EPIC scientific product extraction

9th ESAC SAS Workshop

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XMM-Newton Science Operations Centre

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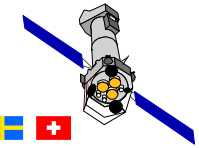

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Camera-dependent screening criteria

Experience of in-flight calibrations allowed to identify a couple of *optimal* camera-dependent screening criteria:

MOS:

- **`#XMMEA_EM`: bit-wise selection expression, automatically removes "bad events" (bad rows, edge effects, spoiled frames, cosmic ray events (MIPs), diagonal events, event beyond threshold …)**
- **`PATTERN=<12`: selection of event shape ("grade" in ASCA), maximises signal-to-noise ratio against non X-ray events. Analysis of single events only (`PATTERN==0`) is supported and calibr**

```
XMMEA_0 = '(FLAG & 0x1) != 0'  / DIAGONAL
XMMEA_1 = '(FLAG & 0x2) != 0'  / CLOSE_TO_CCD_BORDER
XMMEA_5 = '(FLAG & 0x20) != 0' / CLOSE_TO_ONBOARD_BADPIX
XMMEA_6 = '(FLAG & 0x40) != 0' / CLOSE_TO_BRIGHTPIX
XMMEA_8 = '(FLAG & 0x100) != 0' / CLOSE_TO_DEADPIX
XMMEA_9 = '(FLAG & 0x200) != 0' / CLOSE_TO_BADCOL
XMMEA_10= '(FLAG & 0x400) != 0' / CLOSE_TO_BADROW
XMMEA_11= '(FLAG & 0x800) != 0' / IN_SPOILED_FRAME
XMMEA_16= '(FLAG & 0x10000) != 0' / OUT_OF_FOV
XMMEA_17= '(FLAG & 0x20000) != 0' / IN_BAD_FRAME
XMMEA_19= '(FLAG & 0x80000) != 0' / COSMIC_RAY
XMMEA_21= '(FLAG & 0x200000) != 0' / ON_BADPIX
XMMEA_22= '(FLAG & 0x400000) != 0' / REJECTED_BY_GATTI
XMMEA_25= '(FLAG & 0x2000000) != 0' / OUT_OF_CCD_WINDOW
                                    / OUTSIDE_THRESHOLDS
XMMEA_28= '(FLAG & 0x10000000) != 0' / ON_BADROW
XMMEA_29= '(FLAG & 0x20000000) != 0' / BAD_LIE4
XMMEA_30= '(FLAG & 0x40000000) != 0' / UNDERSHOOT
XMMEA_EM= '(FLAG & 0x766b0000) == 0' / Select good MOS events
```

pn:

- **`#XMMEA_EP`: see above**
- **Spectral analysis calibrations available both for single (`PATTERN==0`) and double [`(PATTERN in [1:4])`] events. For spectra use (`FLAG==0`) instead of `#XMMEA_EP`**

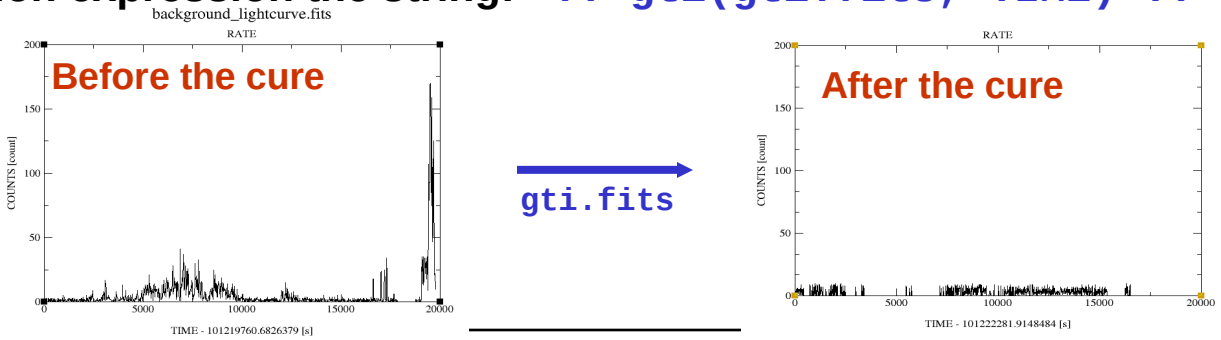
Recipe to clean flaring high background (I)

XMM-Newton sometimes experiences high flaring background periods (soft protons accelerated by magnetic reconnection). They need to be removed before extracting any scientific products:

- **extract a high-energy, single event light-curve, with the expression:**
  PN:`(PI in [10000:12000])&&(PATTERN==0)&&#XMMEA_EP, timebinsize=100 (s)`
  MOS: `(PI>10000)&&(PATTERN==0)&&#XMMEA_EM, timebinsize=100 (s)`
- **create GTI, excluding all "flaring" intervals**

```
tabgtigen table=high_energy_curve.fits gtiset=gti.fits
          expression="RATE=<0.4"    for pn  - or -
          expression="RATE=<0.35"   for MOS
```

- **apply above GTI to any scientific products accumulations, adding to the selection expression the string:** `".. gti(gti.fits, TIME) .."`



Recipe to clean flaring high background (II)

An alternative approach to remove high background periods:

- **based on EPIC pipeline processing products** (dedicated PPS talk):
  Note: PPS produced calibrated event lists are NOT cleaned!
- **However, for PPS EPIC image generation, a GTI is applied (based on a lightcurve in which detected sources already have been excluded)**
- **One can make use of these GTIs (stored as DSS info):**

```
evselect table=inevlist.fits filtertype=dataSubspace
         dssblock=image.fits:PRIMARY keepfilteroutput=yes
         withfilteredset=yes filteredset=outevlist.fits
```

**Note: check lightcurves of all EPIC instruments,
GTIs needed for removal of flaring background can be quite different for different EPIC cameras in the same observation!**

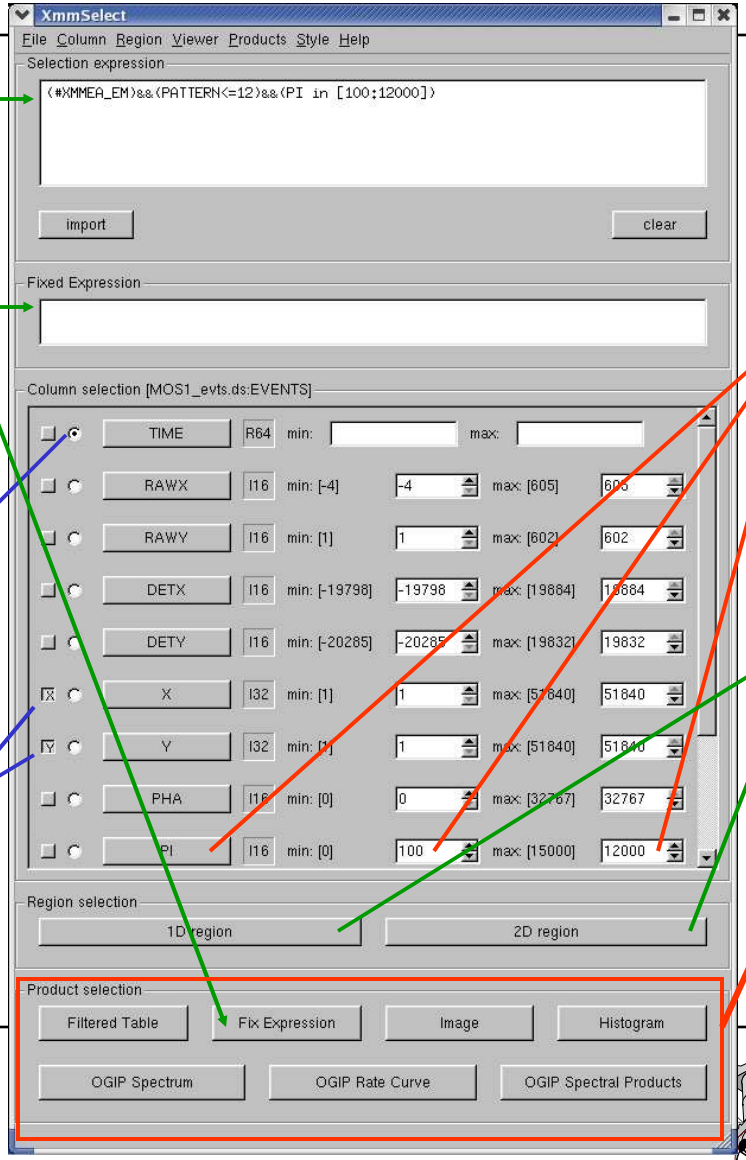
The xmmselect window

Define selection expression here.

Currently defined selection expression can be fixed and the filtered event list used for further processing.

Circles used to define quantities to extract spectra, light curves, histograms.

Checkboxes used to define quantities on which to extract an image.



EVENTS extension columns listed. Column buttons allow to transfer ranges defined in widgets into a selection expression.

One can transfer selection regions defined in 1-D or 2-D (image) plots to selection expression widget.

Products which may be extracted: all the above plus filtered event lists.

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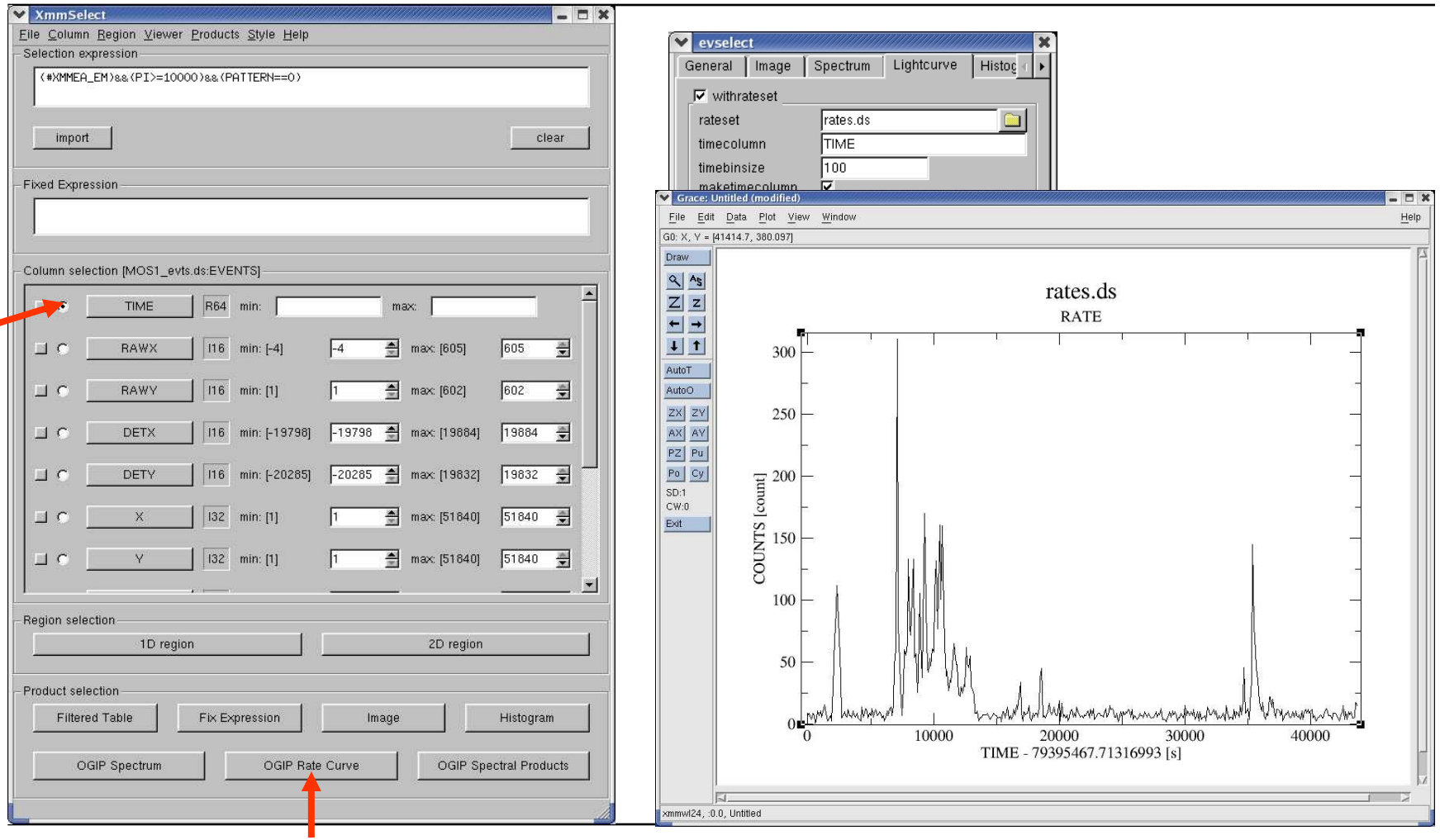
xmmselect: creation of a rate curve



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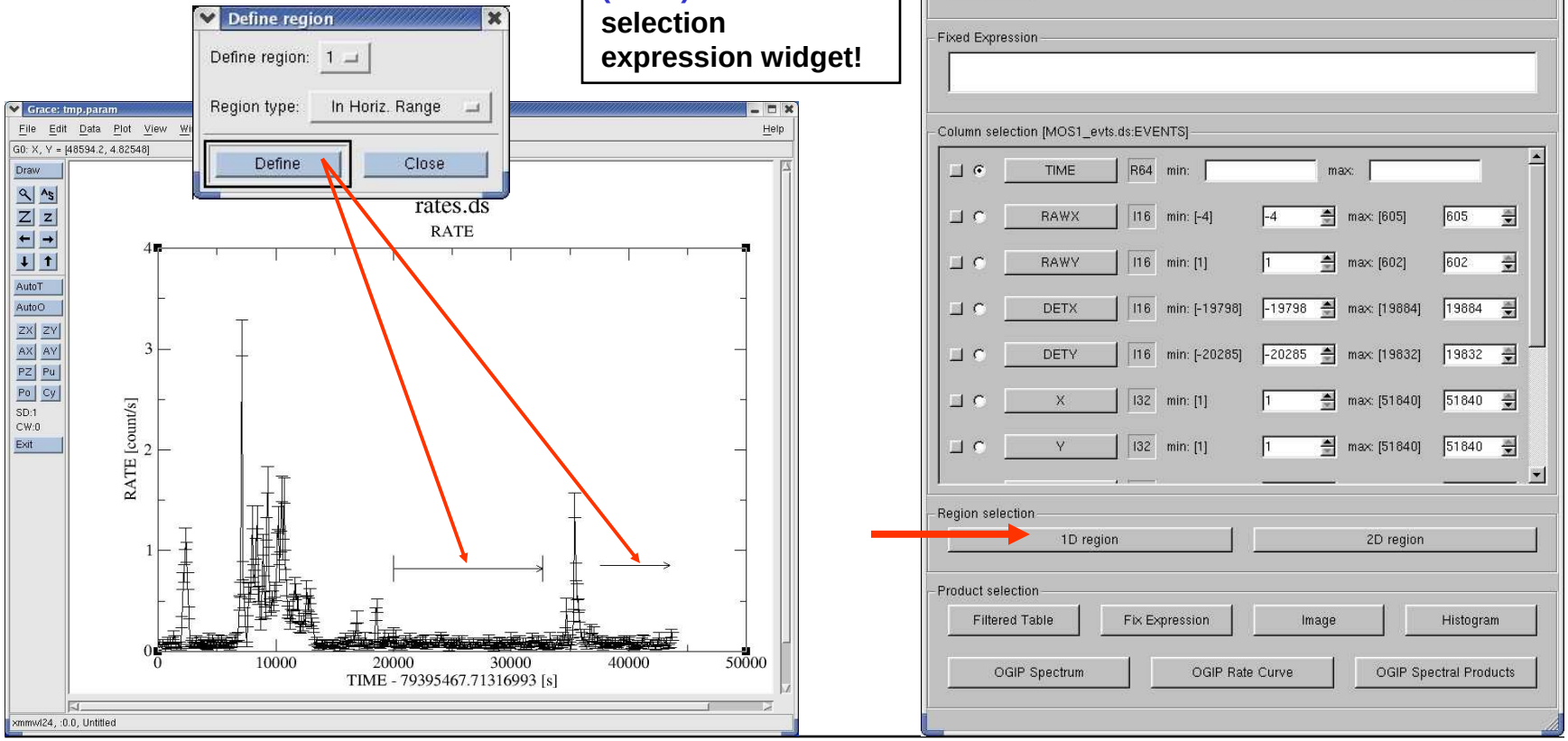
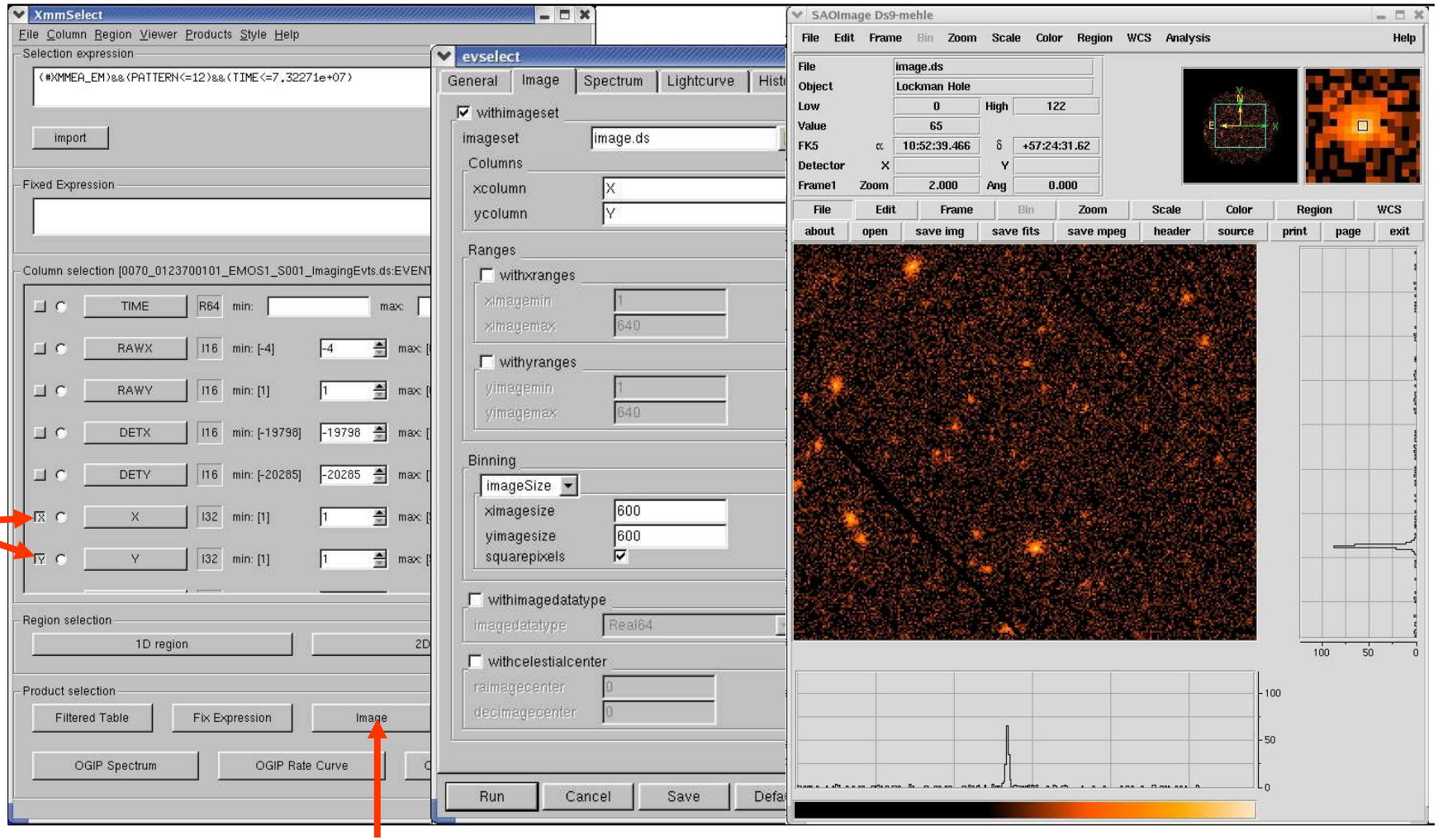
Defining interactively a 1-D (time) interval

In `xmgrace` time intervals can be selected with the "Edit → Regions → Define" function.

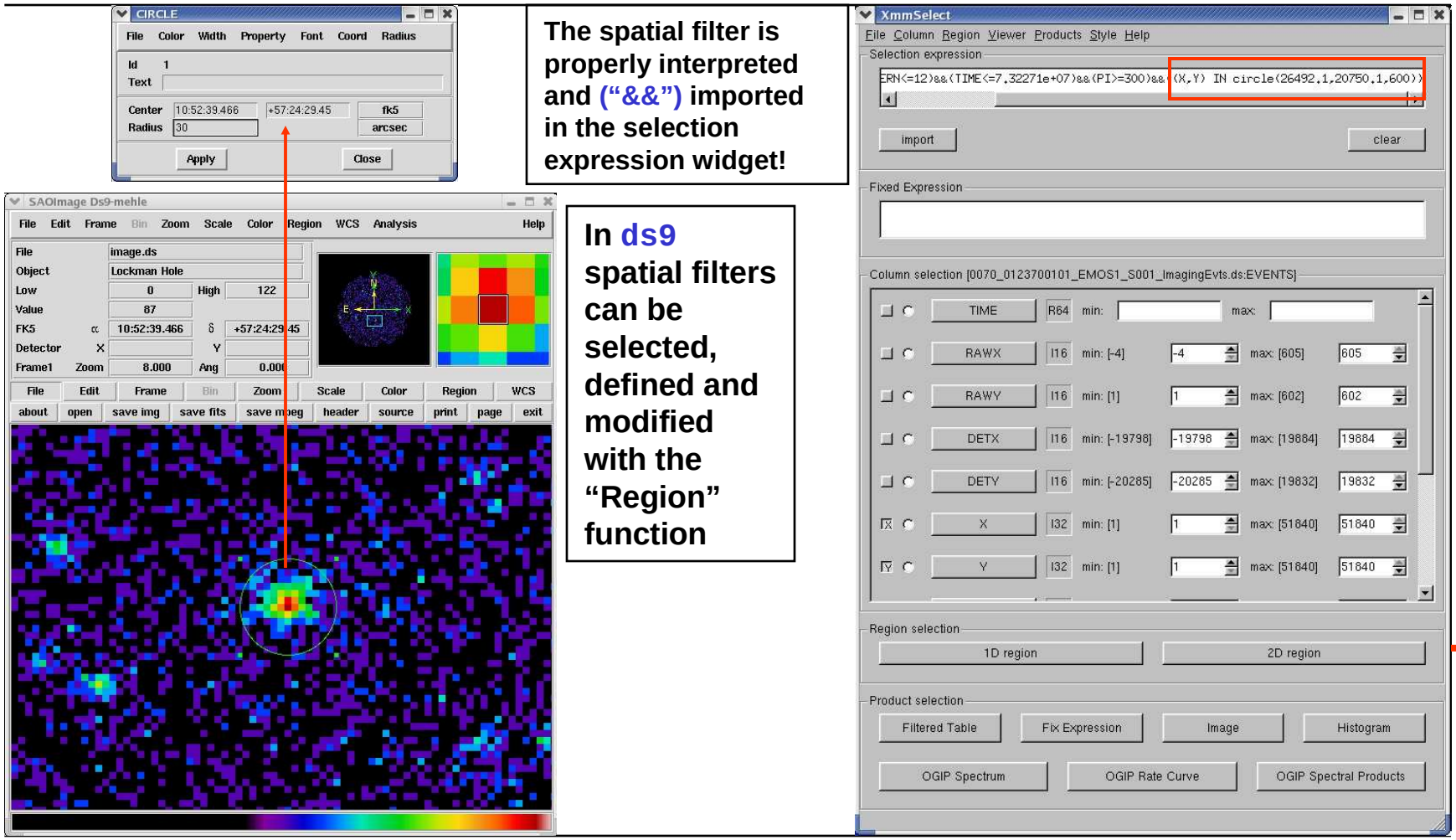
The time filter is properly interpreted and imported ("&&") in the selection expression widget!



`xmmselect`: creation of an X-ray image



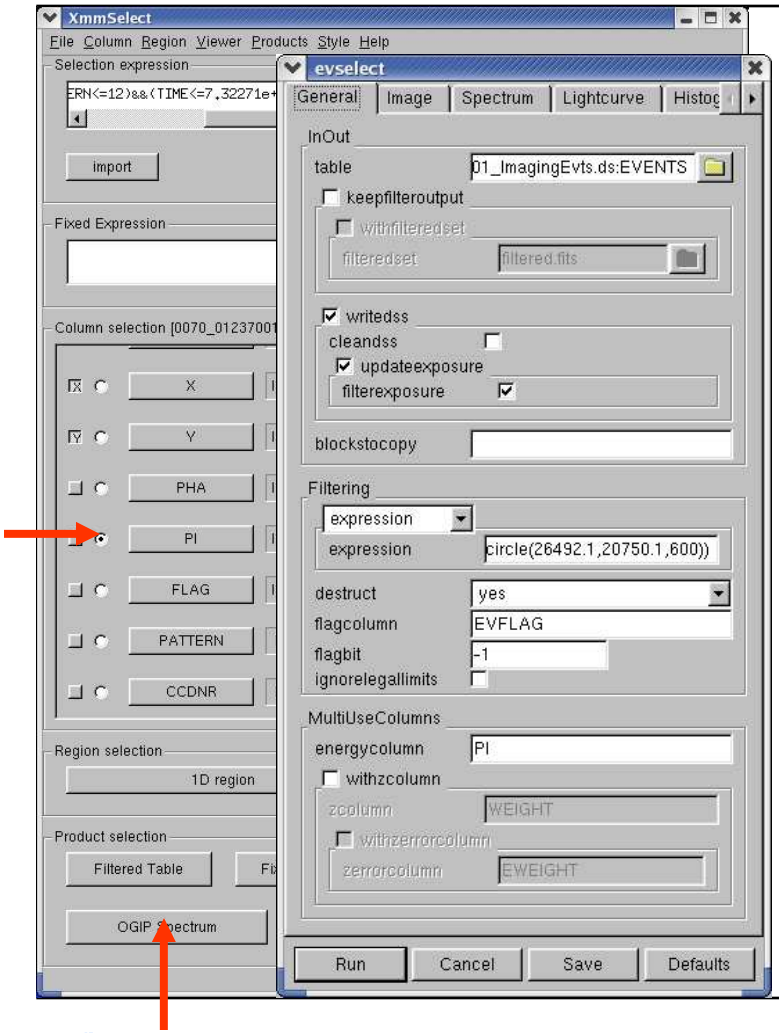
Defining interactively a 2-D spatial region



The spatial filter is properly interpreted and (“&&”) imported in the selection expression widget!

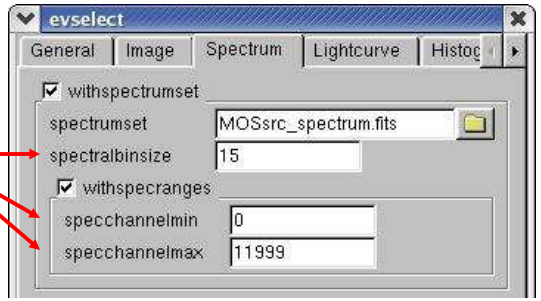
In ds9 spatial filters can be selected, defined and modified with the “Region” function

xmmselect: creation of EPIC spectra

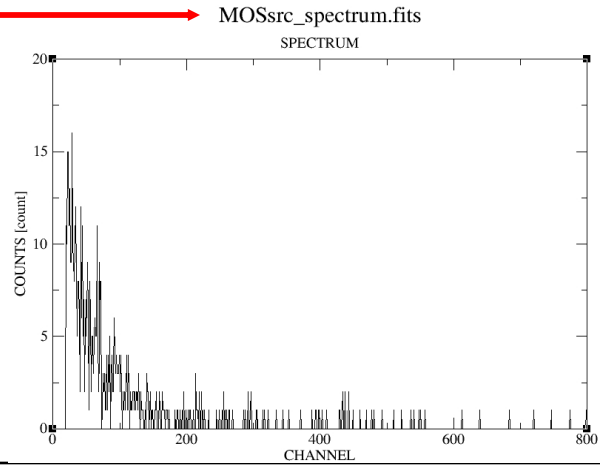


Assuming that one has cleaned the event list for high background & defined a source region (e.g. as a circle).

Parameters set such that MOS canned matrices can be used



"Run": `xmgrace` window appears with the accumulated spectrum.



Use `grppha` to further group the spectrum and see next presentation on *.rmf & *.arf generation

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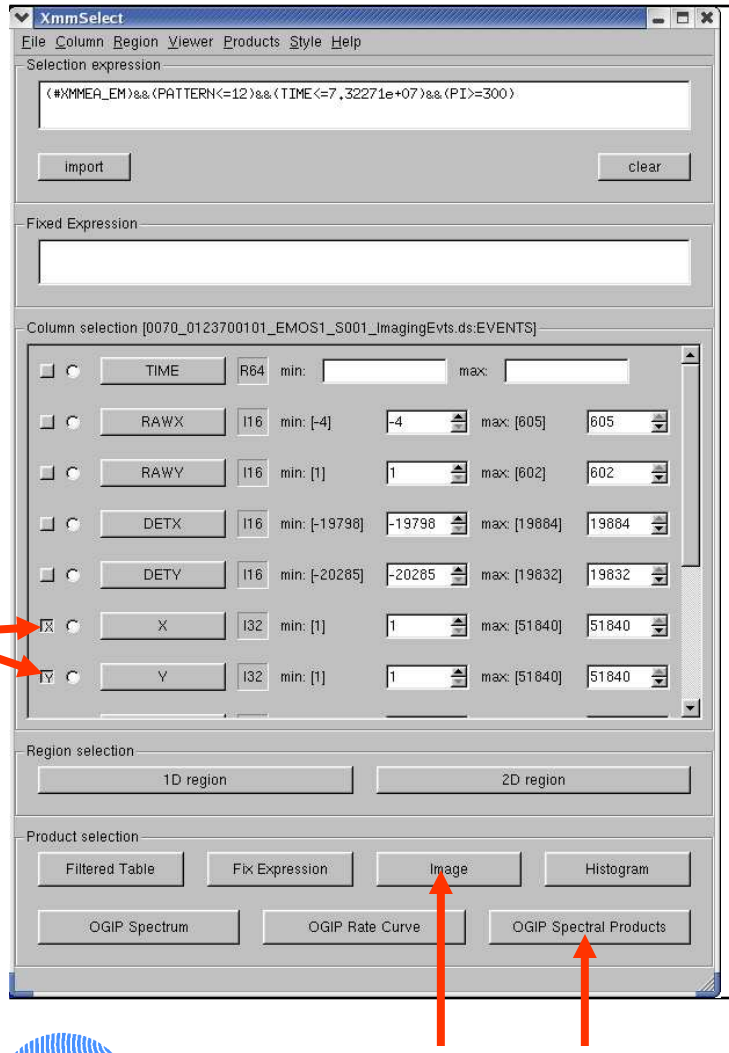
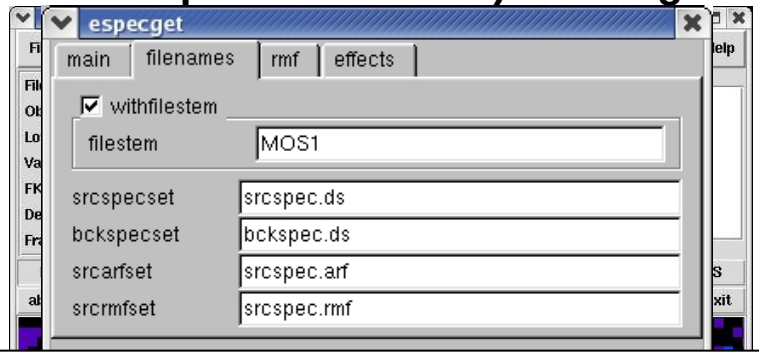
xmmselect: EPIC spectral Products



Generate source & background spectra (and related response matrices) in one go:



produced files:

MOS1_src.ds	**source spectrum**
MOS1_bgd.ds	**background spectrum**
MOS1_src.arf	**ancillary response file (ARF) for source**
MOS1_src.rmf	**redistribution matrix file (RMF) for source**

advantage: background, ARF, RMF are linked to source spectrum via header keywords

Background subtraction issues

1. Background regions from the same observation:

- **imaging: circular region; timing/burst: columns away from source (no RAWY selection!)**
- **MOS: same CCD (timing: evtl. outer CCDs), off-axis, away from source counts**
- **pn: ideally at same distance from CCD readout node, i.e. at same RAWY as source (evtl. on neighbouring CCD)**
- **avoid columns (RAWX) crossing source: "out of time events" ⇒ no annulus**

In this case, the background spectrum extraction follows the same procedure as source spectrum generation. Or, use `xmmselect`: Spectral Products.
Further info: see "EPIC status of calibration and data analysis".

2. Alternatively & especially for extended sources: blank fields or modelling the background (dedicated SAS-WS talk)

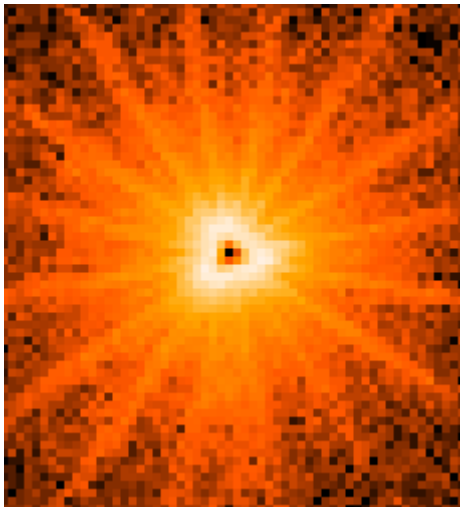
Further info: Background Analysis Page http://xmm.esac.esa.int/external/xmm_sw_cal/background/
(EPIC background components; blank-sky fields, software tools, links, etc)

Pile-up, and how to deal with it

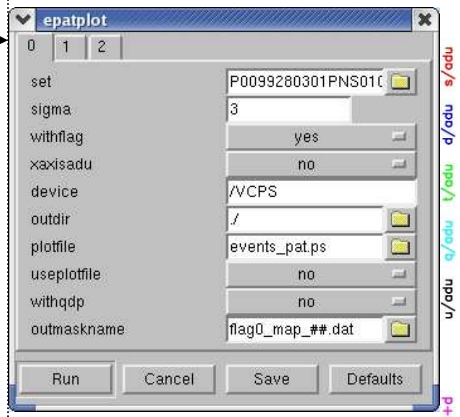
Pile-up ≡ accumulation of *n* events in the same pixel during integration time of a CCD frame.
⇒ Accumulated events interpreted one single event, whose energy $E=E_1+E_2+\ldots+E_n$.
⇒ Pile-up produces both flux loss *and* spectral distortion.

Pile-up may be a problem for *e.g.* Full Frame exposures, if count rate > 0.7 s^{-1} (MOS) / 8 s^{-1} (pn)

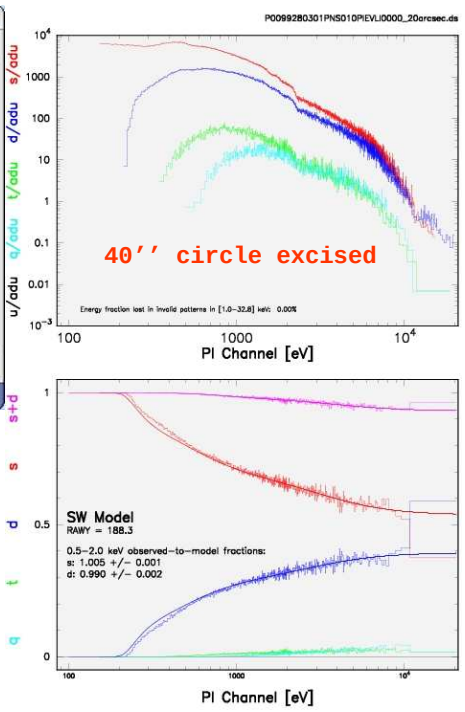
How to recognise it?



“Holes” in the PSF core



PATTERN distribution with energy (data versus model)



How to cure it?

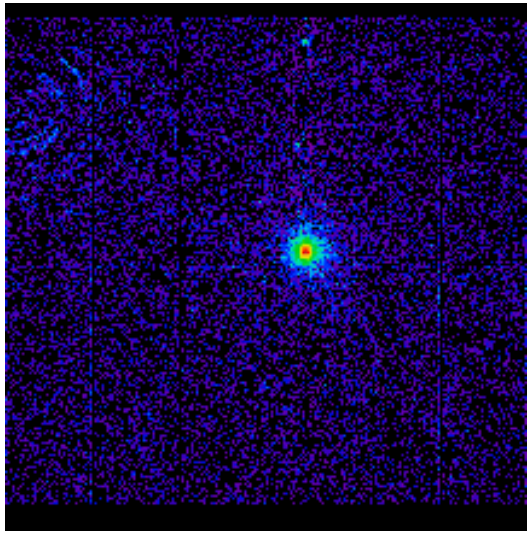
Excising the PSF core

Using single events only

Out-of-time events, and how to deal with them

Out-of-time (OoT) events: photons not only registered during actual integration interval but also during readout of CCD.
OoT events broaden spectral features (wrong CTI correction) and create in images a strip of wrongly reconstructed event positions in RAWY.
Fraction of Oot events scales with mode-dependent ratio of integration and readout time: highest for pn full frame (6.3%) and extended full frame (2.3%) mode (see UHB for further details).

How to recognise it?



image_clean.fits

How to cure it?

Run pipeline task twice:
first creating OoT event list and then the 'normal' calibrated event list:
- OoT event list produced by calling epevents with non-default parameter setting withoutoftime=yes
- new RAWY values simulated by randomly shifting pattern along RAWY axis and performing gain and CTI correction afterwards.

Correcting spectra:
(mostly not needed; in any case only if OoT events overlap with source)
evselect **to create spectra from 'normal' and OoT event list;**
ftools **to copy OoT counts into 'normal' spectrum,**
to scale down and subtract them (see SAS Guide for details).

Note: pattern selection for pn spectra

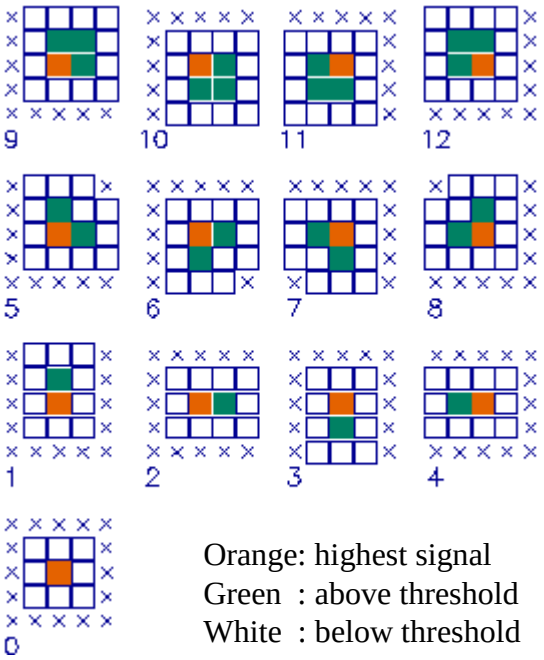
Singles & double events have best energy calibration (compromise most of the valid X-rays).

For 'normal' sources: combined spectra should be analysed to obtain highest signal-to-noise.

However, for bright sources and sources with narrow lines:

- **evtl. extract two spectra & corresponding backgrounds, response & ancillary files: one set for single pixel events (`PATTERN==0`) and another set for doubles (`PATTERN IN [1:4]`)**
- **fitting these two spectra simultaneously will show if there are still problems with pile-up**
- **line features at highest energy resolution will be visible in the single events spectra (singles have slightly better energy calibration)**

pn valid patterns



Orange: highest signal
Green : above threshold
White : below threshold

If pn in timing mode: rate of single to double events depends on source position → always analyse combined spectra (`PATTERN=<4`)

Is my spectrum good enough?

There are three main sources of information to answer this question:

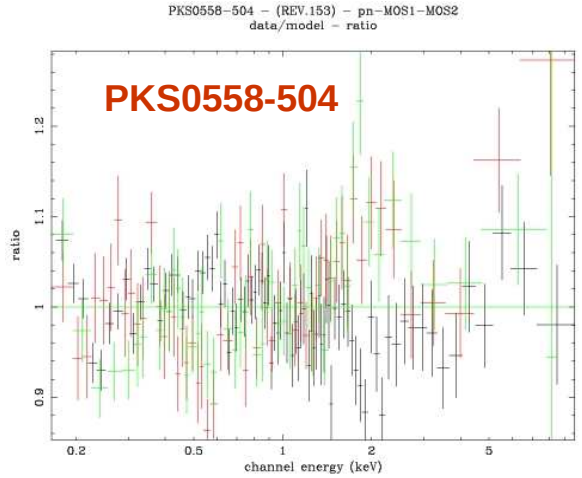
1. CCF release notes: report expected accuracy associated with each individual CCF component.

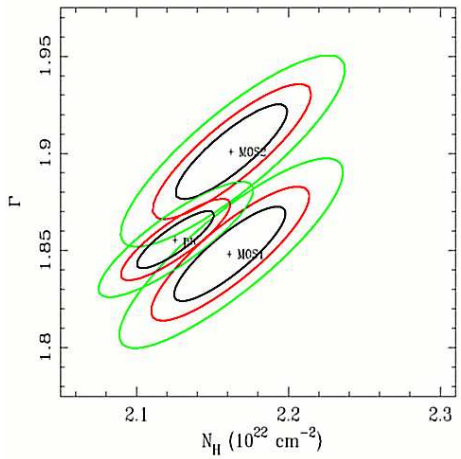
2. EPIC status of calibration and data analysis (XMM-SOC-CAL-TN-0018, via Calibration Portal page): status/quality of calibration implemented in SAS release; outlook on future improvements.

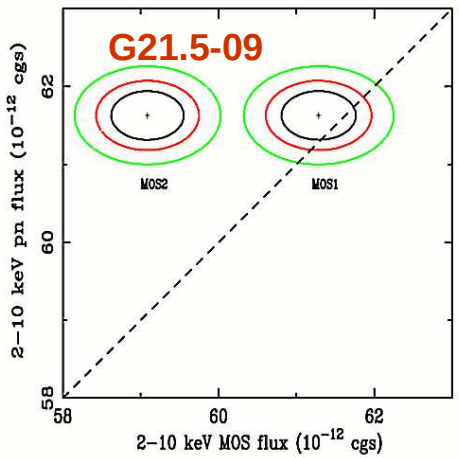
3. Status of cross-calibration (XMM-SOC-CAL-TN-0052): comparing XMM-Newton instruments' calibration (with public SAS & CCFs) amongst each other & with other missions.

4. SAS validation reports: compare expected calibration accuracies on a pre-defined set of XMM-Newton observations. An update of the report is issued for every (major) SAS release.

E.g.







Spectral fitting residuals **MOS/pn spectral fitting and flux comparison**