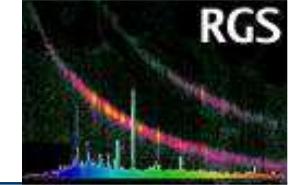


RGS data reduction and analysis of point-like sources

Rosario González-Riestra

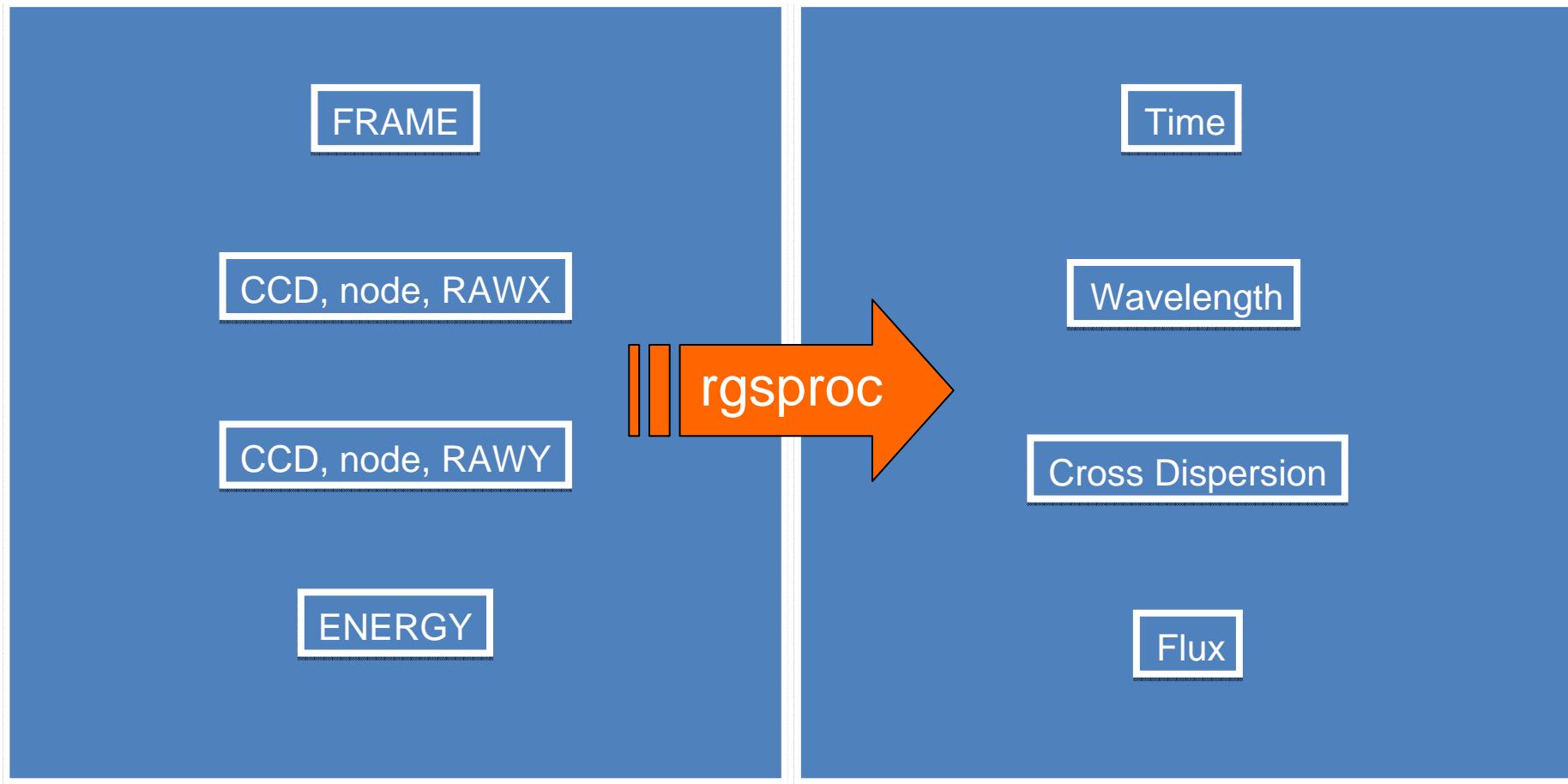
XMM-Newton SOC
ESAC

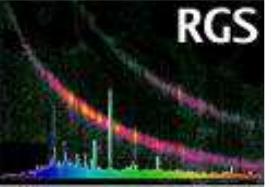
Processing RGS data (I)



from....

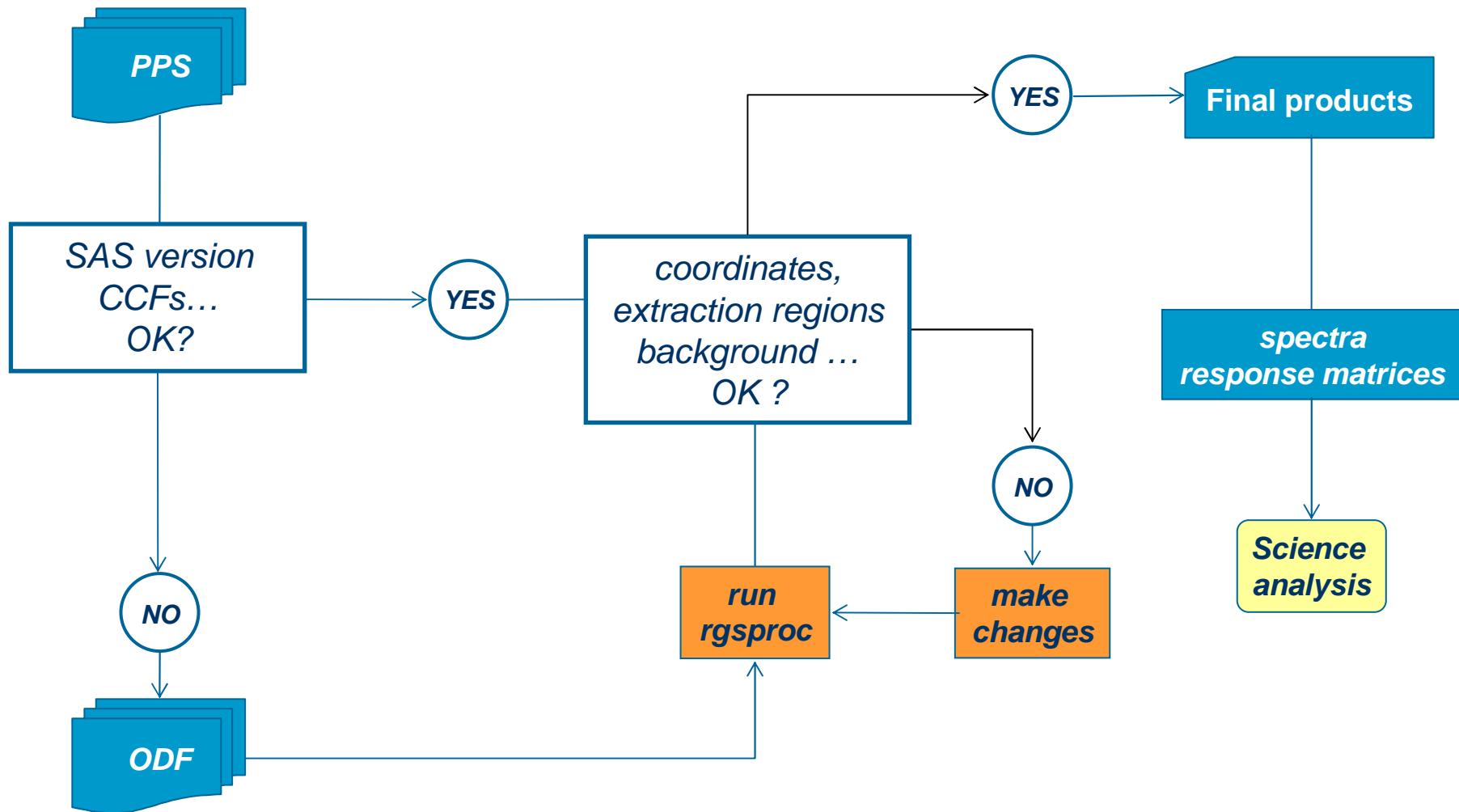
to...

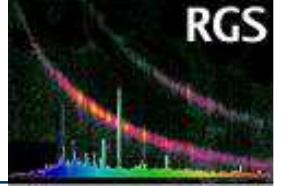




Processing RGS data (II)

Two starting points...



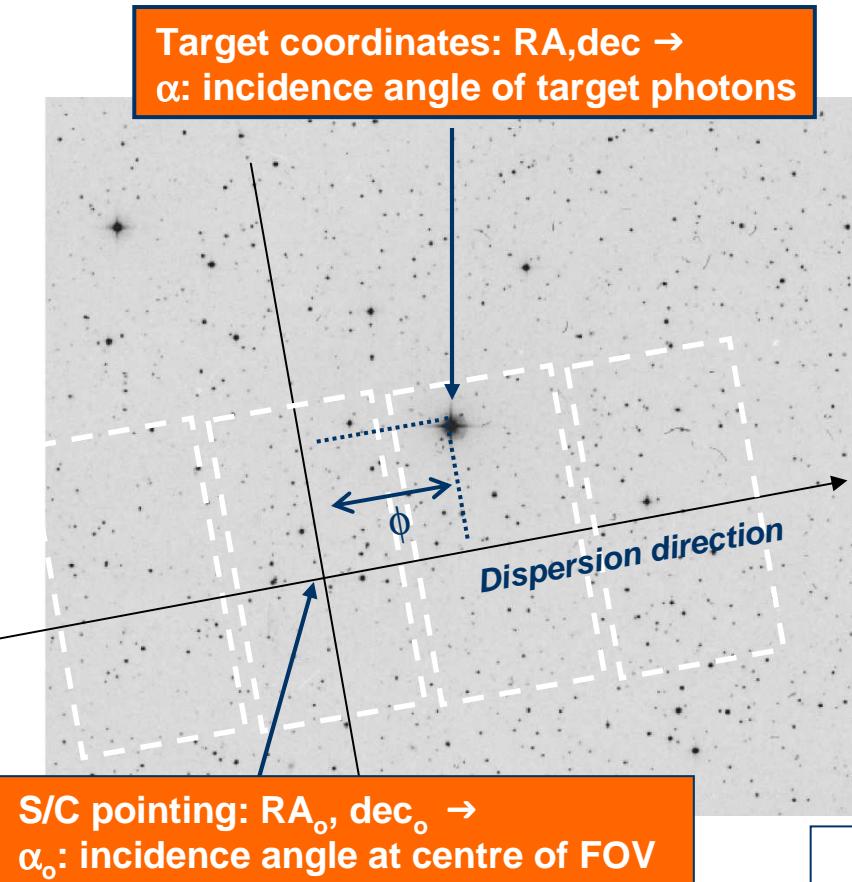
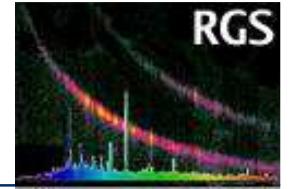


The RGS processing task: rgsproc

- meta-task: interface to ≈ 20 SAS tasks (that can also be run separately)
- controlled by ≈ 80 parameter switches
- six entry and final points (“*processing stages*”)
- 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

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

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



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

measured *known*

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

known *known*

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

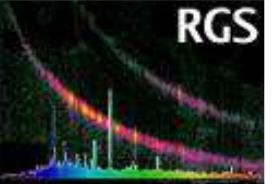
input to rgsproc

known from S/C attitude history file



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

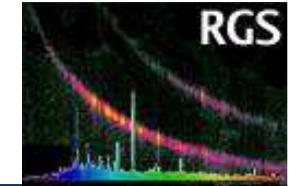
$$1 \text{ arcsec} \approx 2.3 \text{ m}\text{\AA} \text{ (45 km/s at } 15 \text{ }\text{\AA}\text{)}$$



rgsproc: what does it do?

Stage	Task	Purpose	Output
Events	atthkgen	generates attitude file	Source list + intermediate combined event list
	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 ([XY]CORR), 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 (ENERGY), "pattern" (GRADE/SHAPE), coordinates (CHIP[XY],BETA,XDSP)	
	evlistcomb	concatenates event list	
Angles	rgsangles	performs aspect correction (BETA_CORR, XDSP_CORR)	Final event list
Filter	rgsfilter	filters event list, removing unwanted frames and events and adding exposure maps	
Spectra	rgsregions	computes background and source extraction regions for each source	Source and background spectra
	rgsspectrum	extracts source and background spectra	
	rgsbkgmodel	generates model background	
Fluxing	rgsrmfgen	creates response matrix	Response matrices and combined spectrum in physical units
	rgsfluxer	combines several RGS spectra into a single "fluxed" spectrum	
Lightcurve	rgslccorr	creates background-subtracted light curves	Light curve

rgsproc: parameters

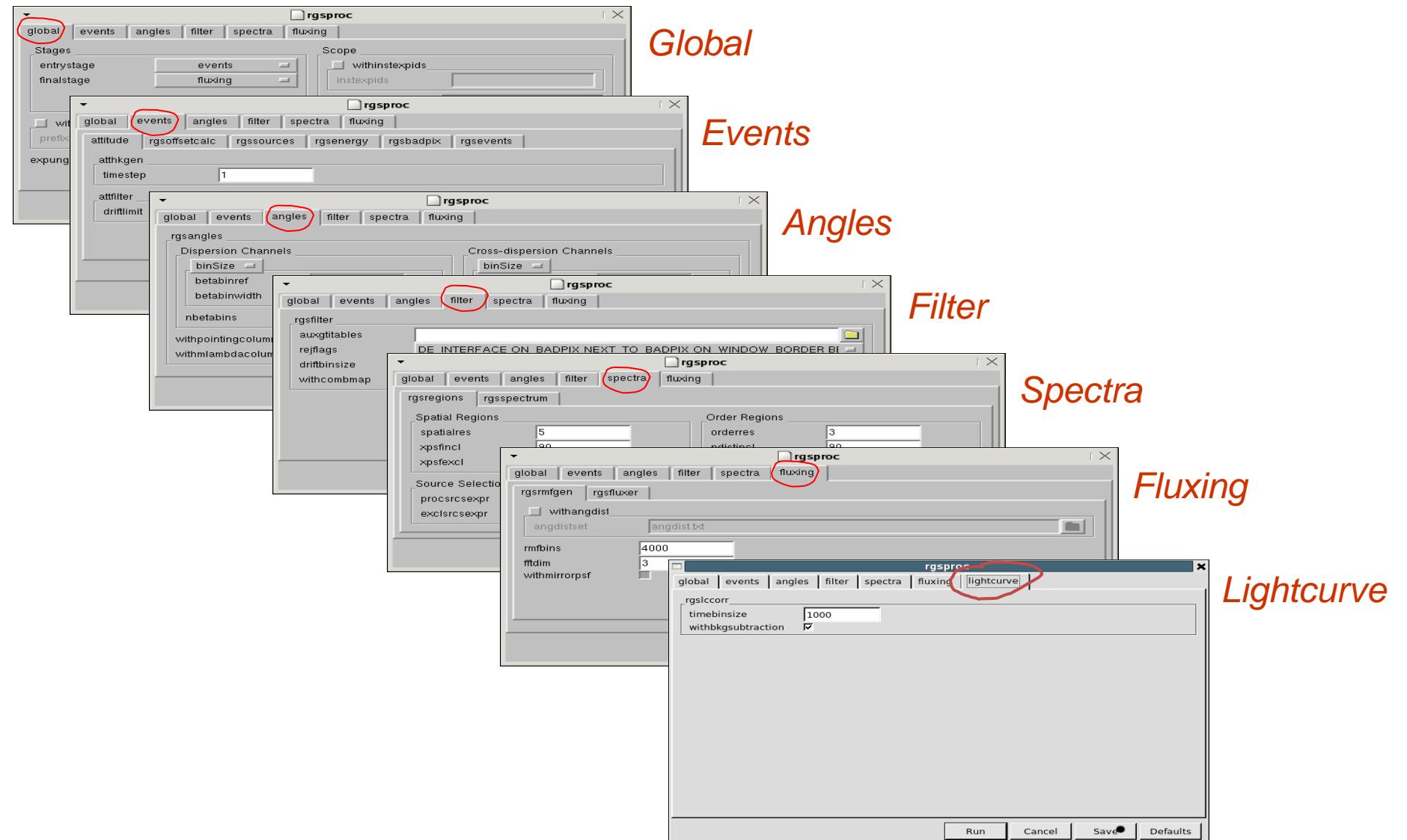


```

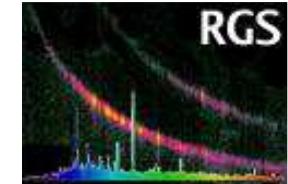
entrystage -- optional,type=string,default=events; (re)start processing at
finalstage -- optional,type=string,default=fluxing; conclude processing at
withinstexpids -- optional,type=bool,constraints="withinstexpids in [0:1]"
instexpids -- optional,type=list<string>,constraints="instexpids in [0:1]"
orders -- optional,type=list<int>,constraints="orders in [2:100]"
expunge -- optional,type=list<string>,constraints="expunge in [0:1]"
withprefix -- optional,type=bool,default=yes; include found hot pixels
prefix -- optional,type=string; prefix for output files
timestep -- optional,type=real,constraints="timestep in [0:100]"
driftlimit -- optional,type=real,constraints="driftlimit in [0:100]"
withepicset -- optional,type=bool,default=yes; include found hot pixels
epicset -- optional,type=dataset; name of dataset containing EPIC spectra
withsrc -- optional,type=bool,default=yes; background correct the spectra
srclabel -- optional,type=string,default="src"
srcrate -- optional,type=real,constraints="srcrate in [0:100]"
srcstyle -- optional,type=string,default="gaussian"
srcra -- optional,type=real,default=-99.0
srcdec -- optional,type=real,default=-9.0
srcdisp -- optional,type=real,default=0.0
srcxdsp -- optional,type=real,default=0.0
attstyle -- optional,type=string,default="gaussian"
attra -- optional,type=real,default=-99.0
attdec -- optional,type=real,default=-9.0
attapos -- optional,type=real,default=0.0
calcoffsets -- optional,type=bool,default=yes; generate background spectra
withoffsethistogram -- optional,type=bool,default=yes; generate background spectra
withdiagoffset -- optional,type=bool,default=yes; generate background spectra
withgain -- optional,type=bool,default=yes; generate background spectra
withcti -- optional,type=bool,default=yes; generate background spectra
withadvisory -- optional,type=bool,default=yes; generate background spectra
withfoundhot -- optional,type=bool,default=yes; include found hot pixels
pixnoiselimit -- optional,type=int,constraints="pixnoiselimit in [0:100]"
colnoiselimit -- optional,type=int,constraints="colnoiselimit in [0:100]"
pixsharpness -- optional,type=int,constraints="pixsharpness in [0:100]"
colsharpness -- optional,type=int,constraints="colsharpness in [0:100]"
detcoord -- optional,type=string,constraints="detcoord in [0:100]"
withdetcoord -- optional,type=string,constraints="withdetcoord in [0:100]"
reconstruct -- optional,type=string,constraints="reconstruct in [0:100]"
betabinning -- optional,type=string,constraints="abetabinning in [0:100]"
betabinref -- optional,type=string,constraints="abetabinref in [0:100]"
betabinwidth -- optional,type=string,constraints="abetabinwidth in [0:100]"
nbetabins -- optional,type=string,constraints="nbetabins in [0:100]"
betamin -- optional,type=real,constraints="betamin in [0:100]"
betamax -- optional,type=real,constraints="betamax in [0:100]"
xdispbinning -- optional,type=string,constraints="xdispbinning in [0:100]"
xdispbinref -- optional,type=string,constraints="xdispbinref in [0:100]"
xdispbinwidth -- optional,type=string,constraints="xdispbinwidth in [0:100]"
nxdispbins -- optional,type=string,constraints="nxdispbins in [0:100]"
xdispmin -- optional,type=real,constraints="xdispmin in [0:100]"
xdispmax -- optional,type=real,constraints="xdispmax in [0:100]"
withpointingcolumn -- optional,type=string,constraints="withpointingcolumn in [0:100]"
withmlambdacolumn -- optional,type=string,constraints="withmlambdacolumn in [0:100]"
rejflags -- optional,type=string,constraints="rejflags in [0:100]"
driftbinsize -- optional,type=string,constraints="driftbinsize in [0:100]"
withcombmap -- optional,type=string,constraints="withcombmap in [0:100]"
auxgtables -- optional,type=string,constraints="auxgtables in [0:100]"
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
xpsfinc1 -- optional,type=real,constraints="xpsfinc1 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
fftdim -- optional,type=int,constraints="fftdim in [1:5]",default=3; convolution size exponent
withmirrorpssf -- 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?



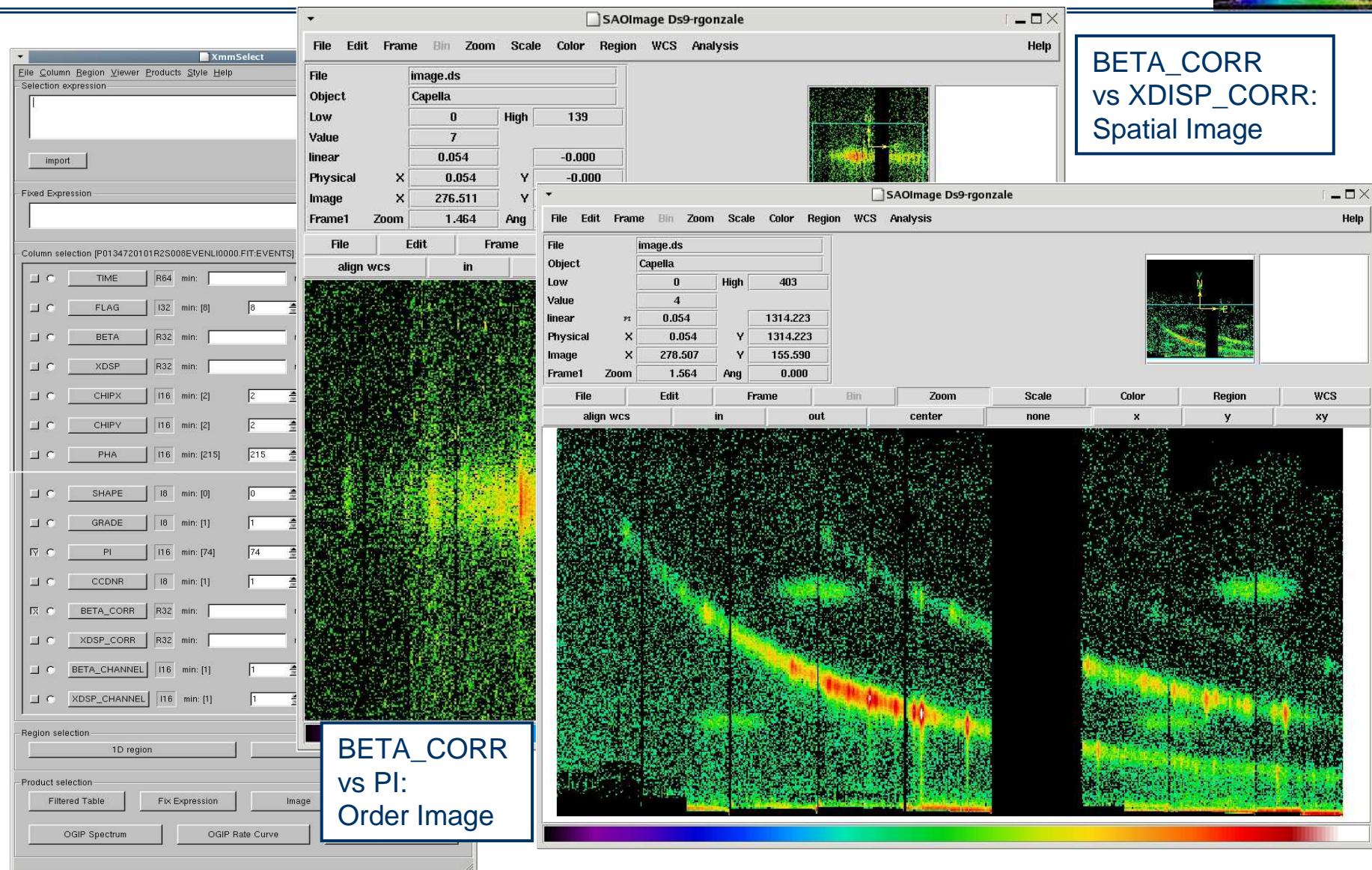
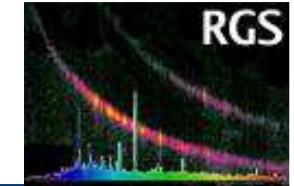
For each RGS and exposure:

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 st and 2 nd order)	Y	Y
P0123456701R1S004SRSPEC1001.FIT P0123456701R1S004SRSPEC2001.FIT	Source Spectra (1 st and 2 nd order)	N	Y
P0123456701R1S004SBSPEC1001.FIT P0123456701R1S004SBSPEC2001.FIT	Source+Bkg Spectra (1 st and 2 nd order)	Y	Y
P0123456701R1S004RSPMAT1001.FIT P0123456701R1S004RSPMAT2001.FIT	Response Matrices (1 st and 2 nd order)	Y	only for 1 st 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	N

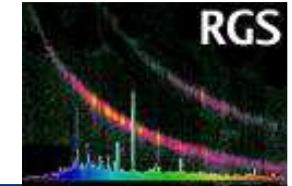
For each observation:

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

The filtered event list



The source list



List of coordinates

Extraction regions

Index	Extension	Type	Dimensions
0	Primary	Image	0
1	SRCLIST	Binary	15 cols X 3
2	RGS1_BACKGROUND	Binary	4 cols X 36
3	RGS1_SRC3_SPATIAL	Binary	4 cols X 16
4	RGS1_SRC3_ORDER_1	Binary	4 cols X 26
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	<input type="checkbox"/> ...
I	20A	E	E	E	E	E	E	
degrees		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:

P0147131101R1S004SRCLI_0000.FIT_3_0

P0147131101R1S004SRCLI_0000.FIT_2_1

P0147131101R1S004SRCLI_0000.FIT_4_2

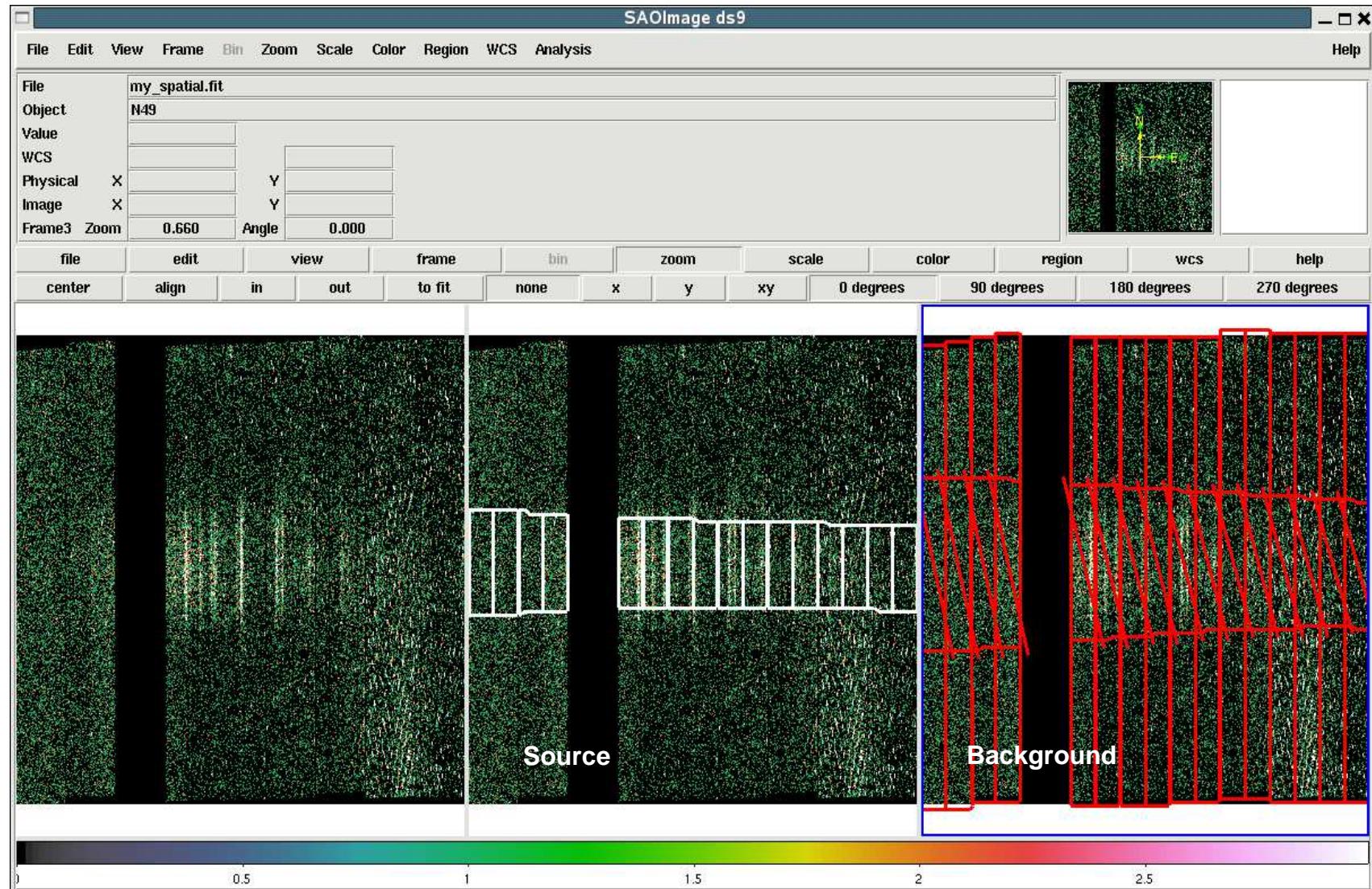
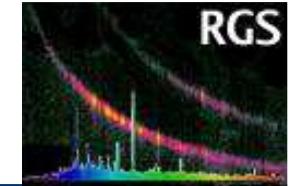
P0147131101R1S004SRCLI_0000.FIT_5_3

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

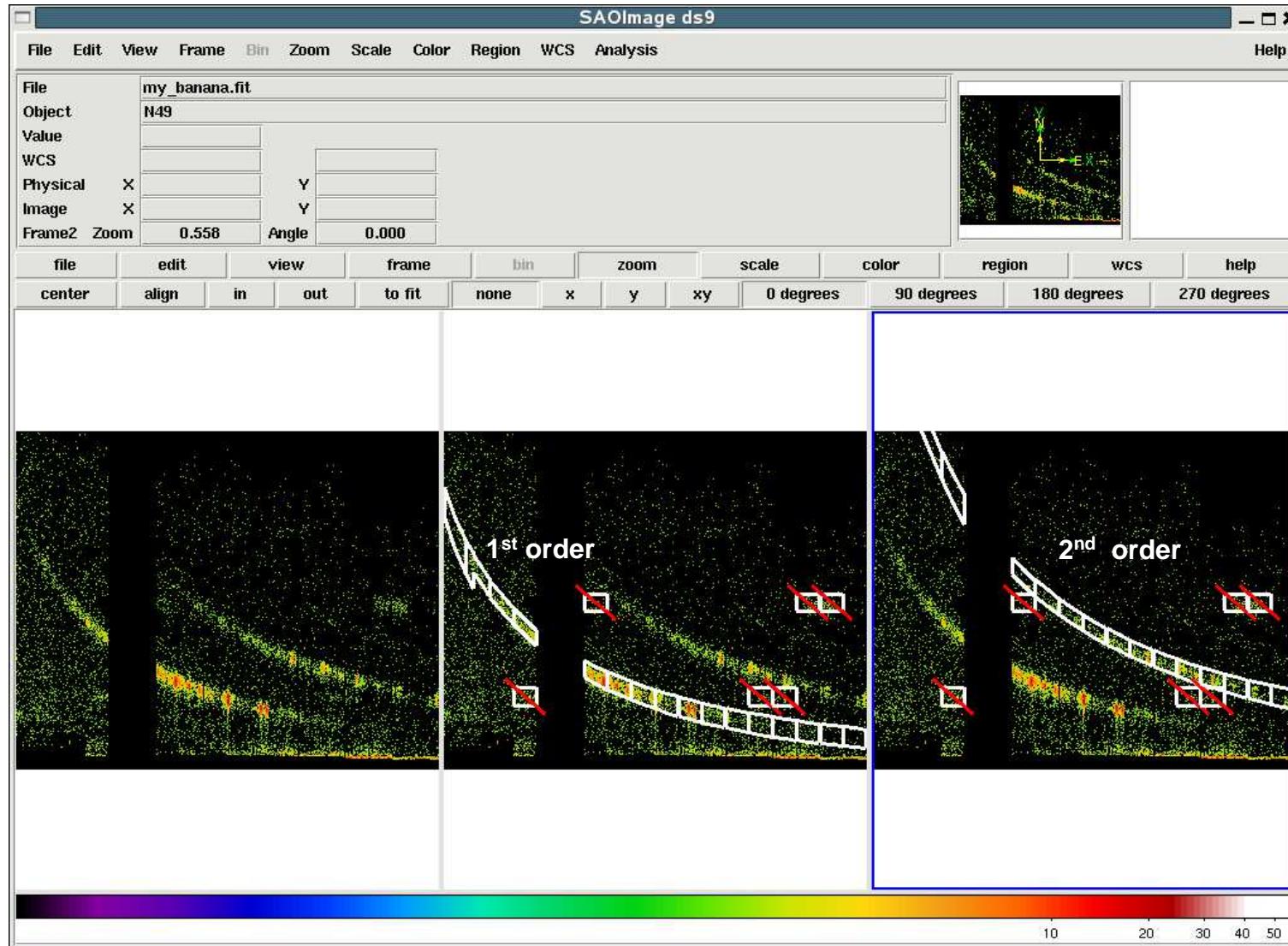
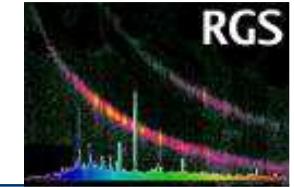
Region definitions can be changed with `rgsregions`. Defaults are:

- 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

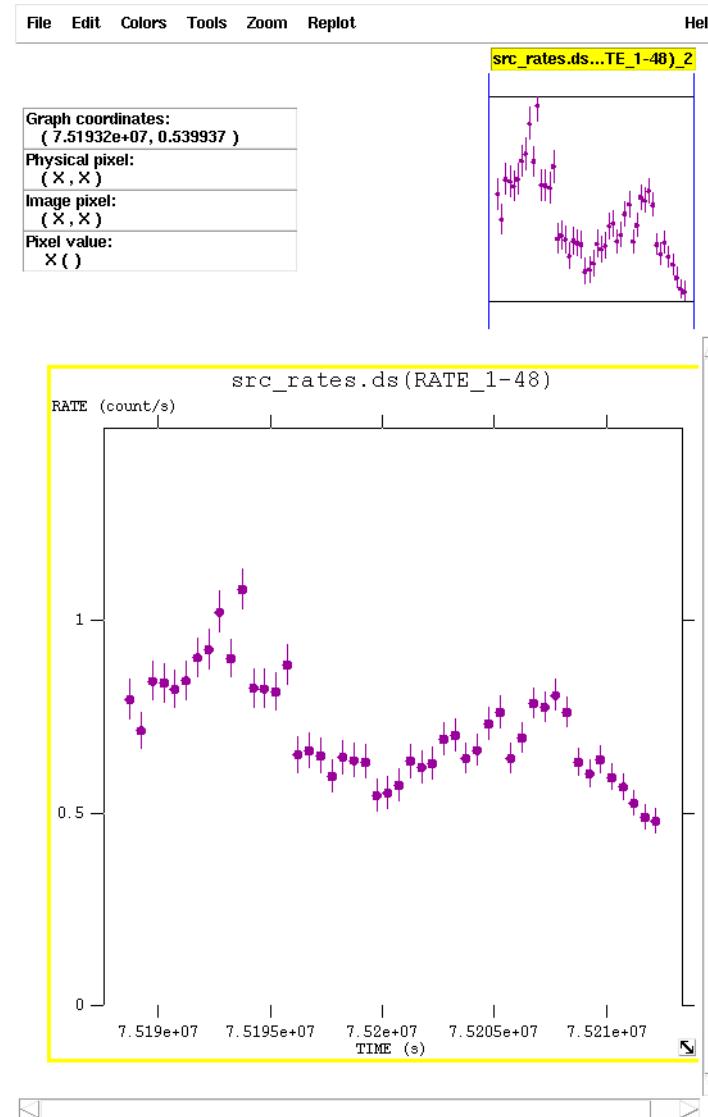


The event list and the extraction regions



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 1st and 2nd 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



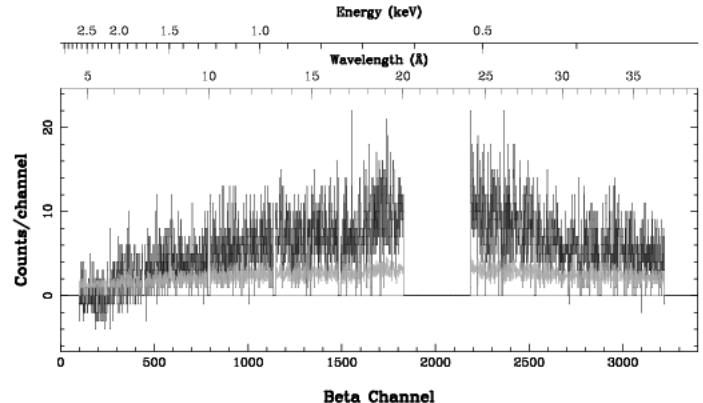


The extracted spectrum

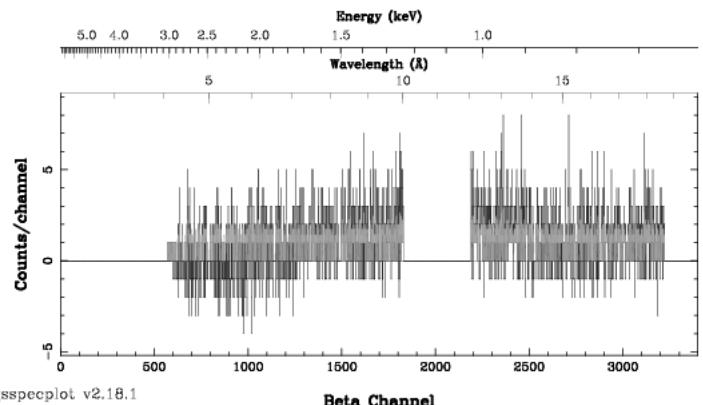
- generated with `rgsspectrum`
- spectra are extracted for 1st and 2nd orders
- default in SAS 10.0: wavelength space
- the `rgsproc` default is the total source spectrum (i.e. NOT background subtracted)
- the background spectrum is produced separately
- a model background can be generated optionally with `rgsbkgmodel`

XMM - RGS2 - OBJECT: Mkn 766 - RA: 184.605 - DEC: 29.5128
OBS-ID: 0098020101 - EXP-ID: Indef - Exp. Time: 22817.4
Key: - data - errors

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



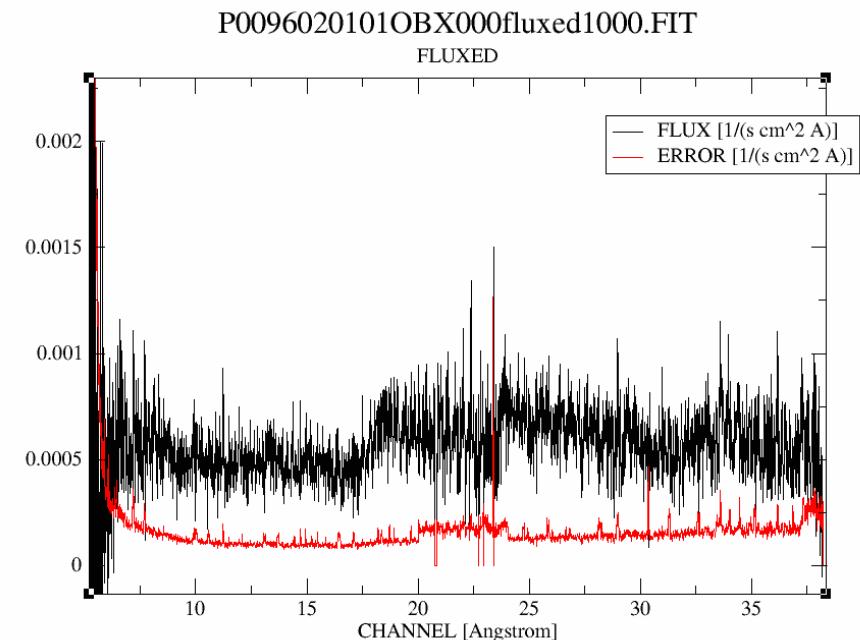
SOURCE ID: 1 - SPECTRUM ORDER: 2 NET SPECTRUM, No rebinning



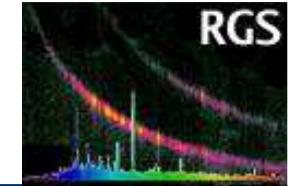
rgsspecplot v2.18.1

The fluxed spectrum

- RGS extracted spectra (channel/counts) can be “fluxed” (converted to physical units: $\text{\AA} / \text{photons cm}^{-2} \text{ s}^{-1} \text{\AA}^{-1}$) with `rgsfluxer`
- This task also merges several spectra to (e.g.) obtain 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

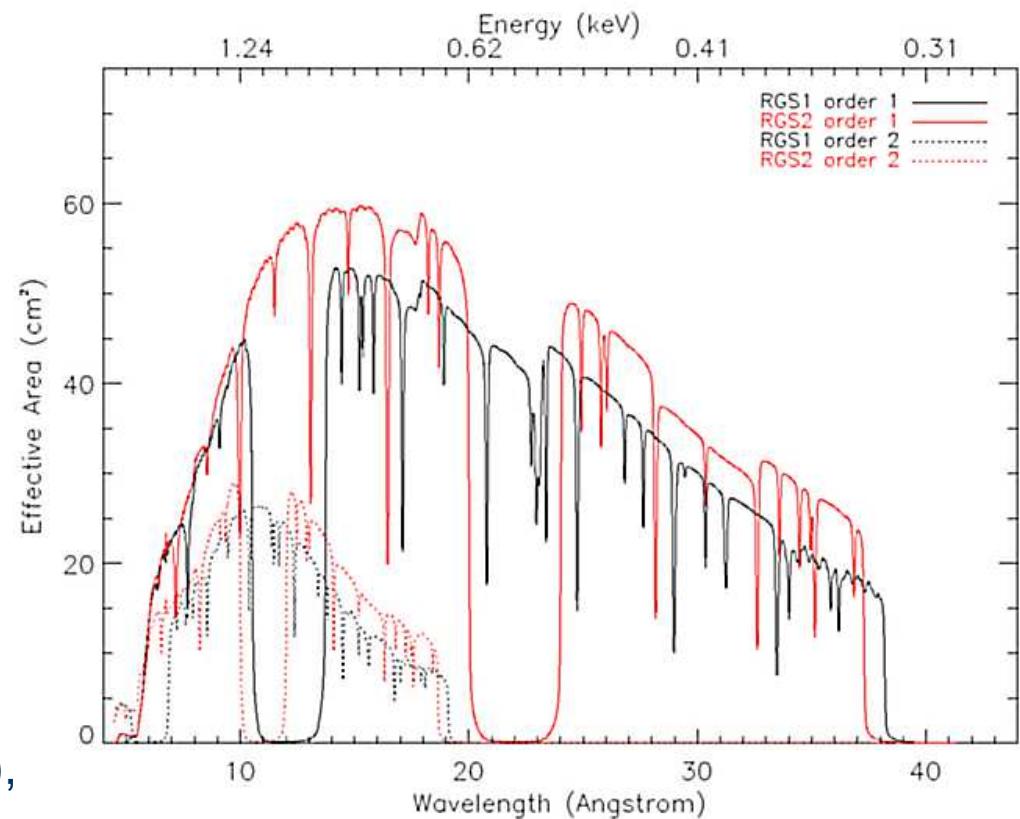


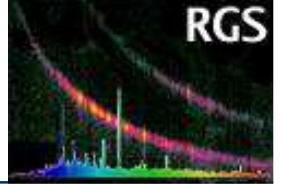
The response matrices



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:
Al (8.3 Å), Mg (9.5 Å), F (18.3 Å),
Mg₂F (17.9 Å), O (23.5 Å)



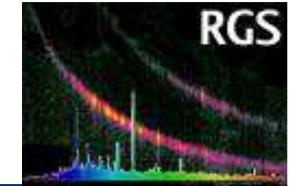


Should I reprocess the data?

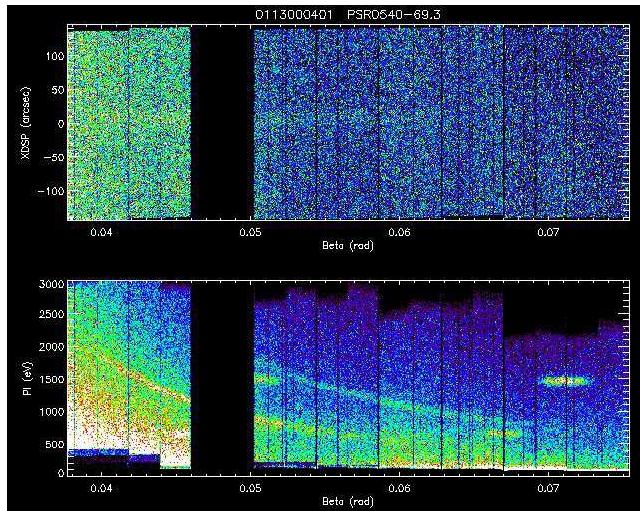
Check:

- SAS version of pipeline products
XPROC0 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)

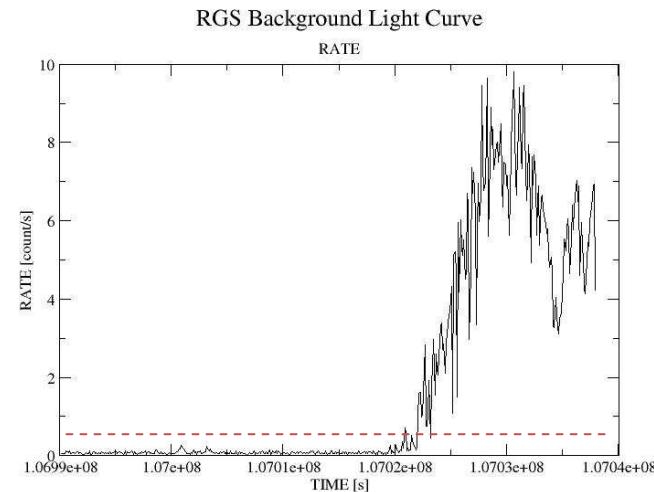


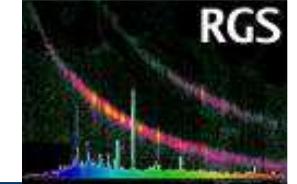
Proton flare during observation \Rightarrow decrease in signal-to-noise !



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

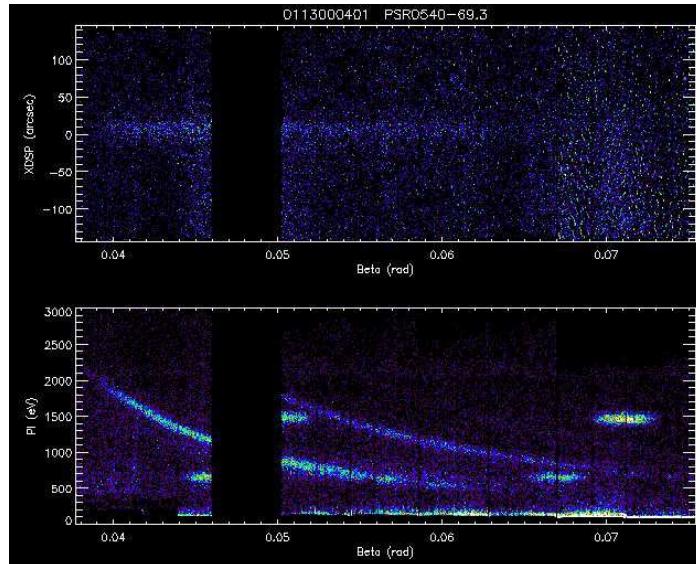
- Derive the binned (10/100 sec) light curve of the background region of CCD#9 with `evselect` or `xmmselect` [or use Pipeline file "FBKTSR"]





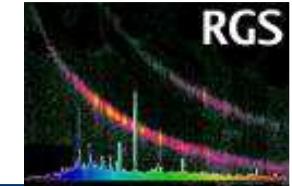
High background (II)

re-run rgsproc from the 'filter' stage:
`rgsproc entrystage=filter auxgtitable=mygti.ds`



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

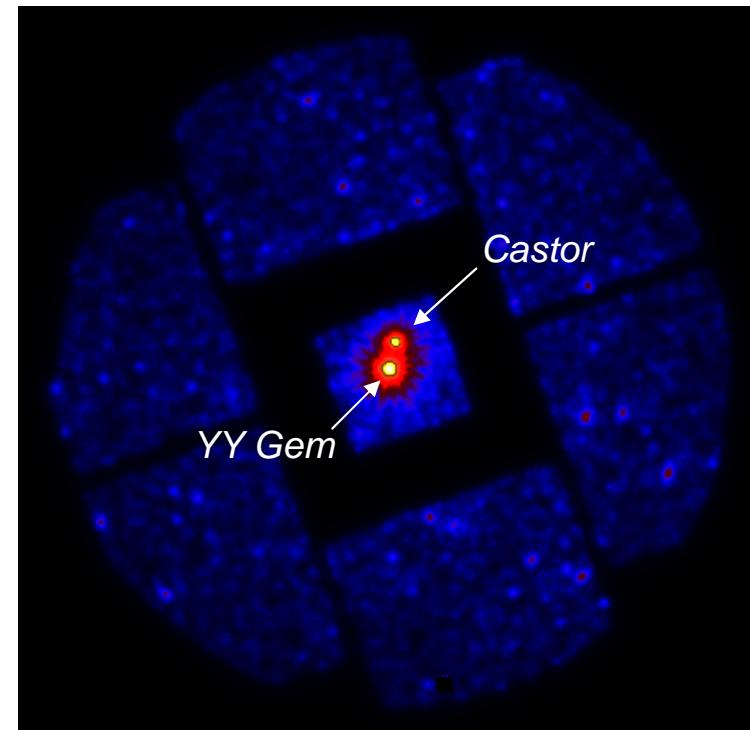
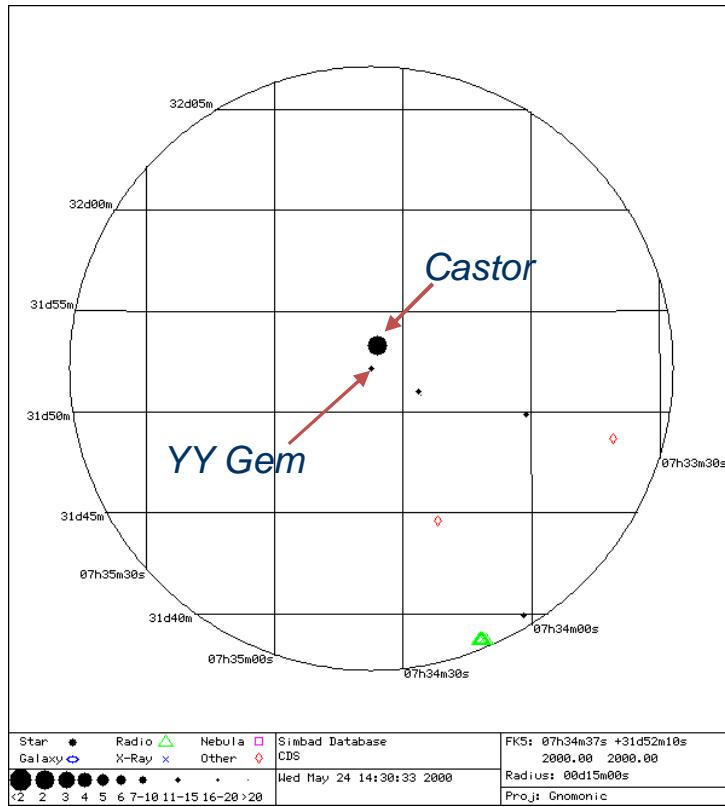
Multiples sources and masks (I)



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

Field with two sources separated by 71"

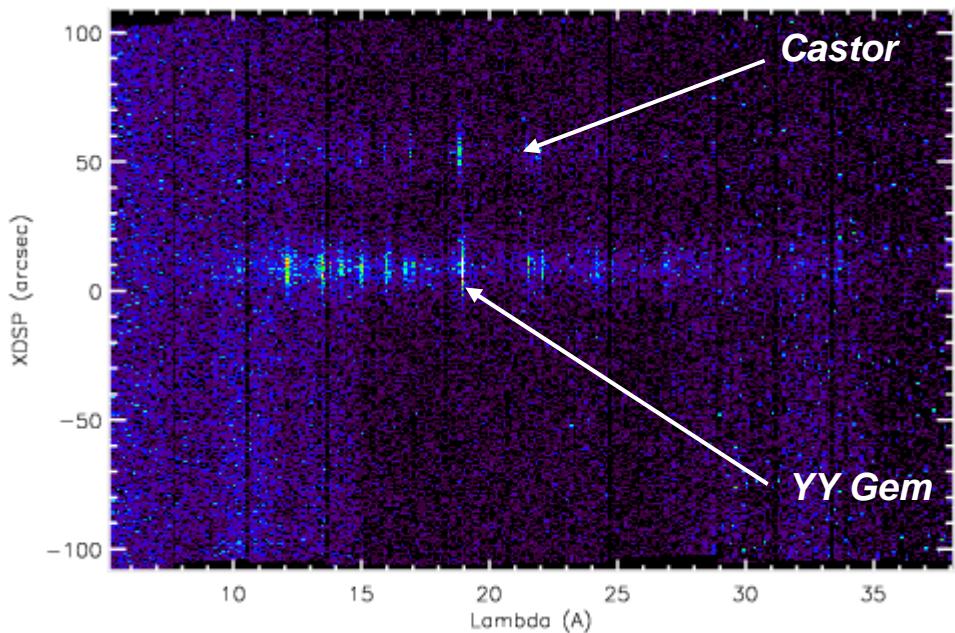
primary source: YY Gem, secondary source: Castor



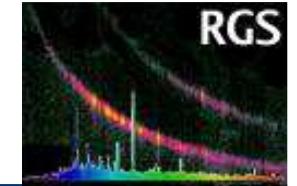
EPIC MOS image

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

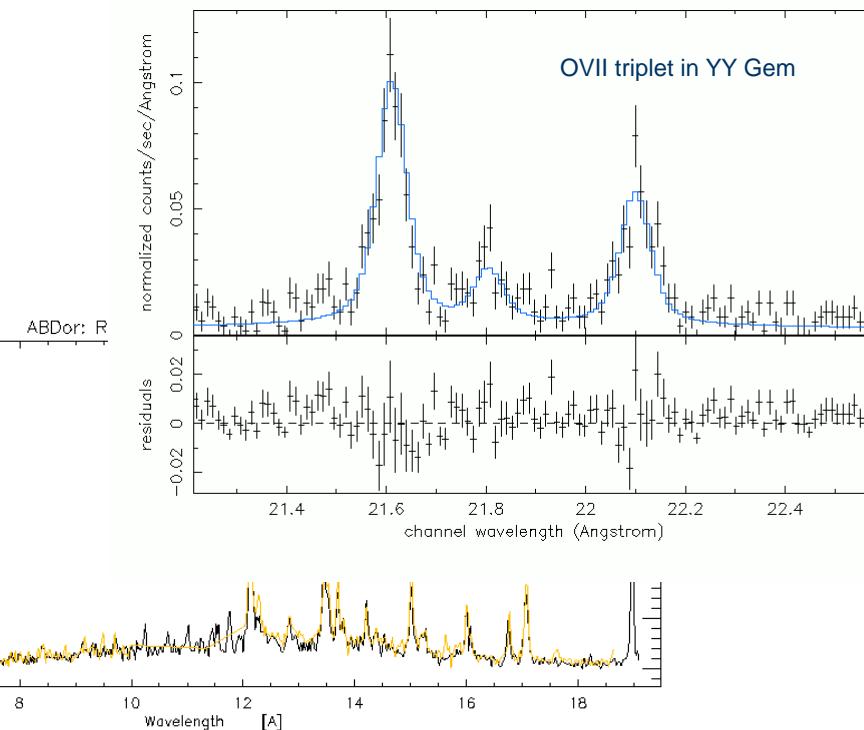
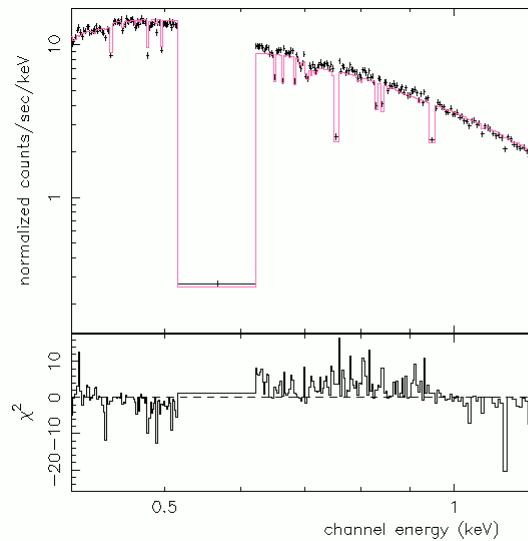


Data analysis

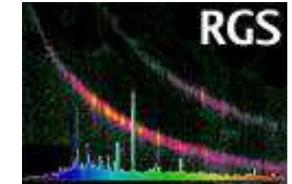


Extracted source + background spectra + response matrix

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



Summary



Data processing with `rgsproc`

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

Validity checks

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

Data analysis

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