

# **RGS data reduction and analysis of point-like sources**

Rosario González-Riestra

XMM-Newton SOC  
ESAC

# Processing RGS data (I)

from....

FRAME

CCD, node, RAWX

CCD, node, RAWY

ENERGY

rgsproc

to...

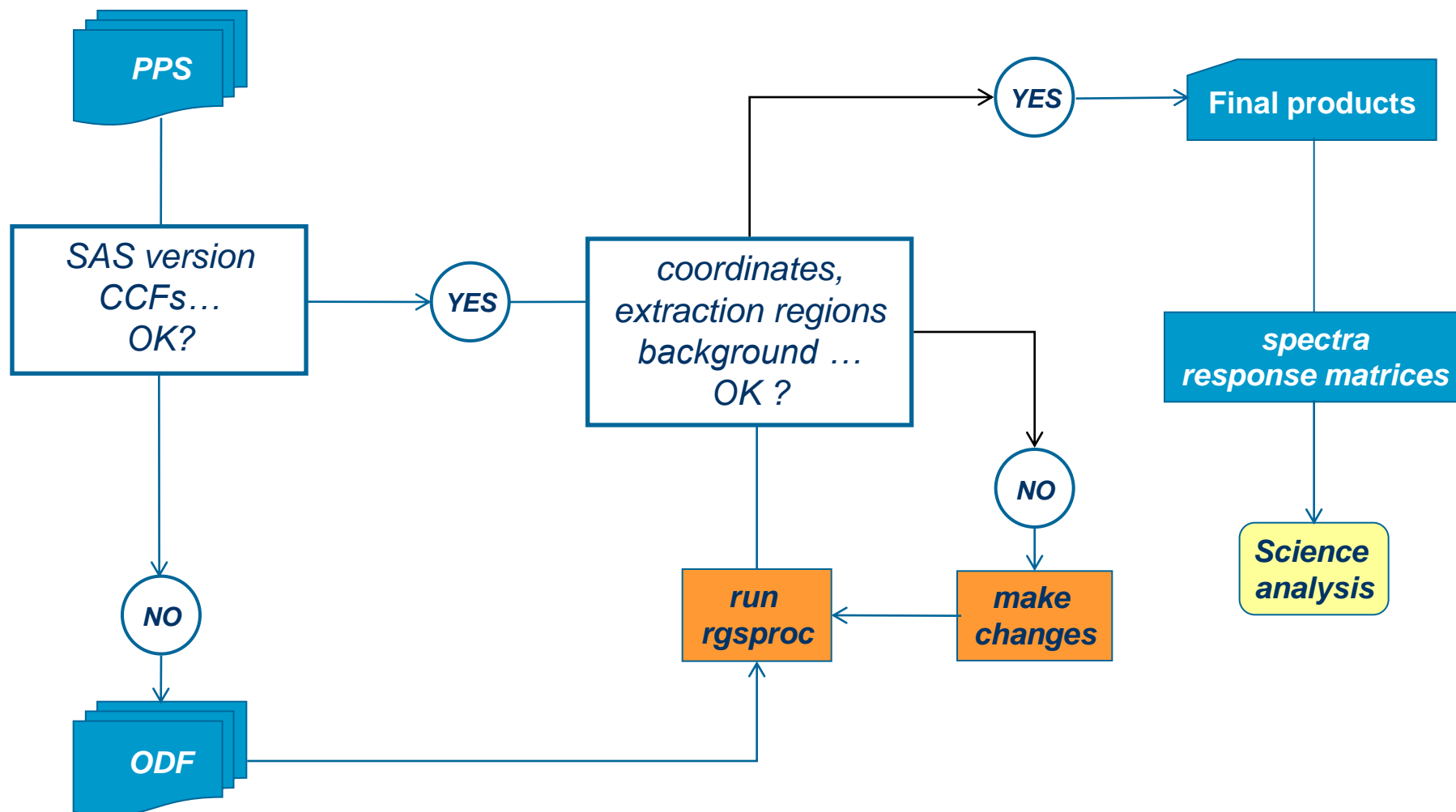
Time

Wavelength

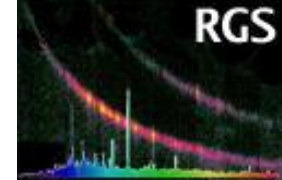
Cross Dispersion

Flux

# Processing RGS data (II)



# The RGS processing task: rgsproc



meta-task: interface to  $\approx 20$  SAS tasks (that can also be run separately)

controlled by  $\approx 80$  parameter switches

six entry and final points (*“processing stages”*)

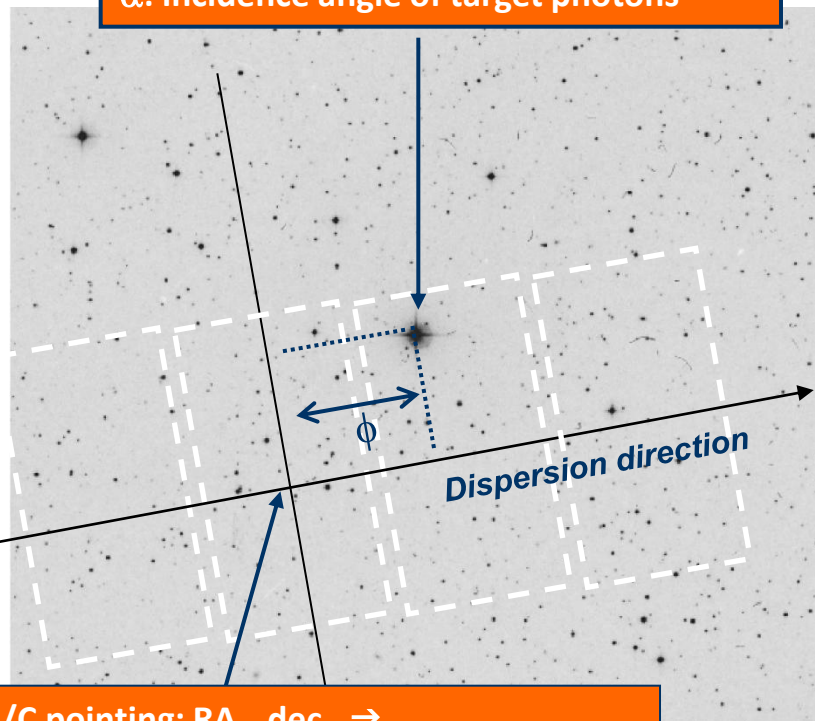
1:events	2:angles
3:filter	4:spectra
5:fluxing	6:lightcurve

produces filtered event lists, light curves, spectra and response matrices

the quality of the results depends critically on the accuracy of the coordinates of the source

# A simplified scheme of the RGS FOV (and why the coordinates are so important!)

Target coordinates: RA,dec →  
 $\alpha$ : incidence angle of target photons



S/C pointing: RA<sub>o</sub>, dec<sub>o</sub> →  
 $\alpha_o$ : incidence angle at centre of FOV

$$\lambda = (\cos \beta - \cos \alpha) d / m$$

*measured*                      *known*

$$\alpha = \alpha_o + \phi F / L$$

*known*                      *known*

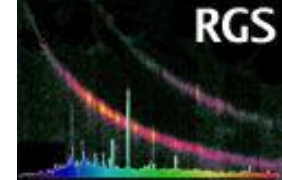
$$\phi = f(\text{RA, dec, RA}_o, \text{dec}_o, \text{P.A.})$$

*input to rgsproc*                      *known from S/C attitude history file*



the wavelength scale and the effective area depend on the position of the source in the FOV

$$1 \text{ arcsec} \approx 2.3 \text{ m\AA} \text{ (45 km/s at } 15 \text{ \AA)}$$



# rgsproc: what does it do?

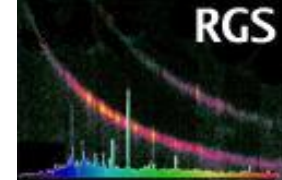
Stage	Task	Purpose	Output
<b>Events</b>	atthkgen	generates attitude file	<b>Source list and intermediate combined event list</b>
	attfilter	filters the attitude file	
	hkgtigen	generates housekeeping GTIs	
	rgsoffsetcalc	uses the diagnostic mode data for offset calculation	
	rgssources	creates the list of sources to processed	
	rgsframes	flags bad frames, convert RAW[XY] to readout node reference system , creates GTI for telemetry drops, calculates dead time	
	rgsenergy	performs energy calibrations, i.e. creates the PI column	
	rgsbadpix	flags bad pixels from CCF and from own analysis	
	rgsevents	reconstructs events: total energy ,pattern and coordinates	
	evlistcomb	concatenates event list	

*Source independent*

<b>Angles</b>	rgsangles	performs aspect correction	<b>Final event list</b>
<b>Filter</b>	rgsfilter	filters event list, removing unwanted frames and events and adding exposure maps	
<b>Spectra</b>	rgsregions	computes background and source extraction regions for each source	<b>Source and background spectra</b>
	rgsspectrum	extracts source and background spectra	
	rgsbkgmodel	generates model background	
<b>Fluxing</b>	rgsrmfgen	creates response matrix	<b>Response matrices and fluxed spectrum</b>
	rgsfluxer	combines several RGS spectra into a single "fluxed" spectrum	
<b>Lightcurve</b>	rgslccorr	creates background-subtracted light curves	<b>Light curve</b>

*Source dependent*

# rgsproc: parameters



entrystage -- optional,type=string,default=events; (re)start processing at

finalstage -- optional,type=string,default=fluxing; conclude processing at

withinstexpids -- optional,type=bool,default=no; include instexpid pixels

instexpids -- optional,type=list<string>; include instexpid pixels

orders -- optional,type=list<int>; constrain order to these values

expunge -- optional,type=list<string>; delete sources with these names

withprefix -- optional,type=bool,default=no; include sources with prefix

prefix -- optional,type=string; prefix for sources to include

timestep -- optional,type=real,constraints="timestep in [0:1000]",default=100; time step in seconds

driftlimit -- optional,type=real,constraints="driftlimit in [0:1000]",default=100; drift limit in seconds

withepicset -- optional,type=bool,default=no; include sources in epicset

epicset -- optional,type=dataset; name of epicset to include

withsrc -- optional,type=bool,default=no; include sources with src

srclabel -- optional,type=string,default=; label for sources to include

srcrate -- optional,type=real,constraints="srcrate in [0:1000]",default=100; source rate in counts/s

srcstyle -- optional,type=string,default=; style for sources to include

srcra -- optional,type=real,default=-99; right ascension in degrees

srcdec -- optional,type=real,default=-99; declination in degrees

srcdisp -- optional,type=real,default=0; dispersion in eV

srcxdsp -- optional,type=real,default=0; x-dispersion in eV

attstyle -- optional,type=string,default=; attenuation style

attra -- optional,type=real,default=-99; attenuation in dB

attdec -- optional,type=real,default=-99; attenuation in dB

attapos -- optional,type=real,default=-99; attenuation in dB

calcoffsets -- optional,type=bool,default=no; use calibration offsets

withoffsethistogram -- optional,type=bool,default=no; use offset histogram

withdiagoffset -- optional,type=bool,default=no; use diagonal offset

withgain -- optional,type=bool,default=no; use gain

withcti -- optional,type=bool,default=no; use CTI

withadvisory -- optional,type=bool,default=no; use advisory

withfoundhot -- optional,type=bool,default=yes; include found hot pixels

pixnoiselimit -- optional,type=real,constraints="pixnoiselimit in [0:1000]",default=100; pixel noise limit in counts/s

colnoiselimit -- optional,type=real,constraints="colnoiselimit in [0:1000]",default=100; column noise limit in counts/s

pixsharpness -- optional,type=real,constraints="pixsharpness in [0:1000]",default=100; pixel sharpness in counts/s

colsharpness -- optional,type=real,constraints="colsharpness in [0:1000]",default=100; column sharpness in counts/s

detcoord -- optional,type=real,constraints="detcoord in [0:1000]",default=100; detector coordinate in counts/s

withdetcoord -- optional,type=bool,default=no; include detector coordinate

reconstruct -- optional,type=bool,default=no; reconstruct sources

betabinning -- optional,type=string,default=; betabinning method

betabinref -- optional,type=string,default=; betabinning reference

betabinwidth -- optional,type=real,constraints="betabinwidth in [0:1000]",default=100; betabinning width in counts/s

nbetabins -- optional,type=int,constraints="nbetabins in [1:1000]",default=1; number of betabinning bins

betamin -- optional,type=real,constraints="betamin in [0:1000]",default=100; betabinning minimum

betamax -- optional,type=real,constraints="betamax in [0:1000]",default=100; betabinning maximum

xdispbining -- optional,type=string,default=; x-dispersion binning method

xdispbins -- optional,type=int,constraints="xdispbins in [1:1000]",default=1; number of x-dispersion bins

xdispbwidth -- optional,type=real,constraints="xdispbwidth in [0:1000]",default=100; x-dispersion width in counts/s

nxdispbins -- optional,type=int,constraints="nxdispbins in [1:1000]",default=1; number of nx-dispersion bins

xdispmid -- optional,type=real,constraints="xdispmid in [0:1000]",default=100; x-dispersion mid in counts/s

xdispmid -- optional,type=real,constraints="xdispmid in [0:1000]",default=100; x-dispersion mid in counts/s

withpointingcolumn -- optional,type=bool,default=no; use pointing column

withmlambdacolumn -- optional,type=bool,default=no; use mlambdacolumn

rejflags -- optional,type=bool,default=no; use rejection flags

driftbinsize -- optional,type=real,constraints="driftbinsize in [0:1000]",default=100; drift bin size in seconds

withcombmap -- optional,type=bool,default=no; use comb map

auxgtitables -- optional,type=string,default=; auxiliary tables

spatialres -- optional,type=int,constraints="spatialres in [2:]",default=5; vertices per node across spatial regions

orderres -- optional,type=int,constraints="orderres in [2:]",default=3; vertices per node across order regions

xpsfincl -- optional,type=real,constraints="xpsfincl in [0:100]",default=90; percent of cross-dispersion PSF included

xpsfexcl -- optional,type=real,constraints="xpsfexcl in [0:100]",default=95; percent of cross-dispersion PSF excluded from background

pdistincl -- optional,type=real,constraints="pdistincl in [0:100]",default=90; percent of pulse-height distribution included

prosrcsexpr -- optional,type=string,default=INDEX==#PRIMESRC; select which sources to process

exclsrcsexpr -- optional,type=string,default=INDEX==#PRIMESRC; select which sources to exclude from background

bkgcorrect -- optional,type=bool,default=yes; background correct the spectra

withbkgset -- optional,type=bool,default=yes; generate background spectra

edgechannels -- optional,type=int,constraints="edgechannels in [0:]",default=2; flag chip-edge channels as dubious

rebin -- optional,type=int,constraints="rebin in [1:]",default=1; dispersion channel rebinning factor

withfracexp -- optional,type=bool,default=no; add FRAC\_EXP column to output files

exposed -- optional,type=real,constraints="exposed in [0:1]",default=0.1; minimum good fractional exposure

badquality -- optional,type=int,constraints="badquality in [0:5]",default=1; QUALITY used to flag bad channels

rmfbins -- optional,type=int,constraints="rmfbins in [1:]",default=4000; number of response energy bins

ftdim -- optional,type=int,constraints="ftdim in [1:5]",default=3; convolution size exponent

withmirrorpsf -- optional,type=bool,default=yes; whether to include the standard mirror PSF distribution

angdistset -- optional,type=file,default=angdist.txt; user-defined angular distribution file

withangdist -- optional,type=bool,default=no; whether to include a custom angular distribution

mergeorders -- optional,type=bool,default=no; flux all orders together

flxformat -- optional,type=string,default=dal; output file format

flxmode -- optional,type=string,default=wavelength; computational mode

flxmin -- optional,type=real,constraints="flxmin in [0:]",default=4; minimum output wavelength or energy

flxmax -- optional,type=real,constraints="flxmax in [0:]",default=39; maximum output wavelength or energy

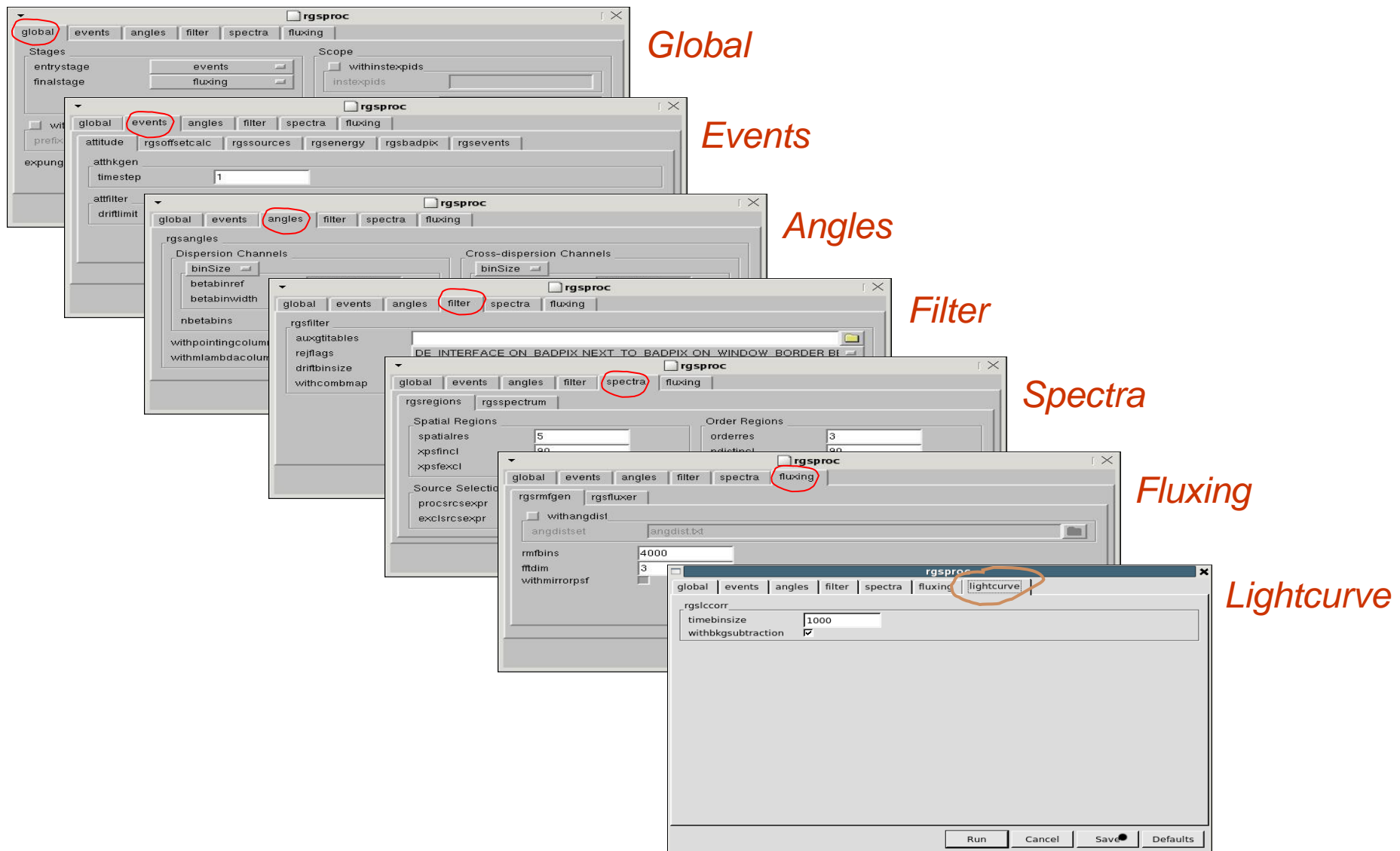
flxbins -- optional,type=int,constraints="flxbins in [1:]",default=3400; number of output bins

flxquality -- optional,type=list<int>,constraints="flxquality in [0:5]",default=0; usable quality in promotion order

withflxnan -- optional,type=bool,default=no; enable alternate NaN value

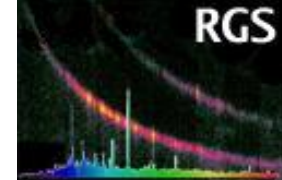
flxnan -- optional,type=real,default=0; alternate NaN value

# rgsproc: the GUI





# What do I get after the processing?



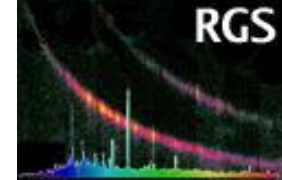
## For each RGS and exposure:

File	Content	rgsproc (default)	PPS
P0123456701R1S004EVENLI0000.FIT	Filtered Event List	Y	Y
P0123456701R1S004SRCLI_0000.FIT	Source List	Y (coord from proposal)	Y (coord from EPIC src list)
P0123456701R1S004BGSPEC1001.FIT P0123456701R1S004BGSPEC2001.FIT	Background Spectra (1 <sup>st</sup> and 2 <sup>nd</sup> order)	Y	Y
P0123456701R1S004SRSPEC1001.FIT P0123456701R1S004SRSPEC2001.FIT	Source Spectra (1 <sup>st</sup> and 2 <sup>nd</sup> order)	N	Y
P0123456701R1S004SBSPEC1001.FIT P0123456701R1S004SBSPEC2001.FIT	Source+Bkg Spectra (1 <sup>st</sup> and 2 <sup>nd</sup> order)	Y	Y
P0123456701R1S004RSPMAT1001.FIT P0123456701R1S004RSPMAT2001.FIT	Response Matrices (1 <sup>st</sup> and 2 <sup>nd</sup> order)	Y	only for 1 <sup>st</sup> order
P0123456701R1S004IMAGE_0000.FIT P0123456701R1S004IMAGE_0000.PNG	Dispersion-CrossDispersion Image	N	Y
P0123456701R1S004ORDIMG0000.FIT P0123456701R1S004ORDIMG0000.PNG	Dispersion-Energy Image	N	Y
P0123456701R1S004EXPMAP0000.FIT	Exposure Map	Y	Y
P0123456701R1S004FBKTSR0000.FIT	Flare Background Timeseries	N	Y
P0123456701R1S004MBSPEC1000.FIT P0123456701R1S004MBSPEC2000.FIT	Model Background Spectra	N	Y
P0123456701R1S004SRTSR_1001.FIT P0123456701R1S004BGTSR_1001.FIT	Source and Background Lightcurves	Y	Y

## For each observation:

File	Content	rgsproc (default)	PPS
P0123456701OBX000fluxed1000.FIT P0123456701OBX000fluxed2000.FIT	Source Fluxed Spectra (1 <sup>st</sup> and 2 <sup>nd</sup> order)	Y	Y

# The filtered event list



**XmmSelect**

File Column Region Viewer Products Style Help

Selection expression

Import

Fixed Expression

Column selection [P0134720101R2S008EVENLI0000.FIT.EVENTS]

<input type="checkbox"/>	TIME	R64	min:	
<input type="checkbox"/>	FLAG	I32	min: [8]	[8]
<input type="checkbox"/>	BETA	R32	min:	
<input type="checkbox"/>	XDSP	R32	min:	
<input type="checkbox"/>	CHIPX	I16	min: [2]	[2]
<input type="checkbox"/>	CHIPY	I16	min: [2]	[2]
<input type="checkbox"/>	PHA	I16	min: [215]	[215]
<input type="checkbox"/>	SHAPE	I8	min: [0]	[0]
<input type="checkbox"/>	GRADE	I8	min: [1]	[1]
<input checked="" type="checkbox"/>	PI	I16	min: [74]	[74]
<input type="checkbox"/>	CCDNR	I8	min: [1]	[1]
<input checked="" type="checkbox"/>	BETA_CORR	R32	min:	
<input type="checkbox"/>	XDSP_CORR	R32	min:	
<input type="checkbox"/>	BETA_CHANNEL	I16	min: [1]	[1]
<input type="checkbox"/>	XDSP_CHANNEL	I16	min: [1]	[1]

Region selection

1D region

Product selection

Filtered Table Fix Expression Image

OGIP Spectrum OGIP Rate Curve

**SAOImage Ds9-rgonzale**

File Edit Frame Bin Zoom Scale Color Region WCS Analysis Help

File image.ds

Object Capella

Low 0 High 139

Value 7

linear 0.054 -0.000

Physical X 0.054 Y -0.000

Image X 276.511 Y

Frame1 Zoom 1.464 Ang

align wcs in

M\_LAMBDA vs PI: Order Image

**SAOImage Ds9-rgonzale**

File Edit Frame Bin Zoom Scale Color Region WCS Analysis Help

File image.ds

Object Capella

Low 0 High 403

Value 4

linear 0.054 1314.223

Physical X 0.054 Y 1314.223

Image X 278.507 Y 155.590

Frame1 Zoom 1.564 Ang 0.000

align wcs in out center none x y xy

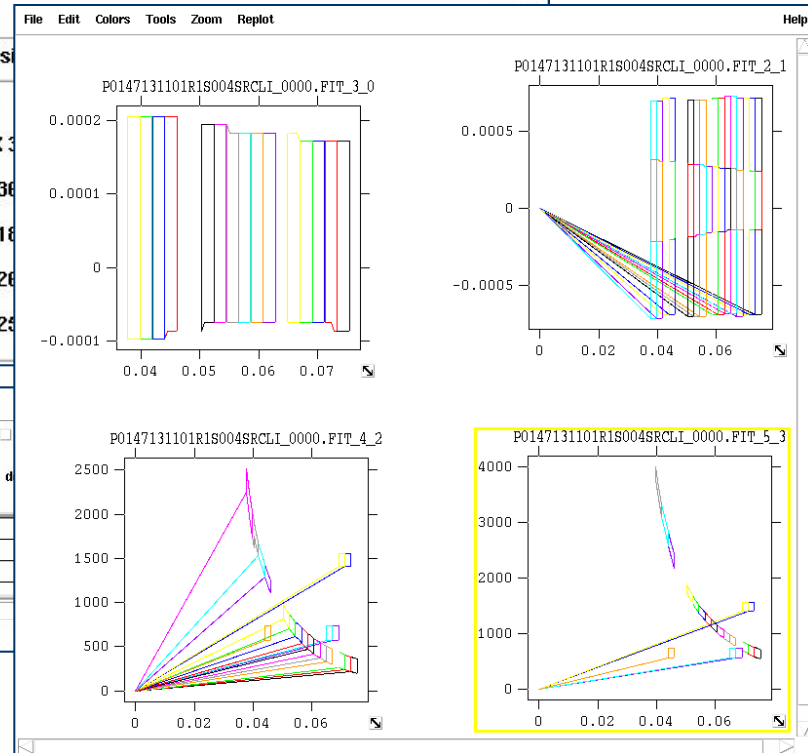
M\_LAMBDA vs XDISP\_CORR: Spatial Image

# The source list

List of coordinates

Extraction regions

File	Edit	Tools	
Index	Extension	Type	Dimensions
<input type="checkbox"/> 0	Primary	Image	0
<input type="checkbox"/> 1	SRCLIST	Binary	15 cols X 3
<input type="checkbox"/> 2	RGS1_BACKGROUND	Binary	4 cols X 36
<input type="checkbox"/> 3	RGS1_SRC3_SPATIAL	Binary	4 cols X 16
<input type="checkbox"/> 4	RGS1_SRC3_ORDER_1	Binary	4 cols X 26
<input type="checkbox"/> 5	RGS1_SRC3_ORDER_2	Binary	4 cols X 25



File Edit Tools								
<input type="checkbox"/> INDEX	<input type="checkbox"/> LABEL	<input type="checkbox"/> RA	<input type="checkbox"/> DEC	<input type="checkbox"/> RATE	<input type="checkbox"/> DELTA_DISP	<input type="checkbox"/> DELTA_XDSP	<input type="checkbox"/> FOV_PHI	
I	20A	E	E	E	E	E	E	
		degrees	degrees	cts/s	arcmin	arcmin	degrees	
1	2	ONAXIS	184.606900	29.811000	0.00	0.000	0.000	0.000
2	1	PROPOSAL	184.607800	29.788660	0.00	1.000	1.000	131.798
3	3	TARGET	184.611000	29.812670	0.00	0.111	-0.213	-114.948
Go to: Edit cell:								

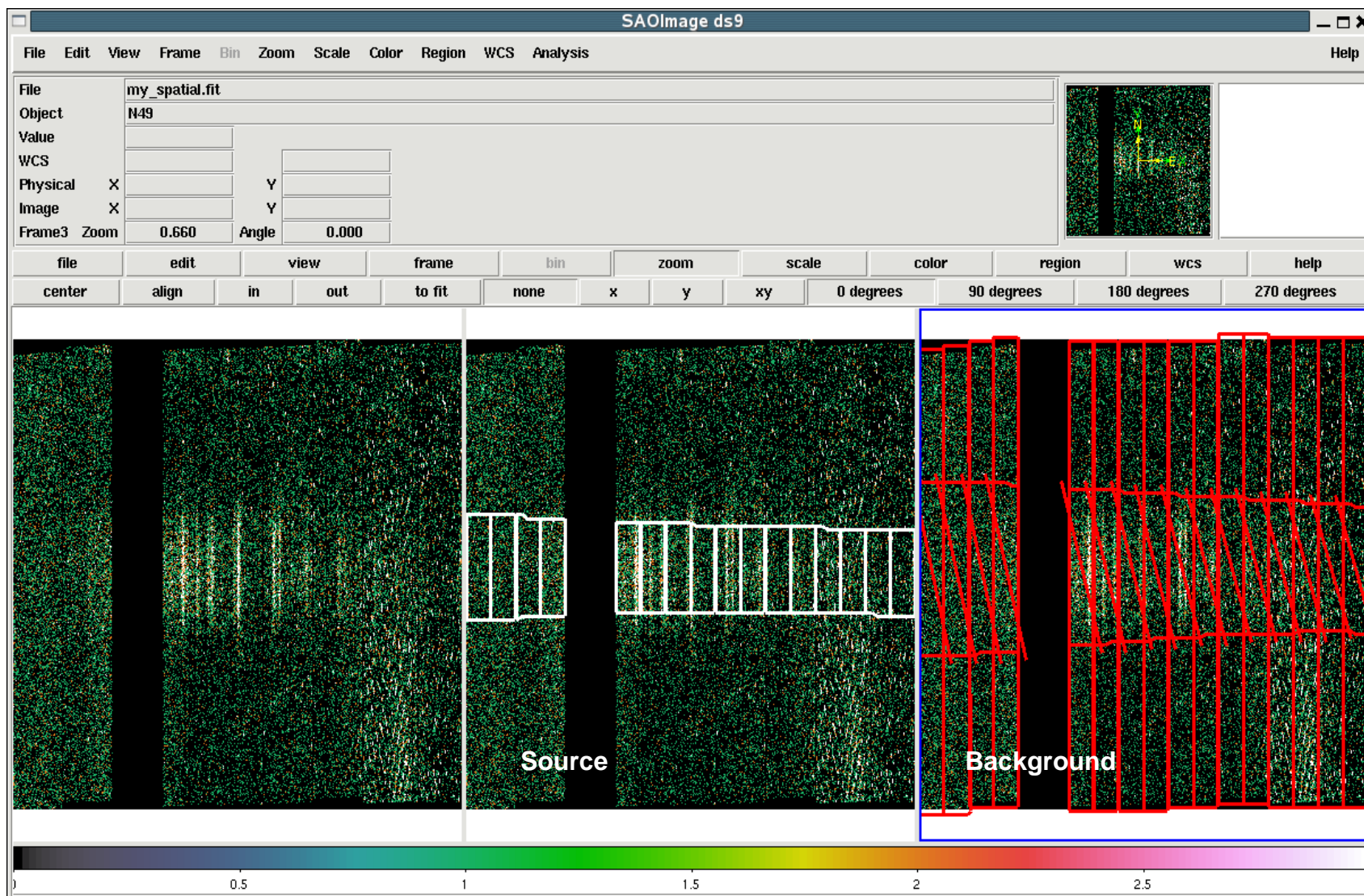
Sources can be added and/or modified with **rgssources**

Region definitions can be changed with **rgsregions**. Defaults are:

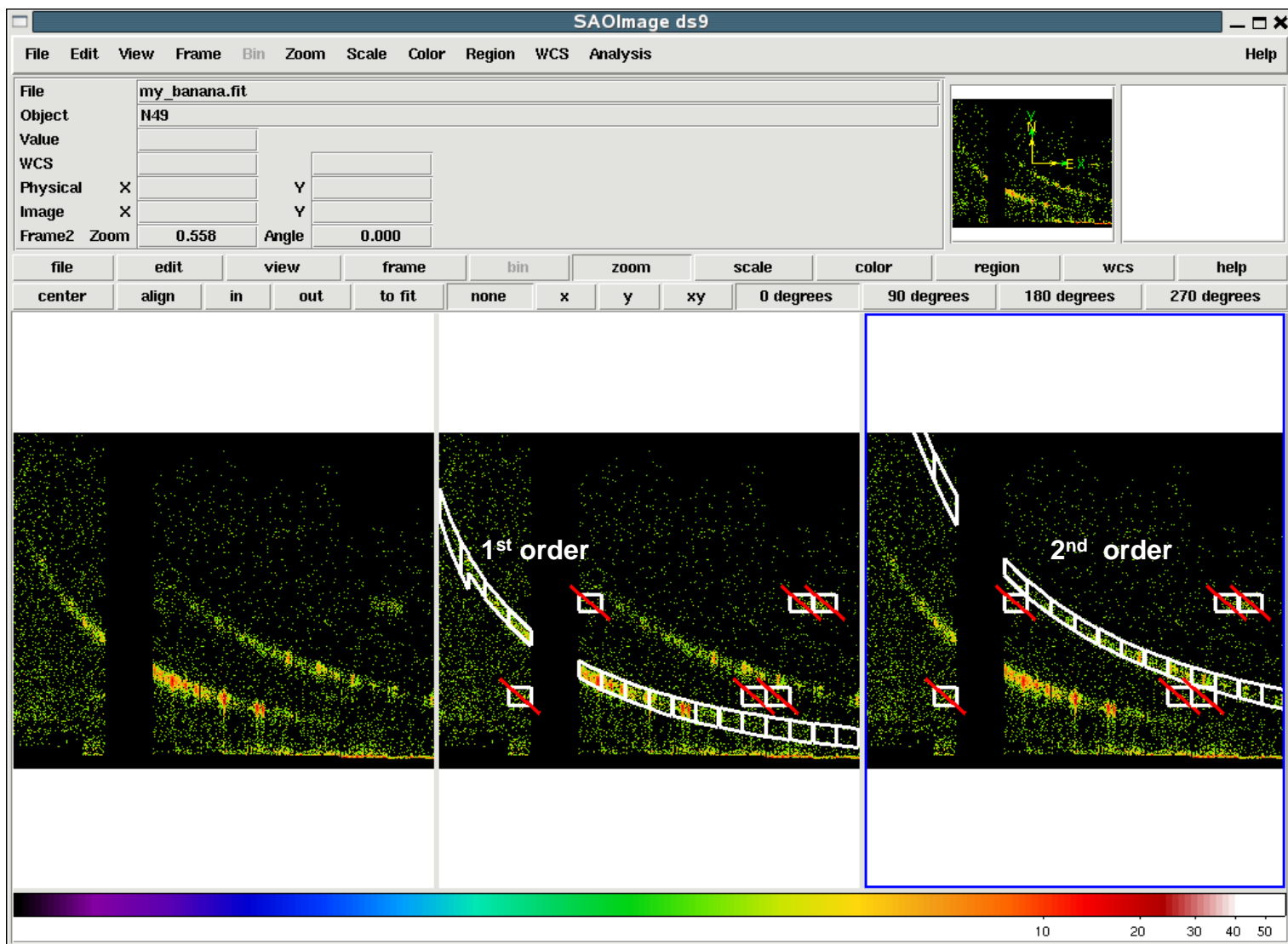
- source spatial: 95% of x-dispersion PSF inclusion
- background spatial: 98% of x-dispersion PSF exclusion
- order mask: 95% of pulse-height distribution



# The event list and the extraction regions



# The event list and the extraction regions



# The light curve

generated with **rgslccorr**

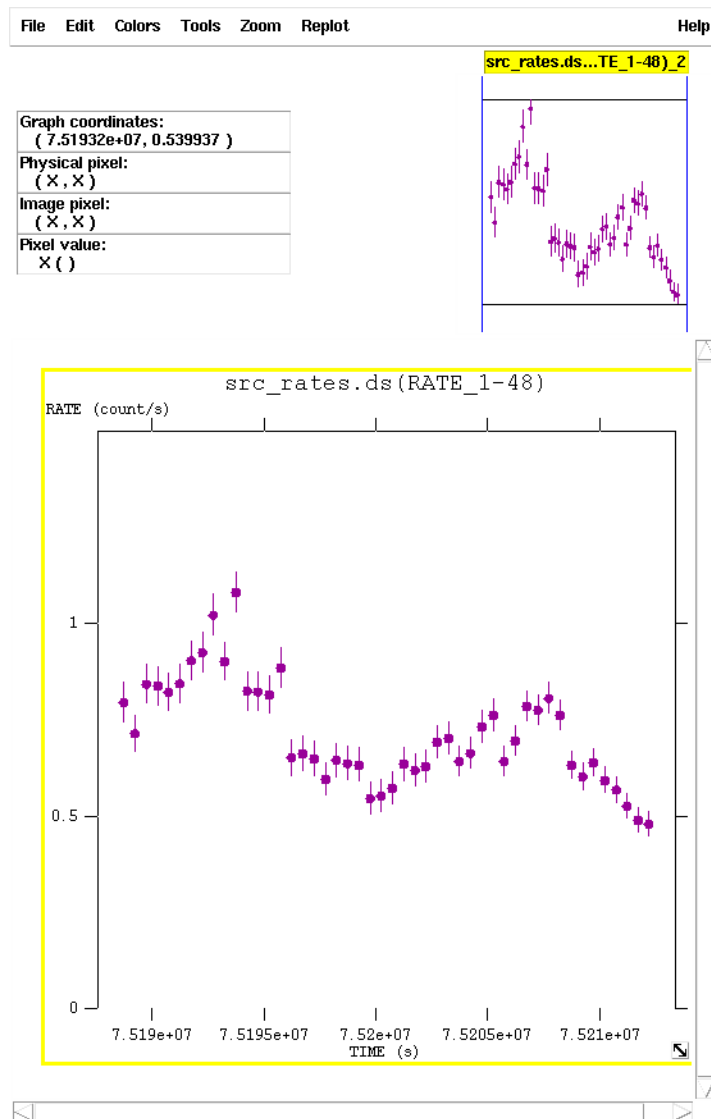
filters the event list file using the source and background region from the source list

light curves are extracted for 1<sup>st</sup> and 2<sup>nd</sup> orders

default in **rgsproc**: with background subtraction and time bin of 1000 s

**rgslccorr** allows the user to select a range of CCDs/wavelength/energy

the background light curve is produced separately



# The extracted spectrum

generated with **rgsspectrum**

spectra are extracted for 1<sup>st</sup> and 2<sup>nd</sup> orders

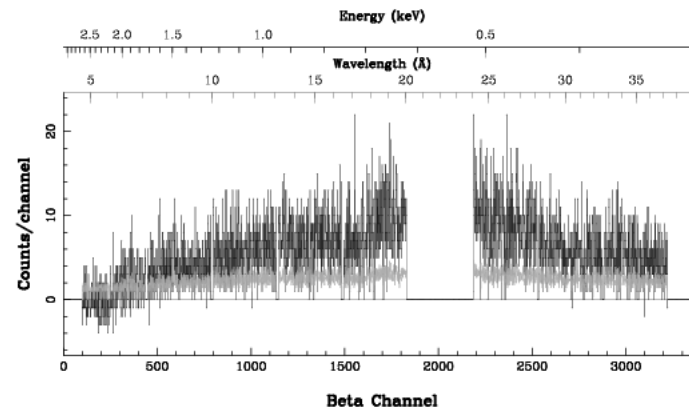
default since SAS 10.0: wavelength space

the **rgsproc** default is the total source spectrum (i.e. NOT background subtracted)

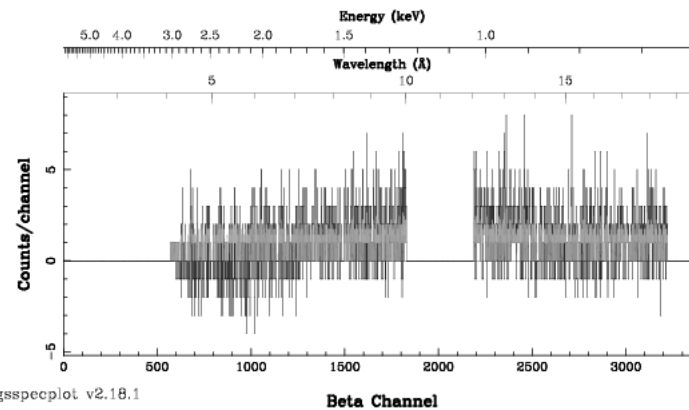
the background spectrum is produced separately

a model background can be generated optionally with **rgsbkgmodel**

XMM - RGS2 - OBJECT: Mkn 706 - RA: 184.605 - DEC: 29.8128  
OBS-ID: 0096020101 - EXP-ID: Indef - Exp. Time: 22817.4  
Key: - data - errors  
SOURCE ID: 1 - SPECTRUM ORDER: 1  
DATE-OBS 2000-05-20T05:39:39  
DATE-END 2000-05-20T12:19:55  
NET SPECTRUM, No rebinning



SOURCE ID: 1 - SPECTRUM ORDER: 2  
NET SPECTRUM, No rebinning



rgsspecplot v2.18.1

# The fluxed spectrum

RGS extracted spectra (channel/counts) can be converted to physical units

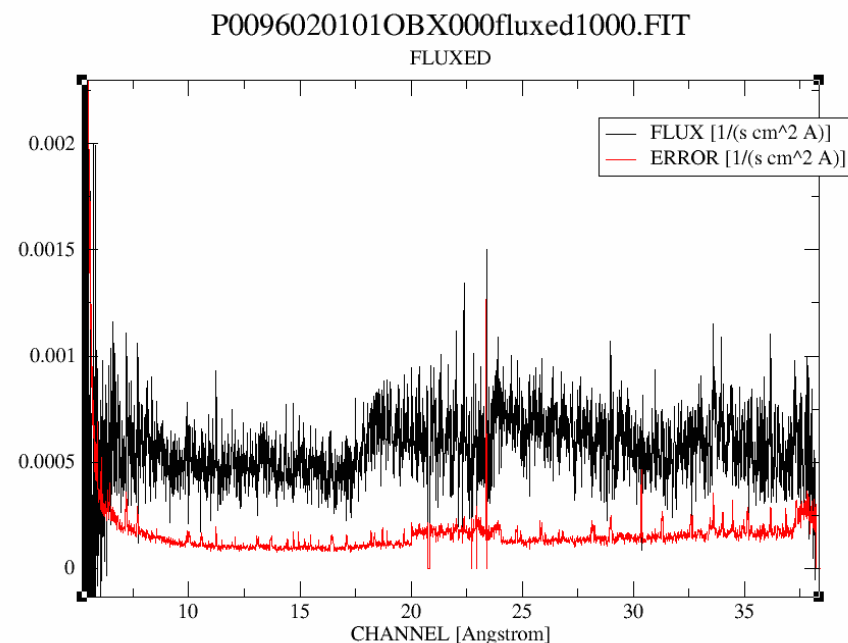
$\text{\AA}$  vs. photons  $\text{cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$

(fluxed) with **rgsfluxer**

This task also merges several spectra to (e.g.) on a single spectrum increasing the signal-to-noise ratio

fluxed spectra must be used with care in spectral fitting codes, since they do not take into account the effects of redistribution.

from RGS countrate to physical flux =>  
extracted spectrum + response matrix





# The response matrices

Response files for each source and order are computed with **rgsrmfgen**

- Effective area depends on data selections both in PI and XDISP

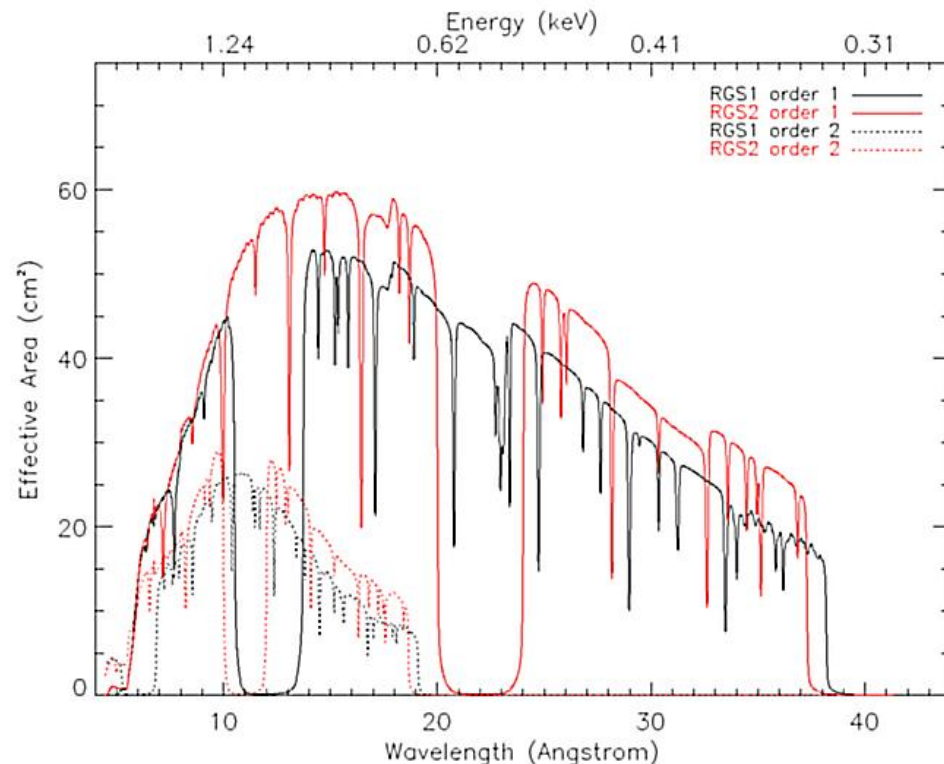
- Inter-chip gaps

- Bad columns

- Wiggles due to sampling of data selection regions

- Failing CCD chains

- Instrumental edges



# Should I reprocess the data?

SAS version of pipeline products

- **PROC0 and PROCDATE**

The calibration index file

- **are there new calibration files?**

Source coordinates and extraction regions

- **are they right?**

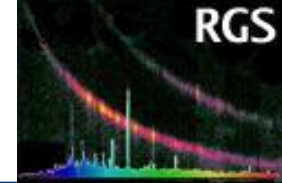
Background

- **was the observation affected by flares?**

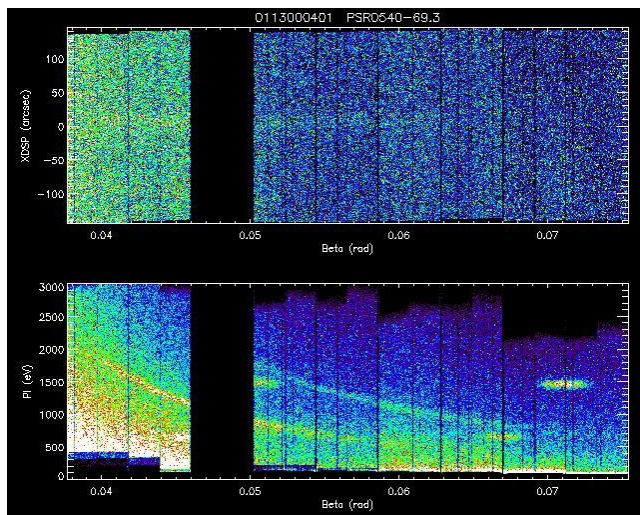
Multiple sources and regions

- **are there several sources within the FOV?**

# High background (I)

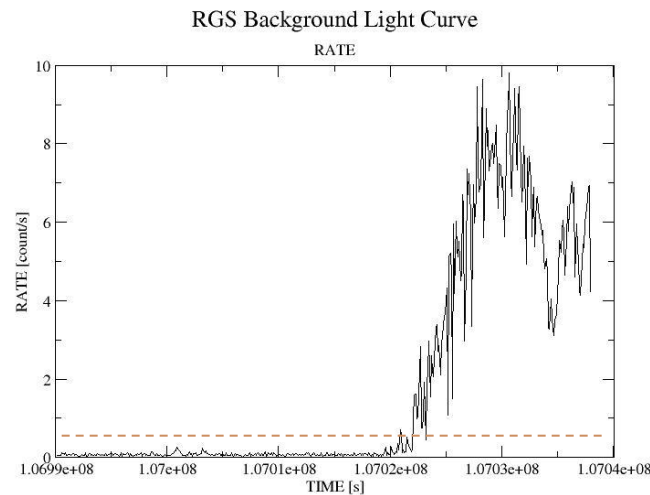


Proton flare during observation  $\Rightarrow$  decrease in signal-to-noise !

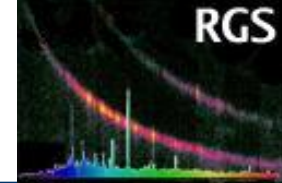


Derive the binned (10/100 sec) light curve of the background region of CCD#9 with `evselect` or `xmmselect` [or use Pipeline file "FBKTSR"]

Select periods with (e.g)  $< 0.5$  c/s and generate GTIs with `tabgtigen`

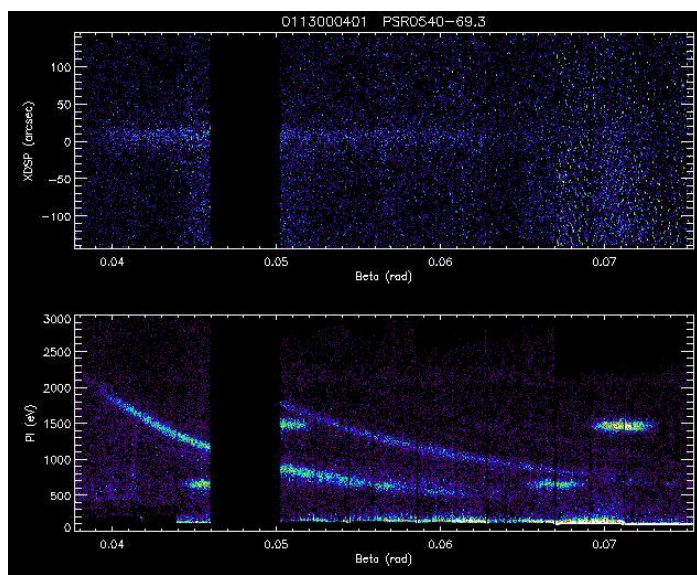


# High background (II)



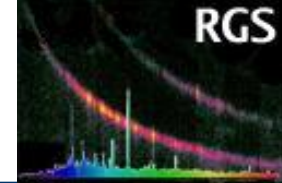
re-run `rgsproc` from the 'filter' stage:

```
rgsproc entrystage=filter auxgtitables=mygti.ds
```



Same observation filtered to  
 $\text{CCD9} < 0.5 \text{ counts/sec}$

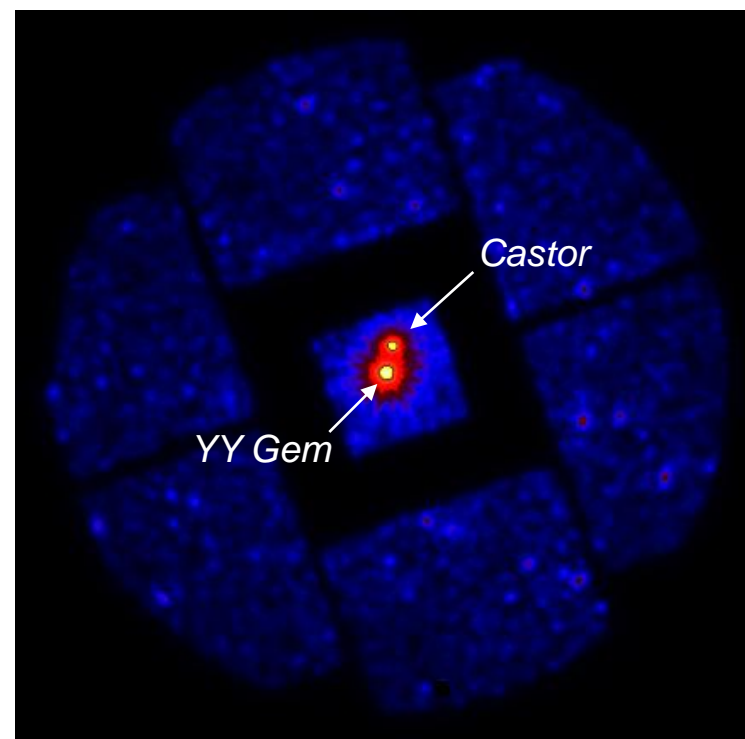
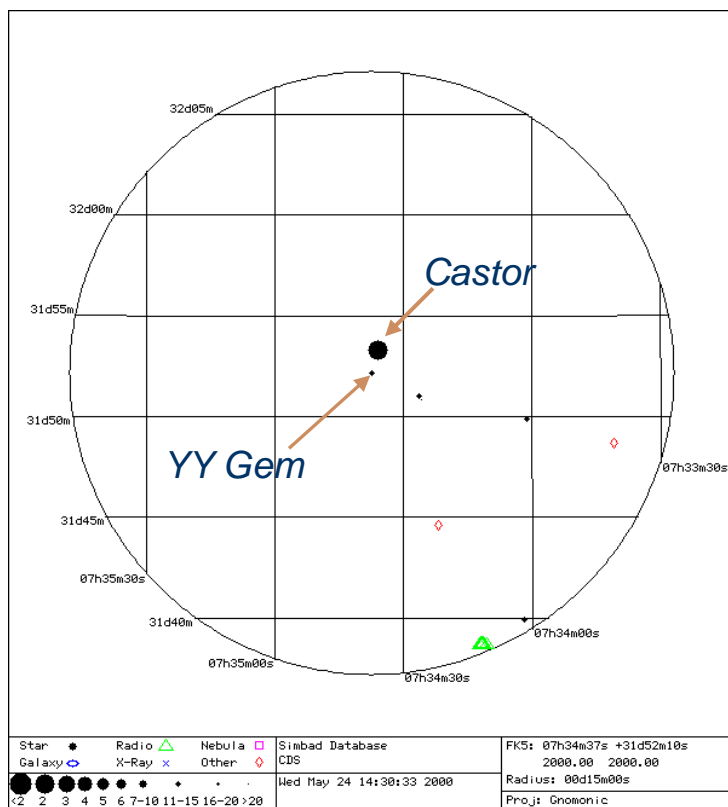
# Multiples sources and masks (I)



If there are several sources in the FOV (YY Gem/ Castor) ...

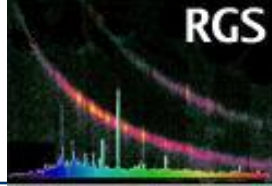
Field with two sources separated by 71''

primary source: YY Gem, secondary source: Castor



EPIC MOS image

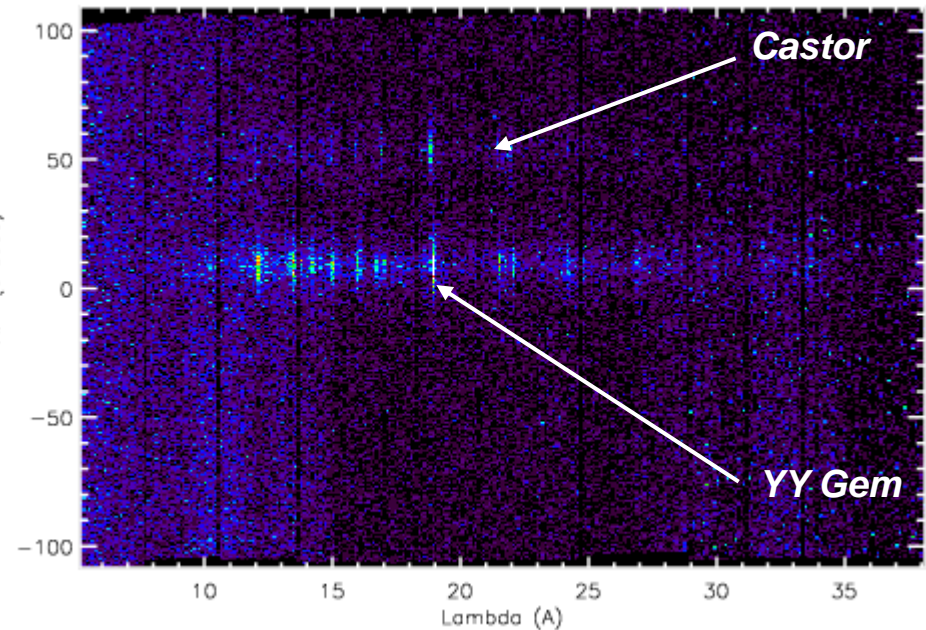
# Multiples sources and masks (II)



Use **rgssources** to add the coordinates of Castor to the SRCLIST table

Use **rgsregions** to create new region masks excluding both sources from the background

Run **rgsproc entrystage=spectra** to extract the new spectrum

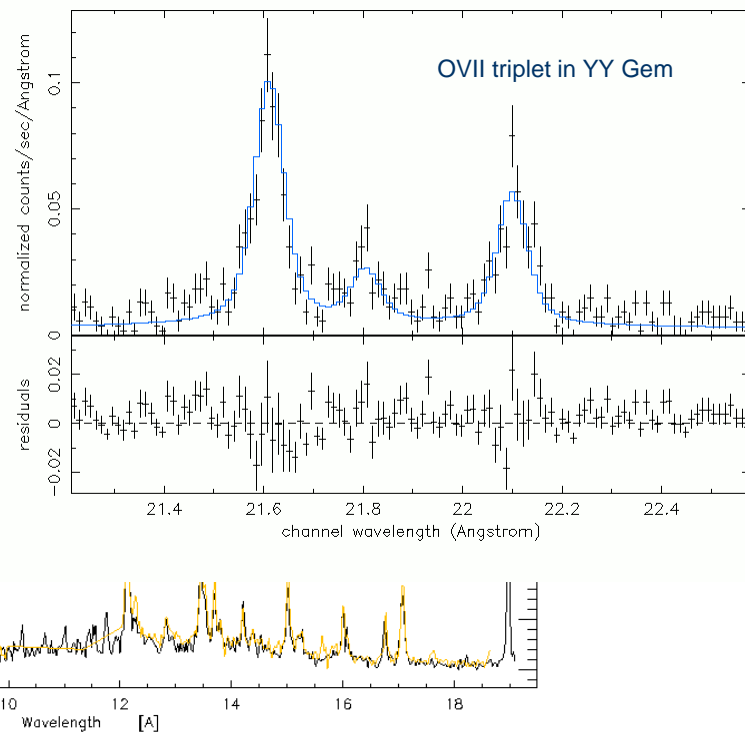
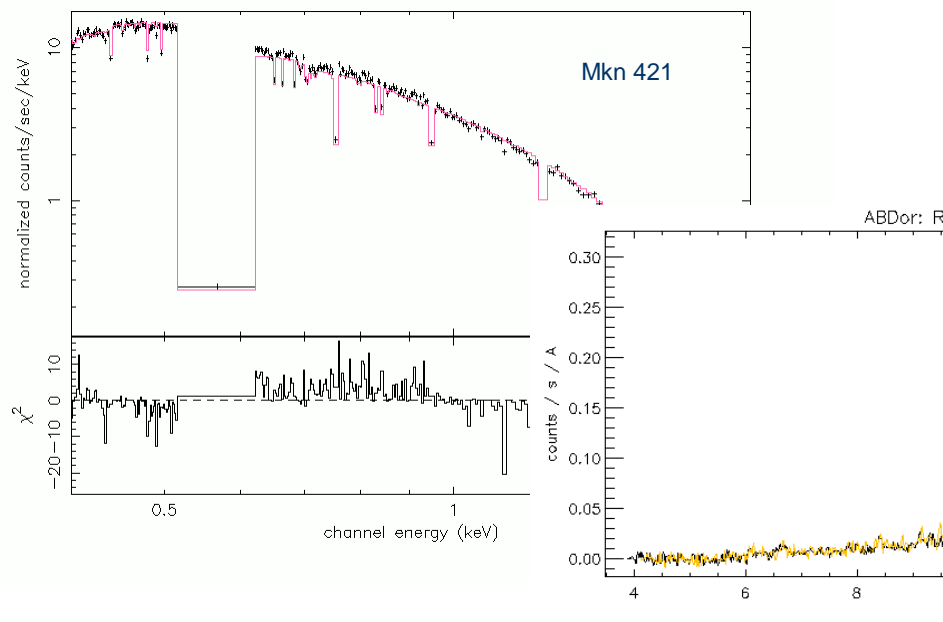




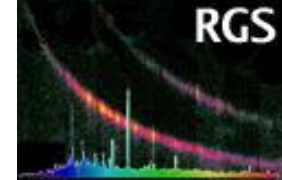
# Data analysis

Extracted source + background spectra + response matrix

Work using specific packages, e.g. XSPEC, SPEX, Sherpa, PintOfAle, ISIS..



# Summary



## Data processing with **rgsproc**

- events
- angles
- filter
- spectra
- fluxing
- lightcurve

## Checks

- PPS version and calibration files
- coordinates, sources and regions
- high background, flares

## Data analysis

- response matrices and effective area
- fitting (model vs observation)