM-X data analysis

This section collects some recipes that can be useful in the analysis of JEM-X data, in analogy to the recipes described in the IBIS cookbook (available at URL http://www.isdc.unige.ch/integral/analysis).

7.1   User GTIs

The way of creating User Good Time Intervals is described in the Introduction to the *INTEGRAL* Data Analysis [1]; a convenient tool `gti_user` exists for this purpose. To use your own GTI within the JEM-X analysis you should set two parameters: `GTI_gtiUser`, defining the location of your file, and `GTI_TimeFormat` defining the time format of the user GTI table. The possible values of the `GTI_TimeFormat` are `IJD` for the Integral Julian Date (see Introduction to the *INTEGRAL* Data Analysis [1]), `UTC`, and `OBT`. Below you find

an example of the command to launch the JEM-X analysis with the default values and the user GTI table
`user_gti.fits`

```
jemx_science_analysis startLevel="COR" endLevel="IMA" \
   COR_outputExists=y \
   DEAD_outputExists=n \
   GTI_gtiUser="user_gti.fits[1]" \
   GTI_TimeFormat="IJD"
```

7.2   Usage of the predefined Bad Time Intervals

Read this to know how to make proper selection of the science windows that should be used in your analysis.

Different things could happen to the instrument during a particular science window. To inform the user on any unusual things that she should be aware of, the list of time intervals which had some anomalies (bad time intervals) has been created and is kept in the latest version of the $REP_BASE_PROD/ic/jmx*i*/lim/jmx*i*_gnrl_bti*.fits file. (To download the files, the user can follow the instructions given to 'rsync' the entire IC structure, as explained in section 6.1).

For JEM-X the BTI are divided into 2 categories:

- BAD_RESPONSE - indicates a problem related to the response of the instrument, most typically linked to rapid gain changes following the re-activation of the unit after a long dormant period, or after a solar flare.

- BAD_CONFIGURATION – indicates cases affected by change of configuration, or any other problem.

For the most conservative data analysis use the following value of the (hidden) GTI_BTI_Names parameter:

```
  GTI_BTI_Names="BAD_CONFIGURATION BAD_RESPONSE"
```

This is also the default value. In case the user wants to analyse data affected by some BTI, the parameter should be modified accordingly (see section 8.2.5). For instance, to analyze periods affected by a solar flare, use `GTI_BTI_Names="BAD_CONFIGURATION"`.

However, you should always be careful while setting this parameter – BTIs are set by the JEM-X team for specific problematic periods; forcing their usage, the reliability of the results can not be guaranteed, especially for fluxes in BAD_RESPONSE cases.

7.3   Rerunning the Analysis

Read this if you would like to redo part of your analysis, e.g. if your run has crashed, or if you want to change some parameters.

In case you want to re-run the analysis with different parameters, run `og_create` but this time with a different "ogid" parameter. This will create a new tree under `obs/ogid` where all the new results will be stored. If the pipeline has crashed[13], in general it is safer to restart your analysis from scratch removing the `obs/ogid` directory and restarting from the `og_create` step.

In any case, we give below a set of recipes that can be useful.

---

[13]If any executable crashes then it terminates with non zero status. The meaning of the status value can be found at http://www.isdc.unige.ch/integral/analysis#Errors

Because of the group concept you cannot just delete the result you do not like and restart the pipeline. All results that were produced in the course of the analysis are linked to the group, and should be detached before you relaunch the script. To do this you can use the *og_clean* program, that will clean an Observation Group up to the level specified with parameter `endLevel`. All data structures with a level equal or prior to `endLevel` will be kept, while the data structure with a later level will be erased. For example, to run the image extraction (IMA level) you should clean from the group whatever comes after the BIN_I level, as this is the level immediately preceding the IMA one.

```
og_clean ogDOL="og_jmx2.fits" endLevel="BIN_I"
```

If og_clean fails it could be due to the fact that the group was corrupted. You should try to fix it with *dal_clean* program

```
dal_clean inDOL="og_jmx2.fits" checkExt="1" backPtrs="1" checkSum="1"
```

and launch *og_clean* only afterwards.

7.3.1 Creating a second mosaic in the Observation Group

If you already extracted a mosaic from the Science Windows in your Observation Group (as explained in section 6.6.4), and now you would like to extract a second mosaic on the same Science Windows (changing e.g. the IMA2_diameter parameter), you will see that **og_jmx2.fits** points to the initial mosaic output (row 2 of the first extension is jmx2_obs_res.fits). This will interfere with the new mosaic you are about to launch. You will need to detach the previous results from the og_group, and rename (or delete) them. To do so you can either clean the og_group with the task `og_clean`, as explained in section 6.6.4, or you can directly detach the former mosaic results from the group:

```
cd $REP_BASE_PROD/obs/og_group
fdelrow og_jmx2.fits+1 2 1 N Y
mv jmx2_mosa_ima.fits jmx2_mosa_ima_original.fits
mv jmx2_obs_res.fits jmx2_obs_res_original.fits
```

With the `fdelrow` command you detach from the first extension of **og_jmx2.fits** row number "2" (= the first row to be deleted, number of rows to be deleted = "1"), you were shown no keyword values, "N", and you agreed to proceed ,"Y". At this point you can run again the mosaic step through *jemx_science_analysis*, with Start and End levels both set to IMA2.

7.4 Combining results from different observation groups

Read this if you have a set of science windows belonging to different runs for which you have already built images, spectra or lightcurves and want to combine the results.

Section 7.4.1 explains how to combine all the existing images in a final mosaic, while section 7.4.2 shows how to merge different lightcurves and spectra.

7.4.1 Creating a mosaic from different observation groups

Suppose you want to analyse 5 Science Windows and are not interested in the final mosaic. You create the group with `og_create` and then you launch the analysis till the imaging step but without the mosaic step (i.e. from COR till IMA, see 6.6). An image is created per Science Window but you do not have the overall final mosaic. If you then change your mind and decide that you want the mosaic, all you have to do is to move in the working directory $REP_BASE_PROD/obs/xxx and relaunch the `jemx_science_analysis`

command with `startLevel="IMA2"`, `endLevel="IMA2"`.

This is relatively simple because all the Science Windows belong to the same group, so combining the results is trivial. But if this is not the case, i.e. if you have run different sets of analysis, each one with its own `og_create` command, then you need to make some intermediate steps [14]. You basically need to create a file that points to all the Science Windows you want to co-add. We call this file an "index". To create an index make a list of the Science Window groups you want to combine and save it as, e.g., **dols.txt**. To ensure a proper work of the software give the full path, i.e. your file should look like

```
/WORKING-DIR/obs/GROUP1/scw/011901060010.001/swg_jmx2.fits
/WORKING-DIR/obs/GROUP1/scw/011901070010.001/swg_jmx2.fits
/WORKING-DIR/obs/GROUP2/scw/012000360010.001/swg_jmx2.fits
/WORKING-DIR/obs/GROUP2/scw/012000370010.001/swg_jmx2.fits
```

The first 2 files belong to a run with the `og_create` parameter "ogid" equal to "GROUP1" while the latter two to a run with "ogid" equal to "GROUP2". /WORKING-DIR/ has to be the extensive name of $REP_BASE_PROD. **WARNING:** make sure that `obs/*/scw/*.001/jmx2_sky_ima.fits` files exist in all the Science Windows you mention, otherwise the merging will not work. Then give the command that actually builds the fits file from the ASCII file:

```
cp dols.txt $REP_BASE_PROD/obs/GROUP1/
cd $REP_BASE_PROD/obs/GROUP1/
txt2idx element="dols.txt" index="index_comb.fits"
```

The file "index_comb.fits" is created and you can look at it with **fv**. In the first extension you have 4 rows, each row has the link to a given swg_jmx2.fits file. What you need to do now is to let the software know that it has to use this particular set of Science Windows for the analysis. You do this by pointing **og_jmx2.fits** to this file. This has to be done because no matter what level of the scientific analysis you are performing, the software will analyse the Science Windows pointed to by **og_jmx2.fits**. Replace the first row of og_jmx2.fits with:

```
cd $REP_BASE_PROD/obs/GROUP1/
ftedit og_jmx2.fits MEMBER_LOCATION 1 index_comb.fits
```

You may check with **fv** that actually the first row of og_jmx2.fits is indeed "index_comb.fits".

At this point you are ready to launch the analysis and to create a joint mosaic:

```
cd $REP_BASE_PROD/obs/GROUP1
jemx_science_analysis ogDOL="og_jmx2.fits" \
   startLevel="IMA2" endLevel="IMA2"
```

See 6.6 for a description of the main parameters of the mosaic step. The above command is valid in case you have just run the ScW analysis part so that you indeed keep the same energy boundaries. Otherwise, if your parameter file has changed in between, you should add in the above the definition of `nChanBins`, `chanLow` and `chanHigh` according to the energy boundaries of the single ScW maps you want to merge.

7.4.2 Combining spectra and lightcurves from different observation groups

In sections 6.7.5 and 6.8.3 you have seen how to merge lightcurves and spectra from different Science Windows belonging to the *same* group. In that case the file **og_jmx2.fits** points to all the Science Windows and it is possible to launch the collecting/merging tools *lc_pick* and *spe_pick* directly on the group (group=og_jmx2.fits+1).

---

[14] Please note that the images that you intend to merge MUST have the same energy boundaries i.e. all the ScW maps must have been analysed in the same way. You cannot merge a 3–10 keV map with a 7–18 keV one.

If you have Science Windows belonging to *different* groups, you need an intermediate step. Basically you need to create a file (an index) that points to all the Science Windows you want to co-add, similarly to the case seen in the previous section. Then this file will be given as input via the "group" parameter at the place of **og_jmx2.fits**.

To create the index make a list of the Science Window groups you want to combine and save it as, e.g., **dols.txt** under $REP_BASE_PROD/obs/. To ensure a proper work of the software give the full path, i.e. your file should look like

/WORKING-DIR/obs/GROUP1/scw/011901060010.001/swg_jmx2.fits
/WORKING-DIR/obs/GROUP1/scw/011901070010.001/swg_jmx2.fits
/WORKING-DIR/obs/GROUP2/scw/012000360010.001/swg_jmx2.fits
/WORKING-DIR/obs/GROUP2/scw/012000370010.001/swg_jmx2.fits

The first 2 files belong to a run with the `og_create` parameter "ogid" equal to "GROUP1" while the latter two to a run with "ogid" equal to "GROUP2". /WORKING-DIR/ has to be the extensive name of $REP_BASE_PROD. **WARNING:** make sure that the lightcurve and spectra result files exist for each Science Window you want to co-add (jmx2_src_lc.fits and jmx2_srcl_spe.fits files).

Then give the command that actually builds the fits file from the ASCII file:

```
cd $REP_BASE_PROD/obs/
txt2idx element="dols.txt" index="index_comb_2.fits"
```

Then run *lc_pick* and *spe_pick* putting the parameter "group" equal to "index_comb_2.fits":

```
cd $REP_BASE_PROD/obs/
lc_pick source="J180108.2-250445" attach=n \
   group=index_comb_2.fits+1 lc=GX5-1.lc.fits emin="3.04"  \
   emax=10.08 instrument="JMX2"
```

GX5-1.lc.fits contains the merged lightcurve of GX 5-1 (source_ID=J180108.2-250445, as can be seen e.g. in the ISDC reference catalog) in the 3.04–10.08 keV band (energy range that of course has to exist in the jmx2_src_lc.fits original files!). Using lc_pick without specifying the energy range, will produce an output file with multiple extensions, one per available energy range.

```
cd $REP_BASE_PROD/obs
spe_pick group="index_comb_2.fits"\
   source="GX 5-1" rootname="GX5-1"  instrument="JMX2"
```

GX5-1_sum_pha.fits (the combined spectrum of GX 5-1) and GX5-1_single_pha2.fits (a file with the four spectra of the initial four Science Windows collected together) are created. *spe_pick* also creates an ARF, appropriate for your particular dataset. This ARF is written to GX5-1_sum_arf.fits and GX5-1_single_arf2.fits files. The names of the response and ancrfile are inserted in the keyword of the final files, so that they are automatically recognised by XSPEC.

7.5   Create your own "user catalog"

Read this if you are familiar with the sources in your field of view and you want to build your own catalog for the Imaging step, spectral and light curve extraction.

As already discussed in section 6.6, it can be very useful to use your own input catalog for the imaging, and in particular spectral and light curve extraction. The easiest way to build it is to modify the general catalog

with the help of the `fcopy` program of FTOOLS. For example, if you want to create a catalog (`usrcat.fits`) with only three sources, Crab, 3C111, and XPer do the following:

```
cd $REP_BASE_PROD
fcopy "$ISDC_REF_CAT[NAME == 'Crab'|| NAME == '3C 111'|| NAME == 'X Per']" usrcat.fits
chmod -w  usrcat.fits
```

If you want to add a new source, not specified in the general reference catalog, add a line to `usrcat.fits` with the help of the **fv** tool, and fill in the Source_ID, NAME, RA_OBJ and DEC_OBJ columns. As Source_ID you can choose whatever you like provided that this identifier is unique.

This catalog can be used in JEM-X analysis, by means of the `CAT_I_usrCat` parameter (see an example in section 6.7.4).

The FLAG column in `usrcat.fits` should be set to 1 (e.g. with the program *fv*), to have the catalog source position information copied, after the IMA step, into the columns RA_CAT and DEC_CAT of jmx*i*_srcl_res.fits. See the Known Issues description in section 9, to force the usage of these coordinates at SPE and LCR levels.

7.6   Barycentrisation

The tool making such a correction is called *barycent*. Note that it re-writes the input file, so it may be worth to copy the original file first. Below we show an example for 4U 1700-377, Science Window number 011800900010 and observation group identification ("ogid" parameter of og_create) equal to "OGID":

```
cd $REP_BASE_PROD/obs/OGID
cp scw/011800900010.001/jmx2_src_lc.fits jmx2_src_lc_011800900010_bar.fits

barycent inCOL=TIME outCOL=TIME \
   outDOL="jmx2_src_lc_011800900010_bar.fits[2]" \
   inDOL='' auxDOL="../../aux/adp/0118.001/orbit_historic.fits" \
   raOBJ=255.9865 decOBJ=-37.84414
```

In the example we have applied barycentrisation to the first energy range of 4U 1700-377 that happens to be in the extension number 2 ("[2]"). Thus the extension you give as "outDOL" depends on the source and energy range you need to correct. The overview of the content of each extension is in the input file jmx2_src_lc.fits, i.e. the first extension (`GROUPING`).

Note that *barycent* tool does not use group concept, and is used directly with the lightcurve, but for it successful work **the REP_BASE_PROD variable should be set** and point to the place in which there is an IC directory, e.g. `directory_of_ic_files_installation__/ic`, or a symbolic link to it (section 6.1).

See more details on *barycent* tool in the Data Analysis section of [1].

7.7   Timing Analysis without the Deconvolution

Read this if you are interested in fast variability studies (up to milliseconds).

In the same way as for ISGRI analysis, also for JEM-X it is possible to do timing analysis in a non binning way, i.e. starting from the single events. This way is suitable for very short time scales (up to milliseconds) and is less recommended for longer time bins for which the the methods described in Sect.6.8 are suitable.

In the example we will use one of the Science Windows with Crab data you have already downloaded (e.g. 010200210010).

In general the table with the events can be very big, so if you are interested in only part of the Science Window (e.g. in the case of a burst) it is better to define a user good time interval (see Section 7) and work within it.

Create with `og_create` observational group $REP_BASE_PROD/obs/crab/og_jemx2.fits, and run analysis from COR to DEAD level, prepare the catalog, with Crab only.

```
cd $REP_BASE_PROD/obs/crab
ibis_science_analysis startLevel=COR endLevel=DEAD jemxNum=2

fcopy infile="$ISDC_REF_CAT[NAME=='Crab']" outfile="crab_cat.fits"
```

For the next command you will need to specify the Instrument Model file to be used. This is a file located in your `$REP_BASE_PROD/ic` folder. In your IC tree you will found several files named jmx*i*_imod_grp_*.fits. Each of them refers to a different period. To identify the file to be used together with your data, you can check the (indicative) validity interval reported in table 6 for each imod file. In our example, based on scw 010200210010, we will use file jmx2_imod_grp_0299.fits .

At this point you are ready to create the lists of photons:

```
cd $REP_BASE_PROD/obs/crab

evts_extract group="og_jmx2.fits" \
events="evts_j2.fits" instrument=JMX2 \
sources="crab_cat.fits" gtiname="MERGED" \
instmod="$REP_BASE_PROD/ic/jmx2/mod/jmx2_imod_grp_0299.fits" \
pif=yes deadc=yes attach=no barycenter=1 timeformat=0 evttype=0
```

For JEM-X it is currently not possible to save the PIF of a given source. The parameter "pif" can be therefore put equally to 'yes' or 'no', as it adds no information to the output file.

Now you can produce the Crab power spectrum:

```
powspec
Ser. 1 filename +options (or @file of filenames +options)[] evts_j2.fits
Name of the window file ('-' for default window)[] -
Newbin Time or negative rebinning[] 0.001
Number of Newbins/Interval[] INDEF
Number of Intervals/Frame[] INDEF
Rebin results? (>1 const rebin, <-1 geom. rebin, 0 none)[]  0
Name of output file[default]
Do you want to plot your results?[] yes
Enter PGPLOT device[] /XW
hardcopy crab_powerspec.ps/PS
```

For the details on *INTEGRAL* absolute timing see Walter et al. 2003 [8].

If your data have many short GTIs (e.g. in the case of telemetry saturation due to a solar flare or when PICsIT is in non standard mode) you can obtain spurious results. A typical case is finding an 8 sec period in your data due to the fact that the telemetry restart is synchronized with an 8 sec frame! When possible, compare your results with IBIS/ISGRI ii_light that is immune to this problem and can reach about 0.1 sec binning.

Table 6: JEM-X imod files instance number to use.
(*indicative.* To have the exact validity range check the FITS file header in your IC tree.)

JEM X-1	
Revolution interval	IMOD instance XXX jmx1_imod_grp_0XXX.fits
1 - 8	300
9 - 14	301
15 - 19	302
20 - 37	303
38 - 44	304
45 - 93	305
94 - 163	306
164 - 197	307
198 - 221	308
222 - 244	309
245 - 310	310
311 - 406	311
407 - 458	312
459 - 532	313
533 - 622	314
623 - 659	315
660 - 713	316
714 - 781	317
782 - 869	318
870 - 934	319
935 - 999	320
1000 -	321

JEM X-2	
Revolution interval	IMOD instance XXX jmx2_imod_grp_0XXX.fits
1 - 5	292
6 - 9	293
10 - 14	294
15 - 37	295
38 - 44	296
45 - 71	297
72 - 93	298
94 - 135	299
136 - 172	300
173 - 197	301
198 - 244	302
245 - 310	303
311 - 389	304
390 - 499	305
500 - 579	306
580 - 659	307
660 - 713	308
714 - 799	309
800 - 855	310
856	311
857 - 869	312
870 - 934	313
935 - 999	314
1000 -	315

8   Basic Data Reduction

In the previous cookbook chapter (Section 6) several examples of the JEM-X data scientific analysis along with the description of the results were given. There you have seen that in order to run Scientific Analysis you should just launch the main script *jemx_science_analysis* with a desired set of parameters. As it was discussed in the Overview (Section 5) processing of the main script consists mainly of a loop over the pointings in the Observation Group calling the script *jemx_scw_analysis*, which in turn consists of smaller scripts unifying the executables with the similar tasks, see Figure 22. In the present chapter we describe these small scripts in more details in order to explain how the main script works and what parameters you have to enter for a proper analysis.

Describing the executables we mention all the parameters that were included as a parameter to the main script. All other parameters are set internally. To know about them type the name of the desired executable with `--v` option. Non-hidden parameters of the main script are marked with a bold font. Usually names of the main script parameters are derived from the corresponding name of the executable parameters by adding as prefix the name of the OSA level at which they are called (e.g. parameter `diameter` of the executable j_ima_mosaic called at IMA2 level of OSA, is named `IMA2_diameter` in the main script. In the rare case when this rule is broken we give both names in the description of the executable. The detailed description of the results produced at each step can be found in the Appendix section.

In the Appendix you also find the description of raw and prepared data with which you start the analysis.

8.1   *j_correction*

This script corrects all data available within the Science Window Group for a given JEM-X detector. It calls two executables that do the actual corrections:

- *j_cor_gain*

- *j_cor_position*

8.1.1   *j_cor_gain*

The executable *j_cor_gain* corrects all science data received at Full, Restricted, Spectral/Timing and Spectral modes for the condition of the individual pixels in the detector, temporal and spatial changes in the detector gain. The telemetry energy bins (PHA channels) of each event are converted to PI energies, using gain determined by

- Temporal gain variations across the detector are determined by the energy channel positions of the fluorescence lines of Cd-109 and Fe-55 sources placed above certain points on each detector. The peak positions are determined every four minutes (256 sec) to give current time variation of the detector gain, and compared to the Cd/Fe positions at a reference time when the Xe fluorescence lines of the gas over the entire detector are known. The values of the found Cd/Fe calibration line positions are kept in the gain history table and are used for gain conversion from PHA to PI channels in two possible ways. For gainModel=0, a linear interpolation between gain corrections is used for each event or spectrum at a given time. For gainModel=2 a time-decay model is used to smooth out statistical noise and discharge glitches at the calibration points. It is recommended that gainModel=2 is used for all processing. gainModel=1 is obsolete and should not be used (it is only included for backward compatibility).

  The JEM-X detector gain varies significantly at the beginning of each revolution for a few hours after the instrument has been switched on. The pattern is very similar each time and modeled in the gain correction step (if the parameter COR_gainModel is not 0).

  Due to aging of the instruments the JEM-X units (in particular JEM-X1) have become sensitive to not only temperature, but also the total hardware trigger-rate of the detector. For COR_gainModel=4,

jemx_science_analyis

jemx_scw_analyis

jemx_obs_analyis

jemx_scw_analyis

j_correction

j_cor_gain

j_cor_position

j_gti

gti_create

gti_attitude

gti_data_gaps

gti_import

gti_merge

j_dead_time

j_dead_time_calc

j_cat_extract

cat_extract

j_image_bin

j_ima_shadowgram

j_imaging

j_ima_iros

q_identify_srcs

j_src_extract_spectra

j_reform_spectra

j_src_extract_lc

j_src_lc

j_bin_spectra

j_bin_evts_spectra

j_bin_spec_spectra

j_bin_bkg_spectra

j_bin_lc

j_bin_evts_lc

j_bin_rate_lc

j_bin_bkg_lc

jemx_obs_analyis

j_ima_mosaic

src_collect

Figure 22: Detailed decomposition of the *jemx_science_analysis* script. Grey boxes correspond to steps already performed for revision 2 data.

the trigger rate dependency is taken into account, while for COR_gainModel=3 the algorithm will not include this dependency in the gain smoothing process.

For some cases, this modeling fails and a Warning with an error code of -321126 is reported. The gain correction program continues using linear interpolation values of the gain correction parameters. This is an ad hoc solution to ensure pipelines continue to run, but implies that the energy determinations of the events will be somewhat off. The corresponding events are flagged as having bad gain determination and may be ignored by subsequent steps or lead to distorted results.

In many cases where linear interpolation is used, gain correction of events will be fine. The user should look at the full detector spectrum produced by level BIN_S to see whether the Xe line peaks at PI channel 209. The default gain smoothing model is now COR_gainModel=4. If the smoothing goes wrong with model four and you dont like the look of the linear interpolation results, try using model 3. All of the foregoing considerations about choice of model number can be ignored if there is an IC table with all the gain corrections already determined. The log file will show whether a gain history table (JMXi-GAIN-OCL) has been used to correct the data. (See below).

- spatial gain variations across the entire detector area. These are initially determined by pre-flight calibration, but have been updated using in-flight calibration based on on the Xe 30 Kev fluorescence lines which can be observed over the whole detector.

- Unusual gain fluctuations hidden from the calibration sources (e.g. hidden gain suppression on the plate) and rare telemetry/procedure changes that can't be dealt with automatically, are handled by having the instrument team deliver instrument characteristics gain history tables, JMXi-GAIN-OCL, to ISDC. These are used automatically by the OSA software instead of the usual gain history tables, if one exists for a given revolution. All the revolutions after 948 have an IC table because of aging and occasionally eccentric behaviour of the instruments. Some revolutions prior to 948 also have IC tables due to odd behaviour. **Delivery of these files is constantly ongoing and users should always check that they have the latest IC/IMOD files before beginning an analysis.** For a complete overview of the gain calibration of every revolution see
http://www.spacecenter.dk/∼oxborrow/sdast/GAINresults.html

The _j_correction_ script will automatically fill this parameter with the DOL of an available IC gain history table if one is available for the revolution to which the SCW belongs.

More details can be found in Section 3.2 and Appendix B.3. _j_cor_gain_ parameters included into the main script are given in Table 7.

For the quality of gain corrections of JEM-X, all users should look at the web-page
http://www.spacecenter.dk/∼oxborrow/sdast/GAINresults.html

Table 7:   _j_cor_gain_ parameters included into the main script.

Name	Type	Description
COR_gainHist	string	DOL of the Index Group with gain variation history JMXi-GAIN-CAL-IDX. Empty string automatically takes the value of any IC Gain History DOL. default: " "

COR_gainModel	integer	With this parameter you choose the smoothing model to be applied.
		possible values:
		-1 (default) Let the algorithm choose between the optimal model to be used.
		0 Linear interpolation between gain history values.
		1 Fixed gain parameters - obsolete. This value will automatically default to model 2.
		2 Exponential gain decay with linear segment immediately after switch. Models the normal time variation of gain slope in a revolution.
		3 Non-trigger dependent model.
		4 Hardware trigger dependency in the smoothing. If there is no significant trigger variation during the revolution, then the program defaults back to model 3.
		default: **-1**

8.1.2 *j_cor_position*

The program works with the data received in Full & Restricted Imaging modes. With the use of the position mapping tables (see Appendix B.4) *j_cor_position* converts detector positions corrected for microstrip plate irregularities into absolute values.

This component also determines whether there are hotspots on the microstrip plate and flags all the events orginating in hotspot areas so that these events can be ignored by the rest of the science analysis. It also flags dubious events coming from dead anodes, inactive areas around the detector and areas around the calibration areas.

See Appendix C.1 for the description of *j_correction* output.

8.2 *j_gti*

This script builds Good Time Interval information from housekeeping data, information about satellite stability and data gaps. It calls the following executables to obtain the GTIs:

- *gti_create*
- *gti_attitude*
- *gti_data_gaps*
- *gti_import*
- *gti_merge*

More information concerning the definition of the Good Time Intervals and the creation of user defined GTIs is given in the Introduction to the *INTEGRAL* Data Analysis, [1].

8.2.1 *gti_create*

This program generates Good Time Intervals (see section 7.1 page 39) depending on housekeeping data and other parameters defining by a limit in a limit table (the time is "bad" if the value of any parameter was out of limit).

Table 8: *gti_create* parameters included into the main script.

Name	Type	Description
GTI_limitTable	string	DOL of table with parameter limits default: " "

8.2.2 *gti_attitude*

A GTI is defined for each period of time where the pointing stability is better than the accepted tolerance . The spacecraft GTI is named ATTITUDE. For slews this GTI is always set to be good independent of any input data.

Table 9: *gti_attitude* parameters included into the main script.

Name (main script)	Name (executable)	Type	Description
GTI_attStability	AttStability	real	Accepted attitude variability [arc min] possible values: `0. − 10800.` default: `3.0`

8.2.3 *gti_data_gaps*

This program generates GTIs depending on the presence of the science data. A time is defined as "bad" if there are missing science packets.

The final GTI is written into the JEMX-1 or JEMX-2 index group and has the name DATA_GAPS.

Table 10: *gti_data_gaps* parameters included into the main script.

Name (main script)	Name (executable)	Type	Description
GTI_gtiJemxNames	JMX1_Mode	string	Names of JEM-X GTIs to be merged
	JMX2_Mode	string	default: " "

8.2.4 *gti_import*

The *gti_import* reads user GTI table and converts it to a table in ISDC format. The user GTI can be defined either in units of OBT, IJD, or UTC. The output is always in OBT. The user table can define either bad or good time intervals. The output time intervals are always good ones. For the definition of the ISDC Julian Date (IJD) and details of user GTIs creation see Introduction to the *INTEGRAL* Data Analysis, [1].

Table 11: *gti_import* parameters included into the main script.

Name (main script)	Name (executable)	Type	Description
GTI_gtiUser	InGTI	string	DOL of the input user GTI default: " "
GTI_TimeFormat	TimeFormat	string	Time format to be used possible values: "IJD", "UTC", "OBT" default: "OBT"

| GTI_Accuracy | Accuracy | string | Accuracy used for OBT to IJD conversion and vice versa
possible values: "any", "inaccurate", "accurate"
default: "any" |

8.2.5 *gti_merge*

This program merges zero, one or more GTIs to a new GTI. It is an AND operation: time in the result GTI is defined to be "good" if this time is in every input GTI defined as "good". It also filters times flagged as Bad Time Intervals (see Section 7.2).

Table 12: *gti_merge* parameters included into the main script.

Name (main script)	Name (executable)	Type	Description
GTI_gtiJemxNames	JMX1_Mode JMX2_Mode	string	Names of JEM-X GTIs to be merged default: " "
GTI_BTI_Dol	BTI_Dol	string	DOL of a bad time interval table. default: " "
GTI_BTI_Names	BTI_Names	string	Periods marked by a type of BTI listed in BTI_Names are excluded from the analysis. Possible values are: BAD_RESPONSE and BAD_CONFIGURATION, which are both excluded by default. The user wishing to analyse data from a period affected by some BTI can remove the BTI type from BTI_Names. However, in general the result will be scientifically invalid, and this functionality must be used with extreme caution. default: "BAD_RESPONSE BAD_CONFIGURATION"

8.3 *j_dead_time*

This script derives a history of dead time values for each polling cycle (8 seconds) for a given JEM-X detector calling a single executable *j_dead_time_calc*. There are no parameters specific to this level in jemx_science_analysis.par file.

8.3.1 *j_dead_time_calc*

The dead time used in standard scientific analysis is calculated from the housekeeping counters that keep track of the fate of every event processed by the on-board software. The time to read in all the detector signals for a single event depends on how quickly the event is discarded due to grey filtering, buffer loss or particle rejection. The time taken for each sort of processing is stored in JMXi-DEAD-MOD (see Table 33 in Appendix B). The read-in time is summed up for all the events to give DEADTIME in JMXi-DEAD-SCP - this deadtime only measures the time that the hardware is occupied with event handling and cannot take in new events and dead time due to buffer losses. A further dead time DEAD_EFF is calculated that includes the effect of grey filter. This factor can be used to correct fluxes and countrates for all detector processing losses. These values however have only 8 secs resolution since this is the frequency of housekeeping packets, therefore, very rapidly varying strong sources must be treated offline for dead time.

Most analysis tools use the DEADTIME value in JMXi-DEAD-SCP and then add the effect of grey filter losses by looking up the grey filter value in the the JMXi_INST-STA instrument status table. These grey filter values have a single event resolution that allows for somewhat better determination of the instantaneous

deadtime. This procedure does not however, replace the need for an offline deadtime analysis for very rapidly varying sources.

8.4 *j_cat_extract*

This script extracts from the ISDC catalogue list of sources relevant to the Science Window in question with the help of *cat_extract* executable. It selects all the sources with fluxes known to be in the selected range and lying in the hollow cone (layer) defined by user. If fluxes are not specified then all sources are selected. It is possible to specify different flux criteria for different layers. Several layers can be mentioned in one call. More information on the ISDC catalogue you find in the Introduction to the *INTEGRAL* Data Analysis, [1].

In Table 13 you find the description of the parameters specific to the CAT_I level.

Table 13: *j_cat_extract* parameters included into the main script

Name	Type	Description
CAT_I_refCat	string	DOL of Reference Catalog default: "${ISDC_REF_CAT}"
CAT_I_usrCat	string	DOL of User Catalog default: " "
CAT_I_radiusMin	string	Low limit for the position selection. default: "0 2.4"
CAT_I_radiusMax	string	High limit for the position selection. default: "2.4 5.8"
CAT_I_fluxDef	string	Column used for flux selection. possible values: "0" – No flux selection "1" – JMXi_FLUX_1 column is used "2" – JMXi_FLUX_2 column is used default: "0"
CAT_I_fluxMin	string	Low limit for flux selection. default: " "
CAT_I_fluxMax	string	High limit for flux selection. default: " "
CAT_I_class	string	Object class of sources to select default: " "
CAT_I_date	real	IJD for the public data. possible values: <0 == all public; 0 == all private; >0 according to 'DAY_ID' default: "-1"

8.5 *j_image_bin*

This script creates shadowgrams in several, user-defined energy bands, calling the *j_ima_shadowgram* executable once for each band.

Standard coordinates retain the original detector square grid. The shadowgrams are made in a normal coordinate system when the hidden parameter `BIN_I_shdType` is equal to 3. The imaging component *j_ima_iros* requires `BIN_I_shdType` to be 2 (the default value in OSA 5.0). In that case the shadowgram is given with raw event positions i.e. no on-ground correction has been applied.

Parameters specific to the BIN_I level are given in Table 14.

8.5.1 *j_ima_shadowgram*

This executable reads the events from the imaging formats (FULL or REST) and sorts them according to their position into a 2D histogram – the shadowgram. The grey filter G and dead time D combined correction factor is evaluated at this step and brought as keyword in the FITS representation of the shadowgram.

TELAPSE	time interval from beginning to end of data window
ONTIME	sum of the good-time-intervals (GTI)
EXPOSURE	ONTIME corrected for greyfilter and deadtime
DEADC	effective fraction surviving when only dead time is considered

An example of a shadowgram with a very strong on-axis source is shown in Fig. 23. The central part of the mask is imaged on the detector and the similarity with the mask pattern (Fig. 5) can be noticed.
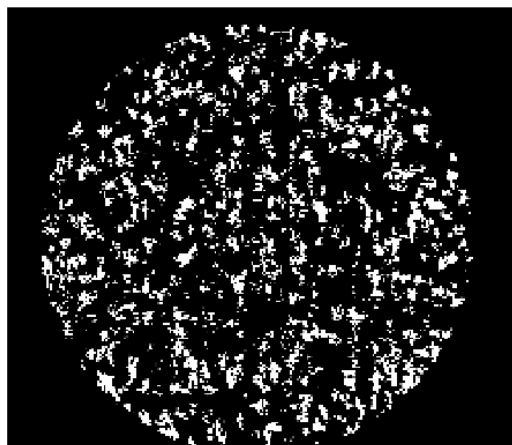
Figure 23: A shadowgram with a strong on-axis source and negligible background.

Table 14: *j_image_bin* parameters included into the main script

Name (main script)	Name (executable)	Type	Description
nChanBins	**nChanBins**	integer	Number of energy-resolved shadowgrams to create. If < 1, shadowgrams are created in standard bands. possible values: `-7 – 100` default: `4`
chanLow	**chanLow**	string	Lower channel boundaries for shadowgrams default: "`46 83 129 160`"
chanHigh	**chanHigh**	string	Upper channel boundaries for shadowgrams default: "`82 128 159 223`"
timeStart	timeStart	real	Start of time interval [IJD] (`-1` – use swgDOL bounds) default: `-1.`
timeStop	timeStop	real	End of time interval [IJD] (`-1` – use swgDOL bounds) default: `-1.`
BIN_I_evtType	evtType	integer	Event type possible values: `0` – FULL, `1` – REST, `-1` – both default: `-1`

BIN_I_shdType	shdType	integer	Type of shadowgram possible values: 1 – standard 2 – raw-standard 3 – regular default: 2
BIN_I_shdRes	shdRes	string	DOL of the output shadowgrams default: " "
BIN_I_rowSelect	rowSelect	string	CFITSIO selection string on events default: "&&STATUS<256"[15]
BIN_I_gtiNames	gtiNames	string	Names of GTI tables to be used default: " "
BIN_I_chanLowDet	chanLowDet	string	Three lower channel boundaries for shadowgrams for source detection default: "46 96 135"
BIN_I_chanHighDet	chanHighDet	string	Three upper channel boundaries for shadowgrams for source detection default: "95 134 178"

8.6 *j_imaging*

This component deconvolves the shadowgrams to make sky images, performs a search for sources and derives flux estimates.

Before OSA5 these tasks were divided into three components (j_ima_basic_recon, j_ima_src_find, and j_ima_cor_intensity) but the new component j_ima_iros does it all. The advantages are e.g. more reliable flux estimates, better images, and better vignetting correction.

This script calls the following executables:

- *j_ima_iros*

- *q_identify_srcs*

Parameters specific to the IMA level are given in Table 15.

Table 15: Parameters specific to the IMA level

Name	Type	Description
IMA_makeNewBPL	boolean	Do you want to create a new backprojection file ? default: no
IMA_newBackProjFile	string	Base name of new backprojection file default: " "
IMA_detAccLimit	integer	Acceptance limit in JMXi-DETE-MOD data structure. Possible values: 1 – 65535 default: 16384
IMA_skyImageDim	integer	Sky image dimension. Possible values: 1:255, 2:511. default: 2

---

[15]Note that the string will be concatenated to an existing radius selection so that the parameter string must begin with a logical operator, such as &&

IMA_useDeadAnodes	boolean	Do you want to include dead anodes areas ? default: `no`
IMA_maxNumSources	integer	Max number of sources in IROS loop default: `10`
IMA_edgeEnhanceFactor	real	Edge enhancement factor. It is used to convert the sky-images to significance maps by amplifying the peaks near the edge relative to those near the center default: `1.0`
IMA_loopLimitPeak	real	Fractional peak power to stop IROS loop default: `0.025`
IMA_detSigSingle	real	Detection significance for source acceptance default: `12.0`
IMA_skyRadiusFactor	real	Sky radius limit factor default: `1.0`
IMA_radiusLimit0	real	Detector radius limit E < 6 keV (mm) default: `120.0`
IMA_radiusLimit1	real	Detector radius limit 6 < E < 12 keV (mm) default: `120.0`
IMA_radiusLimit2	real	Detector radius limit 12 < E < 20 keV (mm) default: `117.0`
IMA_radiusLimit3	real	Detector radius limit E > 20 keV (mm) default: `110.0`
IMA_interactionDepth	real	Mean depth of interaction in the detector (mm) default: `3.0`
IMA_hotPixelLimit	real	Hot pixel limit factor above average default: `4.0`
IMA_skyImagesOut	string	Type of output sky images. There are the following types: RECTIFIED: Rectified (cleaned) intensity maps (in counts/cm^2/s). VARIANCE: Variance maps. RECONSTRUCTED: Reconstructed Residual+Sources maps (in counts/cm^2/s) which only differ from the RECTIFIED maps if sources have been found. RAWINTENSITY: Raw intensity (strength) maps (in counts), for which the vignetting correction is not applied. RESIDUAL: Intensity map (in counts/cm^2/s) after all found source contributions have been subtracted. EXPOSURE: The exposure map PIF: activate the PIF-weighted image generation algorithm (not to be used with mosaic_spec) Only the first five letters are required. default: "`RECONSTRUCTED,VARIANCE`"
IMA_dolBPL	sting	DOL of backprojection file list default: " "

IMA_bkgShdDOL	string	DOL of background shadowgrams default: " "
IMA_signifLim	integer	Minimum number of pixels to make a contribution to a sky image default: "25"
IMA_illumNorm	integer	Flag for special re-normalization default: "0"
IMA_colHreduc	real	[mm] Reduction of collimator height for BPL production default: "0."
IMA_detImagesOut	boolean	Should the images used for source detection be in output? default: "yes"
IMA_userImagesOut	boolean	Do you want the user defined images to be written? default: "n"
IMA_pixelFold	integer	Type of pixelfold 0:none, 1:NL, 2:NJW, 3:NL 1 D default: "1"
IMA_useTrace	boolean	Flag for tracing function calls default: "no"
IMA_tracestring	string	Control string for use of trace default: "0123456789ABCDEF"

8.6.1 j_ima_iros

The j_ima_iros software package has been developed to provide two main outputs:

- sky-images (and corresponding variance maps) derived from JEM–X shadowgrams.

- a list of source candidates extracted from the sky images by an "Iterative Removal Of Sources" (IROS-) algorithm.

j_ima_iros processes data (shadowgrams) from one science window at a time. Combining the sky images or the source candidate lists must be done by subsequent software packages. j_ima_iros can analyze a maximum of 15 shadowgrams (f.i. 15 separate energy bands) from one science window. For an initial survey of the observed sources it is best to divide the data into a limited number of energy bands, e.g. four bands.

j_ima_iros generates its sky images by a simple backprojection algorithm. The necessary information for this step is to see if the path from the detector pixel to the sky pixel is free or blocked by e.g. collimator or mask. Since the geometry of the JEM–X detector with its collimator is complex the raytracing from shadowgram pixels to sky image pixels is quite time consuming.

Therefore the Aperture Response Function is calculated off line by a separate set of subroutines. For every detector pixel (= shadowgram pixel) a list is generated containing all sky-image pixels potentially illuminating this detector pixel. Even when stored in compressed format these "backprojection lists" are of substantial size: about 375 Mbyte (for each JEM–X unit) for sky images with 511x511 pixels of 1.5 arcmin. The advantage is that the backprojection process (which must be repeated many times during the IROS-process) is quite fast - and, very important, the duration of the backprojection step is independent of the steadily increasing complexity of the raytracing model required by our improved understanding of the intricacies of JEM–X.

The backprojection lists are stored as separate IC files `JMXi-BPL.-GRP` under the general IC tree.

The search for sources is conducted in three predefined energy bands irrespective of the user selection of energy bands. Source results will be reported for all energy bands. Sources found in two or three of the search bands will define a 'basic source set' for this observation[16].

Optionally, the user may specify a 'user catalog' (parameter: usrCat) to enhance and control the performance of j_ima_iros. A subset of the sources in the catalog will automatically be selected corresponding to the current field of view.

For strong source candidates found during the first source detection phase of j_ima_iros a catalog match will be searched. If found, the catalog coordinates will be used during the IROS process.

The user may want to force j_ima_iros to analyze a source which is not detected with sufficient strength to be included in the basic source set. This can be done by assigning specific values to the 'FLAG' column of the user catalog.

A value of one will force j_ima_iros to derive flux values for the source. The flux will be derived from a fit including the basic source set plus the desired source. If several sources are marked in this way, a separate fit is performed for each source together with the basic source set.

A value of three for the FLAG will force j_ima_iros to include this source in the basic source set. It can be useful for very strong sources near the edge of the FOV that are not detected because they are too close to the edge or the exposure time is too short. But beware! Forcing irrelevant sources into the IROS process will normally deteriorate the fit.

The pixel size in the sky image is 1.5 arcmin and the dimensions are 511×511 pixels.

The distribution of pixel values in the reconstructed and cleaned image (RECONSTRUCTED) is not Gaussian (see Fig. 24) which implies that the detection significance limit should be set somewhat higher e.g. to 12, than a "number of sigma's"

The presence of the collimator introduces a vignetting of off-axis sources. Also at off-axis angles greater that 2.4 degrees a source is not visible through the mask from the entire detector surface. These two effects together form the vignetting. The vignetting or throughput factor as a function of angle in two direction is shown in Fig. 25. The quadratic cell shape of the collimator introduces the deviation from circular symmetry.

With OSA5.1 images it was realized that the flux determined from the images was a decreasing function of the off-axis angle. This effect is corrected in OSA6 by applying a correction map placed in the BPL IC files to the images before they are written to disk. Therefore the offline tool 'mosaic_spec' can be used to extract source spectra from j_ima_iros images as well as from mosaic images.

8.6.2   *q_identify_srcs*

q_identify_src calculates the distance d between each pair consisting of an expected catalogue source and a source found in the FOV by the ISSW. This distance and the error radii of the sources r_1, r_2 are used to calculate the relative distance, $q = d/\sqrt{r_1^2 + r_2^2}$. It is therefore essential that the quoted position error has a meaningful value. The relative distances are then stored in an array. Two new arrays are then created one ranking each catalogue source with $q \leq$ `relDist` (the largest value of relative distance considered when matching sources) for its proximity to each found source, and the other ranking each found source with $q \leq$ `relDist` for its proximity to each catalogue source. These two arrays are compared and five classes of source matches are found:

- **Good matches:** The found and catalogue source are the best fit to each other alone (relative distance between the match sources is much less than 1.

---

[16]Additionally, sources found with very high significance (see section 6.6.2) in only one band will be added to the' basic source set.
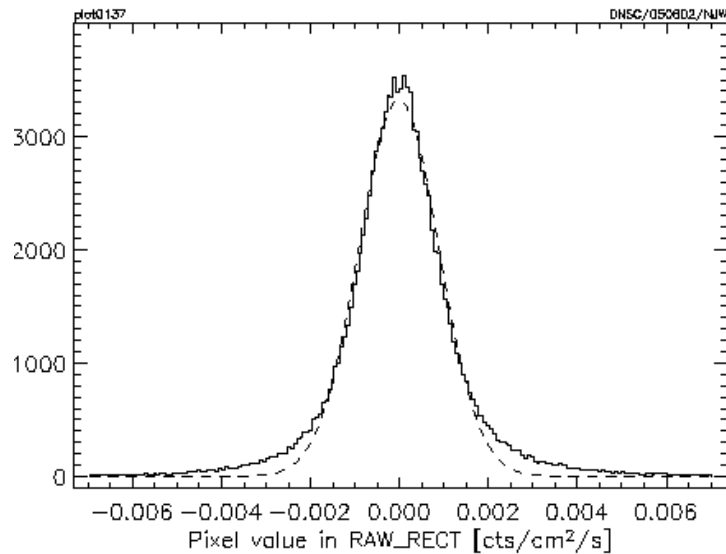
Figure 24: The distribution of pixel values in a RECTIFIED image with only one or two weak sources around the center of the FOV (thick histogram). A Gaussian fit is shown with the dashed curve and it is evident that the wings of the distribution are wider that the fit.

- **Confused Sources:** Two found sources are equally good fits to a particular catalogue source (within the slackness allowed by **distFuzz**,*i.e.,* fractional difference in two relative distances that can be considered insignificant when making a match, and **relDist**) - one of them could be a new source.

- **Multiple Identification:** One found source can be equally well identified with two (or more) catalogue sources (within the slackness allowed by **distFuzz** and **relDist**).

- **New Source:** A found source that cannot be matched to any catalogue source.

- **Not Found Source:** A catalogue source that couldn't be matched to any of the found sources.

  In the case of the two ambiguous categories (Multiple and Confused) the program makes no attempt to separate sources further or resolve conflicts between various possible matches - this should be done by a human. More details on the format of the output result is given in Appendix C.6.2.

Table 16: *q_identify_srcs* parameters included into the main script

Name	Type	Description
IMA_relDist	real	This is a parameter that sets the allowed separation between CAT-sources and RES-sources that are to be considered as the 'same'. relDist is calculated from:relDist=d/$\sqrt{r_1^2 + r_2^2}$. Here d is a distance between the sources and r_1 and r_2 are the error radii. default: `1.5`
IMA_fluxLimit	real	Lower flux limit for alerts of unfound sources [Counts/cm/s^2]. default: `0.0`
IMA_searchRad	real	Range of search grid (in degrees) around nominal found source positions default: `0.25`
IMA_gridNum	integer	Number of grid steps on one side of search grid default: `25`

IMA_distFuzz	real	Fractional difference in the relative distance of two found sources that allows them still to be considered equally good fits for a catalogue source.
		default: `0.15`

8.7   *j_src_extract_spectra*

This script derives JEM-X countrate spectra for all sources found in the current Science Window. It calls a single executable *j_reform_spectra*.

8.7.1   *j_reform_spectra*

Since OSA v.8.0, extraction of source spectra is made through *j_ima_iros*. j_reform_spectra simply reformats the fluxes in the user-defined energy bins. Please see j_ima_iros (Sect. 8.6.1) for more detail.

8.8   *j_src_extract_lc*

This application extracts energy-binned light curves for each found point source in the FOV. Background subtraction is an integral part of the data extraction. The only used executable is *j_src_lc*.

8.8.1   *j_src_lc*

Creates binned lightcurves for each found source in FOV. The output data structure contains a countrate light curve for a given source and a given energy range of the JEM-Xi instrument.

Table 17: *j_src_lc* parameters included into the main script

Name	Type	Description
LCR_timeStep	real	Binning time [s] for lightcurves
		default: `10.`
LCR_evtType	integer	Event type
		possible values:
		`0` – FULL,
		`1` – REST,
		`-1` – both
		default: `-1`
LCR_precisionLevel	integer	Speed - precision level, see more details in Section 8.7.1
		possible values:
		`0` – basic approach
		`20` – more detailed approach
		default: `20`
LCR_tAccuracy	integer	Time Correlation accuracy
		possible values:
		`0` – high,
		`1` – low,
		`3` – any
		default: `3`
LCR_useRaDec	boolean	Use sky coordinates (Ra,Dec) instead of instrument coordinates?
		default: `y`
LCR_rowSelect	string	CFITSIO selection string on events
		default: " "
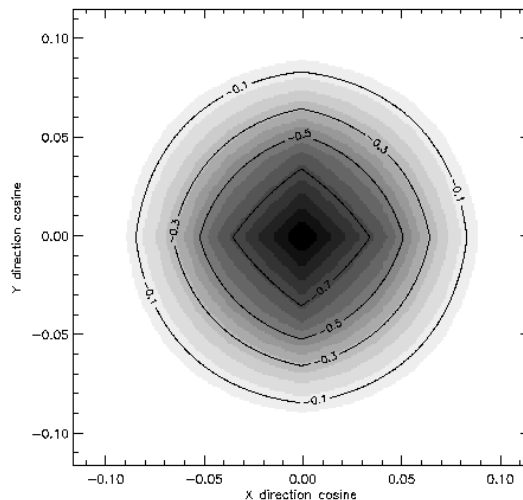
Figure 25: Simplified version of the vignetting array.

8.9   *j_bin_spectra*

This script bins events or Spectral Mode data without deconvolution. It calls the following executables:

- *j_bin_evts_spectra*

- *j_bin_spec_spectra*

- *j_bin_bkg_spectra*

The *j-bin-spectra* deals with background issues in a different fashion than the image reconstruction processes. There is no attempt at subtracting the background during the processing, instead for each generated JEM-X spectrum a corresponding background spectrum or lightcurve is produced by binning of the background model information, using the same binning as the measured spectra.

8.9.1   *j_bin_evts_spectra*

This executable generates detector spectra for a single JEM-X unit from Full Imaging, Restricted Imaging or Spectral/Timing events by binning the event data.

A series of spectra resolved in time or phase over a given period can be produced.

Table 18:   *j_bin_evts_spectra* specific to the BIN_S level

Name (main script)	Name (executable)	Type	Description
BIN_S_rowSelectEvts	rowSelect	string	CFITSIO selection string on events default: " "

BIN_S_evtType	evtType	integer	Data format to bin possible values: -1 – all, 0 – FULL, 1 – REST, 2 – SPTI, 4 – SPEC default: -1

8.9.2 *j_bin_spec_spectra*

This executable generates time resolved spectra for a single JEM-X detector by rebinning data in pure spectrum format to spectra.

The output is written to **JMXi-SPEC-DSP** which has the same structure as the data structures described in Table 52.

Table 19: *j_bin_evts_spectra* specific to the BIN_S level

Name (main script)	Name (executable)	Type	Description
nPhaseBins	nPhaseBins	integer	Number of phase bins ($N < 0 =$ abs(N) equally spaced bins) default: 0
phaseBins	phaseBins	string	Phase bin sizes, separated by space default: " "
BIN_S_rowSelectSpec	rowSelect	string	CFITSIO selection string on spectrum mode data default: " "

8.9.3 *j_bin_bkg_spectra*

This executable generates time resolved spectra for a single JEM-X detector by rebinning background model data to spectra.

Table 20: *j_bin_bkg_spectra* specific to the BIN_S level

Name (main script)	Name (executable)	Type	Description
BIN_S_evtType	evtType	integer	Data format to bin possible values: -1 – all, 0 – FULL, 1 – REST, 2 – SPTI, 4 – SPEC default: -1

8.10 *j_bin_lc*

The *j_bin_lc* script bins event data into lightcurves in different energy bands. The binning format is determined by input parameters to the executables. Empty fields are also binned for use in the background model catalogue.

This script deals with background issues in a different fashion than the image reconstruction processes. There is no attempt at subtracting the background during the processing, instead for each generated JEM-X

lightcurve a corresponding background lightcurve is produced by binning of the background model informa-
tion, using the same binning as the measured lightcurves. It calls the following executables:

- *j_bin_evts_lc*

- *j_bin_rate_lc*

- *j_bin_bkg_lc*

8.10.1 *j_bin_evts_lc*

Bins JEM-X event data to lightcurves.

Table 21: *j_bin_evts_lc* specific to the BIN_T level

Name (main script)	Name (executable)	Type	Description
BIN_T_rowSelect	rowSelect	string	CFITSIO selection string on events default: " "
BIN_T_evtType	evtType	integer	Data format to bin possible values: -1 – all, 0 – FULL, 2 – SPTI, 3 – TIME default: -1
nChanBins	**nChanBins**	integer	Number of channel bins default: 4
chanLow	**chanLow**	string	Lower channel bins (numbers separated by spaces) default: "46 83 129 160"
chanHigh	**chanHigh**	string	Upper channel bins (numbers separated by spaces) default: "82 128 159 223"
LCR_timeStep	timeStep	real	Binning time for lightcurve (sec) default: " 10 "
timeStart	timeStart	real	Time in IJD of start of first time bin (< 0 = use SWG start) default: " -1 "
timeStop	timeStop	real	Time in IJD of end of last time bin (< 0 = use SWG end) default: " -1 "
nPhaseBins	nPhaseBins	integer	Number of phase bins ($N < 0$ = abs(N) equally spaced bins) default: " 0 "
phaseBins	phaseBins	string	Phase bin sizes, separated by space (e.g: 0.1 0.2 0.3 ...) default: " "

8.10.2 *j_bin_rate_lc*

Creates full-detector light curve from RATE data.

Table 22: *j_bin_rate_lc* parameters specific to the BIN_T level

Name (main script)	Name (executable)	Type	Description
LCR_timeStep	timeStep	real	Binning time for lightcurve (sec) default: " 10 "
timeStart	timeStart	real	Time in IJD of start of first time bin (<0 = use SWG start) default: " -1 "
timeStop	timeStop	real	Time in IJD of end of last time bin (<0 = use SWG end) default: " -1 "
nPhaseBins	nPhaseBins	integer	Number of phase bins (N<0 = abs(N) equally spaced bins) default: " 0 "
phaseBins	phaseBins	string	Phase bin sizes, separated by space (e.g: 0.1 0.2 0.3 ...) default: " "

8.10.3   *j_bin_bkg_lc*

Rebin background model data to background lightcurves. None of the parameters of *j_bin_bkg_lc* are included into the main script. The behavior of this program is defined by the outputs of *j_bin_evts_lc* and *j_bin_rate_lc*.

8.11   Observation group level analysis

8.11.1   *j_ima_mosaic*

This executable combines input sky maps produced by j_ima_iros to make JEM-X mosaic images in a single FITS file (named by default jmxi_mosa_ima.fits) comprising each energy band found in the input observation group or selected by the user.

The input intensity IMATYPE (RECONSTRUCTED or RECTIFIED or RAWINTENSITY) is selected by use of the parameter "mapSelect". Note that if the user wants to extract fluxes from the image, only "RECONSTRUCTED" (recommended) or "RECTIFIED" make sense. There are four parameters defining the mosaic skymaps produced in the output file so it can have, for each energy band, up to four image extensions (depending on the chosen options) showing in the following respective order:

1. RECONSTRUCTED (default) or RECTIFIED or RAWINTENSITY (depending on the input intensity IMATYPE; see above): it is the weighted intensity map (counts/cm^2/s) produced by use of the parameter "viewIntens",

2. VARIANCE: the weighted variance map (use "viewVar"),

3. SIGNIFICANCE: the significance map (use "viewSig") defined as the intensity divided by the square root of the variance at each pixel.

4. EXPOSURE: the effective exposure times (use "viewTime") expressed in seconds taking account of the dead time, grey filter effects and vignetting of the JEM-X instruments (Notice: the vignetting used is normalised to 1 at the center of JEM-X FoV so as this corresponds to an effective detector aera of about 70 cm2 in average, depending on the actual energy range). With the latter option an additional map is also produced in the last extension OBS_TIME of the output file that shows the accumulated raw observation times (in seconds).

If sky coordinates (RAcenter, DECcenter) are given as parameters to define the center of the mosaic map, an ordered list of the input images as a function of their respective weights at the given coordinates is displayed for each energy band in the log file.

Starting from OSA10 it is possible (switching the new parameter view_nb to "yes") to output in a separate extension the number of SCWs contributing to each pixel of the mosaic. This new image will be of type NB_SING, and will be the last extension of the mosaic fits file.

j_ima_mosaic can combine any set of JEM-X mosaics, even if they have been obtained with different units. It is however mandatory that the user must attach all the requested mosaics to a group. For instance, if the user wants combine mosaics from the three OSA analyses: mysrc_1_jmx1, mysrc_2_jmx1, mysrc_3_jmx2, the user shall type:

```
dal_create mos_group.fits ""
dal_attach  mos_group.fits obs/mysrc_1_jmx1/jmx1_mosa_ima.fits
    obs/mysrc_2_jmx1/jmx1_mosa_ima.fits
    obs/mysrc_3_jmx2/jmx2_mosa_ima.fits "" ""
```

("" in the first line indicates that we use the default template, which is a group; the final "" "" represents two empty child parameters of dal_attach; indeed dal_attach can attach up to five children in a single invocation).

Now the group is ready, and one can call *j_ima_mosaic*:

```
j_ima_mosaic inObsGrp=mos_group.fits outfile=combined_mosaic.fits moscomb=y
```

The `moscomb` parameter is very important, as it tells *j_ima_mosaic* that we are trying to combine mosaics. The user can use either JMX1 or JMX2.

j_ima_mosaic can now produce mosaics either in the default tangential projection or using AIToff-Hammer projection (useful in particular when mosaicking large parts of the sky, such as for the Galactic Plane Scans). AIToff-Hammer projection can be selected with the parameter `IMA2_AITproj="yes"`.

Table 23:   *j_ima_mosaic* parameters

Name	Type	Description
inObsGrp	string	DOL of observation group default " "
mapSelect	string	Default for Reconstructed (Residual+Sources) Intensity maps, else RECTI for Rectified Intensity maps or RAWIN for Raw Intensity maps default "`RECON`"
dolBPL	string	DOL of the vignetting maps, e.g., ../../ic/jmx1/rsp/jmx1_bpl_grp_0002.fits[JMX1-DMAP-BPL] default " "
radiusSelect	real	Input images selection radius in deg default "5"
eminSelect	real	Minimum energy (keV) to select energy interval default "0"
emaxSelect	real	Maximum energy (keV) to select energy interval default "80"
diameter	real	Diameter in degrees of the mosaic image; 0 allows to fit the size from the angle between input images, < 0: may be used to force larger mosaics default "0"
cdelt	real	Pixel size in degrees at mosaic center default "`0.026`"
RAcenter	real	Center of the mosaic image Right Ascension in degrees (if < 0 use the computed middle position of the mosaic) default "`-1`"

DECcenter	real	Center of the mosaic image Declination in degrees (not used if RAcenter < 0) default "0"	
outfile	string	Mosaic FITS file prefix name (optional) default " "	
viewTime	boolean	Create total exposure Time map? (if Y: produce both raw exposure time map and energy dependent effective exposure maps) default "Y"	
viewIntens	boolean	Create raw Intensity map? default "Y"	
viewVar	boolean	Create Variance map? default "Y"	
viewSig	boolean	Create Significance map? default "Y"	
view_nb	boolean	Create a map that shows the number of input images contributing to each pixel? default "N"	
AITproj	boolean	Produce map in galactic coordinates using AIToff-Hammer projection? default "N"	
print_ScWs	boolean	List input Science Windows in mosaic headers? default "N"	
chatter	integer	Level of test output default "2"	

8.11.2 *src_collect*

This executable combines source data obtained by the imaging analysis for individual Science Windows into a single table covering an Observation Group. It is possible to retrieve only selected results.

Table 24: *src_collect* parameters specific to the IMA2 level

Name (main script)	Name (executable)	Type	Description
IMA2_srcFileDOL	results	string	DOL of the output source list mosaic default:
IMA2_srcselect	select	string	CFITSIO selection string applied to input tables default:
IMA2_srcattach	attach	boolean	Attach resulting table to group? default: n

8.11.3 **j_ima_src_locator**

j_ima_src_locator is a tool to locate point sources in an image. It is included in the OSA 7 distribution but is it is not part of the pipeline.

The primary goal of this tool is to analyze images from JEM-X made by *j_ima_iros* or *j_ima_mosaic* but it can also be used as a generic tool for a FITS image file. The main condition is that the PSF measured in pixels does not vary significantly over the image.

Currently *j_ima_src_locator* operates on a single image, but the functionality to get the images from a DAL

observation group (OG), a DAL science window group (SWG), or a DAL index table (IDX) is being prepared.

Significance map

The starting point for the search for sources is the significance map. If the image is accompanied by a significance map this can be given as a parameter with its DOL.

Detection significance of sources

It is assumed that the significance given in the significance map is evaluated pixel by pixel e.g. based on the number of counts that contribute to each image pixel. The significance of an excess in a pixel in the image is evaluated as the number of excess counts divided by the square-root of the variance (number of sigmas). In order to deal with the fact that the signal from a source is distributed over several adjacent pixels – the number is given by the PSF – a better source significance evaluation is done by combining several pixels around the source.

The distribution of significance values in the map is analyzed and a suggested value for the parameter 'detsigMin' is given in the log file (search for the string 'Suggest').

Variance map

If the search for a significance map has failed the alternative is to use a variance map. For an individual image it can be given by parameter as a DOL. The significance map is constructed by dividing the input image with the 'local RMS' or the square root of the variance map.

Bootstrap variance

In the case of a missing variance map then the 'local RMS' map (square root of the variance) is built by finding the RMS value by a sliding box excluding the pixels that are the highest contributors to the RMS. This method will reduce the effect of the extraordinarily high values of the RMS if there is a source inside the sliding (square) box.

Source fitting

Once a source candidate has been spotted a gaussian fit with both position, sigma and amplitude as free parameters is done around the initial position in the intensity image and both the derived sigma and the peaksize are reported. The best source position is given as the fitted peak position.

Currently there is no way to e.g. freeze the width of the PSF.

Output data structure

The output data structure is named: JMX1-SLOC-RES and is similar to JMXi-SRCL-RES which makes it possible to run e.g. q_identify_srcs and cat2ds9. There are some extra columns with additional information such as SIGMA (result of fitting), PEAKSIZE ('volume' of peak as fitted),

Table 25: *j_ima_src_locator* parameters

Name	Type	Description
inDOL	string	DOL of an image or of a DAL group
		default "`jmos.fits[1]`"
varDOL	string	DOL of corresponding variance map
		default ""
sigDOL	string	DOL of corresponding significance map
		If 'inDOL' is a group the two parameters above are ignored.
		If 'inDOL' is an image then 'sigDOL' is used as significance map
		if not empty; then 'varDOL' is used as variance map if not empty
		default ""

slocRes	string	File for SLOC-RES (override)
		Currently not active. Prepares for jemx_science_analysis script
		default "./jmx1_sloc_res.fits(JMX1-SLOC-RES)"
outFile	string	Name of output FITS file with source results
		Name of output file, that will be placed where DAL_CURRENT_DIR points
		default "jmx1_sloc_res"
catDOL	string	DOL of user defined X-ray catalog
		FITS table with columns RA_OBJ, DEC_OBJ, FLAG for the positions where a source fit is requested irrespective of
		the existence of a source
		default ""
sigmaPSF	real	Defines the (gaussian) PSF width in pixels. Start point for the fitting
		default "1.5"
sigmaFlat	real	(avoid use) If set to a positive number then the input image .. will be flatfielded .. with a gaussian of this sigma before further analysis
		default "0.0"
erode		Determines how much of the edge of the image where the noise often is overwhelming should be excluded from source finding. A high value implies a wide edge to be removed and vice versa.
		default "5.0"
maxNumSrcs	integer	Maximum number of sources to search for A limit to the number of sources. prevents the output file to expand to an unreasonable size.
		default "14"
maxNumCatSrcs	integer	Maximum number of catalog sources to include used to define the amount of memory to allocate to the internal data arrays
		default "14"
boxwidth	integer	Edge dimension of sliding box The edge size of the box used for finding the local RMS. Should be about five times larger than the FWHM of the PSF
		default "11"
detsigMin	real	Detection significance lower limit" With the current scheme put to 14. If you get too many spurious sources then choose a higher value
		default "-0.3"
imaTypes	string	Image types to search for sources .. Only applicable if the input is a group. A good choice is "RECONSTRUCTED"
		default "RECONSTRUCTED"
saveI	boolean	Flag for saving input image
		default "n"
saveF	boolean	Flag for saving flat-fielded image
		default "n"
saveM	boolean	Flag for saving folded image
		default "n"
saveK	boolean	Flag for saving array of amplitudes
		default "n"
saveC	boolean	Flag for saving array of chi squares
		default "n"

saveS	boolean	Flag for saving array of significance
		default "n"
saveR	boolean	Flag for saving array of local RMS values. The 'save?' parameters above should only be set to 'yes' is you are working on a single image
		default "n"
chatter	integer	Level of chattiness
		default "3"

9 Known Issues and Limitations

1. The JEM-X lightcurves are deadtime corrected. DEADC in the lightcurve files are set to 1.0 (for XRONOS compatibility).

2. Due to changes of the on-board configuration, the detection efficiency has changed significantly several times during the mission history. In particular for pointings between revolutions 26 to 45, this means that the measured fluxes of stable sources – in particular at low energy – will strongly depend on the time when the data was taken. These changes are not corrected for in flux units (counts/cm^2/s in the given energy interval) but taken into account in spectral responses.

3. The JEM-X detector gain varies significantly for a few hours after the instrument has been switched on. This mostly affects the beginning of each revolution but can also happen if the instrument was shut down, e.g., for solar flares. The pattern is very similar each time and modeled in the gain correction step even in complicated cases. Nevertheless, it could in principle fail, in which case linear-interpolation gain correction values would be used, which could lead to distorted spectra. Users are advised to check this possibility in case of highly unusual source spectra e.g. by consulting

   http://www.spacecenter.dk/~oxborrow/sdast/GAINresults.html

4. If the gain correction step fails then take a look at the gain history table. Gain correction failure is often signaled by all corrected events having a non-zero STATUS value due to bad gain determination (64). If the gain history for your revolution shows multiple switch on/offs, this may be confusing j_cor_gain. Then remove all gain history values up to the switch on/off just before your SCW being analyzed. For help fitting data in these complicated revolutions contact Dr. Carol Anne Oxborrow at oxborrow@space.dtu.dk .

5. The source coordinates found by j_ima_iros may deviate a little from the true positions and this can occasionally cause inaccurate flux reconstructions from j_src_spectra or j_src_lc. If a good source position is available, it is better to force these coordinates by use of a user catalogue. An example is given in the cookbook (but see also point 8 below).

6. Lightcurves from weak sources may be contaminated by counts from stronger sources in the FOV. This happens because the source extraction does not take into account the presence of the other sources.

7. If you mix FULL and REST data then be sure to give chanMin/Max that match REST channel limits, for example:

   ```
   chanMin:   64  128  160 192
   chanMax:  127  159  191 223
   ```

8. In OSA v.7.0 and later, the source position reported in columns RA_OBJ and DEC_OBJ of JMX*i*-SRCL-RES will always be the one found by *j_ima_iros*. Columns RA_CAT and DEC_CAT reflect the catalog position if a user catalog has been defined. The SPE and LCR levels will read the RA_OBJ and DEC_OBJ columns and do the extraction using those. In order to force the use of the catalog positions – which is recommended – the JMXi-SRCL-RES table must be manipulated e.g. by an ftool, to update columns RA_OBJ and DEC_OBJ.

9. Light curve extraction is unchanged in OSA 10 compared to previous versions in order to allow the easy generation of short-bin light curves. However, long-term stability is not assured in this case; the user interested in long-term light curves or who doesn't need time bins shorter than the length of a science window is advised to generate light curves from the imaging step, as explained in the cook book.

10. It has been noticed that in mosaics of JEM-X images a plus-like depression in the background around certain sources can occur. This can happen for sources that are too weak to be noticed in the search for sources in the individual science windows. The cleaning process excludes (known) source areas. It operates horizontally and vertically since the systematics are strongest in these directions. However, adding many images can amplify the effect of an unnoticed source since the distribution of position angles is quite narrow, in particular for the sources near the galactic center, which is also where the

probability to find a source in the depression caused by a neighboring source is highest. If a source is situated in such an indentation its peaksize is reduced accordingly, whereas there is no change for the source causing the feature. This is solely an image feature so *j_ima_iros* flux determinations are unaltered.

11. A count-limiting mechanism, the grey filter, is actived, when sources corresponding to more than 0.75 Crab on-axis are in the field of view. The grey filter is adjusting itself automatically, according to the rate of events accepted as X-rays and the filling level of the onboard telemetry buffer. Ideally, a grey filter should randomly reject events. However, the mechanism implemented is only pseudo-random. Therefore some care should be taken in interpreting power spectra of arrival times of events from very bright sources with a very significant grey filter, as QPO artifacts may show up. Normally, the automatic grey filter is varying over a science window. This fortunately has the effect of "averaging" out power spectra artifacts, as they are specific to a particular grey filter setting. Therefore, if noticing transient features in the power spectra of very strong sources it should be checked if this is limited to a period of a specific grey filter setting. Please check the User Manual for further explanations.

12. Since 30 March 2012, there is a new instance of the Instrument Model Group (IMOD files version 22) produced by the JEM-X Team. The usage of these new IMOD files is highly recommended, and will be automatic upon update of your copy of the Instrument Characteristics files. Note however that the data are fully reliable only above 5 keV.

13. For the time being it is not trustable to extract spectra of strong sources with "mosaic_spec" from images obtained with the PIF option (6.6.3).

14. The flux of a given source can be obtained either with the "standard" extraction or with mosaic_spec. In case the fluxes obtained with the two methods would differ, it is suggested to consider the one obtained from the standard extraction (SPE level).

15. j_ima_src_locator might interact wrongly with mosaics obtained in AIToff-Hammer projection. In case the mosaics are oriented in galactic coordinates, j_ima_src_locator stores (without converting) G_Lon and G_Lat coordinates of the found sources under the columns RA and DEC of the jmx*i*_sloc_res file.

A   Low Level Processing Data Products

As it was explained in Section 3.1 JEM–X has five different telemetry formats: Full Imaging, Restricted Imaging, Spectral/Timing, Spectral and Timing. The information sent to ground in Restricted Imaging mode is enhanced with the count rate of the events. The time resolution of these Count Rate data is 125 ms, while the rate of the image transfer in this mode depends on the brightness of the source and may be up to 32 seconds for the faintest ones, see Table 2 for an overview.

During data taking JEM–X instruments can switch autonomously between two preplanned modes according to the fill status of an on-board buffer, thus avoiding data loss due to the buffer overflow, if the secondary mode allows higher transmission rate.

In addition to the mode switching there is also a grey filter mechanism which can reduce the telemetry load by rejecting a given number (up to and including 31) out of 32 hardware triggers. The value of the grey filter setting can vary from G=31 (all events are accepted) to G=0 (only one event from each 32 is accepted). In general, value G of grey filter means that 31-G events from 32 are rejected.

Table 26 summarizes all scientific data structures created in these modes. The data structures for JEM–X 1 and JEM–X 2 have the similar names, so to avoid the unnecessary repetition we write JMXi, where it should be replaced by "1" or "2" depending on the instrument.

Table 26: List of JEM–X RAW, PRP and COR Data Structures

Telemetry Format	Raw Data Structure Contains RAW event/spectral data	Prepared Data Structure Contains event/spectral OBTs	Corrected Data Structure Contains Corrected event/spectral data
Full Imaging	JMXi-FULL-RAW	JMXi-FULL-PRP	JMXi-FULL-COR
Restricted Imaging (REST)	JMXi-REST-RAW	JMXi-REST-PRP	JMXi-REST-COR
Count Rate for REST	JMXi-RATE-RAW	JMXi-RATE-PRP	JMXi-RATE-COR
Spectral/Timing	JMXi-SPTI-RAW	JMXi-SPTI-PRP	JMXi-SPTI-COR
Timing	JMXi-TIME-RAW	JMXi-TIME-PRP	JMXi-TIME-COR
Spectral	JMXi-SPEC-RAW	JMXi-SPEC-PRP	JMXi-SPEC-COR

A.1   Raw Data

For each Raw data structure given in the Table 26 there is a data structure with the same name but ending not with RAW but with PRW. These data structures contain package raw data with the information on the telemetry package structure and the position and Local On Board Time (LOBT) of the first event of the package. For the FULL, REST, Spectral and Spectral/Timing modes there are also data structures with names finished with SRW - these data structure contains secondary raw data with the information on the grey filter changes and various marker events transmitted in telemetry stream.

A.1.1   Full Imaging mode

This is the main JEM–X format used for by far the largest part of the data taking. In this mode data have the highest imaging, spectral and timing resolution. The raw data are written to the `JMXi-FULL-RAW` data structure, see details in Table 27. Note that in an effort to compress the transmitted information the time stamping of each event is done relative to the previous event. The LOBT of the first event in each data packet is given in the `JMXi-FULL-PRW` data structure.

Table 27: Content of `JMXi-FULL-RAW` Data Structure.

Column Name	Description
RAWX	X location of the event
RAWY	Y location of the event
PHA	Pulse height of the event
DELTA_TIME	Delta time to previous event

A.1.2   Restricted Imaging mode

This format provides all imaging capabilities of FULL IMAGING, but provides limited spectral resolution (8 channels) and timing resolution (1/8 s for the count rates and up to 32 s for images). It is may be used when the source is too bright (exceeds 120 cts/s) and the full information can't be transmitted to the Earth. In this case raw data with spatial information are written to the `JMXi-REST-RAW` data structure, and count rates data are written to `JMXi-RATE-RAW` see details in Tables 28, 29. As we loose the time information during the accumulation time the events in the packets are ranked according the position of the triggered pixel (all the pixels have some conventional number in accordance of their position). Note that again only the position of the event with the lowest position number is transmitted (you can find it in `JMXi-RATE-PRW`) and for all others in TM only the relative positions are given. Pre-Processing calculates the absolute position and add it to the data structure.

Table 28: Content of `JMXi-REST-RAW` Data Structure.

Column Name	Description
REST_PHA	Pulse height of the event
DELTA_POS	Delta position number of the event
RAWX	X location of the event (calculated by PreProcessing)
RAWY	Y location of the event (calculated by PreProcessing)

Table 29: Content of `JMXi-RATE-RAW` Data Structure.

Column Name	Description
DELTA_COUNT	Delta-countrate
COUNT_RATE	Reconstructed count rate (calculated by PreProcessing)
GREY_FILTER	Grey filter for first event in the count rate

A.1.3   Spectral/Timing mode

This format provides the timing and spectral capabilities of FULL IMAGING, but no imaging. In this case raw data are written to the `JMXi-SPTI-RAW` data structure.

Table 30: Content of `JMXi-SPTI-RAW` Data Structure.

Column Name	Description
PHA	Pulse height of the event
DELTA_TIME	Delta time to previous event

A.1.4   Timing mode

This format provides only the timing information of the FULL IMAGING. In this case raw data are written to the `JMXi-TIME-RAW` data structure.

Table 31: Content of `JMXi-TIME-RAW` Data Structure.

Column Name	Description
DELTA_TIME	Delta time to previous event

A.1.5 Spectral mode

This format provides limited spectral resolution (64 channels) with limited time resolution (1/8 s) for the whole detector (no imaging). In this case raw data are written to the `JMXi-SPEC-RAW` data structure.

Table 32: Content of `JMXi-SPEC-RAW` Data Structure.

Column Name	Description
GREY_FILTER	Grey filter for first event in the spectrum
SPECTRUM	Counts in 64 channels

A.1.6 Prepared Data

The main task of the Science Window Pipeline is to prepare raw data for the following Scientific Analysis. It converts the housekeeping parameters into the physical units and makes some corrections and transformations of the raw data that are not included in Pre-Processing. The Summary of all the prepared data structures with scientific information can be found in Table 26. All these data structures have the only column OB_TIME with the full on-board time of the relevant data.FULL, SPTI and TIME OBTs refer to the individual events. SPEC OBTs give the time of each spectrum and REST OBTs give only the time of each image, so that the OBTs of the events within a single integration period are identical.

A.1.7 Revolution File Data

The gain history table JMXi-GAIN-CAL-IDX and the calibration spectral fitting table JMXi-GAIN-CAL, are both created in the Revolution File Pipeline (RFP) which runs automatically at ISDC before/after/parallel with the Data Preparation step. The spectral fitting file is created every 256 seconds by *j_calib_gain_fitting*, and the RFP then indexes the results into a single gain history table for each revolution. It is this gain history table that gets used automatically in *j_cor_gain*, unless a delivered IC gain history table exists for the revolution being processed.

B   Instrument Characteristics Data used in Scientific Analysis

B.1   The IMOD group

The group `JMXi-IMOD-GRP` contains the instrument model description data structures for JEM–Xi. Table 33 describes those Data Structures from that group that are used in the Scientific Analysis. A specific version of these IC files consists of a number of instances each covering a time period during which the instrument setting and response can be considered constant. The parameter name for all components and the jemx_science_analysis script is "instMod". When given as an empty string the script itself will define an appropriate DOL from the general IC tree (masterfile).

Table 33: Content of `JMXi-IMOD-GRP` Group.

Group Member	Description
	Data Structures used at COR level.

JMXi-DETE-MOD	Contains the description of the JEM–Xi detector plane. Values indicate active and inactive pixels, bad anodes and their neighbours, calibration spectra overflow areas and permanent hotspots if there are any
Data Structures needed for Energy Correction See more details in Section B.3 and Tables 35- 38.	
JMXi-CALB-MOD	Lists the corrected upper limits of the bins used to convert the original 4096 energy channels into 256 calibration telemetry channels. This table is used to bin the calibration data only since this is binned in the DFEE and transmitted as housekeeping. The bin boundaries have been corrected for any ADC non-linearity that might arise during flight.
JMXi-FULB-MOD	Lists the corrected upper limits of the bins used to convert the original 4096 energy channels into 256 full imaging and spectral timing energy telemetry channels. The bin boundaries are corrected for ADC non-linearity.
JMXi-RESB-MOD	Lists the corrected upper limits of the bins used to convert the original 4096 energy channels into 8 restricted imaging telemetry channels The bin boundaries are corrected for ADC non-linearity.
JMXi-SPCB-MOD	Lists the corrected upper limits of the bins used to convert the original 4096 energy channels into 64 spectral mode telemetry channels The bin boundaries are corrected for ADC non-linearity.
JMXi-SPAG-MOD	Contains the fractional corrections in percent to the raw event energy gain coefficients for all event modes from the JEM–Xi instrument as determined by pre-flight calibrations and in-flight data. For each pixel the difference is determined compared to the average gain of the entire detector area. The second slice of this table contains the percent corrections to be applied for each anode due to anode deaths and instabilities. See also Section B.3
JMXi-FBDS-MOD	Lists the nominal energy boundaries of the PI channels for energy measurements obtained with full and spectral-timing modes. This data structure is also used as the EBOUNDS extension of the redistribution matrix file (RMF). See more details in Section B.3 and Table 38.
JMXi-RBDS-MOD	Lists the nominal energy boundaries of the PI channels for energy measurements obtained with restricted imaging mode. See more details in Section B.3 and Table 38.
JMXi-SBDS-MOD	Lists the nominal energy boundaries of the PI channels for spectra obtained in spectrum mode. See more details in Section B.3 and Table 38.
Data Structure used for position correction (see section B.4)	
JMXi-CORX-MOD	Contains the corrected X positions in mm from the center of detector for Full and Restricted Imaging event modes from the JEM–Xi instrument. It is a 2D table with axes along X and Y positions where the raw values are used. See more details in Section B.4.
JMXi-CORY-MOD	The same as JMXi-CORX-MOD but for Y positions
JMXi-PLLX-MOD	Gives the X value (mm) of the lower left corner of the pixel
JMXi-PLLY-MOD	Gives the Y value (mm) of the lower left corner of the pixel
JMXi-PSIZ-MOD	Gives size of each pixel (cm^2)
JMXi-PRED-MOD	Is the pixel redistribution description from the raw pixels on a regular pixel grid
Data Structures used for Dead Time derivation	

JMXi-DEAD-MOD	Contains the dead time model for the read time for different events for both 8MHz and 16 MHz operation of the on-board CPU. TRIGGERS lists the event counter ID number from the on-board software and DEAD8_1 and DEAD16_1 give the time in seconds to do the read in. The usual on-board CPU speed is 16 MHz. Also contains a keyword for the double trigger effect.
Data Structures used for background handling	
JMXi-DBKG-MOD	Contains maps giving the spatial distribution of background counts at a number of energy levels including information about detector areas that should nopt be used.
Data Structure used for imaging and source finding	
JMXi-COLL-MOD	Contains a collimator description in the form of two lists of the coordinates of the collimator lamellae intersections. X- and Y-coordinates of intersection at the top and at the bottom are given in columns XSECTBOT, YSECTBOT, XSECTTOP, and YSECTTOP.
JMXi-MASK-MOD	Contains the mask description of JEM–Xi. It is 2D table with axes along Mask X- and Y -axes.
JMXi-OPNC-MOD	Gives the coordinates (mm) of the centers of the open holes in the mask
JMXi-VIGN-MOD	Contains an array with vignetting factors for the JEM–Xi instrument. It is a 2D table with axes along X and Y-axes. This has been used to correct source intensities for collimator shadowing but is now obsolete.
JMXi-IROS-MOD	Contains some basic parameters for the component: j_ima_iros
Data Structure used for spectral analysis	
JMXi-ENRG-MOD	Contains the table of ENERG_LO (lower limit of channel in keV) and ENERG_HI (upper limit of channel in keV) to be used in conjunction with E_MIN and E_MAX as found in JMXi-FBDS-MOD, JMXi-RBDS-MOD or JMXi-SBDS-MOD for the spectral response matrix.

For full description of these and other data structures see the ISDC webpage.

B.2 The BPL group

The abbreviation "BPL" stands for backprojection lists. Essentially this is the Aperture Response Function describing the visible sky elements from a given detector pixel.

The group `JMXi-BPL.-GRP` contains a compressed table together with three auxiliary arrays plus vignetting arrays. Table 34 describes those Data Structures.

Table 34: Content of `JMXi-BPL.-GRP` Group.

Group Member	Description
JMXi-DALL-BPL	The d_allow array contains for each detector pixel a list of sky directions which have access to this pixel. ("access" here means that more half the pixel area is visible from above the mask along the direction in question) The number of sky-bins in the list corresponding to a given detector pixel is given as an entry in the d_allow_l array, the full 16-bit address of the first direction having access to the pixel is given in the d_allow_p array. The list itself is organized as a difference list: each direction defined by an 8-bit unsigned number giving the difference between in addresses of the previous direction and the current direction. Should two directions differ by more than 254 units, the difference will be written by N bytes with the value 255 and finally a byte with the remaining difference (after subtraction of N*255)
JMXi-DAWL-BPL	Number of sky pixels visible from a given detector pixel

JMXi-DAWP-BPL	Array giving the address of the first sky pixel visible from a given detector pixel
JMXi-DAST-BPL	The d_allow_st array contains for each detector pixel the address of the start of the corresponding list in the d_allow array.
JMXi-DMAP-BPL	51 arrays giving the number of detector pixels illuminated from each sky pixel (vignetting arrays). The 51 arrays corresponds to 51 different radius limits covering the range from 75 to 125 mm) used in selecting events from the shadowgrams.

For full description of these and other data structures see the ISDC webpage.

B.3   Energy Binning: ADC to PI

PHA Binning

The energy values of the events provided in the telemetry are given as a bin number from 0 to 255. These are non-linear groupings of the original 4096 bins of the onboard ADC. `JMXi-***B-MOD` data structures (Table 35) indicate the ADC bins covered by a given telemetry PHA bin. These data structures are part of the instrument model group `JMXi-IMOD-GRP` (Table 33). Each binning table gives a list of the highest ADC channel within each PHA bin.

Each of the different data-taking modes has its own binning table data structure fitting its telemetry energy resolution. Tables with fewer than 256 bins are just subsets of the full 256-bin table.

Table 35: Content of `JMXi-***B-Mod` Data Structures.

Column Name	Description
CHANNEL	Uppermost effective adc channel in a given telemetry bin

See also Section 3.2.1 for more details.

PI Binning

During automatic calibration the original PHA values of the events and spectra are converted into keV values based on the fitting of the Fixed Radiation Source System (FRSS) calibration spectra. The upper part of figure 26 shows the FRSS calibration spectra which are used to determine the detector gain on each of the four anode segments of both units at 4 minute intervals. The standard FRSS setup has a Cd-109 source with a Nickel window, but only one useable doublet is seen: the Cadmium 22.1/25.0 keV lines. This spectrum is shown by the full line.

Anodes 0 and 2 of unit JEM–X each have an Fe-55 source for calibration, and the calibration spectrum from these anode segments is shown with the dotted line. This spectrum is modelled as an unresolved doublet at 5.9/6.1 keV.

The FRSS spectrum is sent down as counts in each of 256 PHA channels (0 to 255) that cover logarithmically sized bins of the 4096 ADC channels of the ADC that registers the Pulse Height Amplitude. The uppermost ADC channel appearing in each PHA channel is given in the binning table JMXi-CALB-MOD in the instrument model group. The upper channel in the last bin must always be 4095. The logarithmic binning of the ADC channels is chosen to reflect the energy resolution of the detector, which is roughly $\Delta E = 0.47\sqrt{E(in keV)}$.

Many things are expected to affect the pulse size the ADC will register for a given event energy: detector temperature, gas pressure, micro-strip plate charging, the age of the gas, and maybe some as yet unknown influences. This is why FRSS spectrum are sent in the housekeeping every 256 seconds to correct the gain
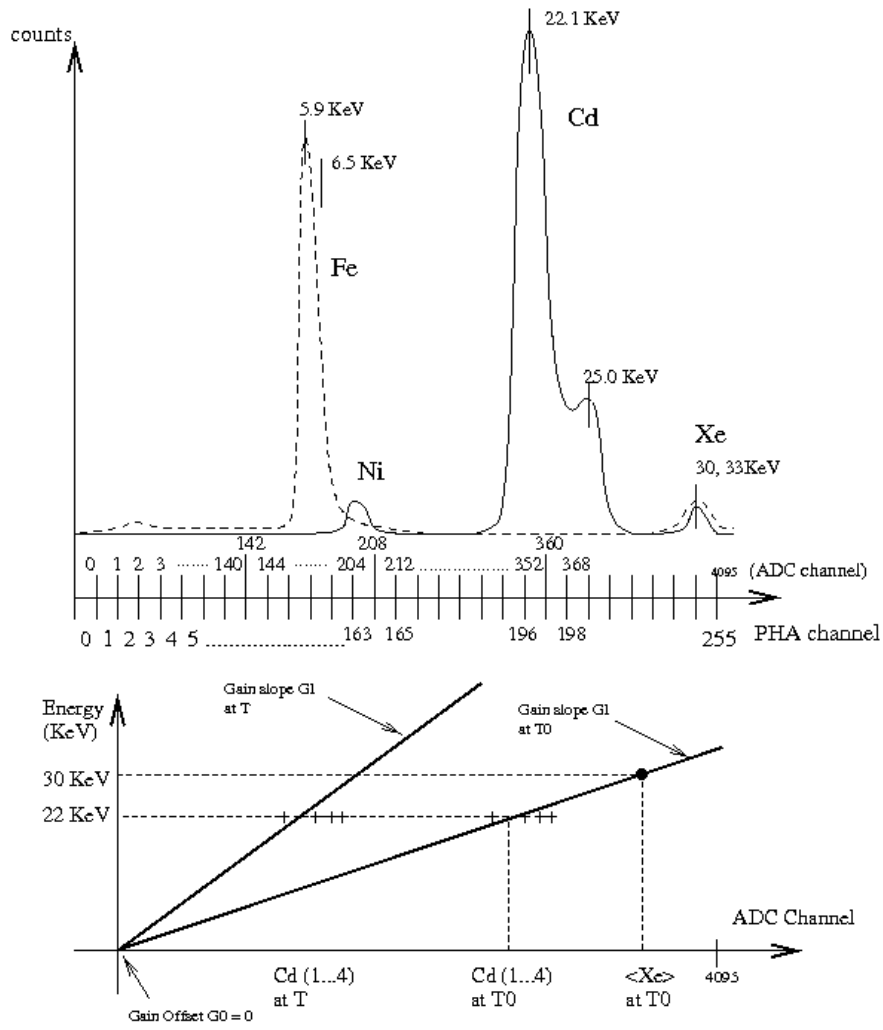
Figure 26: FRSS calibration spectra.

continuously.

Since the ADC is known to be linear to better than the accuracy used by the telemetry we can assume a relationship between event energy and ADC channel, n:

$$E = G_0 + G_1.n \tag{1}$$

The PHA-binned spectra are fitted by gaussian line models and the resulting peak positions at 22.1KeV and 6 KeV are used to find the 'raw' gain conversion factor G1, in KeV per ADC channel for the four minute interval. Both this value of G1 and the peak ADC channels are saved to JMXi-GAIN-CAL as keywords.

The contents of JMXi-GAIN-CAL is tabulated over an entire revolution (and over the entire mission) in a gain history table JMXi-GAIN-CAL-IDX, which is read by j_cor_gain to perform the gain conversion.

In the gain correction program *j_cor_gain* the peak positions are divided by the positions at a reference time and then multiplied by the overall gain of the entire detector at that time, determined from the Xe fluorescence lines in blank field observations at the reference time. This gives the time-corrected gain conversion factor that is used to convert individual event or spectral PHA values to PI values.

In theory the detector ADC offset, G0, can be non-zero, but since an offset factor is already subtracted from the measured energy value by the on-board software, this value will in practice usually be zero. The value of the zero-energy ADC channel is determined by the electronic calibration procedure at the beginning of every revolution. Currently this corresponds to the value subtracted on board. If the zero-point ADC value changes an on-board patch can be used to return the offset value seen in the telemetry to zero again.

G_1 is the gain slope or linear calibration parameter. See the lower part of figure 26. In practice G0 is zero and typical values of G1 are 0.07 KeV per ADC channel for JEM–X1 and 0.05 KeV per ADC channel for JEM–X2.

Table 36: Content of `JMXi-GAIN-CAL-IDX` Index.

Column Name	Description
REVOL	Revolution number
OBT_ACQ	OBT acquisition time in the middle of the integration
INT_TIME	Effective integration time
TSTART	Start time of interval covered by this file
TSTOP	End time of interval covered by this file
G_ZERO_1	Zero channel detector gain from spectrum 1
G_CAL_1	First order detector gain from spectrum 1
RESOL_1	Energy resolution for spectrum 1
PKINT_1	Peak intensity in counts for spectrum 1
PKCHAN_1	ADC channel of line peak for spectrum 1
G_ZERO_2	Zero channel detector gain from spectrum 2
G_CAL_2	First order detector gain from spectrum 2
RESOL_2	Energy resolution for spectrum 2
PKINT_2	Peak intensity in counts for spectrum 2
PKCHAN_2	ADC channel of line peak for spectrum 2
G_ZERO_3	Zero channel detector gain from spectrum 3
G_CAL_3	First order detector gain from spectrum 3
RESOL_3	Energy resolution for spectrum 3
PKINT_3	Peak intensity in counts for spectrum 3
PKCHAN_3	ADC channel of line peak for spectrum 3
G_ZERO_4	Zero channel detector gain from spectrum 4
G_CAL_4	First order detector gain from spectrum 4
RESOL_4	Energy resolution for spectrum 4
PKINT_4	Peak intensity in counts for spectrum 4
PKCHAN_4	ADC channel of line peak for spectrum 4

Table 37: Content of `JMXi-GAIN-CAL` Index.

Column Name	Description
RESID_1	Residual counts of calibration spectrum 1
RESID_2	Residual counts of calibration spectrum 2
RESID_3	Residual counts of calibration spectrum 3
RESID_4	Residual counts of calibration spectrum 4

No useful values of the gain parameters can be found if there is a problem processing the calibration spectra. This problem only arises when housekeeping packets are missing, and is relatively rare. Using either linear interpolation of the gain history table or the decay-model smoothing, makes an unbroken gain history in these cases.

Pre-launch testing of the flight models and experiments with the flight spare indicate that the strength of the FRSS sources illuminating small spots on the detector causes charging phenomena on the microstrip plate such that the gain at these points is not characteristic of the entire anode segment it represents and may also show sudden drops where small discharges occur. This problem is resolved by normalising the gain at each calibration point with the gain determined from the Xe line seen over the entire detector at a particular reference time for which we have plenty of blank-field data. Temporal changes in these normalised gains are then a direct reflection of the gain variation over the entire detector. Reference values of the Xe line and calibration source positions are stored in keywords in the header of JMXi-SPAG-MOD datastructure in the IMOD group (IC data).

Discharge glitches in the calibration spectra are smoothed out of the time variation correction by using a time-smoothing model across an entire revolution of data in *j_cor_gain*.

All data, including the FRSS spectra, are expected to show the 30–33 keV Xenon fluorescence doublet to some extent. These lines are too weak to act as temporal gain variation markers but, at can determined from summing blank field data, how well gain determination functions over the entire detector area.

The correlation (gain) between the PHA and PI channels varies both in time due to temperature, pressure and voltage fluctuations, and across the surface of the detector.

The major part of the spatial gain variation arises from the construction of the microstrip plate and the uniformity of the various strips. This variation is stored as percent differences in line ADC positions in data structure JMXi-SPAG-MOD (Table B). These values have been determined by pre-flight calibrations. However there are secondary corrections to these tables, determined by in-flight monitoring, to correct for dead and unstable anode strips. This Data Structure contains two 2D arrays along X and Y axes with fractional change for each pixel determined by pre-flight calibration in the first slice and secondary corrections determined since launch in the second slice.

The list of the energy boundaries of the PI channels can be found in JEMXi-*BDS-MOD Data Structure (Tables 33,38). Some more details can be also found in Section 3.2.2).

In rebinning our events and spectra from PHA channels to PI channels, we can expect to introduce some inaccuracy into the energy measurements. However the PI channels are carefully chosen to reflect the inherent energy resolution of the detector, so this added error is small compared to the detector energy resolution.

Table 38: Content of `JEMXi-*BDS-MOD` Data Structures.

Column Name	Description
CHANNEL	Channel number
E_MIN	Minimum energy for this channel in keV
E_MAX	Maximum energy for this channel in keV

B.4 Detector positions

Initially the position of an event is given as raw detector pixel numbers, 0–255, where value (0,0) lies outside the active detector area. RAWX and RAWY are integers. During COR processing level, these detector values are corrected for known errors in the position determination across the detector area (with the the help of `JEMXi-CORX-MOD` and `JEMXi-CORY-MOD`). The position correction models provide detector coordinates of each pixel in millimeters from the center of the detector (columns DETX and DETY).

The center-most intersection of the collimator defines the detector center. Each shadowgram pixel is 1 mm, and the origin of the detector coordinates is at [127.5, 127.5] expressed as corrected pixels.

B.5 Detector Response Matrix

The IC file JMXi-RMF-GRP.fits is a grouping table with three children: `JMXi-RMF.-RSP`, `JMXi-FBDS-MOD` and `JMXi-AXIS-ARF`.

`JMXi-RMF.-RSP` is the standard detector response normalized to the sum of 1.0 over the detector channels, see Table 39 for more details.

Table 39: Content of `JMXi-RMF.-RSP` Data Structure.

Column	Description
ENERG_LO	Low energy bound of the energy bin, keV
ENERG_HI	High energy bound of the energy bin, keV
N_GRP	Number of channel subsets for the energy bin
F_CHAN	First channel in each subset for the energy bin
N_CHAN	Number of channels within each subset for the energy bin
MATRIX	Response values for each channel subset for the energy bin

`JMXi-AXIS-ARF` contains ancillary response information for an on-axis source in the JEM–X field of view, see Table 40 for details.

Table 40: Content of `JMXi-AXIS.-ARF` Data Structure.

Column	Description
ENERG_LO	Lower energy boundaries of bins
ENERG_HI	Upper energy boundaries of bins
SPECRESP	Effective area in cm^2 of the detector for a given source taking all effects into account

`JMXi-FBDS-MOD` holds the electronic channels of the detector in Full Imaging Mode. This data structure is a copy of the data structure with the same name in `JMXi-IMOD-GRP.fits` (See Tables 33 and 38). It is simply repeated for completeness.

C   Science Data Products

C.1   *j_correction*

This script corrects all data available within the Science Window Group for a given JEM-X detector.

C.1.1   *j_cor_gain*

The executable *j_cor_gain* corrects all science data received for the condition of the individual pixels in the detector, temporal and spatial changes in the detector gain. The PHA channels of every event are converted to PI energies. Event energies, randomized within their bin and given as floating point keV values, are given in column ENERGY of JMXi-****-COR.

For science events the output consists of energy values given in PI channels. For spectra taken in SPEC mode, the output are spectra rebinned into PI channels (Table 42). Whenever poor gain determination occurs the relevant events or spectra are flagged in the STATUS column of `JMXi-****-COR`, see the possible STATUS values in Table 41.

C.1.2   *j_cor_position*

j_cor_position converts detector positions corrected for microstrip plate irregularities into absolute values (mm from centre of detector). Event positions are randomized within the pixel designated by the two event telemetry values RAWX and RAWY, and given as floating point values in columns DETX and DETY of JMXi-****-COR.

If an event falls in an area where the position determination is known to be bad, then a flag is raised in the STATUS column of the relevant -COR extension. Bad areas of the detector are signaled in the correction table extensions by having one or both position values equal to 1000.0 plus the corrected position value.

The possible values of STATUS are given in the Table 41

Table 41:   Possible corrected event STATUS values

Value	Meaning
0	Event good for all analysis purposes
4	Events fall on anode segment with a dead anode in the calibration area (currently 4th anode on JEM-X 2)
8	Event has uncertain time correlation
16	Event comes from an anode regarded as bad
32	Event comes from position next to a bad anode
64	Bad energy due to poor detector gain history determination
128	Bad energy determination due to event position
256	Bad X position determination
512	Bad Y position determination
1024	Possibly leaked event from a calibration source
2048	Event detected before SETUP at beginning of Science Window
4096	Event from outside active area of detector
8192	Event coming from known hotspot on detector

As you see these STATUS values are the powers of 2. If events are failed in more then one way then STATUS is equal to the sum of the corresponding values, the back reconstruction has no problems and rise no ambiguity.

Events that fail in one or more ways can still be used for some purposes: binned spectra don't require

good position determinations; uncertainties in gain determination don't affect sky images etc. Therefore each program here after can select all the events that are appropriate for making high quality science data products with the best possible statistics.

The content of the corrected data structures for the different data modes is given in Table 42

Table 42: Content of `JMXi-****-COR` Data Structures.

Column Name	Description
JMXi-FULL-COR	
DETX	Corrected X location of the event on the detector
DETY	Corrected Y location of the event on the detector
PI	Pulse Invariant energy of the event
STATUS	'Goodness' of the corrected events
JMXi-REST-COR	
DETX	Corrected X location of the event on the detector
DETY	Corrected Y location of the event on the detector
REST_PI	Pulse Invariant energy of the event
STATUS	'Goodness' of the corrected events
JMXi-RATE-COR	
RATE_CORR	Corrected count rate
STATUS	'Goodness' of the data
JMXi-SPTI-COR	
PI	Pulse Invariant energy of the event
STATUS	'Goodness' of the corrected events
JMXi-SPEC-COR	
SPEC_CORR	Corrected Counts in the 64 PI channels
STATUS	'Goodness' of the corrected spectra

The TIME data do not have a -COR data structure, as the on-board time is calculated at ISDC during the Data Preparation, so the corrected TIME events are in `JMXi-TIME-PRP`

C.2   *j_gti*

This script builds Good Time Interval information from housekeeping data, information about satellite stability, and data gaps. As a result the program writes the merged GTI into the output GTI table `JMXi-GNRL-GTI` (Table 43).

Table 43: Content of `JMXi-GNRL-GTI` Data Structure.

Column Name	Description
OBT_START	On-board time of start of the GTI
OBT_END	On-board time of end of the GTI
START	IJD time of start of the GTI
STOP	IJD time of stop of the GTI
UTC_START	UTC time of start of the GTI
UTC_STOP	UTC time of stop of the GTI

C.3   *j_dead_time*

At this step dead time is calculated. It is saved to `JMXi-DEAD-SCP` (Table 44) which is stored once for each science window.

Table 44: Content of `JMXi-DEAD-SCP` Data Structure.

Column Name	Description
OB_TIME	OBT of the dead time calculation
DEADTIME	Fractional input dead time not including grey filter losses
RATE_COR	Factor for correcting count rates, not including grey filter losses
DEAD_EFF	Total effective dead time including grey filter

C.4   *j_cat_extract*

The output catalogue of the selected sources is written to a new source list with the same structure `JMXi-SRCL-CAT`.

Table 45: Content of `JMXi-SCAL-BKG` and `JMXi-SCAL-DBG` Data Structures.

Column Name	Description
DELTAOBT	Delta-OBT from beginning of Science Window
SCALFACT	Scaling factor

C.5   *j_image_bin*

This script creates shadowgrams in several, user-defined energy bands. The result shadowgram can be represented in either 'skew' or 'standard' system and is appended to the index group `JMXi-EVTS-SHD-IDX`.

Table 46: Content of `JMXi-EVTS-SHD-IDX`

Column Name	Description
OBTSTART	OBT start of integration
OBTEND	OBT end of integration
TELAPSE	Total observation elapsed time in seconds
EXPOSURE	Mean exposure time over the detector plane
CHANMIN	Lowest channel of the energy range
CHANMAX	Highest channel of the energy range
SHDIDEN	Shadowgram identification number
SHDTYPE	Shadowgram type (1:standard, 2:raw, 3:regularized)
EVNTYPES	Code for event types (0:FULL, 1:REST, -1:both)

C.6   *j_imaging*

C.6.1   *j_ima_iros*

This executable makes a basic image reconstruction for the input shadowgrams in the index group (`JMXi-EVTS-SHD-IDX`). The resulting sky image `JMXi-SKY.-IMA` is constructed backprojection.

The information on the found sources and their fluxes is written to the `JMXi-SRCL-RES` data structure.

Table 47: Content of `JMXi-SRCL-RES` Data Structure.

Column Name	Description
SOURCE_ID	ISDC unique source identifier
DAY_ID	Modified Julian Date of source's first identification
NAME	One commonly used name for the source
CLASS	source classification code

RA_OBJ	Source right ascension in degrees
DEC_OBJ	Source declination in degrees
ERR_RAD	Error radius
RELDIST	Relative distance of the source ($= d/(r1 + r2)$), where d is a distance to catalog source identified with the source and rn are the respective error radii of the sources.
SPA_MODL	Model for source spatial extension (point, disk, ellipse, square, gaussian, Bspline, etc..)
SPA_NPAR	Number of parameters for source spatial extension
SPA_PARS	Parameters for source spatial extension
SPE_MODL	Model for source spectrum (XSPEC syntax)
SPE_NPAR	Number of parameters for source spectrum
SPE_PARS	Parameters for source spectrum
VAR_MODL	Model for source intensity variability (const, sin, burst)
VAR_NPAR	Number of parameters for source intensity variability
VAR_PARS	Parameters for source intensity variability
COMMENTS	Comments
SPI_FLUX_1	SPI flux in the soft SPI energy band
SPI_FLUX_2	SPI flux in the hard SPI energy band
ISGR_FLUX_1	ISGRI flux in the soft ISGRI energy band
ISGR_FLUX_2	ISGRI flux in the hard ISGRI energy band
PICS_FLUX_1	PICsIT flux in the soft PICsIT energy band
PICS_FLUX_2	PICsIT flux in the hard PICsIT energy band
JEMX_FLUX_1	JEMX flux in the soft JEMX energy band
JEMX_FLUX_2	JEMX flux in the hard JEMX energy band
E_MIN	Lower energy boundaries
E_MAX	Upper energy boundaries
FLUX	Flux values
FLUX_ERR	Flux errors
SEL_FLAG	Source selection flag
DETSIG	Source detection significance in JEM-X
FLAG	Generic flag
COSX_JMX	Direction cosine between X-axis and source in instrument coordinates
COSY_JMX	Direction cosine between Y-axis and source in instrument coordinates
COSZ_JMX	Direction cosine between Z-axis and source in instrument coordinates

C.6.2   *q_identify_srcs*

q_identify_src updates the columns in `JMXi-SRCL-RES` with source name and identifier.

C.7   *j_src_extract_spectra*

This script derives JEM-X countrate spectra for all sources found in the current Science Window.

Output is in three data structures: `JMXi-SRCL-BSP` contains the background spectra at each source location, which have been used to correct the source spectrum itself. Background spectra are stored in PHA II format.

`JMXi-SRCL-SPE` contains the spectra for each individual found source. Spectra are stored in PHA II format.

`JMXi-SRCL-ARF` contains ancillary response for each source. The ARFs are stored in the ARF II format. (The ARF is scaled to the total detector area to correspond to the stored spectra. The scaling will probably be changed so that it corresponds to the source illuminated area.)

Table 48: Content of `JMXi-SRCL-BSP` Data Structure.

Column Name	Description
SPEC_NUM	Reference Number of spectrum in this row
ROWID	Unique identifier of spectrum
CHANNEL	Array of channel numbers for the countrates
RATE	Array of countrates in the defined channels
STAT_ERR	Array of estimated statistical uncertainty of the countrates
SYS_ERR	Array of estimated systematical uncertainty of the countrates
QUALITY	Array of quality flags for the channels
EXPOSURE	Effective integration time for the spectrum
TELAPSE	Total elapsed time of the data in seconds
ONTIME	Sum of good time intervals in seconds
DEADC	Deadtime correction factor
TFIRST	Start of the integration time interval in IJD
TLAST	End of the integration time interval in IJD

Table 49: Content of `JMXi-SRCL-SPE` Data Structure.

Column Name	Description
SPEC_NUM	Reference Number of spectrum in this row
ROWID	Unique identifier
CHANNEL	Array of channel numbers for the countrates
RATE	Array of countrates in the defined channels
STAT_ERR	Array of estimated statistical uncertainty of the countrates
SYS_ERR	Array of estimated systematical uncertainty of the countrates
QUALITY	Array of quality flags for the channels
BACKFILE	File and row of corresponding background spectrum
BACKSCAL	Background scaling factor
ANCRFILE	File and row of corresponding ARF
EXPOSURE	Effective integration time for the spectrum
TELAPSE	Total elapsed time of the data in seconds
ONTIME	Sum of good time intervals in seconds
DEADC	Deadtime correction factor
TFIRST	Start of the integration time interval in IJD
TLAST	End of the integration time interval in IJD
EVT_TYPE	Event type

Table 50: Content of `JMXi-SRCL-ARF` Data Structure.

Column Name	Description
ARF_NUM	Reference Number of ARF data in this row
ENERG_LO	Lower energy boundaries of bins
ENERG_HI	Upper energy boundaries of bins
SPECRESP	Effective area in cm^2 of the detector for a given source taking all effects into account

C.8 *j_src_extract_lc*

This application extracts energy-binned light curves for each found point source in the FOV. Background subtraction is an integral part of the data extraction. The only used executable is *j_src_lc*.

C.8.1   *j_src_lc*

Creates binned lightcurves for each found source in FOV. The output data structure `JMXi-SRC.-LCR` (see Table 51) contains a countrate light curve for a given source and a given energy range of the JEM-Xi instrument.

Table 51: Content of `JMXi-SRC.-LCR` Data Structure.

Column Name	Description
TIME	Time of measurement for the bin
TIMEDEL	Integration time for the bin
RATE	Countrate in the given energy band
ERROR	Countrate error in the the given energy band
BRATE	Background countrate in the given energy band
BERROR	Background countrate error in the given energy band
BARYTIME	Barycentric time for the bin

C.9   *j_bin_spectra*

This script bins events or Spectral Mode data without deconvolution.

C.9.1   *j_bin_evts_spectra*

This executable generates detector spectra for a single JEM-X unit from Full Imaging, Restricted Imaging or Spectral/Timing events by binning the event data.

The output data structures are `JMXi-FULL-DSP`, `JMXi-REST-DSP` and `JMXi-SPTI-DSP`. These data structures are compatible with XSPEC.

Table 52:   Content of `JMXi-FULL-DSP`, `JMXi-REST-DSP` and `JMXi-SPTI-DSP` Data Structures.

Column Name	Description
SPEC_NUM	Reference Number of spectrum in this row
ROWID	Unique descriptive string for each spectrum
CHANNEL	Array of channel numbers for the countrates
RATE	Array of countrates in the defined channels
STAT_ERR	Array of estimated statistical uncertainty of the countrates
SYS_ERR	Array of estimated systematical uncertainty of the countrates
QUALITY	Array of quality flags for the channels
BACKFILE	File and row of corresponding background spectrum
BACKSCAL	Background scaling factor
EXPOSURE	Effective integration time [s] for the spectrum
TSTART	Start of the integration time interval in IJD
TSTOP	End of the integration time interval in IJD

C.9.2   *j_bin_bkg_spectra*

This executable generates time resolved spectra for a single JEM-X detector by rebinning background model data to spectra.

The output data structures are listed in Table 53 and has structure similar to one described in Table 52 but without BACKFILE and BACKSCAL columns.

Table 53:   List of the *j_bin_bkg_spectra* output Data Structures

Name	Description
JMXi-FULL-BSP	Contains time resolved background spectra for Full Imaging data.
JMXi-REST-BSP	Contains time resolved background spectra for Restricted Imaging data.
JMXi-SPEC-BSP	Contains time resolved background spectra for Spectrum Format data.
JMXi-SPTI-BSP	Contains time resolved background spectra for Spectral/Timing data.

C.10   *j_bin_lc*

The *j_bin_lc* script bins event data into lightcurves in different energy bands. There are two possible outputs of this program: normal lightcurves and period-folded lightcurves. In the case of nPhaseBins=0 Data Structures JMXi-DETE-LCR-IDX and JMXi-DETE-LCR are filled. JMXi-DETE-LCR contains a countrate lightcurve for the whole JEM-Xi detector binned from event or countrate data.

In the case nPhaseBins>0 Data Structures JMXi-DETE-FLC-IDX and JMXi-DETE-FLC are filled. JMXi-DETE-FLC contains a countrate lightcurve folded with a given period for the whole JEM-Xi2 detector binned from event or countrate data.

Table 54: Content of `JMXi-DETE-LCR-IDX` Data Structure.

Column Name	Description
DATAMODE	Science format used to create lightcurve (FULL or REST)
CHANMIN	Lowest channel of the energy range
CHANMAX	Highest channel of the energy range
E_MIN	Lower bound of the energy range
E_MAX	Upper bound of the energy range

Table 55: Content of `JMXi-DETE-LCR` Data Structure.

Column Name	Description
TIME	Time of measurement for the bin
TIMEDEL	Integration time for the bin
RATE	Countrate in the given energy band
ERROR	Countrate error in the the given energy band
BRATE	Background countrate in the given energy band
BERROR	Background countrate error in the given energy band
BARYTIME	Barycentric time for the bin

Table 56: Content of `JMXi-DETE-FLC-IDX` Data Structure.

Column Name	Description
DATAMODE	Science format used to create lightcurve (FULL or REST)
CHANMIN	Lowest channel of the energy range
CHANMAX	Highest channel of the energy range
E_MIN	Lower bound of the energy range
E_MAX	Upper bound of the energy range
PERIOD	Period in seconds with which the lightcurve was folded
PHASZERO	Time of phase zero in IJD

Table 57: Content of `JMXi-DETE-FLC-IDX` Data Structure.

Column Name	Description
PHASE	Phase of the center of the bin

PHASEDEL	Half width in phase units (0-1) for the bin
RATE	Countrate in the given energy band
ERROR	Countrate error in the the given energy band
BRATE	Background countrate in the given energy band
BERROR	Background countrate error in the given energy band
BARYTIME	Barycentric time for the bin

C.11 Observation group level analysis

C.11.1 *j_ima_mosaic*

This executable creates the mosaic images of all the science windows used in the analysis. The output is written to the `J_MOSAIC_#.fits` files, where the number # indicates the energy band. In these files you find the mosaic images JMXi-MOSA-IMA data structures for each kind of "IMATYPE" mosaic maps. However, only some of the included keywords are relevant, as shown in the following table.

Table 58: Content of `JMXi-MOSA-IMA-IDX`

Column Name	Description
IMATYPE	Type of image
NAXIS1	Size of the mosaic image in axis 1
NAXIS2	Size of the mosaic image in axis 2
EXTNAME	Extension name of the template
INSTRUMENT	JEM-X instrument: JMX1 or JMX2
TSTART	Start time of the observation (IJD)
TSTOP	End time of the observation (IJD)
TELAPSE	Total elapsed time (s)
BUNIT	Pixel units
CTYPE1	Projection name: "RA—TAN","1962"
CTYPE2	Projection name: "DEC—TAN","1962"
CRVAL1	Sky coord. ref. 1. axis (deg)
CRVAL2	Sky coord. ref. 2. axis (deg)
CD1_1	Transformation (deg)
CD2_2	Transformation (deg)
CD1_2	Transformation (deg)
CD2_1	Transformation (deg)
CRPIX1	Sky pixel ref. 1. axis (pixel)
CRPIX2	Sky pixel ref. 2. axis (pixel)
E_MIN	Lower Energy limit (keV)
E_MEAN	Mean Energy (keV)
E_MAX	Upper Energy limit (keV)
IMATYPE	Type of sky map shown

C.11.2 *src_collect*

This executable combines source data obtained by the imaging analysis for individual Science Windows into a single table covering an Observation Group. It is possible to retrieve only selected results, *e.g.,* just for a given source. The result is written to jemxi/jmxi_obs._res.fits file. The description of JMXi-OBS.-RES data structure is given in the Table 59.

Table 59: Content of `JMXi-OBS.-RES` Data Structure.

Column Name	Description
SWID	Science Window identifier

SOURCE_ID	ISDC unique source identifier
NAME	One commonly used name for the source
RA_OBJ	Source right ascension in degrees
DEC_OBJ	Source declination in degrees
ERR_RAD	Error radius in degrees
DETSIG	Source detection significance in JEM-X
OFFANGLE	Off-axis angle in degrees
EBIN_NUM	Number of used elements in E_MIN, E_MAX, FLUX, FLUX_ERR
E_MIN	Lower energy boundaries
E_MAX	Upper energy boundaries
FLUX	Flux values in counts$(100cm^2)^{-1}s^{-1}$
FLUX_ERR	Flux errors in counts$(100cm^2)^{-1}s^{-1}$
DEADC	Mean deadtime (& greyfilter) correction factor
EXPOSURE	Mean exposure time over the detector plane in seconds
TSTART	Start time of the observation (IJD)
TSTOP	End time of the observation (IJD)
SEL_FLAG	Source selection flag
FLAG	Generic flag
COSX_JMX	Direction cosine between X-axis and source in instrum. coordinates
COSY_JMX	Direction cosine between Y-axis and source in instrum. coordinates
COSZ_JMX	Direction cosine between Z-axis and source in instrum. coordinates

D *jemx_science_analysis* parameters description

Table 60: *jemx_science_analysis* parameters description

Name	Type	Description
ogDOL	string	DOL of the Observational Group to be analyzed. default: " "
jemxNum	integer	JEM-X instrument number (1 or 2) default: `2`
startLevel	string	Analysis level at which analysis begins. The names of the possible analysis levels are listed in the table 4 default: "`COR`"
endLevel	string	Analysis level at which analysis finishes. The names of the possible analysis levels are listed in the table 4. default: "`IMA2`"
skipLevels	string	Analysis levels to be skipped (use with caution!) default: "`BKG,LCR,BIN_T`"
chatter	integer	Verbosity level possible values: `0 – 5` `2` – normal default: `2`
clobber	boolean	Clobber existing output data? default: `y`
osimData	boolean	Input data was created by ISDC simulator? default: `n`
ignoreScwErrors	boolean	Ignore all SW processing errors? default: `n`
Parameters copied to several binning data tasks		
nChanBins	integer	Number of energy-resolved shadowgrams to create. If < 1, shadowgrams created in standard bands. Possible values: `-7 – 100` default: `4`
chanLow	string	Lower channel boundaries for shadowgrams and lightcurves default: "`46 83 129 160`"
chanHigh	string	Upper channel boundaries for shadowgrams and lightcurves default: "`82 128 159 223`"
timeStart	real	Start of time interval [IJD] `-1` – use Science Window bounds default: `-1`

timeStop	real	End of time interval [IJD] `-1` – use Science Window bounds default: `-1`
nPhaseBins	integer	Number of phase bins (N<0 = abs(N) equally spaced bins) default: `0`
phaseBins	string	Phase bin sizes, separated by space default:
radiusLimit	real	Use events within this detector radius [mm] possible values: `0.0` –`130.0` default: `122.0`

<table>
<tr><td colspan="3" align="center">Parameters required for Instrument Characteristics selection</td></tr>
<tr><td>IC_Group</td><td>string</td><td>DOL of the Instrument Characteristics master group. This group is accessed by the script to find the calibration data relevant for the current Science Window.
default:""<br>"<code>../../idx/ic/ic_master_file.fits[GROUPING,1]</code>"</td></tr>
<tr><td>IC_Alias</td><td>string</td><td>Selection alias for Instrument Characteristics. By changing this alias different instances of IC data can be selected.
default: "<code>OSA</code>"</td></tr>
<tr><td>instMod</td><td>string</td><td>DOL of JEM-X Instrument Model Group
(empty=find in IC)
default:""</td></tr>
<tr><td>response</td><td>string</td><td>Filename of standard RMF and ARF
(empty=find in IC)
default:""</td></tr>
</table>

<table>
<tr><td colspan="3" align="center">Parameters specific to corrections (COR)</td></tr>
<tr><td>COR_gainHist</td><td>string</td><td>DOL of the Index Group with gain variation history. This data is stored per revolution and thus not accessible via the IC system.
default: ""</td></tr>
<tr><td>COR_gainModel</td><td>integer</td><td>Gain history smoothing model to be applied
possible values:
<code>-1</code> (default) Let the algorithm choose between the optimal model to be used.
<code>0</code> Linear interpolation between gain history values,
<code>1</code> This model is obsolete.
<code>2</code> Exponential gain decay with linear segment immediately after switch. Models normal time variation of gain in a revolution
<code>3</code> Non-trigger dependent model.
<code>4</code> Hardware trigger dependency in the smoothing. If there is no significant trigger variation during the revolution, then the program defaults back to model 3.
default: <code>-1</code></td></tr>
</table>

COR_outputExists	boolean	Assume already existing output default: "n"
COR_randPos	boolean	Should output positions be randomized within the pixel? default: "n"

Parameters specific to Good Time Intervals (**GTI**)		
GTI_gtiUser	string	DOL of the input user GTI default: " "
GTI_TimeFormat	string	Time format to be used possible values: "IJD", "UTC", "OBT" default: "IJD"
GTI_BTI_Dol	string	DOL of a bad time interval table. default: " "
GTI_BTI_Names	string	Input Bad Time Interval names to be considered default: "BAD_RESPONCE BAD_CONFIGURATION"
GTI_attTolerance	real	Accepted attitude variability [arc min] default: 0.5
GTI_limitTable	string	DOL of table with parameter limits default: " "
GTI_gtiJemxNames	string	Names of instrumental GTIs to be included in merged GTI default: " "
GTI_gtiScNames	string	Names of spacecraft GTIs to be included in merged GTI default: " "
GTI_MergedName	string	Name of merged GTI to be used in analysis default: "MERGED"
GTI_Accuracy	string	Used accuracy for OBT to IJD conversion and vice versa possible values: "any", "inaccurate", "accurate" default: "any"
GTI_AttStability_Z	real	Accepted attitude stability tolerance of Z axis [arcmin] default: "3.0"

Parameters specific to Dead Time Calculation (**DEAD**)		
DEAD_outputExists	boolean	Assume already existing output default: "n"

Parameters specific to catalog extraction (**CAT_I**)		
CAT_I_refCat	string	DOL of the Reference Catalog default: "$ISDC_REF_CAT"

CAT_I_usrCat	string	DOL of the User Catalog. Currently not used. default: ""
CAT_I_radiusMin	string	Low limit for the position selection. Can be multiple limits with separating blank default: "0 2.4"
CAT_I_radiusMax	string	High limit for the position selection. Can be multiple limits with separating blank default: "2.4 5.8"
CAT_I_fluxDef	string	Column used for flux selection. default: "0"
CAT_I_fluxMin	string	Low limit for flux selection. default: " "
CAT_I_fluxMax	string	High limit for flux selection. default: " "
CAT_I_class	string	Object class of sources to select default: " "
CAT_I_date	real	IJD for the public data. possible values: <0 – all public; 0 – all private; >0 – according to DAY_ID default: "-1"
Parameters specific to shadowgram binning (**BIN_I**)		
BIN_I_evtType	integer	Event type possible values: 0 – FULL, 1 – REST, -1 – both default: -1
BIN_I_shdType	integer	Type of shadowgram possible values: 0 – skew 1 – shadowgram based on corrected event positions 2 – shadowgram based on raw event positions (required for j_ima_iros) 3 – shadowgram based on regularized detector pixels default: 2
BIN_I_shdRes	string	DOL of the output shadowgrams default: " "
BIN_I_rowSelect	string	CFITSIO selection string on events. Ensures removal of all hotspot events and other seriously bad events default: "&&STATUS<256&& "

BIN_I_gtiNames	string	Names of GTI tables to be used default: " "
BIN_I_chanLowDet	string	Three lower channel boundaries for shadowgrams for source detection default: " 46 96 135"
BIN_I_chanHighDet	string	Three upper channel boundaries for shadowgrams for source detection default: "95 134 178"

Parameters specific to imaging (**IMA**)		
IMA_makeNewBPL	boolean	Do you want to create a new backprojection file ? default: `no`
IMA_newBackProjFile	string	Base name of new backprojection file default: " "
IMA_detAccLimit	integer	Acceptance limit in JMXi-DETE-MOD data structure. Possible values: `1` – `65535` default: `16384`
IMA_skyImageDim	integer	Sky image dimension. Possible values: 1:255, 2:511. default: `2`
IMA_useDeadAnodes	boolean	Do you want to include dead anodes areas ? default: `no`
IMA_maxNumSources	integer	Max number of sources in IROS loop default: `10`
IMA_edgeEnhanceFactor	real	Edge enhancement factor. It is used to convert the sky-images to significance maps by amplifying the peaks near the edge relative to those near the center default: `1.0`
IMA_loopLimitPeak	real	Fractional peak power to stop IROS loop default: `0.025`
IMA_detSigSingle	real	Detection significance for source acceptance default: `12.0`
IMA_skyRadiusFactor	real	Sky radius limit factor default: `1.0`
IMA_radiusLimit0	real	Detector radius limit E < 6 keV (mm) default: `120.0`
IMA_radiusLimit1	real	Detector radius limit 6 < E < 12 keV (mm) default: `120.0`
IMA_radiusLimit2	real	Detector radius limit 12 < E < 20 keV (mm) default: `1107.0`

IMA_radiusLimit3	real	Detector radius limit E > 20 keV (mm) default: `110.0`
IMA_interactionDepth	real	Mean depth of interaction in the detector (mm) default: `3.0`
IMA_hotPixelLimit	real	Hot pixel limit factor above average default: `4.0`
IMA_skyImagesOut	string	Type of output sky images. There are the following types: RECTIFIED: Rectified (cleaned) intensity maps (in counts/cm^2/s). VARIANCE: Variance maps. RECONSTRUCTED: Reconstructed Residual+Sources maps (in counts/cm^2/s) which only differ from the RECTIFIED maps if sources have been found. RAWINTENSITY: Raw intensity (strength) maps (in counts), for which the vignetting correction is not applied. RESIDUAL: Intensity map (in counts/cm^2/s) after all found source contributions have been subtracted PIF: activate the PIF-weighted image generation algorithm (not to be used with mosaic_spec) Only the first five letters are required. default: "`RECONSTRUCTED,VARIANCE`"
IMA_dolBPL	string	DOL of backprojection file list default: "`empty`"
IMA_bkgShdDOL	string	DOL of background shadowgrams default: "`empty`"
IMA_relDist	real	Limit of relative distance (mm) to catalog position used for identifying sources default: `1.5`
IMA_fluxLimit	real	Lower flux limit for alerts of unfound sources [Counts/s^2] default: `0.000`
IMA_searchRad	real	Range of search grid around nominal found source positions default: `5.00`
IMA_gridNum	integer	Number of grid steps on one side of search grid default: `10`
IMA_distFuzz	real	'Fuzz' allowed in relative distances default: `0.15`
IMA_signifLim	integer	Minimum number of pixels to make a contribution to the sky image default: `25`
IMA_illumNorm	integer	Flag for special re-normalization default: `0`
IMA_collHreduc	real	[mm] Reduction of collimator height for BPL production" default: `0.`

IMA_detImagesOut	boolean	Should the images used for source detection be in output? default: `yes`
IMA_userImagesOut	boolean	Do you want the user defined images to be written? default: `no`

Parameters specific to source spectra extraction (**SPE**)		
SPE_InSourceResult	string	Input source result (JMXi-SRCL-RES) default: " "
SPE_OutSourceSpectrum	string	Output source spectra (JMXi-SRCL-SPE) default: " "
SPE_OutSourceARF	string	Output source spectra (JMXi-SRCL-ARF) default: " "

Parameters specific to source lightcurve extraction (LCR)		
LCR_timeStep	real	Binning time for spectra in seconds, negative value means that time bin is equal to the science window exposure. default: `0.0`
LCR_vignCorr	boolean	Correct for vignetting? Forced to "yes". Vignetting correction is always applied. default: `y`
LCR_evtType	integer	Event type (0=FULL, 1=REST, -1=both) possible values: `0` – FULL, `1` – REST, `-1` – both default: `-1`
LCR_precisionLevel	integer	Speed - precision level, see more details in Section 8.7.1 possible values: `20` – the only value presently supported. default: `20`
LCR_fluxScaling	integer	Flux scaling to area possible values: `1` – Full area open to the illumination `2` – 100cm^2 `3` – 1cm^2 default: `3`
LCR_skipNearDeadAnode	boolean	Ignore pixels near dead anodes? default: `y`
LCR_skipHotSpot	boolean	Ignore pixels in hotspot area? default: `n`

LCR_tAccuracy	integer	Time Correlation accuracy possible values: 0 – high, 1 – low, 3 – any default: 3
LCR_rowSelect	string	CFITSIO selection string on events default: " "
LCR_useRaDec	boolean	Use sky coordinates (Ra,Dec) instead of instrument coordinates? default: y
LCR_overrideCollTilt	real	Value of collimator tilt parameter. If <0 use Instrument Model Group value. default: -1.0

Parameters specific to detector spectra binning (**BIN_S**)

BIN_S_timeStep	real	Binning time [s] for spectra (0.0=bin all data) default: "0.0"
BIN_S_rowSelectEvts	string	CFITSIO selection string on events default: ""
BIN_S_rowSelectSpec	string	CFITSIO selection string on spectrum mode data default: ""
BIN_S_evtType	integer	Data format to bin possible values: -1 – all, 0 – FULL, 1 – REST, 2 – SPTI, 4 – SPEC default: -1

Parameters specific to detector lightcurve binning (BIN_T)

BIN_T_rowSelect	string	CFITSIO selection string on events default: ""
BIN_T_evtType	integer	Data format to bin possible values: -1 – all, 0 – FULL, 1 – REST, 2 – SPTI, 4 – SPEC default: -1

Parameters specific to *jemx_obs_analysis* (IMA_2)

IMA2_mapSelect	string	Types of images to be selected. Possible values: RAW_RECT: Rectified (cleaned) intensity maps (in counts/cm^2/s). RAW_INT: raw intensity (strength) maps (in counts), for which the vignetting correction should not have been applied at the IMA level (by use of "NOVIGN" in the IMA_skyImagesOut parameter line) but is applied at the mosaicking level. RES+SRC: reconstructed Residual+Sources maps (in counts/cm^2/s) which only differ from the RAW_RECT maps if sources have been found at the IROS imaging level. default: "RAW_RECT"
IMA2_radiusSelect	real	Input images selection radius in degrees default: 4.8
IMA2_eminSelect	real	Minimum energy (keV) to select energy interval default: 0.0
IMA2_emaxSelect	real	Maximum energy (keV) to select energy interval default: 80.0
IMA2_diameter	real	Diameter in degrees of the mosaic image (0: allows to fit the mosaic size from the inputs, < 0: can be used for larger mosaics) default: 0.0
IMA2_cdelt	real	Pixel size in degrees at mosaic center default: 0.026
IMA2_RAcenter	real	Center of the mosaic image Right Ascension in degrees (If <0 use the computed middle position of the mosaic) default: -1
IMA2_DECcenter	real	Center of the mosaic image Declination in degrees (not used if RAcenter <0) default: 0.0
IMA2_outfile	string	Prefix of the mosaic FITS file for each energy band default: ""
IMA2_viewTime	boolean	Create total exposure time map? (if Y → OBS_TIME_n.fits, where n is the number of combined input skymaps) default: "y"
IMA2_viewIntens	boolean	Create raw Intensity map? default: "y"
IMA2_viewVar	boolean	Create Variance map? default: "y"
IMA2_viewSig	boolean	Create Significance map? default: "y"
IMA2_view_nb	boolean	Create a map that shows the number of input images contributing to each pixel? default "n"

IMA2_dolBPL	string	DOL of the vignetting maps, e.g., ../../ic/jmx1/rsp/jmx1_bpl_grp_0002.fits[JMX1-DMAP-BPL] default: ""
IMA2_print_ScWs	boolean	List input Science Windows in mosaic headers? default: "n"
IMA2_AITproj	boolean	Project map in galactic coordinates using AIToff-Hammer projection? default: "n"
IMA2_srcFileDOL	string	DOL of the output source list mosaic default:""
IMA2_srcselect	string	CFITSIO selection string applied to input tables default:""
IMA2_srcattach	boolean	Attach resulting table to group? default: y

References

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[2] JEM-X observer's manual http://integral.esac.esa.int/AO10/AO10_JEMX_ObsMan.pdf 1

[3] JEM-X Analysis Scientific Validation Report http://www.isdc.unige.ch/integral/download/osa/doc/current/osa_sci_val_jemx.pdf 1

[4] ISDC/OSA–INST-GUIDE Installation Guide for the *INTEGRAL* Data Analysis System. http://www.isdc.unige.ch/integral/download/osa/doc/current/osa_inst_guide.pdf 16

[5] IASW for JEM-X /DPE -Software Specification Document. Space Research Center PAS, Warsaw. Version 1.11 16/06/00.

[6] Fenimore & Cannon, 1978, Appl. Opt., 17, 337.

[7] Instrument Specific Software for JEM-X Architectural Design Document http://www.spacecenter.dk/~oxborrow/sdast/ISSW/ADD10.0.ps

[8] Walter, R.; Favre, P.; Dubath, P. et al., 2003, A&A 411, L25 45