

XMM-Newton Data Reduction Tutorial



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Università di Bologna

Slides made by
Eleonora Torresi
(INAF-OAS Bologna)



Outline

- The spacecraft
- Webpage, software and data download
- Data structure

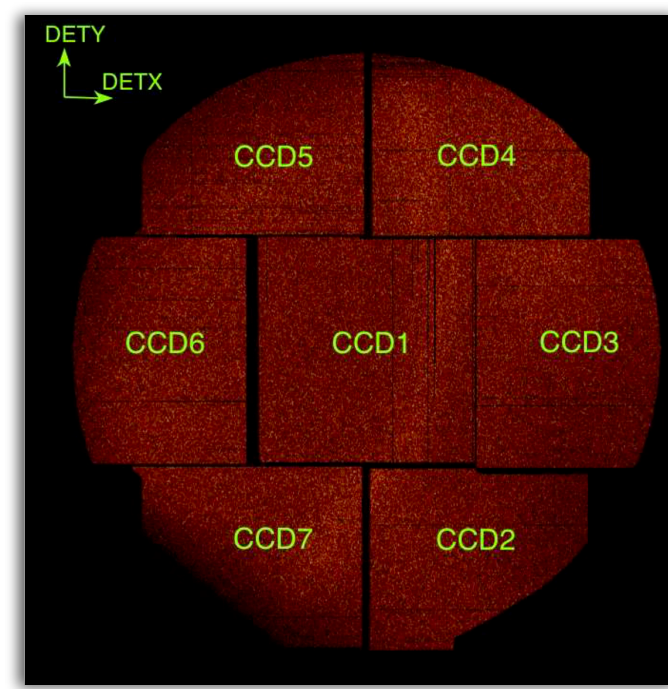
- SAS
- Data re-processing
- Data reduction:
 - > filtering for high particle background
 - > selection of good time intervals (GTI)
 - > selection of source and background extraction regions
- EPIC science modes
- Pileup

- Extraction of source and background spectra
- RMF & ARF
- Grouping

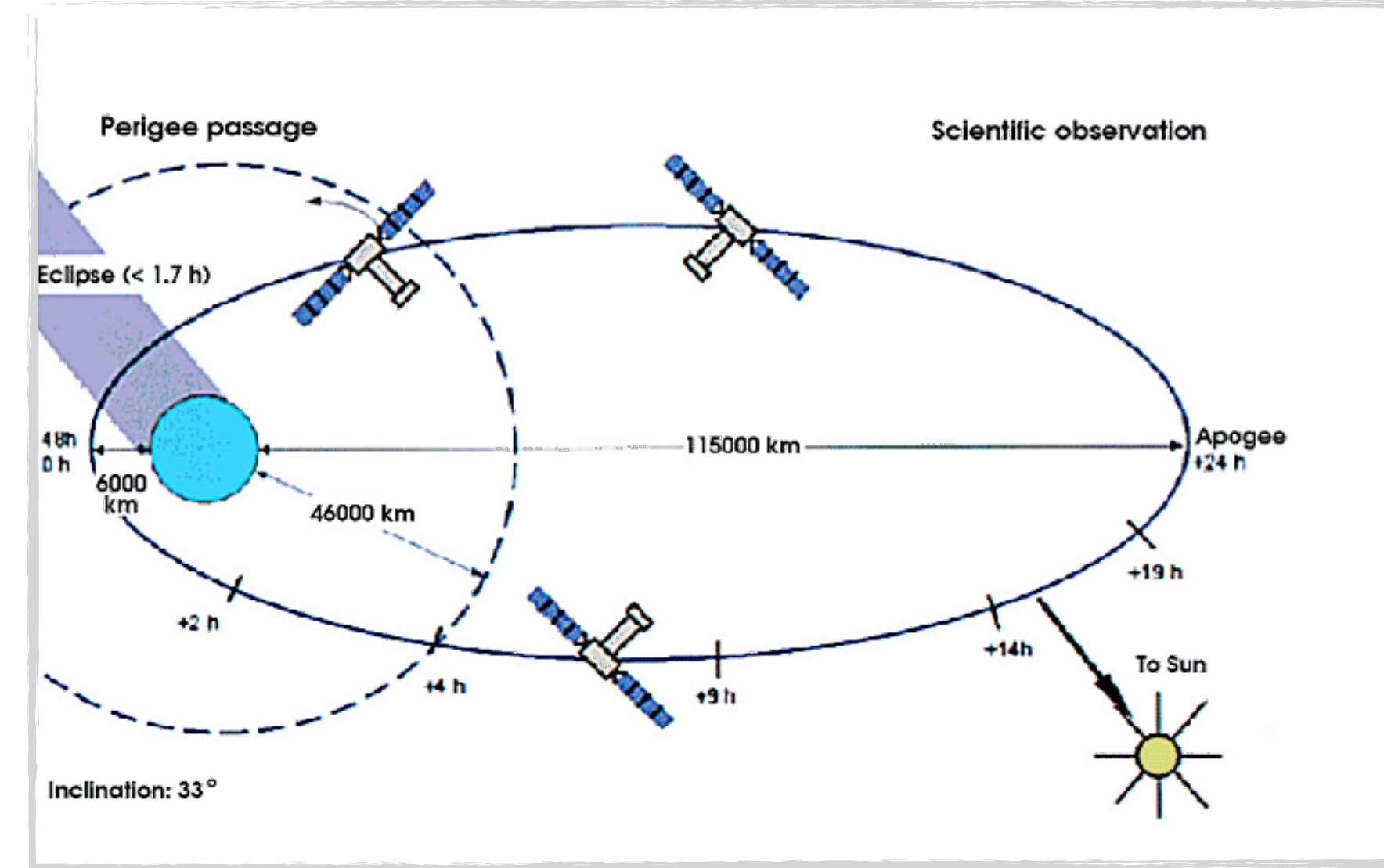
- Light curve extraction



The spacecraft

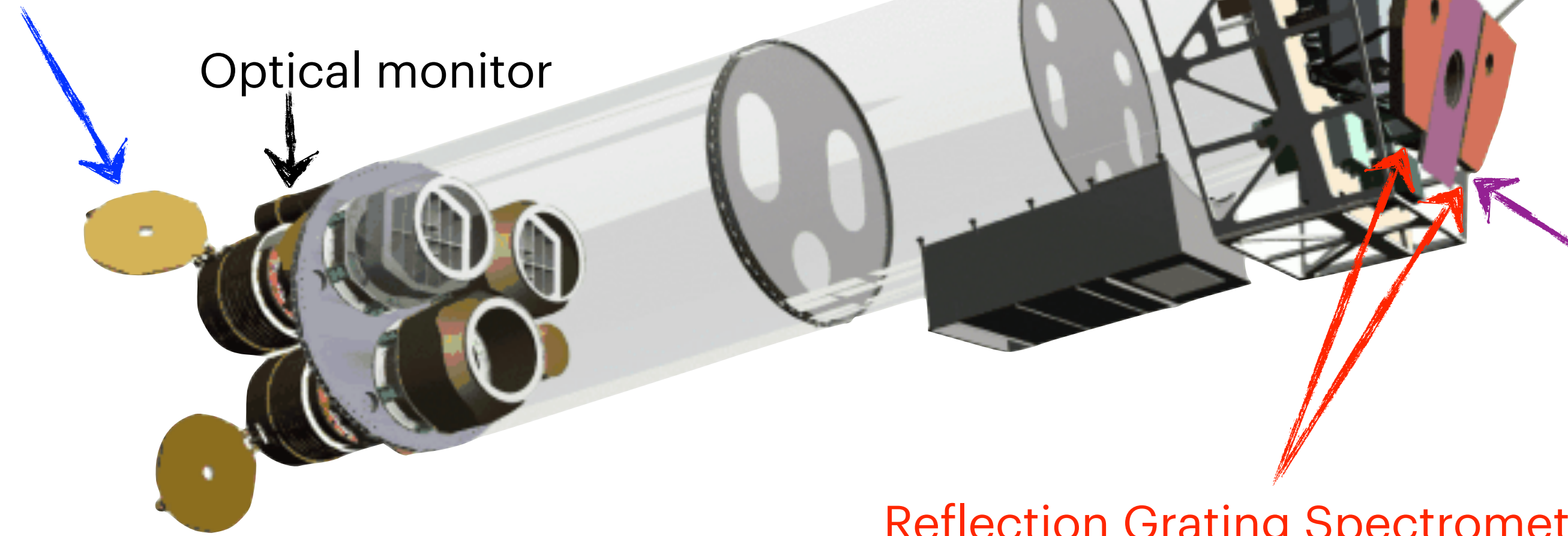


EPIC MOS cameras



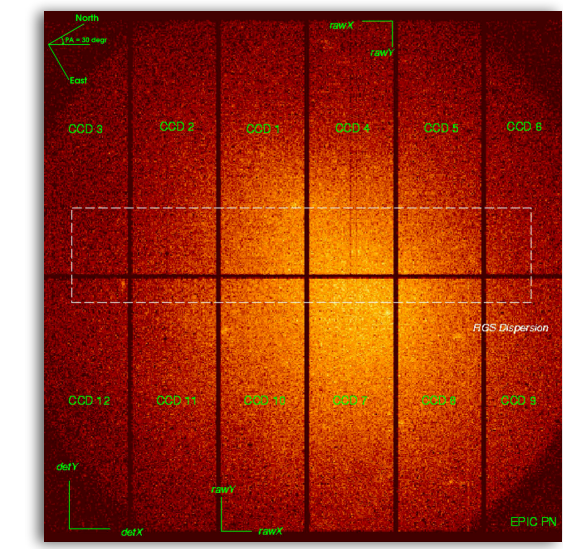
Highly elliptical orbit around the Earth
Inclination 40 degrees to the Equator

X-RAY TELESCOPES



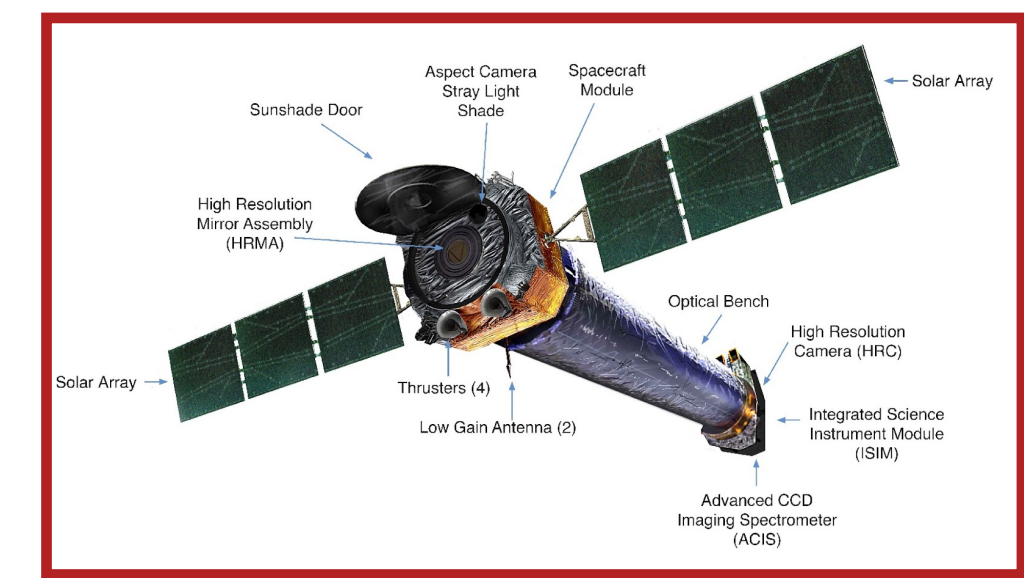
Optical monitor

EPIC PN camera



Reflection Grating Spectrometers (RGS)

All instruments in the focal plane operational for each observation



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

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 SCIENCE 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 Interchange 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

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Name

Equatorial

Galactic

Target in Field Of View Circle Box

Name

3C 33

for Resolve



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Target in Field Of View Circle Box

Name

3C 33

for Resolve



▶ Observation and Proposal filters

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Results #1

OBSERVATIONS (2)

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

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<input checked="" type="checkbox"/>			1					3C33	01h 08m 52.85s	+13d 20' 13.8"	754	0.01	2004-01-21 17:06:11	2004-01-21 19:34:37	8906	RADIO GALAXY RADIO LOUD/STEEP SPECT	HARDCASTLE, MARTIN	GO	

- ODF
- PPS
- IMAGES
- SOURCES
- SPECTRA
- LIGHT_CURVES





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XMM-Newton Science Archive




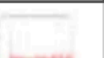










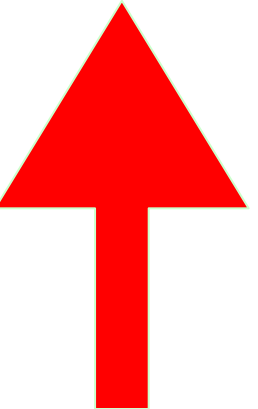
[Back to Search](#) [Close all](#) 

 **Results #1** 

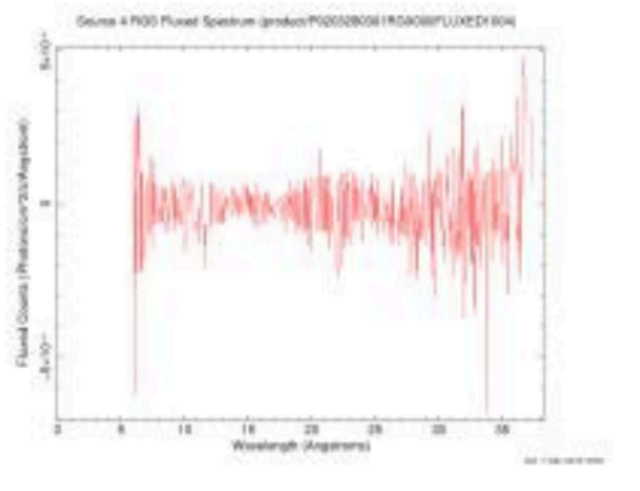
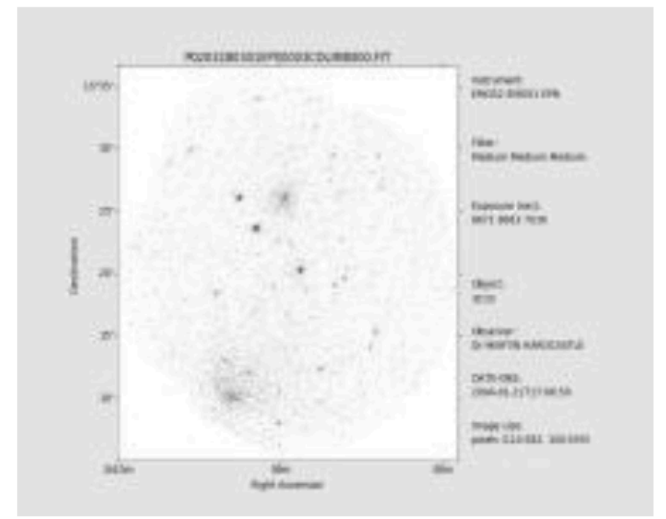
 **OBSERVATIONS (2)** 

[Columns](#)
[Column units](#)
[Display selected](#)
[Add to Basket](#)
[Save table as](#)
[Send table to](#)
[Reprocess](#)
[RGS Spectra](#)

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<input type="checkbox"/>			0203280101					3C33	01h 08m 52.85s	+13d 20' 13.8"	745	0.01	2004-01-04 04:49:31	2004-01-04 08:59:23
<input checked="" type="checkbox"/>			0203280301					3C33	01h 08m 52.85s	+13d 20' 13.8"	754	0.01	2004-01-21 17:06:11	2004-01-21 19:34:37



Details for Observation 0203280301



[Summary](#)
[Science Exposures](#)
[Publications](#)

Obs. ID	0203280301
Revolution	754
Target	3C33
Exposures	3 EPIC, 1 OM, 2 RGS

Proposal Abstract

A SEARCH FOR THE GROUP ENVIRONMENTS OF LOW-POWER FR II RADIO GALAXIES

Although a good deal of indirect evidence points towards moderate or poor groups as the environment of low-luminosity (and therefore typical) FR II radio galaxies, there are almost no direct X-ray observations of the required hot, confining medium. An FR II radio source would have a dramatic effect on the gas in a group, heating and potentially expelling a significant fraction of it, with important consequences for our understanding of group evolution. In order to characterize the X-ray environments of typical FR II sources, we propose a small survey of the nearest few FR II sources of intermediate size drawn from the well-studied 3CRR catalogue. Our observations will allow us to detect, and measure the properties of, group-scale emission around our targets.

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XMM-Newton Science Archive



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Results #1

OBSERVATIONS (2)

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

			Obs.ID	EPIC	RGS	BKGD	ESASky	Target	RA	DEC	Rev	Distance	Start Date	End Date	Dur.	Target Type	PI name	Prop. Program	P
<input type="checkbox"/>			0203280101					3C33	01h 08m 52.85s	+13d 20' 13.8"	745	0.01	2004-01-04 04:49:31	2004-01-04 08:59:23	14992	RADIO GALAXY RADIO LOUD/STEEP SPECT	HARDCASTLE, MARTIN	GO	
<input checked="" type="checkbox"/>			0203280301					3C33	01h 08m 52.85s	+13d 20' 13.8"	754	0.01	2004-01-21 17:06:11	2004-01-21 19:34:37	8906	RADIO GALAXY RADIO LOUD/STEEP SPECT	HARDCASTLE, MARTIN	GO	

- ODF
- PPS
- IMAGES
- SOURCES
- SPECTRA
- LIGHT_CURVES

odf= observation data files => raw data

0203280301.tar.gz

Data structure

example: 0203280301.tar.gz -> tar -zxvf 0203280301.tar.gz

-z= unzip
-xvf=untar

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ODF files

MOS1
MOS2

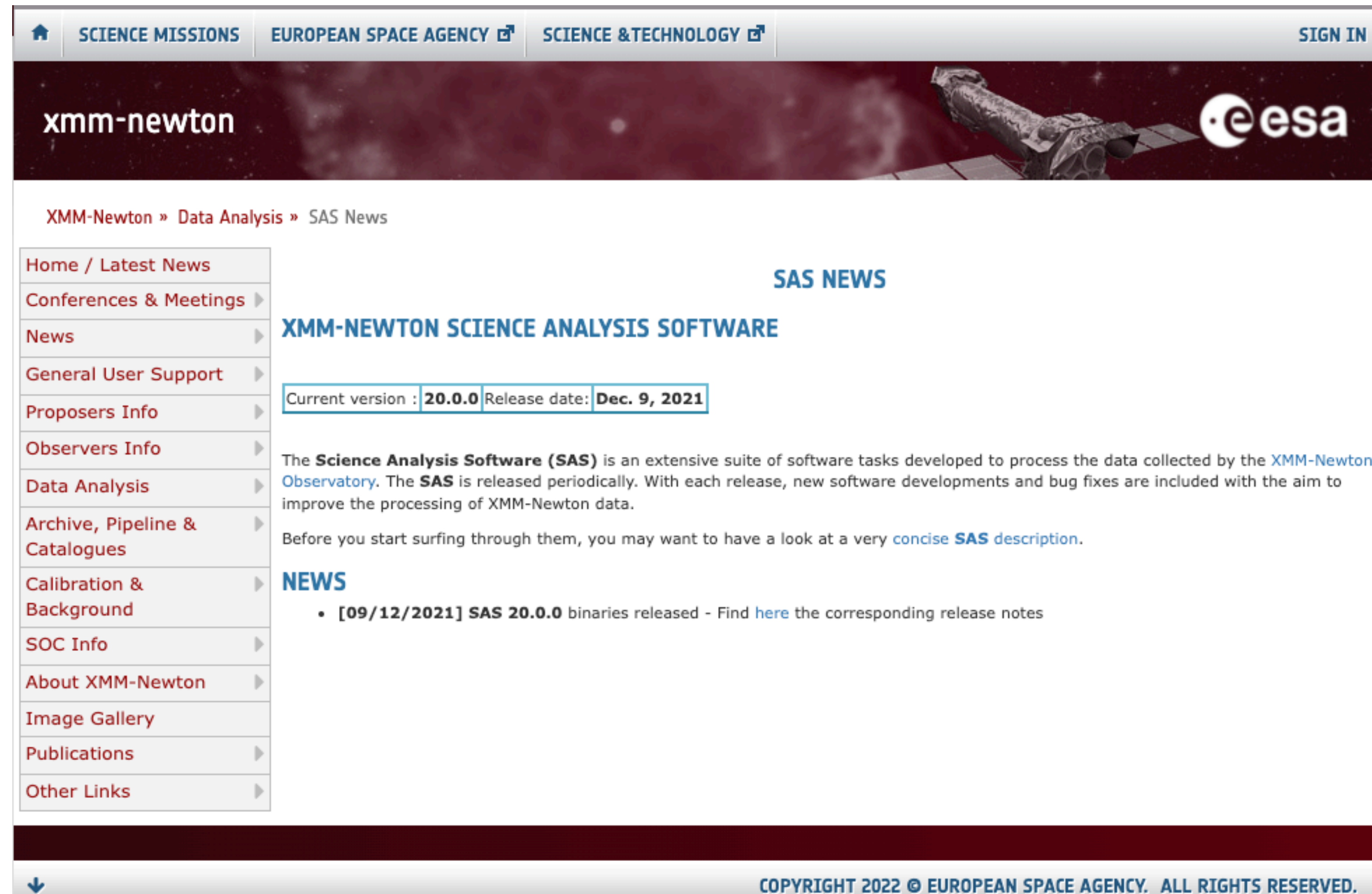
OM

pn

RGS1

RGS2

Standard Analysis System (SAS)



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XMM-Newton » Data Analysis » SAS News

SAS NEWS

XMM-NEWTON SCIENCE ANALYSIS SOFTWARE

Current version : **20.0.0** Release date: **Dec. 9, 2021**

The **Science Analysis Software (SAS)** is an extensive suite of software tasks developed to process the data collected by the **XMM-Newton Observatory**. The **SAS** is released periodically. With each release, new software developments and bug fixes are included with the aim to improve the processing of XMM-Newton data.

Before you start surfing through them, you may want to have a look at a very [concise SAS description](#).

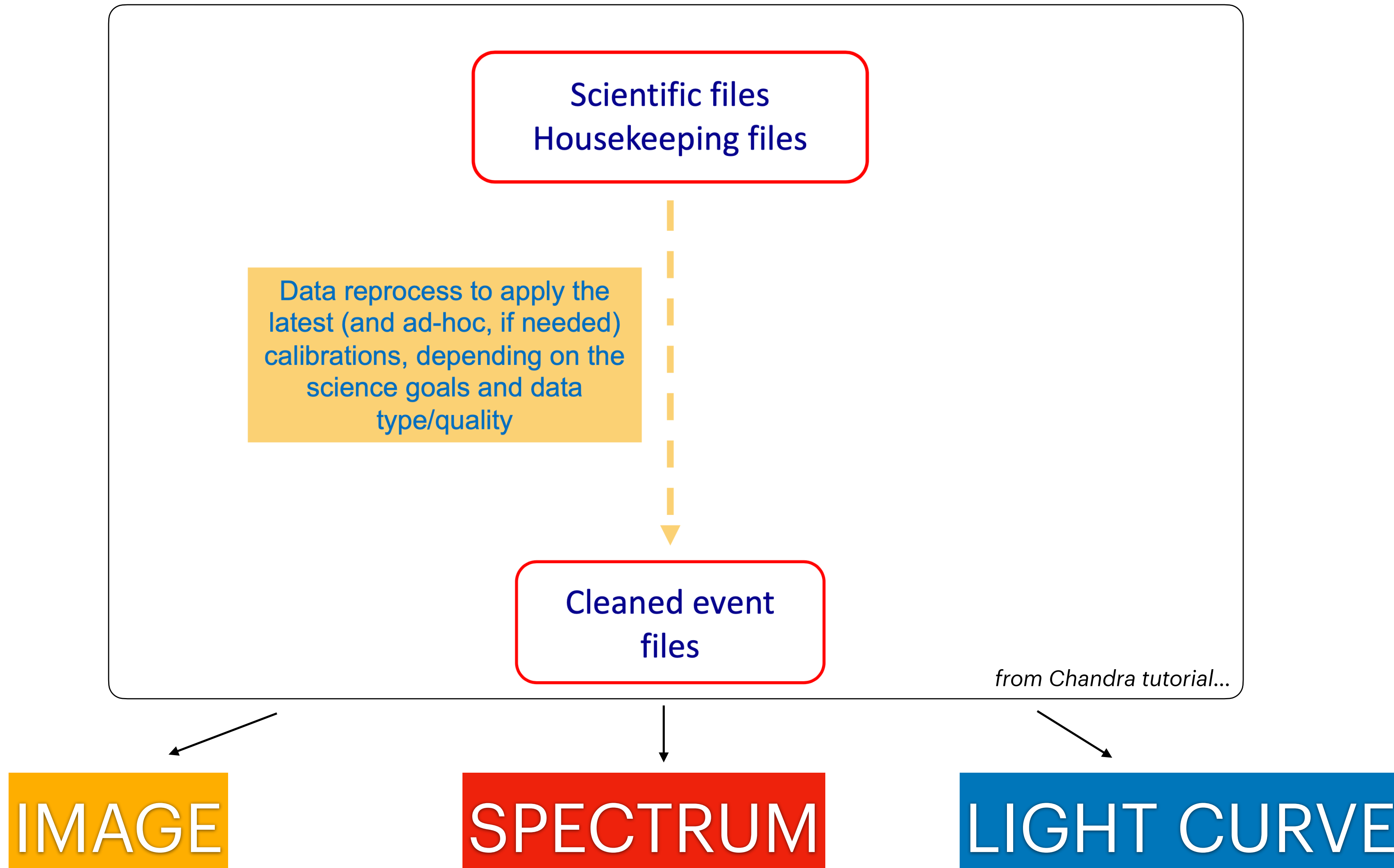
NEWS

- **[09/12/2021] SAS 20.0.0** binaries released - Find [here](#) the corresponding release notes

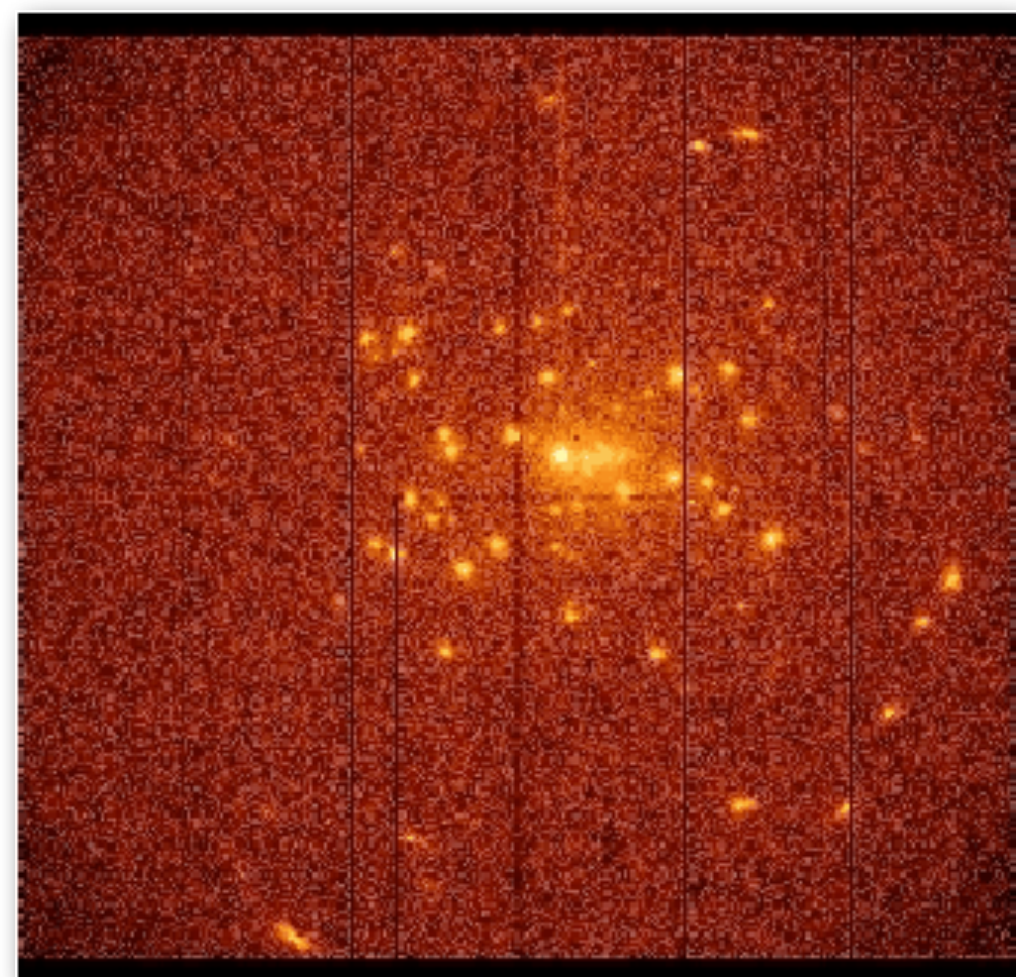
↓ COPYRIGHT 2022 © EUROPEAN SPACE AGENCY. ALL RIGHTS RESERVED.

Data reduction

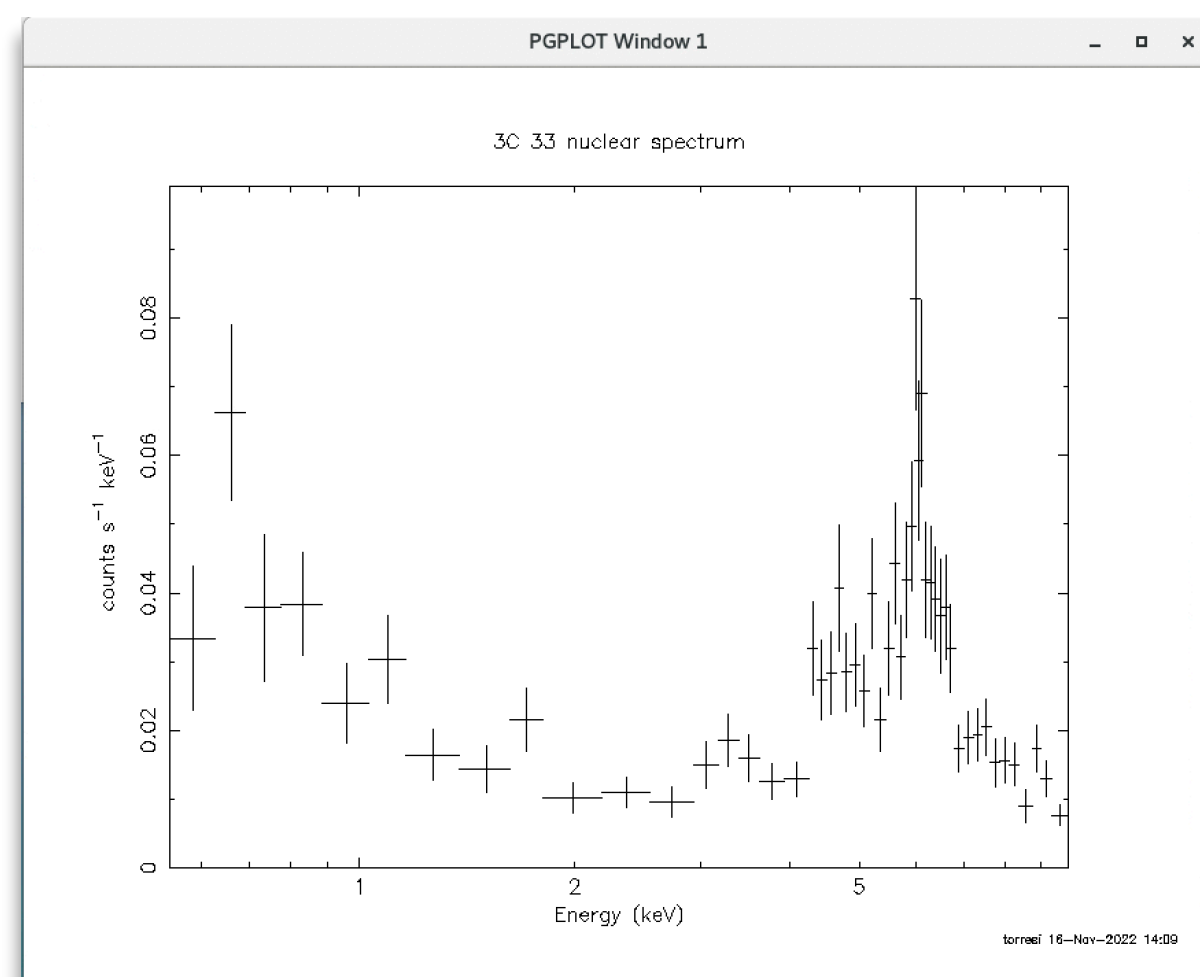
SAS threads



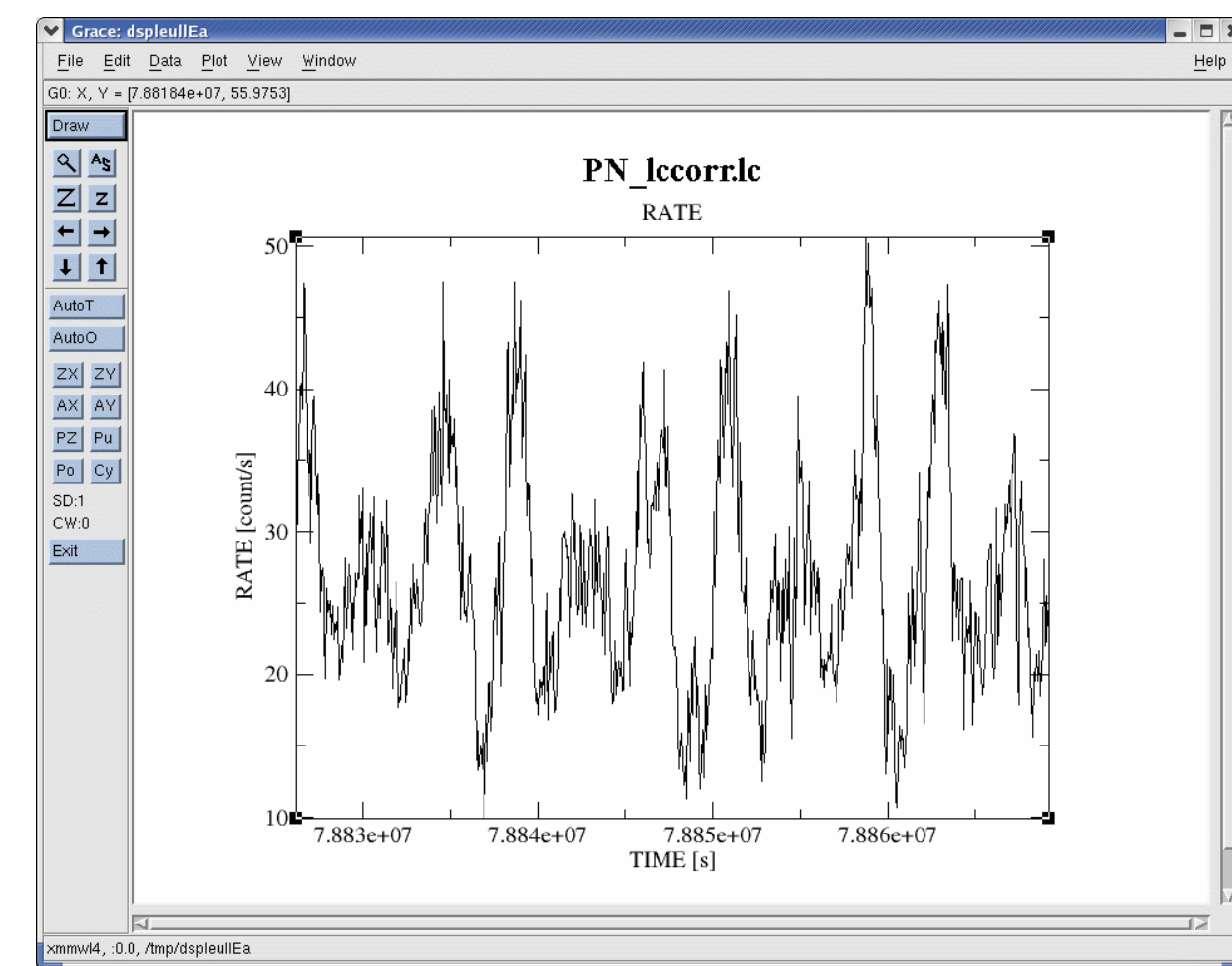
IMAGE



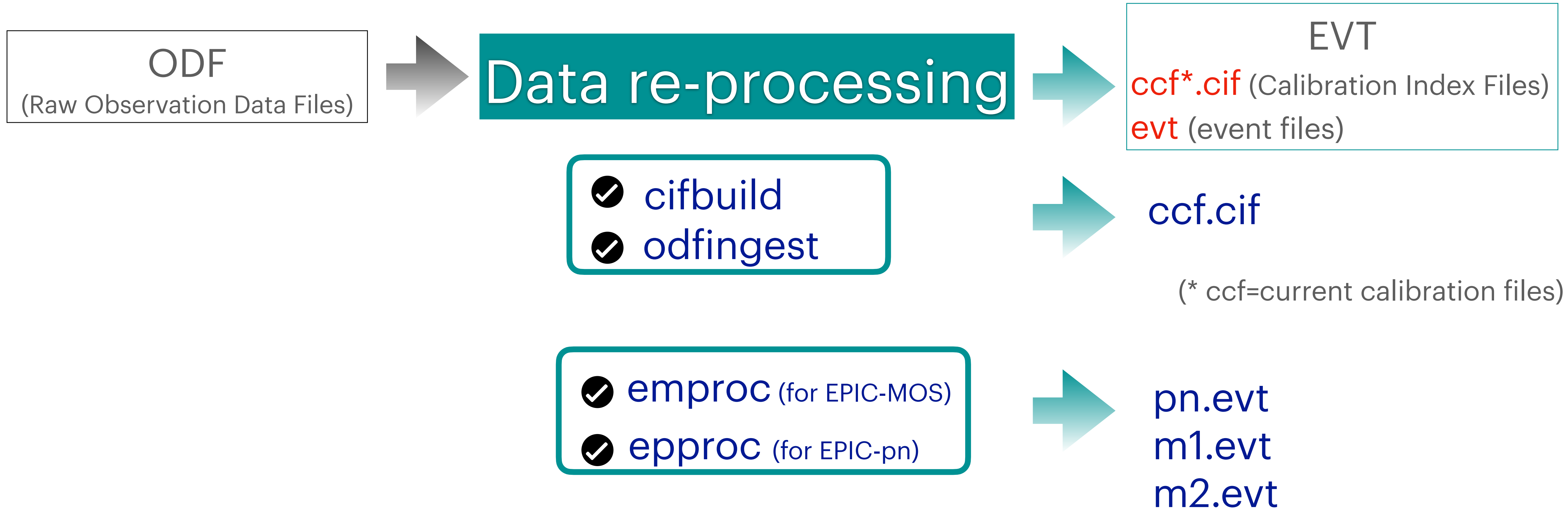
SPECTRUM



LIGHT CURVE



Data re-processing (= creation of **event files**)



fv pn.evt

#rows=#counts

Index	Extension	Type	Dimension	View								
0	Primary	Image	0	Header	Image	Table						
1	EVENTS	Binary	15 cols X 131297 rows	Header	Hist	Plot	All	Select				
2	OFFSETS	Binary	3 cols X 14 rows	Header	Hist	Plot	All	Select				
3	EXPOSU01	Binary	2 cols X 95904 rows	Header	Hist	Plot	All	Select				
4	BADPIX01	Binary	5 cols X 72 rows	Header	Hist	Plot	All	Select				
5	DLIMAP01	Binary	3 cols X 200 rows	Header	Hist	Plot	All	Select				
6	HKAUX01	Binary	2 cols X 4789 rows	Header	Hist	Plot	All	Select				
7	EXPOSU02	Binary	2 cols X 95901 rows	Header	Hist	Plot	All	Select				
8	BADPIX02	Binary	5 cols X 68 rows	Header	Hist	Plot	All	Select				
9	DLIMAP02	Binary	3 cols X 200 rows	Header	Hist	Plot	All	Select				

X,Y -> image
 Time -> light curve
 PHA, PI -> spectrum

fv pn.evt

fv: Binary Table of pn.evt[1] in /blasco/users/torresi/LAB-X/Fall_2022/3C33_LABX/pn/

File Edit Tools Help

Select	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	
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Invert	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	1.910934147154E+08	23	24	-4118	13485	18376	16096	24	211	0	1	5121	0	1	1.910934146937E+08
2	1.910934172390E+08	41	84	-5619	8551	18939	21222	158	835	0	0	0	0	1	1.910934172615E+08
3	1.910934173916E+08	7	47	-2815	11608	20313	17308	21	209	0	4	5121	0	1	1.910934174082E+08
4	1.910934174143E+08	13	47	-3294	11601	19875	17503	33	279	0	2	5122	0	1	1.910934174082E+08
5	1.910934173875E+08	58	64	-7048	10182	16984	20286	2635	13720	0	0	0	0	1	1.910934174082E+08
6	1.910934184187E+08	14	119	-3355	5690	22147	22960	111	585	0	0	0	0	1	1.910934184353E+08
7	1.910934196784E+08	34	125	-5034	5146	20818	24122	2918	24348	0	2	5121	0	1	1.910934196825E+08
8	1.910934197620E+08	45	14	-5919	14325	16389	16033	30	400	1	78	1	1	1	1.910934197559E+08
9	1.910934199950E+08	10	115	-3048	6034	22294	22523	30	158	0	0	0	0	1	1.910934199760E+08
10	1.910934209479E+08	64	146	-7536	3436	19192	26679	377	2097	4	0	0	0	1	1.910934209297E+08
11	1.910934212498E+08	11	42	-3096	11994	19902	17064	965	4788	0	0	0	0	1	1.910934212232E+08
12	1.910934246840E+08	39	13	-5436	14441	16788	15736	39	192	32	0	0	0	1	1.910934246713E+08
13	1.910934246531E+08	39	17	-5405	14090	16954	16047	31	692	1	96	1	1	1	1.910934246713E+08
14	1.910934253051E+08	4	111	-2520	6289	22679	22081	31	160	0	0	0	0	1	1.910934253316E+08
15	1.910934259405E+08	19	173	-3791	1226	23505	27235	40	297	8	0	0	0	1	1.910934259185E+08
16	1.910934283720E+08	11	122	-3167	5397	22436	23155	255	1330	0	0	0	0	1	1.910934283396E+08
17	1.910934289507E+08	49	146	-6305	3404	20336	26223	2870	15263	0	0	0	0	1	1.910934289265E+08
18	1.910934291953E+08	6	138	-2736	4076	23352	24200	866	6695	0	1	5121	0	1	1.910934292200E+08
19	1.910934303410E+08	10	161	-3039	2187	23818	26056	28	155	0	0	0	0	1	1.910934303205E+08
20	1.910934320374E+08	23	146	-4097	3414	22362	25344	42	225	0	0	0	0	1	1.910934320078E+08
21	1.910934323060E+08	43	175	-5762	1046	21764	28177	2745	19547	0	7	5121	1	1	1.910934323013E+08
22	1.910934341115E+08	4	16	-2581	14133	19533	14895	26	232	0	3	5121	1	1	1.910934341354E+08
23	1.910934341378E+08	4	21	-2555	13784	19695	15205	34	160	0	0	0	5	1	1.910934341354E+08
24	1.910934362451E+08	61	13	-7263	14438	15110	16459	159	1076	1	2	1	0	1	1.910934362630E+08
25	1.910934363497E+08	54	140	-6705	3949	19754	25880	62	343	0	0	0	0	1	1.910934363364E+08
26	1.910934365385E+08	43	184	-5761	328	22048	28836	27	158	0	0	0	0	1	1.910934365565E+08

Go to: Edit cell:

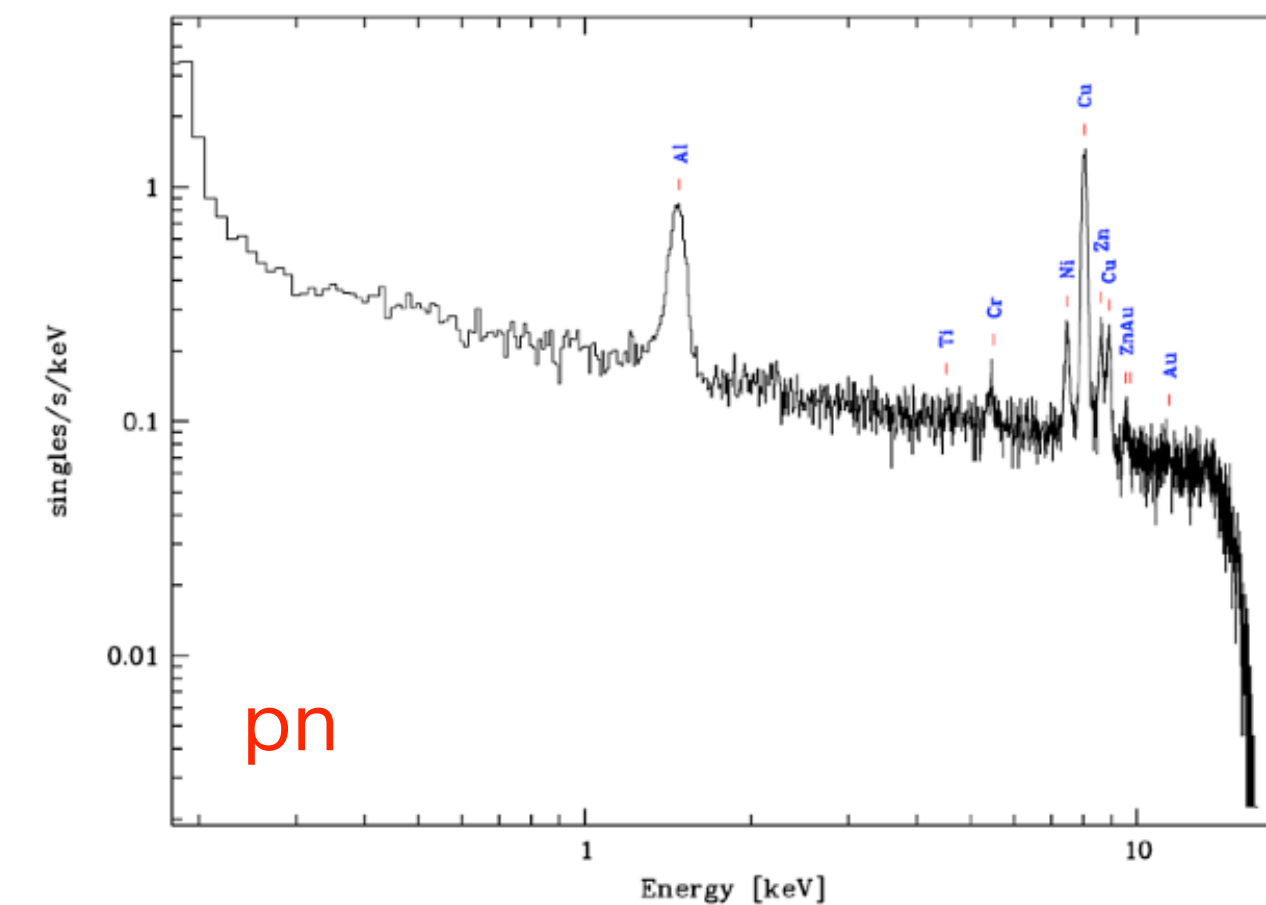
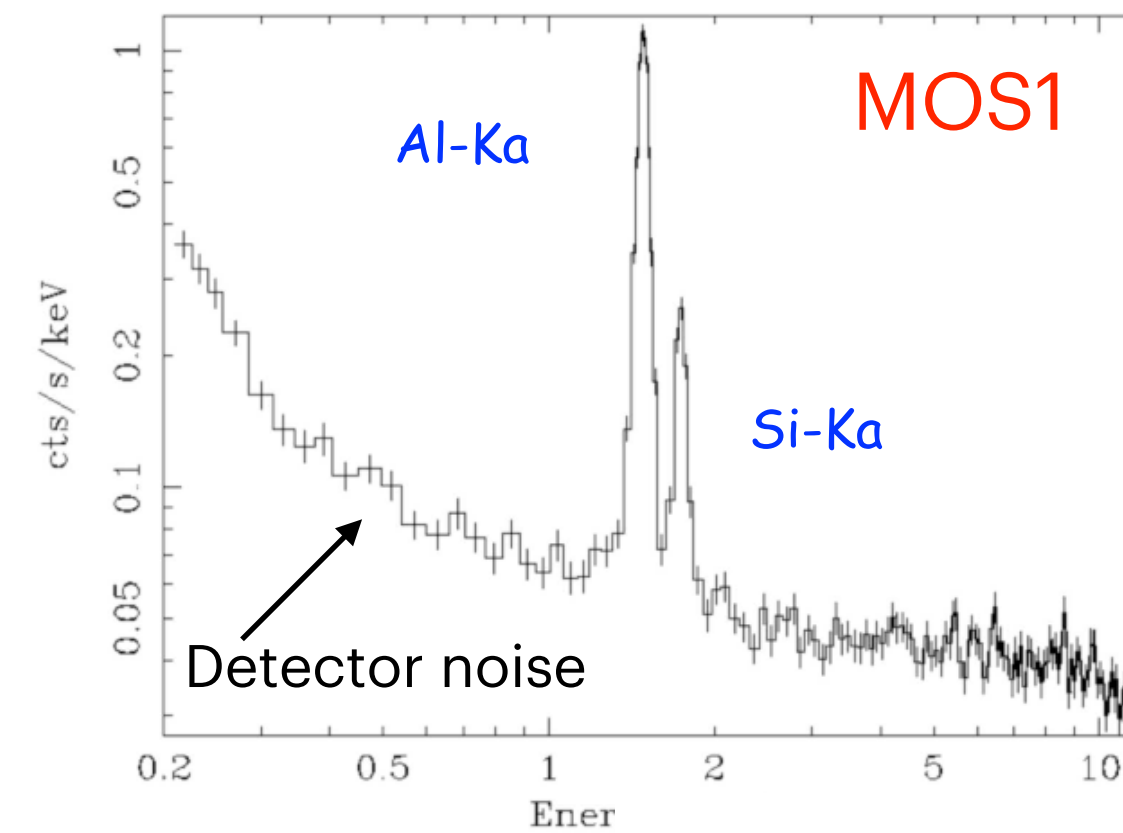
Filtering against high background periods

EPIC particle induced background

(above a few keV)

Internal '*quiescent*' component

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



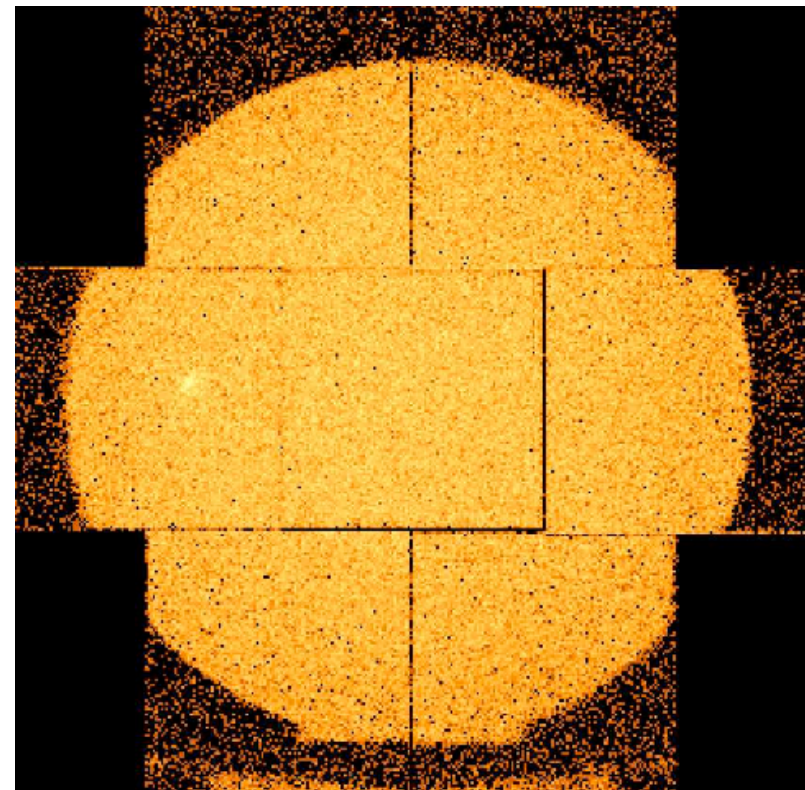
Filtering against high background periods

EPIC particle induced background

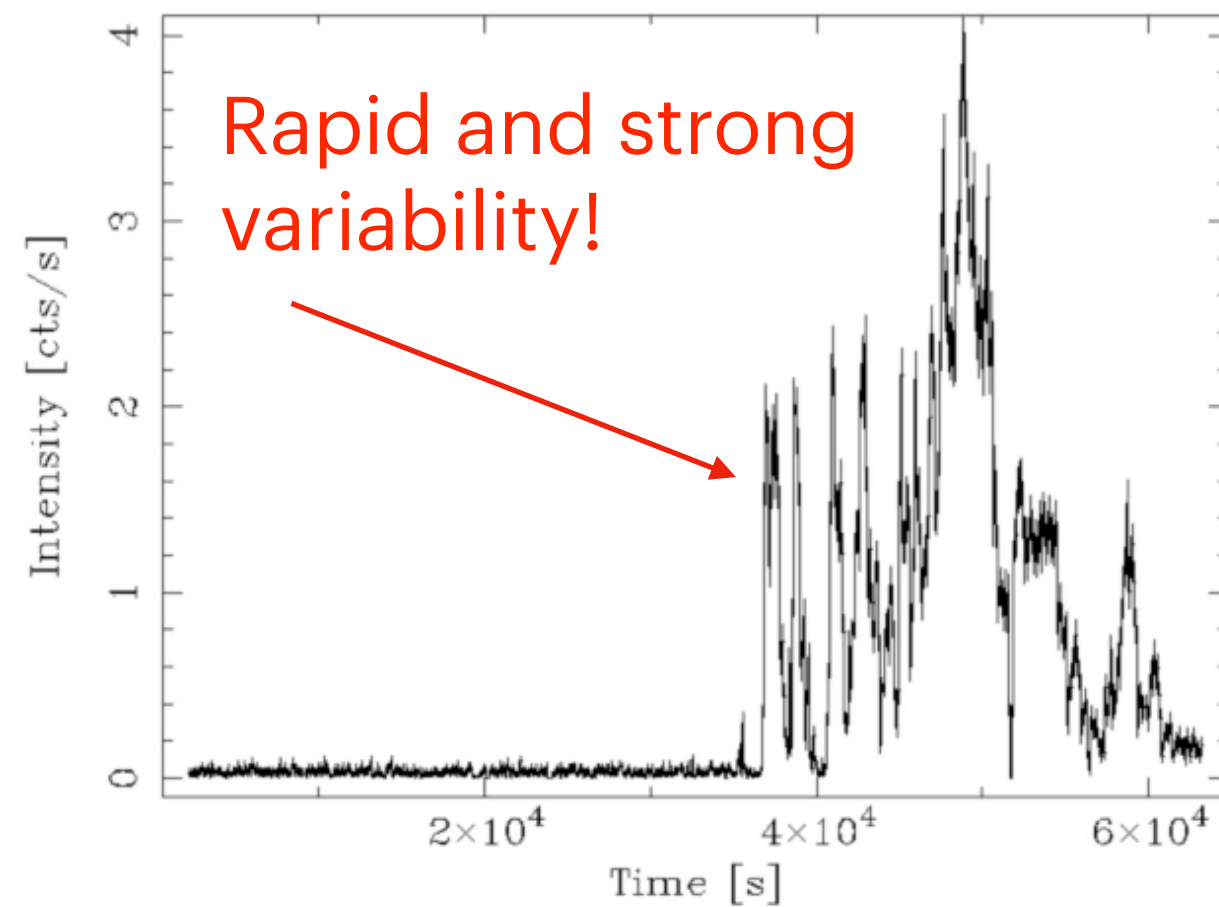
(above a few keV)

External '*flaring*' component

strong and rapid variability; currently attributed to **soft protons** ($E_p < \text{a few } 100 \text{ keV}$) likely organized in clouds populating the Earth's magnetosphere (above a few keV)



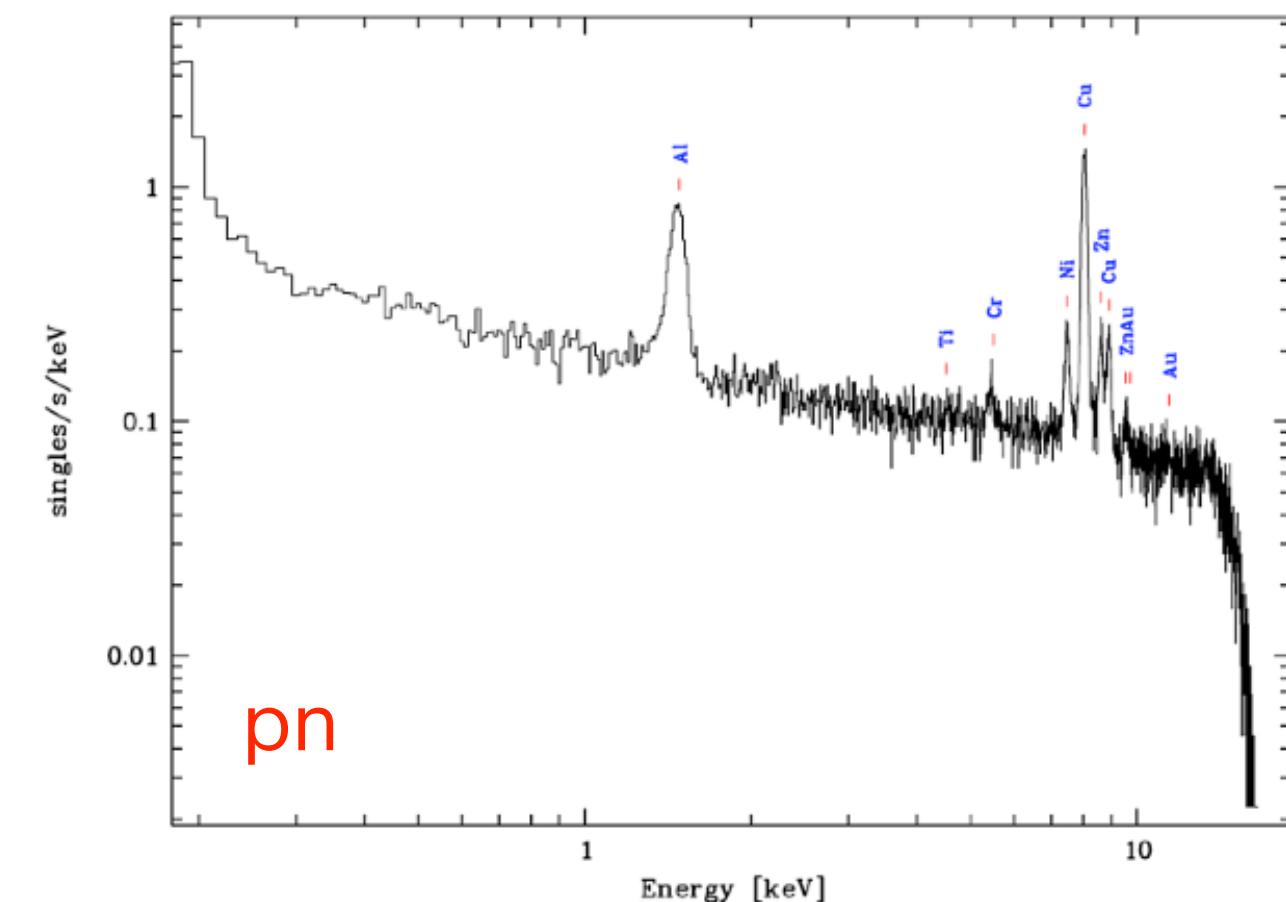
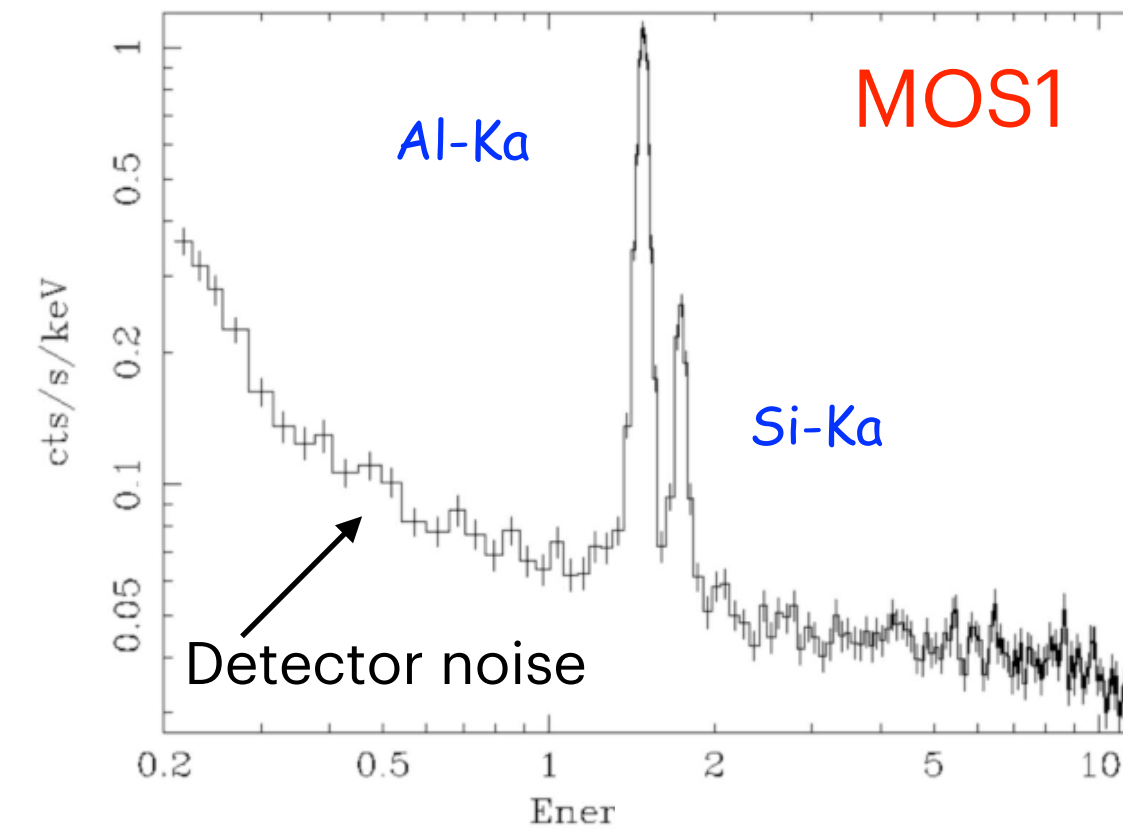
MOS2 observation
badly affected by soft proton
flares



MOS1 light curve
badly affected by soft proton flares

Internal '*quiescent*' component

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



Creation of a light curve above 10 keV

How to filter an EPIC event list for periods of high background *flaring* activity

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_** && (PI>10000&&PI<12000) && (PATTERN==0)'  
withrateset=yes rateset="lcurve_sup10.lc" timebinsize=100 maketimecolumn=yes makeratecolumn=yes
```

maketimecolumn=If true, include a time column in the FITS table when creating a time series;

makeratecolumn=If true, produces a lightcurve containing a RATE, rather than a COUNTS column. An ERROR column is also produced.

Notice that the EPIC-pn energy range selected for producing the background light curve includes events only up to 12 keV. The reason for this is to avoid hot pixels being misidentified as very high energy events.

Creation of a light curve above 10 keV

How to filter an EPIC event list for periods of high background *flaring* activity

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
```

What are event patterns?

Event selection is performed on-board to allow the transmission of useful data only. Certain X-ray events are not valid because they are empty pixels, while others are expected to be split between pixels.

The SAS software allows these data to be reconstructed to a single value in the event list.

Table 7: List of EPIC event patterns

Camera	Mode	X-ray generated pattern					no X-ray ¹
		singles	doubles	triples	quadruples	higher	
MOS	imaging	0	1-4	5-8	9-12	13-25	26-31 ²
	timing	0	1				2,3
pn	imaging	0	1-4	5-8	9-12		> 12
	timing	0	1-4			5-12	> 12

Calibrated patterns

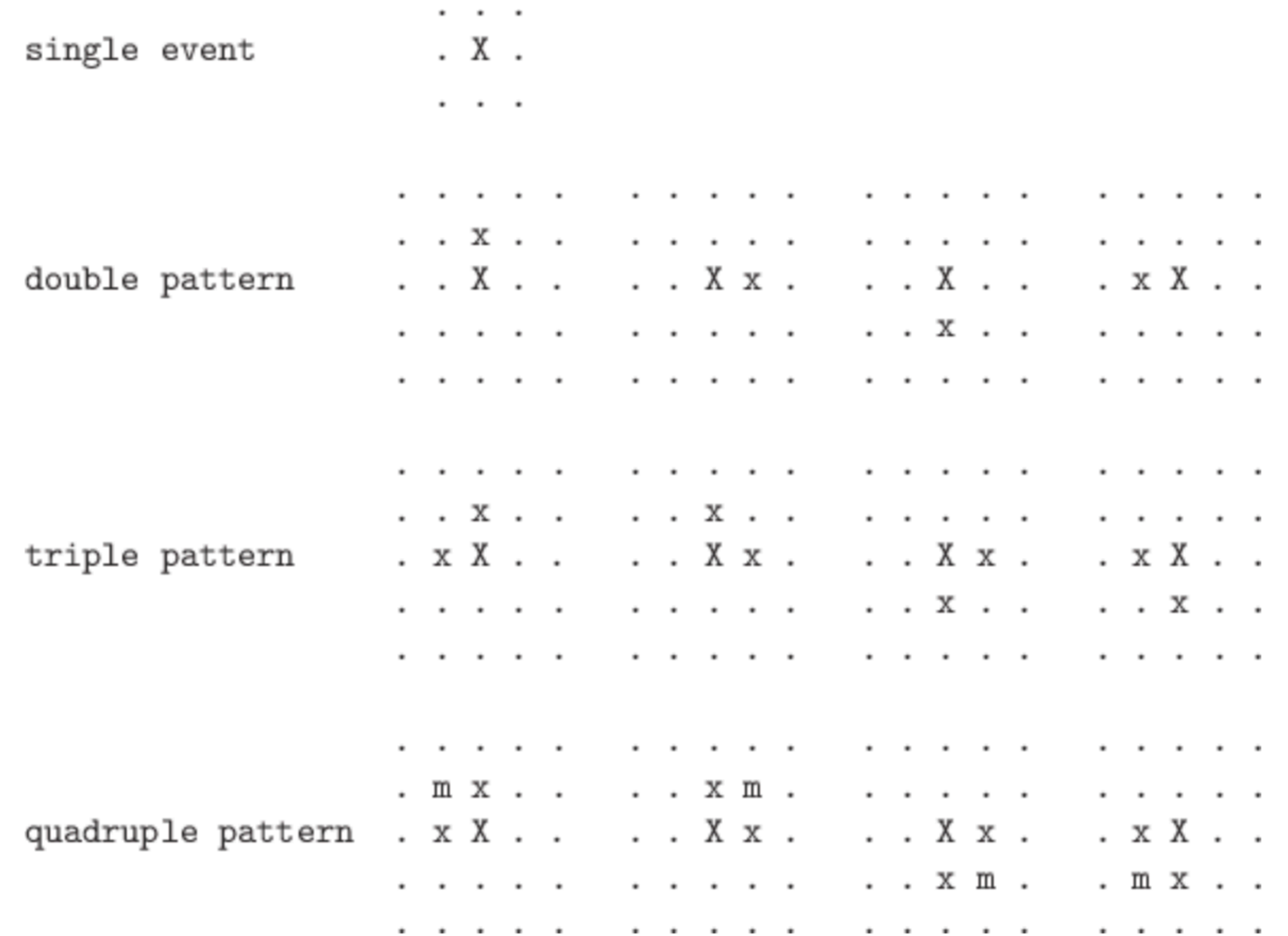


Figure 13: List of valid EPIC-pn patterns (cf. figure 12). Here "." marks a pixel without an event above threshold, "X" is the pixel with the maximum charge ("main pixel"), "x" is the pixel with a non-maximum charge, "m" is the pixel with the minimum charge. These 13 figures refer to the SAS PATTERN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

To visualize the produced lightcurve



[gruppo03@login06]pn>lcurve

lcurve 1.0 (xronos6.0)

Number of time series for this task[1]

Ser. 1 filename +options (or @file of filenames +options)[PN_lccorr.lc] lcurve_sup10.lc

Series 1 file 1:lcurve_sup10.lc

Selected FITS extensions: 1 - RATE TABLE;

Source Start Time (d) 14877 19:43:02.447

FITS Extension 1 - `RATE ` Stop Time (d) 14879 04:01:06.166

No. of Rows 1163 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 ... 14877.82155610235 (days) 19:43: 2:447 (h:m:s:ms)

Expected Stop 14879.16743247951 (days) 4: 1: 6:166 (h:m:s:ms)

Minimum Newbin Time 100.00000 (s)

for Maximum Newbin No.. 1163

Default Newbin Time is: 227.38310 (s) (to have 1 Intv. of 512 Newbins)

Type INDEF to accept the default value

Newbin Time or negative rebinning[100]

Newbin Time 100.00000 (s)

Maximum Newbin No. 1163

Default Newbins per Interval are: 512

(giving 3 Intervals of 512 Newbins each)

Type INDEF to accept the default value

Number of Newbins/Interval[512]

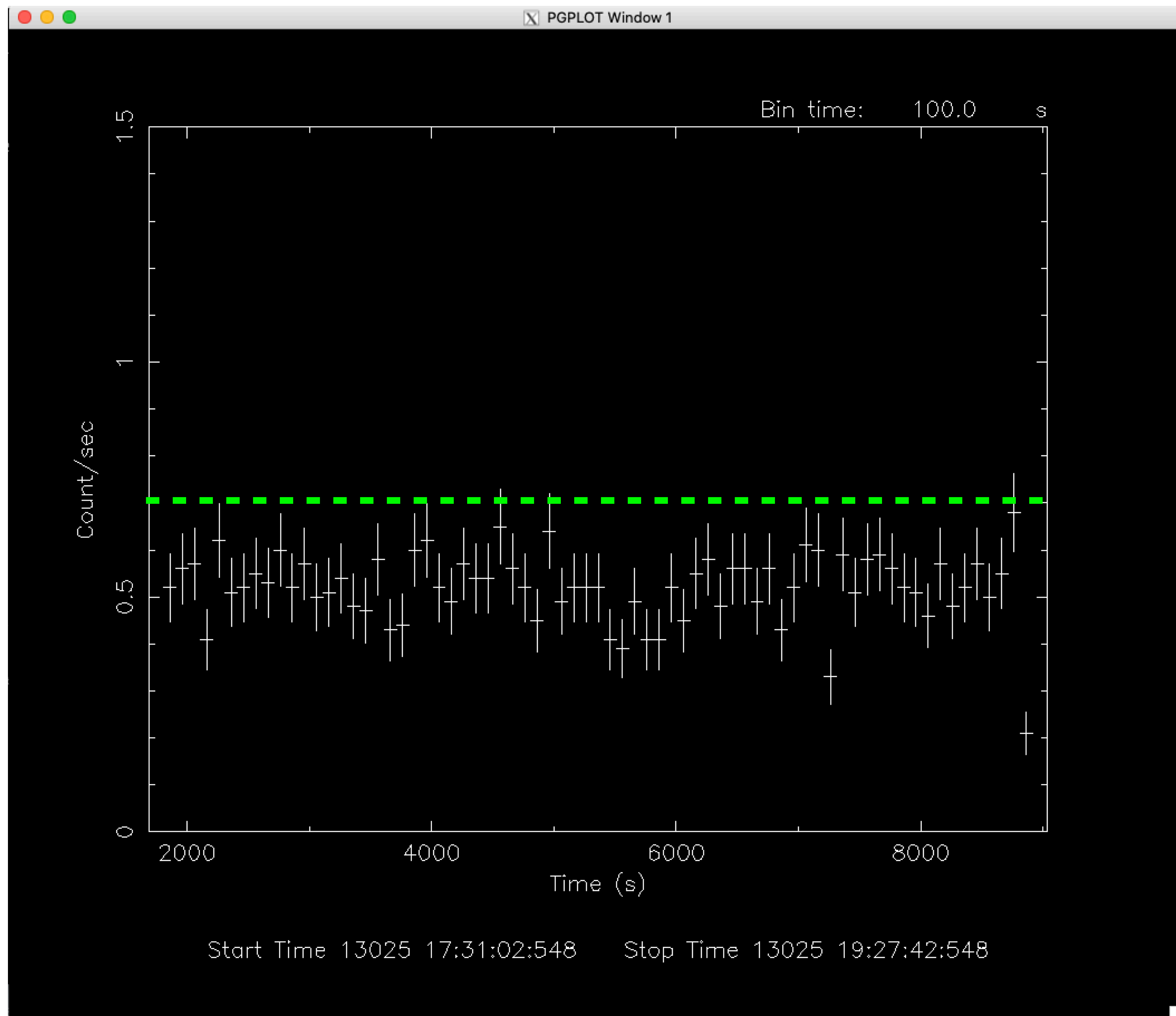
Maximum of 3 Intvs. with 512 Newbins of 100.000 (s)

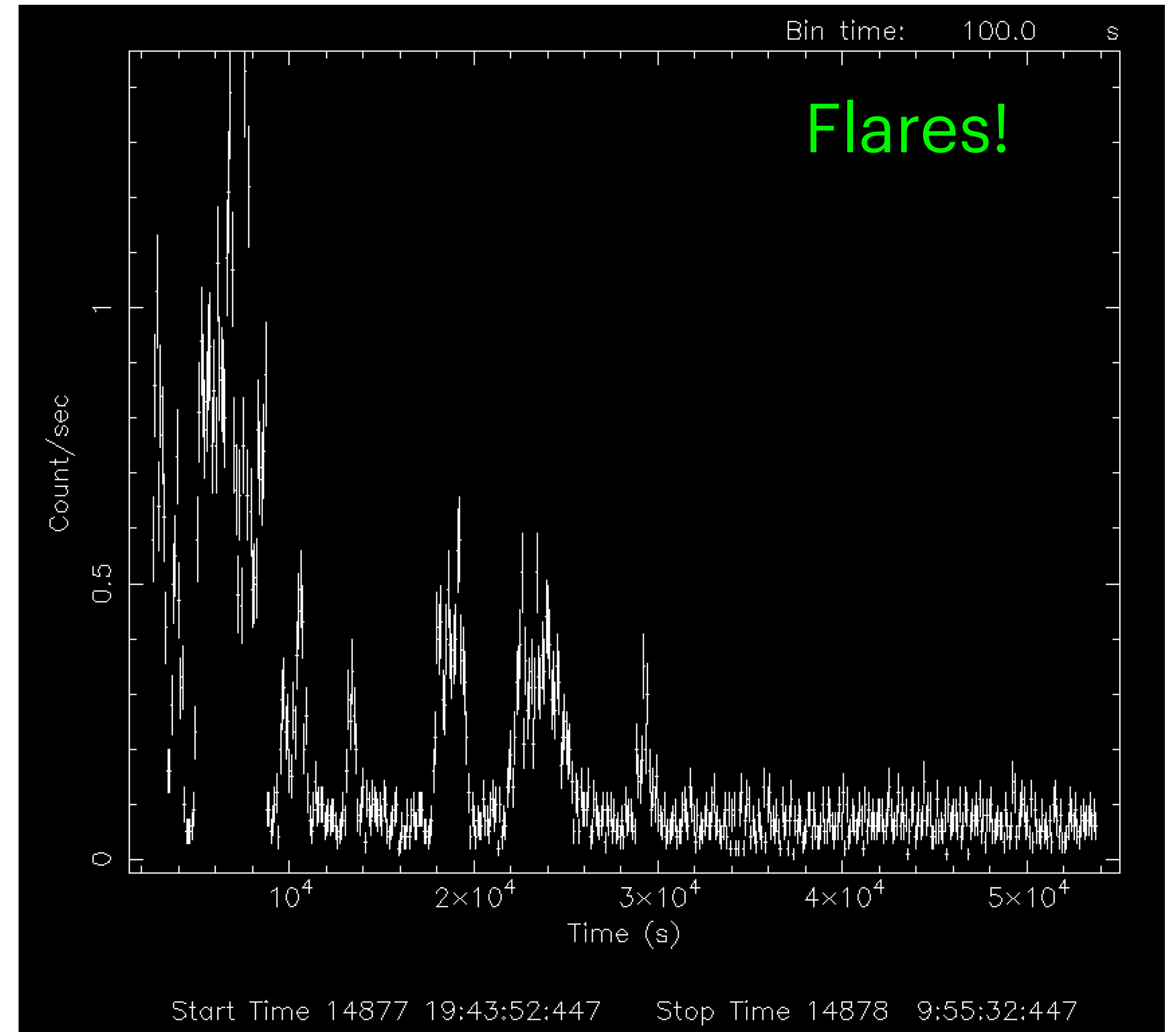
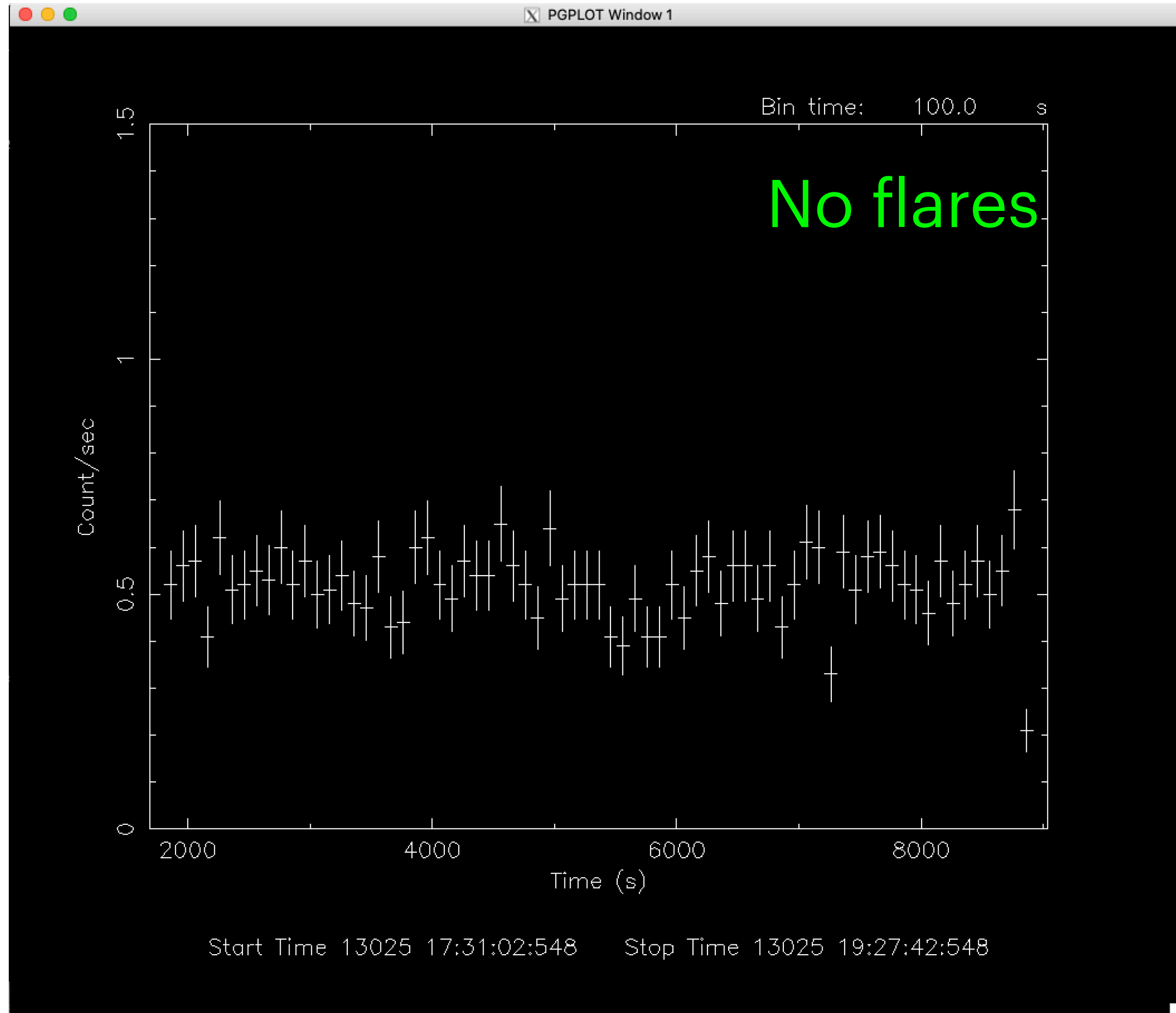
Name of output file[output.lc]

Do you want to plot your results?[yes]

Enter PGPLOT device[/xw]

512 analysis results per interval

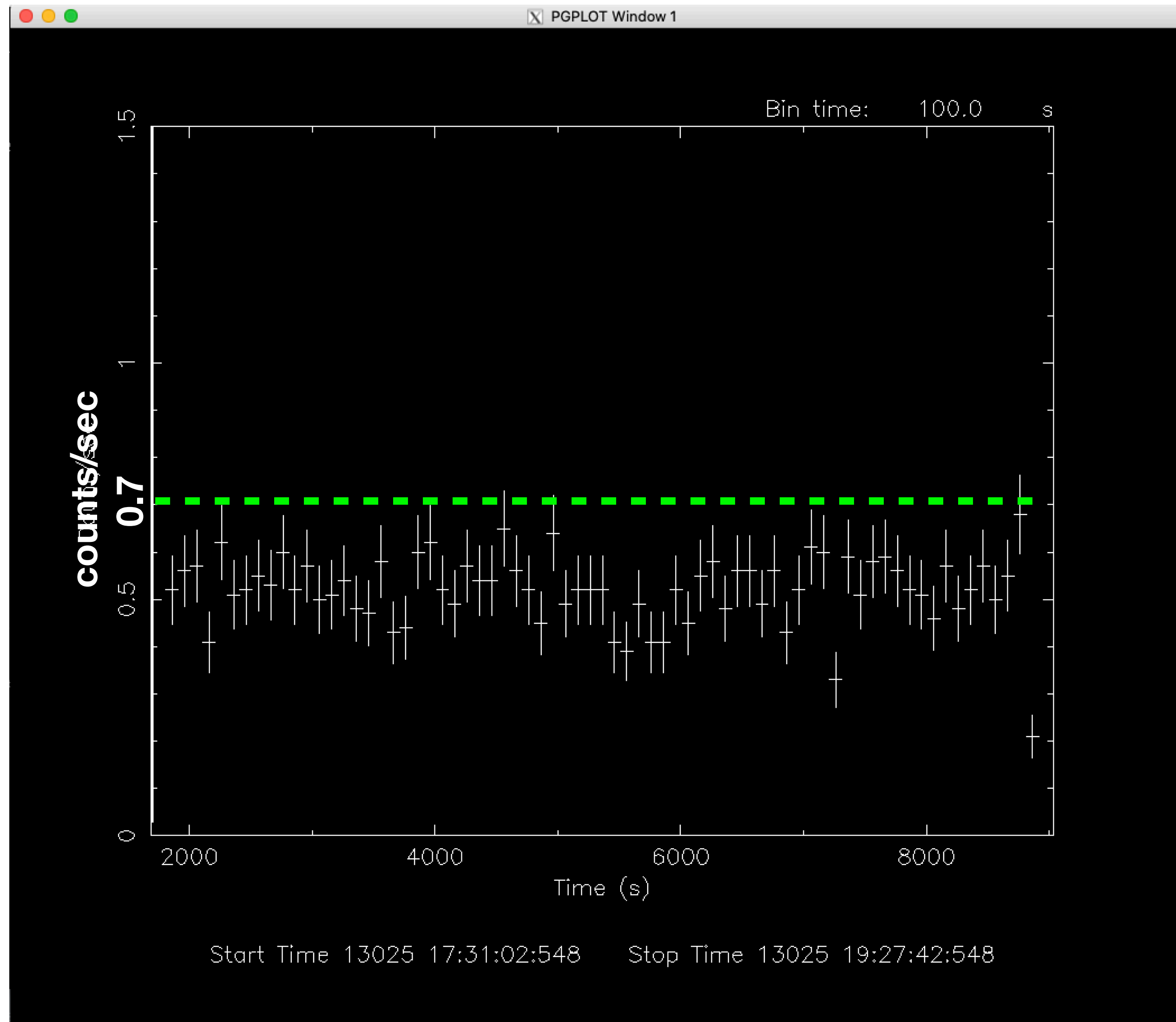




Possible error! Disconnect from login06 and reconnect

```
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**



```
tabgtigen table=lcurve_sup10.lc gtiset=good_bkg.gti expression='RATE<0.7'
```


Generation of a **cleaned event file**

pn

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

filteredset= the name of the file to which the filtered event list is to be written. If this parameter is set, then **keepfilteroutput** is automatically set to true.

updateexposure= update exposure information in event lists (keywords LIVETIME, LIVETInn, ONTIME, and ONTIME n n) and in spectrum files (keyword EXPOSURE).

cleandss= controls the use of data subspace cleaning, which deletes components from the data subspace which select no events from the event list.

writess= controls the writing of data subspace information to the output data files.

Generation of a **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**

fv: Binary Table of pn.evt[1] in /blasco/users/torresi/LAB-X/Fall_2022/3C33_LABX/pn/

File Edit Tools Help

Select	TIME	RAWX	RAWY	DETX	DETY	X	Y	PHA	PI	FLAG	PATTERN
D	I	I	I	I	I	J	J	I	I	J	B
s	pixel	pixel	0.05 arcsec	0.05 arcsec	0.05 arcsec	0.05 arcsec	channel	eV			
Invert	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	1.910949802434E+08	50	110	7331	-8630	37610	31914	30	151	0	0
2	1.910936738810E+08	28	142	-9935	3770	16856	27317	24	151	0	0
3	1.910987199062E+08	20	183	-11361	-2593	18051	33727	24	151	0	0
4	1.910968628259E+08	35	24	11477	-15702	44206	36781	30	151	65536	0
5	1.910990361903E+08	29	187	-10571	-2284	18655	33132	24	151	0	0
6	1.910961221517E+08	62	98	-7817	-9592	24065	38764	31	151	2097160	0
7	1.910970038855E+08	1	133	3105	4529	28542	21483	26	151	4	0
8	1.910974374096E+08	62	45	-7897	-13947	25707	42799	33	151	2097160	0
9	1.910945815748E+08	48	181	-11601	516	16606	30964	22	151	0	0
10	1.910967549282E+08	15	169	-14269	1567	13740	31049	25	151	0	0
11	1.910971991752E+08	56	151	3922	3037	29881	22532	26	151	0	0
12	1.910989785826E+08	35	162	5695	2135	31866	22663	24	151	0	0
13	1.910968081495E+08	57	186	-13624	-2308	15859	34356	22	151	0	0
14	1.910990163098E+08	48	14	-6206	14311	16131	16159	30	151	0	0
15	1.910954398068E+08	46	116	-16806	5925	9691	28042	27	151	0	0
16	1.910962318820E+08	21	160	-5831	-4511	23889	33312	28	151	0	0
17	1.910999689040E+08	1	167	-2130	-3895	27049	31288	31	151	4	0
18	1.910993828217E+08	57	134	-17669	4455	9477	29733	26	151	0	0
19	1.910989936606E+08	60	164	-12546	1956	15170	30012	22	151	0	0
20	1.910960863435E+08	41	151	-14993	-5262	15764	37611	27	151	0	0
21	1.910968742872E+08	43	185	12176	-2456	39631	24330	24	151	0	0
22	1.910997870684E+08	51	199	2000	-1237	29798	27218	30	151	0	0
23	1.910989410890E+08	44	177	-14728	-3097	15155	35516	22	151	0	0
24	1.910960325198E+08	37	194	-9900	-1697	19041	32328	24	151	0	0
25	1.910967498674E+08	33	154	11287	-5002	39817	27021	26	151	0	0
26	1.910957214857E+08	57	167	-13697	-3921	16427	35868	23	151	0	0

Go to: Edit cell: 151

Generation of a **cleaned event file**

MOS 1

```
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
```

MOS 2

```
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
```

Raw event file (pn.evt)

fv: Summary of pn.evt in /blasco/users/torresi/LAB-X/Fall_2022/3C33_LABX/pn/

Index	Extension	Type	Dimension	View				
0	Primary	Image	0	Header	Image	Table		
1	EVENTS	Binary	15 cols X 131297 rows	Header	Hist	Plot	All	Select
2	OFFSETS	Binary	3 cols X 14 rows	Header	Hist	Plot	All	Select
3	EXPOSU01	Binary	2 cols X 95904 rows	Header	Hist	Plot	All	Select
4	BADPIX01	Binary	5 cols X 72 rows	Header	Hist	Plot	All	Select
5	DLIMAP01	Binary	3 cols X 200 rows	Header	Hist	Plot	All	Select
6	HKAUX01	Binary	2 cols X 4789 rows	Header	Hist	Plot	All	Select
7	EXPOSU02	Binary	2 cols X 95901 rows	Header	Hist	Plot	All	Select
8	BADPIX02	Binary	5 cols X 68 rows	Header	Hist	Plot	All	Select
9	DLIMAP02	Binary	3 cols X 200 rows	Header	Hist	Plot	All	Select

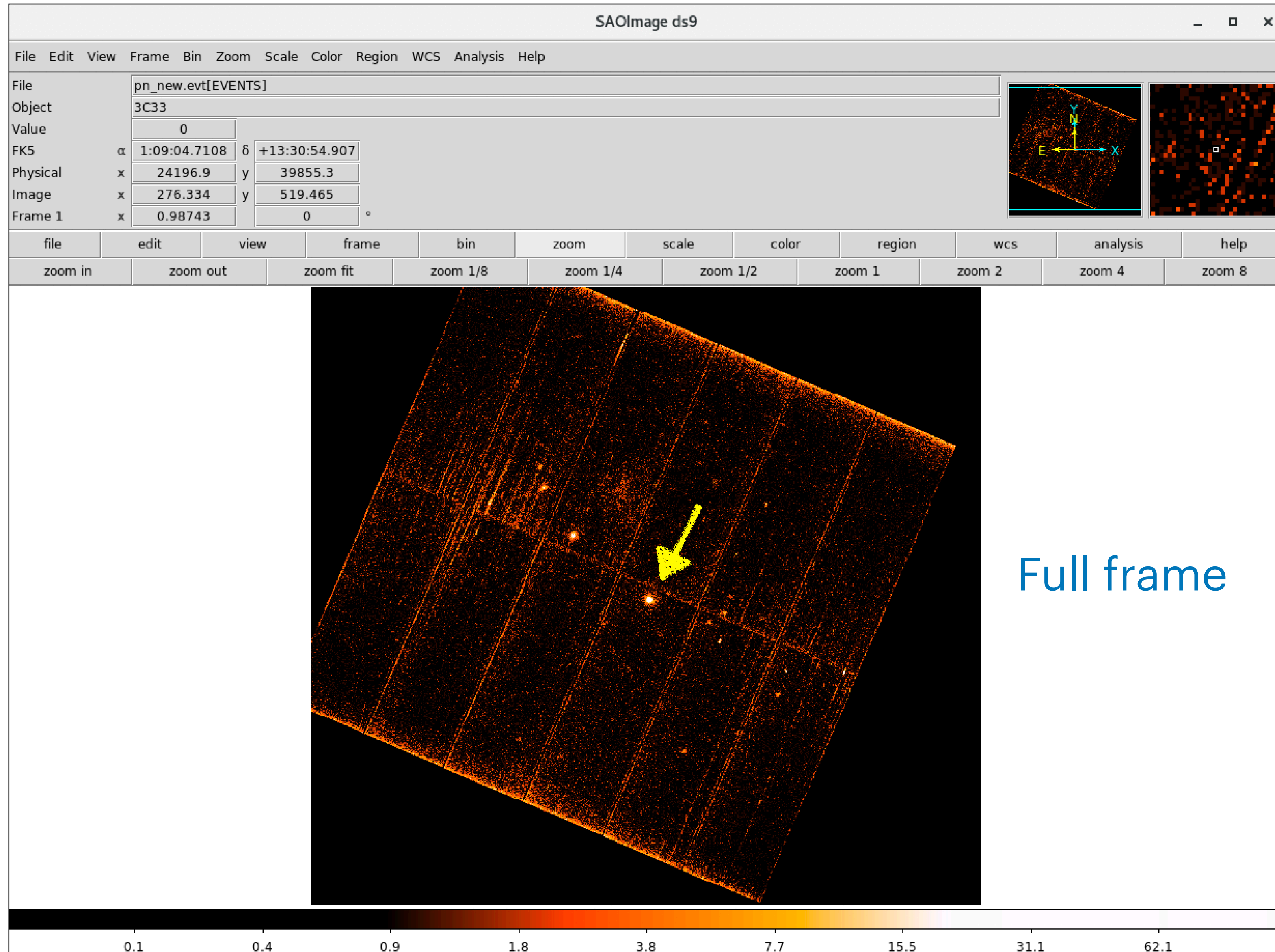


Cleaned event file (pn_new.evt)

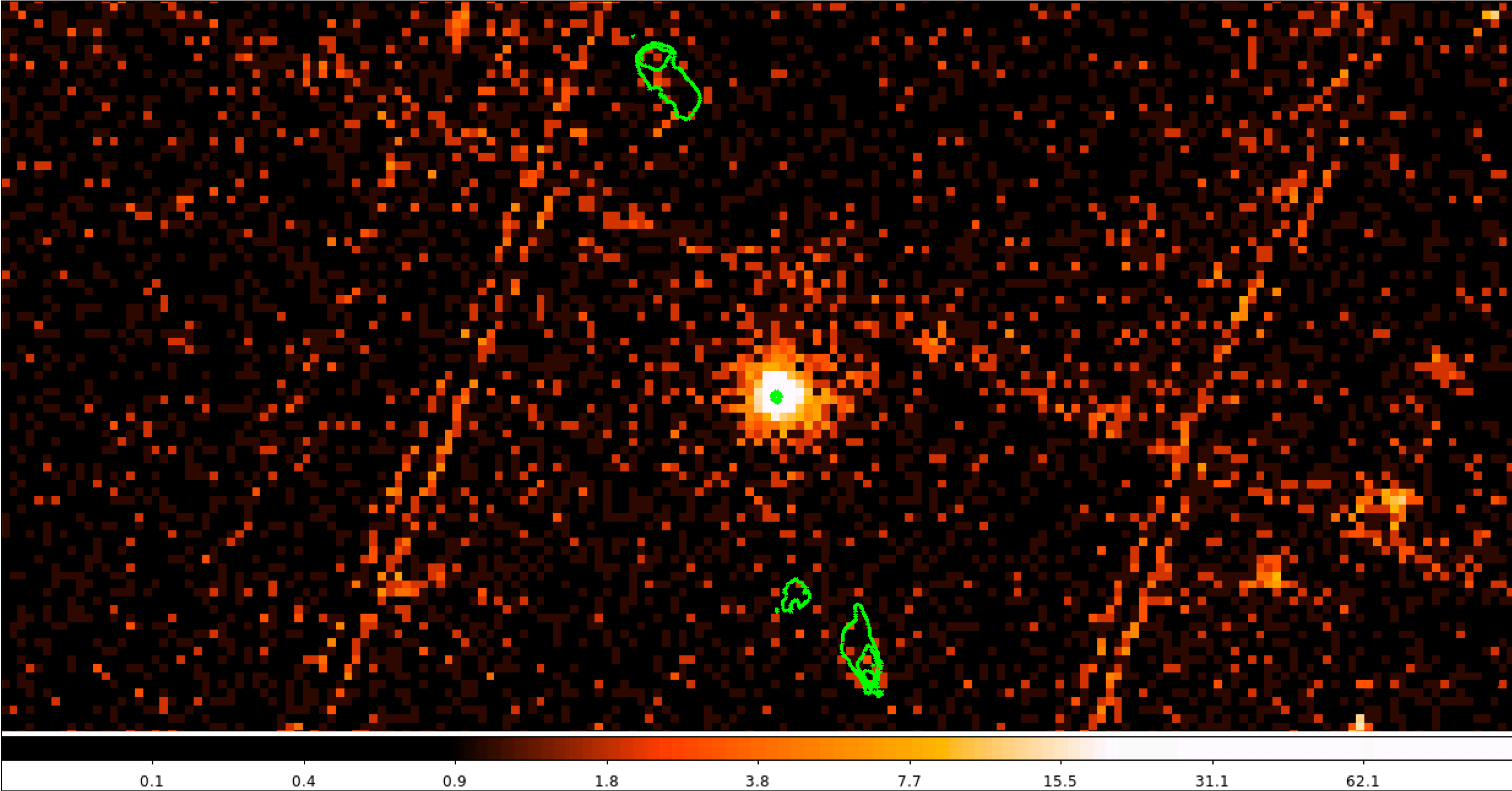
fv: Summary of pn_new.evt in /blasco/users/torresi/LAB-X/Fall_2022/3C33_LABX/pn/

Index	Extension	Type	Dimension	View				
0	Primary	Image	0	Header	Image	Table		
1	EVENTS	Binary	15 cols X 125977 rows	Header	Hist	Plot	All	Select
2	OFFSETS	Binary	3 cols X 14 rows	Header	Hist	Plot	All	Select
3	EXPOSU01	Binary	2 cols X 95904 rows	Header	Hist	Plot	All	Select
4	BADPIX01	Binary	5 cols X 72 rows	Header	Hist	Plot	All	Select
5	DLIMAP01	Binary	3 cols X 200 rows	Header	Hist	Plot	All	Select
6	HKAUX01	Binary	2 cols X 4789 rows	Header	Hist	Plot	All	Select
7	EXPOSU02	Binary	2 cols X 95901 rows	Header	Hist	Plot	All	Select
8	BADPIX02	Binary	5 cols X 68 rows	Header	Hist	Plot	All	Select
9	DLIMAP02	Binary	3 cols X 200 rows	Header	Hist	Plot	All	Select

> ds9 pn_new.evt &



Zoomed image with radio (VLA 5GHz) contours overlaid



Source extraction region

Display the cleaned image with **ds9**

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

```
> ds9 pn_new.evt &
```

```
> scale log
```

```
> bin (block 2, 4, ...)
```

```
> Region
```

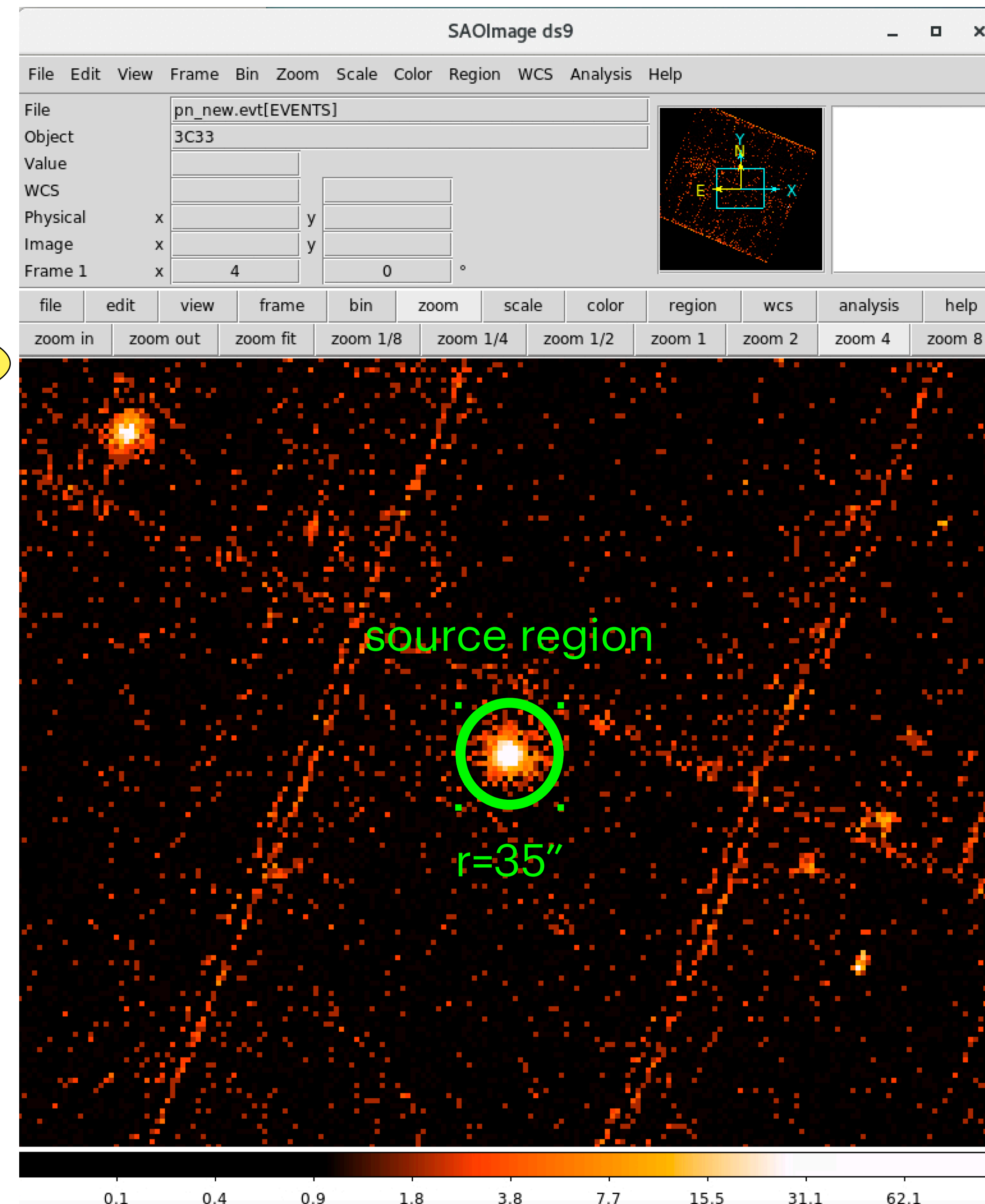
```
> save region
```

```
> file format 'ds9'
```

```
> coordinates 'physical'
```

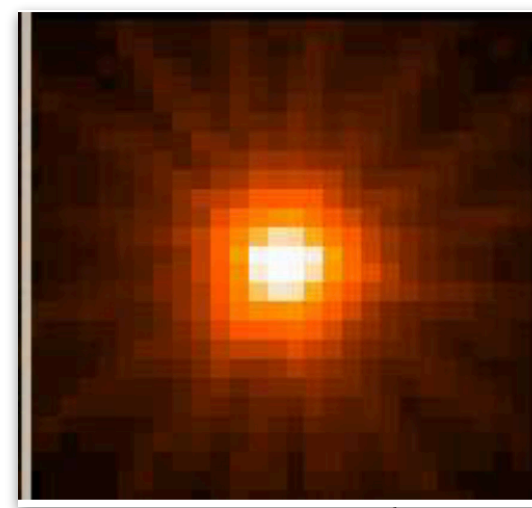
```
> source.reg
```

```
circle(27720.501,27069.104,700.00011)
```

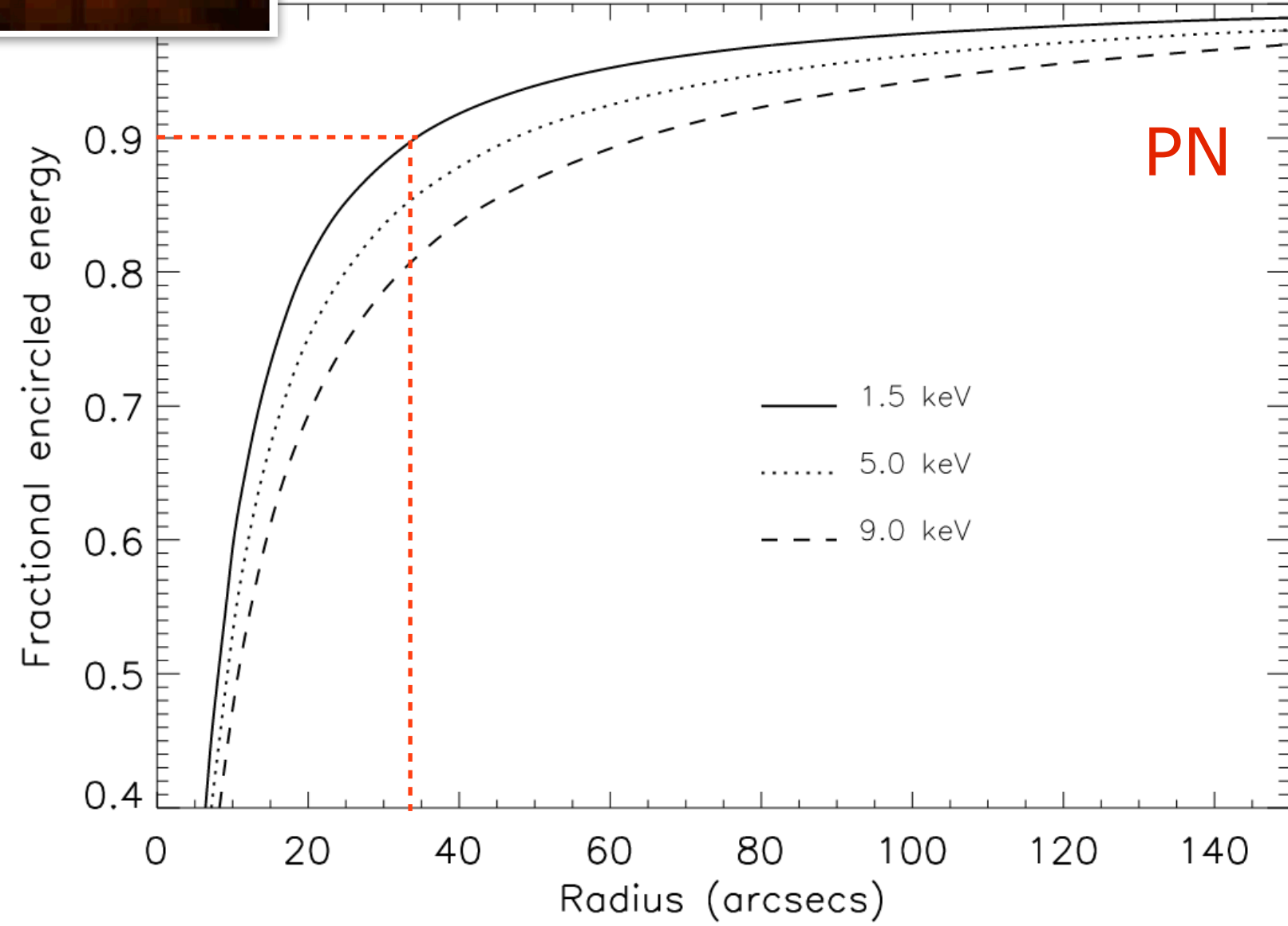


Fraction encircled energy

Fraction of photons contained within a certain angular radius



EPN encircled energy fraction

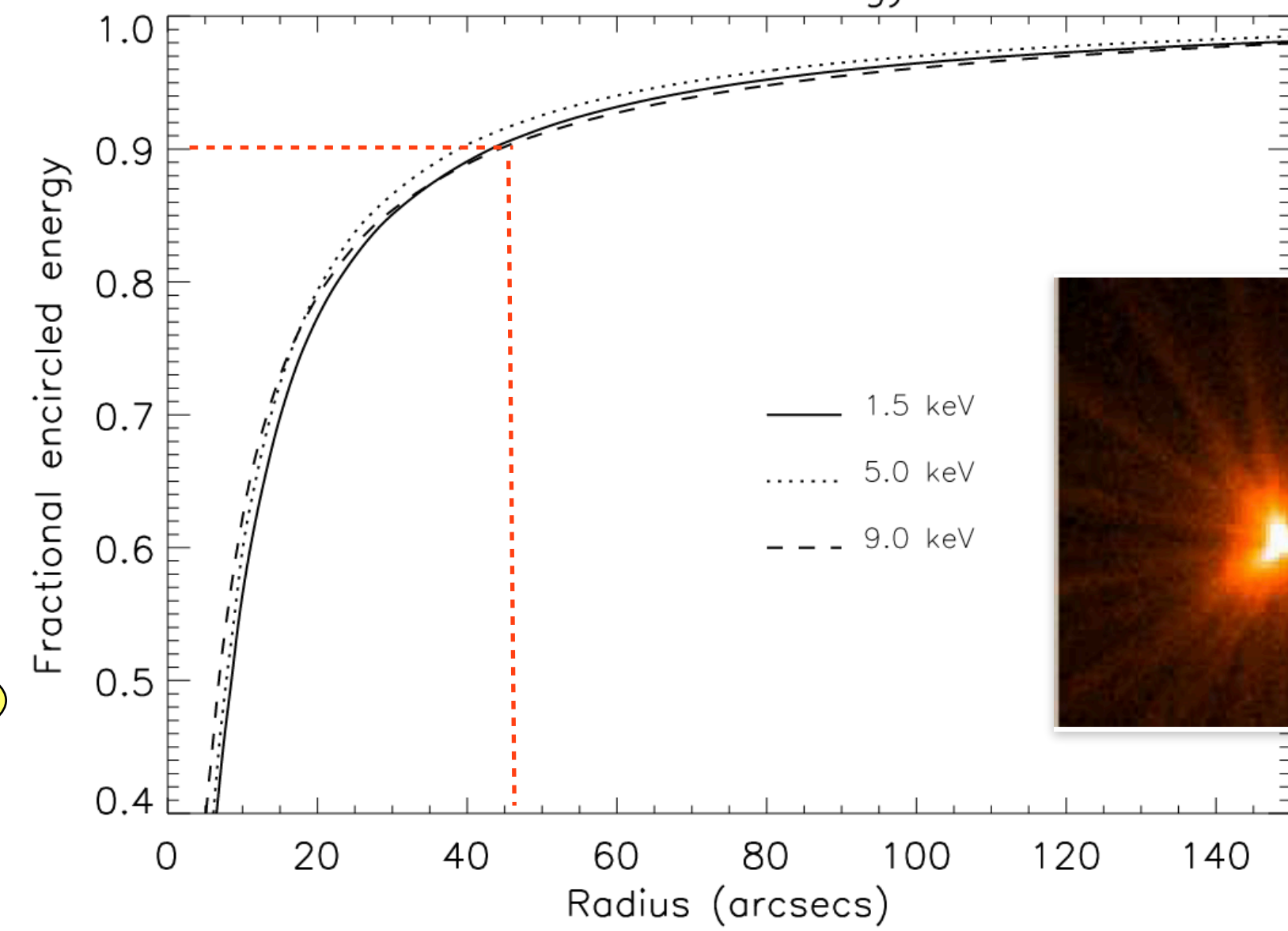


on-axis — point-like source

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

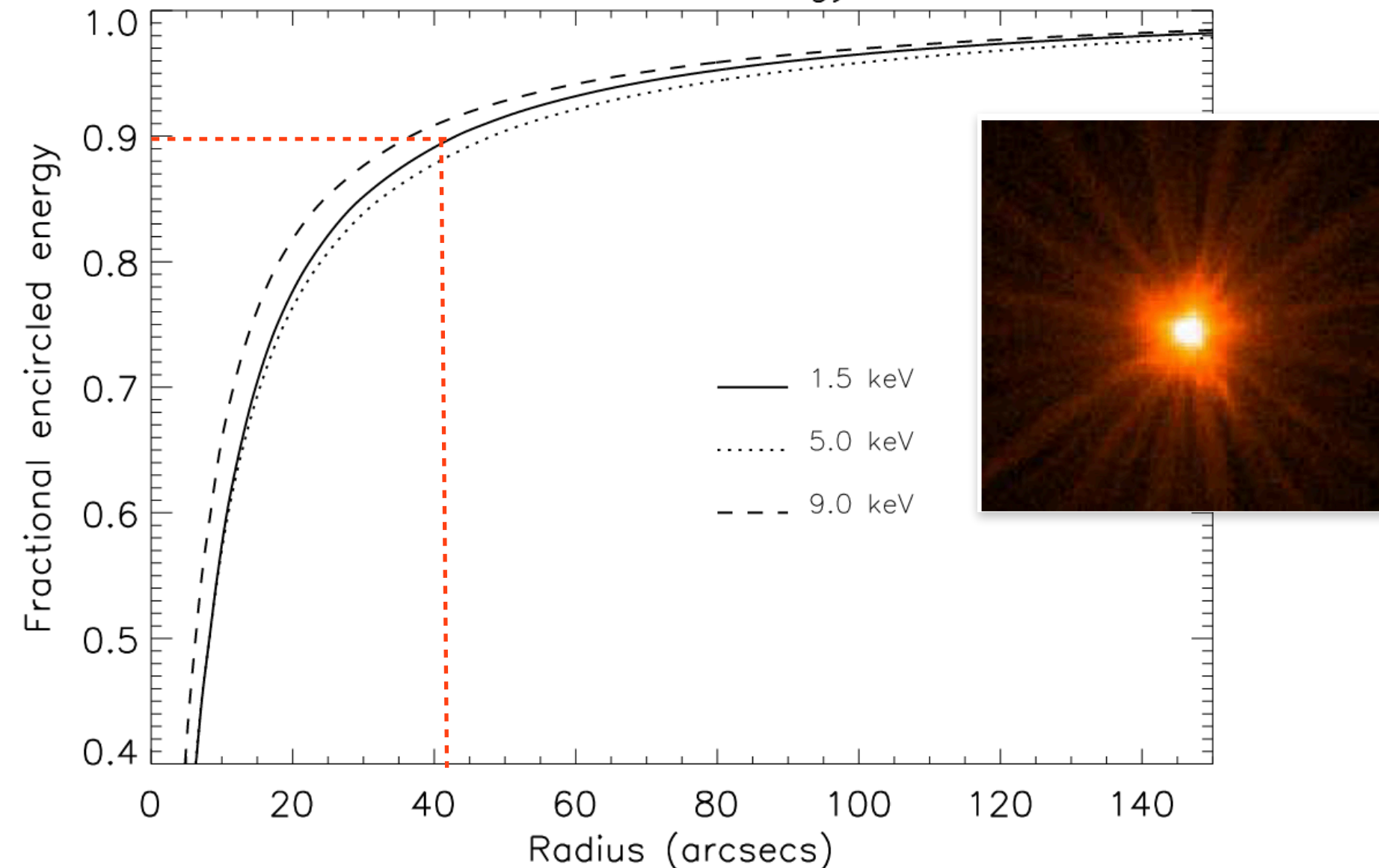
Each instrument has its own on-axis PSF

EMOS2 encircled energy fraction **MOS2**



from the center of the PSF

EMOS1 encircled energy fraction **MOS1**



The core of XMM on-axis PSF is **narrow** and **varies little** in the 0.1-6 keV band (major XMM strong point!)

see also Dadina's lesson

Background extraction region

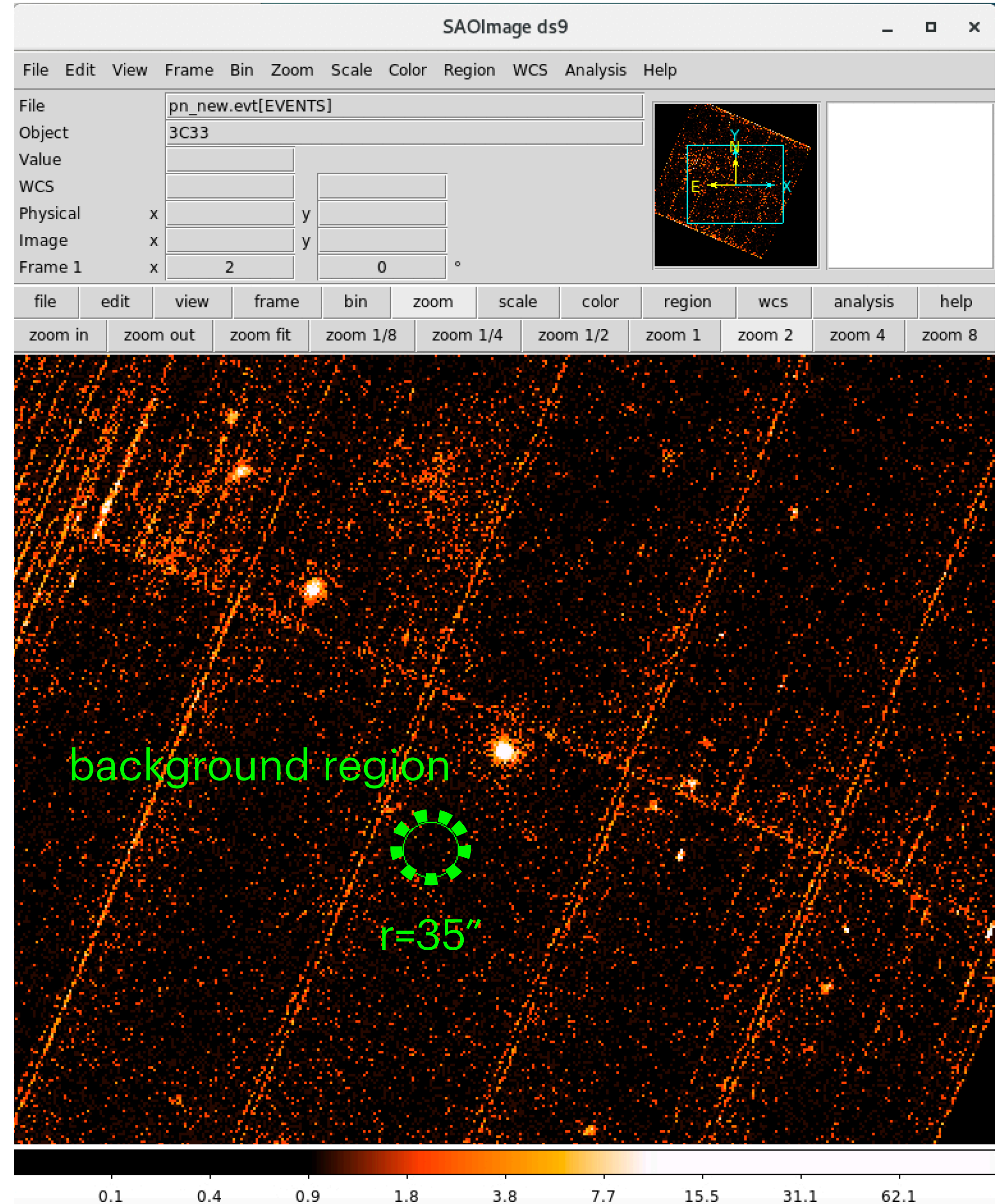
Display the cleaned image with *ds9*

```
ds9 pn_new.evt &
```

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

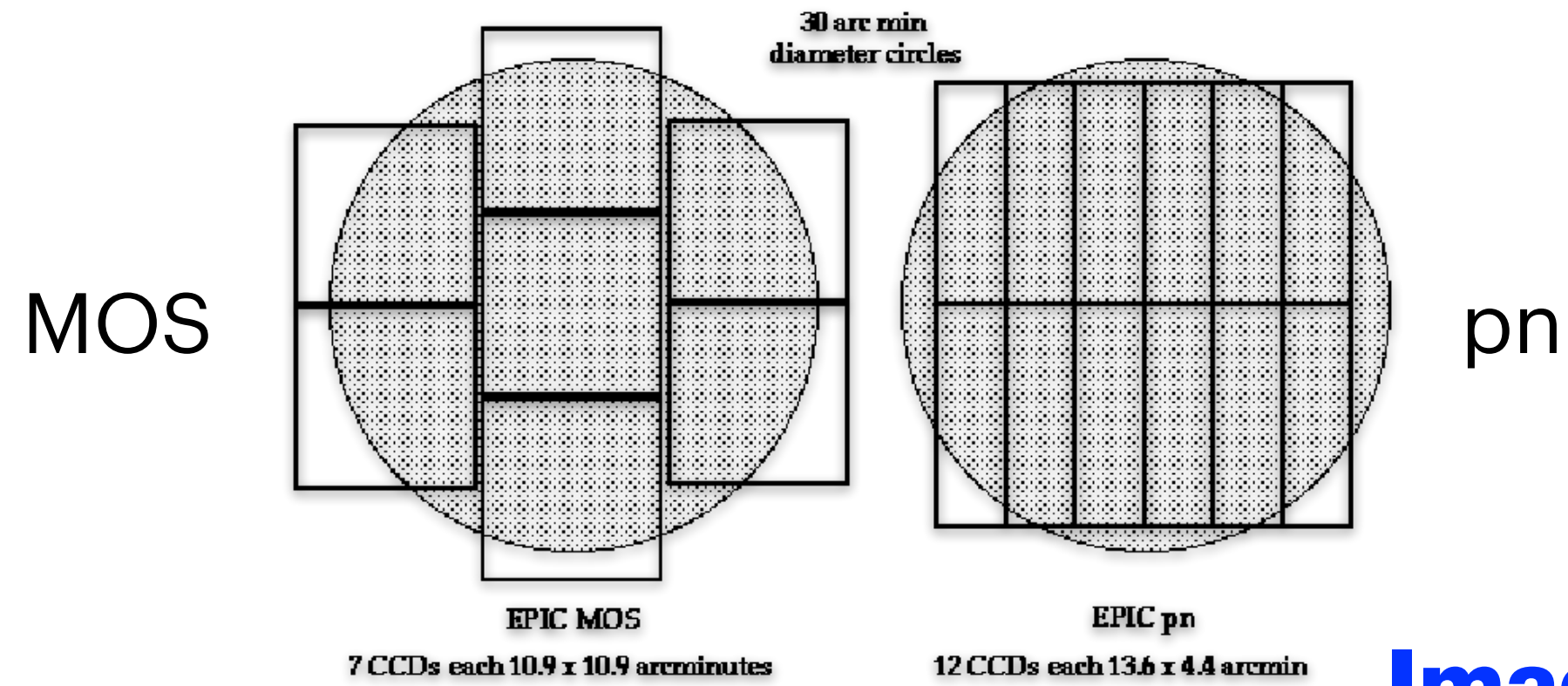
- > Region
- > save region
- > file format 'ds9'
- > coordinates 'physical'
- > `back.reg`

```
circle(25864.501,24541.104,700.00011)
```



EPIC Science Modes

Comparison of focal plane organisation of EPIC MOS and pn cameras



XMM FoV 30'

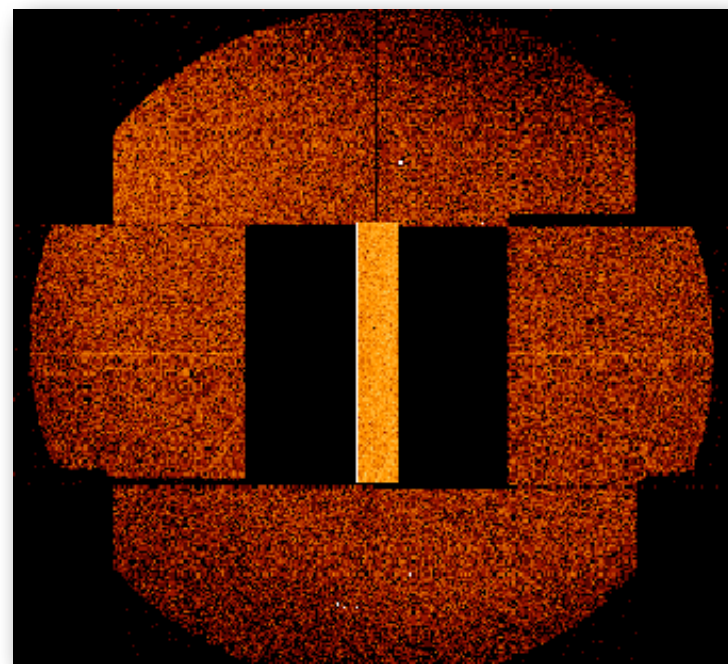
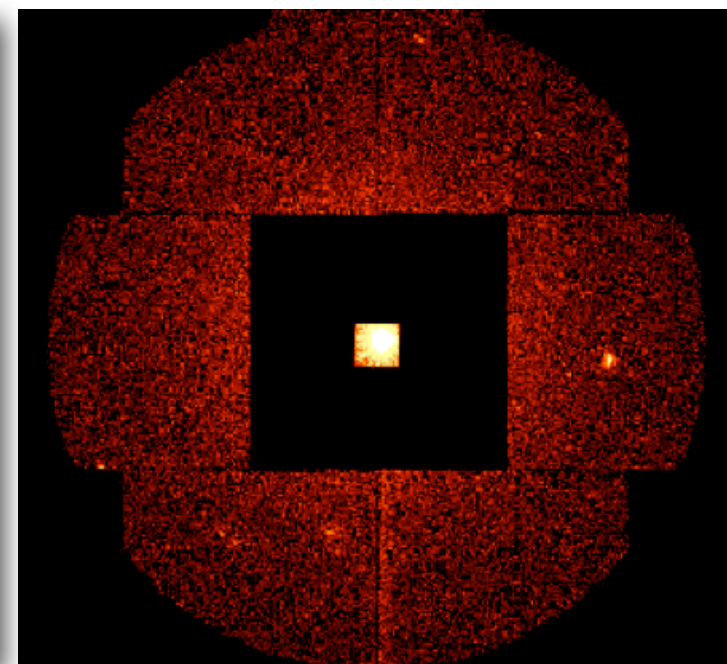
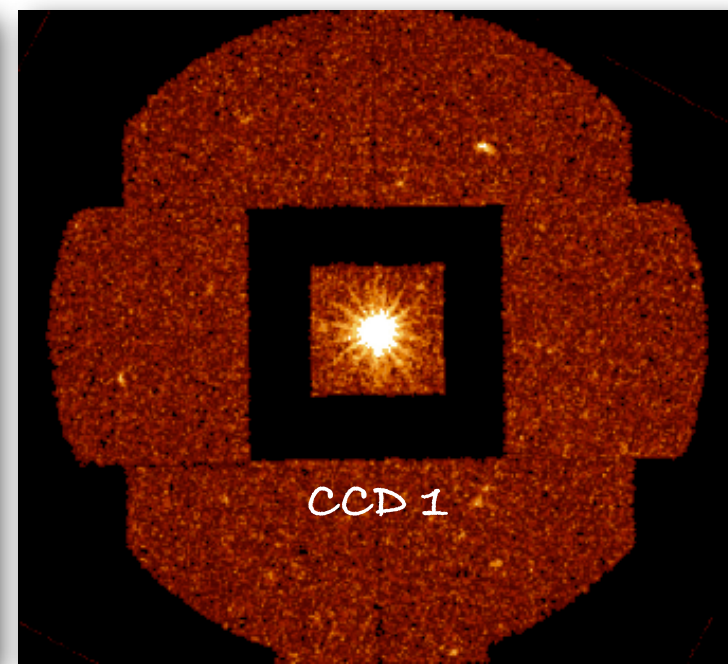
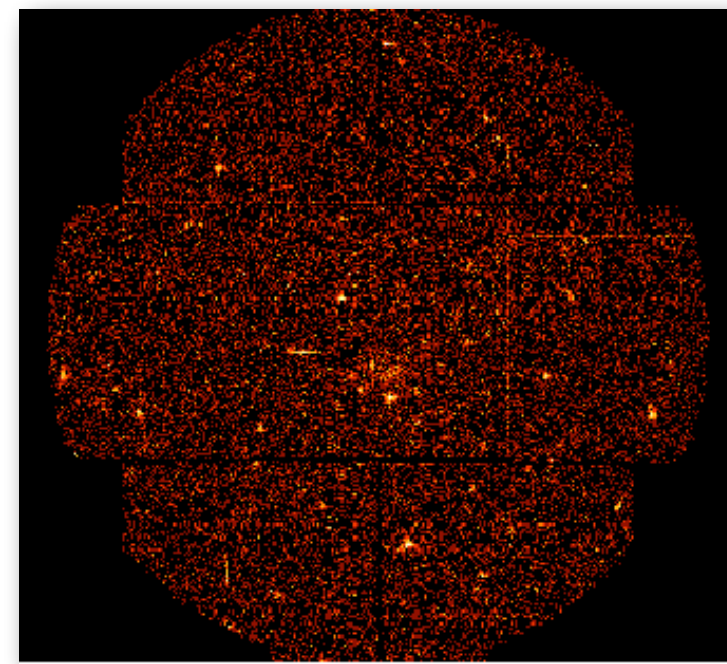
Imaging modes

Timing Mode

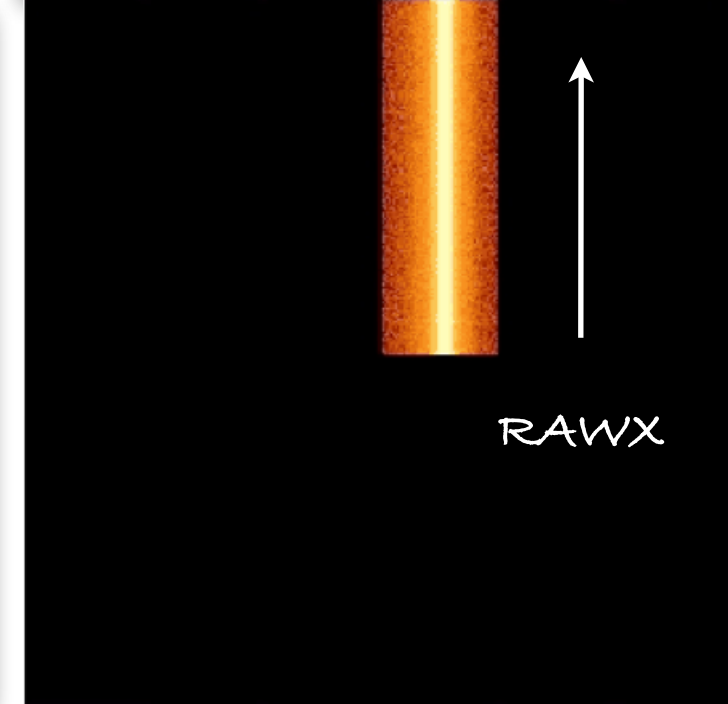
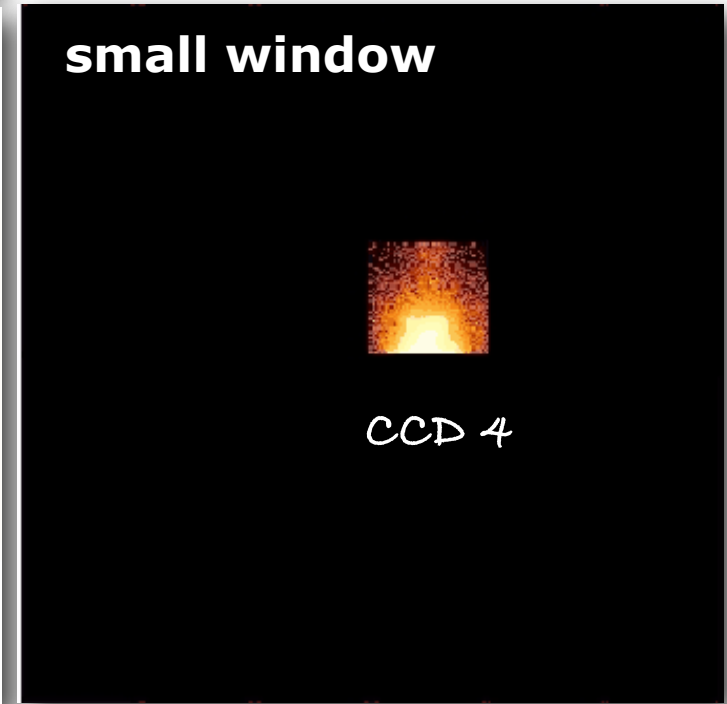
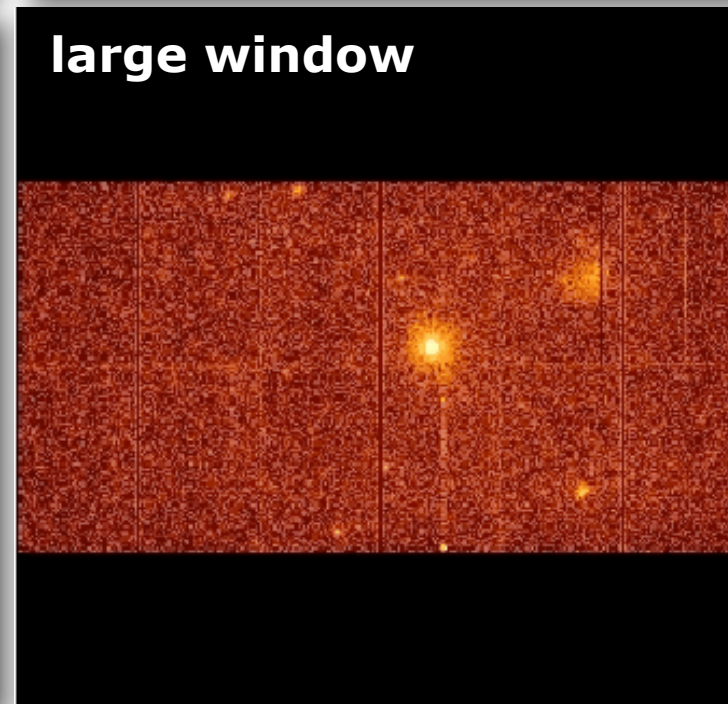
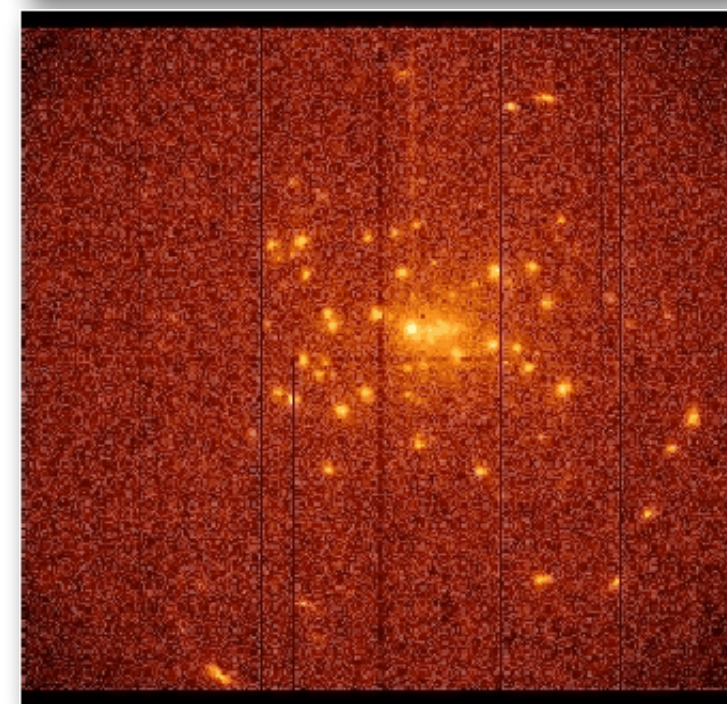
Full Frame

Partial Window

MOS



pn

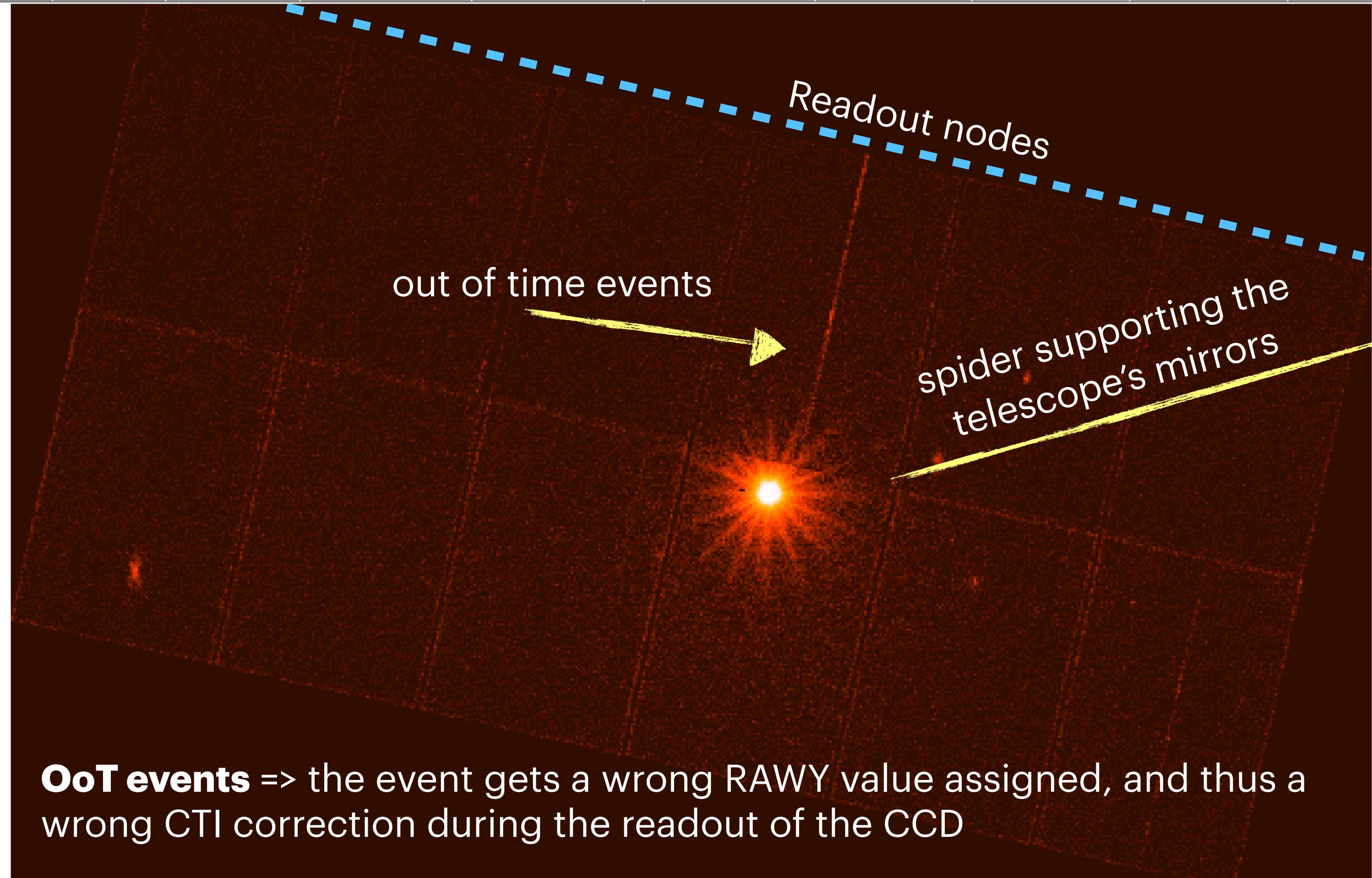
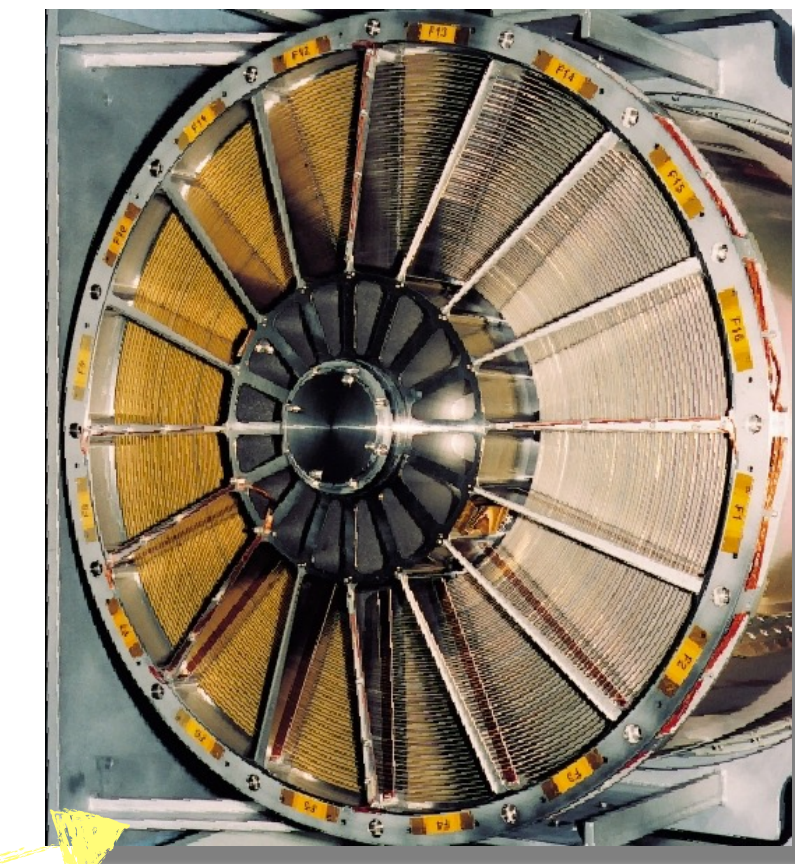
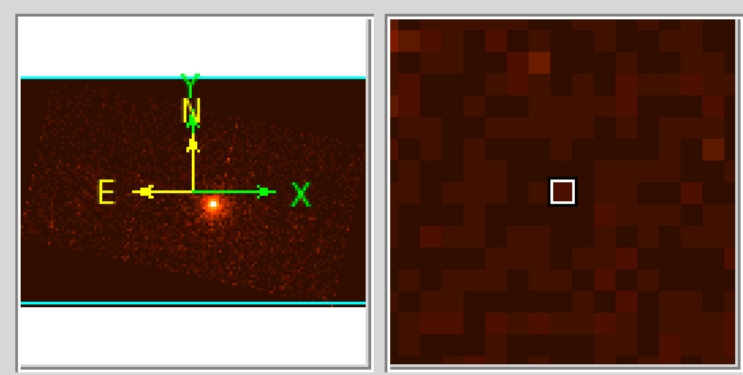


SAOImage ds9

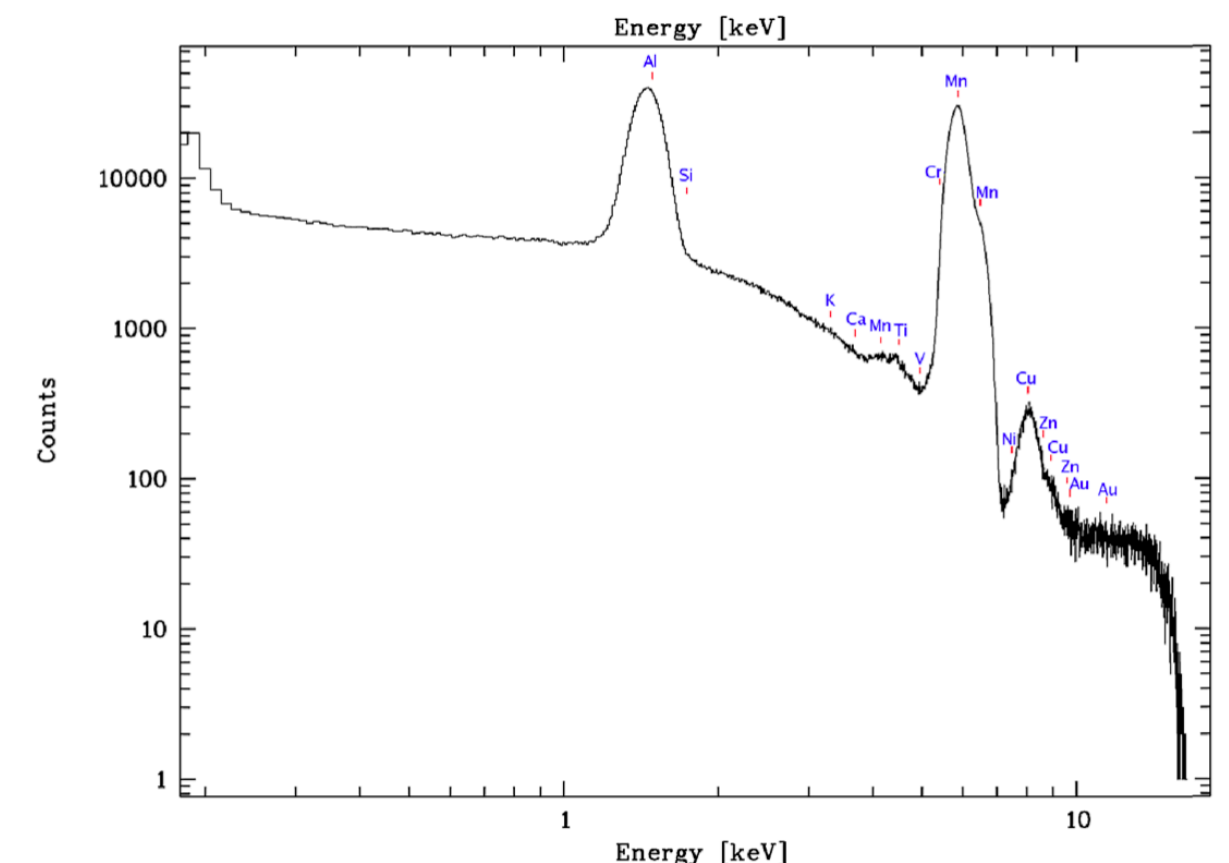
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help

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 °

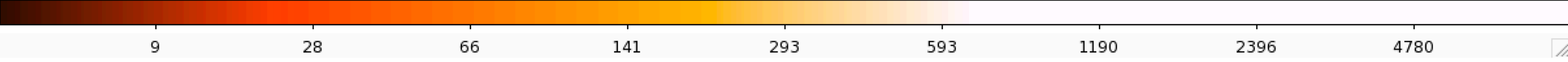
file edit view frame bin zoom scale color region wcs help
 - + to fit zoom 1/8 zoom 1/4 zoom 1/2 zoom 1 zoom 2 zoom 4 zoom 8



OoT events => the event gets a wrong RAWY value assigned, and thus a wrong CTI correction during the readout of the CCD



OoT events broaden spectral features in a systematic way



Photon PILE-UP

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. \(2015\)](#)

Many photons arrive **almost at the same time** in the **core of the PSF** which results influenced by pile-up

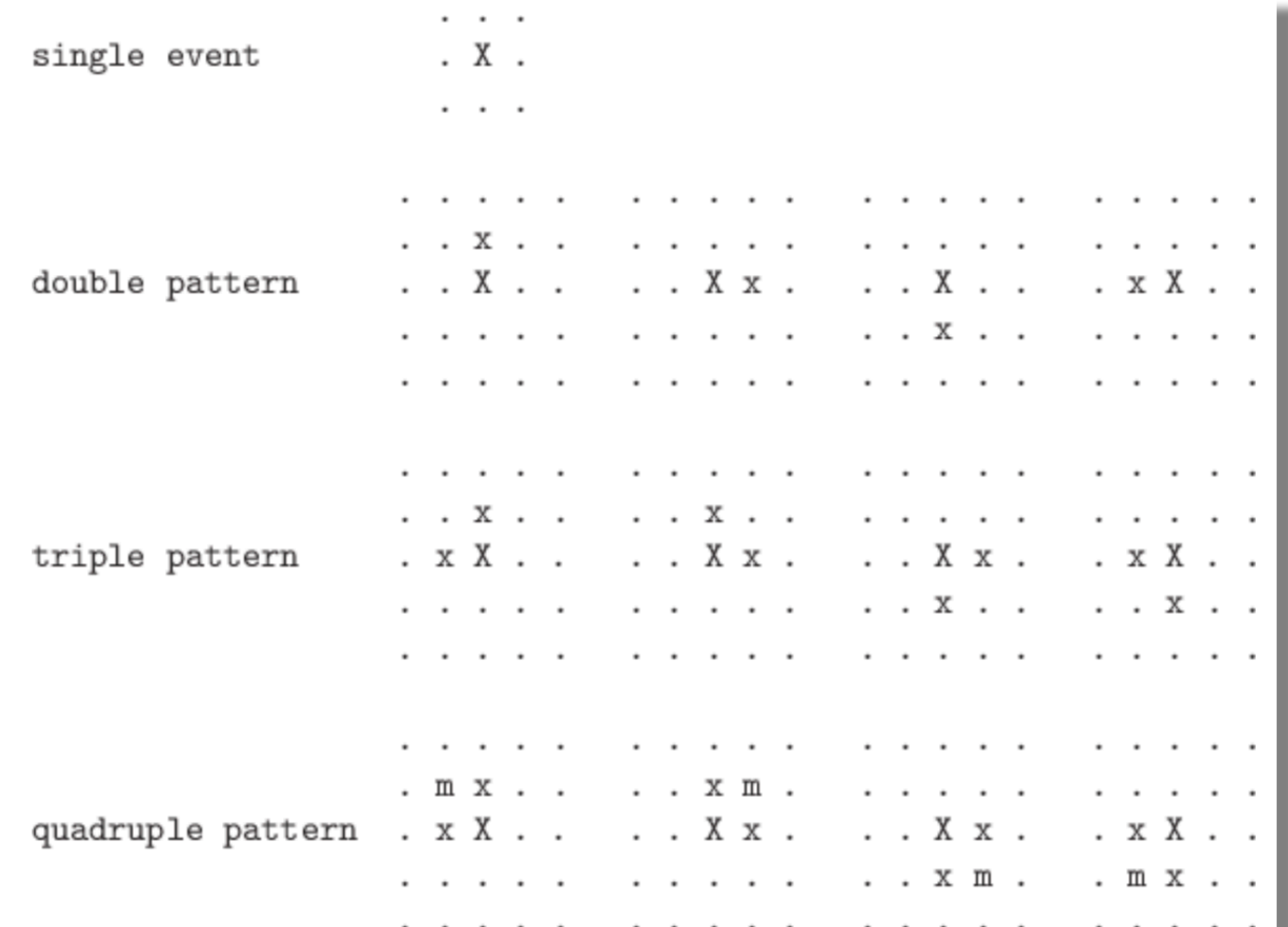
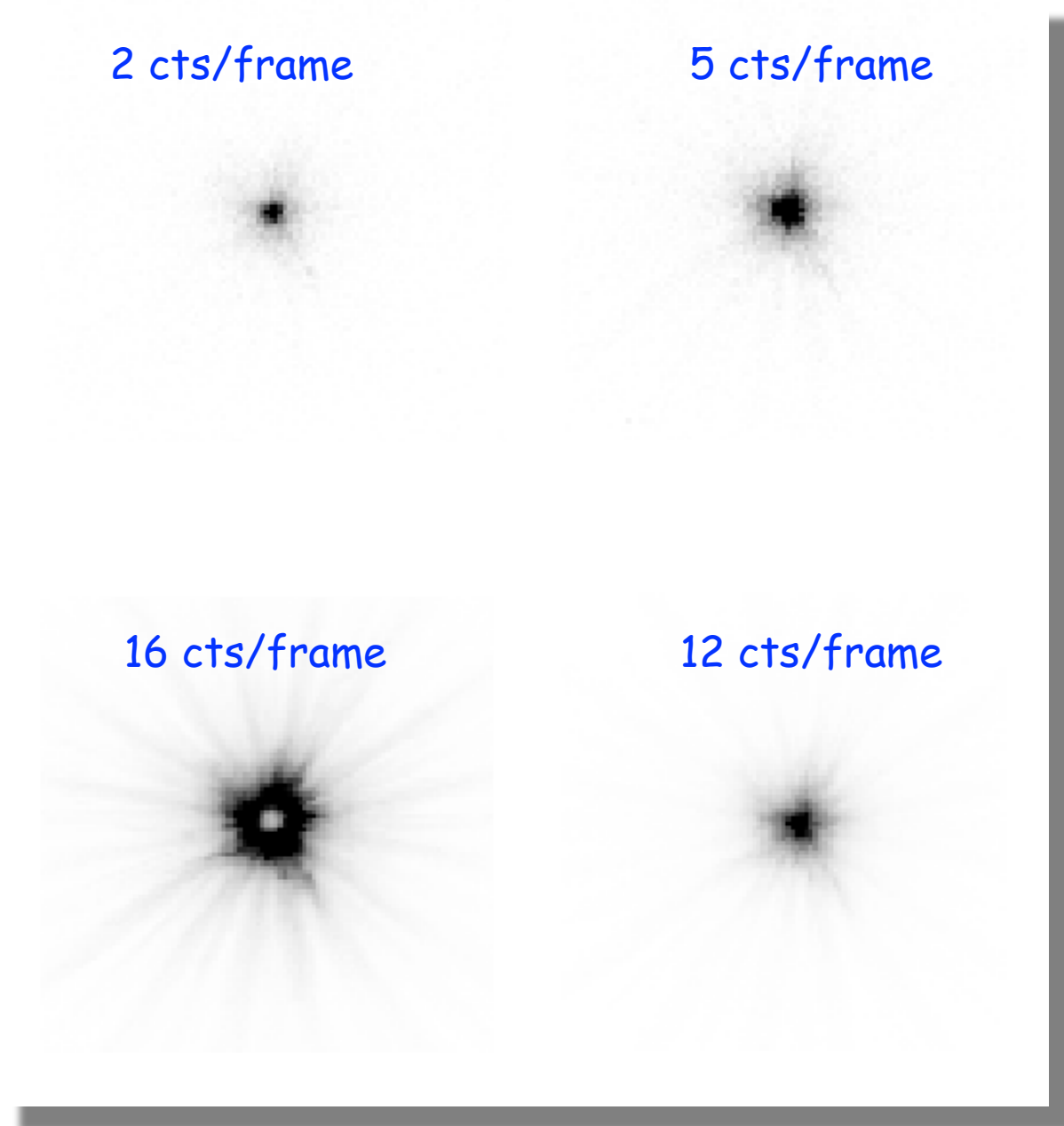


Figure 13: List of valid EPIC-pn patterns (cf. figure 12). Here "." marks a pixel without an event above threshold, "X" is the pixel with the maximum charge ("main pixel"), "x" is the pixel with a non-maximum charge, "m" is the pixel with the minimum charge. These 13 figures refer to the SAS PATTERN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

The spectral response is compromised

- Photon loss
- Energy distortion
- Pattern migration

MOS (central CCD; pixels) [1 pixel = 1.1"]	Time res- olution	Live time ¹ [%]	Max. count rate ² diffuse ³ (total) [s ⁻¹]	Max. count rate ² (flux) point source [s ⁻¹] ([mCrab] ⁴)
Full frame (600×600)	2.6 s	100.0	150	0.50 (0.17)
Large window (300×300)	0.9 s	99.5	110	1.5 (0.49)
Small window (100×100)	0.3 s	97.5	37	4.5 (1.53)
Timing uncompressed (100×600)	1.75 ms	100.0	N/A	100 (35)
pn (array or 1 CCD; pixels) [1 pixel = 4.1"]	Time res- olution	Live time ¹ [%]	Max. count rate ² diffuse ³ (total) [s ⁻¹]	Max. count rate ² (flux) point source [s ⁻¹] ([mCrab] ⁴)
Full frame ⁵ (376×384)	73.4 ms	99.9	1000(total)	2 (0.23)
Extended full frame ^{5,6} (376×384)	199.1 ms	100.0	370	0.7 (0.09)
Large window (198×384)	47.7 ms	94.9	1500	3 (0.35)
Small window (63×64)	5.7 ms	71.0	12000	25 (3.25)
Timing (64×200)	0.03 ms	99.5	N/A	800 (85)
Burst (64×180)	7 μs	3.0	N/A	60000 (6300)

Check for the presence of pile-up

Diagnostic tool for pileup: **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" or device="/GIF" plotfile="pnf_pat.gif"
```

```
[torresi@login06]pn>export SAS_CCF='/blasco/users/torresi/LAB-X/Fall_2022/3C33_LABX/evt/ccf.cif'  
[torresi@login06]pn>epatplot set=pnf.evt device="/CPS" plotfile="pnf_pat.ps"  
epatplot:- Executing (routine): epatplot set=pnf.evt modifyinset=yes sigma=3 withflag=yes xaxisadu=no device=/CPS o  
utdir=./ plotfile=pnf_pat.ps useplotfile=yes withqdp=no withdetxy=no withsrcxy=yes outmaskname=flag0_map_##.dat wit  
houtoutputmask=no backgroundset=bkg_events.fits withbackgroundset=no backscal=1 usermode=0 withusermode=no userrawy=19  
0 withuserrawy=no ccdlimits='1 64 1 200 1 12' plotxrange='0 0' plotyrange='0 0' pileupnumberenergyrange='500 2000'  
-w 1 -V 4  
epatplot:- epatplot (epatplot-1.22) [xmmsas_20211130_0941-20.0.0] started: 2022-11-16T10:57:22.000  
epatplot:- epatplot 1.22 is running...  
epatplot:-  
epatplot:-          s          d          t          q  
epatplot:- 0.6375 0.3228 0.0176 0.0220  
epatplot:-  
epatplot:- 0.5-2.0 keV observed-to-model fractions:  
epatplot:- s: 0.955 +/- 0.094  d: 1.168 +/- 0.156  
epatplot:-  
epatplot:- PostScript output written to file pnf_pat.ps  
epatplot:- epatplot (epatplot-1.22) [xmmsas_20211130_0941-20.0.0] ended: 2022-11-16T10:57:23.000  
[torresi@login06]pn>gv pnf_pat.ps&
```

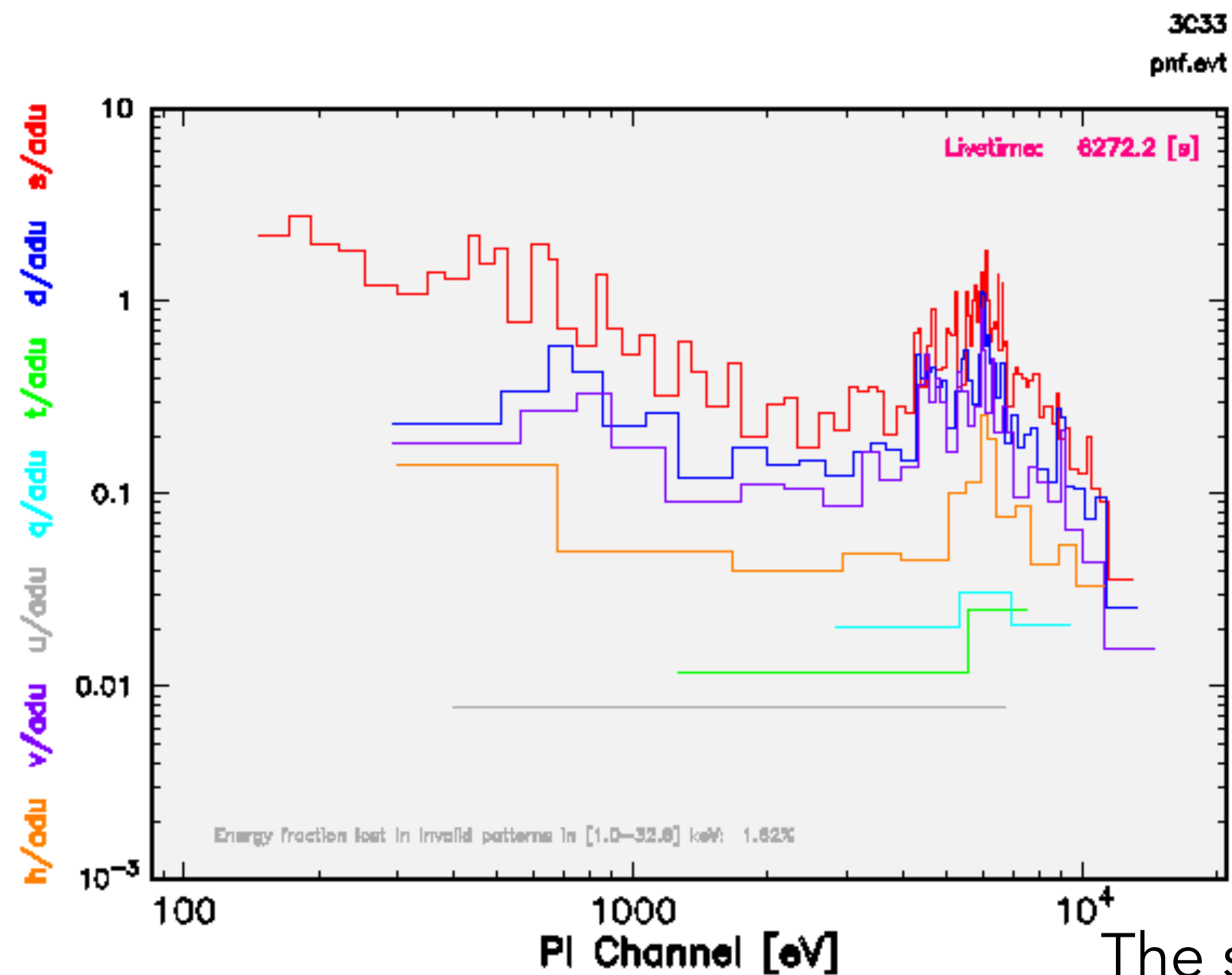
Epatplot compares the ratios of single- and double-events with standard values to check if there is a deviation (hence, pile-up)

How to visualize .ps of .gif files

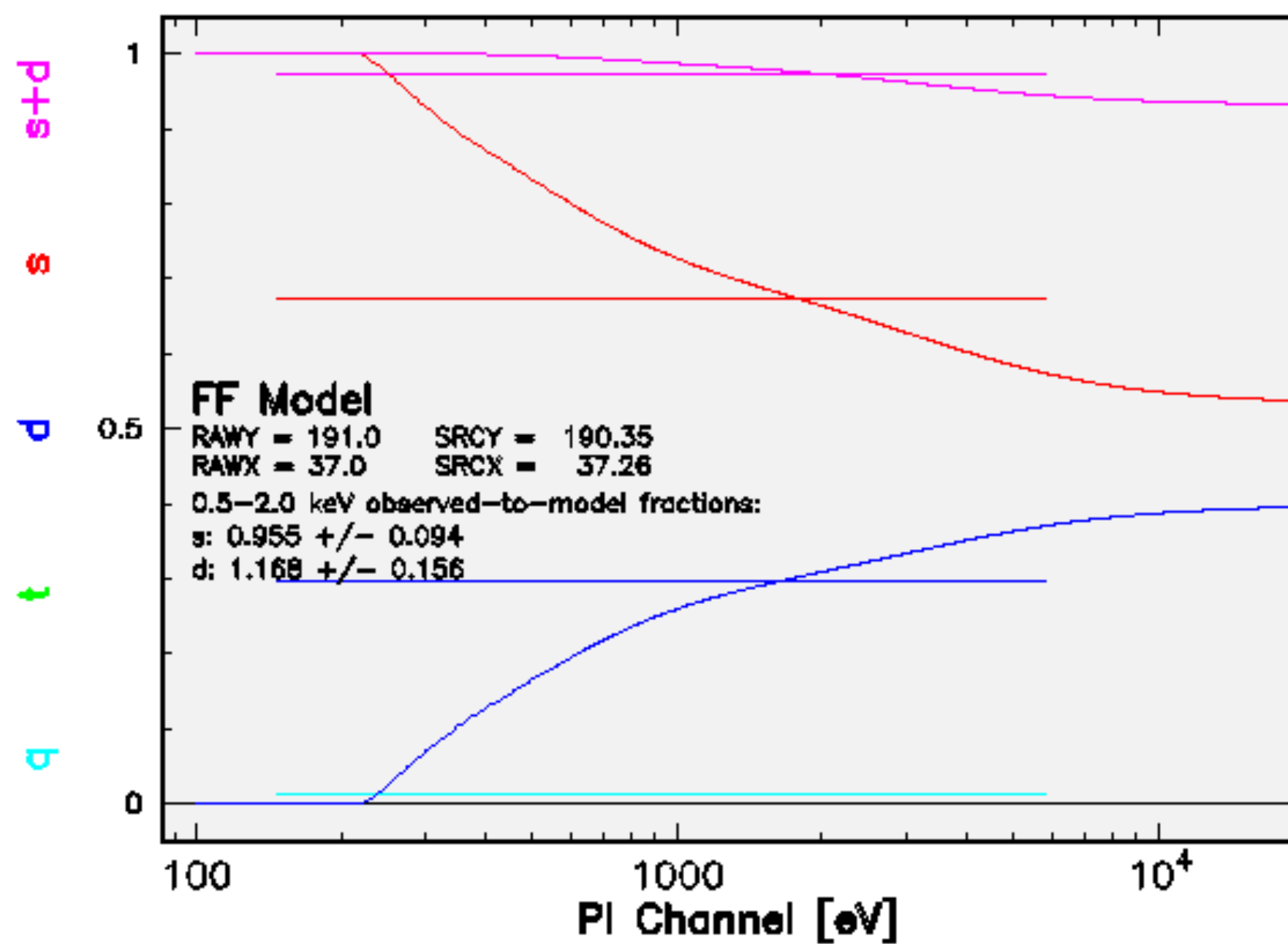
gv **pnf_pat.ps**

evince **pnf_pat.ps**

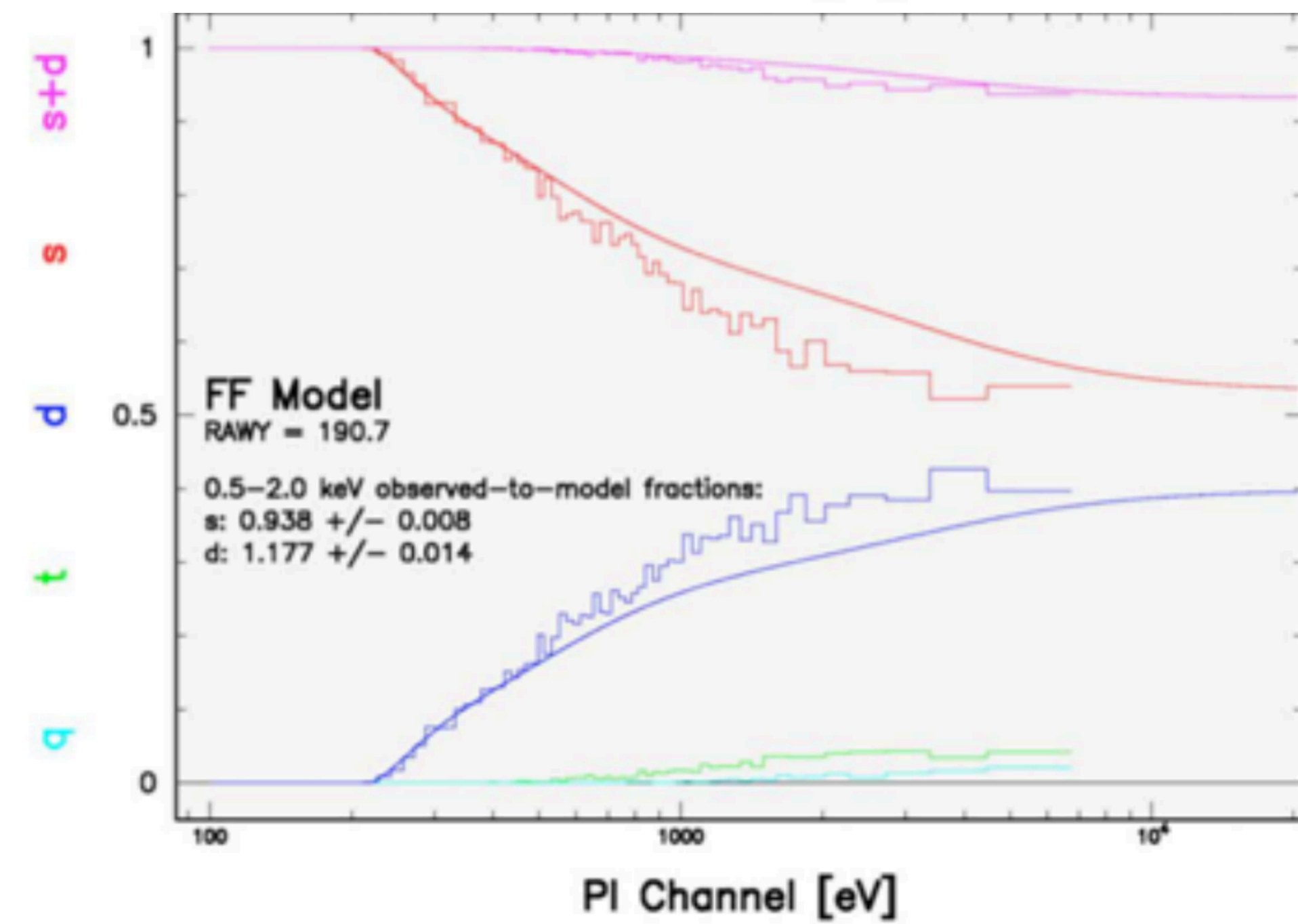
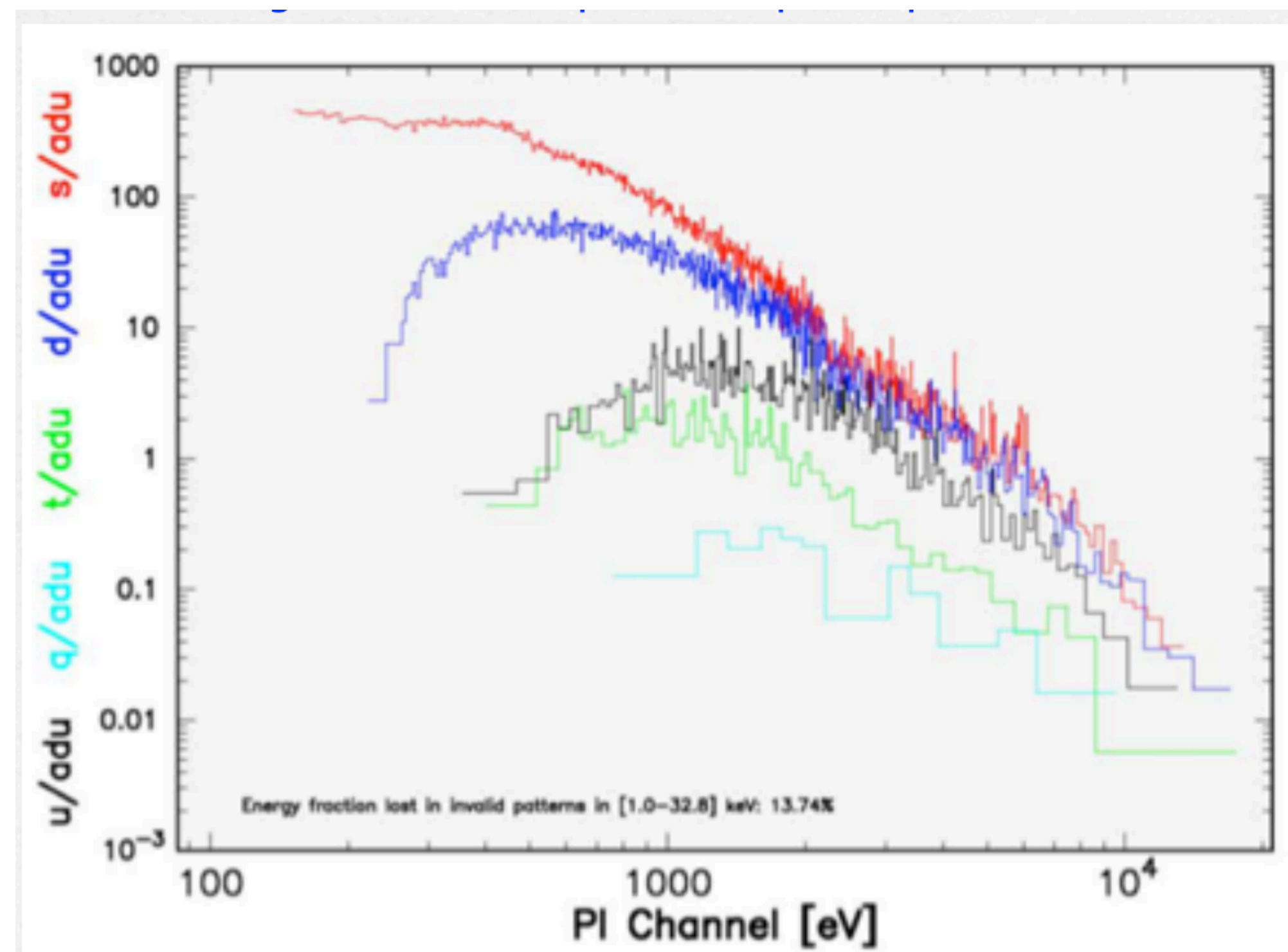
gimp **pnf_pat.gif**



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))'
```



source.reg

spectralbinsize= binning factor for spectral creation (size of each bin in instrumental eV)

specchannelmin= the minimum channel number to consider for spectrum creation

specchannelmax= the maximum channel number to consider for spectrum creation

Spectrum extraction

MOS 1

```
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))'
```

MOS 2

```
evselect table=mos2_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  
(25864.501,24541.104,700.00011))'
```



back.reg

Background extraction

MOS 1

```
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  
(25864.501,24541.104,700.00011))'
```

MOS 2

```
evselect table=mos2_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  
(25864.501,24541.104,700.00011))'
```

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**

MOS 1

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

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

MOS 2

backscale spectrumset=**source_spectrum.fits** badpixlocation=**mos2_new.evt**

backscale spectrumset=**back_spectrum.fits** badpixlocation=**mos2_new.evt**

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:

$$\text{AREA} = \text{GEOMETRIC AREA} - \text{CCD GAPS} - \text{BAD PIXELS}$$

```
fv: Header of source_spectrum.fits[1] in /blasco/users/torresi/LAB-X/Fall_2022/3C33_LABX/pn/
File Edit Tools Help
Search for: BACKSCAL Find Case sensitive? No
RESPFILE= 'NONE' / Name of response file
DSTYP1 = 'CCDNR' / data subspace descriptor: name
DSTYP2 = 'FLAG' / data subspace descriptor: name
DSTYP3 = 'PI' / data subspace descriptor: name
DSUNI3 = 'eV' / data subspace descriptor: units
DSTYP4 = 'TIME' / data subspace descriptor: name
DSUNI4 = 's' / data subspace descriptor: units
DSTYP5 = 'FLAG' / data subspace descriptor: name
DSTYP6 = 'PATTERN' / data subspace descriptor: name
DSTYP7 = 'POS (X, Y)' / data subspace descriptor: name
DSVAL1 = '1' / data subspace descriptor: value
DSFORM2 = 'X' / data subspace descriptor: data type
DSVAL2 = 'b00xx00000x0xxxxxxxxxxxxxxxxxxxx' / data subspace descriptor: value
DSVAL3 = '(150:' / data subspace descriptor: value
DSVAL4 = 'TABLE' / data subspace descriptor: value
DSREF4 = ':GTI00004' / data subspace descriptor: reference
DSVAL5 = '0' / data subspace descriptor: value
DSVAL6 = ':4' / data subspace descriptor: value
DSVAL7 = 'TABLE' / data subspace descriptor: value
DSREF7 = ':REG00107' / data subspace descriptor: reference
2DSVAL1 = '2' / data subspace descriptor: value
2DSREF4 = ':GTI00104' / data subspace descriptor: reference
3DSVAL1 = '3' / data subspace descriptor: value
3DSREF4 = ':GTI00204' / data subspace descriptor: reference
4DSVAL1 = '4' / data subspace descriptor: value
4DSREF4 = ':GTI00304' / data subspace descriptor: reference
5DSVAL1 = '5' / data subspace descriptor: value
5DSREF4 = ':GTI00404' / data subspace descriptor: reference
6DSVAL1 = '6' / data subspace descriptor: value
6DSREF4 = ':GTI00504' / data subspace descriptor: reference
7DSVAL1 = '7' / data subspace descriptor: value
7DSREF4 = ':GTI00604' / data subspace descriptor: reference
8DSVAL1 = '8' / data subspace descriptor: value
8DSREF4 = ':GTI00704' / data subspace descriptor: reference
9DSVAL1 = '9' / data subspace descriptor: value
9DSREF4 = ':GTI00804' / data subspace descriptor: reference
10DSVAL1 = '10' / data subspace descriptor: value
10DSREF4 = ':GTI00904' / data subspace descriptor: reference
11DSVAL1 = '11' / data subspace descriptor: value
11DSREF4 = ':GTI01004' / data subspace descriptor: reference
12DSVAL1 = '12' / data subspace descriptor: value
12DSREF4 = ':GTI01104' / data subspace descriptor: reference
MTYPE1 = 'POS' / DM Keyword: Descriptor name
MFORM1 = 'X, Y'
EXPOSURE= 6.27215711148456E+03 / Weighted live time of CCDs in the extraction re
BACKSCAL= 1542180 / Scaling factor for background
TLMIN1 = 0
TLMAX1 = 4095
END
BACKSCAL= 1542180 / Scaling factor for background
```

Source

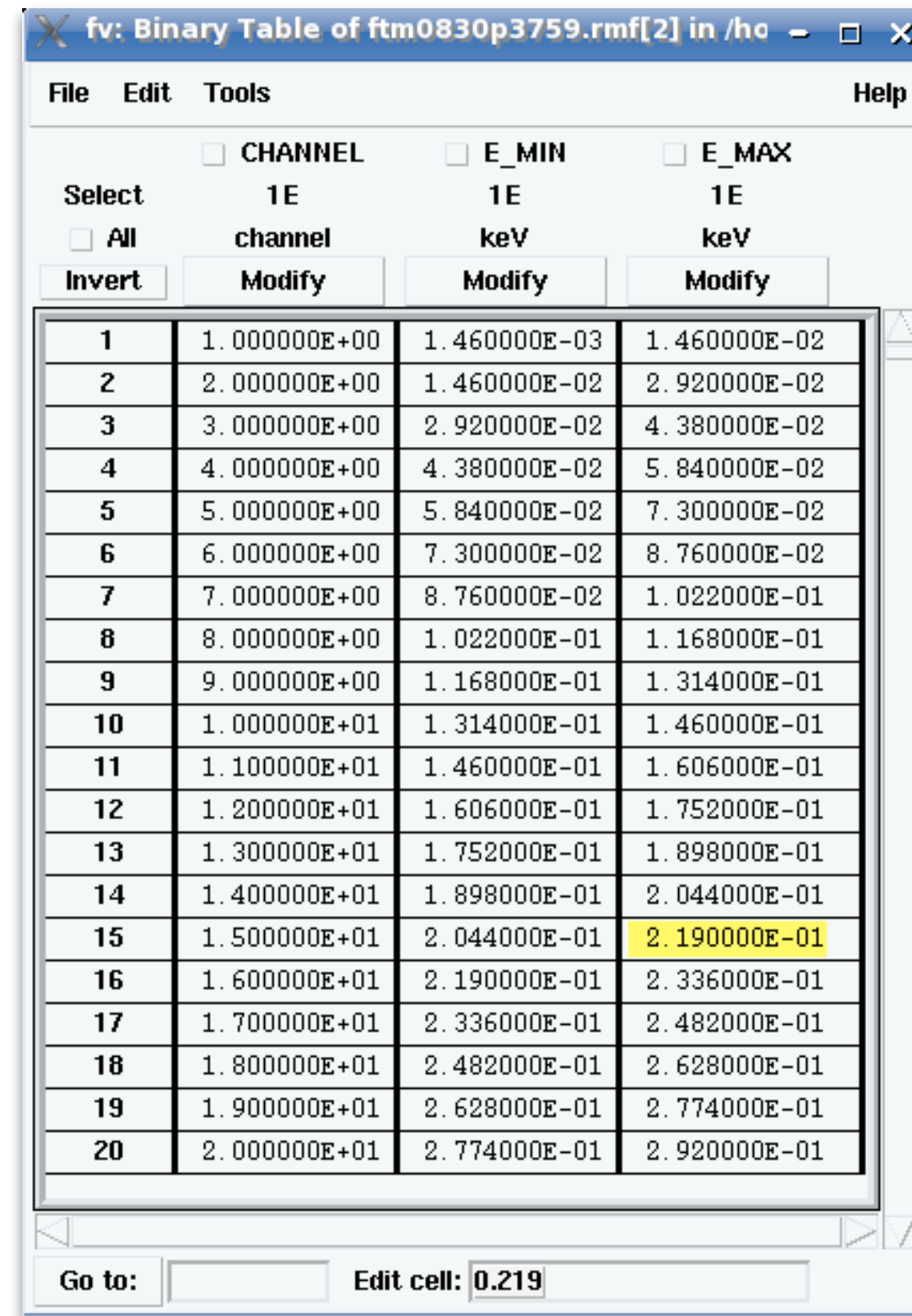
```
fv: Header of back_spectrum.fits[1] in /blasco/users/torresi/LAB-X/Fall_2022/3C33_LABX/pn/
File Edit Tools Help
Search for: Find Case sensitive? No
DSVAL2 = 'b00xx00000x0xxxxxxxxxxxxxxxxxxxx' / data subspace descriptor: value
DSVAL3 = '(150:' / data subspace descriptor: value
DSVAL4 = 'TABLE' / data subspace descriptor: value
DSREF4 = ':GTI00004' / data subspace descriptor: reference
DSVAL5 = '0' / data subspace descriptor: value
DSVAL6 = ':4' / data subspace descriptor: value
DSVAL7 = 'TABLE' / data subspace descriptor: value
DSREF7 = ':REG00107' / data subspace descriptor: reference
2DSVAL1 = '2' / data subspace descriptor: value
2DSREF4 = ':GTI00104' / data subspace descriptor: reference
3DSVAL1 = '3' / data subspace descriptor: value
3DSREF4 = ':GTI00204' / data subspace descriptor: reference
4DSVAL1 = '4' / data subspace descriptor: value
4DSREF4 = ':GTI00304' / data subspace descriptor: reference
5DSVAL1 = '5' / data subspace descriptor: value
5DSREF4 = ':GTI00404' / data subspace descriptor: reference
6DSVAL1 = '6' / data subspace descriptor: value
6DSREF4 = ':GTI00504' / data subspace descriptor: reference
7DSVAL1 = '7' / data subspace descriptor: value
7DSREF4 = ':GTI00604' / data subspace descriptor: reference
8DSVAL1 = '8' / data subspace descriptor: value
8DSREF4 = ':GTI00704' / data subspace descriptor: reference
9DSVAL1 = '9' / data subspace descriptor: value
9DSREF4 = ':GTI00804' / data subspace descriptor: reference
10DSVAL1 = '10' / data subspace descriptor: value
10DSREF4 = ':GTI00904' / data subspace descriptor: reference
11DSVAL1 = '11' / data subspace descriptor: value
11DSREF4 = ':GTI01004' / data subspace descriptor: reference
12DSVAL1 = '12' / data subspace descriptor: value
12DSREF4 = ':GTI01104' / data subspace descriptor: reference
MTYPE1 = 'POS' / DM Keyword: Descriptor name
MFORM1 = 'X, Y'
EXPOSURE= 6.27215711148456E+03 / Weighted live time of CCDs in the extraction re
BACKSCAL= 1540700 / Scaling factor for background
TLMIN1 = 0
TLMAX1 = 4095
END
BACKSCAL= 1540700 / Scaling factor for background
```

Background

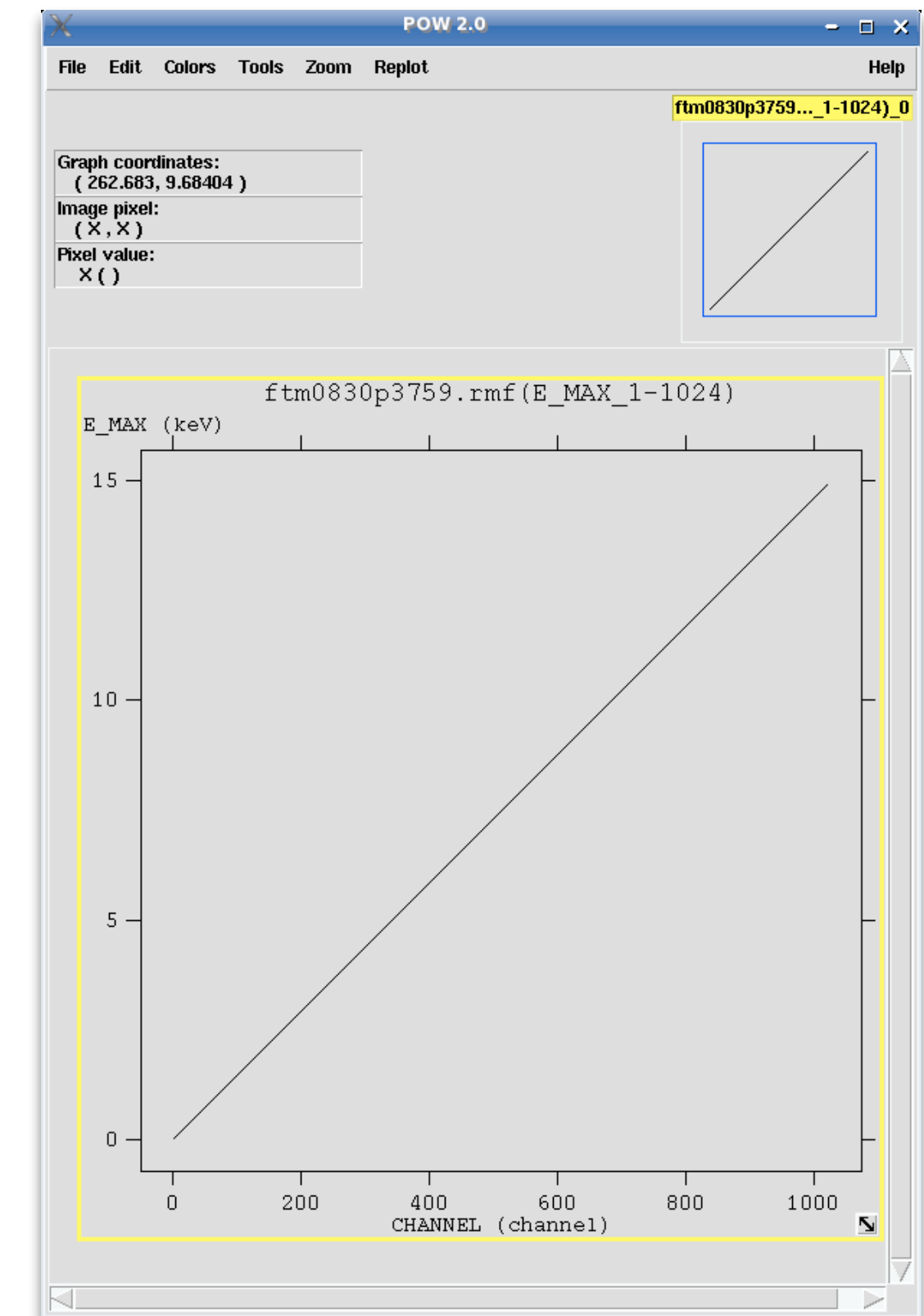
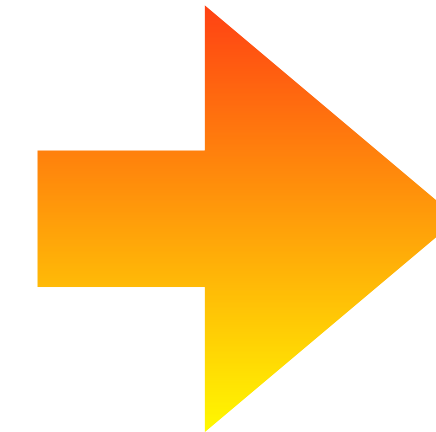
Redistribution Matrix File (RMF)

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

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



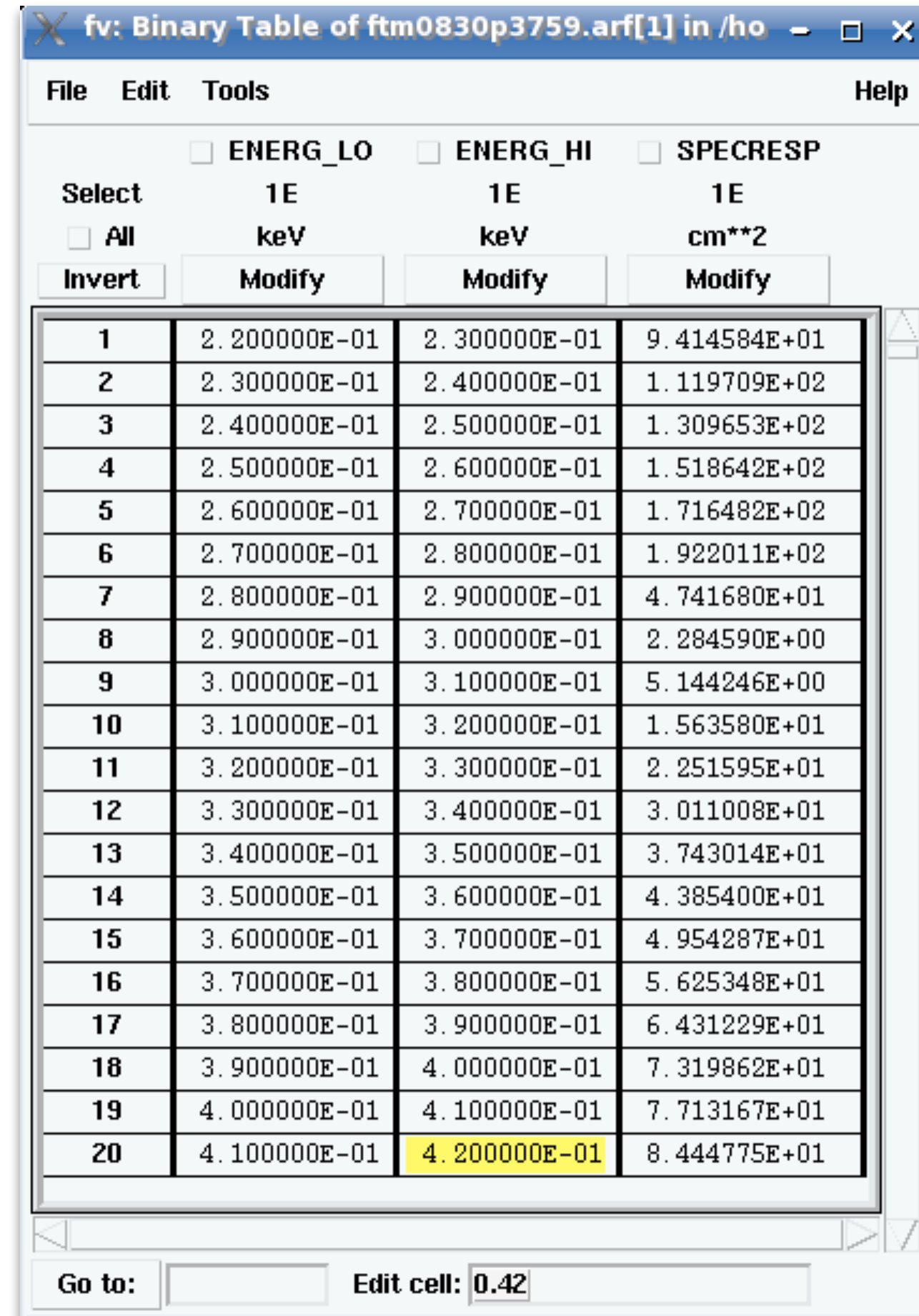
	CHANNEL	E_MIN	E_MAX
Select	1E	1E	1E
<input type="checkbox"/> All	channel	keV	keV
Invert	Modify	Modify	Modify
1	1.000000E+00	1.460000E-03	1.460000E-02
2	2.000000E+00	1.460000E-02	2.920000E-02
3	3.000000E+00	2.920000E-02	4.380000E-02
4	4.000000E+00	4.380000E-02	5.840000E-02
5	5.000000E+00	5.840000E-02	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



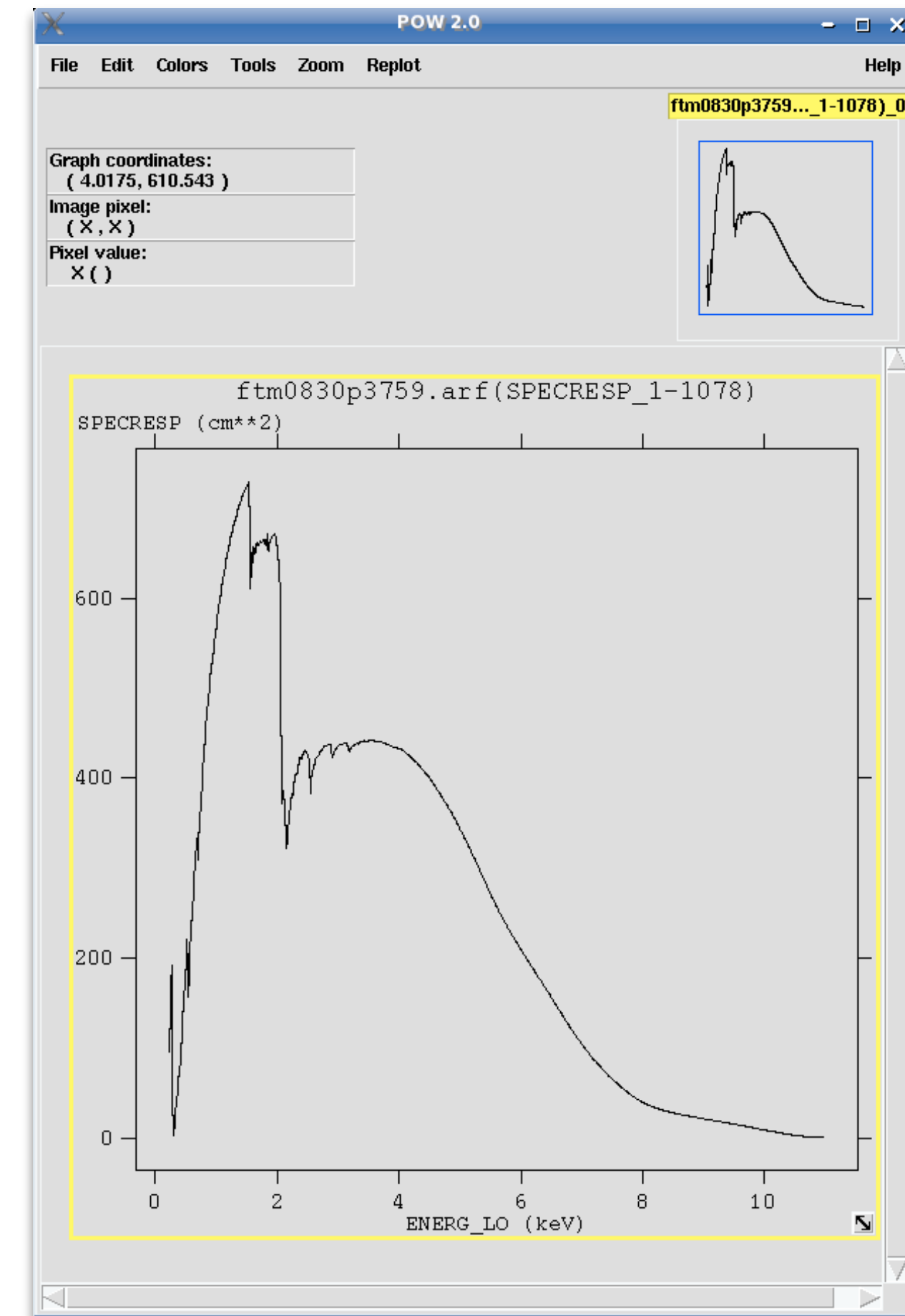
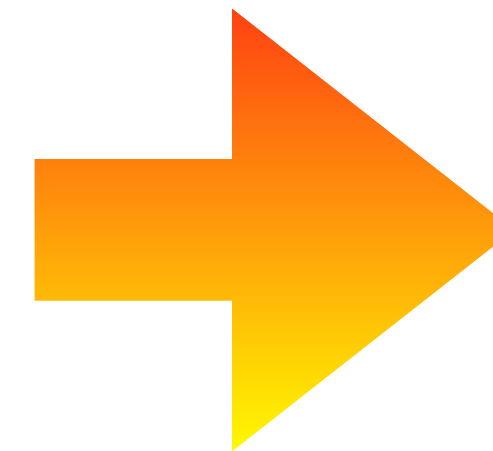
Ancillary Response File (ARF)

```
arfgen spectrumset=source_spectrum.fits arfset=pn.arf withrmfset=yes rmfset=pn.rmf  
badpixlocation=pn_new.evt detmaptype=psf (for point sources; for extended sources -> flat)
```

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

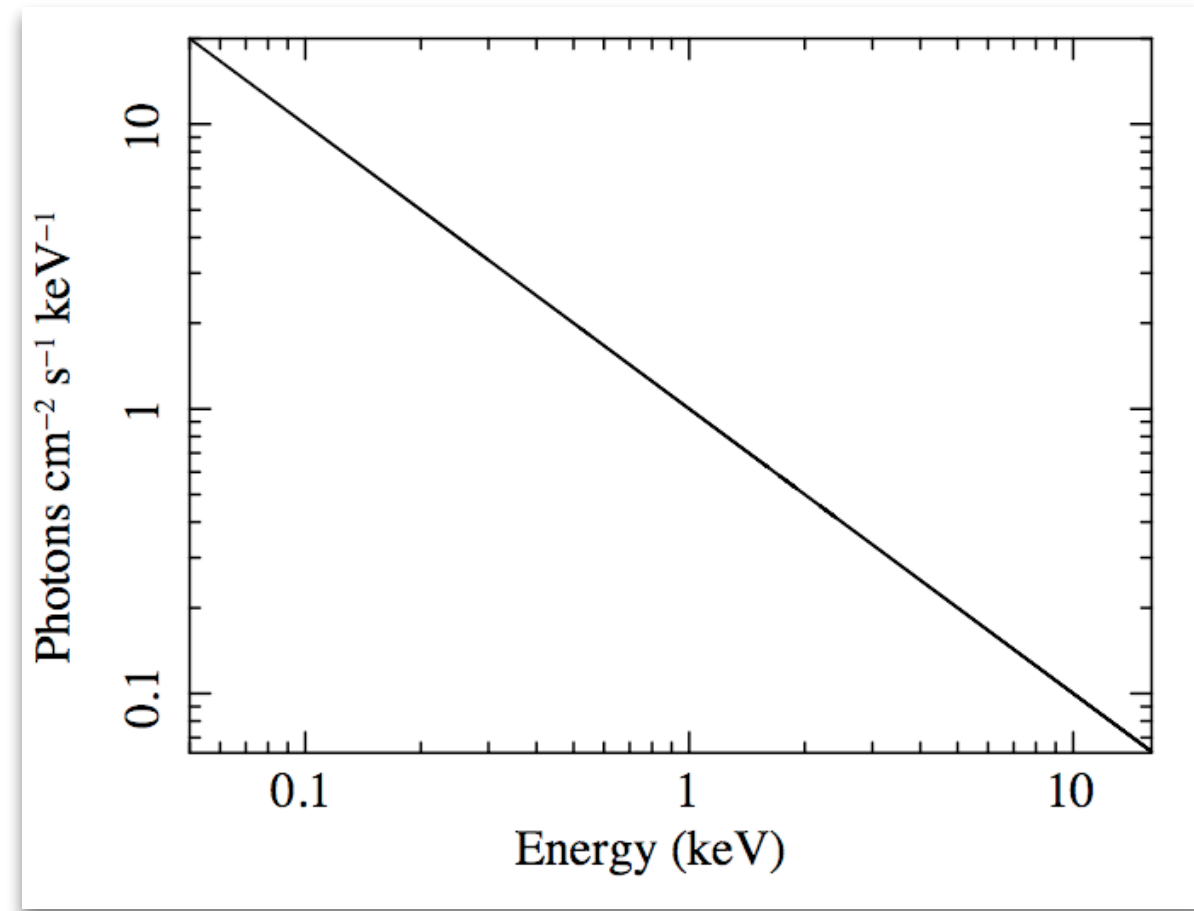


	ENERG_LO	ENERG_HI	SPECRESP
1	2.200000E-01	2.300000E-01	9.414584E+01
2	2.300000E-01	2.400000E-01	1.119709E+02
3	2.400000E-01	2.500000E-01	1.309653E+02
4	2.500000E-01	2.600000E-01	1.518642E+02
5	2.600000E-01	2.700000E-01	1.716482E+02
6	2.700000E-01	2.800000E-01	1.922011E+02
7	2.800000E-01	2.900000E-01	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

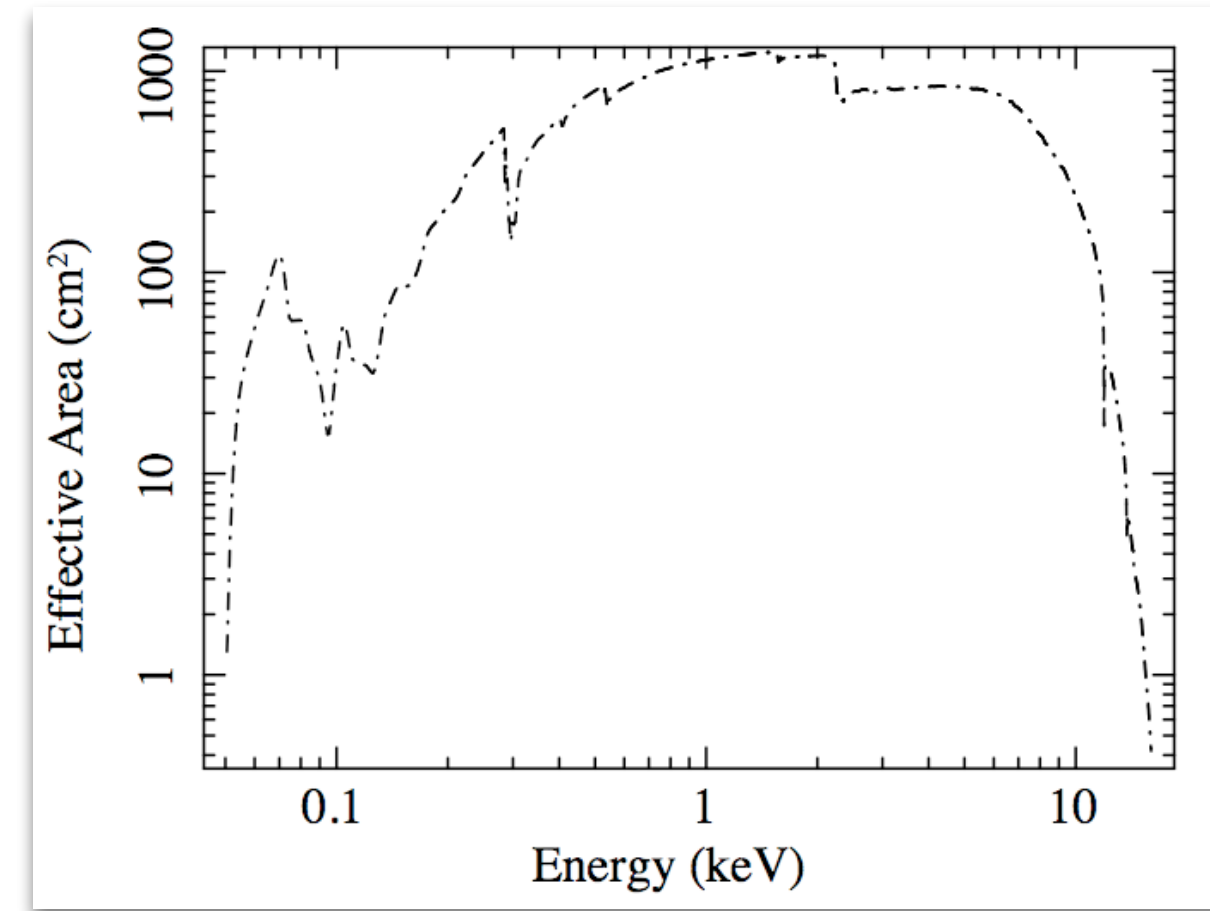


** arfgen: fatal error (NoCifSpecified), '/prod_oasbo/sas/xmmsas_20210317_1624/evt' is neither the name of a directory nor the name of a CIF
>export SAS_CCF='/blasco/users/gruppoXX/datadir/evt/ccf.cif'

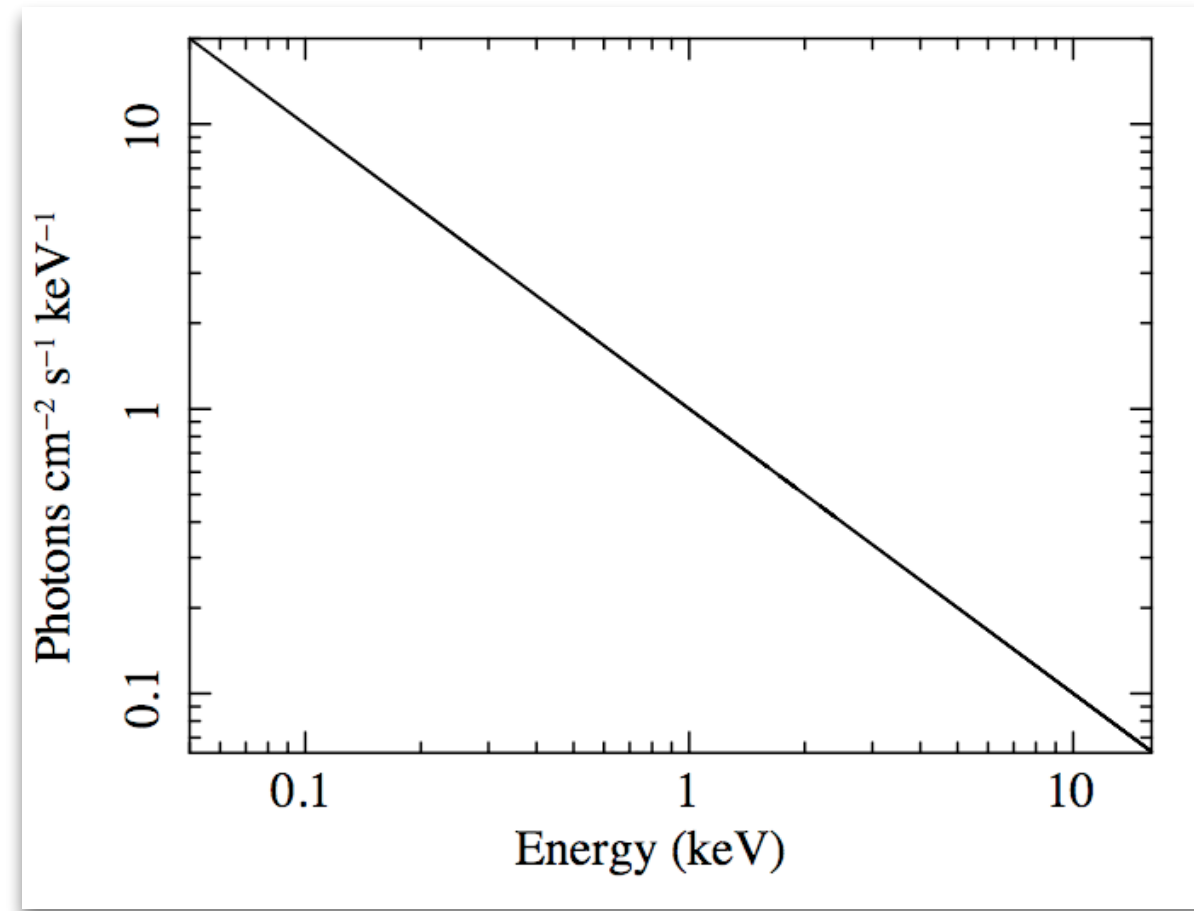
The combination of RMF and ARF produces the input spectrum weighted by telescope area and detector efficiencies versus energy



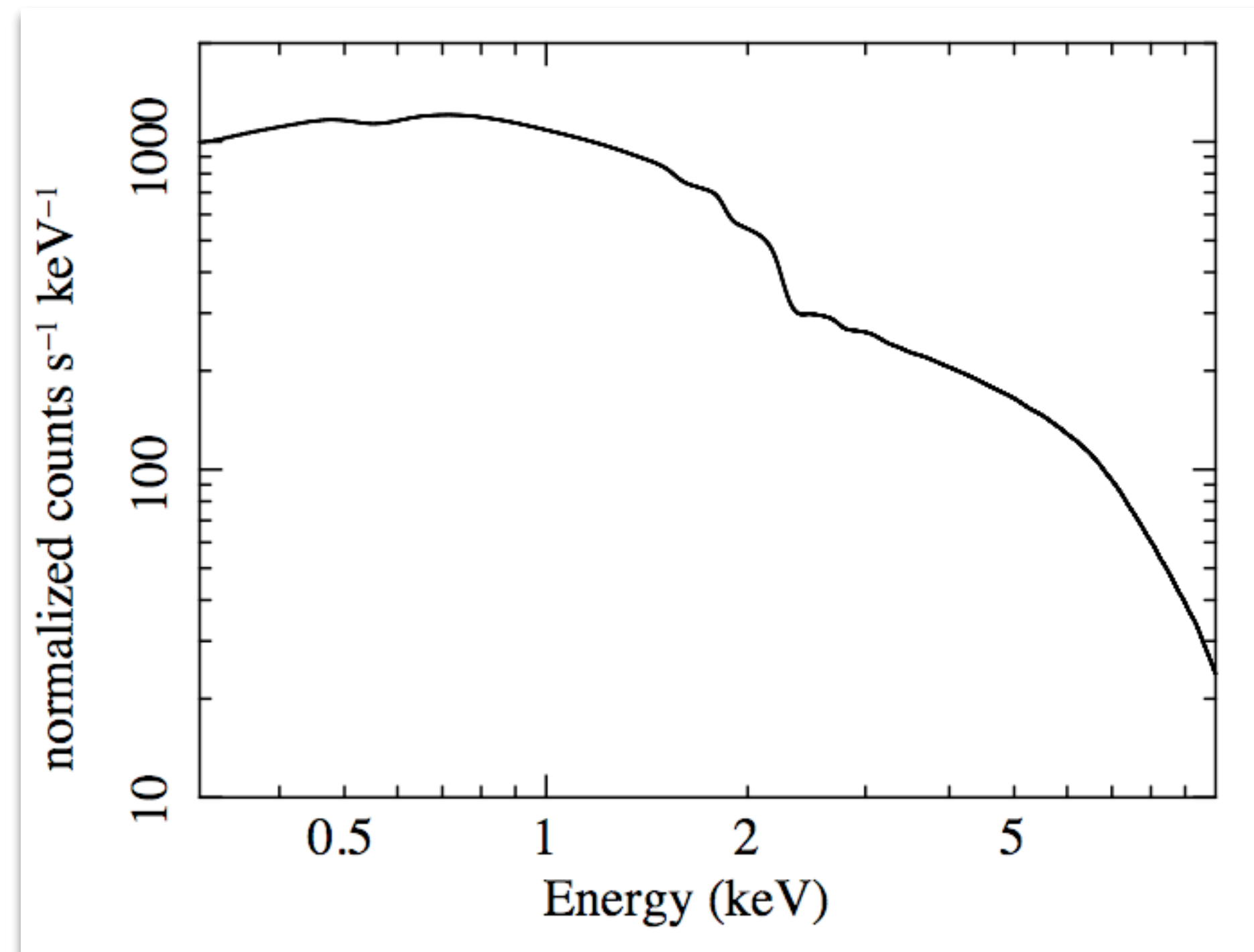
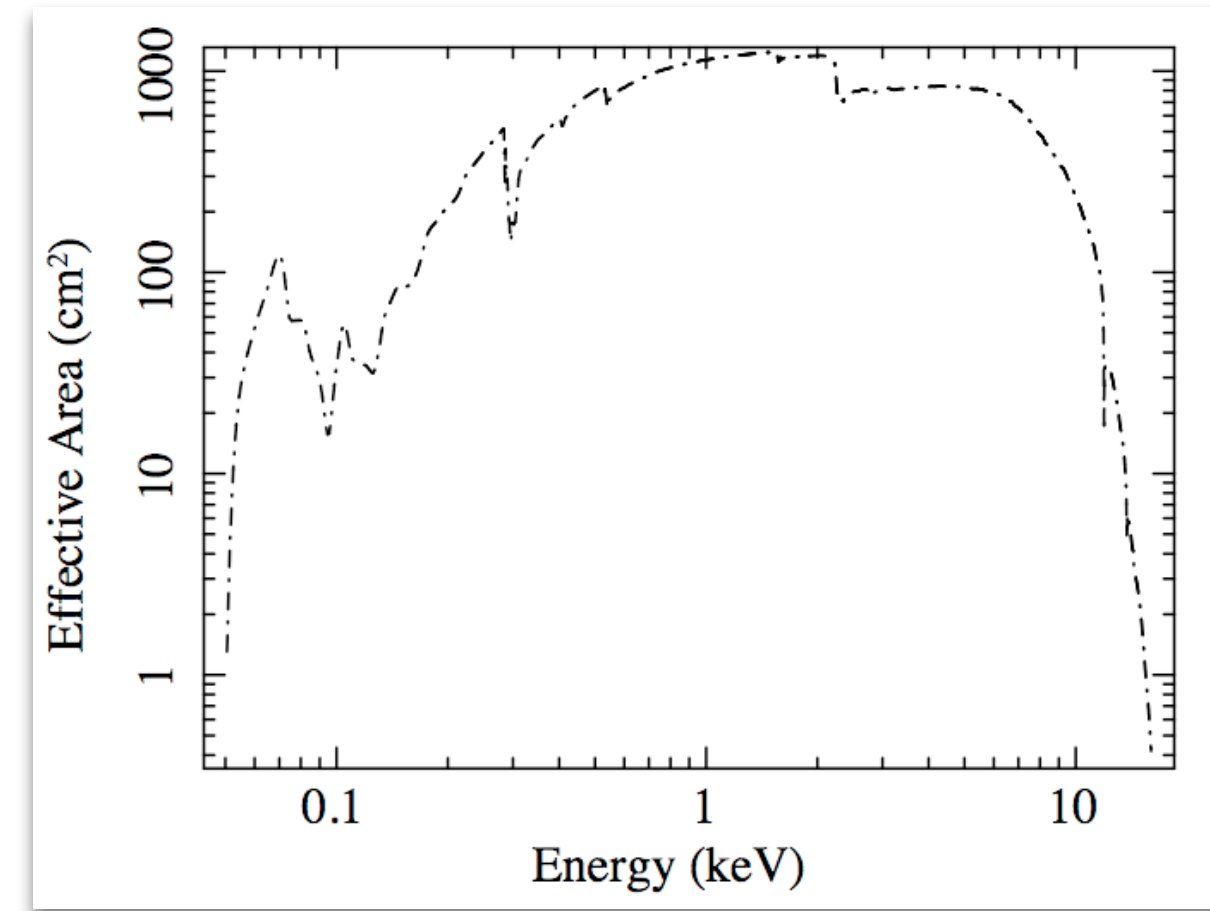
⊗



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



⊗



Grouping

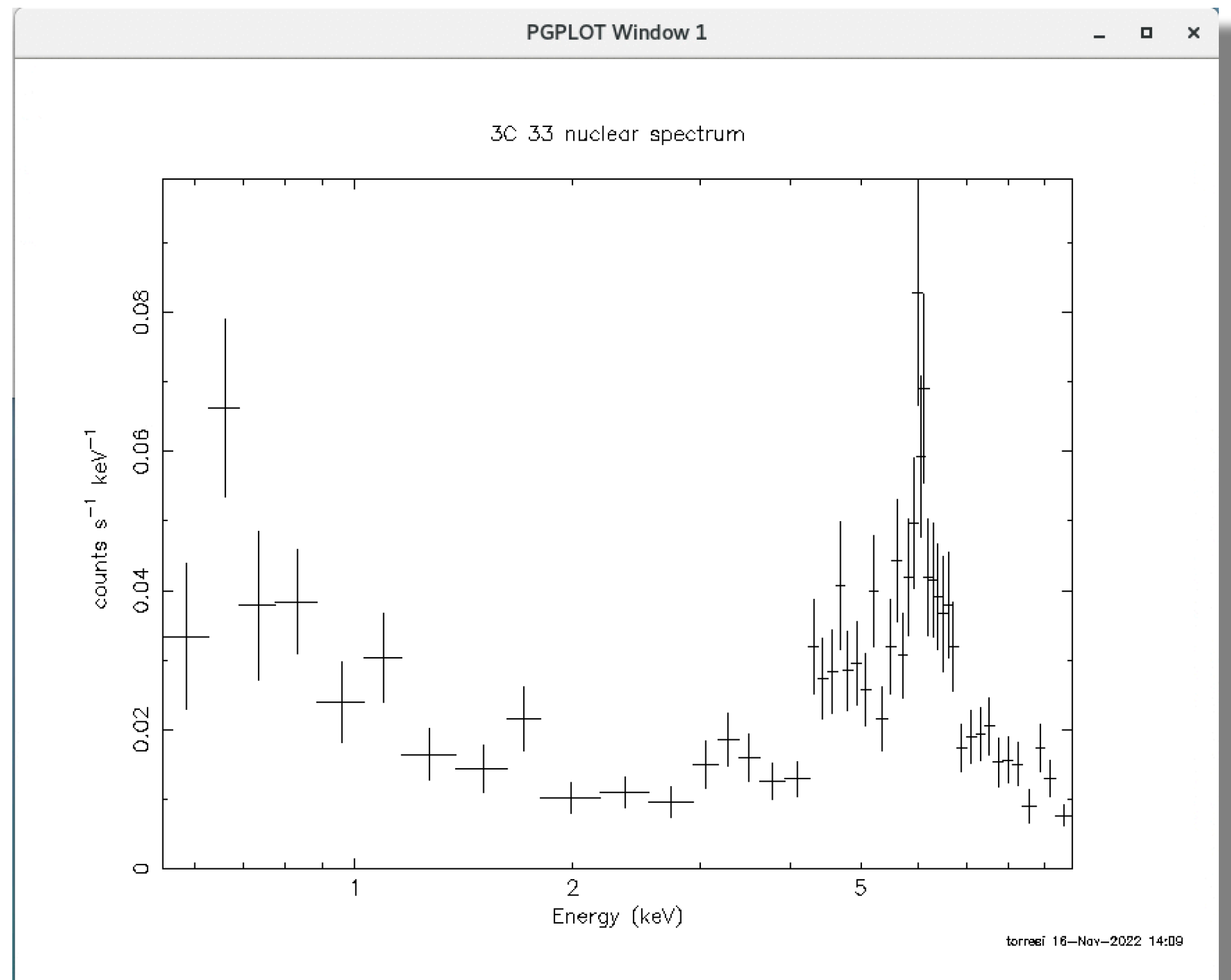
In order to apply the χ^2 statistics (Gaussian distribution) you need to have at least 25 counts in each bin of your spectrum. Otherwise Cash statistics (Poisson distribution) is preferred (see also Statistics Tutorial).

```
grppha source_spectrum.fits pn_25.grp comm="chkey RESPFILE pn.rmfile & 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

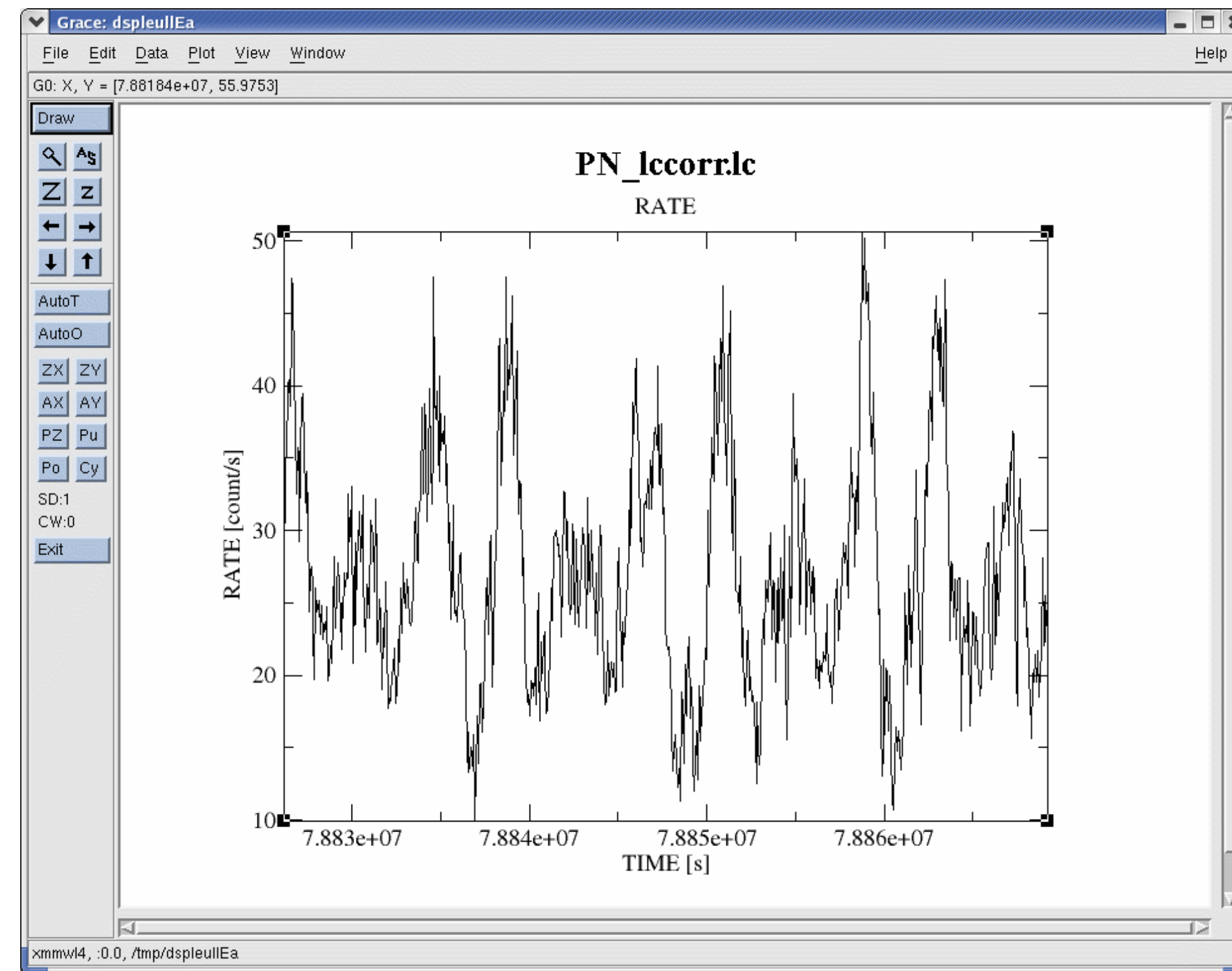
see XSPEC tutorial

Light curve

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 [2000:10000]))' withrateset=yes rateset="PN_source_lightcurve_raw.lc" timebinsize=100 maketimecolumn=yes  
makecolumn=yes
```

MOS 1

```
evselect table=mos1_new.evt energycolumn=PI expression='#XMMEA_EM&&(PATTERN<=12)&& ((X,Y) IN circle(25910.5,25870.5,400)&& (PI in [2000:10000]))' withrateset=yes rateset="MOS1_source_lightcurve_raw.lc" timebinsize=100 maketimecolumn=yes  
makecolumn=yes
```

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

MOS 2

```
evselect table=mos2_new.evt energycolumn=PI expression='#XMMEA_EM&&(PATTERN<=12)&& ((X,Y) IN circle(25910.5,25870.5,400)&& (PI in [2000:10000]))' withrateset=yes rateset="MOS2_source_lightcurve_raw.lc" timebinsize=100 maketimecolumn=yes  
makecolumn=yes
```

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 [2000:10000]))' withrateset=yes rateset="PN_light_curve_background_raw.lc" timebinsize=100 maketimecolumn=yes  
makecolumn=yes
```

MOS 1

```
evselect table=mos1_new.evt energycolumn=PI expression='#XMMEA_EM&&(PATTERN<=12)&& ((X,Y) IN circle(25910.5,25870.5,400)&& (PI in [2000:10000]))' withrateset=yes rateset="MOS1_light_curve_background_raw.lc" timebinsize=100 maketimecolumn=yes  
makecolumn=yes
```

MOS 2

```
evselect table=mos2_new.evt energycolumn=PI expression='#XMMEA_EM&&(PATTERN<=12)&& ((X,Y) IN circle(25910.5,25870.5,400)&& (PI in [2000:10000]))' withrateset=yes rateset="MOS2_light_curve_background_raw.lc" timebinsize=100 maketimecolumn=yes  
makecolumn=yes
```

source-background lightcurve: **epiclccorr**

pn

```
epiclccorr srctslst=PN_source_lightcurve_raw.lc eventlist=pn_new.evt outset=PN_lccorr.lc bkgtslist=PN_light_curve_background_raw.lc  
withbkgset=yes applyabsolute corrections=yes
```

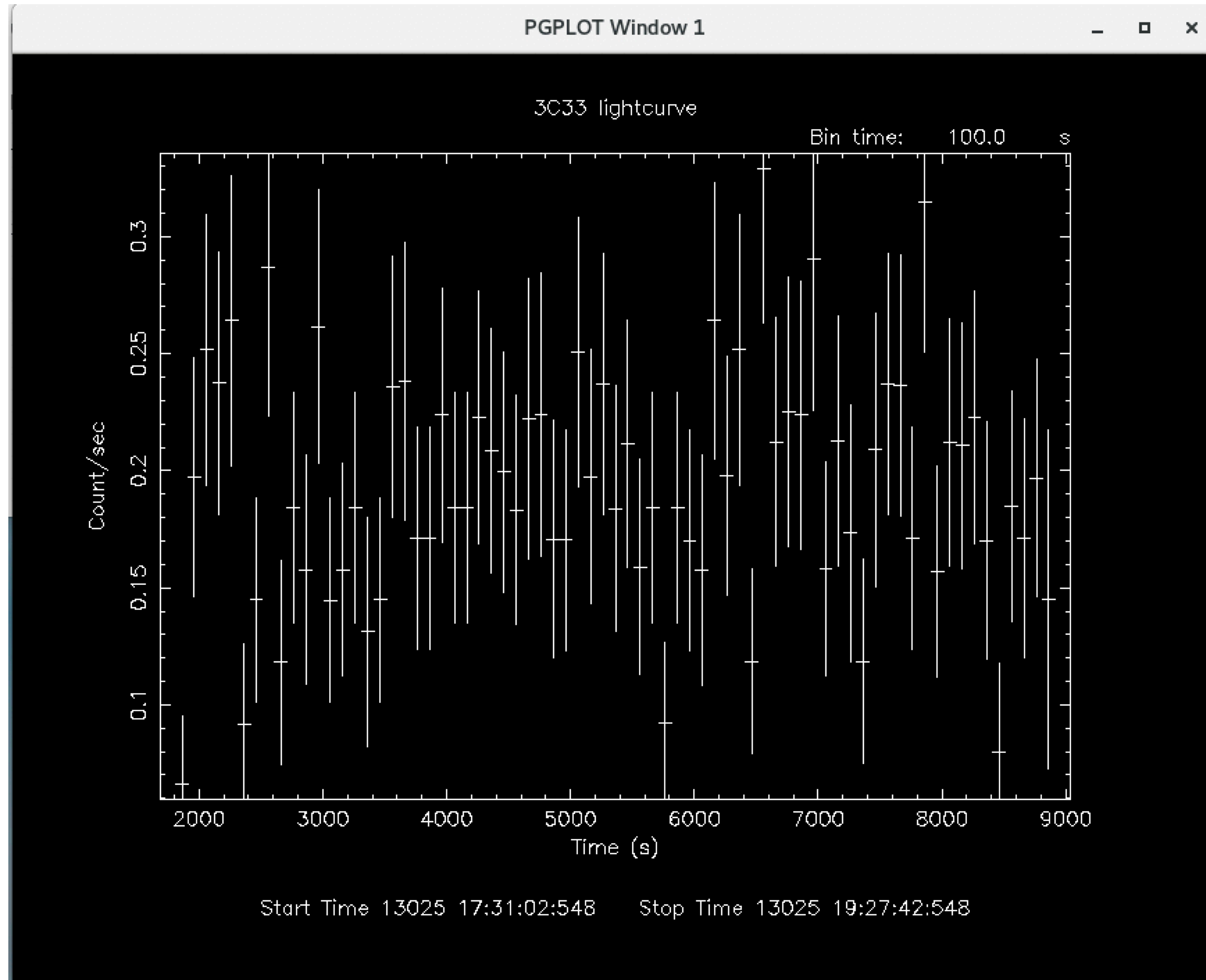
MOS 1

```
epiclccorr srctslst=MOS1_source_lightcurve_raw.lc eventlist=mos1_new.evt outset=MOS1_lccorr.lc  
bkgtslist=MOS1_light_curve_background_raw.lc withbkgset=yes applyabsolute corrections=yes
```

MOS 2

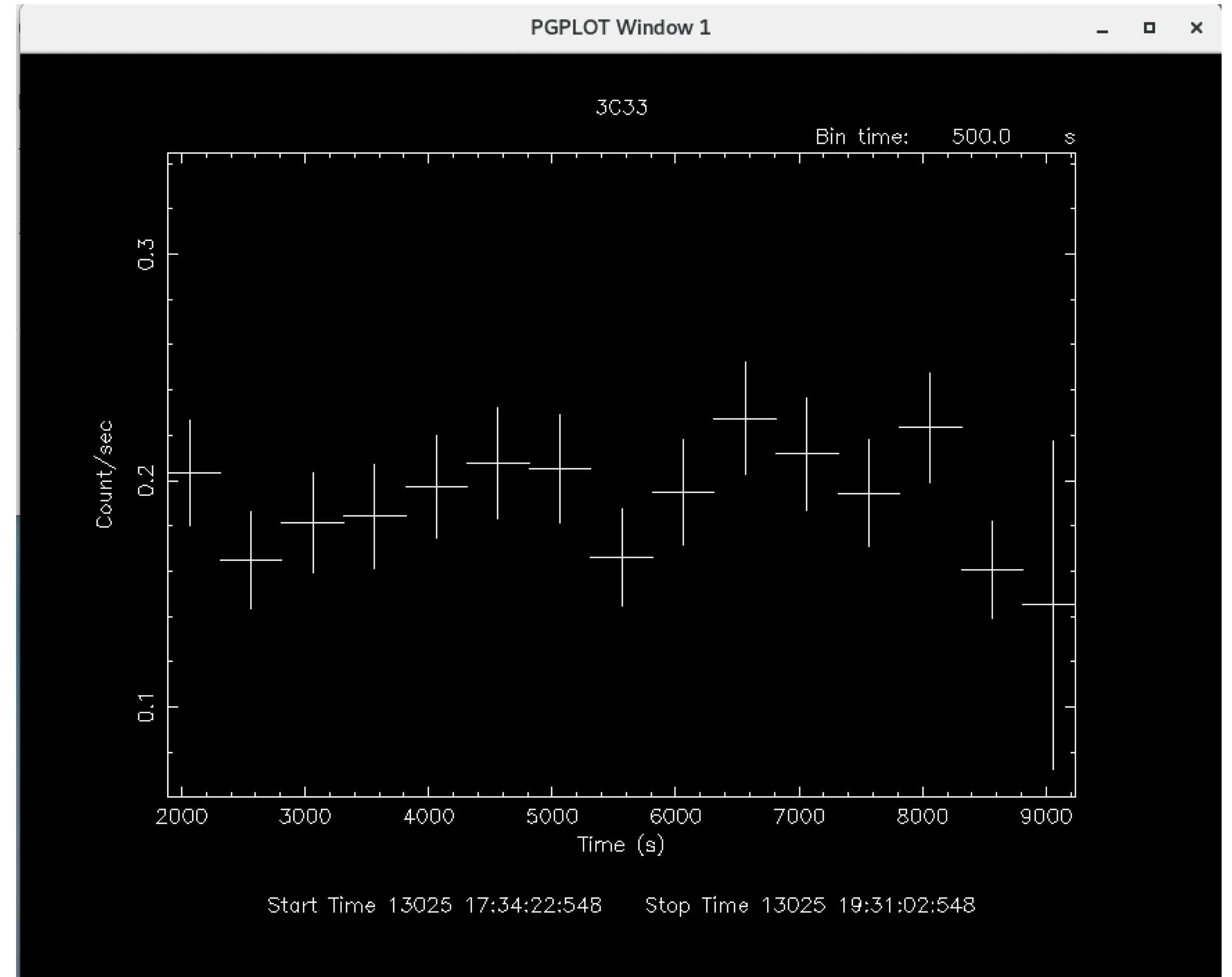
```
epiclccorr srctslst=MOS2_source_lightcurve_raw.lc eventlist=mos2_new.evt outset=MOS2_lccorr.lc  
bkgtslist=MOS2_light_curve_background_raw.lc withbkgset=yes applyabsolute corrections=yes
```


source-background lightcurve: **epiclcorr**



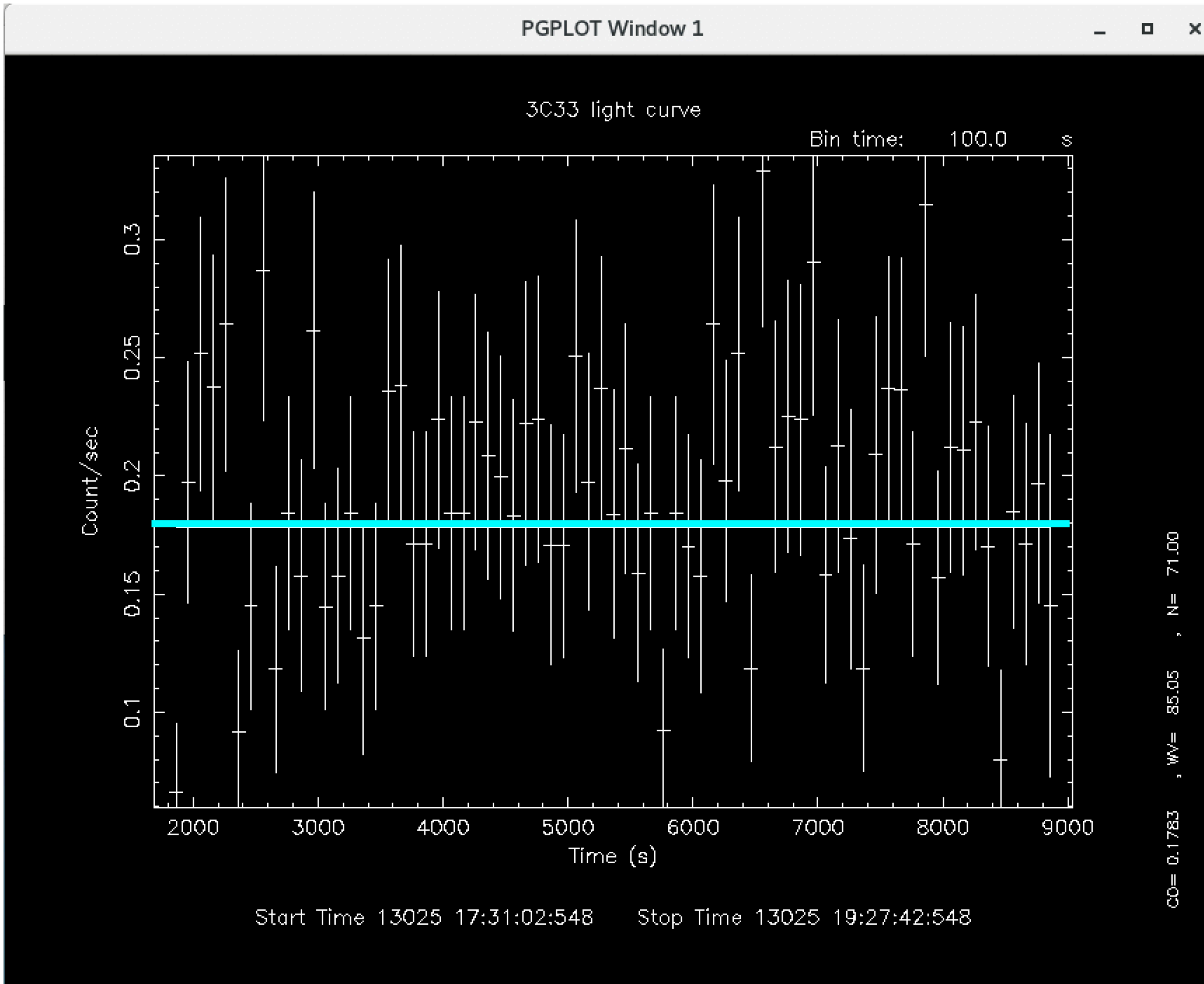
bin=100

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



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;
ν = n - 1: degrees of freedom;

```

PLT> mo con
  1 CO: VAL( 1.000 ), SIG( 0.000 ), PLO( 0.000 ), PHI( 0.000 )?

PLT> fit
Fitting group 2, from 1.688E+03 to 9.038E+03
Fitting 71 points in a band of 71.
  1.00000000
(-3) W-VAR= 85.07
(-4) W-VAR= 85.05
0.178321302
    
```

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 = (71-1)

The chance probability, Q , is:

$1-0.163=0.8937$ the source is variable at ~89% (the acceptance threshold for variability is 99.9%)