

XMM-Newton data analysis: tutorial



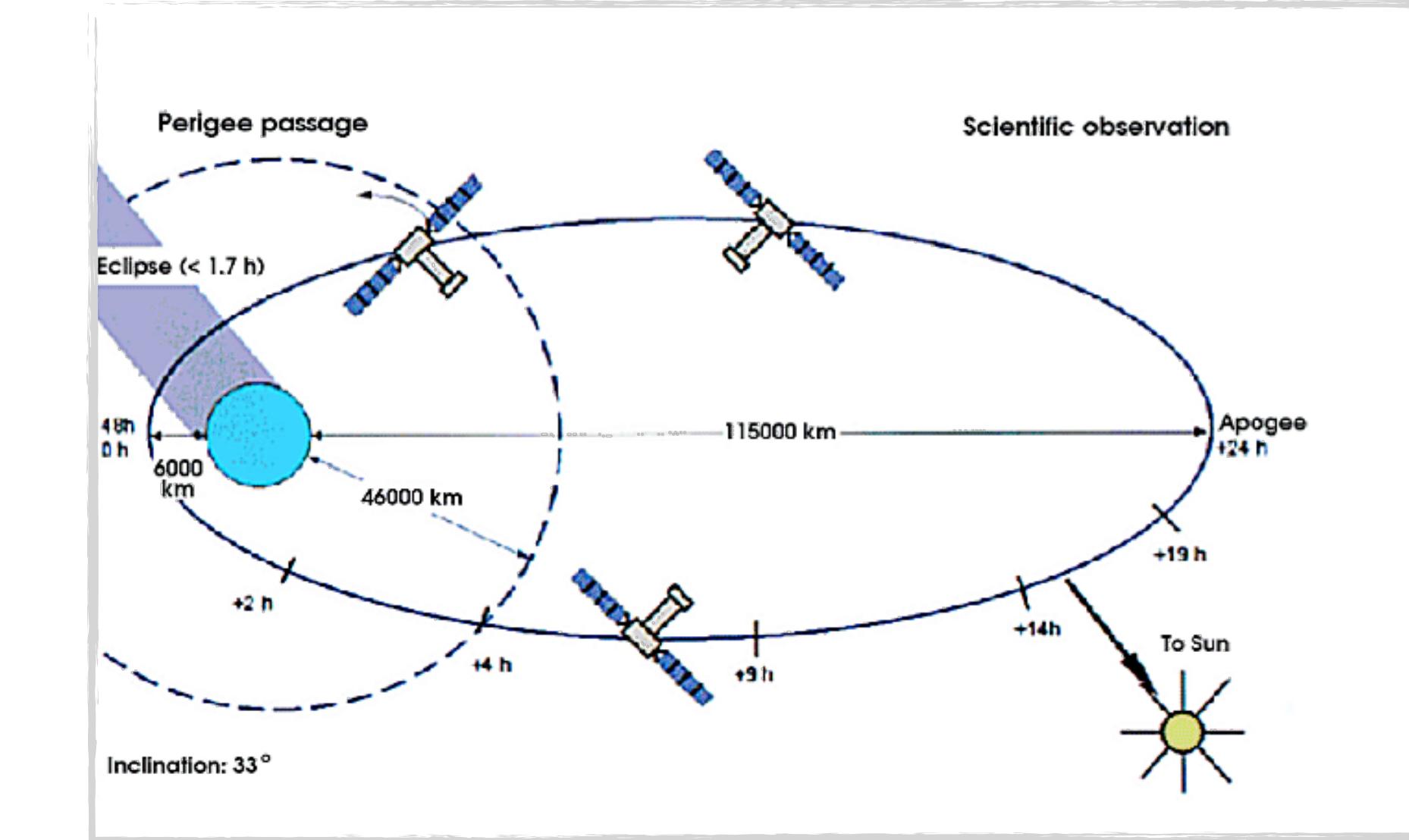
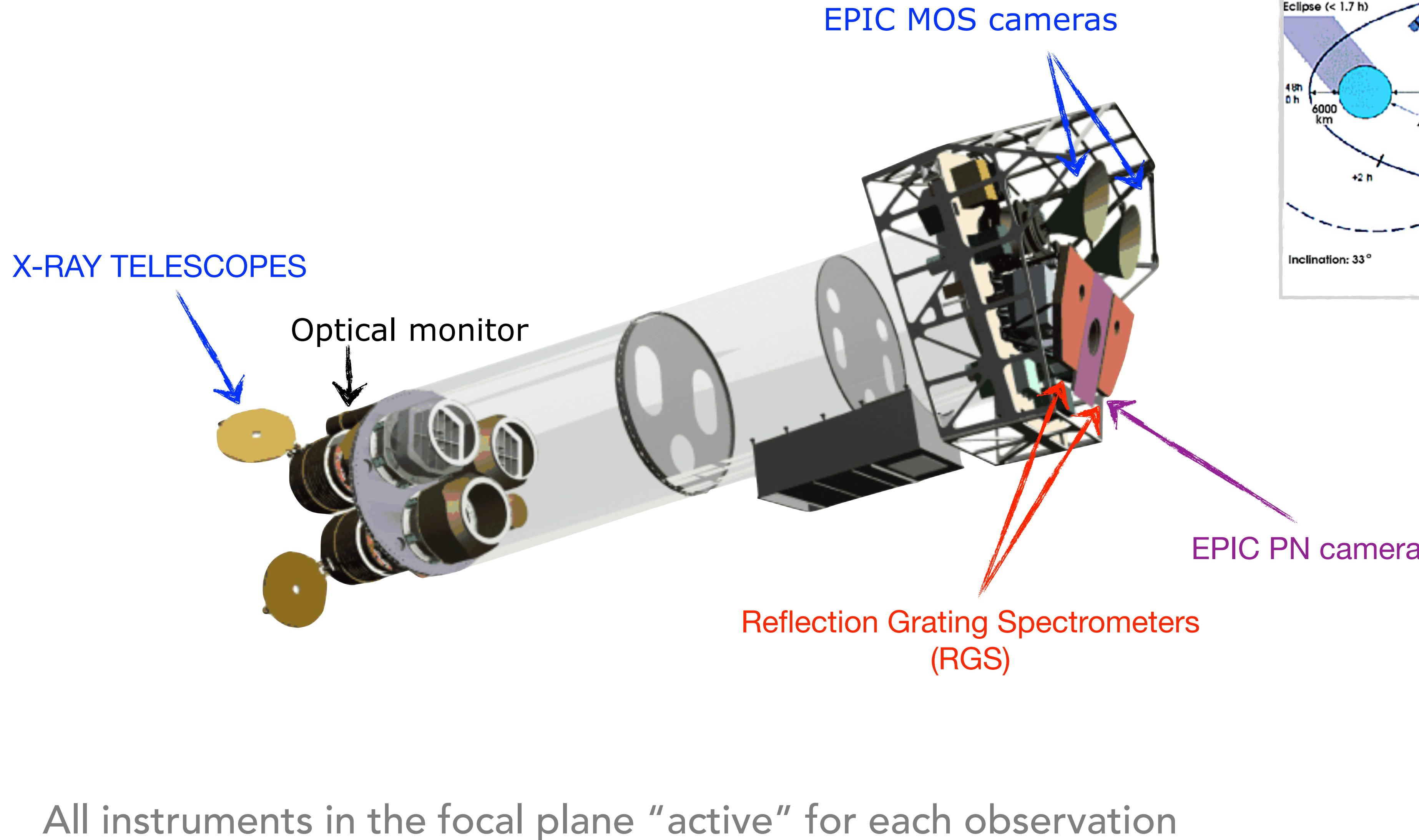
Astrophysics Laboratory course: AA 2021/22

25.02.2022

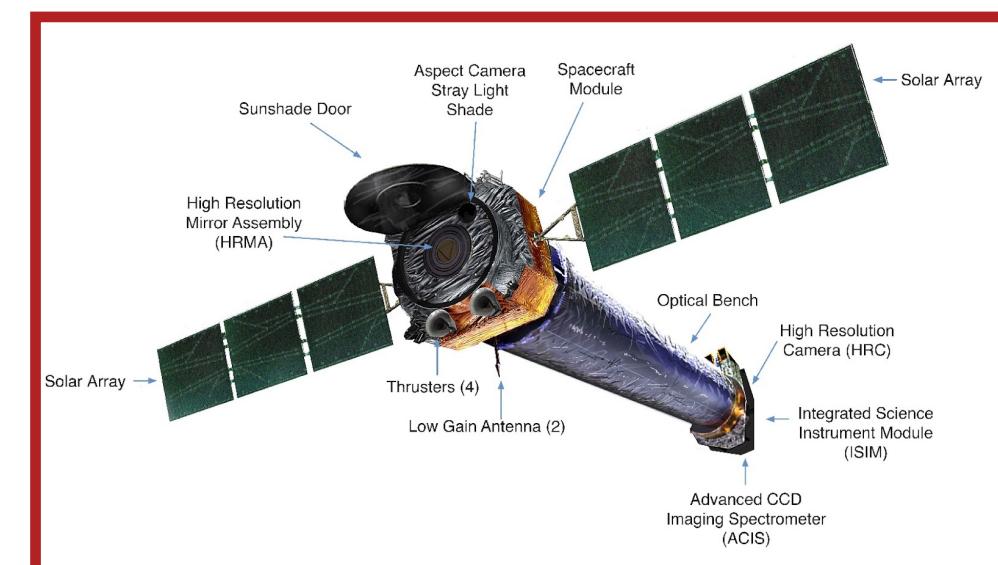
Outline

- The spacecraft
- Webpage, software and data download
- Data structure
- SAS
- Data re-processing
- Data reduction:
 - filtering for high particle background
 - selection of good time intervals (GTI)
 - selection of source and background extraction regions
- EPIC science modes
- Pileup
- Extraction of source and background spectra
- RMF & ARF
- Grouping
- (Background corrected) light curve extraction

The spacecraft



Highly elliptical orbit around the Earth
Inclination 40 degrees to the Equator



See M. Dadina's presentation & C. Vignali's presentation

XMM-Newton archive & data download

<https://www.cosmos.esa.int/web/xmm-newton/xsa>

XMM-Newton » Archive, Pipeline & Catalogues » XMM-Newton Science Archive

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XMM-NEWTON SCIENCEX ARCHIVE (XSA)

INDEX

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- Download Full XMM-Newton Catalogues and datasets **New**
- Tools
- Watchouts
- Notes on the XSA releases **New**
- Documentation
- Questions, Comments

ACCESS TO XMM-NEWTON DATA AND SOURCE CATALOGUES

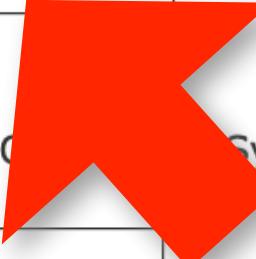
[Search the XMM-Newton Science Archive \(XSA\)](#)

Direct access to the XSA data via URL or AIO (Archive InterOperability System):

[Command line and URL access to the XSA data](#)

Astroquery and TAP (Table Access Protocol) access to the XSA Database:

[Astroquery and TAP queries to the XSA Database](#)





XMM-Newton Science Archive Search

Position File

- Name
- Equatorial
- Galactic

Target in Field Of View Circle Box

Name

3C 111

for Resolve

► Observation and Proposal filters

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[Send table to](#)
[RGS Spectra](#)

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<input type="checkbox"/>			0065940101					3C 111	04h 18m 21.07s	+38d 01' 32.6"	231	0.07	2001-03-14 12:56:44	2001-03-15 01:23:52	44828	SEYFERT RADIO LOUD STEEP RADIO SP	Eracleous, Michael	GO

Public Date	PPS ver	Coord. Obs
Public data	17.56_20190403_1200	-
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XMM-Newton Science Archive

HOME SEARCH COMMAND & URL ACCESS INTERACTIVE ANALYSIS TAP QUERIES ASTROQUERY

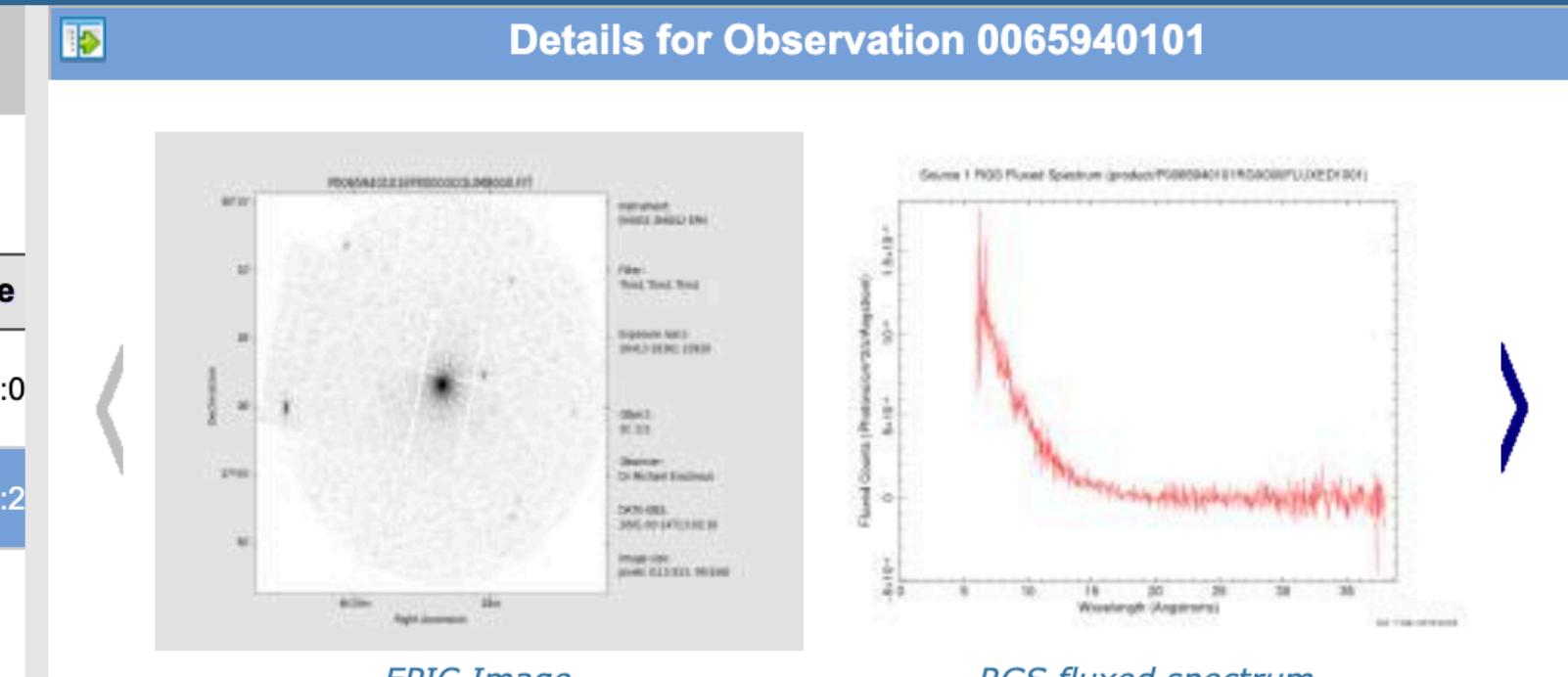
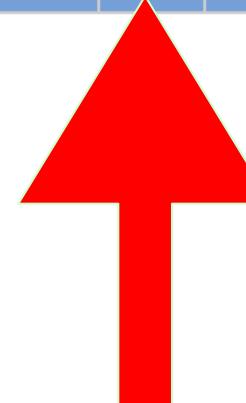


Back to Search Close all

Results #1

OBSERVATIONS (2)

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Summary Science Exposures Publications

Obs. ID	0065940101
Revolution	231
Target	3C 111
Exposures	3 EPIC, 14 OM, 2 RGS

Proposal Abstract

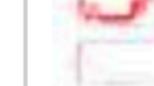
Structure of the Accretion Flows in Broad-Line Radio Galaxies

We propose to observe four of the X-ray brightest broad-line radio galaxies in order to investigate the differences between the profiles of the Fe K lines of radio-loud and radio quiet AGNs. We will obtain spectra with very high signal-to-noise ratio with EPIC so that we can fit the line profiles with disk models and determine the range of radii in the disk where the lines originate. This constitutes a test of scenarios for the difference between radio-loud and radio-quiet AGNs since such scenarios predict different disk structures and by extension different line profiles.

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 - [SPECTRA](#)
 - [LIGHT_CURVES](#)

0552180101.tar.gz

How to copy the downloaded file in your working directory

- FTP clients (Fugu, Cyberduck, Filezilla, etc.)
- `scp 0552180101.tar.gz gruppoXX@login05.iasfbo.inaf.it:/home/gruppoXX`

Data structure

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MOS1
MOS2

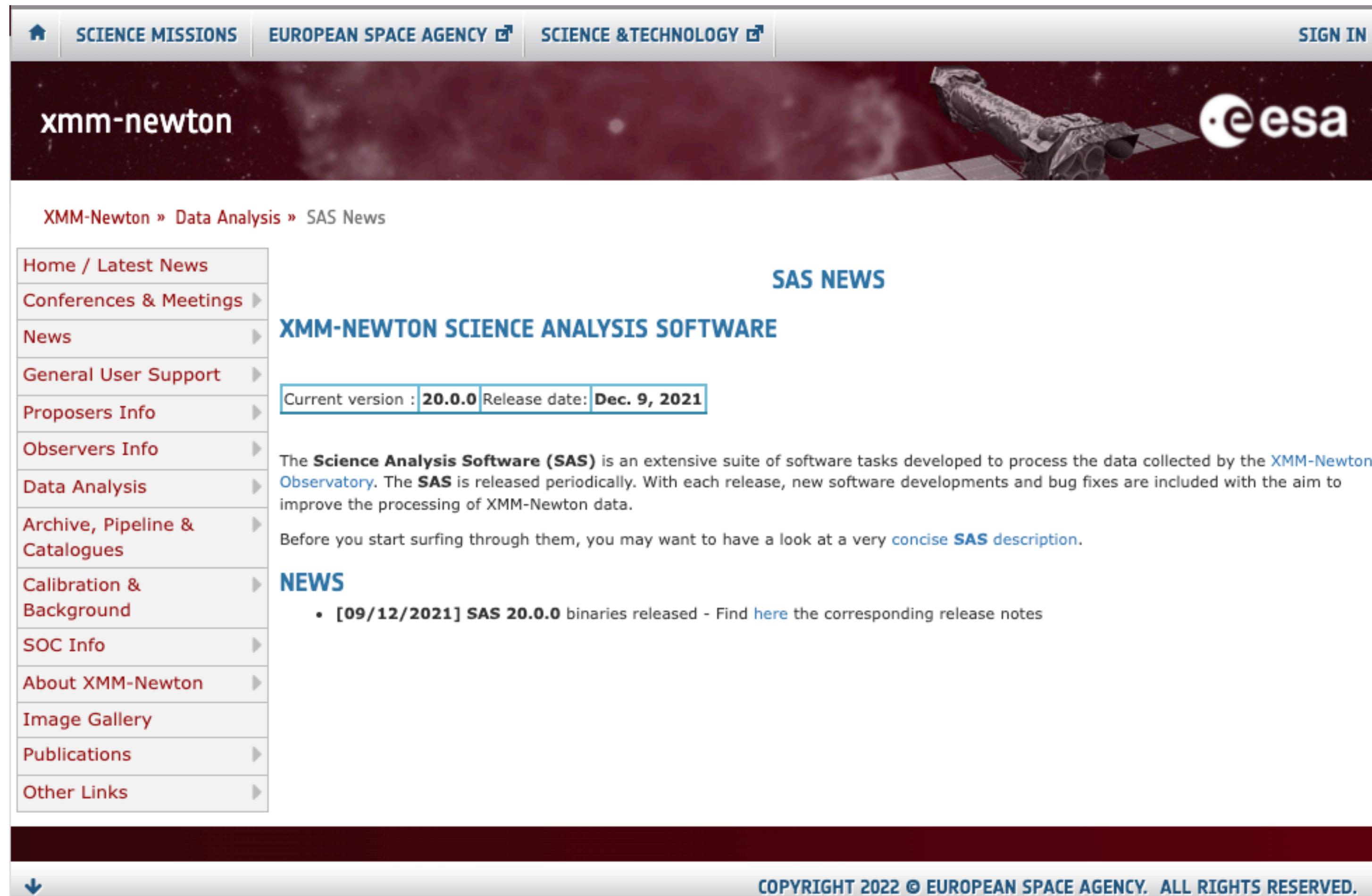
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pn

RGS1

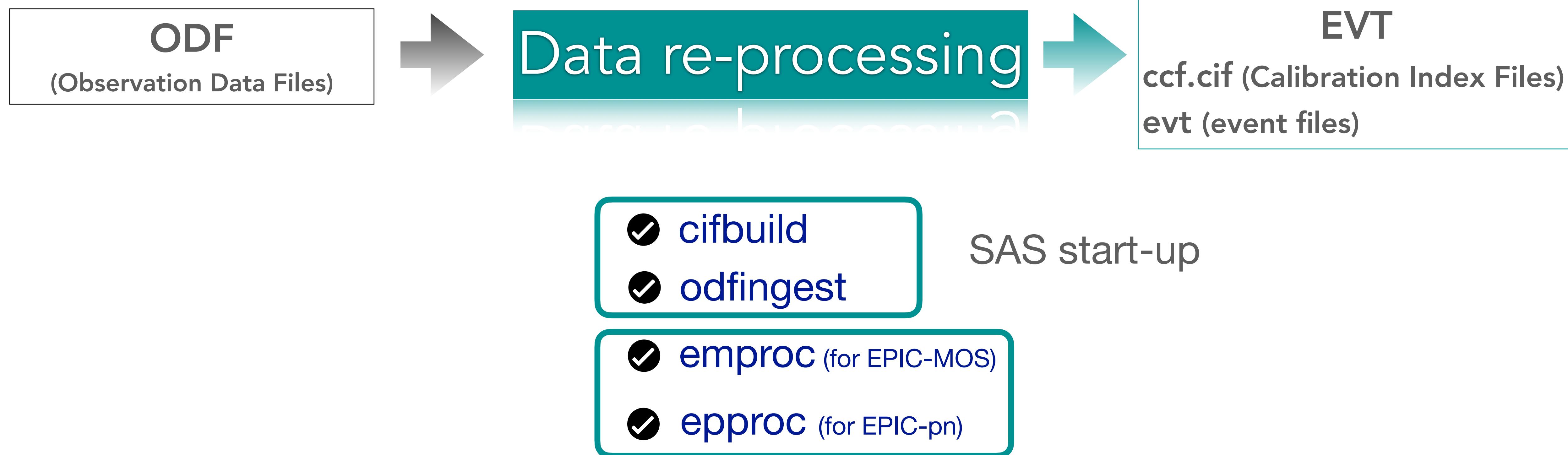
RGS2

Standard Analysis System (SAS)

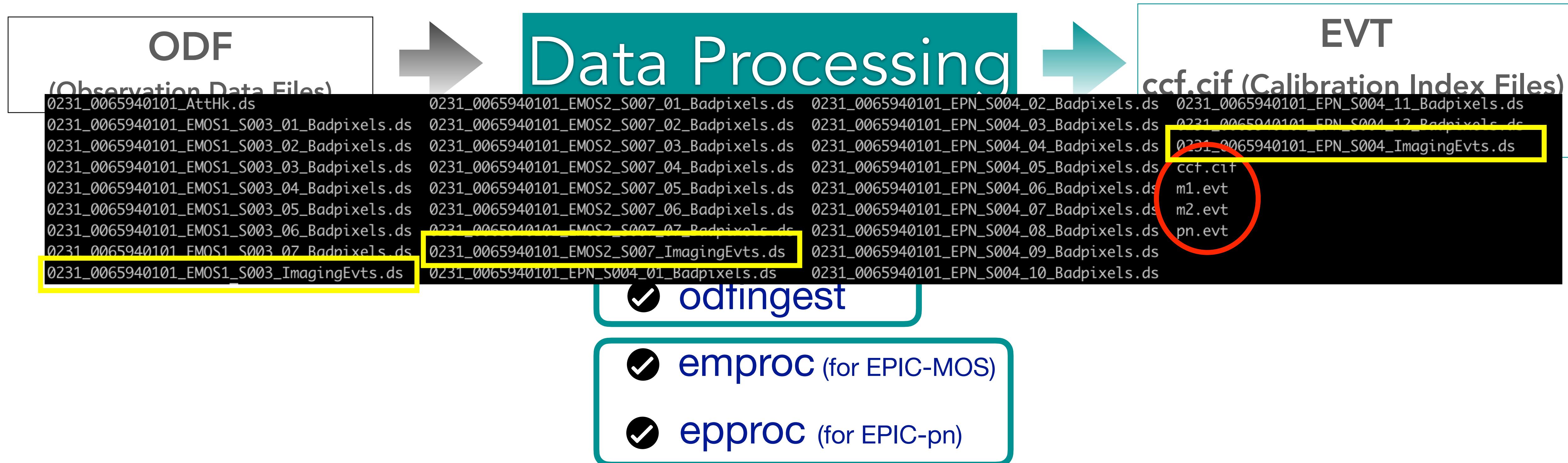


The screenshot shows the 'SAS News' section of the XMM-Newton website. At the top, there's a navigation bar with links for 'SCIENCE MISSIONS', 'EUROPEAN SPACE AGENCY', 'SCIENCE & TECHNOLOGY', and 'SIGN IN'. Below the navigation is a banner featuring the 'xmm-newton' logo and the 'esa' logo. The main content area has a dark background with a space-themed image. On the left, a sidebar menu lists various links: Home / Latest News, Conferences & Meetings, News, General User Support, Proposers Info, Observers Info, Data Analysis, Archive, Pipeline & Catalogues, Calibration & Background, SOC Info, About XMM-Newton, Image Gallery, Publications, and Other Links. The right side features a 'SAS NEWS' header, followed by a section titled 'XMM-NEWTON SCIENCE ANALYSIS SOFTWARE'. It displays the current version as '20.0.0' and the release date as 'Dec. 9, 2021'. Below this, a paragraph explains what the SAS is and its purpose. Further down, there's a 'NEWS' section with a bullet point about the release of SAS 20.0.0 binaries. At the bottom, there's a copyright notice: 'COPYRIGHT 2022 © EUROPEAN SPACE AGENCY. ALL RIGHTS RESERVED.'

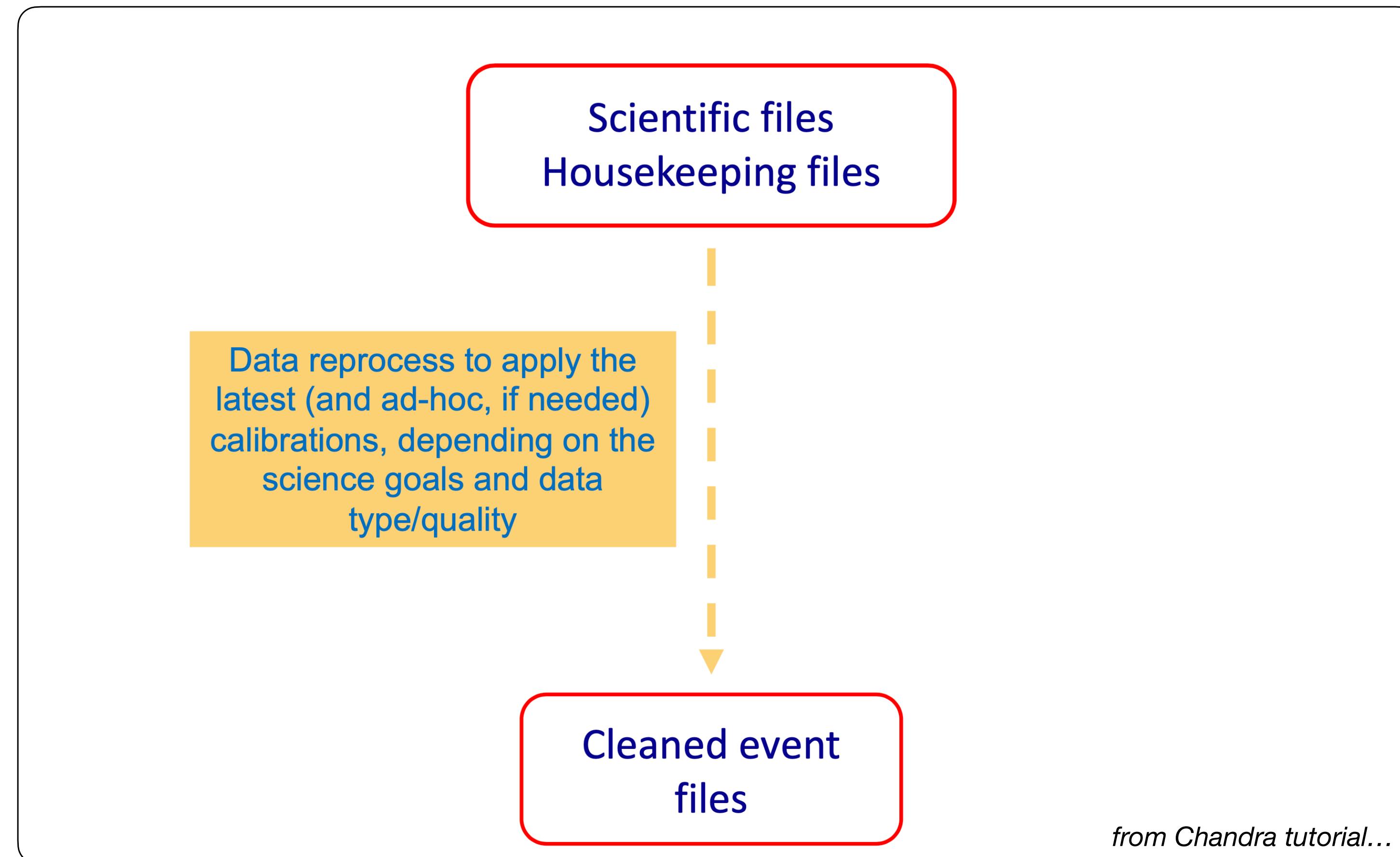
Data re-processing:



Data re-processing:



Data Reduction



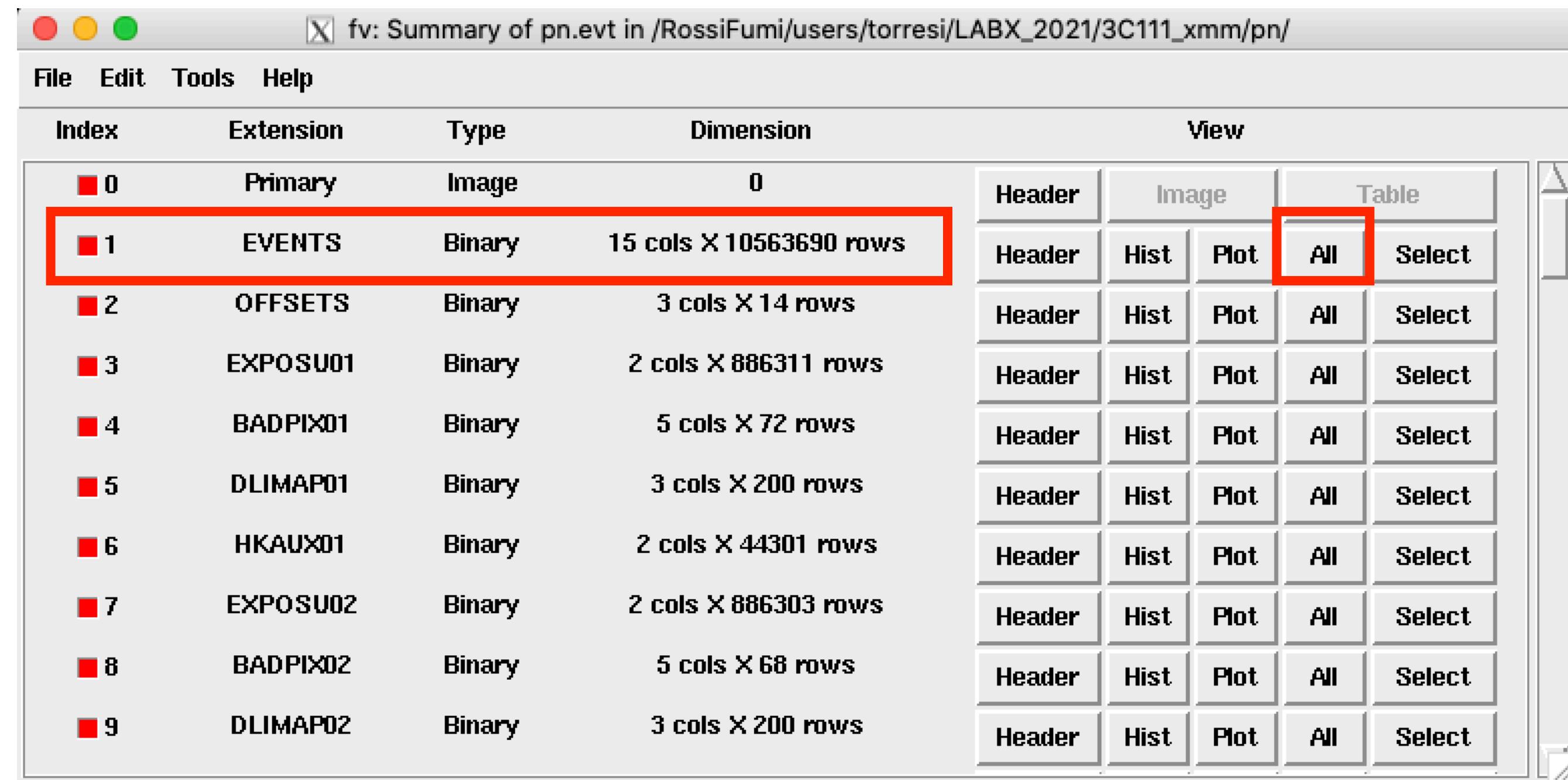
IMAGE

SPECTRUM

LIGHT CURVE

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#rows = #counts



X,Y -> image
Time -> light curve
Energy -> spectrum

fv pn.evt

#rows=

fv: Summary of pn.evt in /RossiFumi/users/torresi/LABX_2021/3C111_xmm/pn/

fv: Binary Table of pn.evt[1] in /RossiFumi/users/torresi/LABX_2021/3C111_xmm/pn/

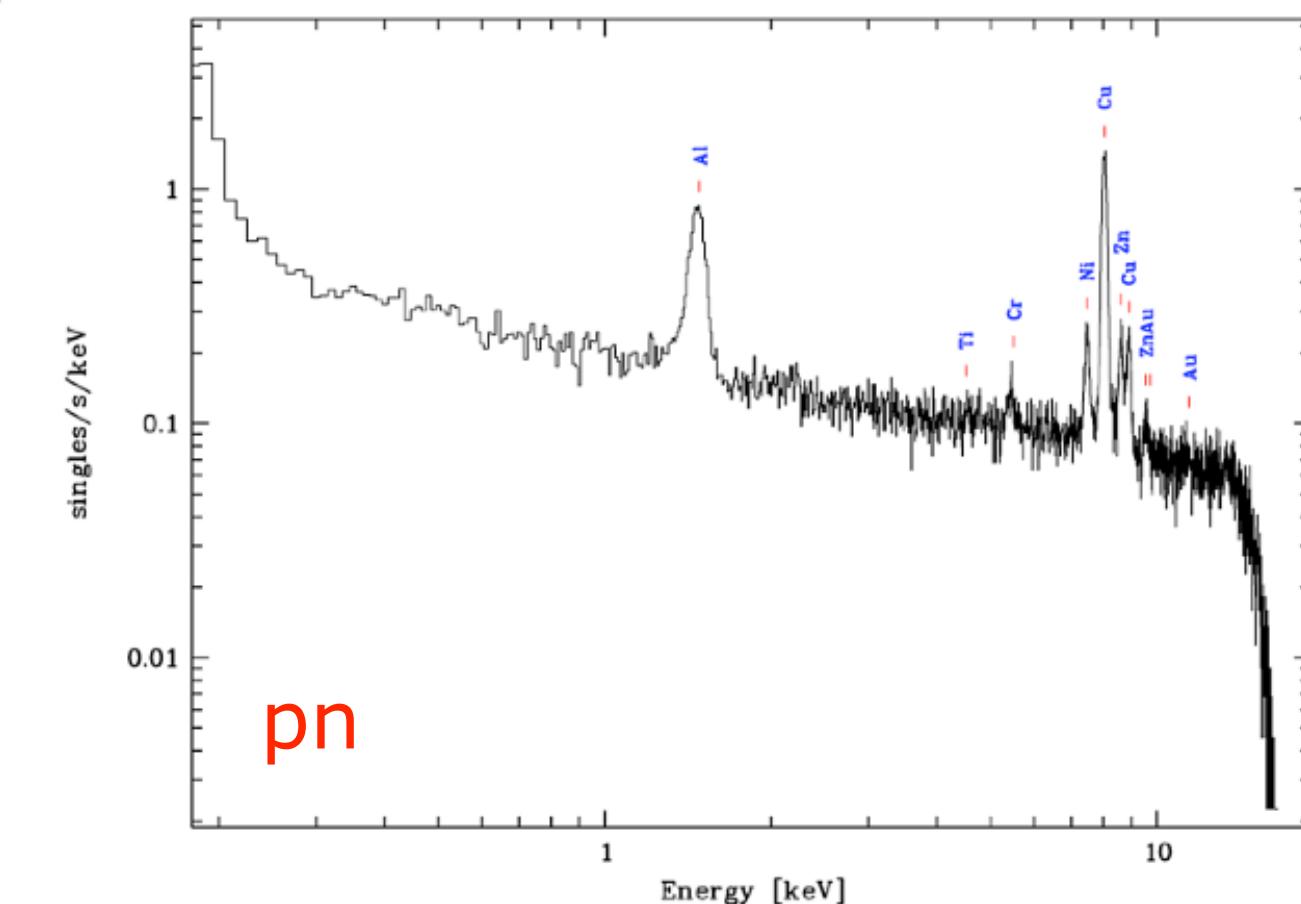
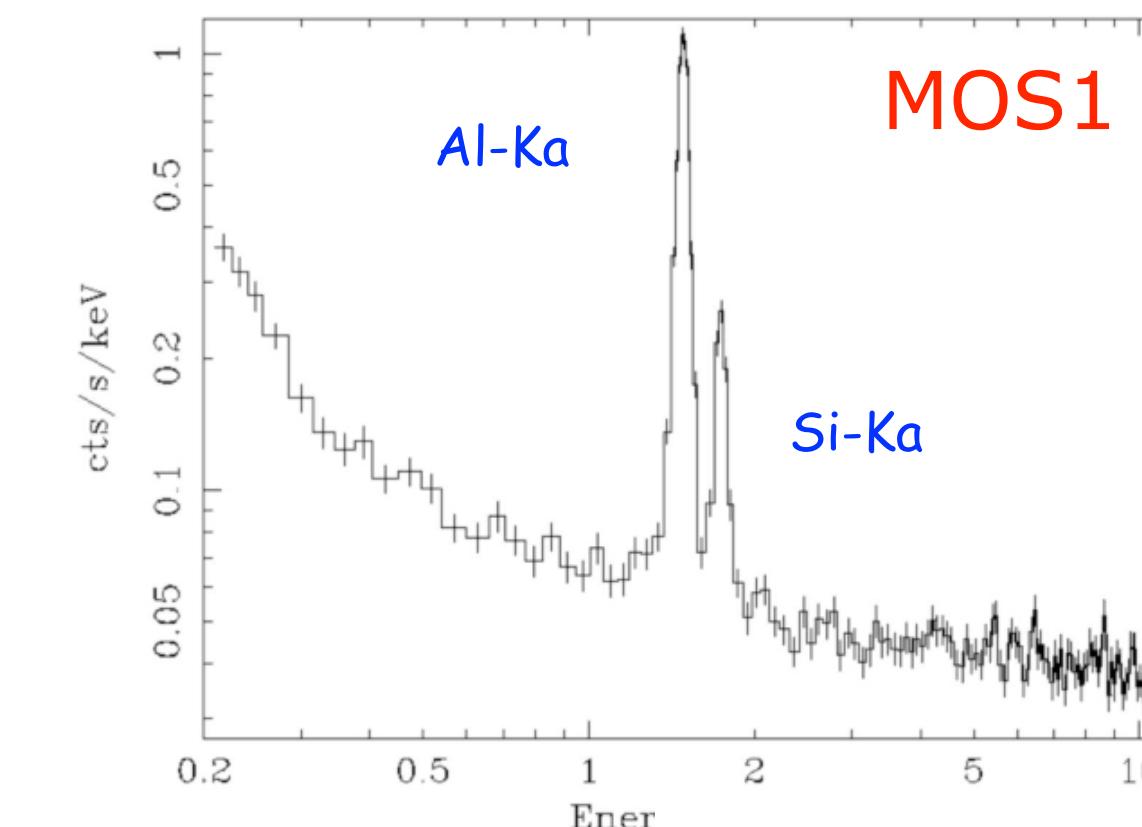
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Select	D	I	I	I	I	J	J	I	I	J	B	I	B	B	D
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3	1.009638775176E+08	46	132	-6049	4557	20381	23994	31	291	0	3	5122	1	1	1.009638774951E+08
4	1.009638774790E+08	46	138	-5980	4137	20539	24389	22	233	0	4	5123	4	1	1.009638774951E+08
5	1.009638775139E+08	46	150	-5991	3091	20753	25413	23	241	0	3	5124	1	1	1.009638774951E+08
6	1.009638794362E+08	24	144	-4198	3643	22385	24488	136	1031	0	1	5121	0	1	1.009638794493E+08
7	1.009638806363E+08	50	172	-6326	1271	20817	27263	38	409	0	4	5121	0	1	1.009638806409E+08
8	1.009638806306E+08	55	172	-6742	1298	20405	27326	34	340	0	2	5122	0	1	1.009638806409E+08
9	1.009638806432E+08	64	172	-7476	1286	19691	27495	43	614	5	207	3	0	1	1.009638806409E+08
10	1.009638834399E+08	4	165	-2579	1890	24343	25852	329	1700	0	0	0	0	1	1.009638834531E+08
11	1.009638856608E+08	6	181	-2726	560	24486	27183	2334	19753	0	3	5121	1	1	1.009638856457E+08
12	1.009638866421E+08	2	174	-2422	1127	24661	26563	872	7050	0	11	5121	1	1	1.009638866466E+08
13	1.009638878099E+08	12	185	-3187	241	24104	27593	353	3002	0	7	5121	1	1	1.009638877905E+08
14	1.009638927632E+08	42	124	-5690	5292	20573	23199	365	1899	0	0	0	0	1	1.009638927476E+08
15	1.009638928897E+08	33	200	-4922	-1024	22682	29202	1227	6470	4	0	0	0	1	1.009638928906E+08
16	1.009638944018E+08	56	102	-6864	7074	19043	21711	49	470	5	1	1	0	1	1.009638944158E+08
17	1.009638957090E+08	1	142	-2305	3806	24199	23922	292	1512	4	0	0	0	1	1.009638957028E+08
18	1.009638967794E+08	47	128	-6129	4891	20231	23685	27	248	0	1	5121	2	1	1.009638967990E+08
19	1.009638967981E+08	47	140	-6125	3905	20447	24647	24	236	0	1	5122	5	1	1.009638967990E+08
20	1.009638967894E+08	47	152	-6104	2977	20667	25549	24	350	1	78	3	1	1	1.009638967990E+08
21	1.009638967825E+08	47	173	-6104	1236	21041	27249	27	267	0	1	5124	4	1	1.009638967990E+08
22	1.009638968113E+08	15	175	-3474	1002	23660	26912	611	3896	0	3	5125	1	1	1.009638967990E+08
23	1.009638993268E+08	5	188	-2620	-61	24723	27766	244	1509	0	1	5121	0	1	1.009638993252E+08
24	1.009639017368E+08	24	166	-4212	1776	22773	26315	31	158	0	0	0	2	1	1.009639017561E+08
25	1.009639021557E+08	15	184	-3465	323	23815	27573	128	676	0	0	0	0	1	1.009639021374E+08
26	1.009639033902E+08	3	169	-2501	1536	24496	26181	1060	5469	0	0	0	0	1	1.009639033767E+08
27	1.009639071054E+08	62	104	-7352	6869	18611	22016	21	209	0	3	5121	1	1	1.009639070944E+08
28	1.009639071103E+08	61	107	-7282	6617	18734	22247	29	819	1	98	2	0	1	1.009639070944E+08
29	1.009639071140E+08	11	144	-3162	3599	23406	24309	24	235	0	1	5123	2	1	1.009639070944E+08

Filtering against high background

EPIC particle induced background

Internal 'quiescent' component

high energy particles interacting with the structure surrounding the detectors and the detectors themselves

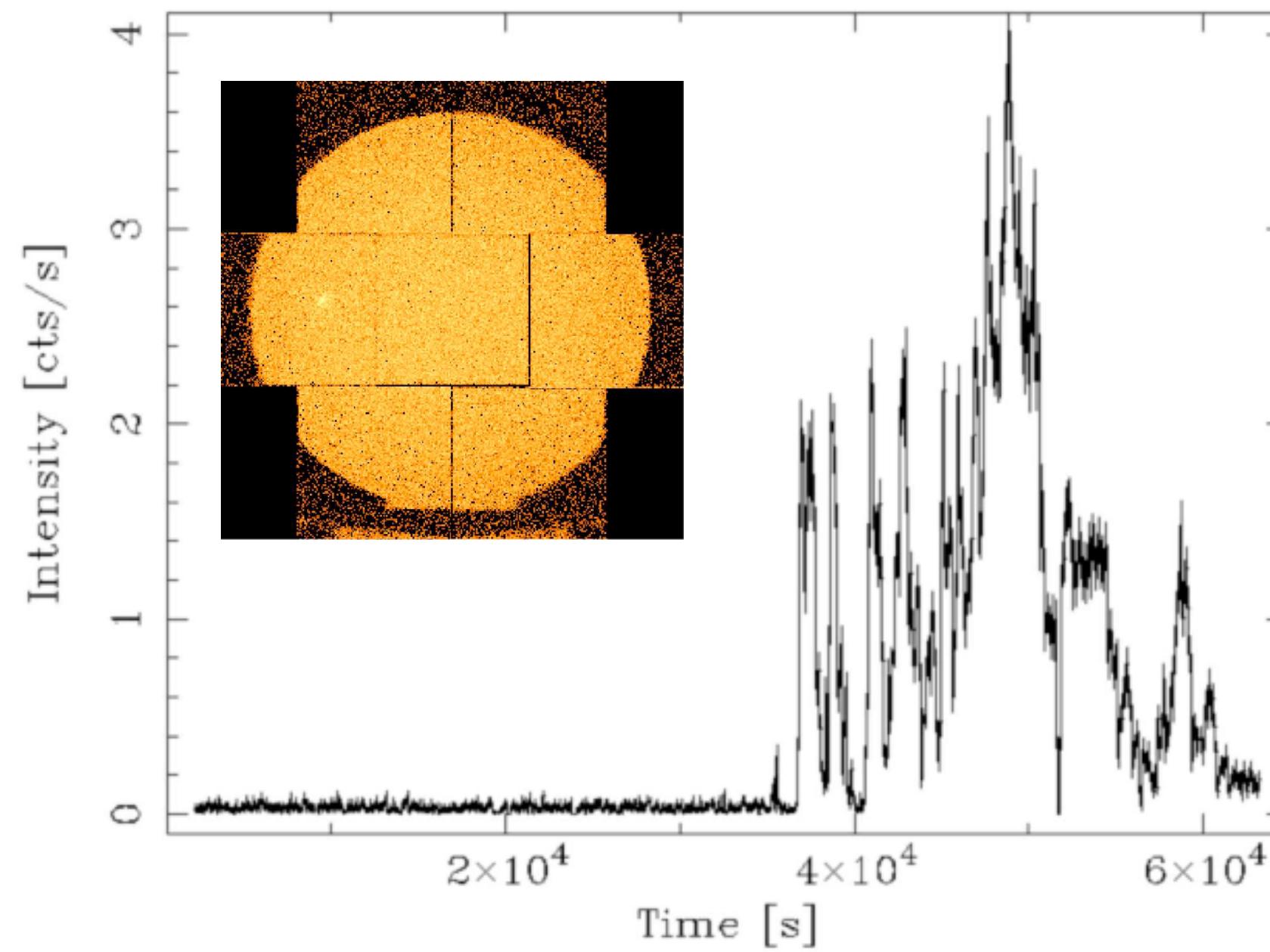


Filtering against high background

EPIC particle induced background

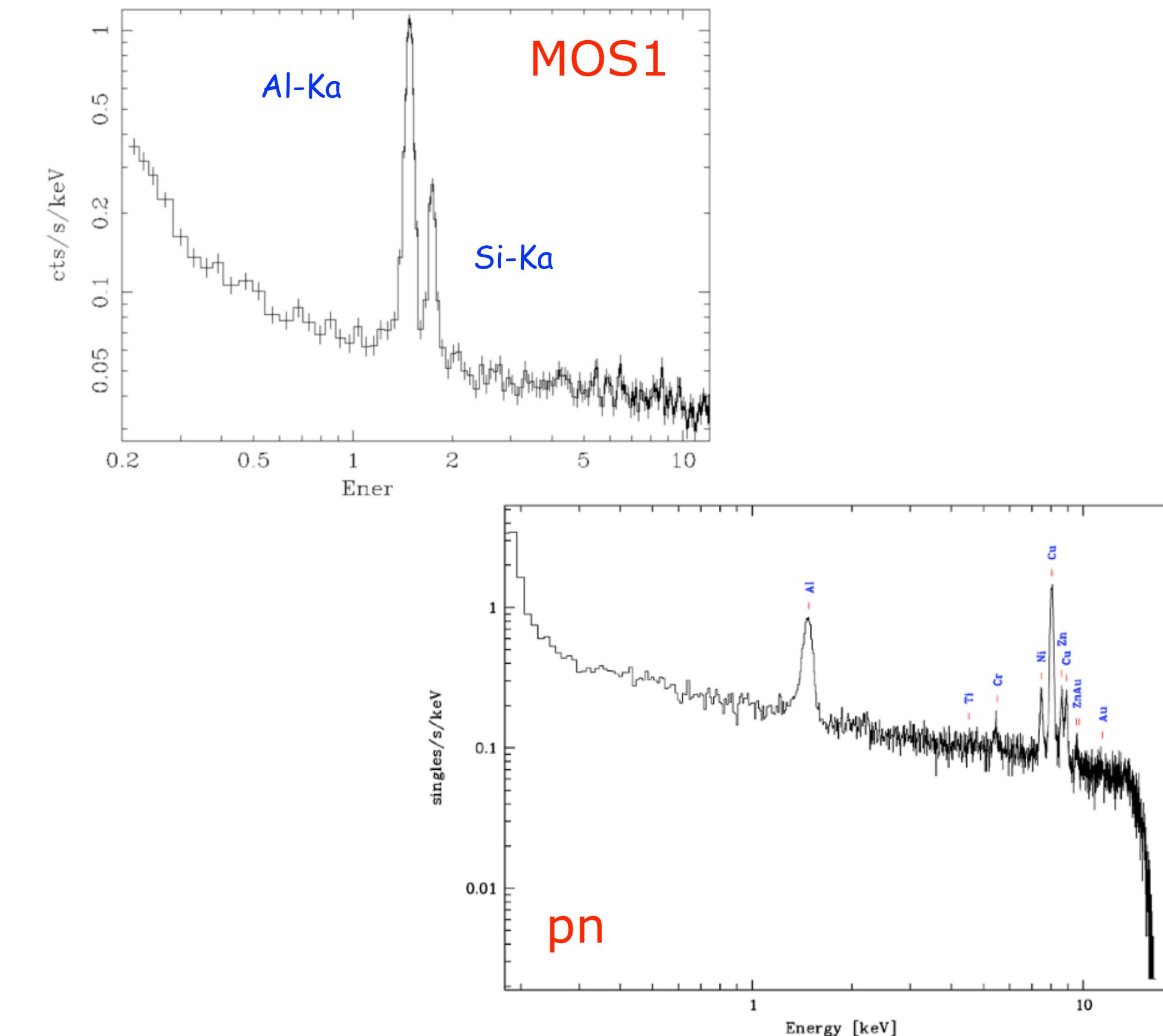
External 'flaring' component

strong and rapid variability; currently attributed to soft protons ($E_p <$ a few 100 keV) likely organized in clouds populating the Earth's magneto-sphere



Internal 'quiescent' component

high energy particles interacting with the structure surrounding the detectors and the detectors themselves



Extract a single event (i.e. pattern zero only), high energy light curve, from the event file to identify intervals of flaring particle background:

pn:

```
evselect table=pn.evt energycolumn=PI expression='#XMMEA_EP && (PI>10000&&PI<12000) && (PATTERN==0)'  
withrateset=yes rateset="lcurve_sup10.lc" timebinsize=100 maketimecolumn=yes makeratecolumn=yes
```

MOS1:

```
evselect table=m1.evt energycolumn=PI expression='#XMMEA_EM && (PI>10000) &&(PATTERN==0)' withrateset=yes  
rateset="lcurve_sup10.lc" timebinsize=100 maketimecolumn=yes makeratecolumn=yes
```

MOS2:

```
evselect table=m2.evt energycolumn=PI expression='#XMMEA_EM && (PI>10000) &&(PATTERN==0)' withrateset=yes  
rateset="lcurve_sup10.lc" timebinsize=100 maketimecolumn=yes makeratecolumn=yes
```

Table 7: List of EPIC event patterns

Camera	Mode	X-ray generated pattern			
		singles	doubles	triples	quadruples
MOS	imaging	0	1-4	5-8	9-12
pn	imaging	0	1-4	5-8	9-12

single event	. . .	. X .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
double pattern	. . . . .	. . . . .	. . X x .	. . X . .	. . x X .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
triple pattern	. . . . .	. . . . .	. . x . .	. . x . .	. . X x .	. . X x .	. . x X .	. . x X .	. . x X .	. . x X .	. . x X .	. . x X .
quadruple pattern	. . . . .	. . . . .	. . m x .	. . x m .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .

Figure 13: List of valid EPIC-pn patterns (cf. figure 12). Here " ." marks a pixel without an event above threshold, "X" is the pixel with the maximum charge ("main pixel"), "x" is the pixel with a non-maximum charge, "m" is the pixel with the minimum charge. These 13 figures refer to the SAS PATTERN codes 0 (singles), 1-4 (doubles), 5-8 (triples) and 9-12 (quadruples), respectively. The RAWX co-ordinate is running rightward and the RAWY co-ordinate running upward.

> lcurve

```
[torresi@login01]pn>lcurve

lcurve 1.0 (xronos6.0)

Number of time series for this task[1]
Ser. 1 filename +options (or @file of filenames +options)[lcurve_sup10.lc]
Series 1 file 1:lcurve_sup10.lc

Selected FITS extensions: 1 - RATE TABLE;

Source ..... Start Time (d) .... 11982 13:31:12.443
FITS Extension .... 1 - `RATE` Stop Time (d) .... 11983 01:16:11.936
No. of Rows ..... 423 Bin Time (s) .... 100.0
Right Ascension ... Internal time sys... Converted to TJD
Declination ..... Experiment ..... XMM EPN
Filter ..... Thin1
Corrections applied: Vignetting - No ; Deadtime - No ; Bkgd - No ; Clock - Yes

Selected Columns: 3- Time; 1- Y-axis; 2- Y-error;

File contains binned data.

Name of the window file ('-' for default window)[-]

Expected Start ... 11982.56333845733 (days) 13:31:12:443 (h:m:s:ms)
Expected Stop .... 11983.05291592991 (days) 1:16:11:936 (h:m:s:ms)

Minimum Newbin Time 100.00000 (s)
for Maximum Newbin No.. 423

Default Newbin Time is: 100.00000 (s) (to have 1 Intv. of 423 Newbins)
Type INDEF to accept the default value

Newbin Time or negative rebinning[100]

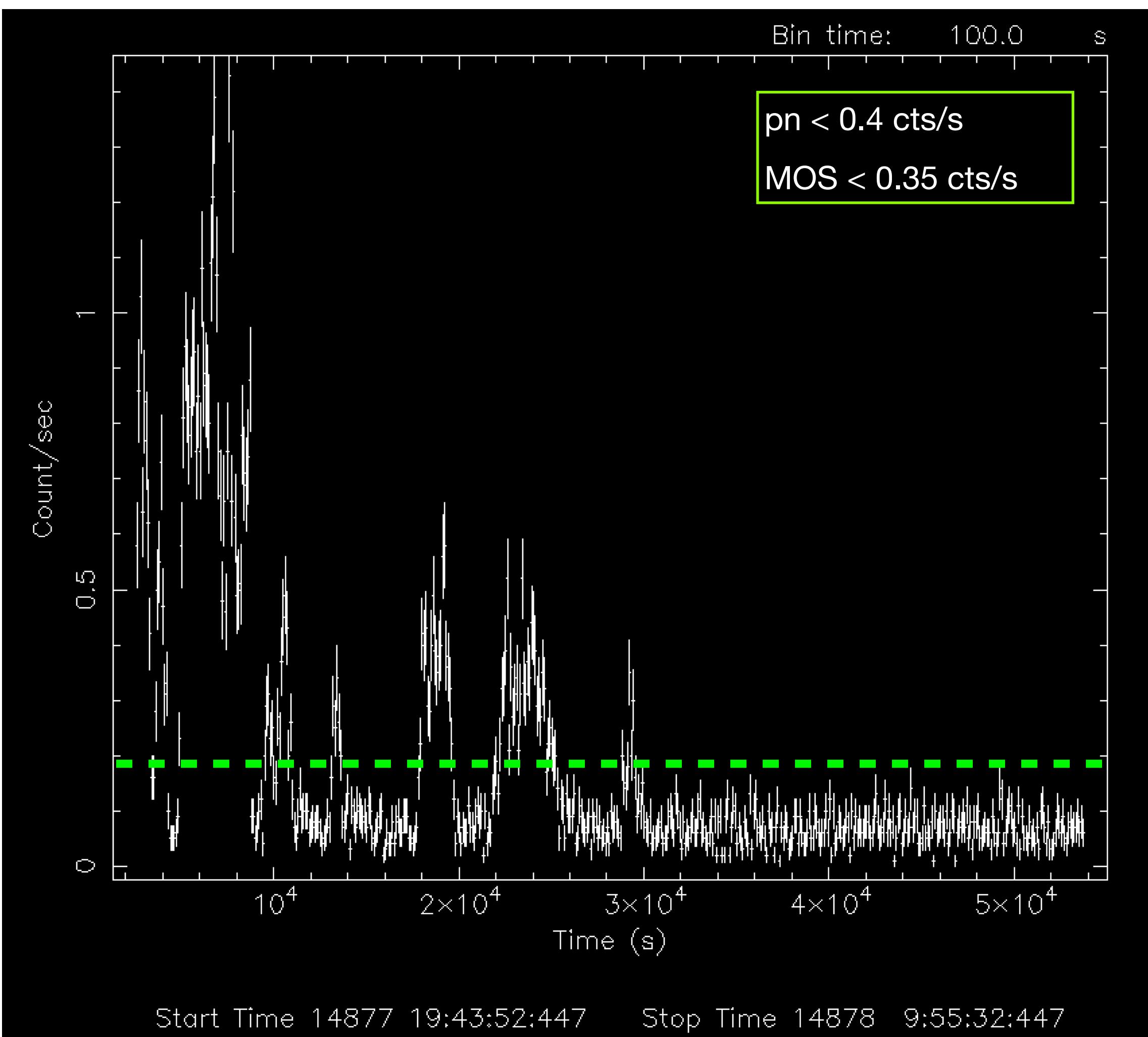
Newbin Time ..... 100.00000 (s)
Maximum Newbin No. 423

Default Newbins per Interval are: 423
(Giving 1 Interval of 423 Newbins)
Type INDEF to accept the default value

Number of Newbins/Interval[423]
Maximum of 1 Intvs. with 423 Newbins of 100.000 (s)
Name of output file[test.flc]
Do you want to plot your results?[yes]
Enter PGPLOT device[/xw]

423 analysis results per interval

100% completed
```



Possible error!

```
PGPLOT /xw: cannot connect to X server [localhost:12.0]
To plot vs. Time (s), please enter
PGPLOT file/type:
```

Selection of GOOD TIME INTERVALS (GTI)

```
tabgtigen table=lcurve_sup10.lc gtiset=good_bkg.gti expression='RATE<0.2'
```

Generation of the cleaned event file

pn:

```
evselect table=pn.evt expression='#XMMEA_EP && (PI>150) && (GTI(good_bkg.gti,TIME))' withfilteredset=yes  
keepfilteroutput=yes filteredset=pn_new.evt updateexposure=yes cleandss=yes writedss=yes
```

MOS1:

```
evselect table=m1.evt expression='#XMMEA_EM && (PI > 150) && (GTI(good_bkg.gti,TIME))' withfilteredset=yes  
keepfilteroutput=yes filteredset=mos1_new.evt updateexposure=yes cleandss=yes writedss=yes
```

MOS2:

```
evselect table=m2.evt expression='#XMMEA_EM && (PI > 150) && (GTI(good_bkg.gti,TIME))' withfilteredset=yes  
keepfilteroutput=yes filteredset=mos2_new.evt updateexposure=yes cleandss=yes writedss=yes
```

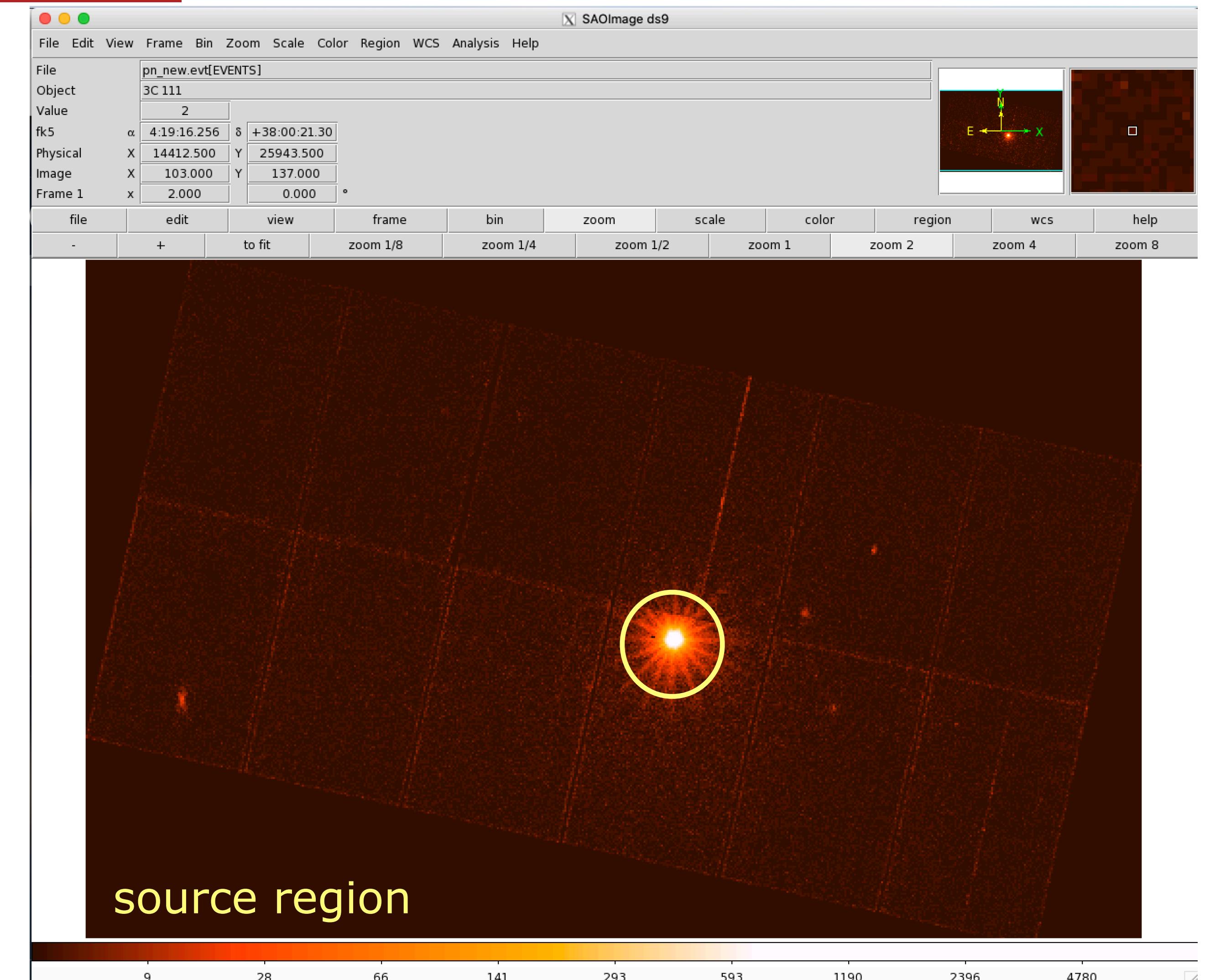
Source & background extraction regions

Display the cleaned pn image with **ds9**

ds9 pn_new.evt &

> scale log
> bin (block 2, 4, ...)

> Region
> save region
> file format ‘ds9’
> coordinates ‘physical’
> **source.reg**

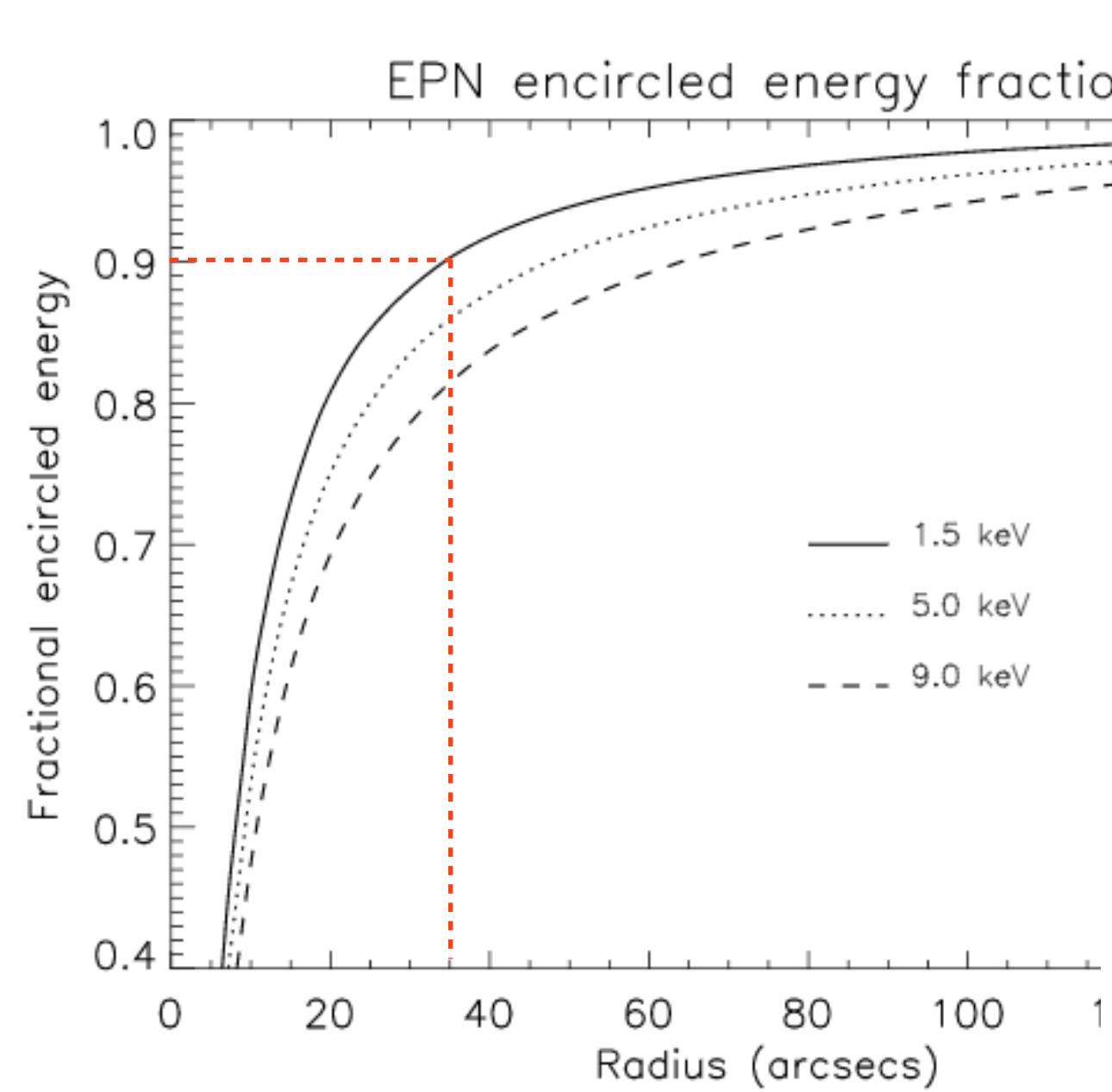


circle(27404.411,27351.501,799.99999)

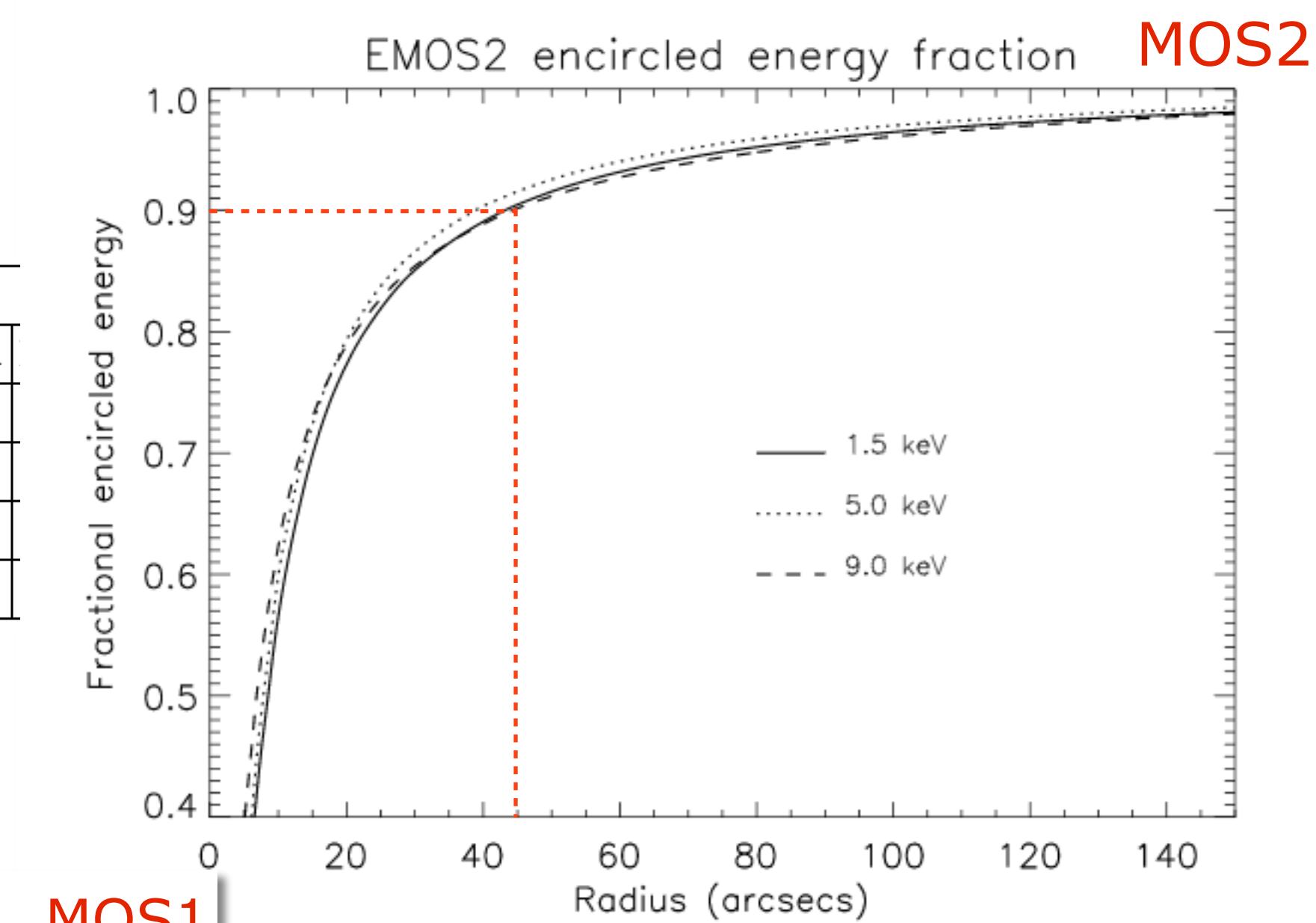
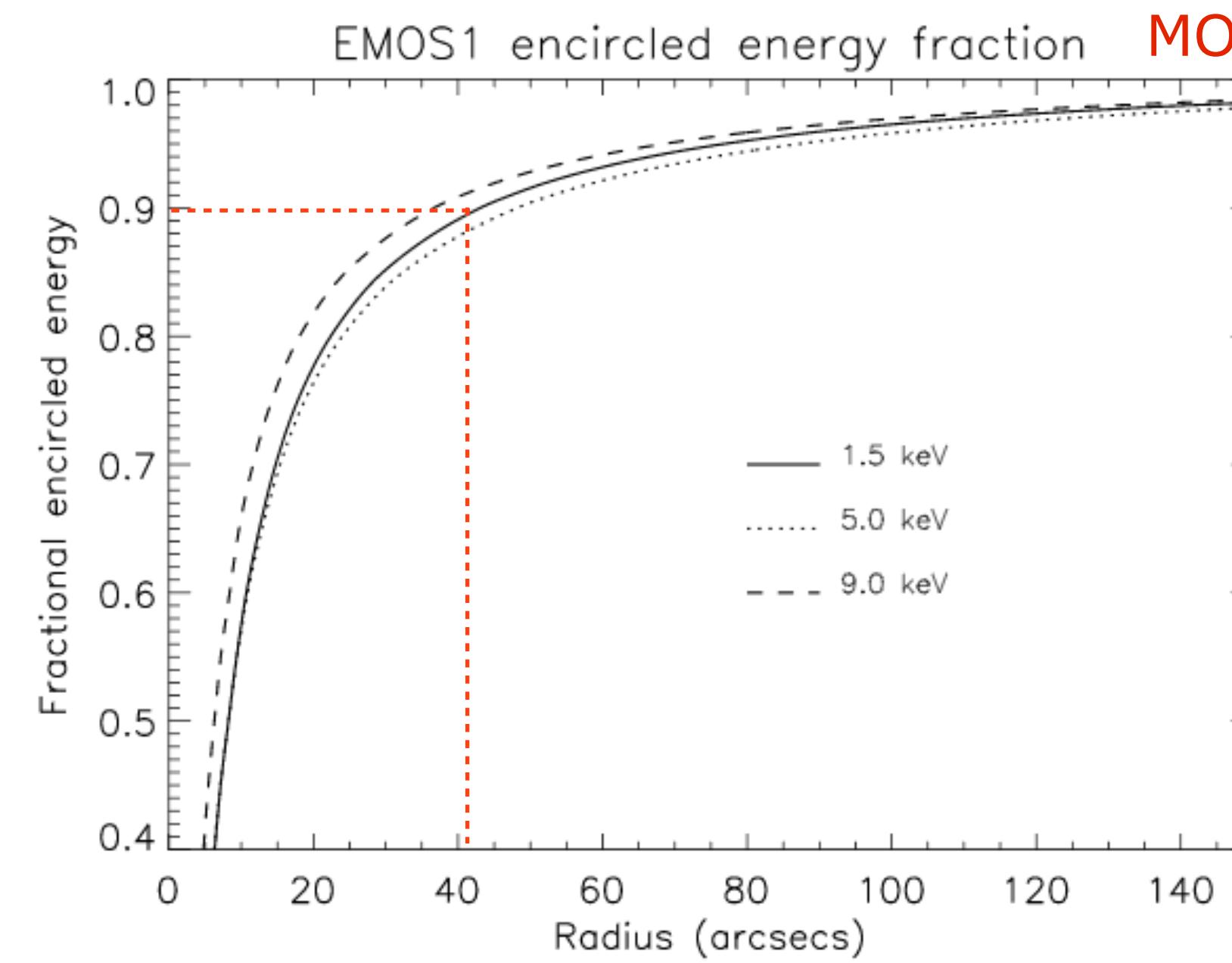
<http://ds9.si.edu/doc/user/binning/index.html>

Encircled energy fraction

Fraction of photons contained within a certain angular radius (on-axis)



Extraction radius (arcsec)	Camera		
	MOS-1	MOS2	EPN pointed
15	0.68	0.69	0.71
30	0.83	0.83	0.88
45	0.89	0.89	0.93
60	0.92	0.93	0.95



see also Dadina's lesson

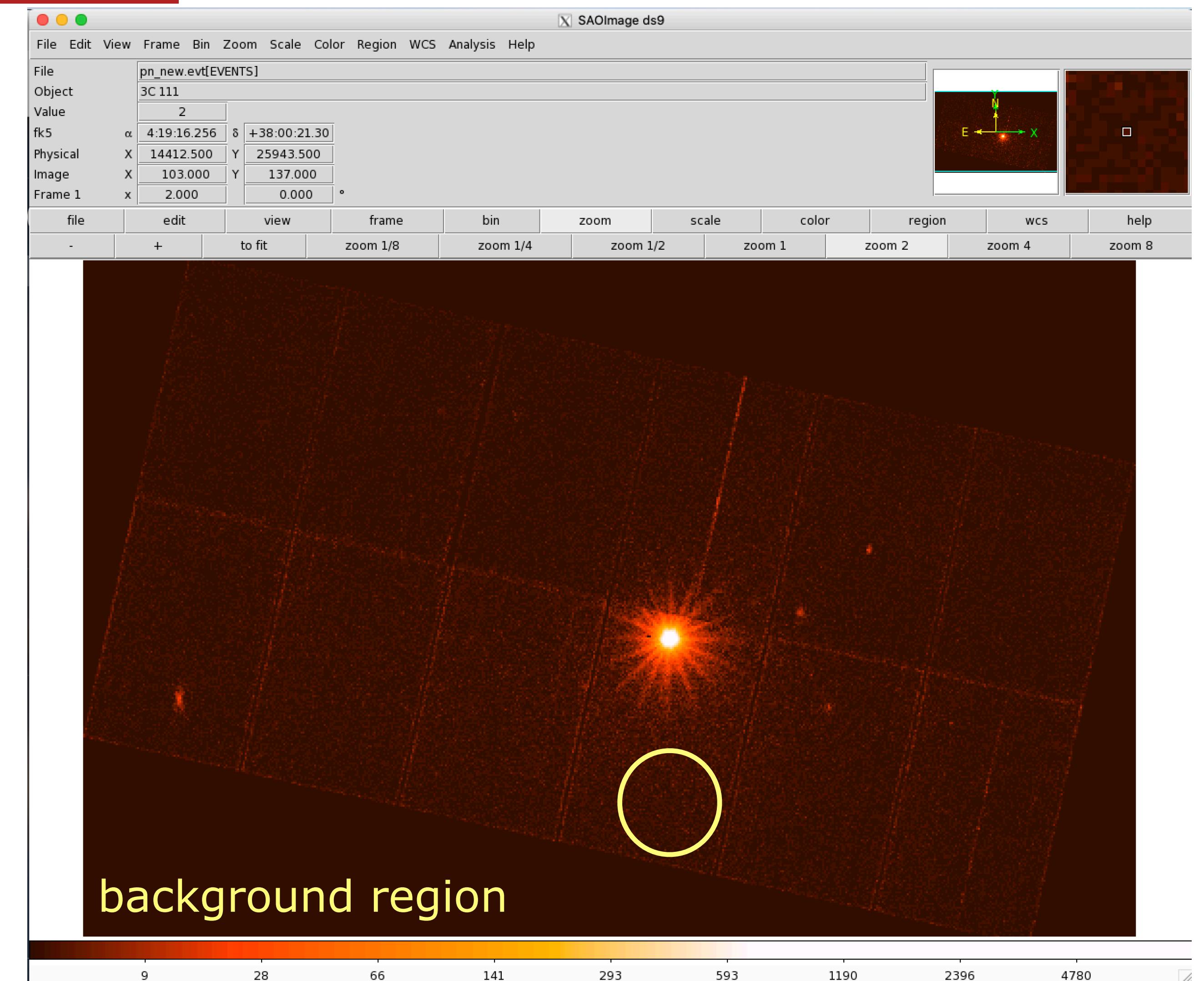
Source & background extraction regions

Display the cleaned pn image with **ds9**

ds9 pn_new.evt &

> scale log
> bin (block 2, 4, ...)

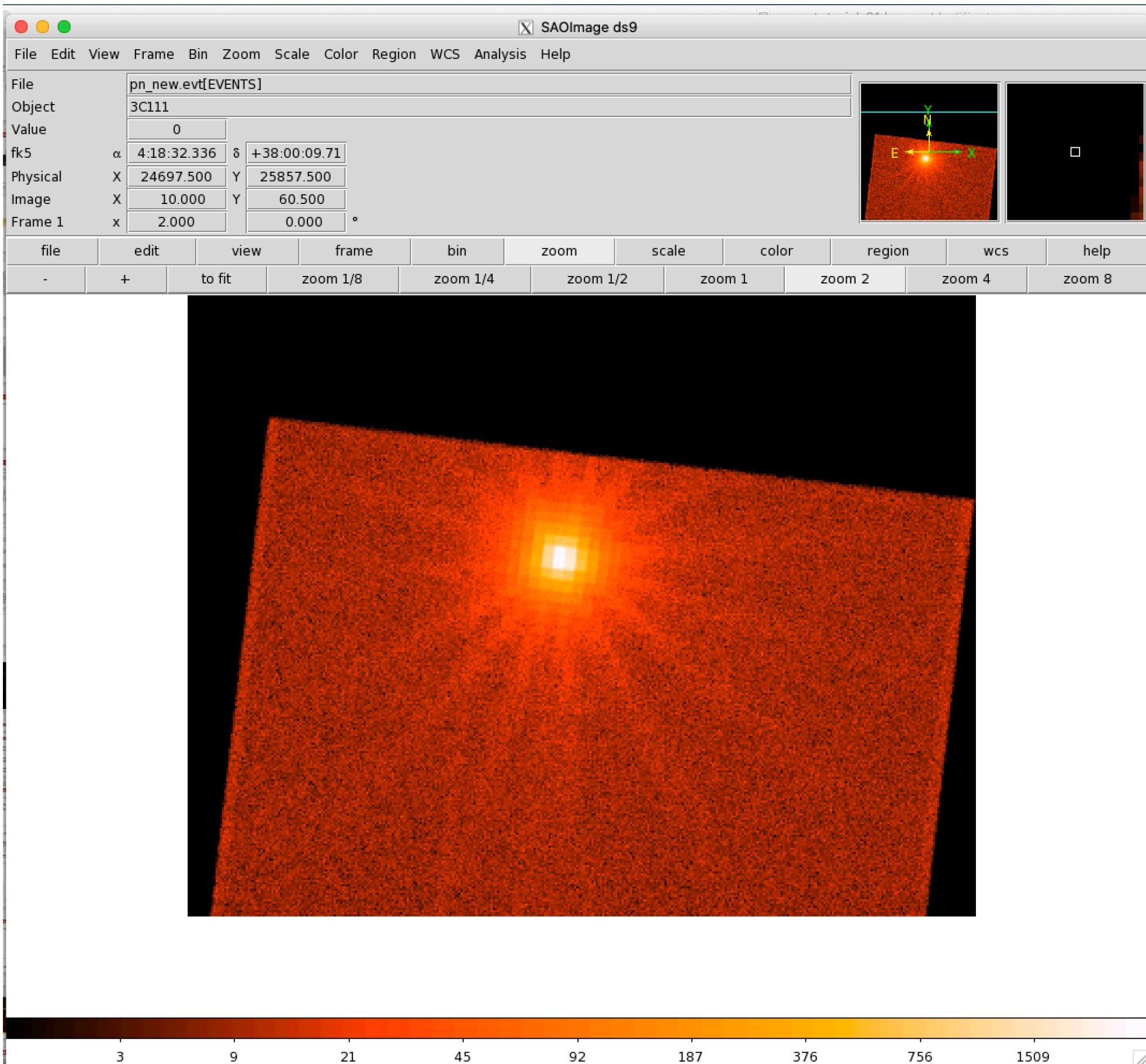
> Region
> save region
> file format ‘ds9’
> coordinates ‘physical’
> **back.reg**



circle(27948.55,22135.48,799.99999)

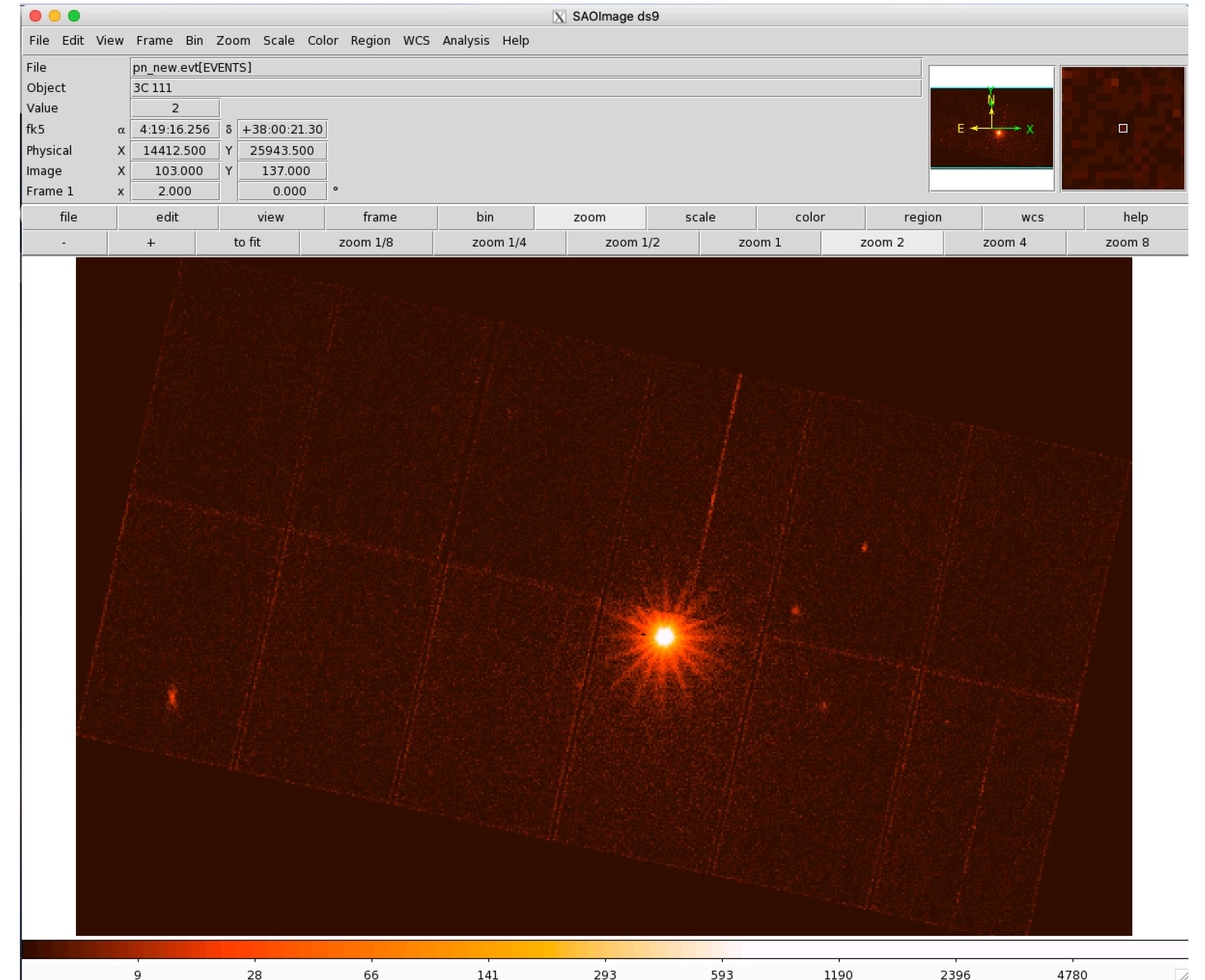
<http://ds9.si.edu/doc/user/binning/index.html>

2009



small window

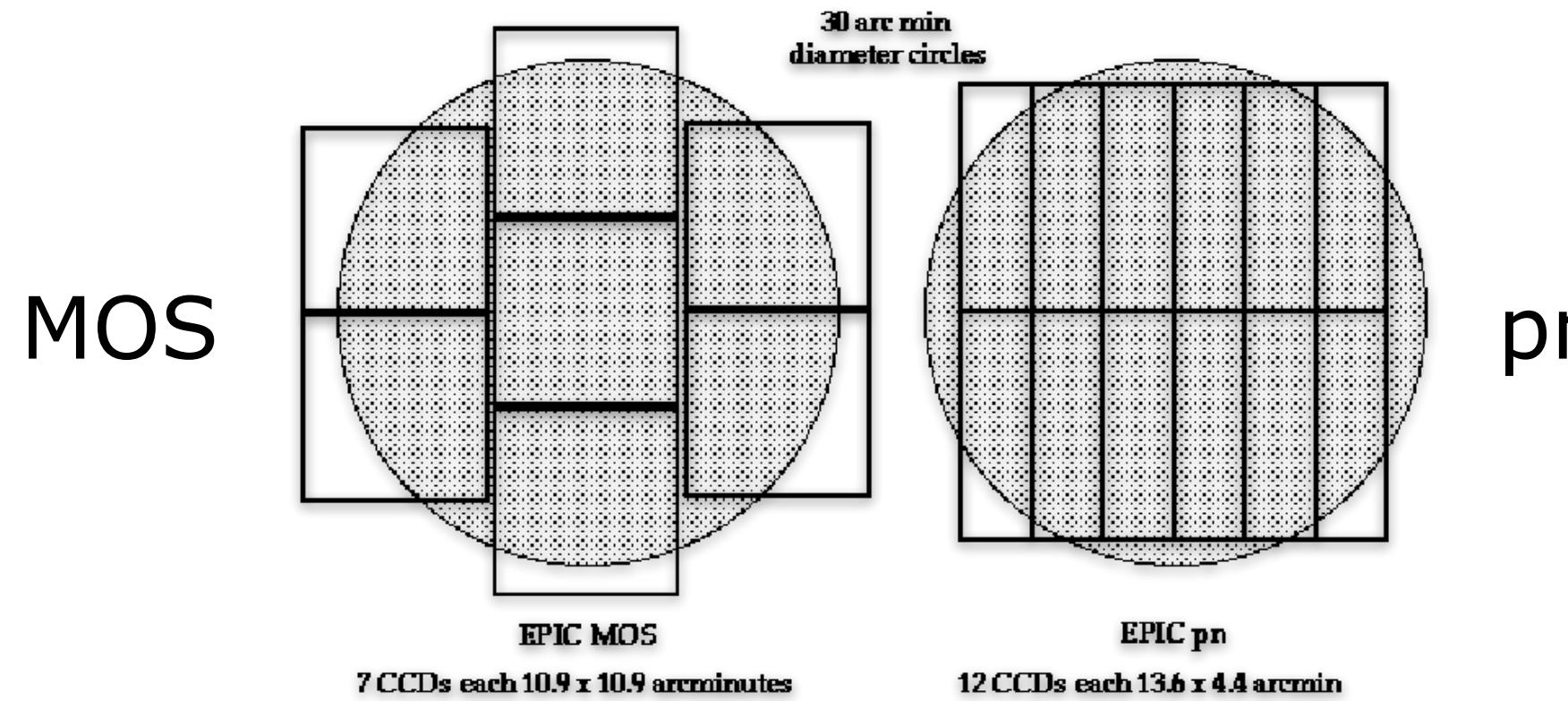
2001



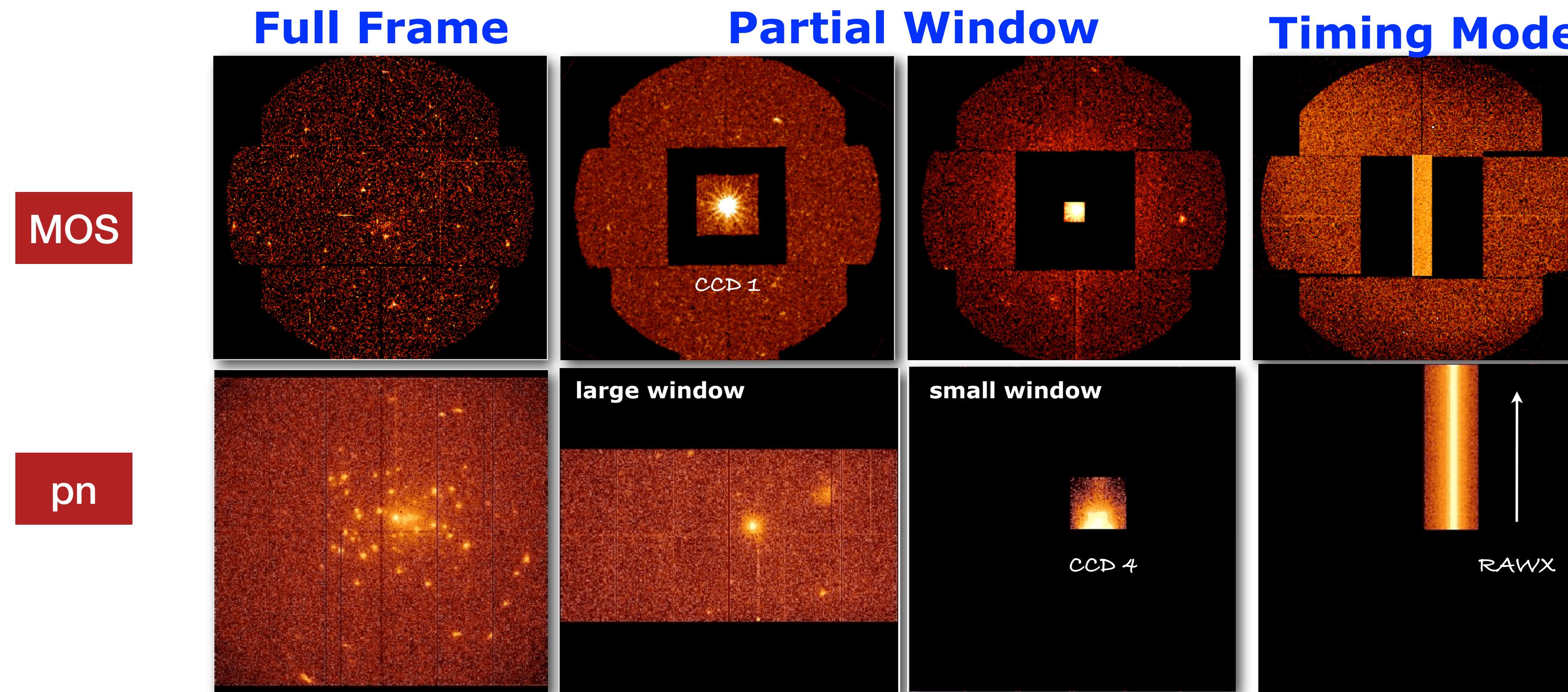
large window

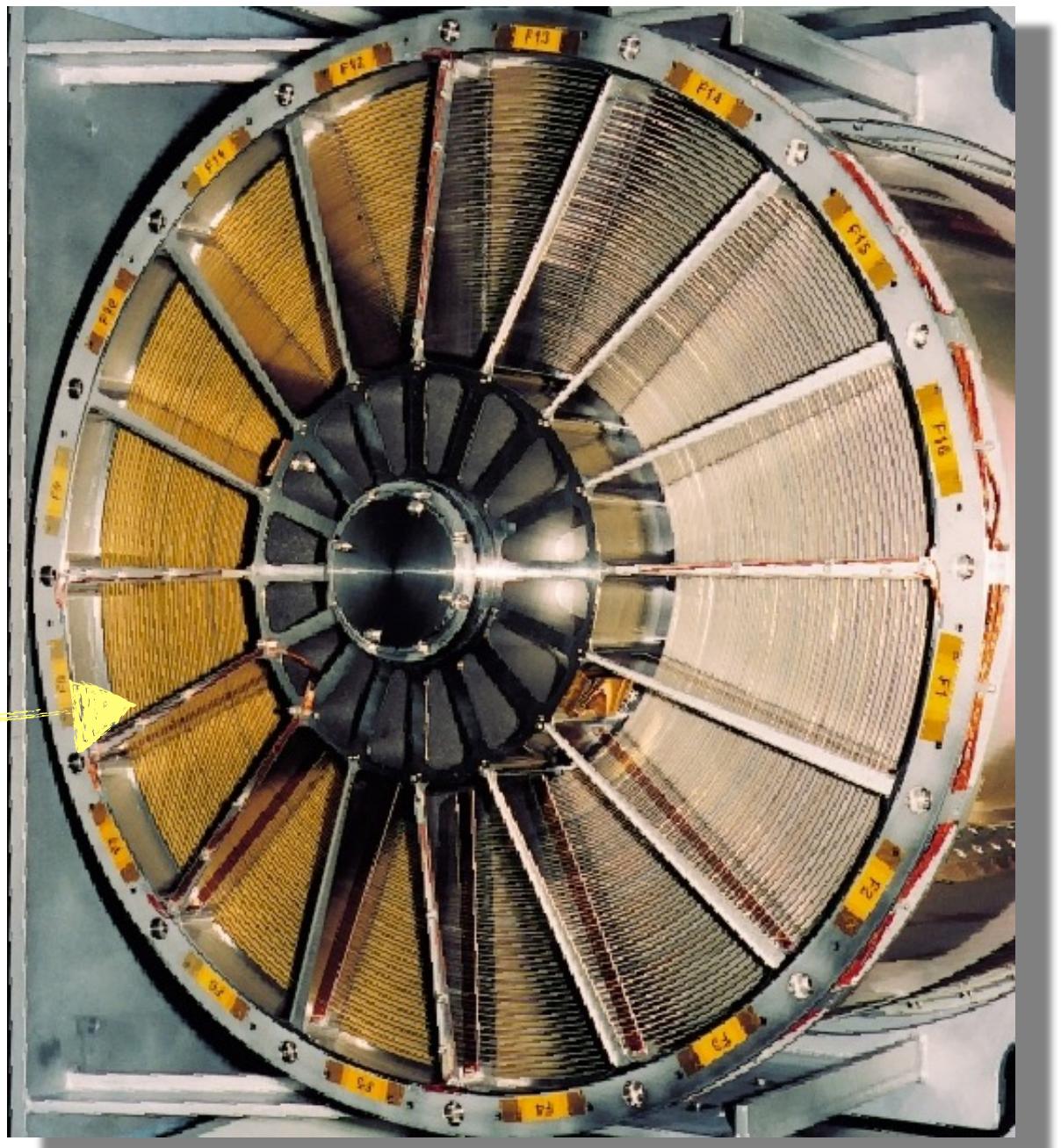
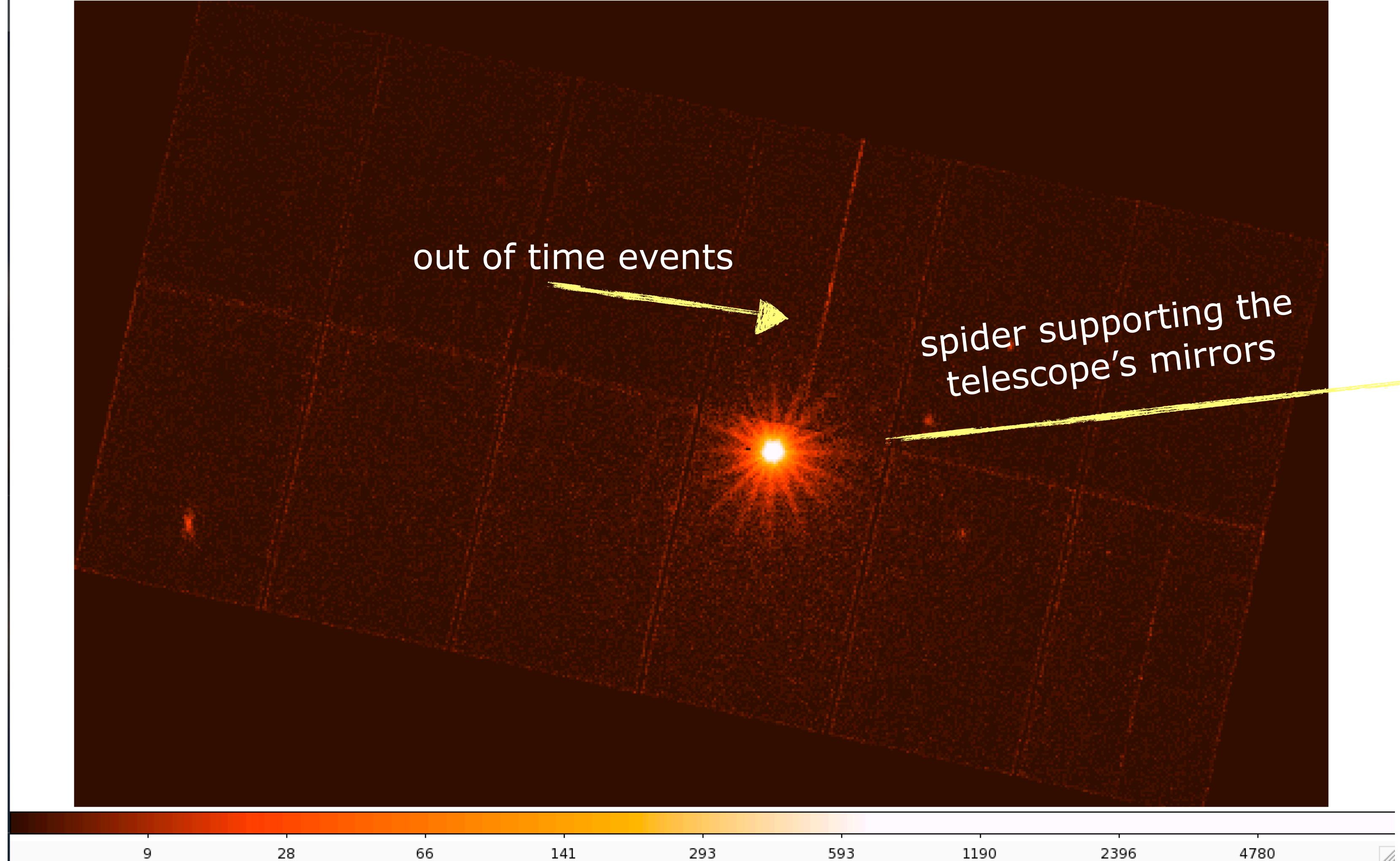
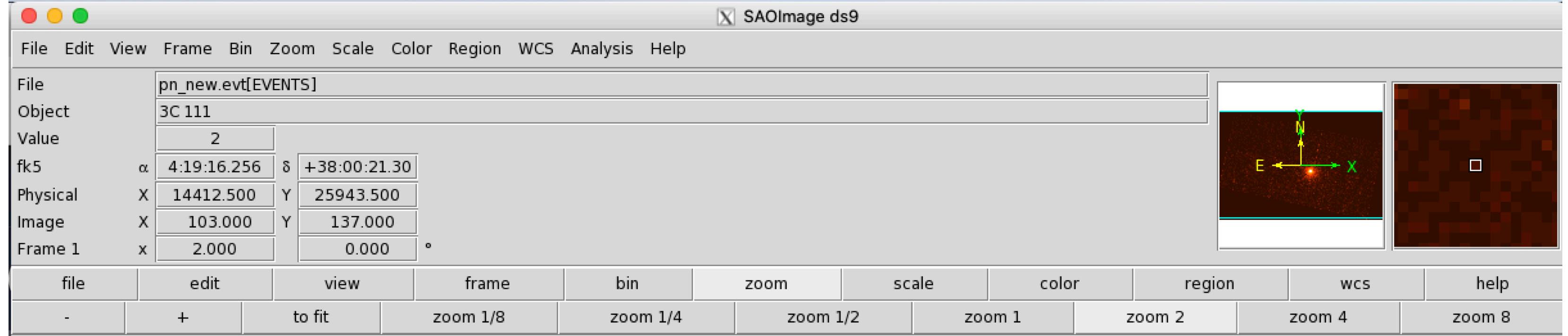
EPIC Science Modes

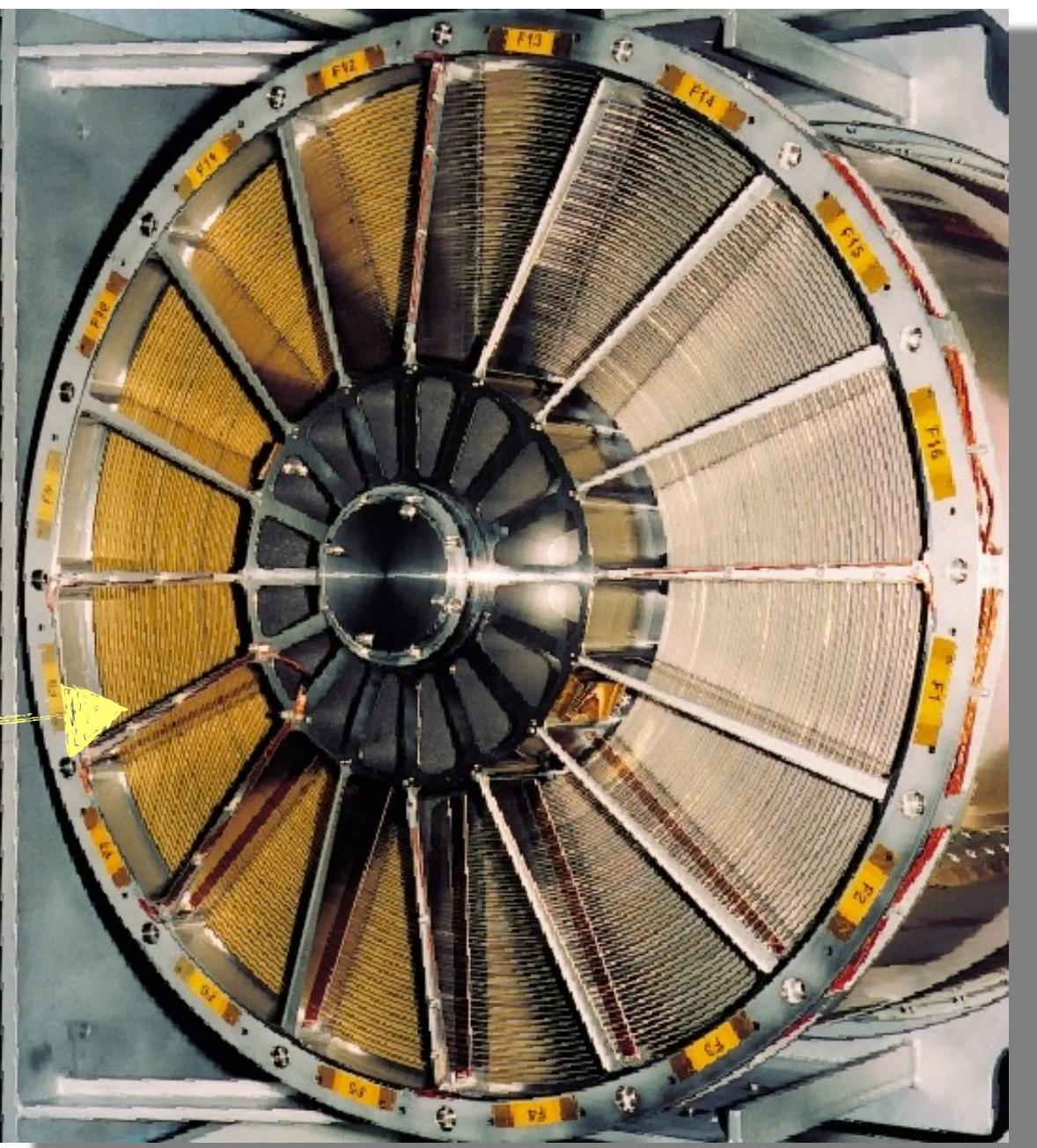
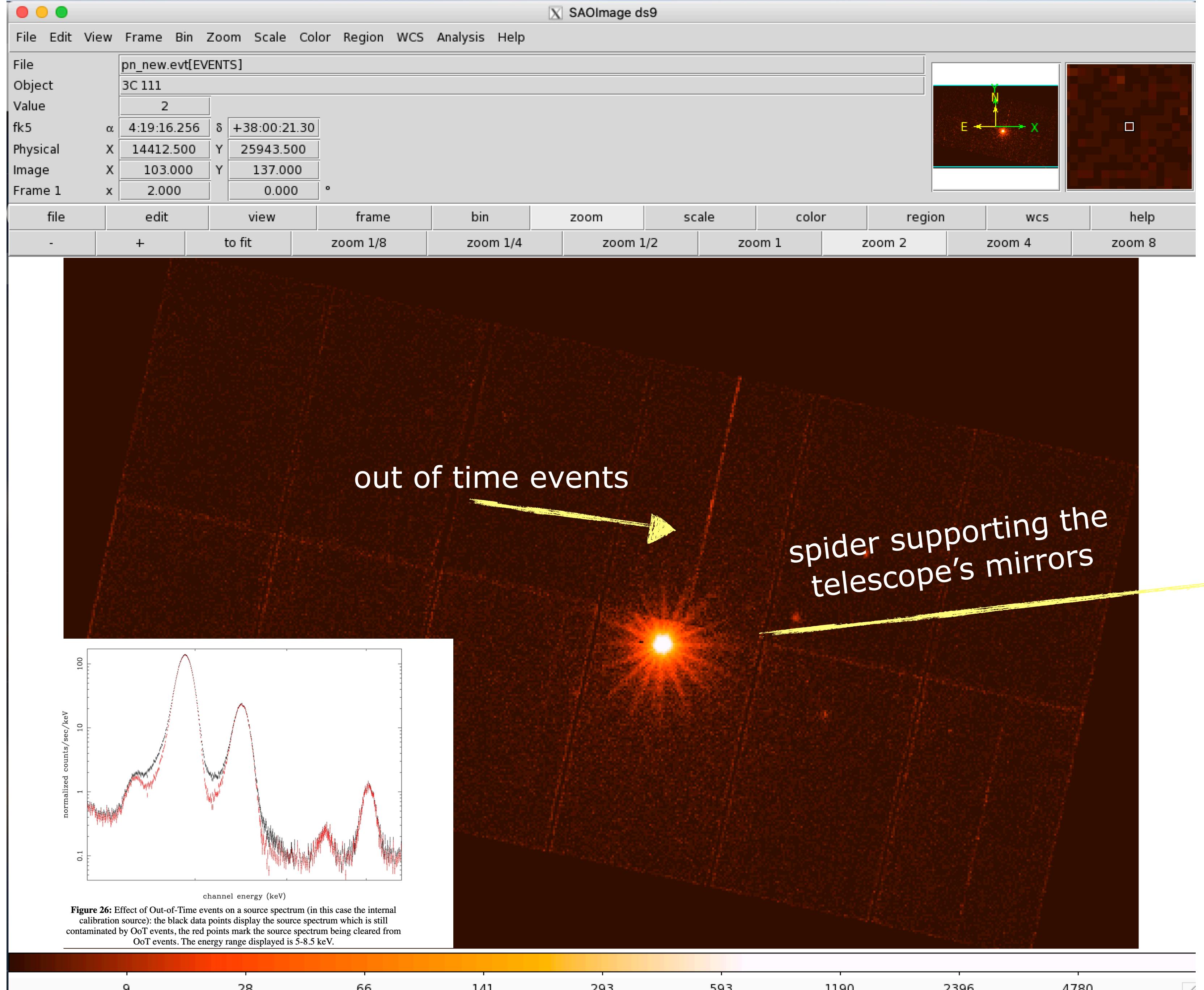
Comparison of focal plane organisation of EPIC MOS and pn cameras



XMM FoV 30'







PILEUP

<https://www.cosmos.esa.int/web/xmm-newton/sas-thread-epatplot>

Arrival of two or more independent photons at nearby pixels that are erroneously read as one single event (whose energy is the sum of the energies of the individual photons) [Jethwa et al. \(2015\)](#)

The figure displays four grayscale images arranged in a 2x2 grid, illustrating the effect of noise on point-like sources. The top-left image shows a single point source with a very faint, diffuse halo. The top-right image shows a similar source with a slightly more pronounced halo. The bottom-left image shows a source with a clearly visible, well-defined multi-ring diffraction pattern. The bottom-right image shows a source with a very strong, sharp diffraction pattern and significant noise artifacts, appearing as a dark central spot surrounded by concentric rings and a noisy background.

2 cts/frame

5 cts/frame

16 cts/frame

12 cts/frame

single event	. . .	. X .	. . .	. . .
double pattern	. . .	. . X . .	. . . X x .	. . . X . .
triple pattern	. . .	. . X . .	. . . X . .	. . . X x . .
quadruple pattern	. . .	. m X . .	. . X m .	. . . X . .
	. . .	. x X . .	. . X x .	. . X x . .
	. . .	. . . . .	. . X m .	. m X . .

Figure 13: List of valid EPIC-pn patterns (cf. figure 12). Here " ." marks a pixel without an event above threshold, "X" is the pixel with the maximum charge ("main pixel"), "x" is the pixel with a non-maximum charge, "m" is the pixel with the minimum charge. These 13 figures refer to the SAS PATTERN codes 0 (singles), 1-4 (doubles), 5-8 (triples) and 9-12 (quadruples), respectively. The RAWX co-ordinate is running rightward and the RAWY co-ordinate running upward.

- Photon loss
 - Energy distortion
 - Pattern migration

epatplot

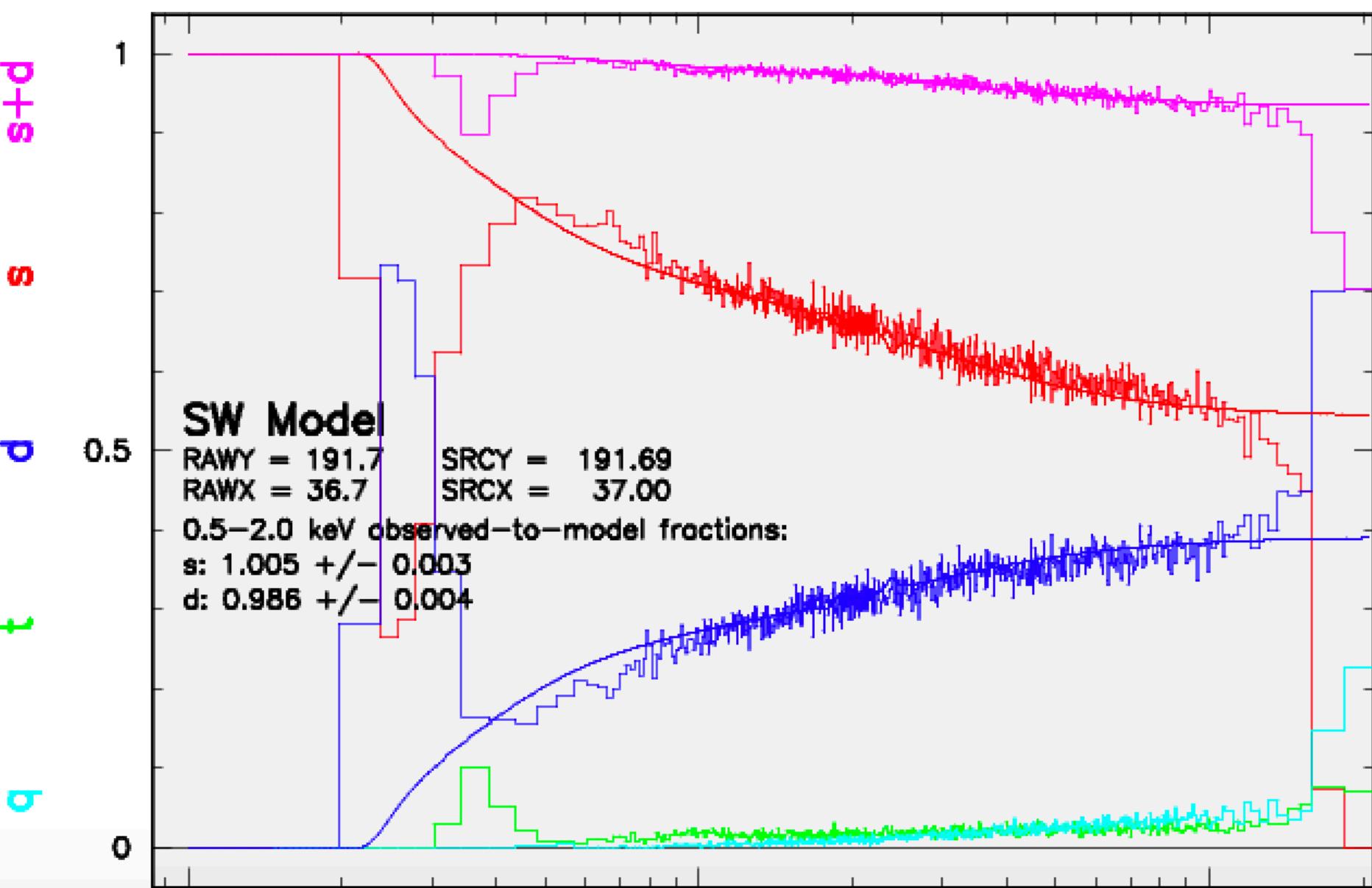
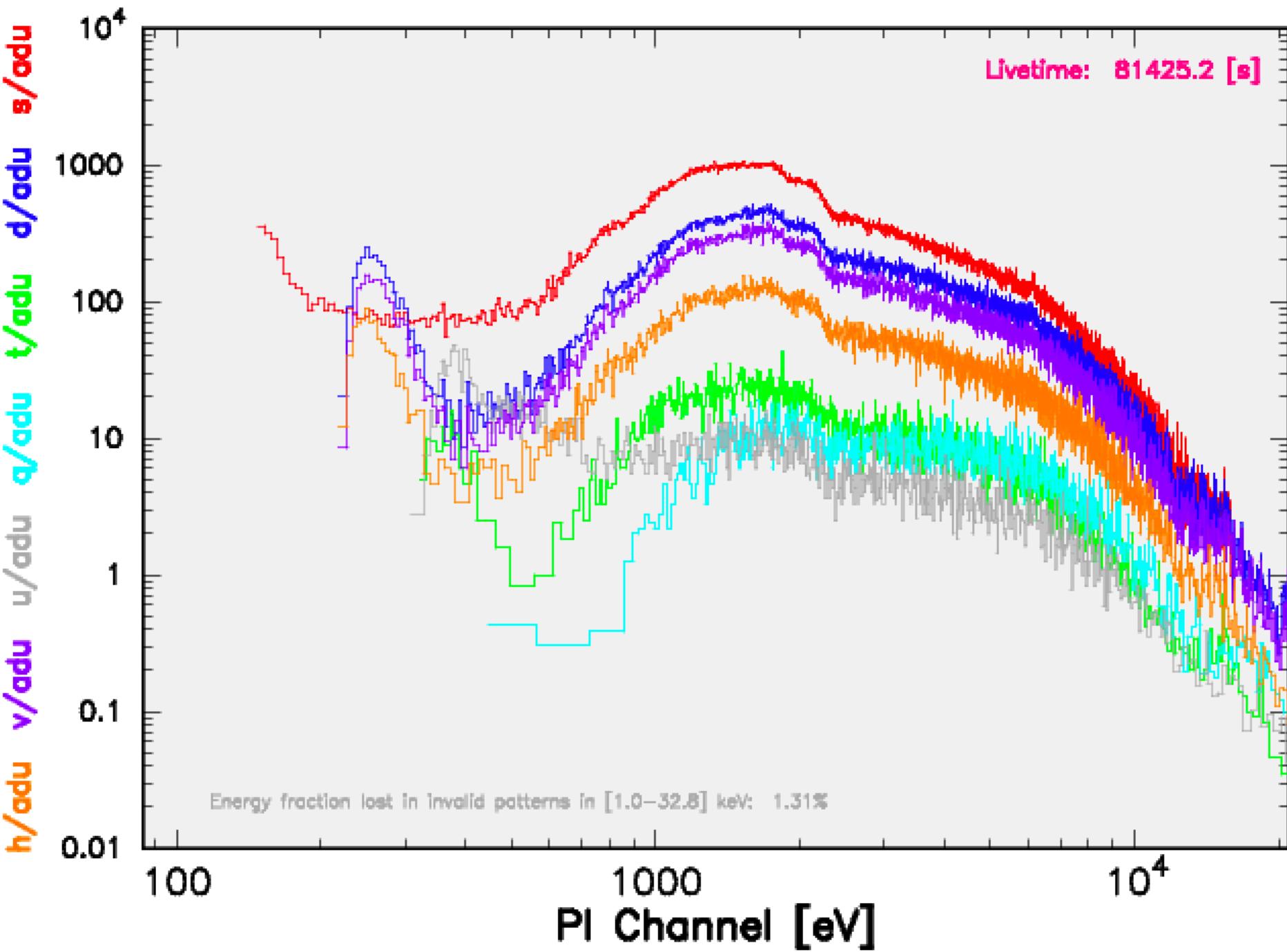
```
evselect table=pn_new.evt withfilteredset=yes filteredset=pnf.evt keepfilteroutput=yes expression="((X,Y) IN circle (25910.5,25870.5,400))"
```

```
epatplot set=pnf.evt device="/CPS" plotfile="pnf_pat.ps"
```

```
epatplot:- epatplot (epatplot-1.22) [xmmsas_20190531_1155-18.0.0] started: 2021-02-25T11:38:46.000
epatplot:- epatplot 1.22 is running...
epatplot:-
epatplot:-      s      d      t      q
epatplot:-  0.6414  0.3234  0.0195  0.0157
epatplot:-
epatplot:- 0.5-2.0 keV observed-to-model fractions:
epatplot:- s: 1.005 +/- 0.003    d: 0.986 +/- 0.004
epatplot:-
epatplot:- PostScript output written to file pnf_pat.ps
epatplot:- epatplot (epatplot-1.22) [xmmsas_20190531_1155-18.0.0] ended: 2021-02-25T11:40:33.000
[torresi@login01]pn>
```

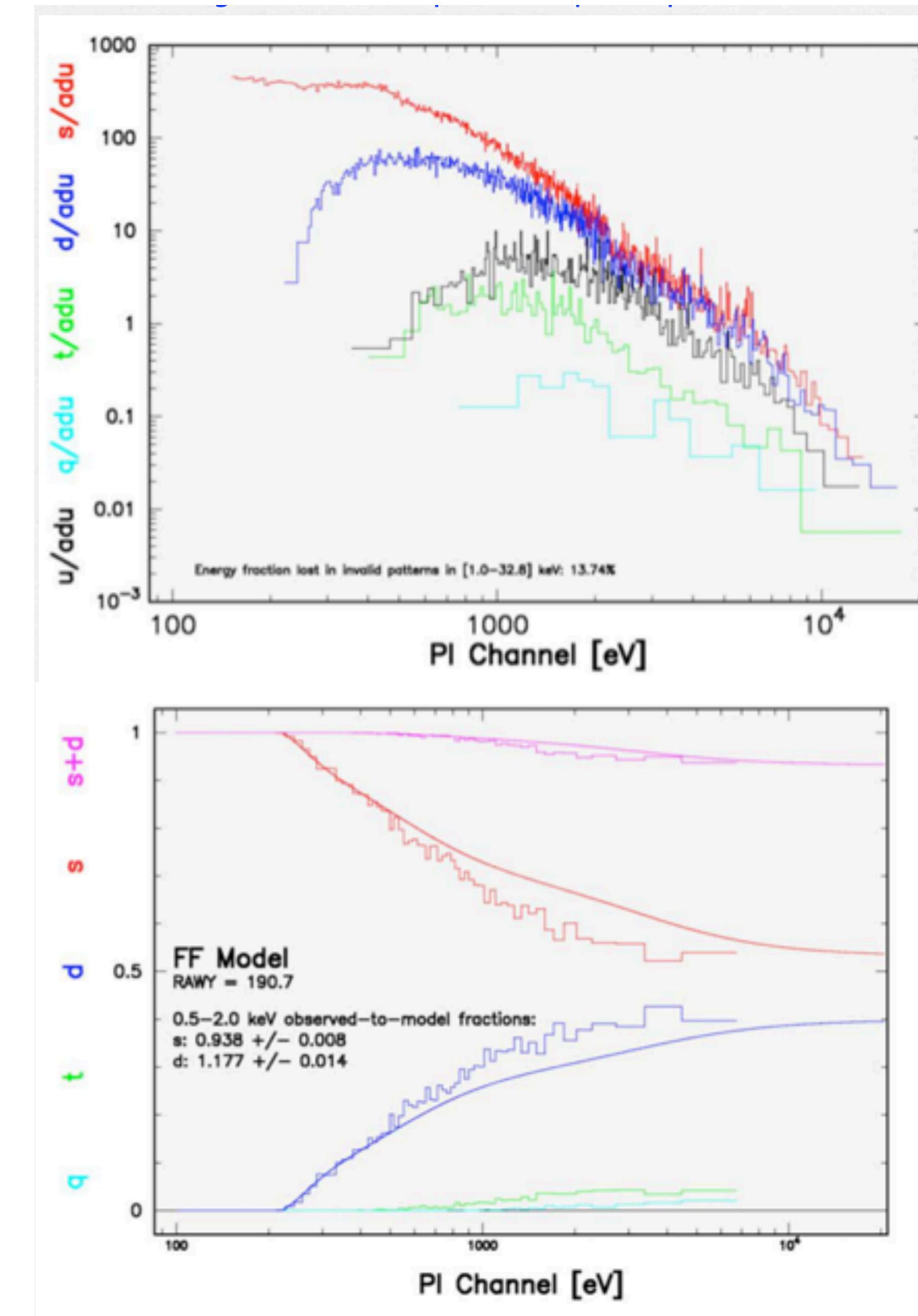
```
gv pnf_pat.ps
```

```
evince pnf_pat.ps
```



The source is not piled up!

While, in this case, the source IS piled up



SPECTRUM EXTRACTION

pn:

```
evselect table=pn_new.evt withspectrumset=yes spectrumset=source_spectrum.fits energycolumn=PI spectralbinsize=5
withspecranges=yes specchannelmin=0 specchannelmax=20479 expression='(FLAG==0) && (PATTERN<=4) && ((X,Y) IN circle
(27874.528,26645.58,699.9999))'
```

MOS1:

```
evselect table=mos1_new.evt withspectrumset=yes spectrumset=source_spectrum.fits energycolumn=PI spectralbinsize=15
withspecranges=yes specchannelmin=0 specchannelmax=11999 expression='(FLAG==0) && (PATTERN<=12) && ((X,Y) IN circle
(28090.5,24221.5,775.48791))'
```

BACKGROUND EXTRACTION

pn:

```
evselect table=pn_new.evt withspectrumset=yes spectrumset=back_spectrum.fits energycolumn=PI spectralbinsize=5
withspecranges=yes specchannelmin=0 specchannelmax=20479 expression='(FLAG==0) && (PATTERN<=4) && ((X,Y) IN circle (,,))'
```

MOS1:

```
evselect table=mos1_new.evt withspectrumset=yes spectrumset=back_spectrum.fits energycolumn=PI spectralbinsize=15
withspecranges=yes specchannelmin=0 specchannelmax=11999 expression='(FLAG==0) && (PATTERN<=12) && ((X,Y) IN circle (,,))'
```

BACKSCALE

The BACKSCALE task calculates the area of a source region used to make a spectral file.

This task takes into account any bad pixels or chip gaps and writes the result into the BACKSCAL keyword of the SPECTRUM table

The final value is:

AREA= GEOMETRIC AREA-CCD GAPS-BAD PIXELS

pn:

```
backscale spectrumset=source_spectrum.fits badpixlocation=pn_new.evt
```

```
backscale spectrumset=back_spectrum.fits badpixlocation=pn_new.evt
```

MOS1:

```
backscale spectrumset=source_spectrum.fits badpixlocation=mos1_new.evt
```

```
backscale spectrumset=back_spectrum.fits badpixlocation=mos1_new.evt
```

Redistribution Matrix File (RMF)

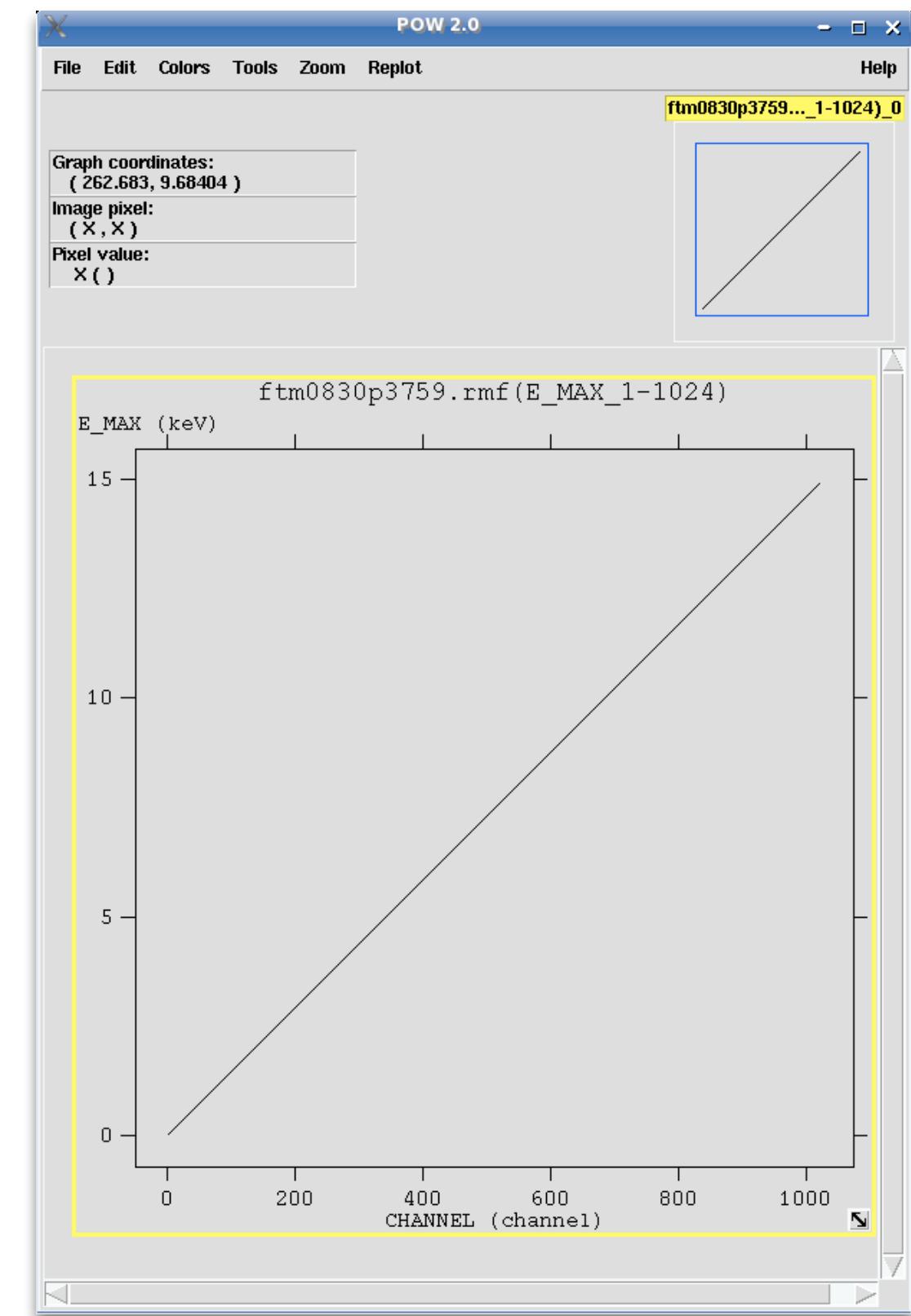
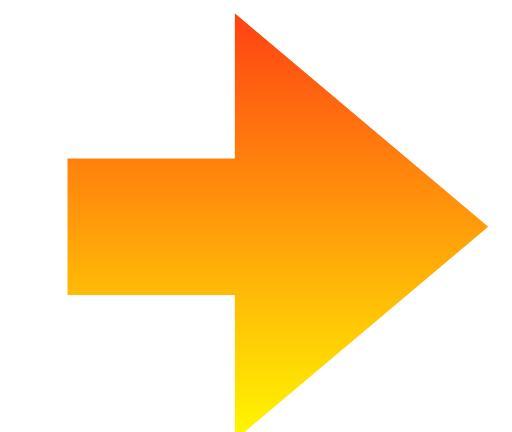
```
rmfgen spectrumset=source_spectrum.fits rmfset=pn.rmf
```

The RMF associates to each instrument channel (l) the appropriate photon energy (E)

fv: Binary Table of `ftm0830p3759.rmf[2]` in /hc

	CHANNEL	E_MIN	E_MAX
1	1.000000E+00	1.460000E-03	1.460000E-02
2	2.000000E+00	1.460000E-02	2.920000E-02
3	3.000000E+00	2.920000E-02	4.380000E-02
4	4.000000E+00	4.380000E-02	5.840000E-02
5	5.000000E+00	5.840000E-02	7.300000E-02
6	6.000000E+00	7.300000E-02	8.760000E-02
7	7.000000E+00	8.760000E-02	1.022000E-01
8	8.000000E+00	1.022000E-01	1.168000E-01
9	9.000000E+00	1.168000E-01	1.314000E-01
10	1.000000E+01	1.314000E-01	1.460000E-01
11	1.100000E+01	1.460000E-01	1.606000E-01
12	1.200000E+01	1.606000E-01	1.752000E-01
13	1.300000E+01	1.752000E-01	1.898000E-01
14	1.400000E+01	1.898000E-01	2.044000E-01
15	1.500000E+01	2.044000E-01	2.190000E-01
16	1.600000E+01	2.190000E-01	2.336000E-01
17	1.700000E+01	2.336000E-01	2.482000E-01
18	1.800000E+01	2.482000E-01	2.628000E-01
19	1.900000E+01	2.628000E-01	2.774000E-01
20	2.000000E+01	2.774000E-01	2.920000E-01

Go to: Edit cell: 0.219



Ancillary Response File (ARF)

```
arfgen spectrumset=source_spectrum.fits arfset=pn.arf withrmfset=yes rmfset=pn.rmf  
badpixlocation=pn_new.evt detmaptype=psf
```

The ARF includes information on the effective area, filter transmission and any additional energy-dependent efficiencies, i.e. the efficiency of the instrument in revealing photons

fv: Binary Table of `ftm0830p3759.arf[1]` in /ho

File Edit Tools Help

ENRG_LO ENRG_HI SPECRESP

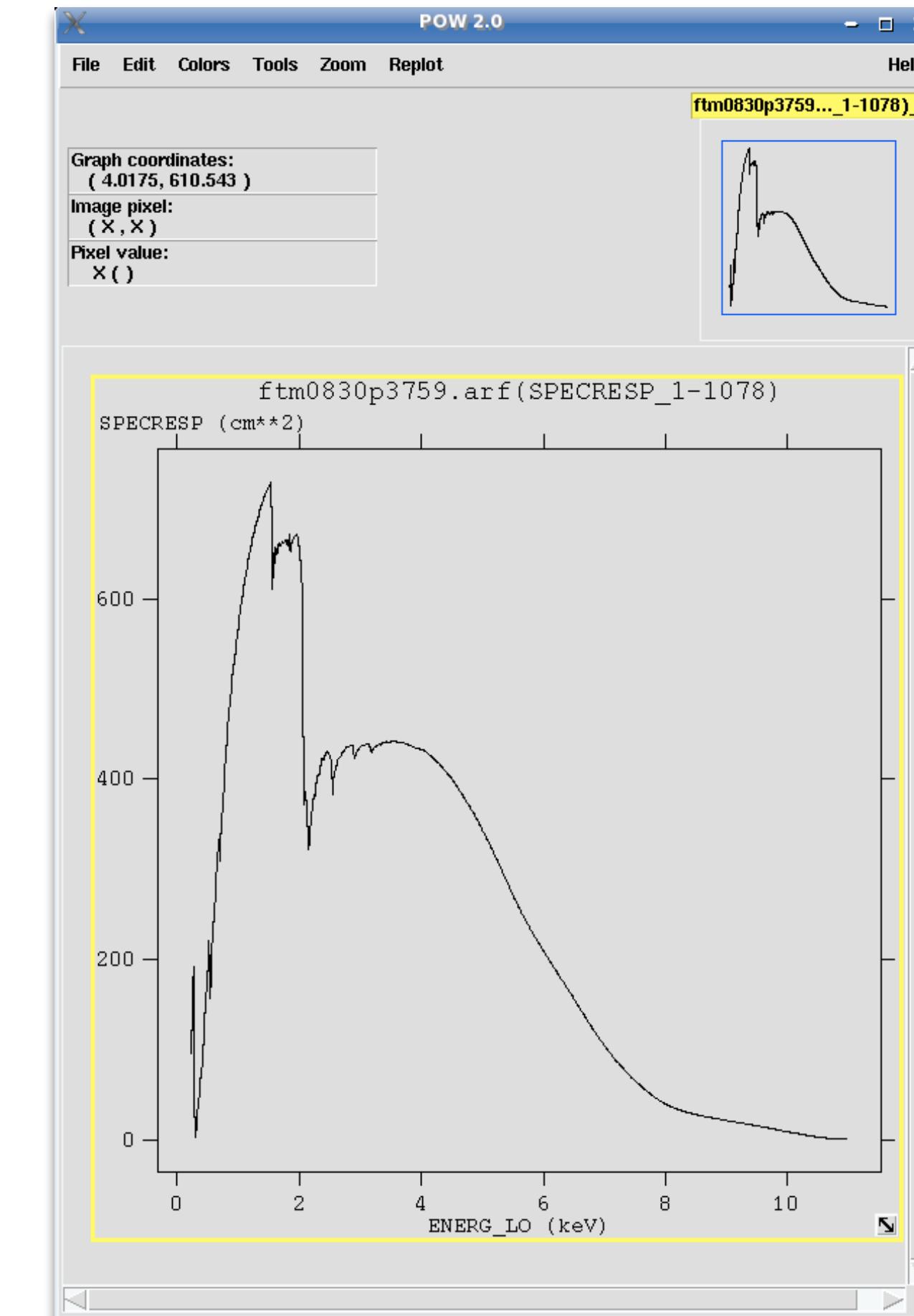
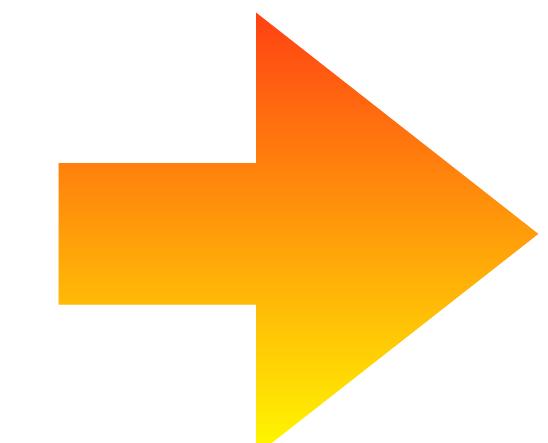
Select 1E 1E 1E
keV keV cm**2

All keV keV cm**2

Invert Modify Modify Modify

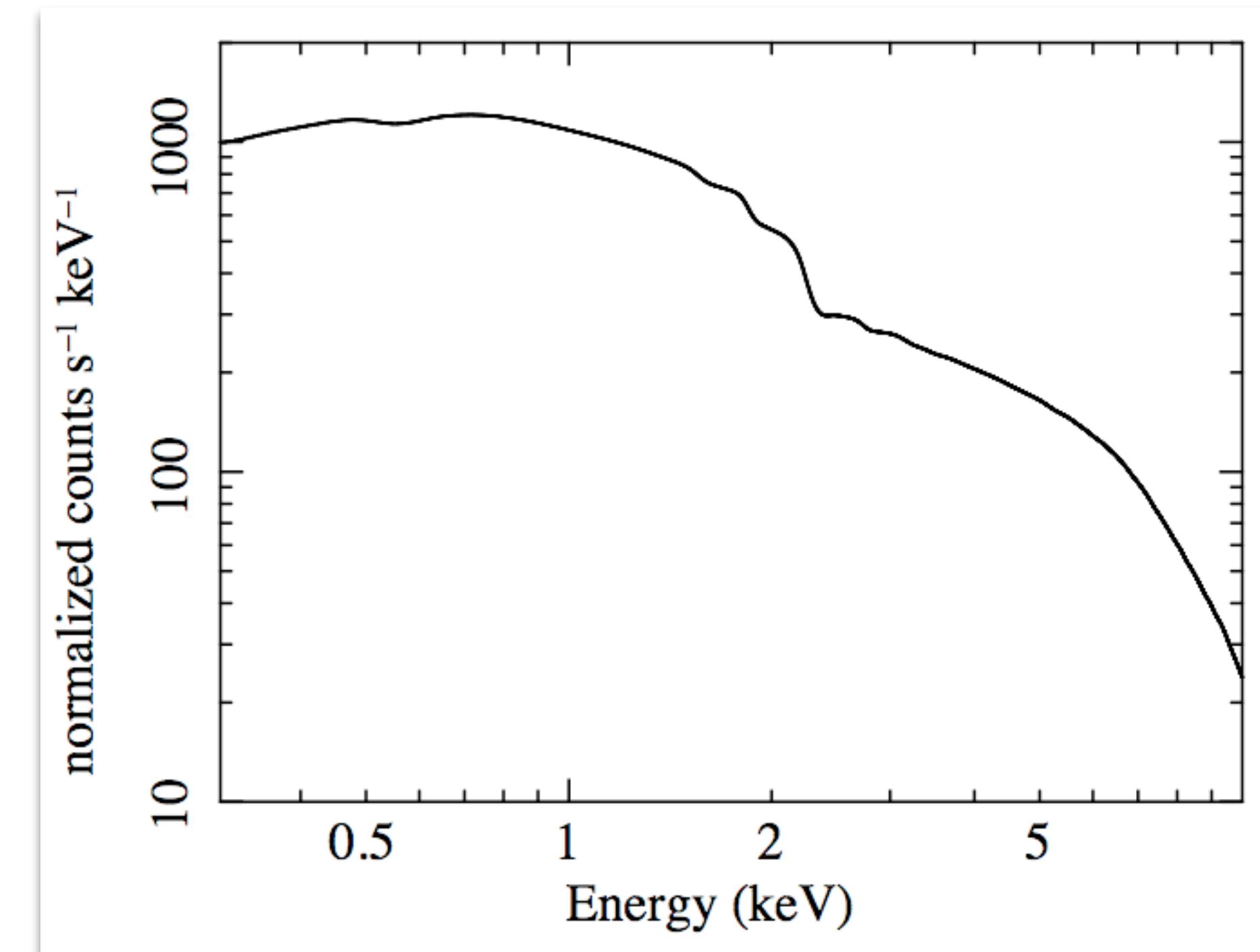
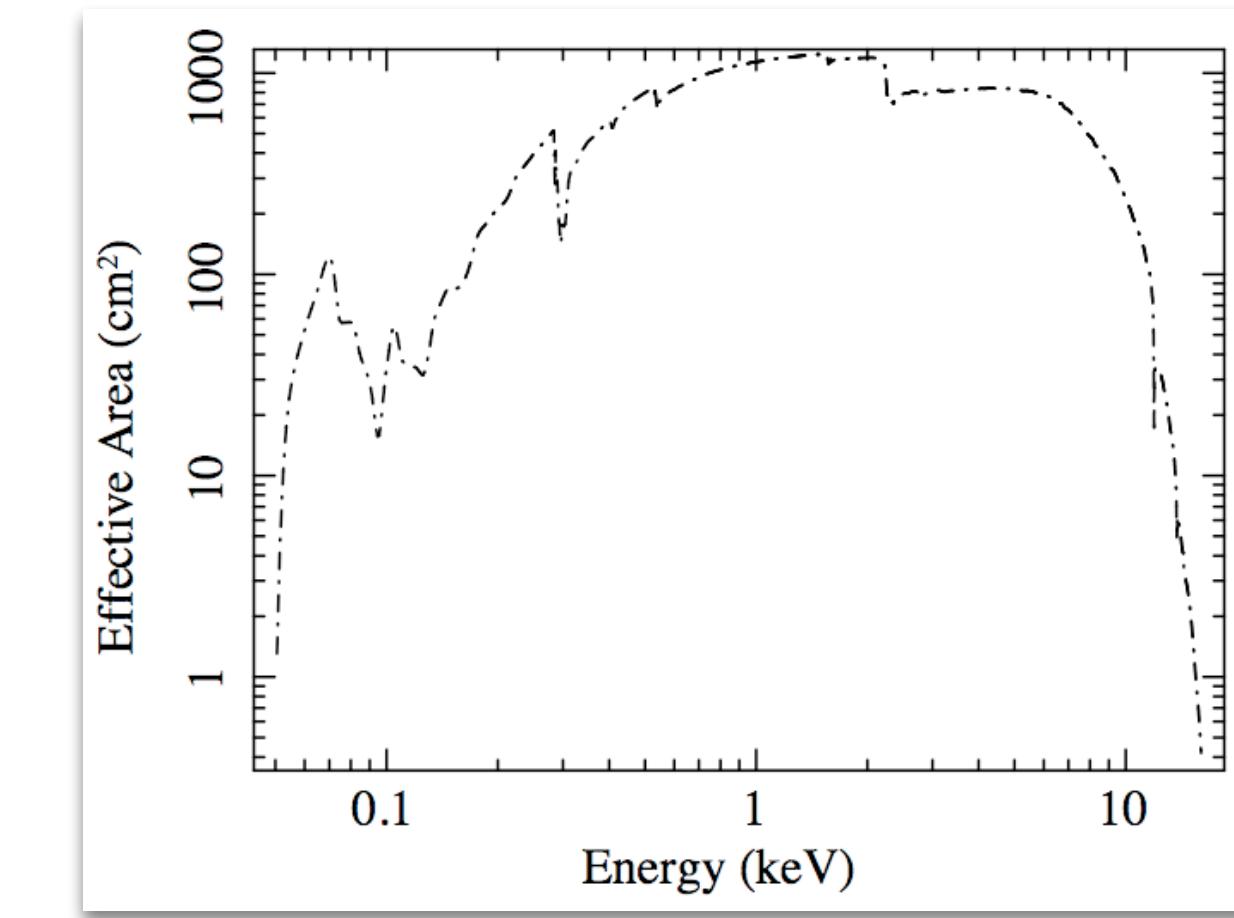
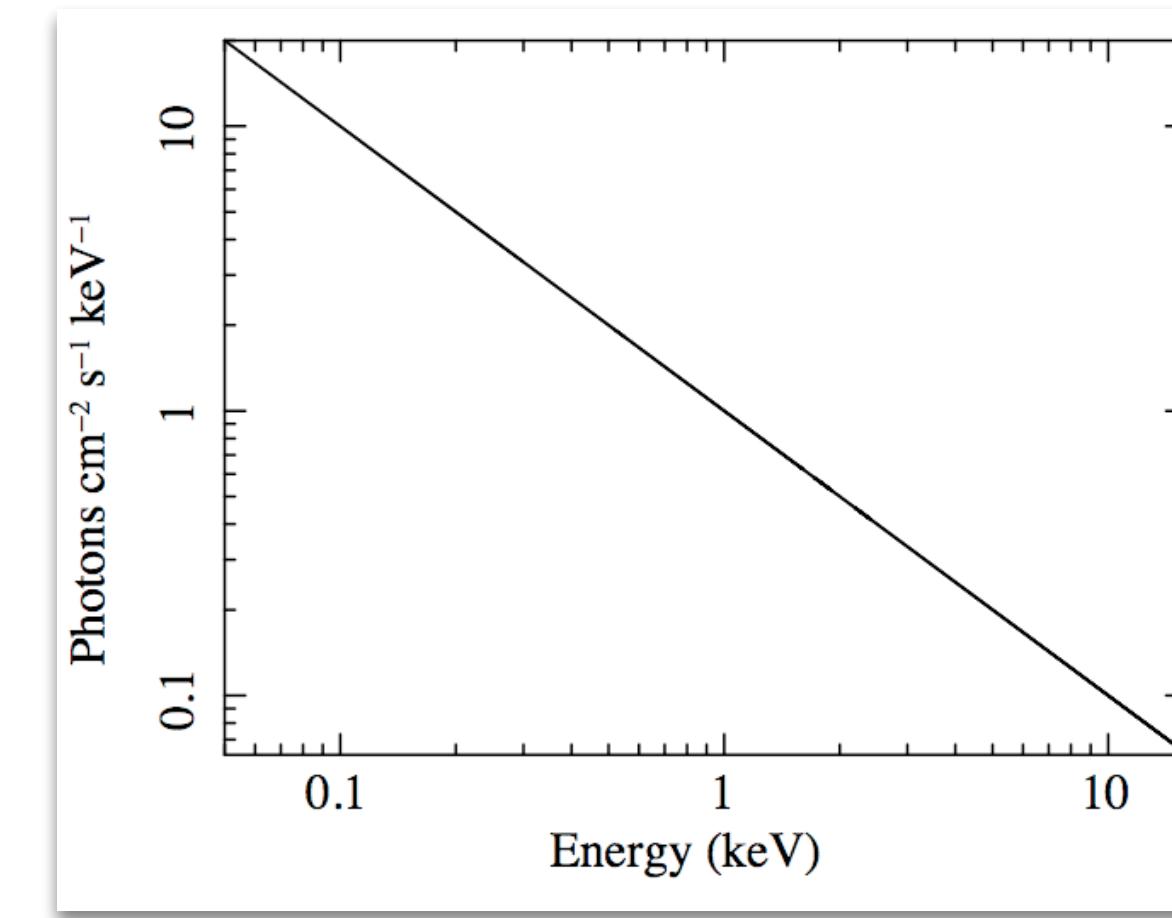
1	2.200000E-01	2.300000E-01	9.414584E+01
2	2.300000E-01	2.400000E-01	1.119709E+02
3	2.400000E-01	2.500000E-01	1.309653E+02
4	2.500000E-01	2.600000E-01	1.518642E+02
5	2.600000E-01	2.700000E-01	1.716482E+02
6	2.700000E-01	2.800000E-01	1.922011E+02
7	2.800000E-01	2.900000E-01	4.741680E+01
8	2.900000E-01	3.000000E-01	2.284590E+00
9	3.000000E-01	3.100000E-01	5.144246E+00
10	3.100000E-01	3.200000E-01	1.563580E+01
11	3.200000E-01	3.300000E-01	2.251595E+01
12	3.300000E-01	3.400000E-01	3.011008E+01
13	3.400000E-01	3.500000E-01	3.743014E+01
14	3.500000E-01	3.600000E-01	4.385400E+01
15	3.600000E-01	3.700000E-01	4.954287E+01
16	3.700000E-01	3.800000E-01	5.625348E+01
17	3.800000E-01	3.900000E-01	6.431229E+01
18	3.900000E-01	4.000000E-01	7.319862E+01
19	4.000000E-01	4.100000E-01	7.713167E+01
20	4.100000E-01	4.200000E-01	8.444775E+01

Go to: Edit cell: 0.42



** arfgen: fatal error (NoCifSpecified), `/prod_oasbo/sas/xmmsas_20210317_1624/evt' is neither the name of a directory nor the name of a CIF
>export SAS_CCF='/home/torresi/3C111/evt/ccf.cif'

The combination of RMF and ARF produces the input spectrum weighted by telescope area and detector efficiencies versus energy.



GROUPING

In order to apply the χ^2 statistics (Gaussian distribution) you need to have at least 25 counts in each bin of your spectrum. Otherwise Cash statistics (Poisson distribution) is preferred (see also Statistics Tutorial).

```
grppha source_spectrum.fits pn\_25.grp comm="chkey RESPFILE pn.rmf & chkey ANCFILE pn.arf & chkey  
BACKFILE back_spectrum.fits & group min 25 & exit"
```

GROUPING

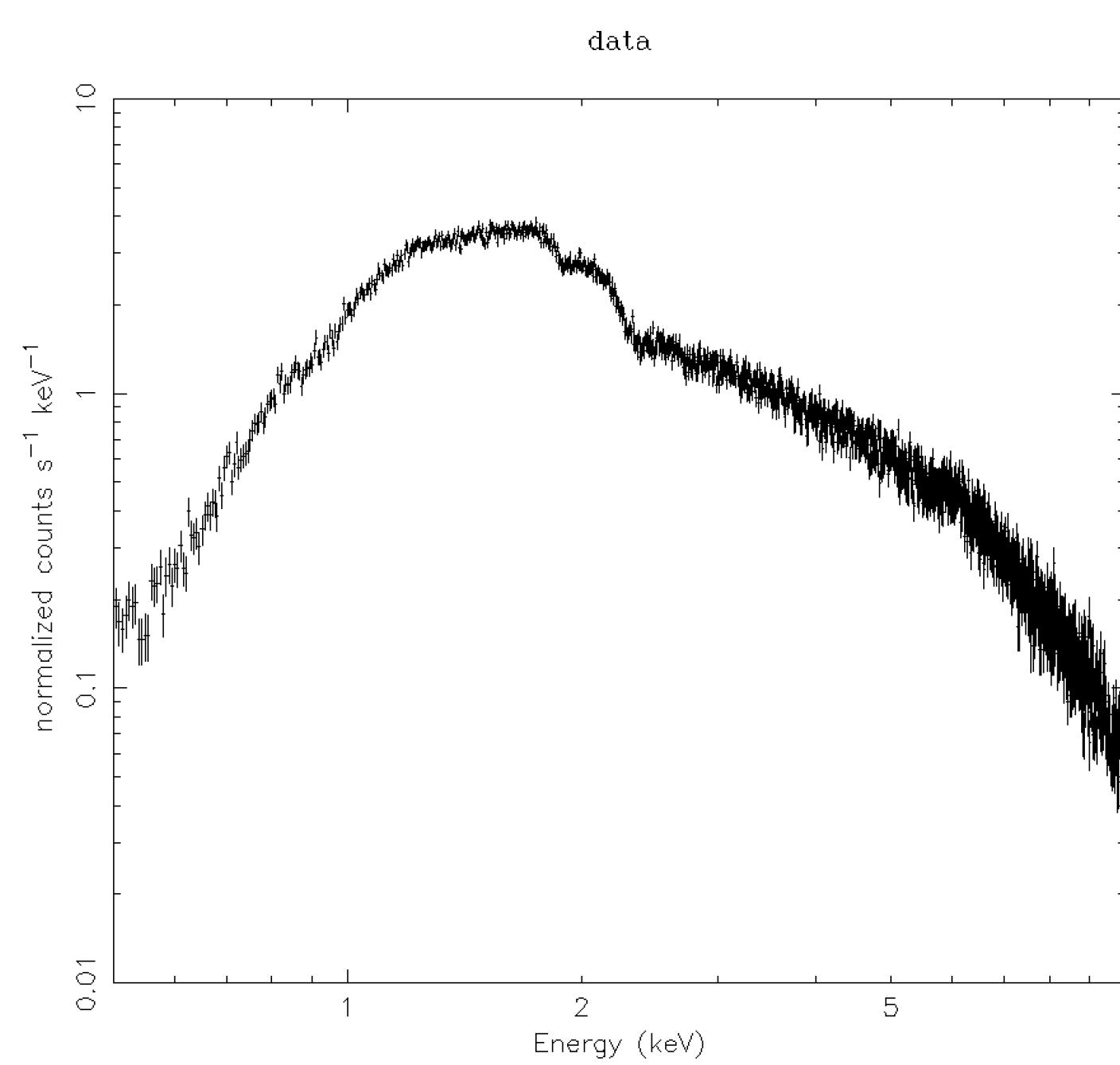
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```
grppha source_spectrum.fits pn\_25.grp comm="chkey RESPFILE pn.rmf & chkey ANCFILE pn.arf & chkey  
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```



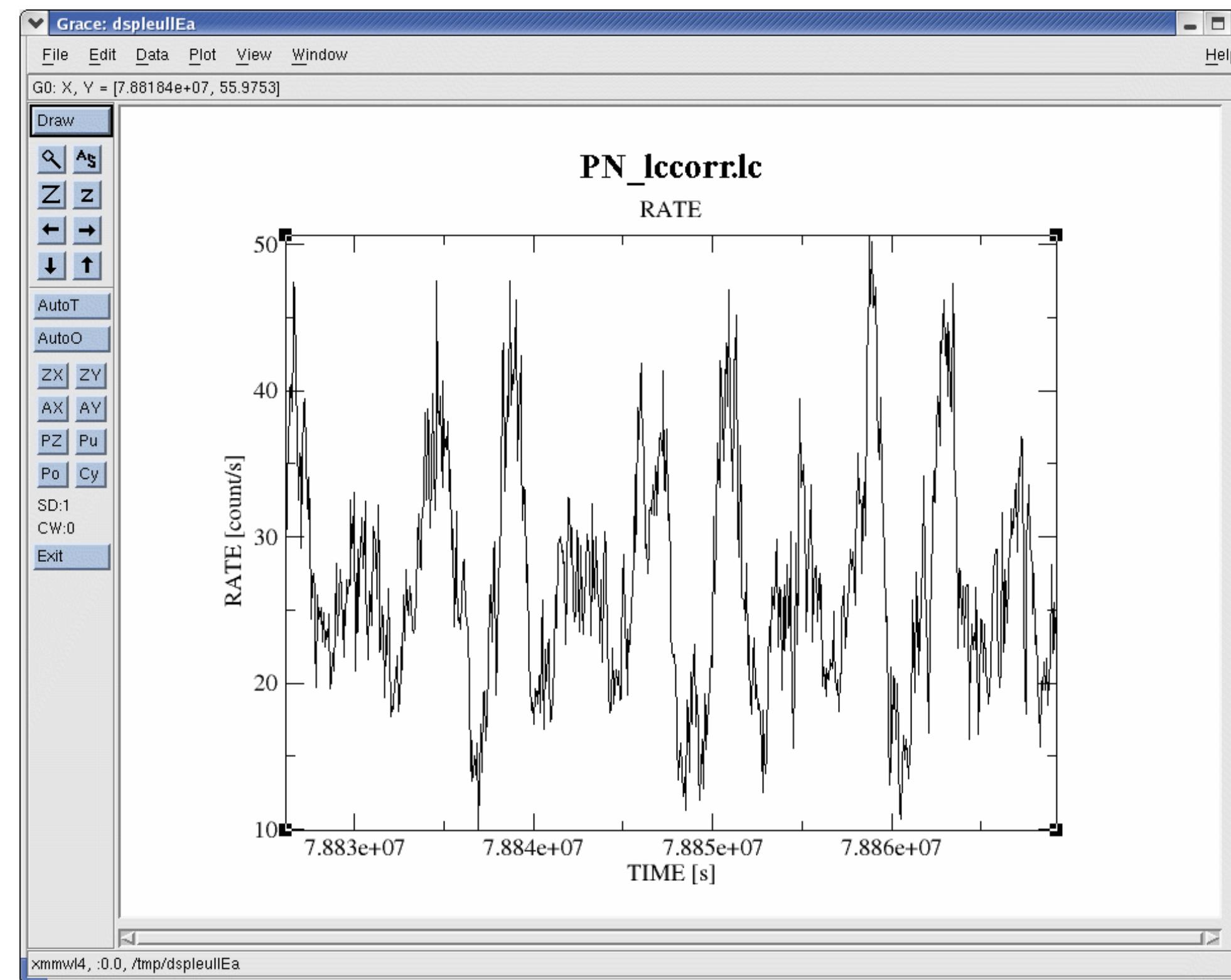
see XSPEC tutorial...

LIGHT CURVE

<https://www.cosmos.esa.int/web/xmm-newton/sas-thread-timing>

A light curve is the plot of the flux of a source vs time. It shows if and how the flux of the source varies during a certain time series.

The variability of a source can manifest on different time scales.



source+background lightcurve

pn:

```
evselect table=pn_new.evt energycolumn=PI expression='#XMMEA_EP&&(PATTERN<=4)&& ((X,Y) IN circle(25910.5,25870.5,400)&& (PI in [200:10000]))' withrateset=yes rateset="PN_source_lightcurve_raw.lc" timebinsize=100 maketimecolumn=yes makeratecolumn=yes
```

MOS1:

```
evselect table=mos1_new.evt energycolumn=PI expression='#XMMEA_EM&&(PATTERN<=12)&& ((X,Y) IN circle(25910.5,25870.5,400)&& (PI in [200:10000]))' withrateset=yes rateset="MOS_source_lightcurve_raw.lc" timebinsize=100 maketimecolumn=yes makeratecolumn=yes
```

The longer is the temporal bin the lower is the resolution but the higher is the S/N.

background lightcurve

pn:

```
evselect table=pn_new.evt energycolumn=PI expression='#XMMEA_EP&&(PATTERN<=4)&& ((X,Y) IN circle(25910.5,25870.5,400)&& (PI in [200:10000]))' withrateset=yes rateset="PN_light_curve_background_raw.lc" timebinsize=100 maketimecolumn=yes makeratecolumn=yes
```

MOS1:

```
evselect table=mos1_new.evt energycolumn=PI expression='#XMMEA_EM&&(PATTERN<=12)&& ((X,Y) IN circle(25910.5,25870.5,400)&& (PI in [200:10000]))' withrateset=yes rateset="MOS_light_curve_background_raw.lc" timebinsize=100 maketimecolumn=yes makeratecolumn=yes
```

source-background lightcurve: epiclccorr

pn:

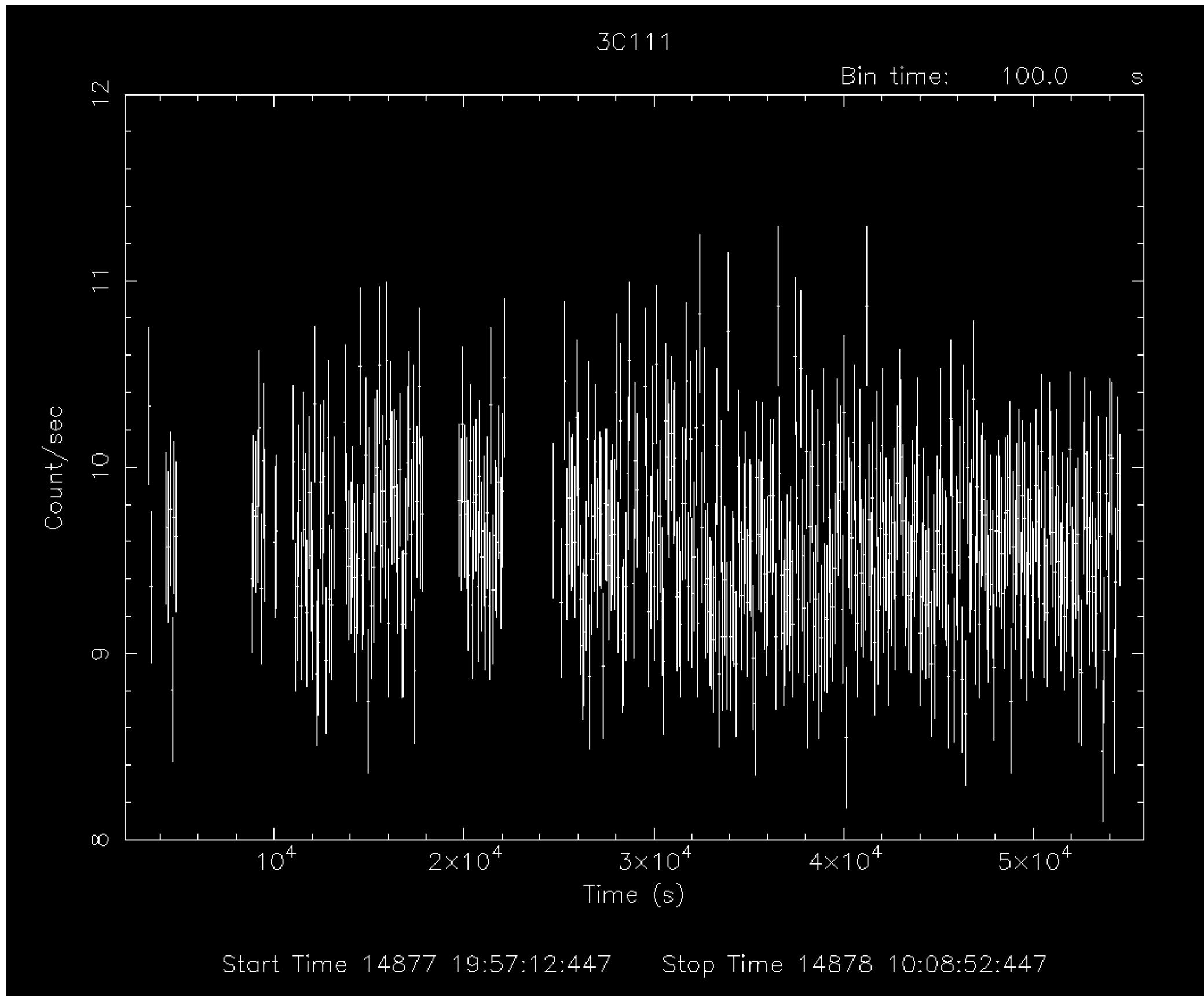
```
epiclccorr srctslist=PN_source_lightcurve_raw.lc eventlist=pn_new.evt outset=PN_lccorr.lc  
bkgtslist=PN_light_curve_background_raw.lc withbkgset=yes applyabsolutecorrections=yes
```

MOS1:

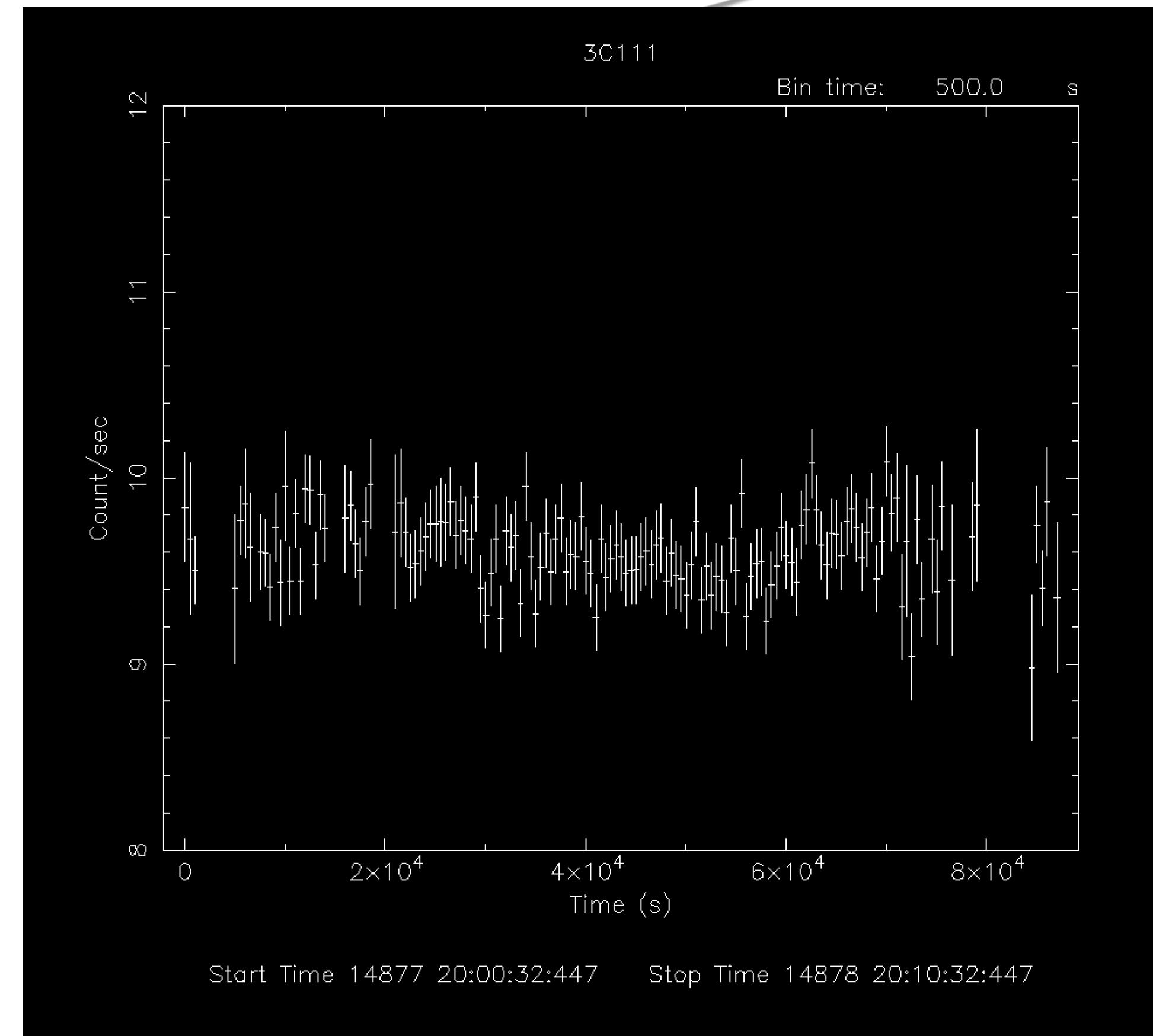
```
epiclccorr srctslist=MOS1_source_lightcurve_raw.lc eventlist=mos1_new.evt  
outset=MOS1_lccorr.lc bkgtslist=MOS1_light_curve_background_raw.lc withbkgset=yes  
applyabsolutecorrections=yes
```

source-background lightcurve: epiclccorr

The longer is the temporal bin the lower is the resolution but the higher is the S/N.

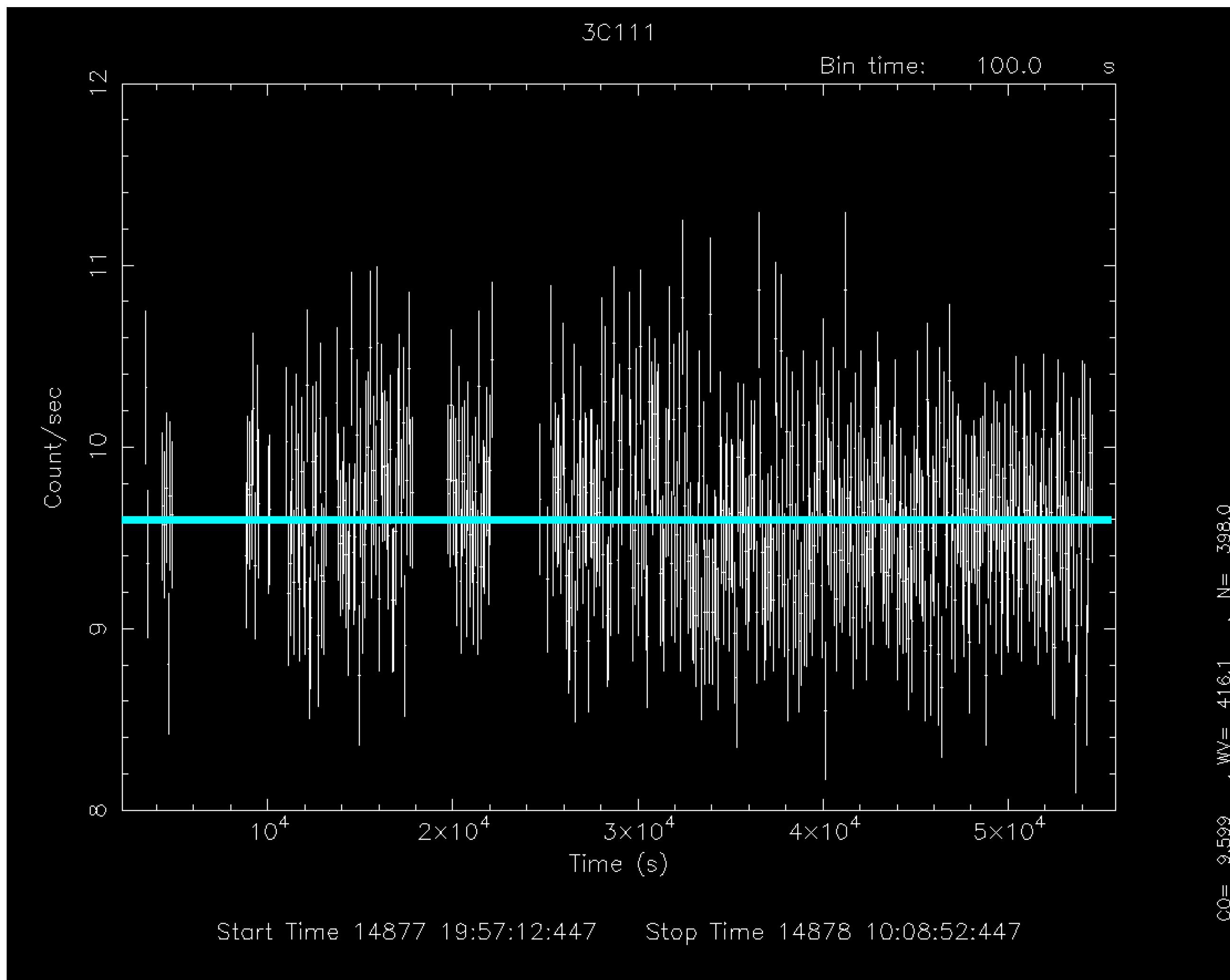


bin=100



bin=500

source-background lightcurve: epiclccorr



$$\chi^2_{\nu} = \frac{1}{\nu} \sum_{i=1}^n \frac{(c_i - \langle c \rangle)^2}{\sigma_i^2}$$

c_i observed counts in every temporal bin i;
 σ_i Poissonian error;
 $\langle c \rangle$ average count during the observation;
 $\nu=n-1$ degrees of freedom;

```
PLT> mo cons
 1 CO: VAL( 1.000 ), SIG( 0.000 ), PLOC( 0.000 ), PHIC( 0.000 )?

PLT> fit
Fitting group 2, from 2.155E+03 to 5.581E+04
Fitting 398 points in a band of 398.
 1.00000000
(-3) W-VAR= 416.3
(-4) W-VAR= 416.1
(-5) W-VAR= 416.1
 9.59943771
PLT> pl
PLT>
```

Compute the probability of the result being due to chance

<https://www.fourmilab.ch/rpkp/experiments/analysis/chiCalc.html>

Calculate probability from X^2 and d

One of the most common chi-square calculations is determining, given the measured X^2 value for a set of experiments with a degree of freedom d , the probability of the result being due to chance. Enter the X^2 and d values in the boxes below, press the **Calculate** button, and the probability will appear in the Q box.

Given $X^2=$ and $d=$ (398-1)

The chance probability, Q , is:

$1-0.2459=0.7541$ the source is variable at ~75% (the acceptance threshold of variability is 99.9%)

Summary

- **Download** the data from the archive
- **Data re-processing**
- **Data reduction:**
 - filtering for high particle background
 - selection of good time intervals (GTI)
 - selection of source and background extraction regions
- Check for the presence of **pileup**
- **Extraction** of source and background **spectra**
- Generate **RMF & ARF**
- **Grouping** (if possible...)
- (Background corrected) **light curve extraction**

