XMM-Newton Data Analysis Workshop

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Spectral analysis of point-like sources with EPIC

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`evselect:` the SAS extractor

In order to extract scientific products (spectra, light curves, images, histograms) one needs a software machine able to binning appropriate columns of an event lists, while applying event filtering "on-the-fly"

What is called `extractor` in the LHEASOFT world (with its user interface `xselect`), or `dmextract` in CIAO, is the SAS `evselect`

`evselect` has a GUI interface, `xmmselect`, which allows the user to perform all the `evselect` tasks in a button-driven, user-friendly way

This presentation will be focused on the usage of `xmmselect`. However, each `xmmselect` operation has its corresponding `evselect` command-line translation. *E.g.:* if one wants to extract a spectrum from a region of 128 sky pixels around (18000,18000) and with PATTERN in the range 0-12, from a `MOS1.evt` event list:

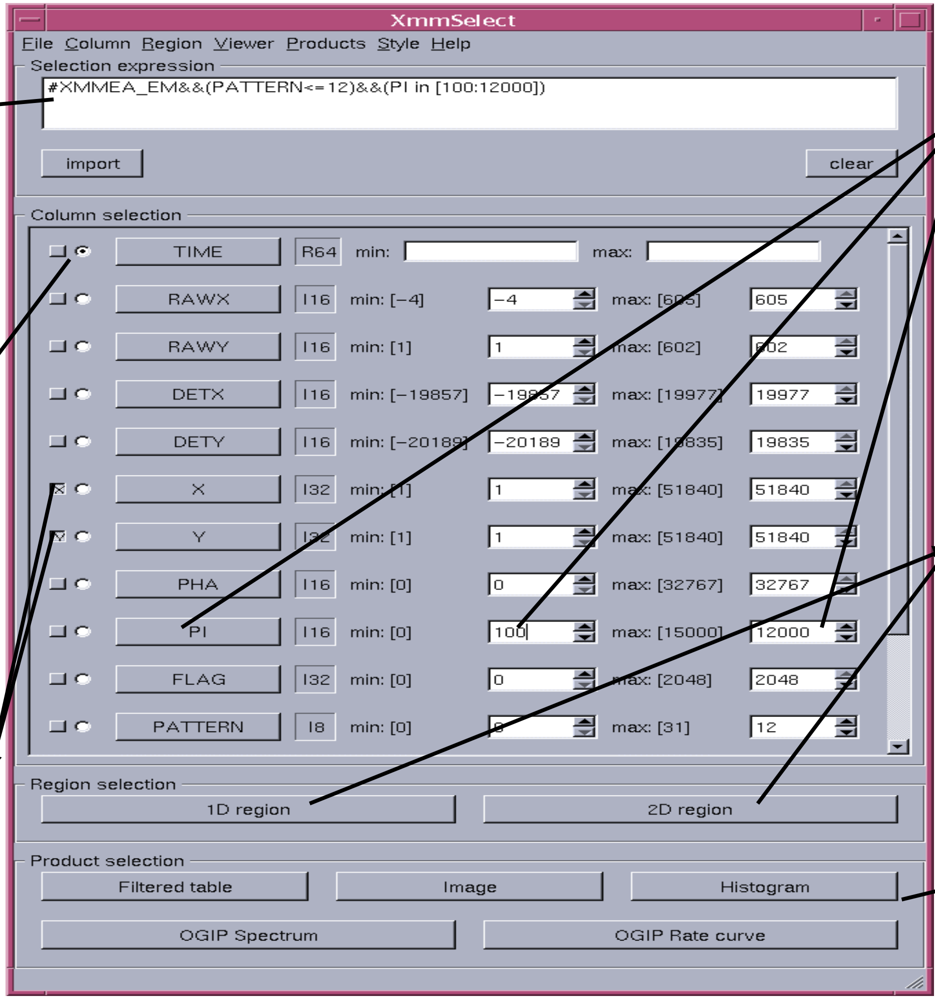
```
evselect table="MOS1.evt:EVENTS" withspectrumset=yes
spectrumset="my_spectrum.pi" energycolumn="PI" expression="((X,Y)
in circle(18000,18000,128))&&(PATTERN=<12)"
```

The `xmmselect` window

Here the selection expression is defined

Circles are used to define the quantities to extract **spectra, light curves, histograms**

Checkboxes are used to define the quantities on which to extract an **image**



The EVENTS extension columns are listed. Column buttons allow to transfer the ranges defined in the widgets to the selection expression

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

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

Camera-dependent screening criteria

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

Dump of the `XMMEA_*` section of a MOS event list header

```
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
[illegible]
XMMEA_17= '(FLAG & 0x20000) != 0' / IN_BAD_FRAME
XMMEA_19= '(FLAG & 0x80000) != 0' / COSMIC_RAY
[illegible] / ON_BADPIX
XMMEA_22= '(FLAG & 0x400000) != 0' / REJECTED_BY_GATTI
XMMEA_25= '(FLAG & 0x2000000) != 0' / OUT_OF_CCD_WINDOW
[illegible] THRESHOLDS
XMMEA_28= '(FLAG & 0x10000000) != 0' / ON_BADROW
XMMEA_29= '(FLAG & 0x20000000) != 0' / BAD_E3E4
XMMEA_30= '(FLAG & 0x40000000) != 0' / UNDERSHOOT
XMMEA_EM= '(FLAG & 0x766b0000) == 0' / Select good MOS events
```

MOS:

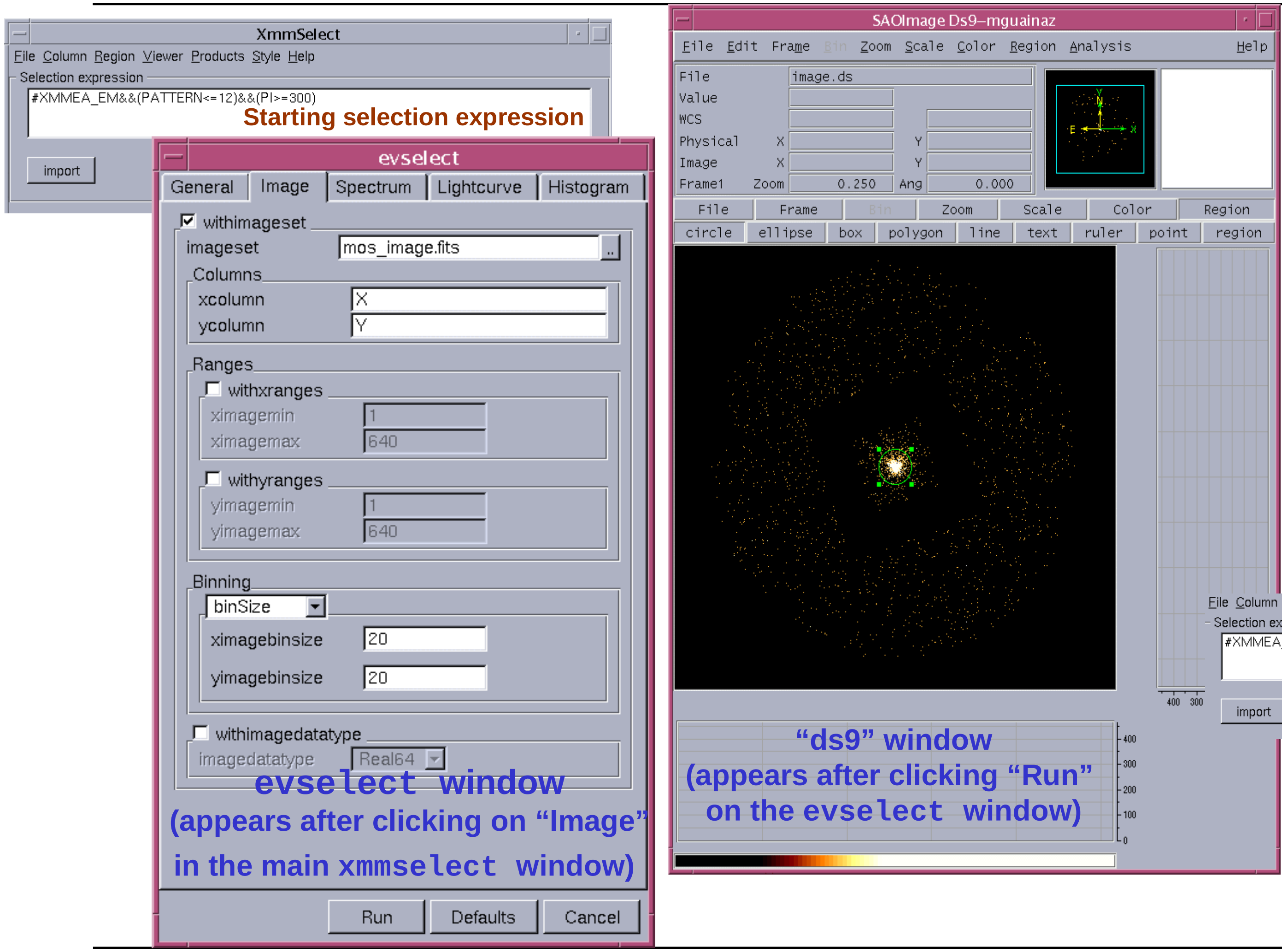
- **`#XMMEA_EM`: this is a bitwise selection expression, which allows to automatically remove "bad events" in terms of bad rows, edge effects, spoiled frames, GATTI rejection, cosmic ray events, diagonal events, event beyond threshold and so on**

- **`PATTERN=<12`: this selection of the event shape ("grade" in ASCA) maximises the signal-to-noise ratio against non X-ray events. Analysis of spectra extracted from single events only (`PATTERN==0`) is supported and calibrated as well**

pn:

- **`#XMMEA_EP`: see above**
- **Spectral analysis calibrations are available for both single (`PATTERN==0`) and double [`(PATTERN=>1)&&(PATTERN<4)`] events**

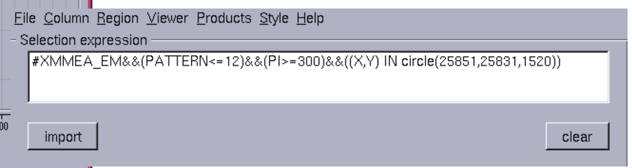
Defining interactively a spatial region



evselect window (appears after clicking on "Image" in the main xmmselect window)

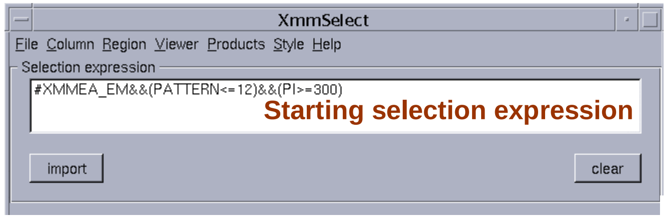
"ds9" window (appears after clicking "Run" on the evselect window)

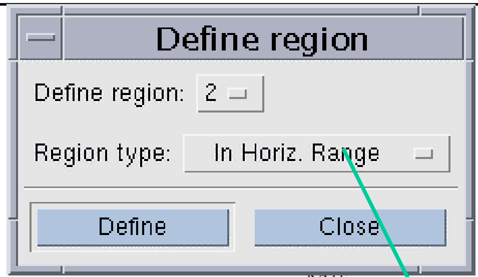
If now one clicks on the "2D region button" of the main xmmselect window ...



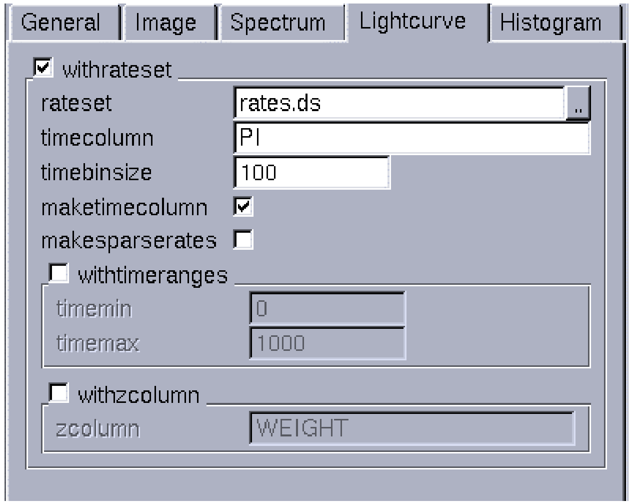
The spatial filter is properly ("&&") imported in the selection expression widget!

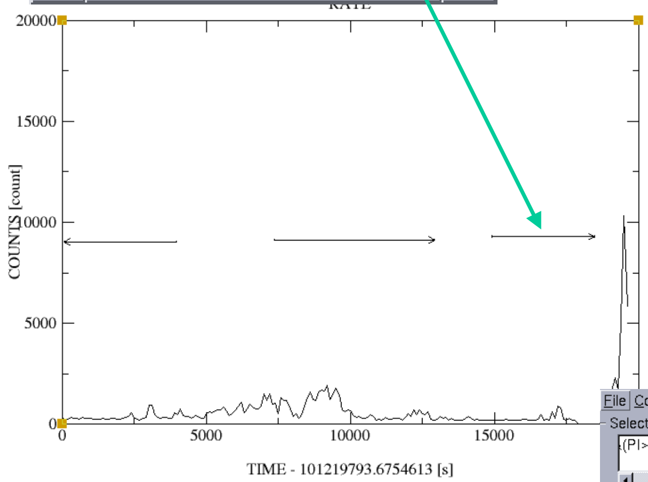
Defining interactively a 1-D (time) interval

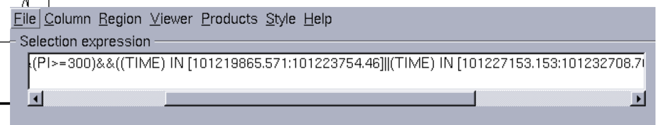




If now one clicks on the "1D region button" of the main `xmmselect` window ...







The `evselect` window appears when "OGIP light curve" is clicked

A `grace` window appears with the accumulated light curve after "Run". In `grace` time intervals can be selected with the "Define region" function

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

Background subtraction issues

1. In general, it is advisable to extract the background spectrum from source-free, nearby regions on the same chip. Good geometry choices are a circular region at the same off-axis angle (in the MOS) or on the same raw coordinates row (in the pn), or an annulus around the source. The background spectrum extraction follows in this case the same procedure as the source

2. Alternatively, blank fields files, available on the XMM-Newton calibration pages, can be used. This is a good choice for windowed modes, where most likely no enough room is available to extract meaningful background spectra. Source and background spectra needs to be extracted from the same regions in detector coordinates, and using of course the same screening criteria.
When spectra are extracted from blank sky field, the `EXPOSURE` keyword (exposure time) needs to be manually updated:

```
fparkey EXPOSURE my_background.fits value
```

3. XMM-Newton experiences sometimes high flaring background periods, most likely due to soft protons accelerated by magnetic reconnection. They needs to be removed before extracting any scientific products, according to the following recipe:

Recipe to clean flaring high background

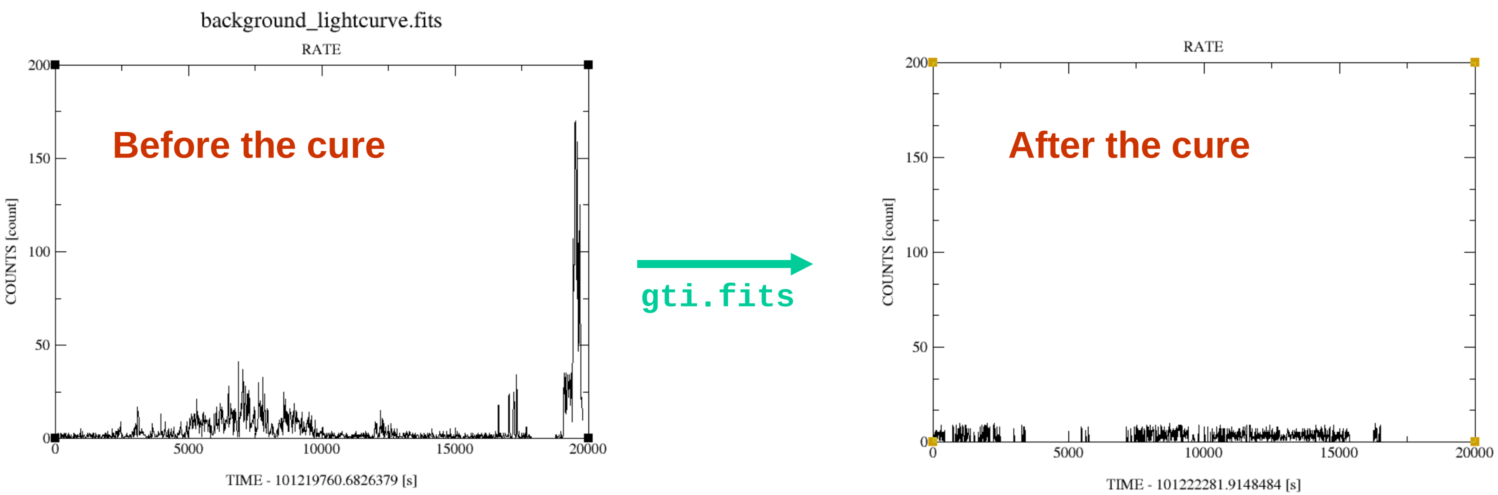
- **extract a high-energy (E > 10 keV), single event light-curve, with the expression:**

```
(PI>10000)&&(PATTERN==0)&&#XMMEA_E[MP]
```

- **create a GTI, excluding all the “flaring” intervals**

```
tabgtigen table=“high_energy_curve.fits” gtiset=gti.fits expression=“COUNTS<15”
```

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

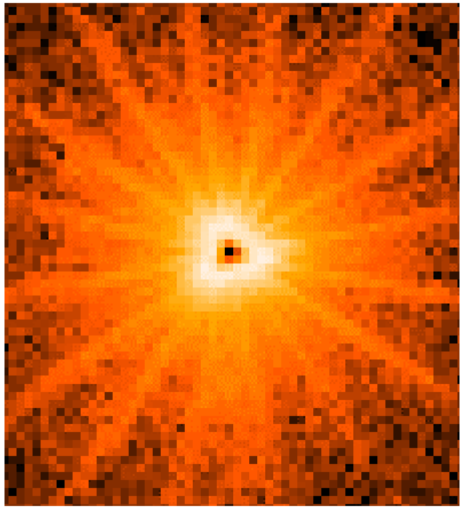


Pile-up, and how to deal with it

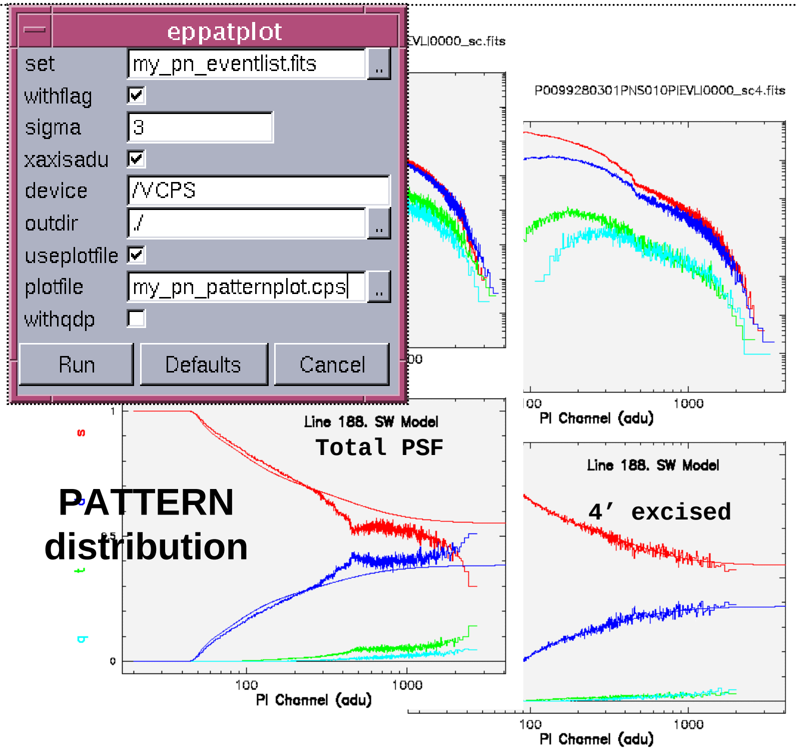
Pile-up is the accumulation of *n* events in the same pixel during the time a CCD frame is read out. The accumulated events are interpreted as one single event, whose energy $E=E_1+E_2+\ldots+E_n$. Pile-up produces therefore both flux loss *and* spectral distortion.

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

How to recognise it?



"Holes" in the PSF core



How to cure it?

Excising the PSF core

Using single events only

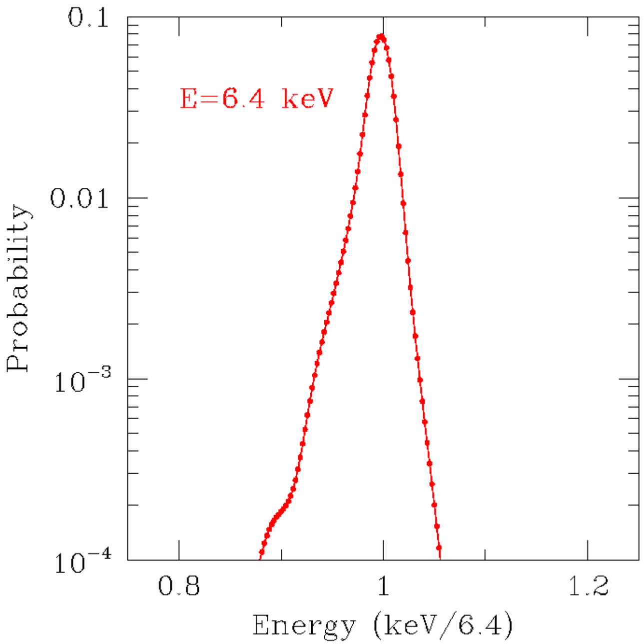
The concept of “response matrix”

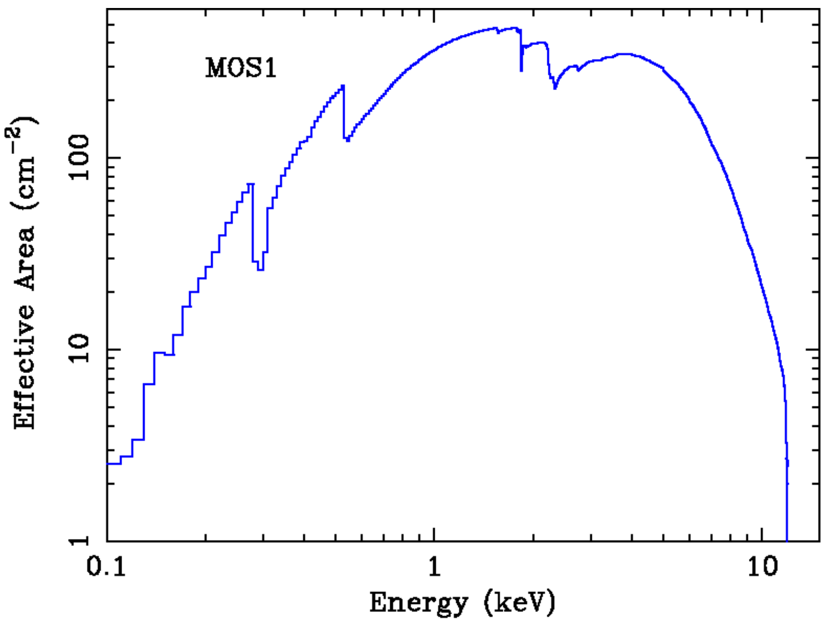
Spectra are created in counts. The information to convert the counts to physical units during the spectral analysis is contained in the response matrix. It is the product of:

the redistribution matrix (a.k.a. “`*.rmf`”)

*****

the effective area vector (a.k.a. “ancillary file”, “`*.arf`”)





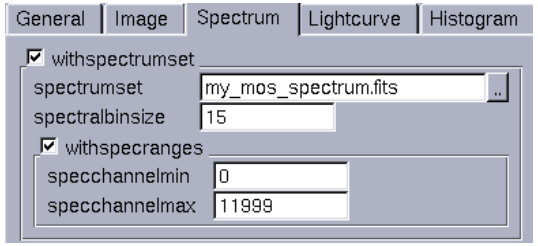
“Pre-canned” response matrices

Standard (“pre-canned”) EPIC response matrices are available in the XMM-Newton calibration pages for the analysis of point-like, on-axis sources. Several matrices are available, according to different:

- **cameras (MOS1, MOS2, pn)**
- **filters (thin, medium, thick)**
- **pattern distribution [“0” (singles) or “0-12” for the MOS cameras; “0” (singles) “1-4” (doubles) or “singles+doubles” for the pn camera]**
- **source position in raw coordinates (pn only)**

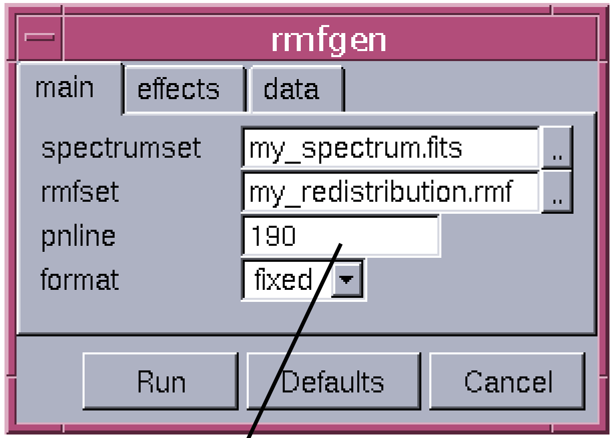
Their use requires particular spectral ranges and binnings to be applied during the spectral extraction:

	specchannelmin	specchannelmax	spectralbinsize
MOS	0	11999	15
pn	0	20479	5

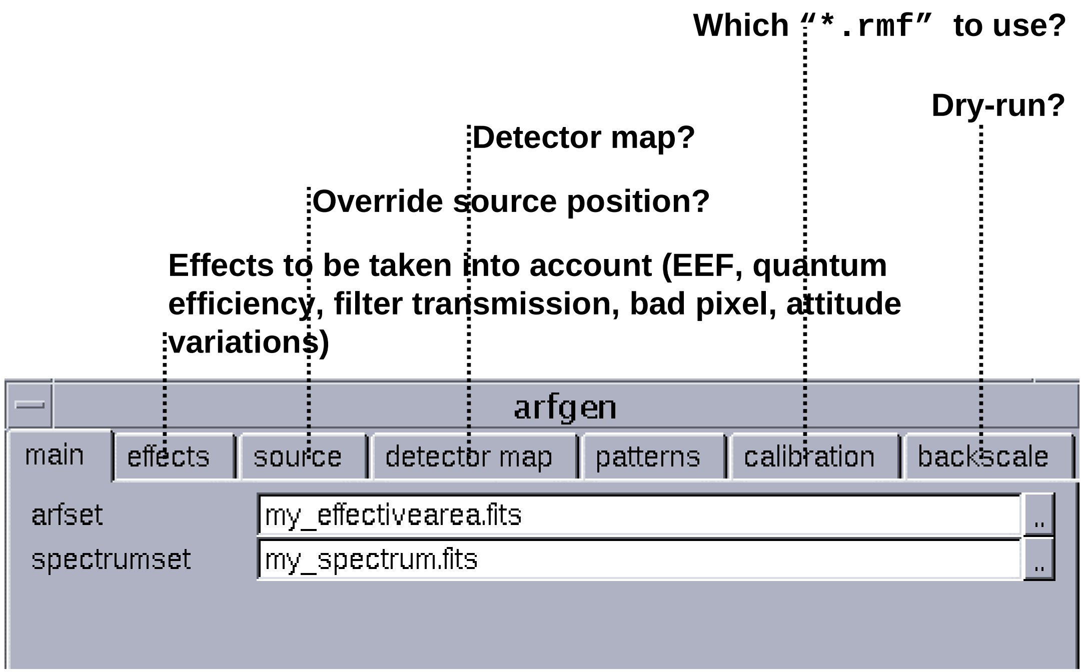


SAS tasks to generate EPIC responses

Alternatively, EPIC response matrices can be generated using the SAS tasks `rmfgen` and `arfgen`, which create customised responses for a given input EPIC spectrum



Raw coordinates position of the spectrum source



A "mixed case" is also possible: generate an `"*.arf:"` on the basis of a "pre-canned" `"*.rmf"`

Which matrix shall I use?

Generally, the “pre-canned” matrices follow more closely the development of the on-flight calibrations. In case of discrepant results fitting a point-like, on-axis source, the results obtained with them are to be considered more reliable.

However, the difference with the matrices generated by the SAS tasks is getting smaller and smaller, and is now virtually negligible for most practical cases

Moreover, SAS task-generated matrices allow greater flexibility, although they still suffer of some limitations (PSF correction is currently accurate only if the extraction regions are circular)

A comparison between the performances of “pre-canned” and SAS-generated matrix is contained (and “frequently” updated) in the SAS validation reports

SAS-generated

“mixed”

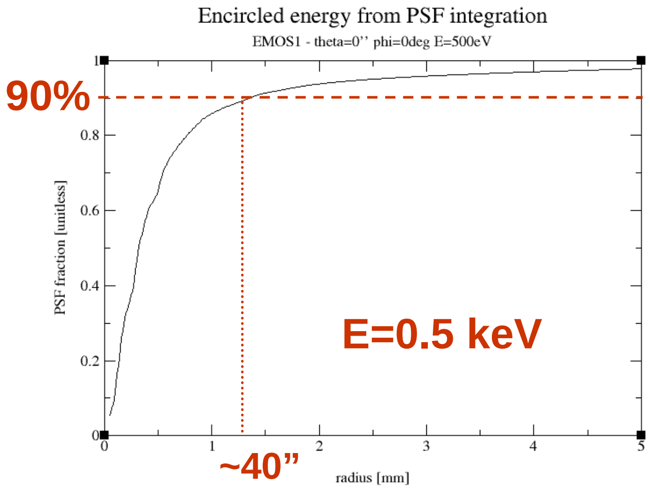
pre-canned

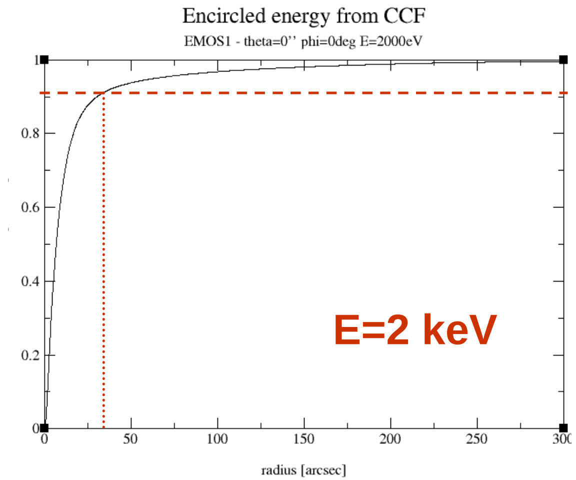
Scenario	Γ	N_H (10^{22} cm^{-2})	χ^2/ dof
MOS1			
1.	$1.92^{+0.03}_{-0.03}$	2.36 ± 0.04	285.8/183
2.	$1.95^{+0.03}_{-0.02}$	2.40 ± 0.04	240.0/183
3. (PATTERN=0-12)	$1.86^{+0.02}_{-0.03}$	2.28 ± 0.04	222.2/183
3. (PATTERN=0)	$1.90^{+0.04}_{-0.03}$	$2.32^{+0.02}_{-0.04}$	184.5/172
MOS2			
1.	$1.86^{+0.03}_{-0.02}$	2.28 ± 0.04	332.0/183
2.	1.90 ± 0.03	2.29 ± 0.04	211.9/183
3. (PATTERN=0-12)	1.82 ± 0.03	2.19 ± 0.04	235.6/183
3. (PATTERN=0)	1.86 ± 0.03	$2.22^{+0.05}_{-0.04}$	211.8/170
p-n			
1.	1.93 ± 0.02	$2.36^{+0.04}_{-0.03}$	422.0/224
2.	1.96 ± 0.02	$2.42^{+0.03}_{-0.04}$	353.0/224
3. (PATTERN=0)	1.86 ± 0.02	2.24 ± 0.03	324.1/224
3. (PATTERN=0-4)	1.87 ± 0.02	$2.28^{+0.02}_{-0.03}$	290.4/212

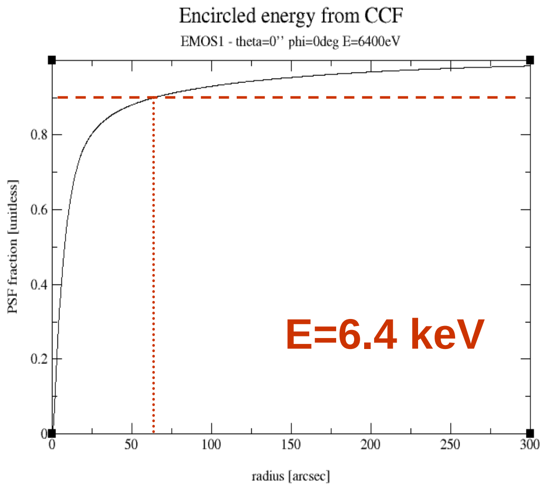
Table 2: G21.5-0.9 observation best-fit parameters. Errors are at the 90% confidence level for one interesting parameter. Indices refer to the three "paths" available to generate EPIC response matrices with SAS v5.1

How big is an optimal source extraction region?

Apart from specific scientific needs, the optimal source extraction region aims at maximising the net signal-to-noise *at all energies*, while avoiding crossing the chip boundaries (if one wants to avoid specific chip-dependent background corrections). One has therefore to refer to the CCF Encircled Energy Functions







The SAS response matrix generation tasks take already properly into account the encircled energy fraction, provided that the extraction region is circular.

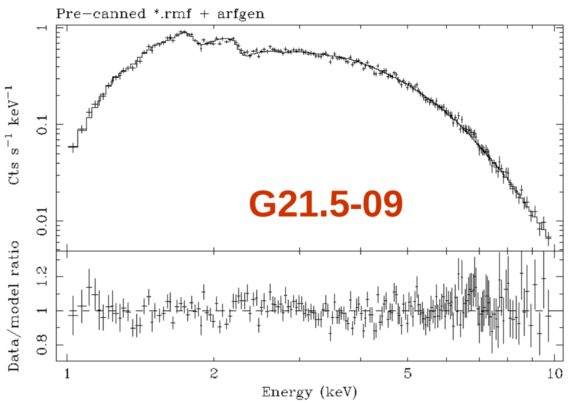
The "pre-canned" EPIC response matrices correspond to an infinite extraction radius. A correction on the flux for the finite-radius photon loss needs to be applied downstream

Is my spectrum good enough?

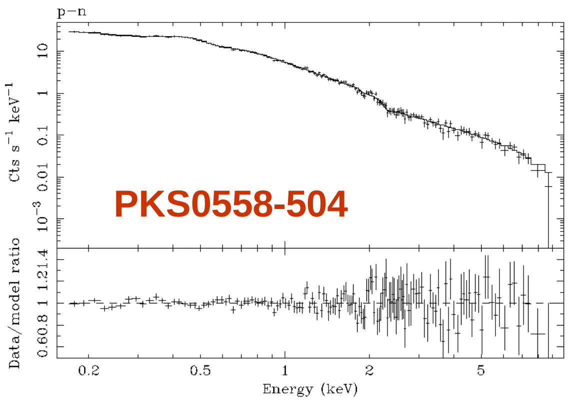
There are two main sources of information to answer this question:

1. the CCF release notes, which report the expected accuracy associated with each individual CCF component

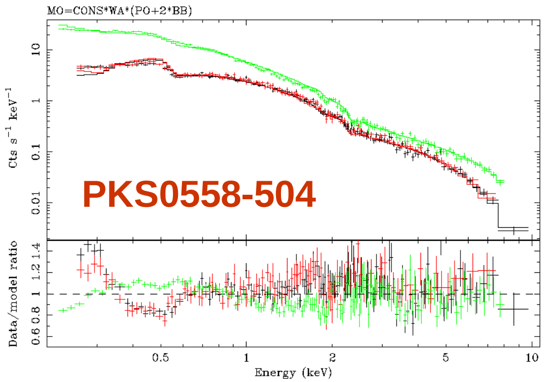
2. The SAS validation reports, which compare the expected calibration accuracies on a pre-defined set of XMM-Newton observations. An update of the report is issued at every new SAS release



Quality of MOS spectral fitting



Quality of pn spectral fitting



MOS/pn comparison

I have forgotten everything ...

No panic! All the information included in this presentation are available on the web:

- **SAS**: **`http://xmm.vilspa.esa.es/sas`**

- **SAS User Guide**:
`http://xmm.vilspa.esa.es/sas/documentation/userguide.ps.gz`

- **Calibration and calibration files**: **`http://xmm.vilspa.esa.es/calibration/`**

- **Quality of EPIC response matrices**:
`http://xmm.vilspa.esa.es/docs/documents/PS-TN-0043-2-0.ps.gz`

- **SAS validation data and report**:
`http://xmm.vilspa.esa.es/public/xmm_sas_sv.html`

- **EPIC background issues**:
`http://xmm.vilspa.esa.es/docs/documents/CAL-TN-0016-1-0.ps.gz`

If everything else fails, send an e-mail to the HelpDesk: **`xmmhelp@xmm.vilspa.esa.es`**