XMM-Newton data analysis: tutorial

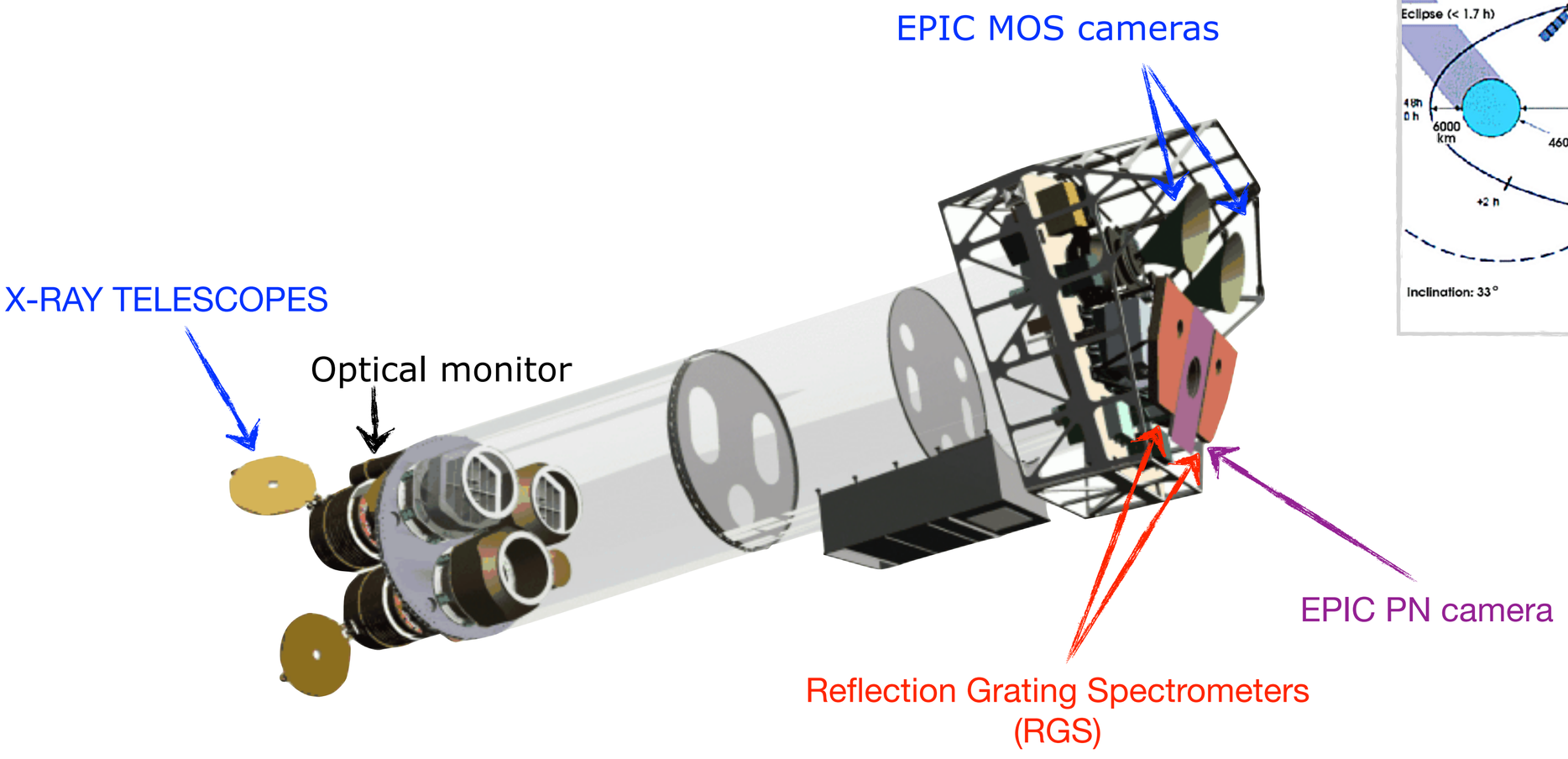
Astrophysics Laboratory course: AA 2021/22

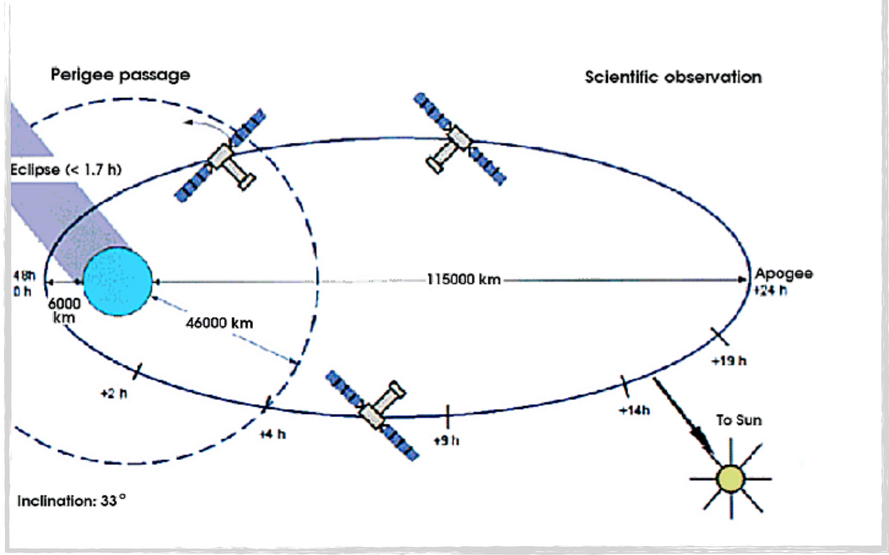
25.02.2022

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

All instruments in the focal plane “active” for each observation

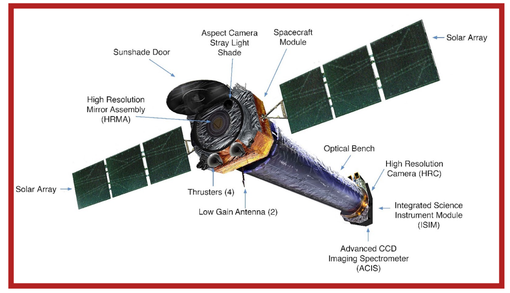


Image courtesy of Dornier Satellitensysteme GmbH and ESA

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

XMM-Newton archive & data download

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

- Home / Latest News
- XMM-Newton 20th Anniversary
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- News
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- Observers Info
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- Archive, Pipeline & Catalogues
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- SOC Info
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XMM-NEWTON SCIENCEX ARCHIVE (XSA)

INDEX

- Access to XMM-Newton Data and Source Catalogues
- 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 Inter[illegible]ystem):

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

▶ Display options

Reset Form

Catalogue Search >

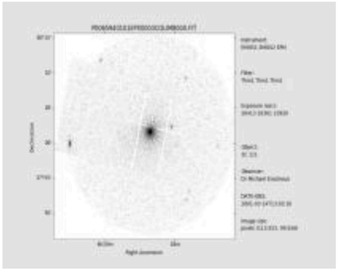
Submit

			Obs.ID	EPIC	RGS	BKGD	ESASky	Target	RA	DEC	Rev	Distance	Start Date	End Date	Dur.	Target Type	PI name	Prop. Program
☐	⬇	🔎	0552180101					3C111	04h 18m 21.27s	+38d 01' 35.7"	1683	0	2009-02-15 17:25:11	2009-02-17 04:01:23	124572	RADIO GALAXY RADIO LOUD/FLAT SPECT FLAT RADIO SP	MARSCHER, ALAN	GO
☐	⬇	🔎	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

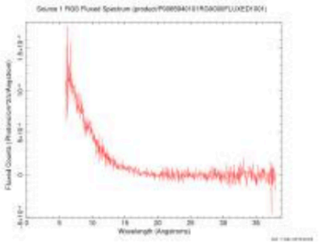
Public Date	PPS ver	Coord. Obs
Public data	17.56_20190403_1200	-
Public data	17.56_20190403_1200	RXTE

			Obs.ID	EPIC	RGS	BKGD	ESASky	Target	RA	DEC	Rev	Distance	Start Date	End Date
☐	⬇	🔎	0552180101					3C111	04h 18m 21.27s	+38d 01' 35.7"	1683	0	2009-02-15 17:25:11	2009-02-17 04:0
☑	⬇	🔎	0065940101					3C 111	04h 18m 21.07s	+38d 01' 32.6"	231	0.07	2001-03-14 12:56:44	2001-03-15 01:2

Details for Observation 0065940101



EPIC Image



RGS fluxed spectrum

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 differneces 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 scenrios predict different disk structures and by extension different line profiles.

Show Quality Report

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XMM-Newton Science Archive

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Back to Search | Close all

Results #1

OBSERVATIONS (2)

Columns | Column units | Display selected | Add to Basket | Save table as | Send table to | RGS Spectra

			Obs.ID	EPIC	RGS	BKGD	ESASky	Target	RA	DEC	Rev	Distance	Start Date	End Date
☐	⬇	🔎	0552180101					3C111	04h 18m 21.27s	+38d 01' 35.7"	1683	0	2009-02-15 17:25:11	2009-02-17 04:01:23
☑	⬇							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

ODF
PPS
IMAGES
SOURCES
SPECTRA
LIGHT_CURVES

0552180101.tar.gz

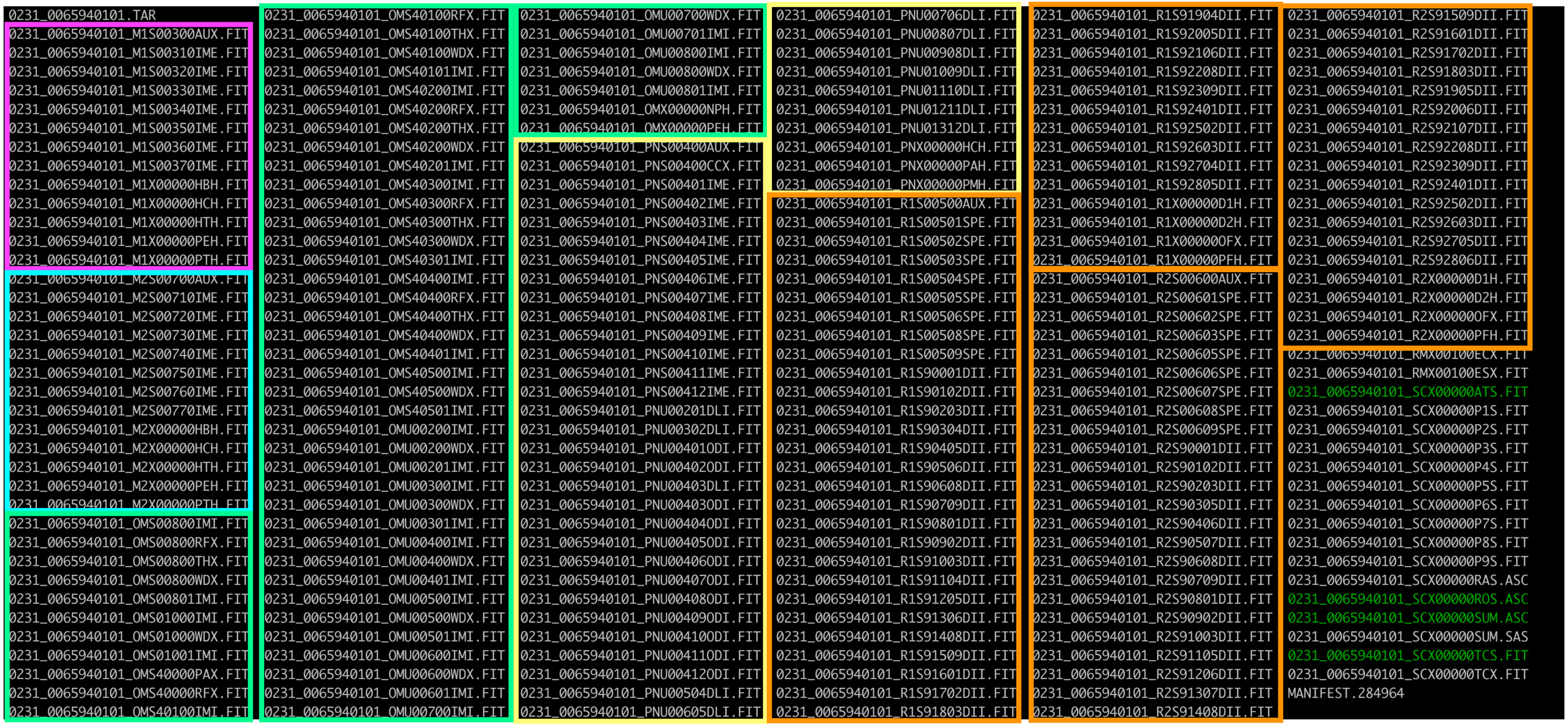
How to copy the downloaded file in your working directory

- FTP clients (Fugu, Cyberduck, Filezilla, etc.)

- scp 0552180101.tar.gz gruppoXX@login05.iasfbo.inaf.it:/home/gruppoXX

Data structure

0552180101.tar.gz > tar -zxvf 0552180101.tar.gz



MOS1
MOS2

OM

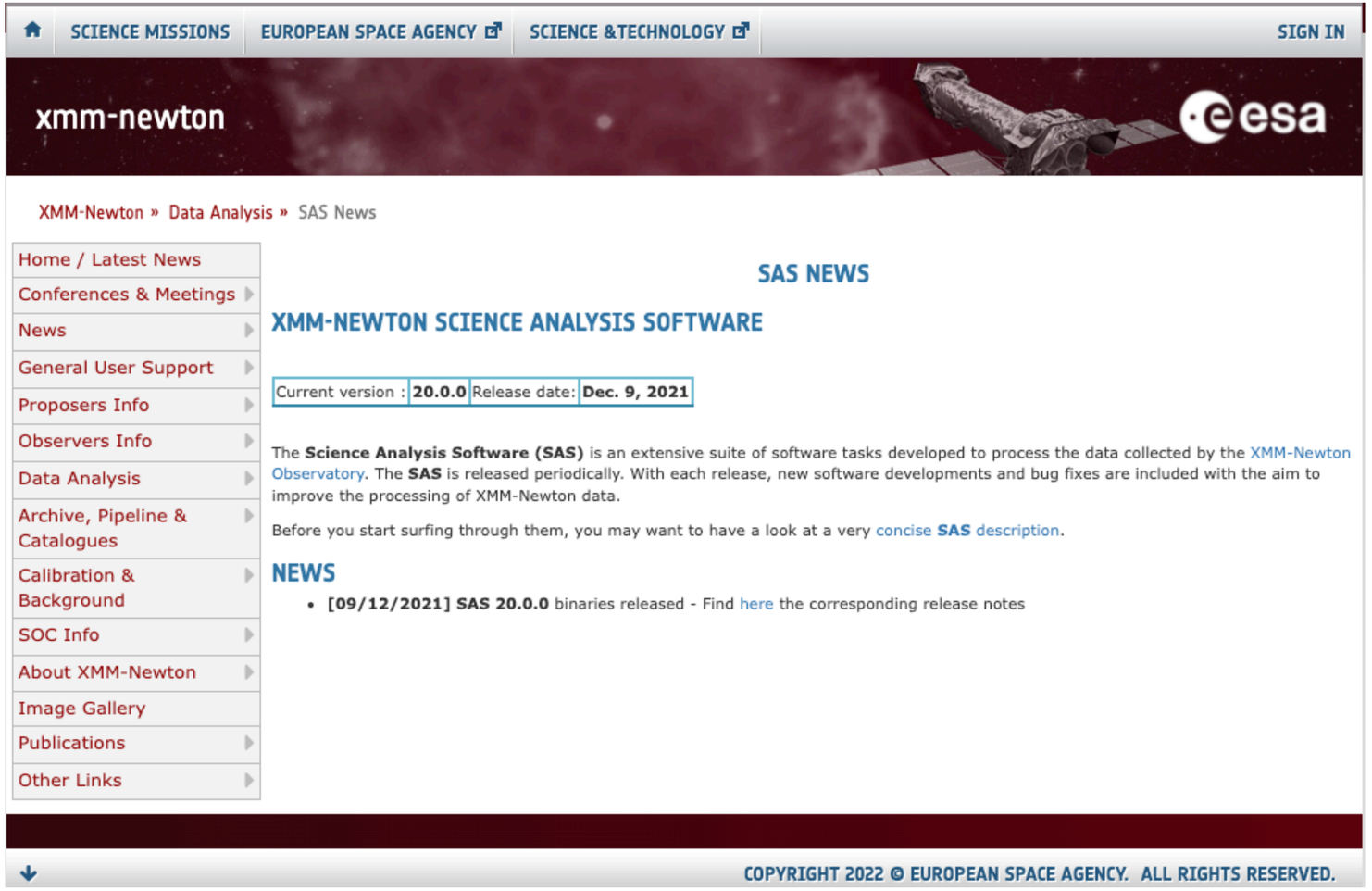
pn

RGS1

RGS2

Data analysis

Standard Analysis System (**SAS**)



Data re-processing:

ODF
(Observation Data Files)

→ **Data re-processing** →

EVT
ccf.cif (Calibration Index Files)
evt (event files)

- ✔ cifbuild
- ✔ odfingest

SAS start-up

- ✔ emproc (for EPIC-MOS)
- ✔ epproc (for EPIC-pn)

Data re-processing:

ODF

(Observation Data Files)

Data Processing

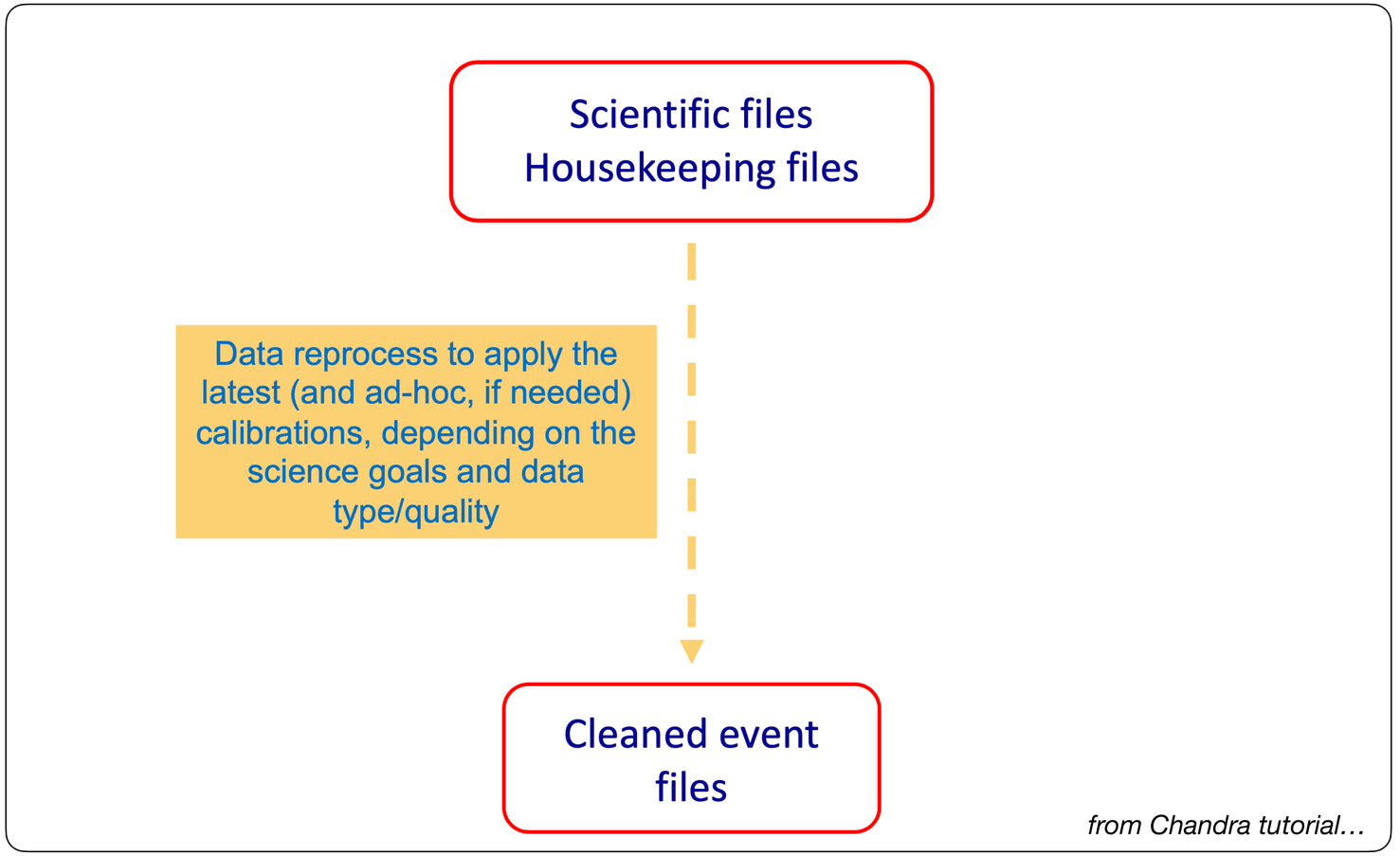
EVT

ccf.cif (Calibration Index Files)

```
0231_0065940101_AttHk.ds                    0231_0065940101_EMOS2_S007_01_Badpixels.ds  0231_0065940101_EPN_S004_02_Badpixels.ds  0231_0065940101_EPN_S004_11_Badpixels.ds
0231_0065940101_EMOS1_S003_01_Badpixels.ds  0231_0065940101_EMOS2_S007_02_Badpixels.ds  0231_0065940101_EPN_S004_03_Badpixels.ds  0231_0065940101_EPN_S004_12_Badpixels.ds
0231_0065940101_EMOS1_S003_02_Badpixels.ds  0231_0065940101_EMOS2_S007_03_Badpixels.ds  0231_0065940101_EPN_S004_04_Badpixels.ds  0231_0065940101_EPN_S004_ImagingEvts.ds
0231_0065940101_EMOS1_S003_03_Badpixels.ds  0231_0065940101_EMOS2_S007_04_Badpixels.ds  0231_0065940101_EPN_S004_05_Badpixels.ds  ccf.cif
0231_0065940101_EMOS1_S003_04_Badpixels.ds  0231_0065940101_EMOS2_S007_05_Badpixels.ds  0231_0065940101_EPN_S004_06_Badpixels.ds  m1.evt
0231_0065940101_EMOS1_S003_05_Badpixels.ds  0231_0065940101_EMOS2_S007_06_Badpixels.ds  0231_0065940101_EPN_S004_07_Badpixels.ds  m2.evt
0231_0065940101_EMOS1_S003_06_Badpixels.ds  0231_0065940101_EMOS2_S007_07_Badpixels.ds  0231_0065940101_EPN_S004_08_Badpixels.ds  pn.evt
0231_0065940101_EMOS1_S003_07_Badpixels.ds  0231_0065940101_EMOS2_S007_ImagingEvts.ds   0231_0065940101_EPN_S004_09_Badpixels.ds
0231_0065940101_EMOS1_S003_ImagingEvts.ds   0231_0065940101_EPN_S004_01_Badpixels.ds   0231_0065940101_EPN_S004_10_Badpixels.ds
```

- ✔ odfingest
- ✔ emproc (for EPIC-MOS)
- ✔ epproc (for EPIC-pn)

Data Reduction



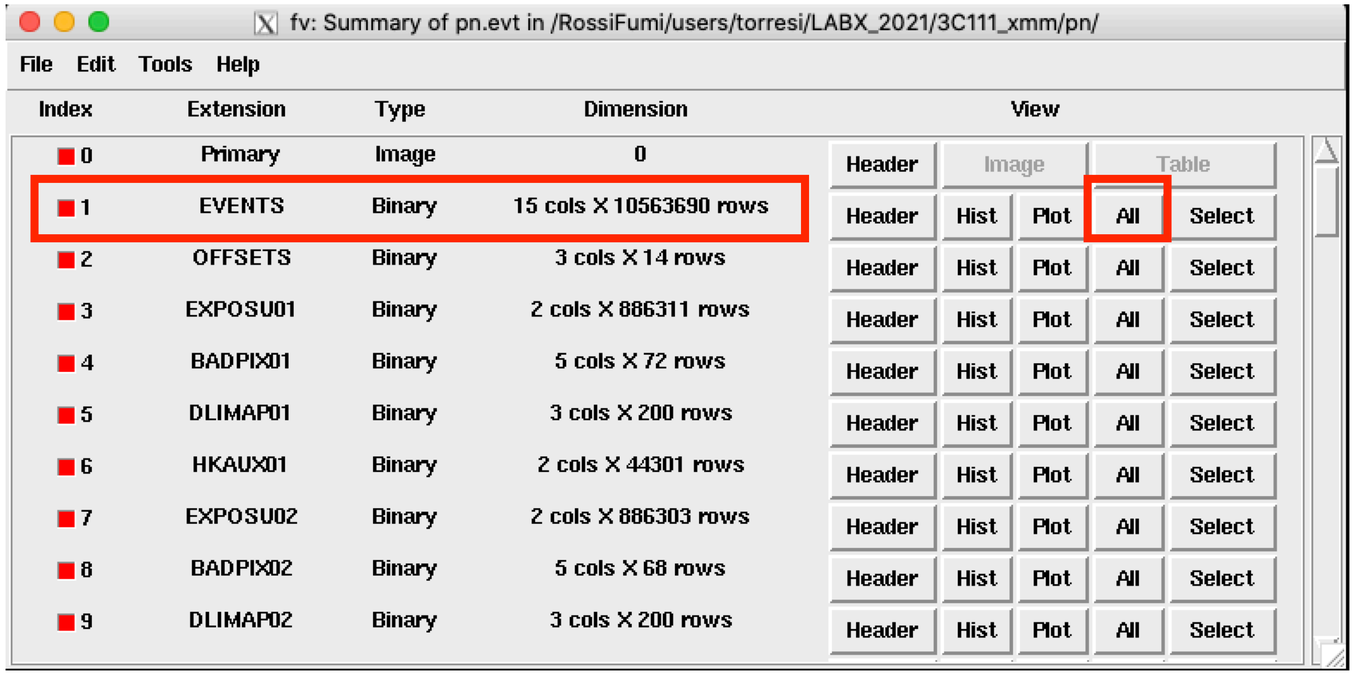
IMAGE

SPECTRUM

LIGHT CURVE

fv pn.evt

#rows=#counts



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

fv pn.evt

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

File Edit Tools Help

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

File Edit Tools Help

#rows=

Select / All / Invert	TIME	RAWX	RAWY	DETX	DETY	X	Y	PHA	PI	FLAG	PATTERN	PAT_ID	PAT_SEQ	CCDNR	TIME_RAW
	D	I	I	I	I	J	J	I	I	J	B	I	B	B	D
	s	pixel	pixel	0.05 arcsec	0.05 arcsec	0.05 arcsec	0.05 arcsec	channel	eV						s
	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	1.009638769452E+08	12	117	-3187	5809	22906	22156	1069	6095	0	2	5121	0	1	1.009638769231E+08
2	1.009638775018E+08	45	125	-5930	5147	20370	23392	29	285	0	2	5121	0	1	1.009638774951E+08
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

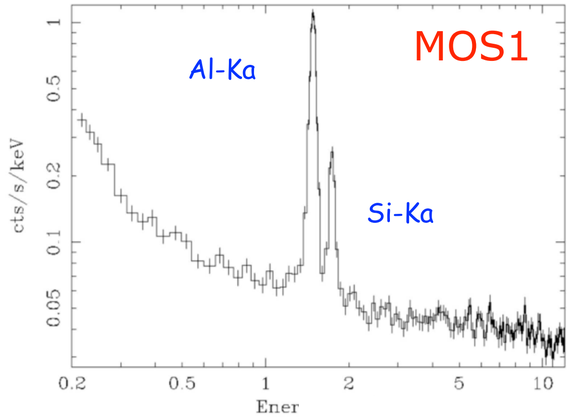
Go to: Edit cell:

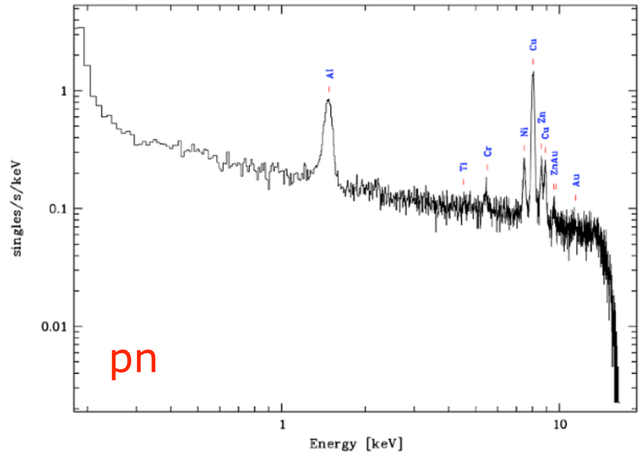
Filtering against high background

EPIC particle induced background

Internal ‘quiescent’ component

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



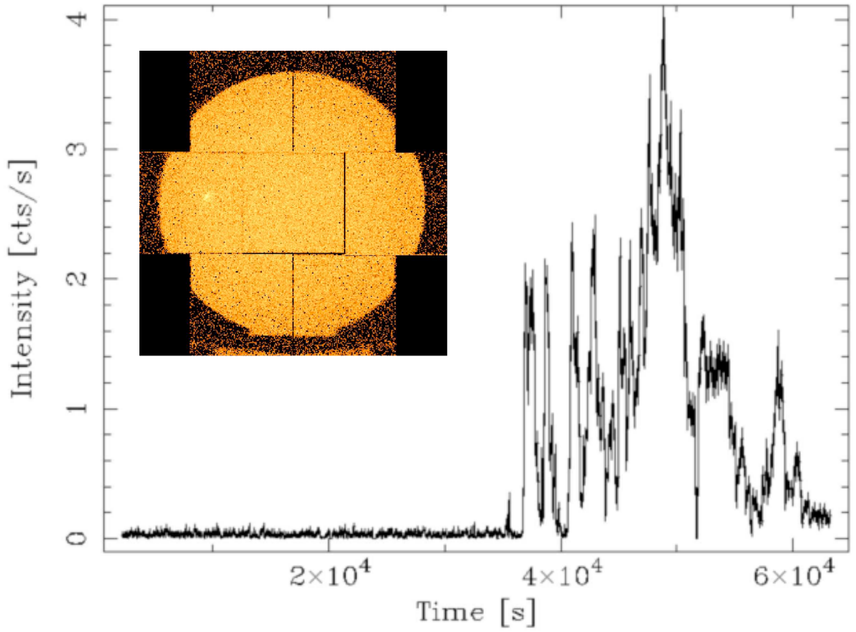


Filtering against high background

EPIC particle induced background

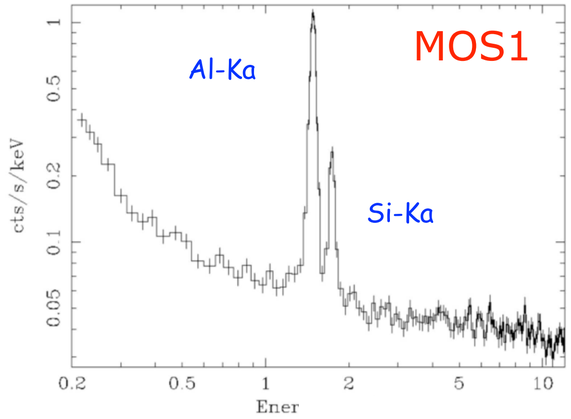
External ‘flaring’ component

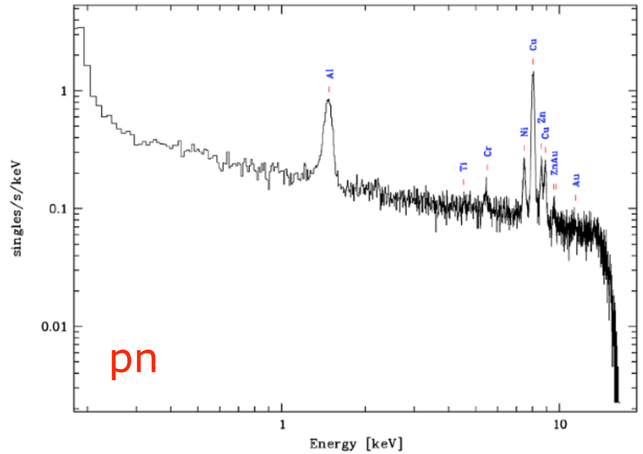
strong and rapid variability; currently attributed to soft protons (E_p < a few 100 keV) likely organized in clouds populating the Earth’s magneto-sphere



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

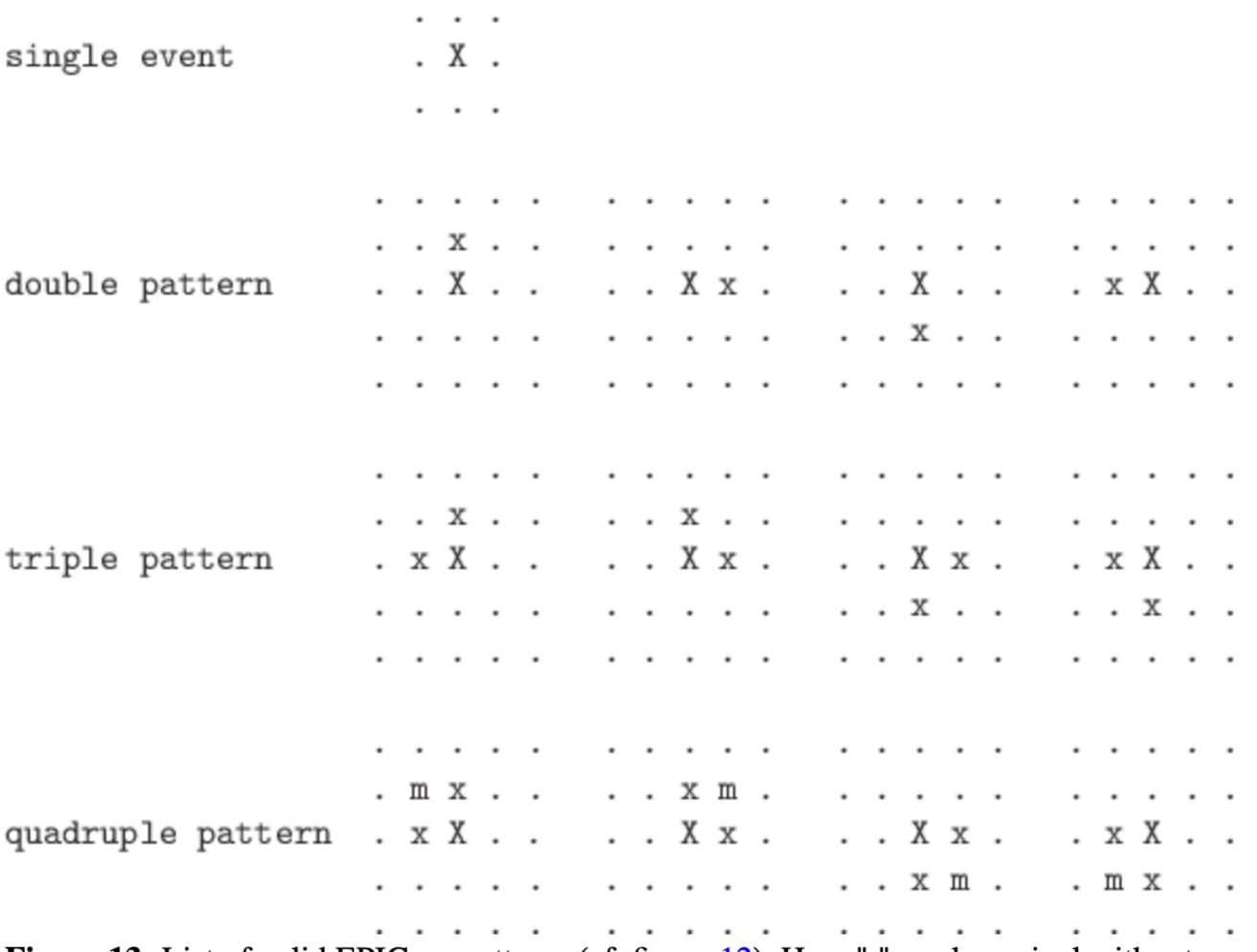
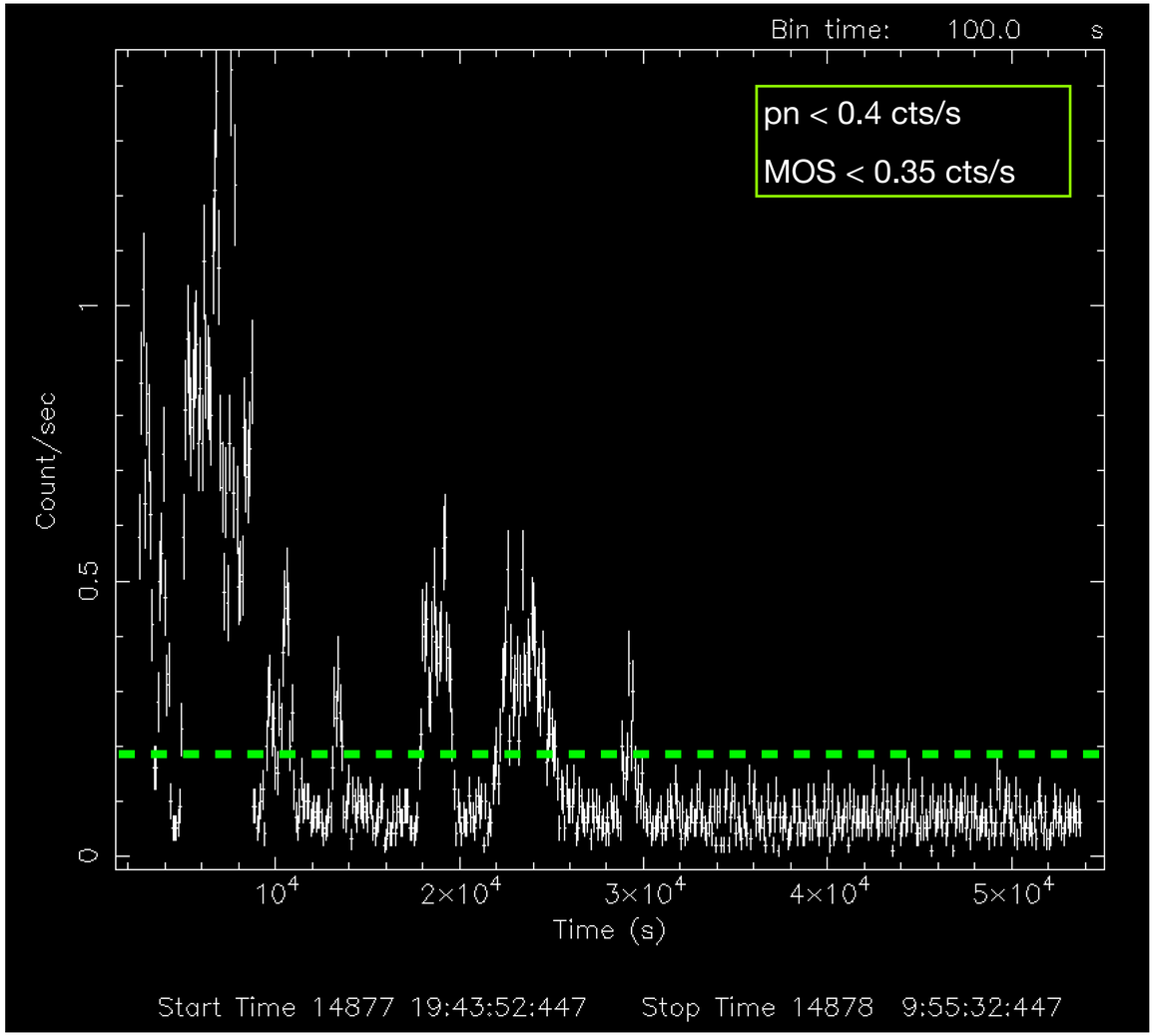


Figure 13: List of valid EPIC-pn patterns (cf. figure 12). Here "." marks a pixel without an event above threshold, "X" is the pixel with the maximum charge ("main pixel"), "x" is the pixel with a non-maximum charge, "m" is the pixel with the minimum charge. These 13 figures refer to the SAS PATTERN 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
```

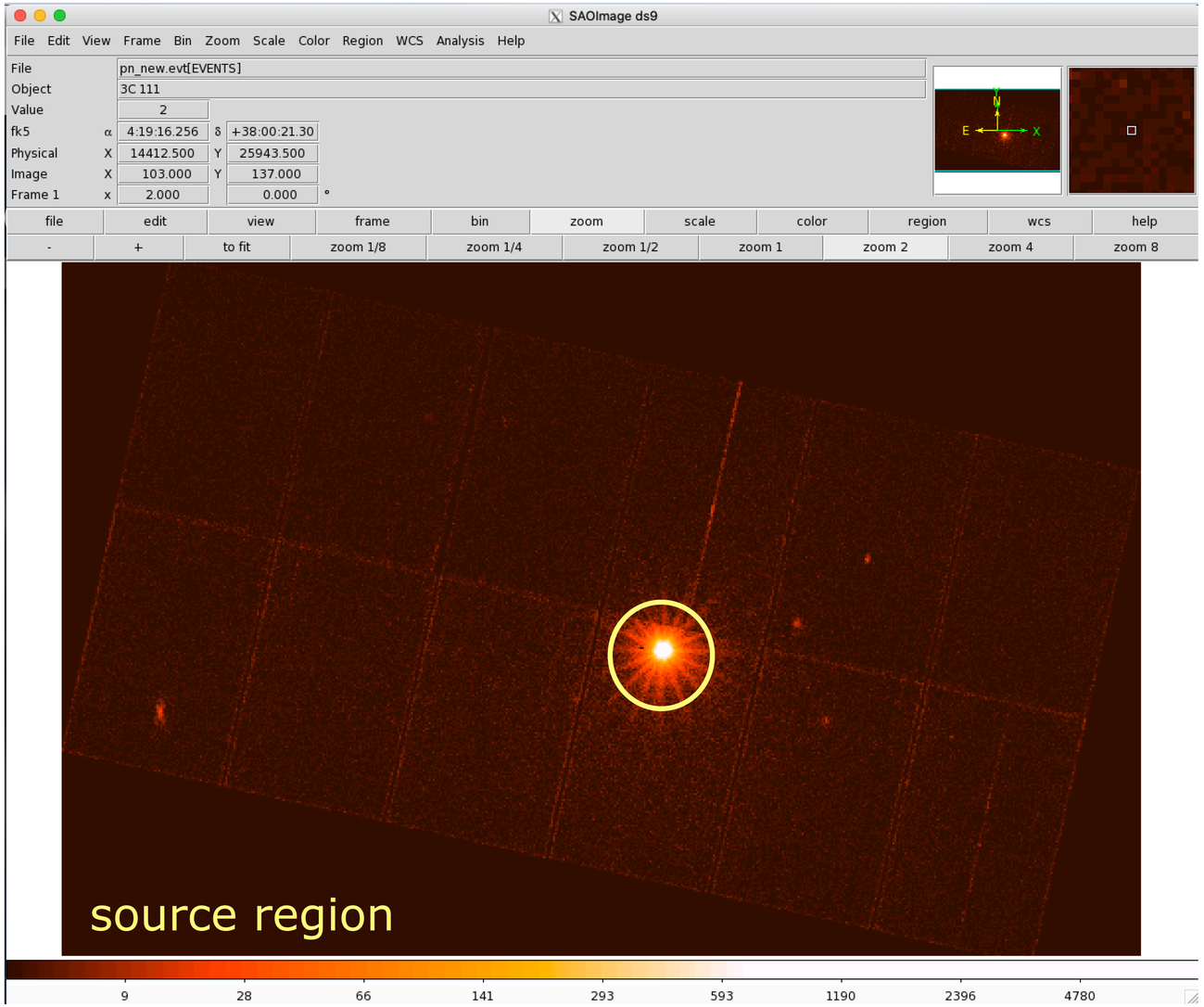
Source & background extraction regions

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

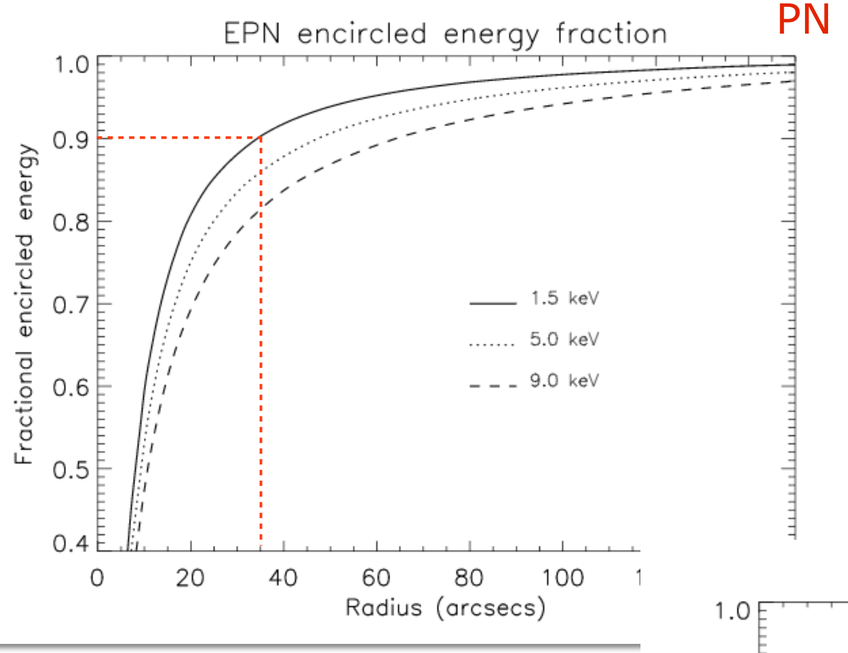


circle(27404.411,27351.501,799.99999)

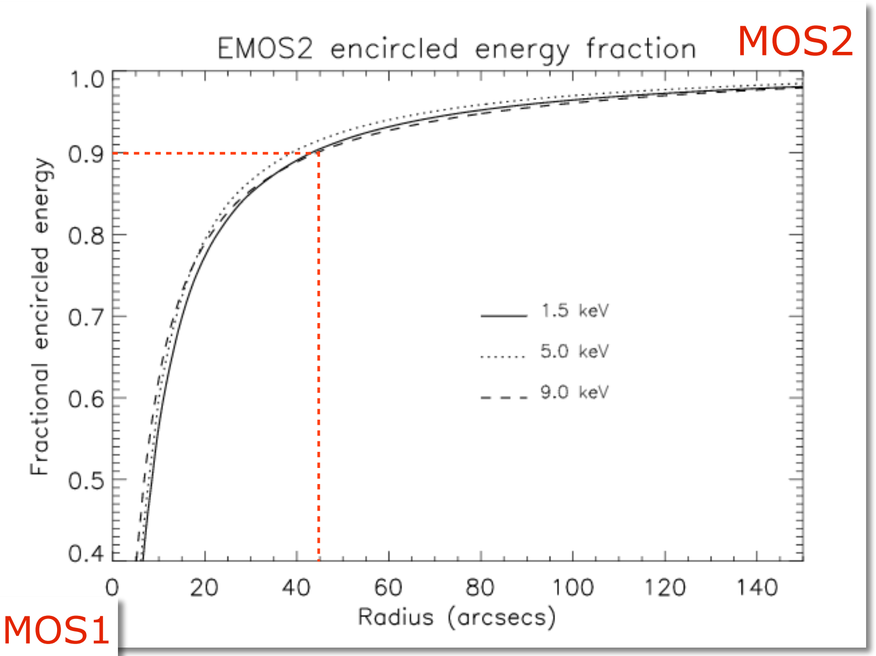
http://ds9.si.edu/doc/user/binning/index.html

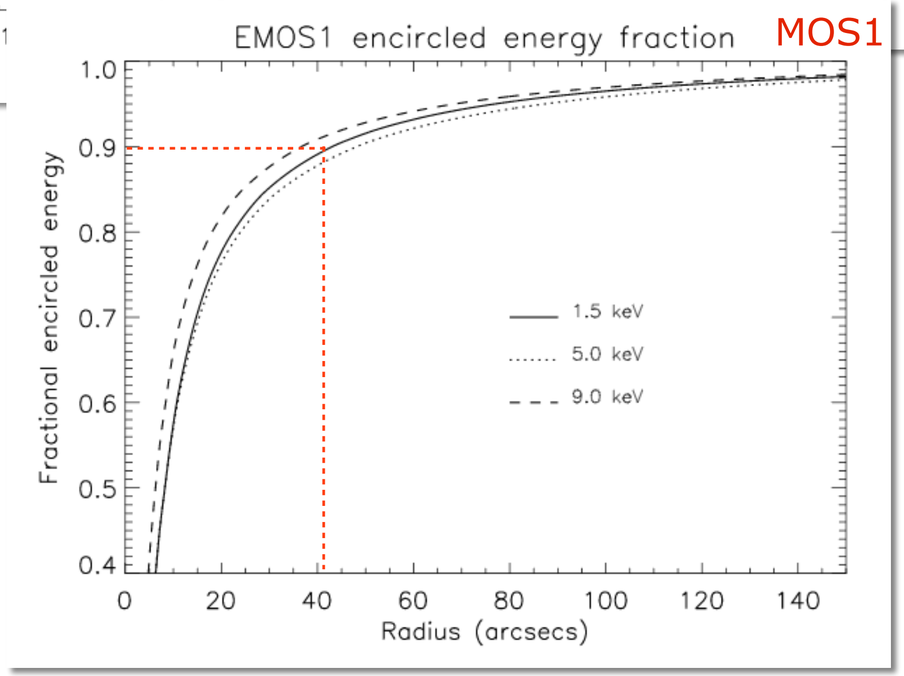
Encircled energy fraction

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



Extraction radius	Camera		
(arcsec)	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

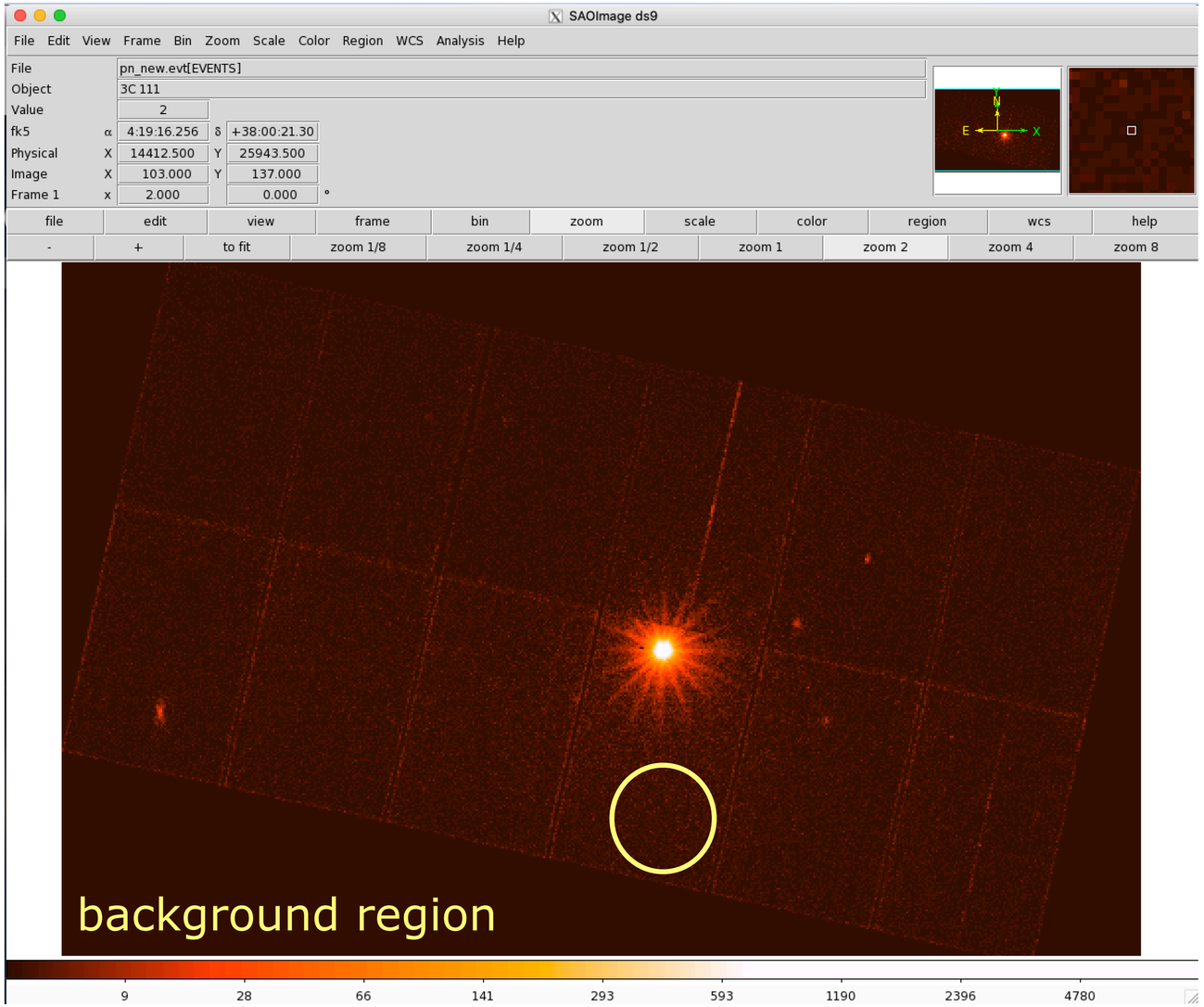
Source & background extraction regions

Display the cleaned pn image with ***ds9***

```
ds9 pn_new.evt &
```

> scale log
> bin (block 2, 4, …)

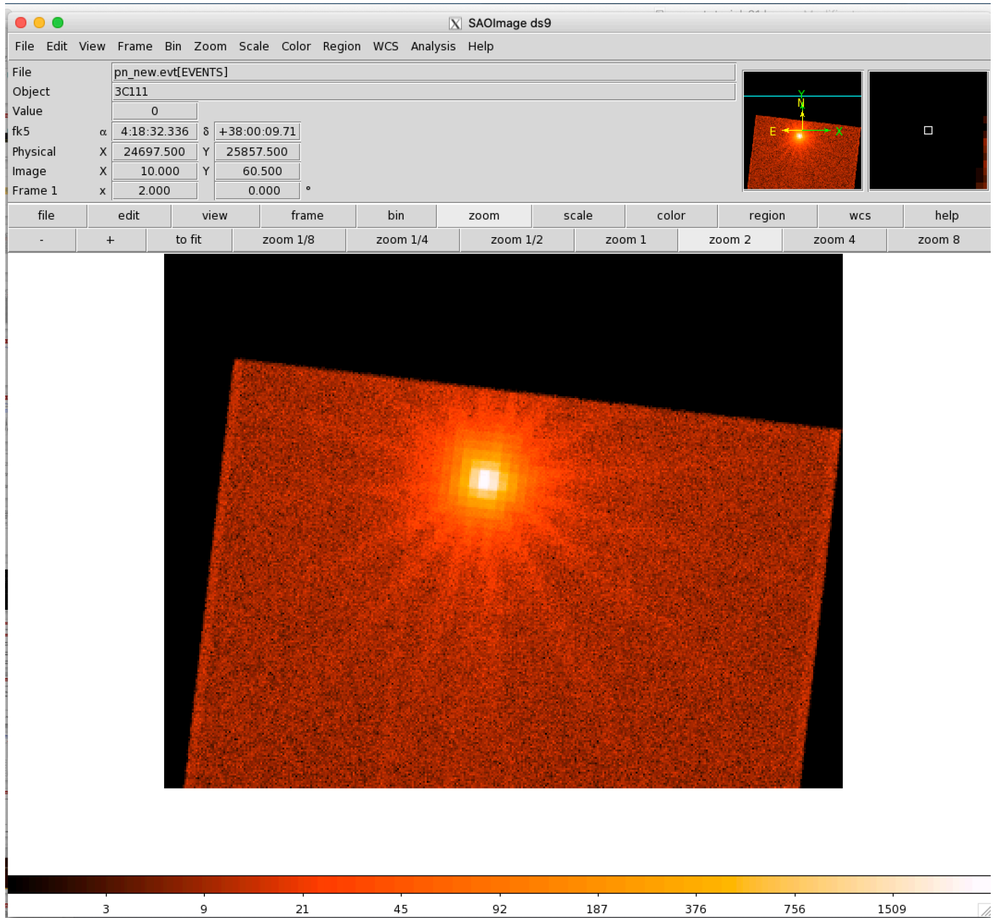
> Region
> save region
> file format ‘ds9’
> coordinates ‘physical’
> back.reg



circle(27948.55,22135.48,799.99999)

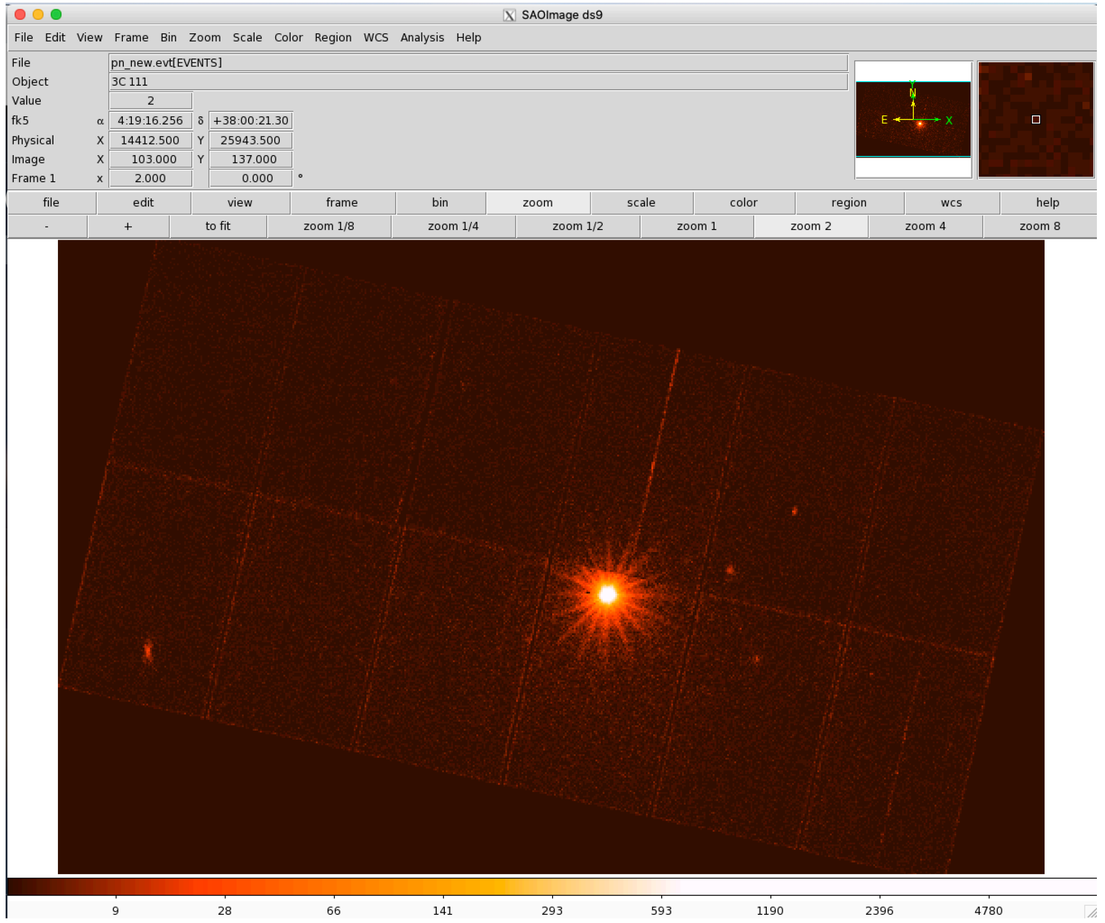
http://ds9.si.edu/doc/user/binning/index.html

2009



small window

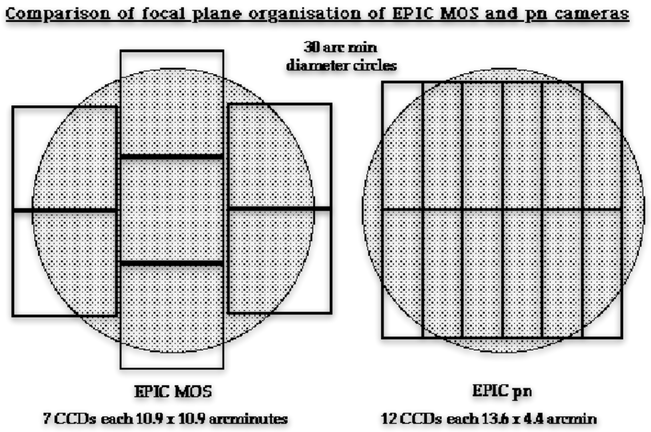
2001



large window

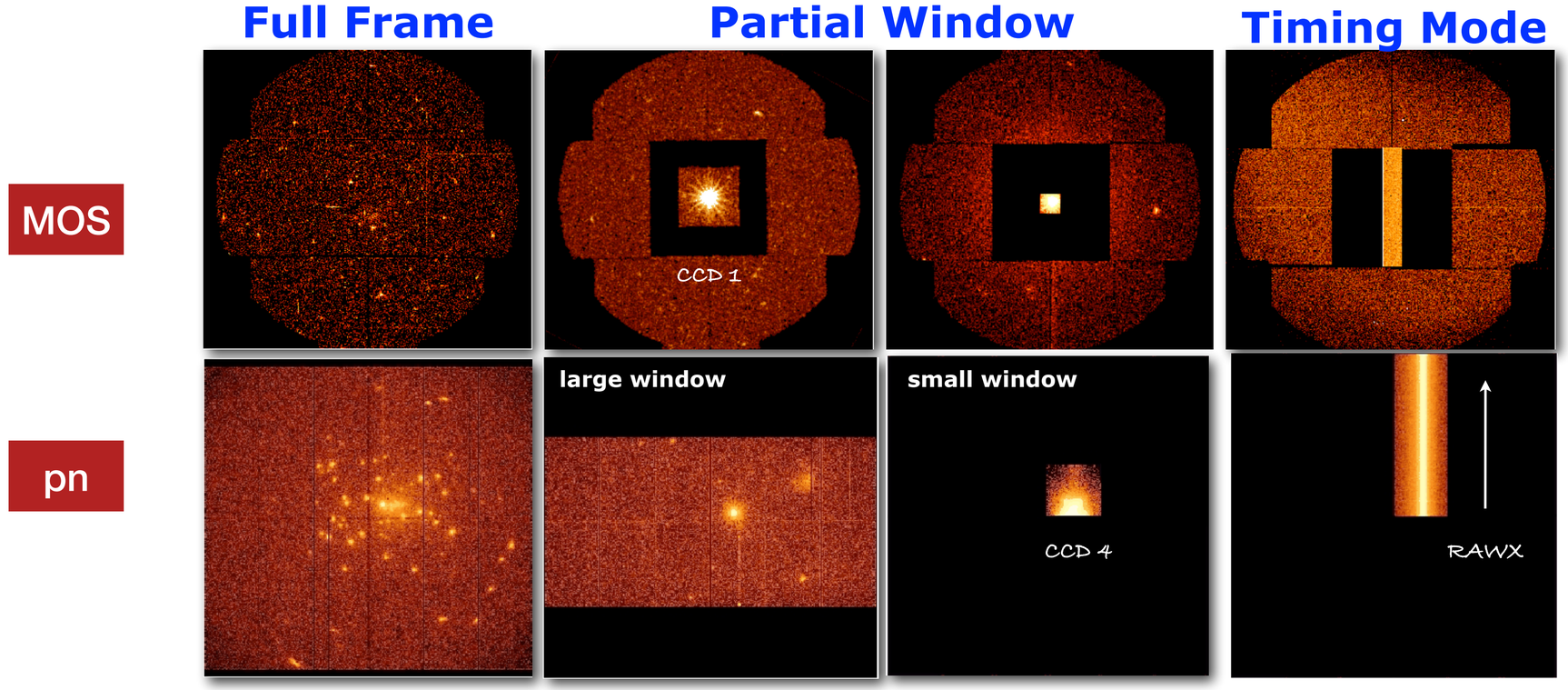
EPIC Science Modes

MOS



pn

XMM FoV 30’



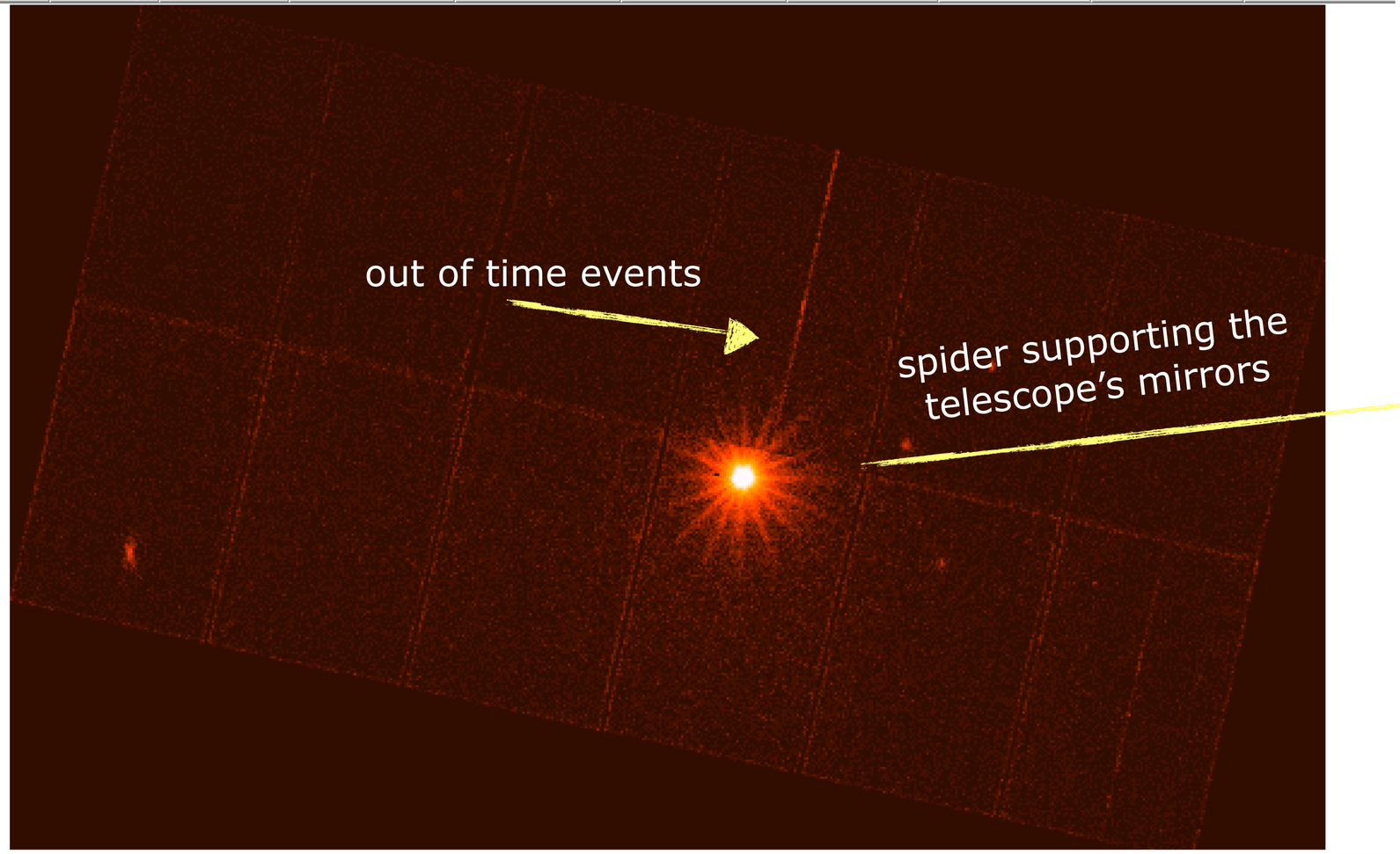
SAOImage ds9

File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help

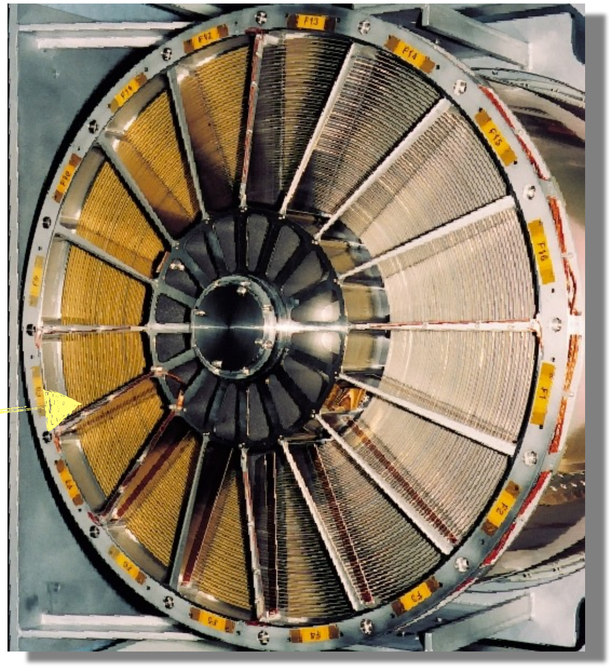
File	pn_new.evt[EVENTS]			
Object	3C 111			
Value	2			
fk5	α	4:19:16.256	δ	+38:00:21.30
Physical	X	14412.500	Y	25943.500
Image	X	103.000	Y	137.000
Frame 1	x	2.000		0.000 °

file edit view frame bin zoom scale color region wcs help

- + to fit zoom 1/8 zoom 1/4 zoom 1/2 zoom 1 zoom 2 zoom 4 zoom 8



9 28 66 141 293 593 1190 2396 4780



SAOImage ds9

File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help

File	pn_new.evt[EVENTS]			
Object	3C 111			
Value	2			
fk5	α	4:19:16.256	δ	+38:00:21.30
Physical	X	14412.500	Y	25943.500
Image	X	103.000	Y	137.000
Frame 1	x	2.000		0.000 °

file edit view frame bin zoom scale color region wcs help

- + to fit zoom 1/8 zoom 1/4 zoom 1/2 zoom 1 zoom 2 zoom 4 zoom 8

out of time events

spider supporting the telescope's mirrors

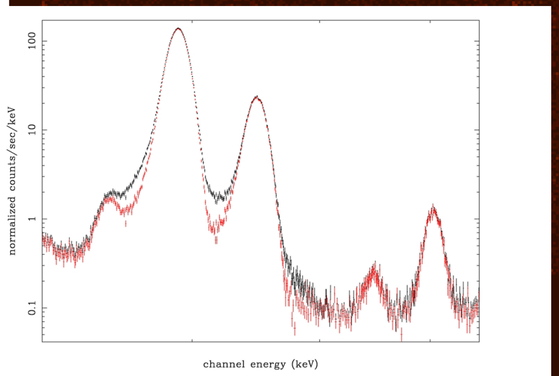
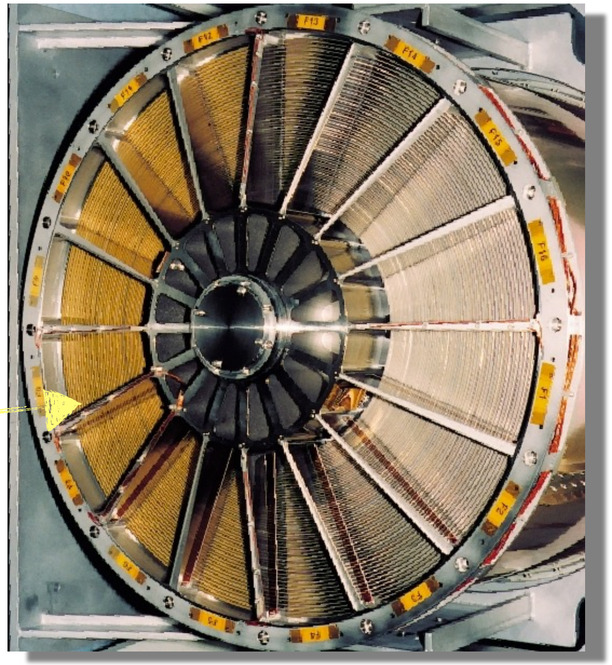


Figure 26: Effect of Out-of-Time events on a source spectrum (in this case the internal calibration source): the black data points display the source spectrum which is still contaminated by OoT events, the red points mark the source spectrum being cleared from OoT events. The energy range displayed is 5-8.5 keV.

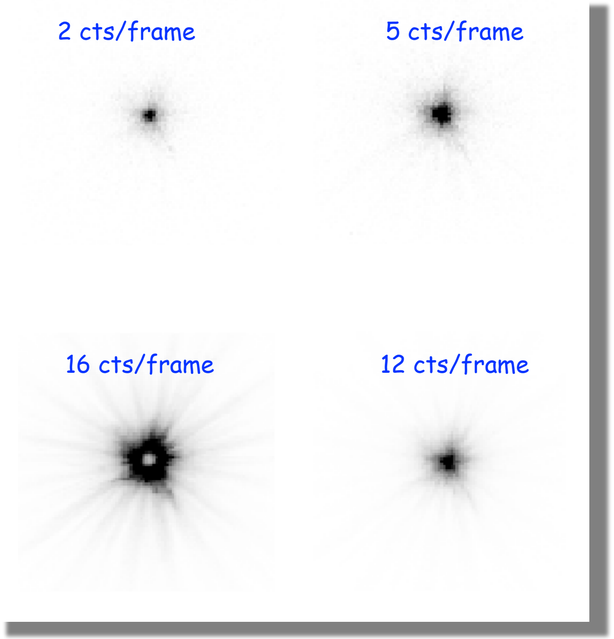
9 28 66 141 293 593 1190 2396 4780



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)



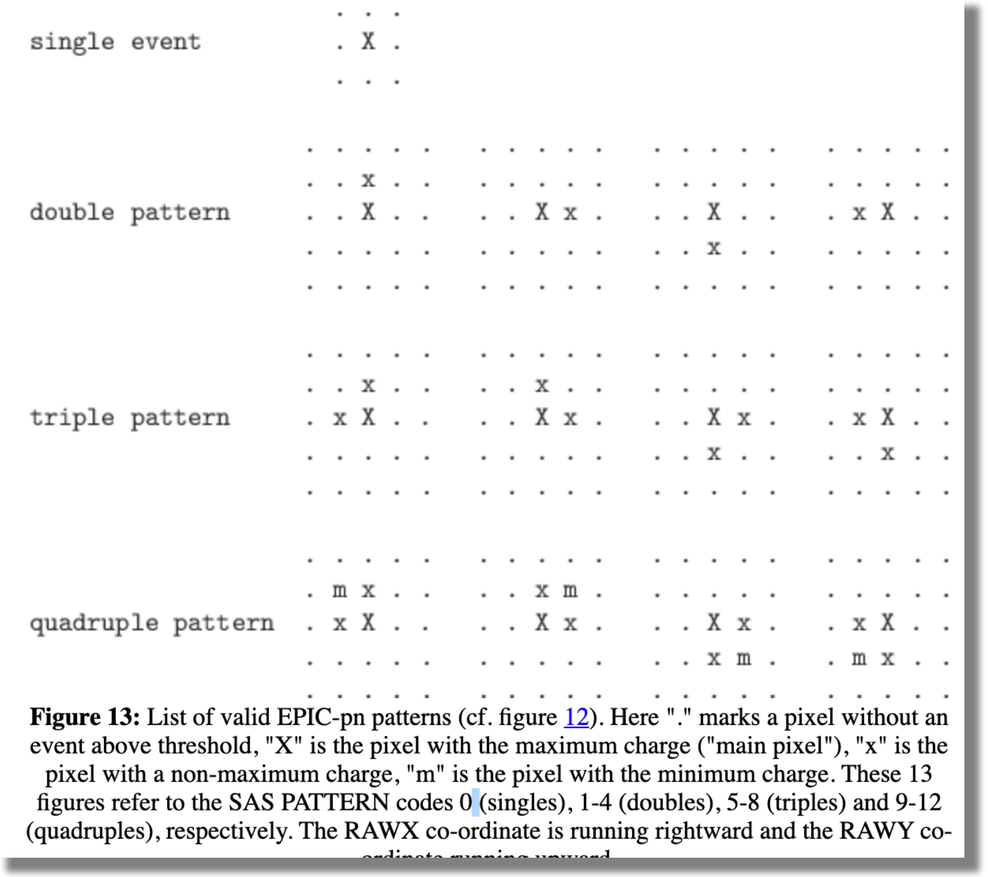


Figure 13: List of valid EPIC-pn patterns (cf. figure 12). Here "." marks a pixel without an event above threshold, "X" is the pixel with the maximum charge ("main pixel"), "x" is the pixel with a non-maximum charge, "m" is the pixel with the minimum charge. These 13 figures refer to the SAS PATTERN 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

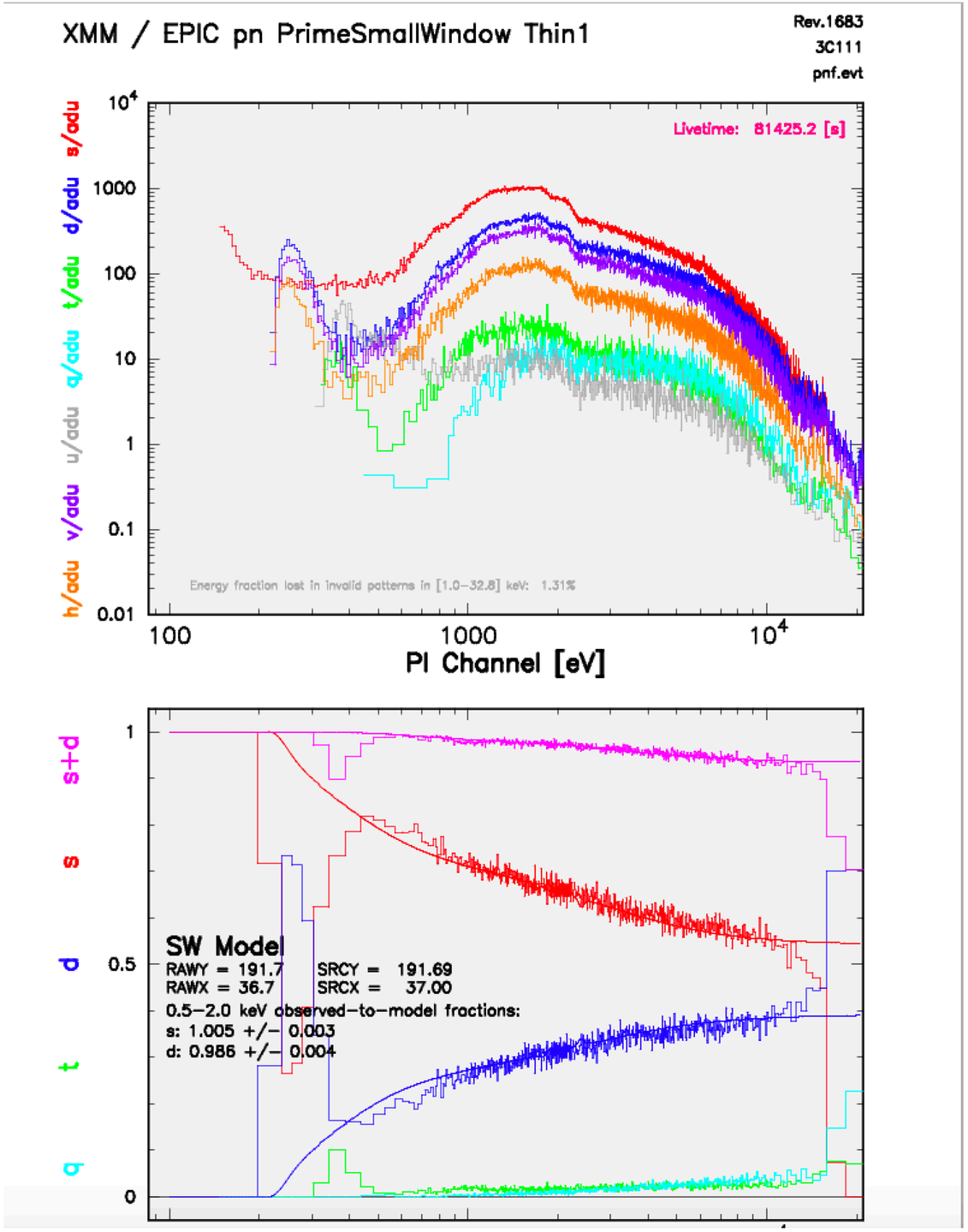
evselect table=**pn_new.evt** withfilteredset=yes filteredset=**pnf.evt** keepfilteroutput=yes expression="((X,Y) IN circle (25910.5,25870.5,400))”

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>
```

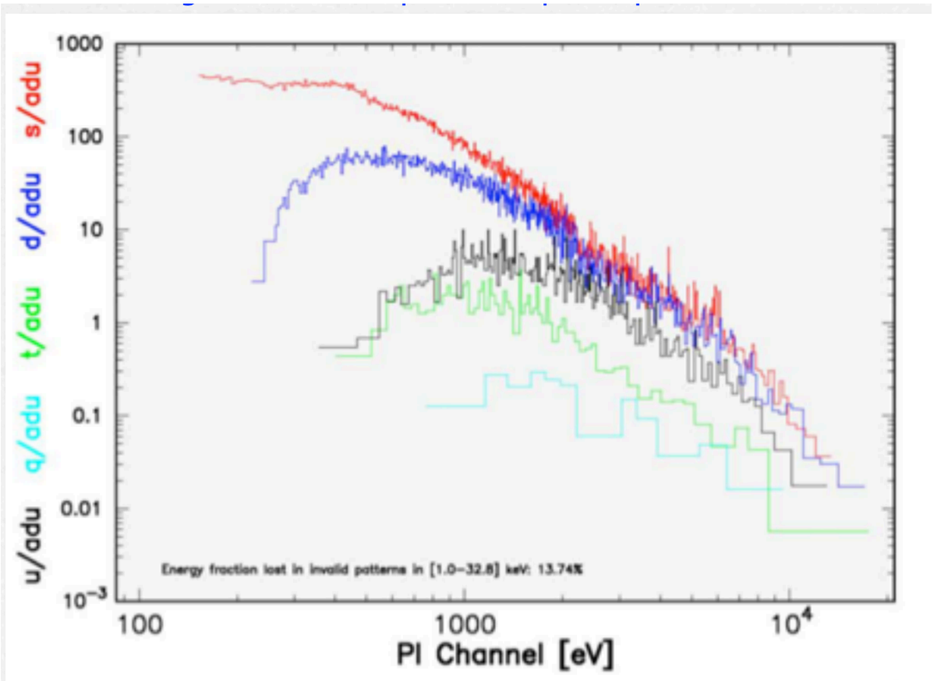
gv **pnf_pat.ps**

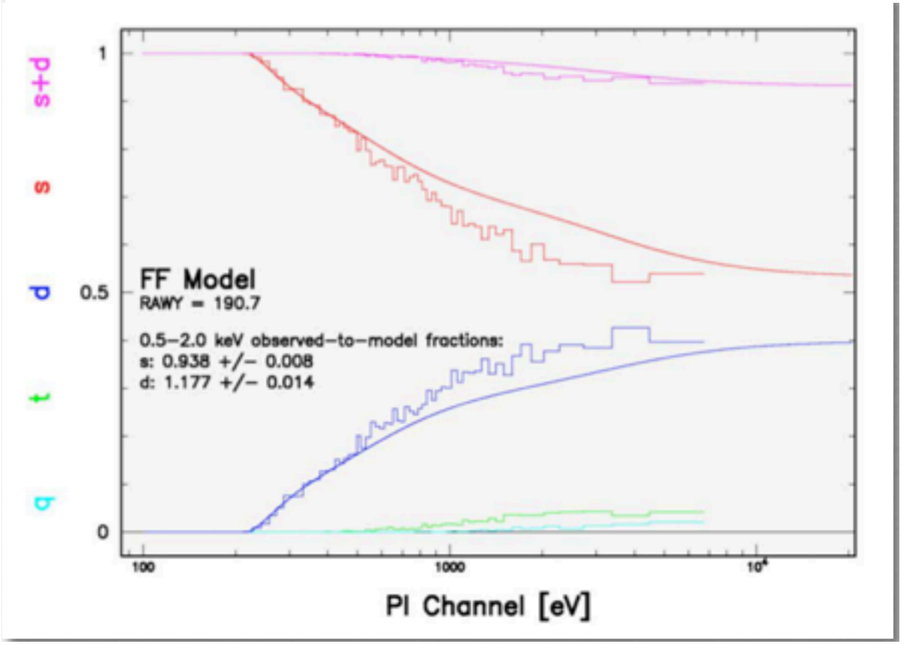
evince **pnf_pat.ps**



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(27874.528,26645.58,699.99999))'
```

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:

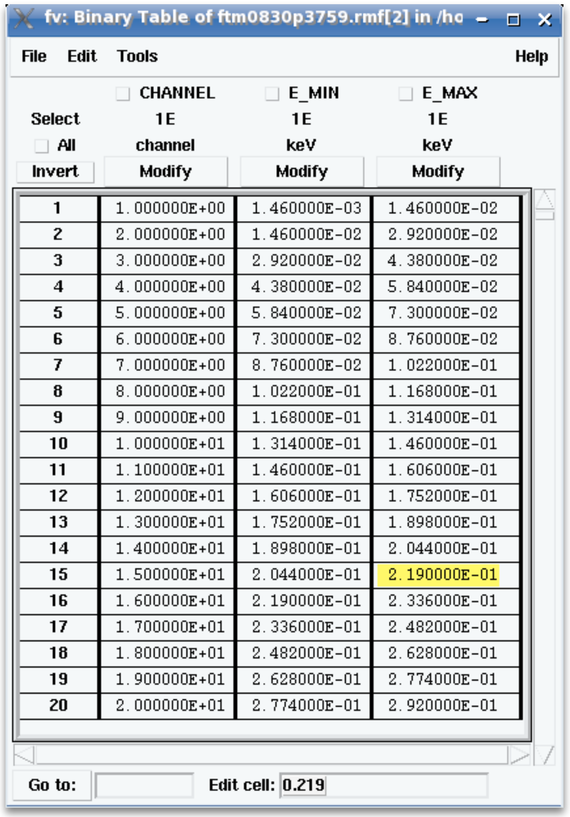
backscale spectrumset=**source_spectrum.fits** badpixlocation=**mos1_new.evt**

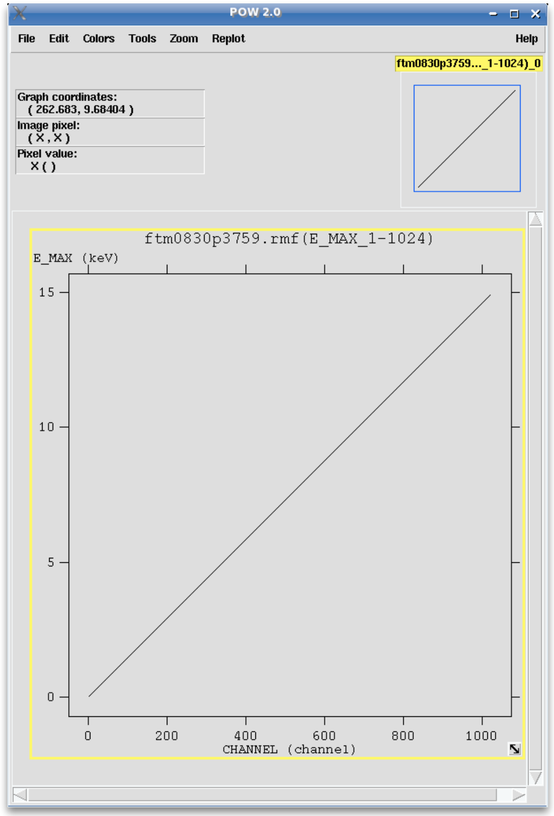
backscale spectrumset=**back_spectrum.fits** badpixlocation=**mos1_new.evt**

Redistribution Matrix File (RMF)

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

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

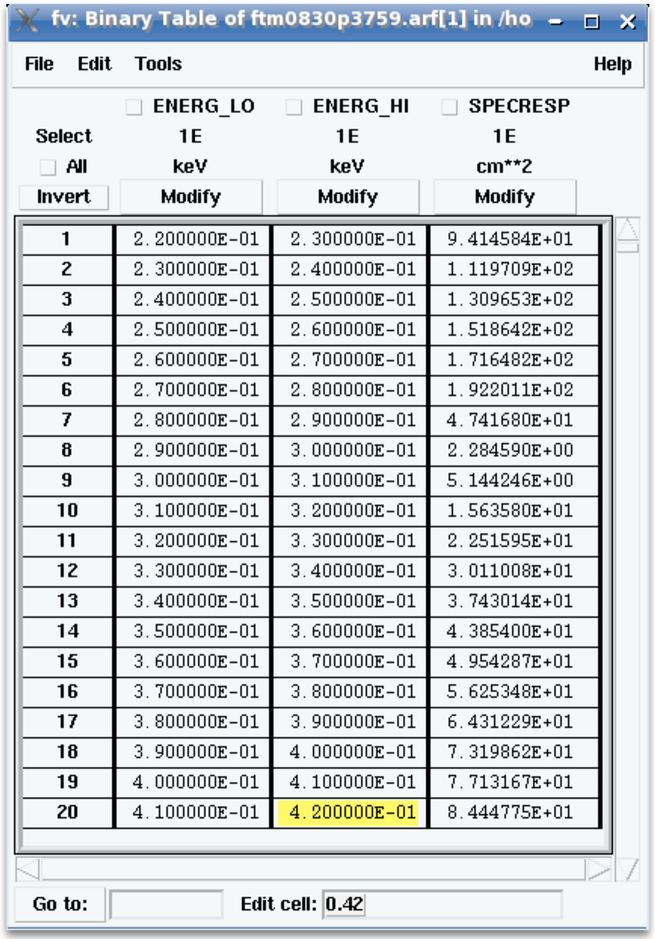


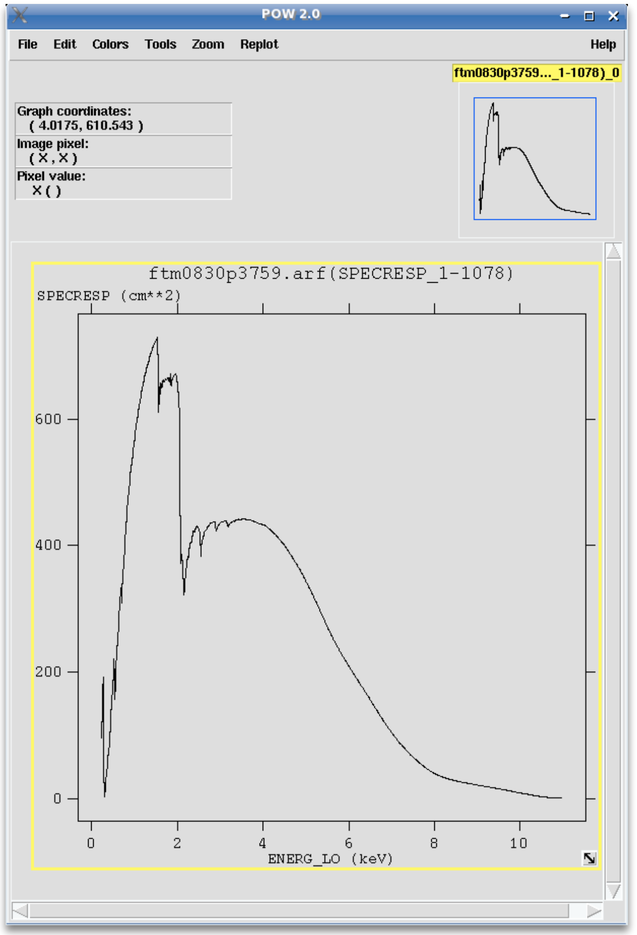


Ancillary Response File (ARF)

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

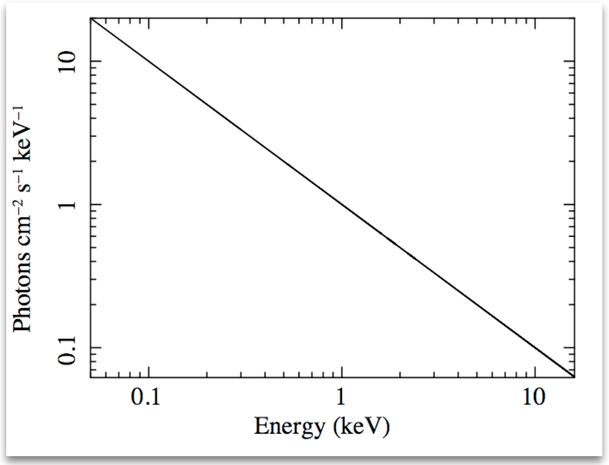
The ARF includes information on the effective area, filter transmission and any additional energy-dependent efficiencies, i.e. the efficiency of the instrument in revealing photons

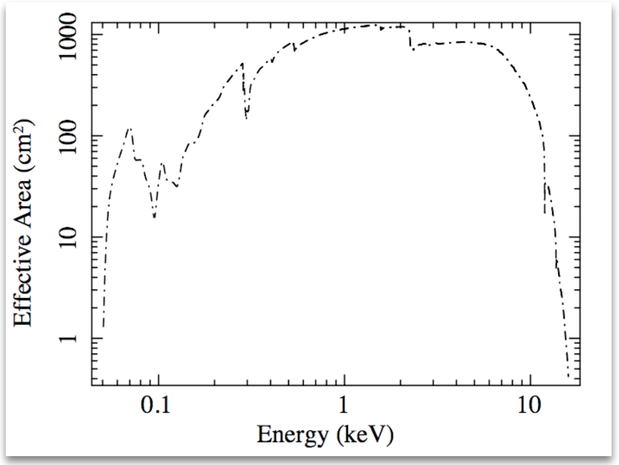


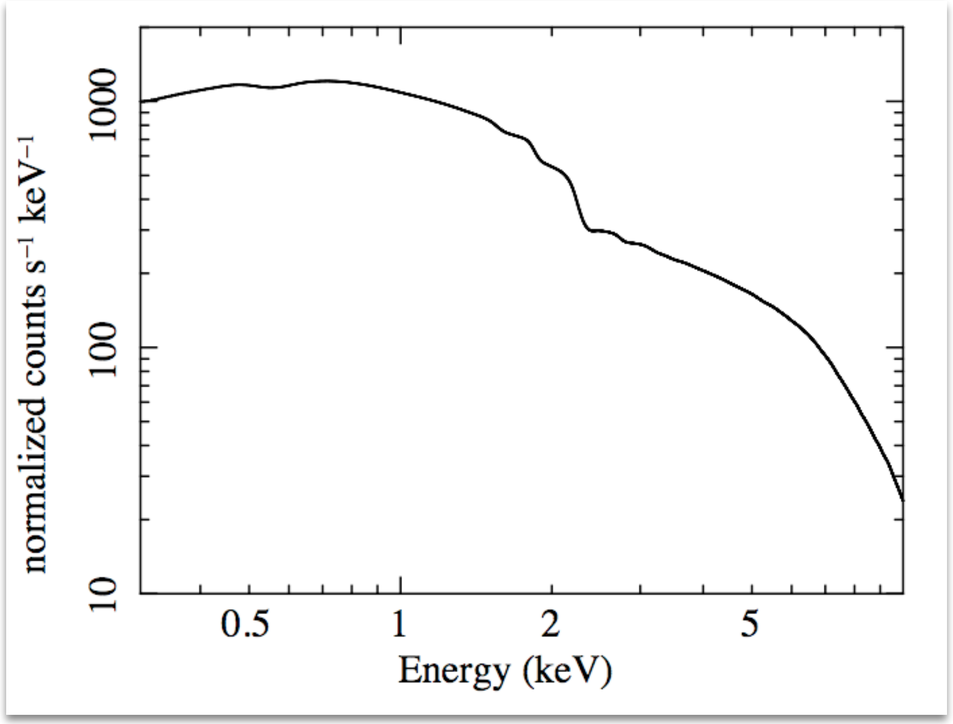


** arfgen: fatal error (NoCifSpecified), `/prod_oasbo/sas/xmmsas_20210317_1624/evt' is neither the name of a directory nor the name of a CIF
>export SAS_CCF='/home/torresi/3C111/evt/ccf.cif'

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 ANCRFILE pn.arf & chkey BACKFILE back_spectrum.fits & group min 25 & exit"
```

GROUPING

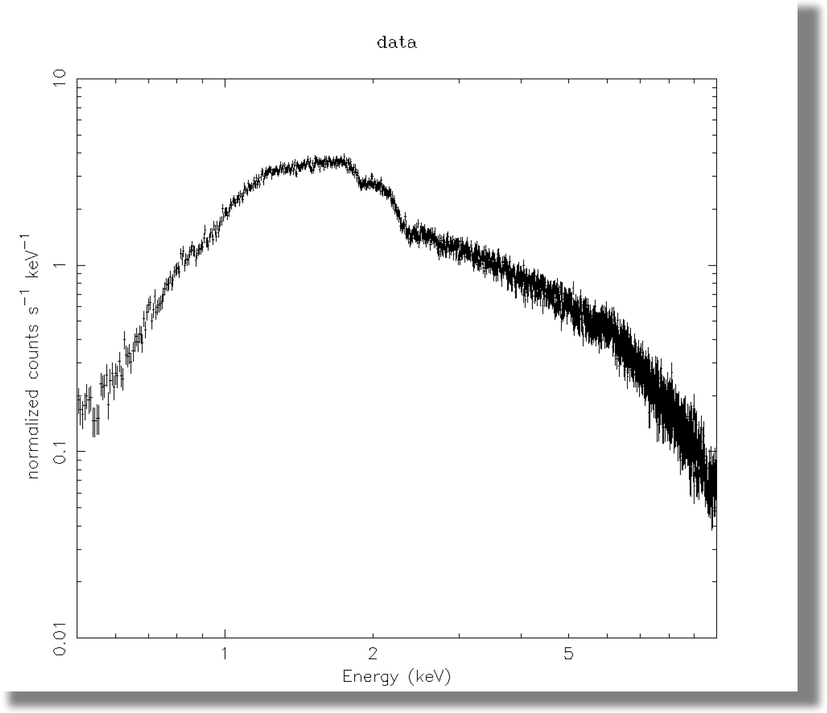
In order to apply the χ^2 statistics (Gaussian distribution) you need to have at least 25 counts in each bin of your spectrum. Otherwise Cash statistics (Poisson distribution) is preferred (see also Statistics Tutorial).

```
grppha source_spectrum.fits pn_25.grp comm="chkey RESPFILE pn.rmf & chkey ANCRFILE pn.arf & chkey BACKFILE back_spectrum.fits & group min 25 & exit"
```

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 ANCRFILE **pn.arf** & chkey BACKFILE **back_spectrum.fits** & **group min 25** & exit"



Xspec

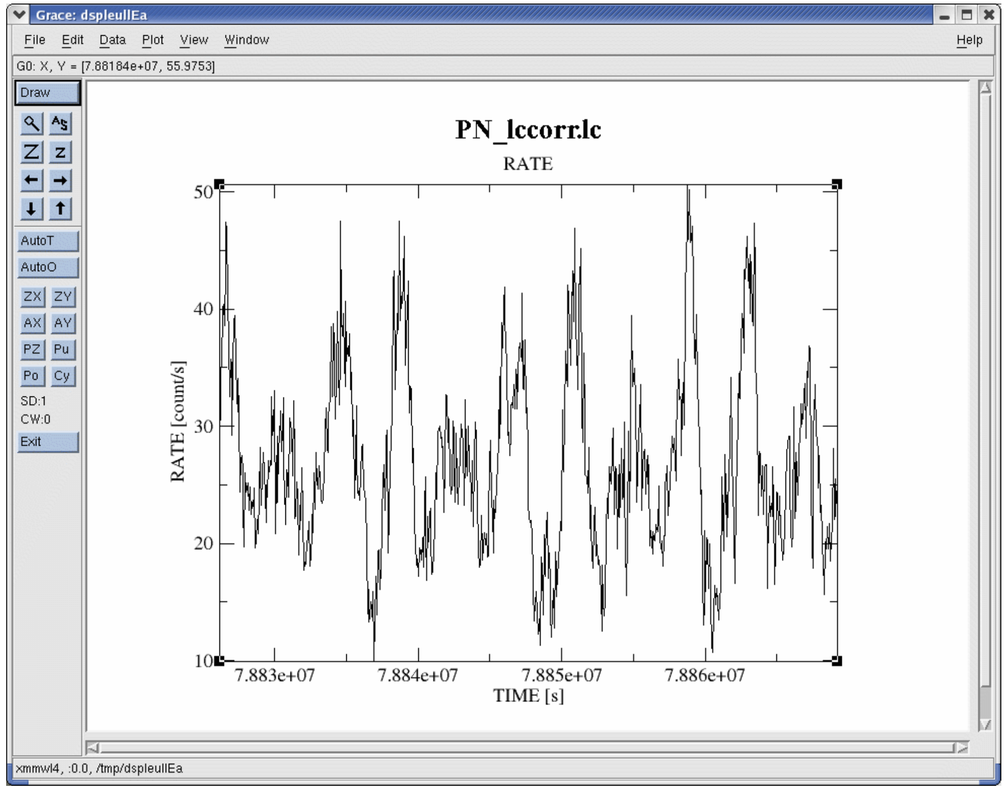
see XSPEC tutorial…

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:

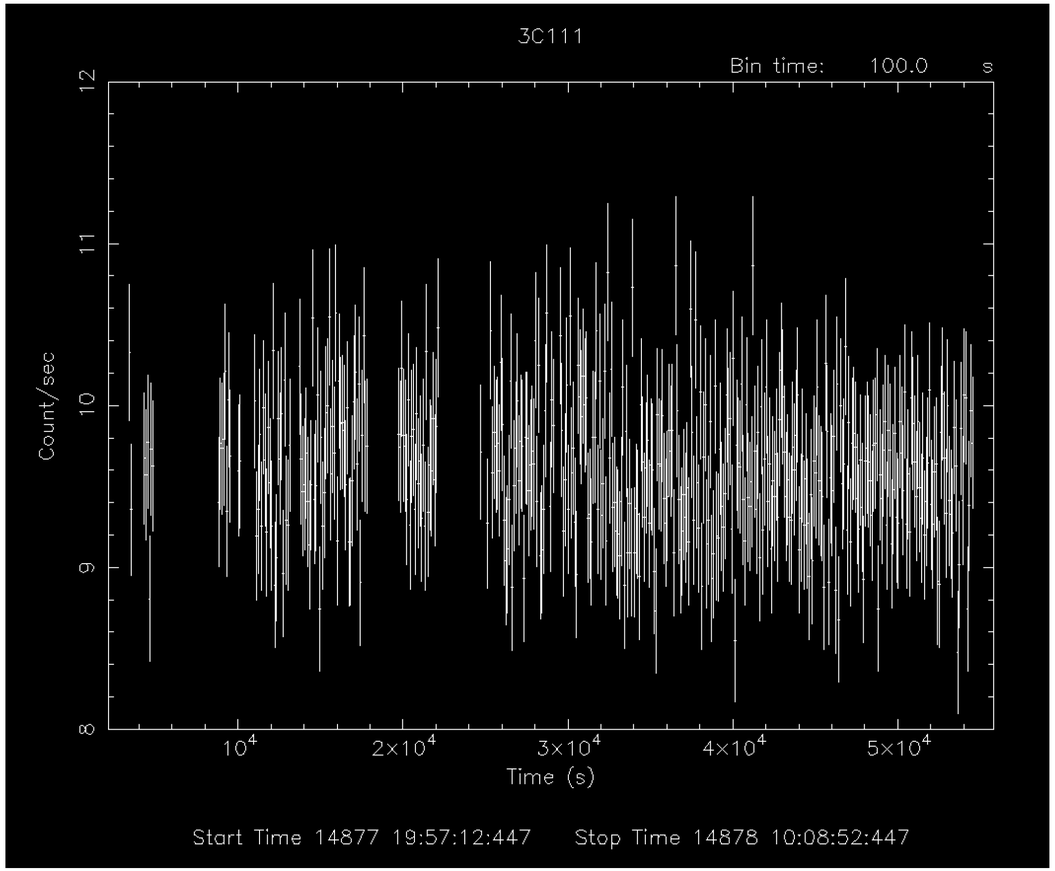
epiclccorr srctslist=**PN_source_lightcurve_raw.lc** eventlist=**pn_new.evt** outset=**PN_lccorr.lc** bkgtslist=**PN_light_curve_background_raw.lc** withbkgset=yes applyabsolutecorrections=yes

MOS1:

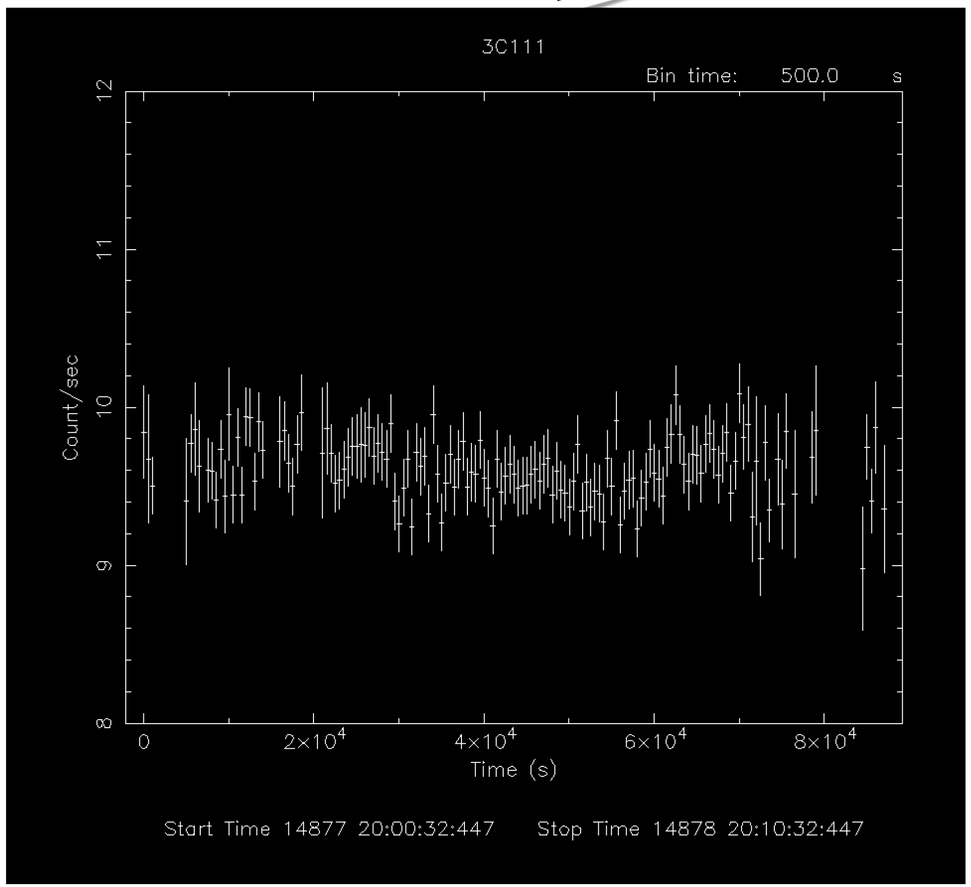
epiclccorr srctslist=**MOS1_source_lightcurve_raw.lc** eventlist=**mos1_new.evt** outset=**MOS1_lccorr.lc** bkgtslist=**MOS1_light_curve_background_raw.lc** withbkgset=yes applyabsolutecorrections=yes

source-background lightcurve: epiclccorr

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

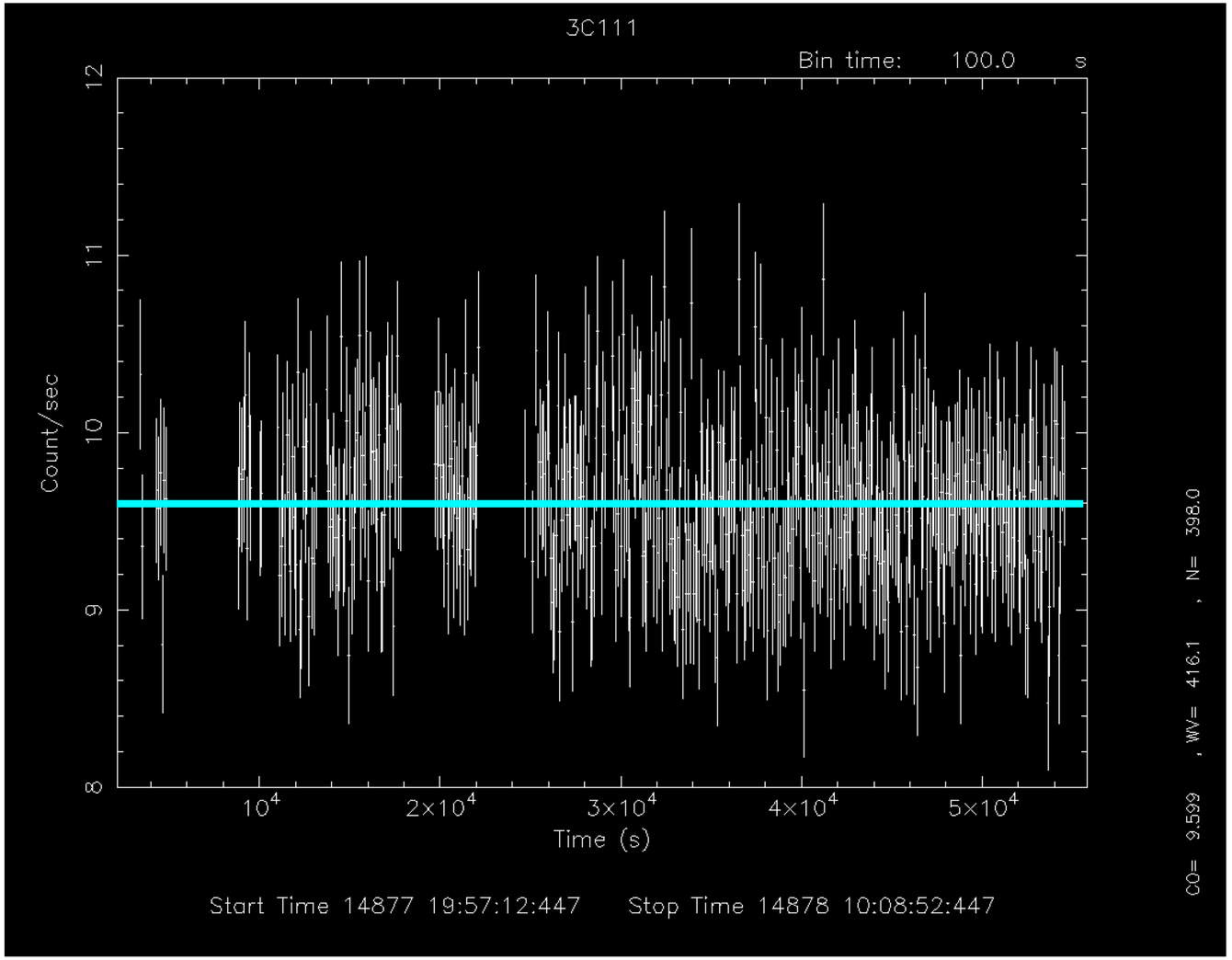


bin=100



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;
<c> average count during the observation;
v=**n-1** degrees of freedom;

```
PLT> mo cons
  1 CO: VAL(  1.000    ), SIG(  0.000    ), PLO(  0.000    ), PHI(  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

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Calculate probability from X^2 and d

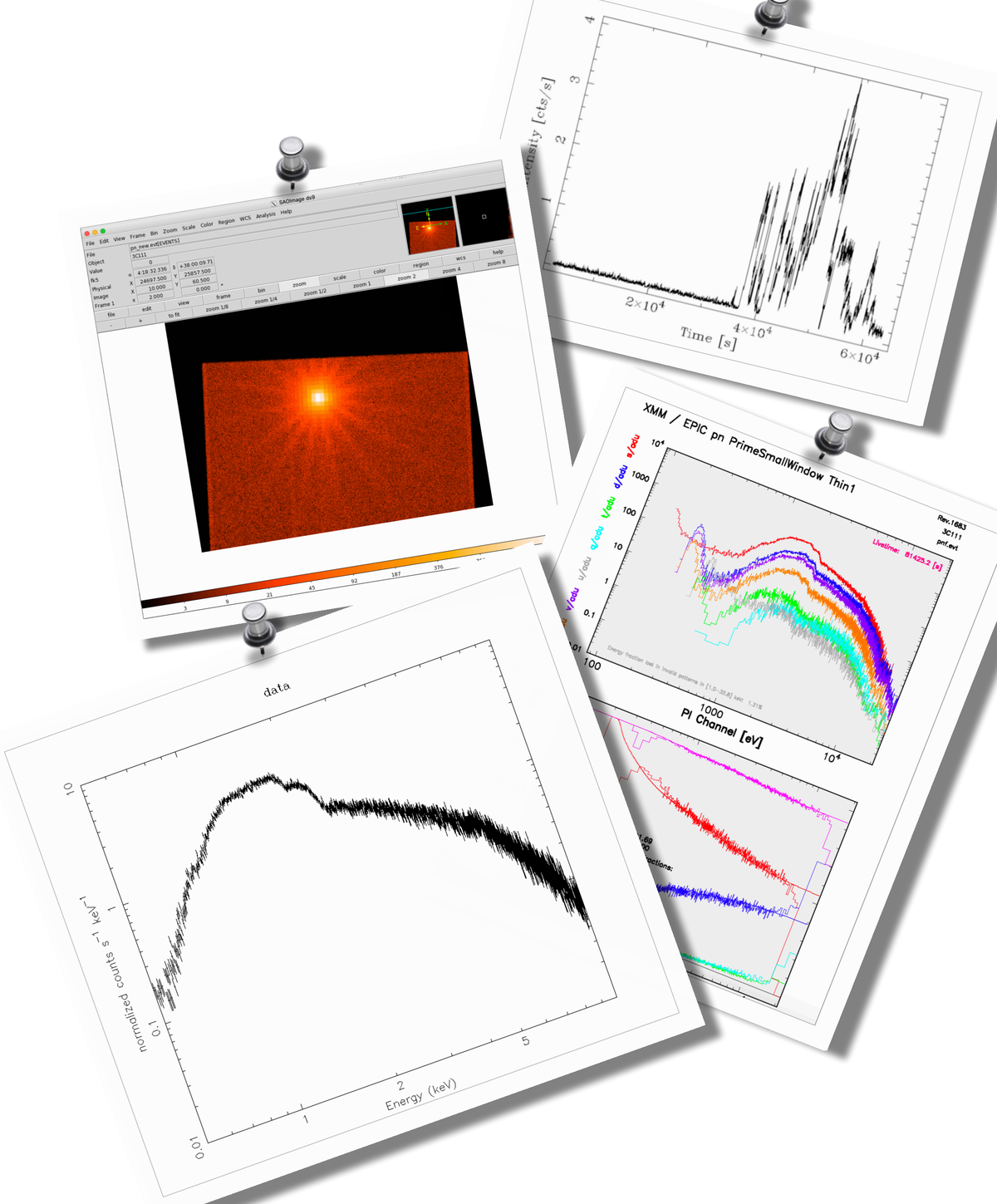
One of the most common chi-square calculations is determining, given the measured X^2 value for a set of experiments with a degree of freedom d, the probability of the result being due to chance. Enter the X^2 and d values in the boxes below, press the **Calculate** button, and the probability will appear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

Given X^2= 416 and d= 397 (398-1)

Calculate

The chance probability, Q, is: 0.2459

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**