There is life after the event lists *Generation of scientific products with SAS*

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(with contributions by Matthias Ehle^(EPIC scientific products), Carlos Gabriel^(source detection), Rosario Gonzalez-Riestra^(RGS), Antonio Martin-Carrillo^(Timing Modes), Richard Saxton^(source catalogs))

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Important announcement



The most important slide of this Workshop is coming



ch 2019

This is the announcement

Almost any reduction tasks you may want to accomplish with Chandra or XMM-Newton data is explained in the **data analysis "threads"**

CIAO: http://cxc.harvard.edu/ciao/threads/index.html
SAS: http://xmm.esac.esa.int/sas/current/documentation/threads/

In this talk I will show you examples of what you can find in the **SAS threads**, pointing to their link

The XMM-Newton grand-scheme



Event lists

	When?	Where [position	on]?	Who [e	nergy]	? Wh [X-ray or	at particle]?
	□ TIME D s	□ X J 0.05 ARCSECONDS	☐ Y J 0.05 ARCSECONDS	☐ PHA I CHAN	□ PI I CHAN	PATTERN B	□ CCDNR B	
1	9.506202266412E+07	23743	21330	423	1447	2	1	
2	9.506202266412E+07	28728	21990	25	98	0	1	
3	9.506202527717E+07	28176	31623	25	97	0	1	
4	9.506202527717E+07	29829	30841	327	1131	0	1	
5	9.506202527717E+07	23686	19319	541	1854	0	1	
6	9.506203046611E+07	25510	32711	1810	6171	0	1	
7	9.506203566620E+07	29814	28823	102	360	0	1	
8	9.506203826626E+07	26635	30601	2062	7028	0	1	
9	9.506204346625E+07	26429	20314	443	1519	4	1	
10	9.506204606629E+07	20691	28728	1608	5471	3	1	
11	9.506204606629E+07	27989	29777	202	700	0	1	
12	9.506204606629E+07	21937	25667	117	402	2	1	
13	9.506204866632E+07	28132	32491	462	1589	0	1	
14	9.506204866632E+07	27204	29741	904	3095	0	1	
15	9.506205126638E+07	22124	20257	290	994	0	1	
16	9.506205906643E+07	23193	18795	1398	4771	0	1	
17	9.506206166646E+07	23224	19326	276	950	0	1	
18	9.506206946653E+07	27755	28979	183	637	0	1	
19	9.506207206939E+07	22533	29563	33	118	0	1	

Lecture content

- 1. How to create EPIC scientific products (spectra, light curves, images)
- [Interlude: How to optimize the signal-to-noise ratio of your EPIC spectra and images]
- 3. How to deal with background
- 4. How to deal with pile-up in EPIC
- How to calculate the instrument responses (EPIC, and RGS)
 R(I,E) amd A(E) in K.Arnaud's talk
- 6. rgsproc extracts RGS spectra automatically for me (you remember this, don't you?). Can I trust them?



Lecture content

How to create EPIC scientific products (spectra, light curves, images)





The SAS extractor

\$> xmmselect table=\${event_list} &

		🛛 XmmSelect	ĸ	
Here the selection expression is defined.		Eile Column Region Viewer Products Style Help Selection expression import clear - Fixed Expression		The EVE column Column to trans defined
Circles are used]	Column selection [0580_0140950101_EPN_S003_ImagingEvts.ds:EVENTS]		express
to define the quantities to extract spectra, light curves, histograms.		TIME R64 min: max: RAWX I16 min: [1] 1 1 64 1 RAWX I16 min: [2] 2 max: [200] 200 1 RAWV I16 min: [2] 2 max: [200] 200 1 DETX I16 min: [-18263] -18263 max: [13860] 13680 1 DETY I16 min: [-17527] -1752 max: [15325] 15325 1 C X I32 min: [1] 1 max: [51840] 51840] 51840 1	/	One car selection defined (image) selection widget
Checkboxes are used to define the quantities on which to extract an image.		Y I32 min: [1] 1 max: [51840] 51840 # Region selection 1D region 2D region # Product selection 2D region # # Filtered Table Fix Expression Image # # OGIP Spectrum OGIP Rate Curve OGIP Spectral Products		Produce may be all the filtered

The EVENTS extension columns are listed. Column buttons allow to transfer the ranges defined in the widgets to the selection expression.

One can transfer selection regions defined in a 1-D or 2-D (image) plots to the selection expression widget

Products which may be extracted: all the above plus filtered event lists.



xmmselect: creation of a rate curve

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https://www.cosmos.esa.int/web/xmm-newton/sas-thread-mos-xmmselect-spectrum

Lecture content







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xmmselect: creation of an X-ray image

	https://www.cosmos.esa.int/web/xmm-	newton/sas-thread-esasimag
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Defining interactively a 2-D spatial region

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Source selection in timing EPIC modes

Do not include the top of the chip in *Burst Mode* (pile-up ...). Avoid RAWX>160 (Kirsch et al., 2006, A&A, 453, 173)

- Timing (MOS/pn) and Burst Modes do not create standard images in detector or raw coordinates. Where to extract the source?
- In pn timing and burst modes take a box in the RAWX and RAWY coordinates plane, *e.g.* (RAWX,RAWY) IN box(36.75,100.75,6.75,96.75,0)
- In MOS Timing Mode, create a pseudo-image in the (RAWX,TIME) plane or an histogram in RAWX, and decide the range in RAWX corresponding to your source
- Then proceed with arfgen and rmfgen

Burst Mode

RAW

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xmmselect: creation of EPIC spectra

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OGIP Spectrum	

Assuming that one has cleaned the event list for high background & defined a source region (e.g. as a circle).



A note on spectral binning





Lecture content

How to create "background" products (and, by passing) optimizing the signal-to-noise ratio of your data



Whence does background come from?

The full table is available at:

https://www.cosmos.esa.int/web/xmm-newton/epic-background-components

	PARTICLES			PHOTONS		
	SOFT PROTONS	INTERNAL (cosmic-ray induced)	ELECTRONIC NOISE	HARD X-RAYS	SOFT X-RAYS	
Source	Few x 100 keV solar protons, accelerated by magnetospheric reconnection events. Dominate times of high-BG.	Interaction of High Energy particles (cosmic rays) with detector - associated instrumental fluorescence. Main MOS ref.	 Bright pixels & (parts of) columns. CAMEX readout noise (pn). (3) (4) (5)Artificial Low-E enhancements in outer MOS CCDs (Also dark current - thought negligible). 	X-ray background (AGN etc), Single Reflections from outside FOV, Out-of-time (OOT) events (pn)	Local Bubble, Galactic Disk, Galactic Halo, Solar Wind Charge Exchange (SWCX) SWCX, Single Reflections from outside FOV, Out-of-time (OOT) events (pn)	
	remove					

model



High background "flares"

XMM-Newton is particularly affected by an annoying problem:





Cleaning high background

XMM-Newton sometimes experiences high flaring background periods (soft protons accelerated by magnetic reconnection), as well as high background close to perigee. They need to be removed before extracting any scientific products:

- extract a high-energy, single event light-curve, with the expression: PN:(PI in [10000:12000])&&(PATTERN==0)&&#XMMEA_EP MOS: (PI>10000)&&(PATTERN==0)&&#XMMEA_EM
- create GTI, excluding all "flaring" intervals
 tabgtigen table=high_energy_curve.fits gtiset=gti.fits
 expression="RATE=<0.4" for pn or expression="RATE=<0.35" for MOS</pre>
- apply above GTI to any scientific products accumulations, adding to the selection expression the string: "...gti(gti.fits, TIME) ..."



https://www.cosmos.esa.int/web/xmm-newton/sas-thread-mos-spectrum

Instrumental background is complex

EPIC-pn example





Spectrum of the instrumental background

Image of the instrumental background M.Guainazzi: "SAS II.", COSPAR Capacity Building Workshop, IISER, 10th March 2019

How to create background products



MOS: an annulus concentric to the "source" is the best choice pn: avoid annuli, choose a circle close to the "source"



How to deal with "pile-up" [stay very awake NOW! if you work with bright sources for instance X-ray Binaries]





Pile-up – the tale of 1 pixel and 2 photons



What is pile-up?





How to correct it?

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

- How to check if there is pile-up?
 - SAS task epatplot
 - Compare the count rate of your source with the tables in Jethwa et al., 2015, A&A, 581, 104
- How to avoid pile-up?
 - [Choose the correct instrumental mode when proposing something – too late for you here at the Workshop]
 - Remove the core of the PSF affected by pile-up
- How to cure pile-up?
 - rmfgen [...] correctforpileup=yes
 - pileup convolution model in XSPEC/ISIS

None of these method is perfect. Better avoid piled-up data



Lecture content

How to calculate the EPIC responses



Creation of EPIC responses?

Image - Calculates the redistribution matrix (RMF)
> rmfgen spectrumset=myspec.ds rmfset=myspec.rmf

□ arfgen – Calculates the instrument effective area (ARF)

- Standard call (point source):
- > arfgen spectrumset=myspec.ds arfset=myspec.arf
- Call for extended sources:
- > arfgen spectrumset=myspec.ds arfset=myspec.arf extendedsource=yes badpixlocation=myevents.FIT detmaptype=flat
- For extended sources it is better to use a <u>detector map</u>:
 evselect withimageset=yes imageset=coarseimage.ds
 xcolumn=DETX ycolumn=DETY expression=<region surrounding the source>

> arfgen spectrumset=myspec.ds arfset=myspec.arf extendedsource=yes detmaptype=dataset detmaparray=coarseimage.ds







Lecture content

You may ask: "Why do you leave RGS at the very end?"





RGS reduction is ludicrously simple

Answer: because in principle all you need to do to create RGS spectra is running:

\$> rgsproc



Analysis of RGS data





The extracted spectra

By default, spectra are extracted for both orders (1st and 2nd) for the nominal boresight position

• the rgsproc default is the <u>total</u> source spectrum (NOT background subtracted) in counts/channel

 the background spectrum and response matrices are also produced → you can start the spectral analysis

spectra

This plot is available in the XSA for quick-look

XMM - ROS2 - OBJECT: Mkm 766 - 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





RGS background subtraction

Two ways to perform RGS background subtraction:

- off-axis areas from the same observation (default in rgsproc)
- Templates from blank fields.
 - Advantages:
 - Higher statistics of the background spectra (higher geometrical area, longer exposure time)
 - Avoid source contamination for extended sources
 - Improves detection of weak features
 - Disadvantages:
 - Is it really the background of my observation?

• rgsproc withbackgroundmodel=yes

• http://xmm.esac.esa.es/docs/documents/CAL-TN-0058-1-1.ps.gz

Validity checks I.: extraction regions

https://www.cosmos.esa.int/web/xmm-newton/sas-thread-rgs



Offset target? Try: rgsproc withsrc=yes srcra=<RA> srcdec=<Dec>

Changing source or size of the extraction regio

https://www.cosmos.esa.int/web/xmm-newton/sas-thread-rgs2



Sources can be added/modified with rgssources

Region definitions can be changed with rgsregions or:

rgsproc xpsfincl=95 xpsfexcl=98 pdistincl=95

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

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Validity checks II: high background





The same observation with high background

- Create a 10-100 s binned light curve for background region in CCD=9
 - evselect table=RGSevents.fits withrateset=yes rateset=RGS.lcu expression="CCD==9&&(REGION(PxxxxxyyyyRleeeeSRCLI_00 00.FIT:RGS1_BACKGROUND:BETA_CORR,XDSP_CORR)"
- Create a GTI file for count rate<0.5 s⁻¹
 - tabgtigen table=RGS.lcu timebinsize=1 expression="RATE.LE.0.5" gtiset=CCD9.gti
- Re-run pipeline using the GTI created in the previous step
 - rgsproc auxgtitables=CCD9.gti entrystage=3:filter finalstage=5:fluxing



Conclusion

Cooking is art.

High-energy data reduction is also art. Just following blindly the instructions spoils the soup

[photos are taken from a recipe of the *melanzane alla* parmigiana": a typical Sicilian dish]