Analysis of EPIC data of Extended Sources

14th XMM-Newton SAS Workshop

June 2 – June 6, 2014

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XMM-Newton Science Operations Centre

Status

- **Analysis of extended sources is *complex*, *challenging* and *time-consuming***
  - ***The analysis of extended sources is reduced to the knowledge of the background***

- **There are some "official" SAS recipes**

- **Since 2005: XMM-Newton EPIC Background working group (BGWG) *"A steering and supervising committee to provide the user with clear information on the EPIC Background and (SAS)-Tools to treat the EPIC Background correctly for various TBD scenarios"***

  http://xmm2.esac.esa.int/external/xmm_sw_cal/background/ (also info on RGS/OM)

  - **Table summarizing temporal, spectral & spatial properties of EPIC background components**
  - **Progress & Meetings of the XMM-Newton EPIC Background working group**

  - **Products:**
    - **XMM-Newton Blank Sky background files & related software**
    - **Filter Wheel Closed data**
    - **XMM-Newton Extended Source Analysis Software package (ESAS)**
    - **Links to related papers** **(new threads just available)**

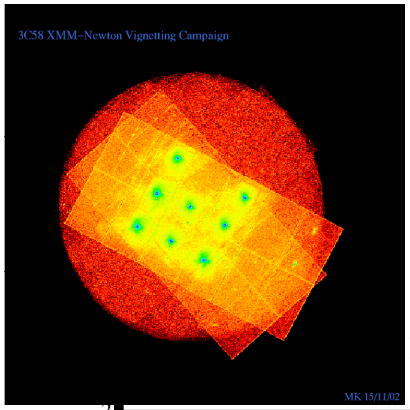
Status

BKG components & their temporal, spectral, spatial properties are summarized at

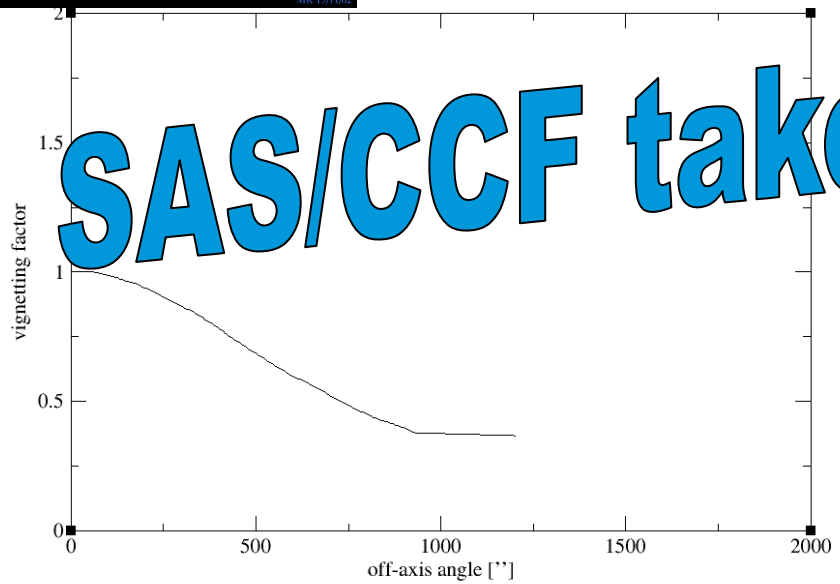
http://www.star.le.ac.uk/~amr30/BG/BGTable.html

- **Particles**:
  - High energy penetrating (CR) hitting directly the CCD or indirectly by fluorescence when hitting satellite components
  - Soft protons flares
- **Electronic Noise**:
  - Bright pixels or columns, readout noise, etc ….
- **Photons**:
  - Cosmic X-ray background
  - Solar wind charge exchange
  - Reflections from out of FoV sources, OoT events etc….

Why is it so difficult ?

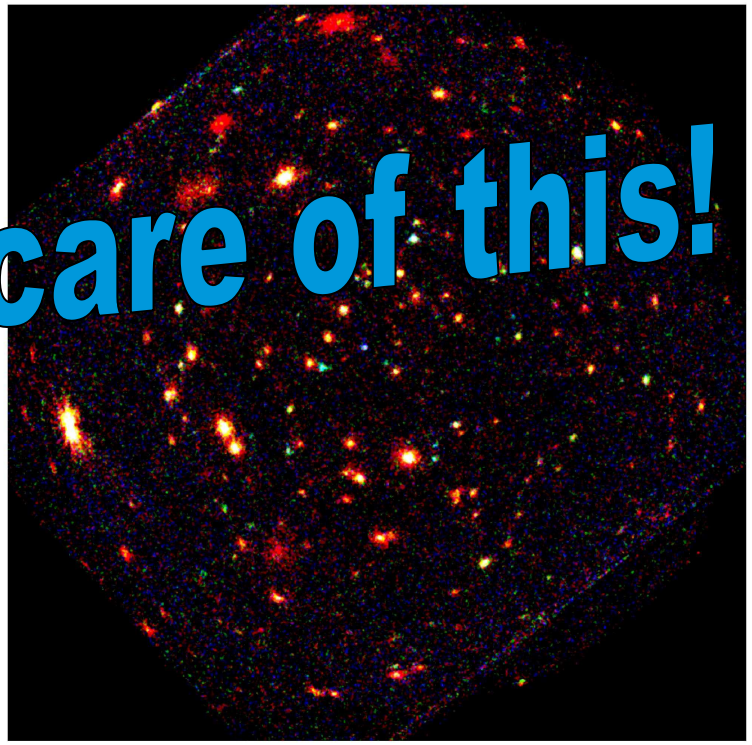


I. Vignetting



II. Point Spread Function

XMM-NEWTON SCIENCE RESULTS

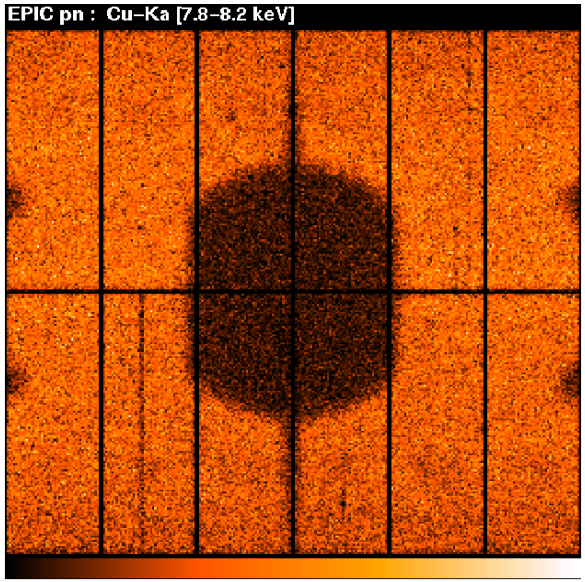


6 December 2000 Fig. 8

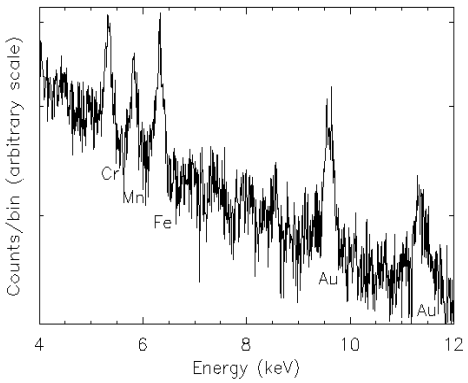
SAS/CCF takes care of this!

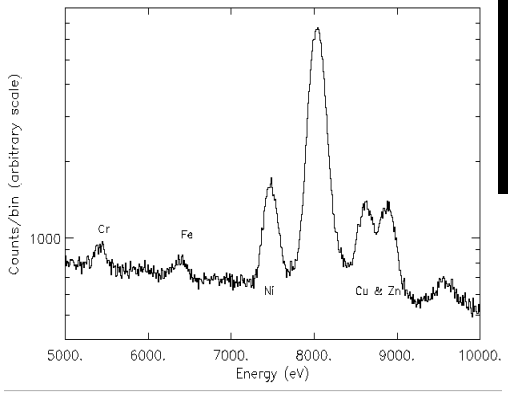
xmm-newton
European Space Agency

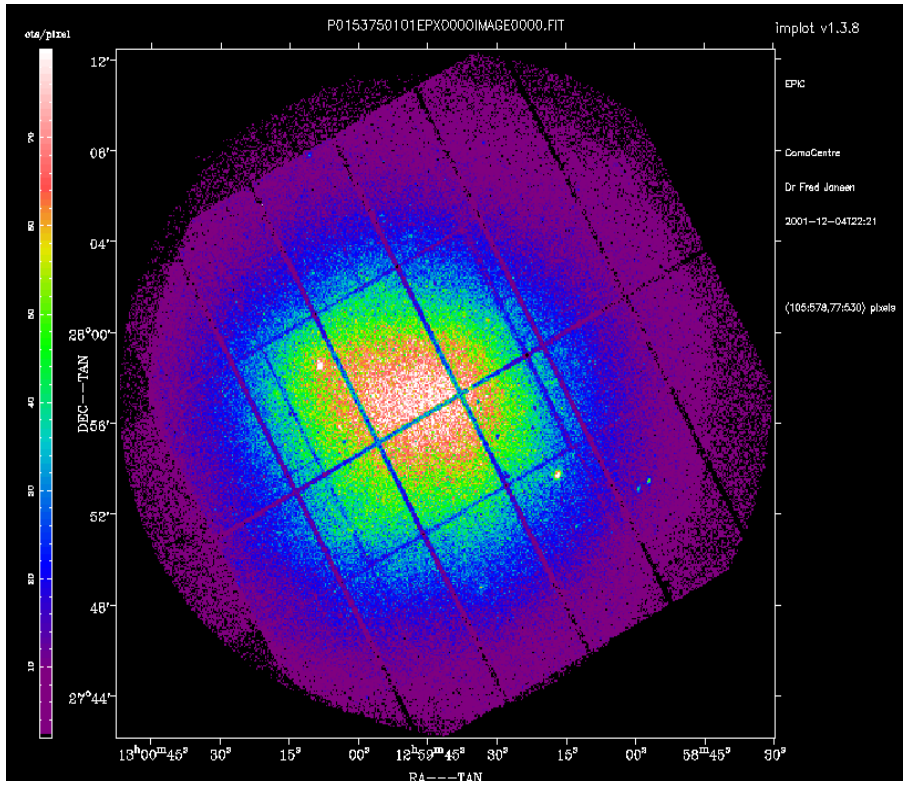
Why is it so difficult (still) ?



III. Spatial background variability





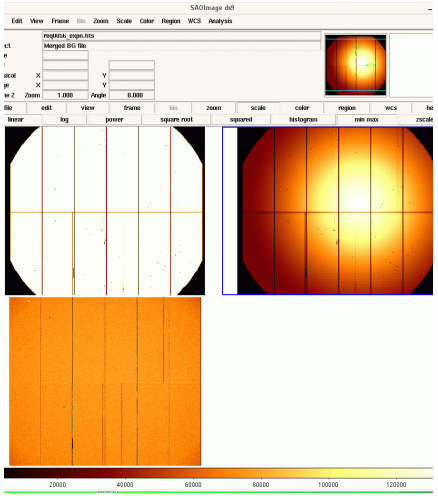


IV. Lack of background in FOV

The EPIC Background Analysis Web Page: Products of the EPIC BGWG

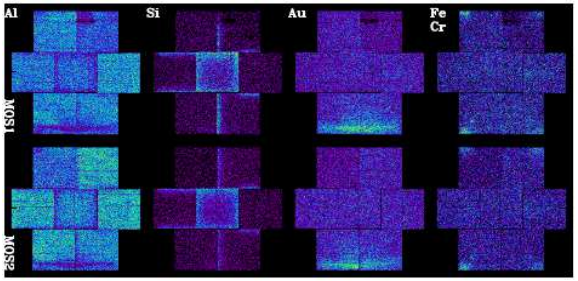
- **I. Blank Sky Background Event Files**

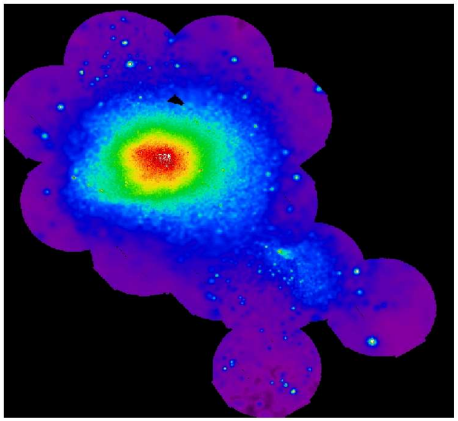
  Developed at LUX by the EPIC Blank Sky team based on the work of J. Carter and A. Read (A&A 464, p1155, 2007)



- **II. Filter Wheel Close Data (FWC)**

  Repository of FWC Data maintained at the SOC, ESAC





- **III. XMM-Newton Extended Source Analysis Software (XMM-ESAS)**

  Developed by S.Sembay at the NASA/GSFC XMM-Newton Guest Observer Facility (GOF) in cooperation with the XMM-Newton SOC and the Background Working Group.

Which background to use? – 1. Blank Sky Fields

- Often no statistically useful background region in the observation field-of-view
  ⇒ use "blank sky fields" to generate background spectra

- Need to extract BKG far from target source. Source may be so extended that no local background is visible in FoV.

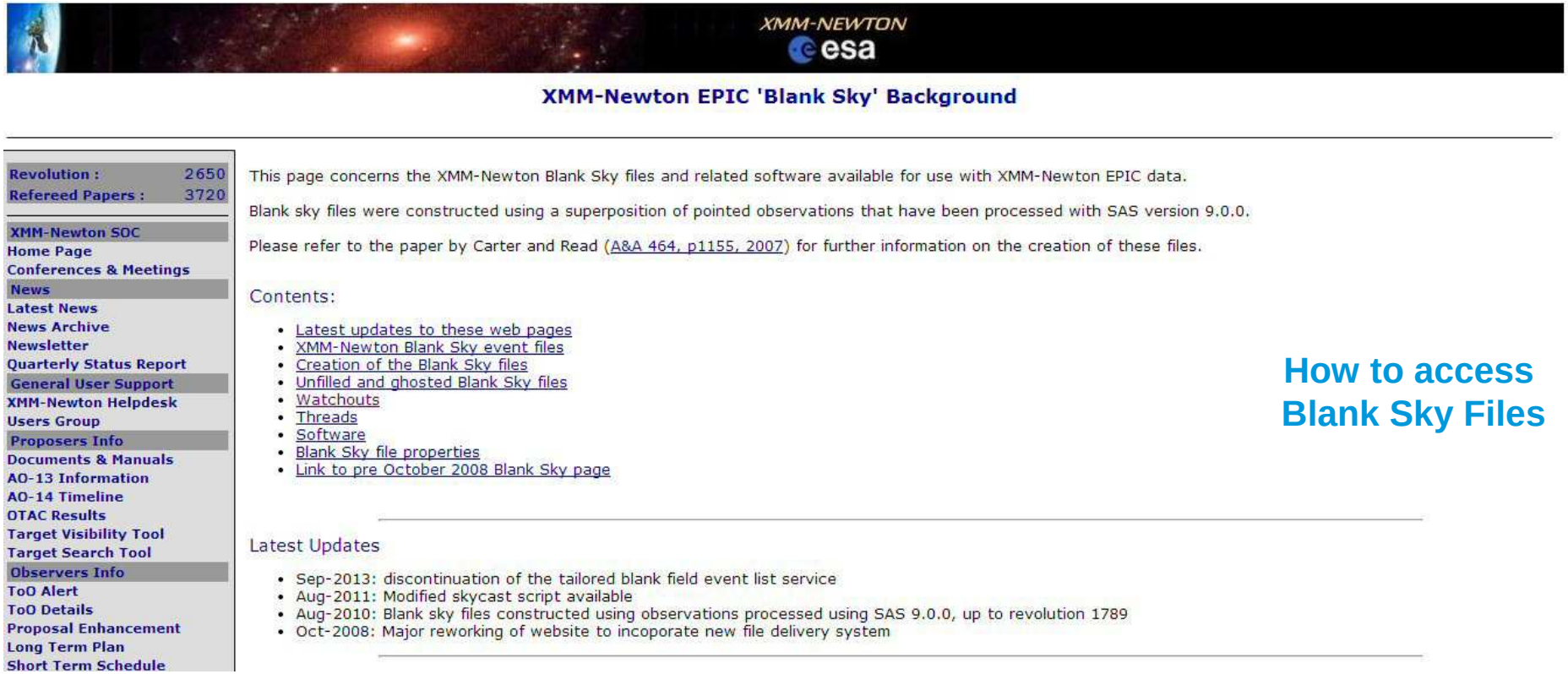
  - Off-axis BKG can be highly inappropriate in analysing (nominally on-axis located) targets:

    - effective area of mirrors changes with off-axis angle
    - instrumental fluorescence
    - spectral response depends on detector position

- Recommended option **(files produced for by Read & Carter, Uni. Leicester): Paper by Carter & Read; A&A, 1155, 2007**

Which background to use? – 1. Blank Sky Fields

http://xmm2.esac.esa.int/external/xmm_sw_cal/background/blank_sky.shtml

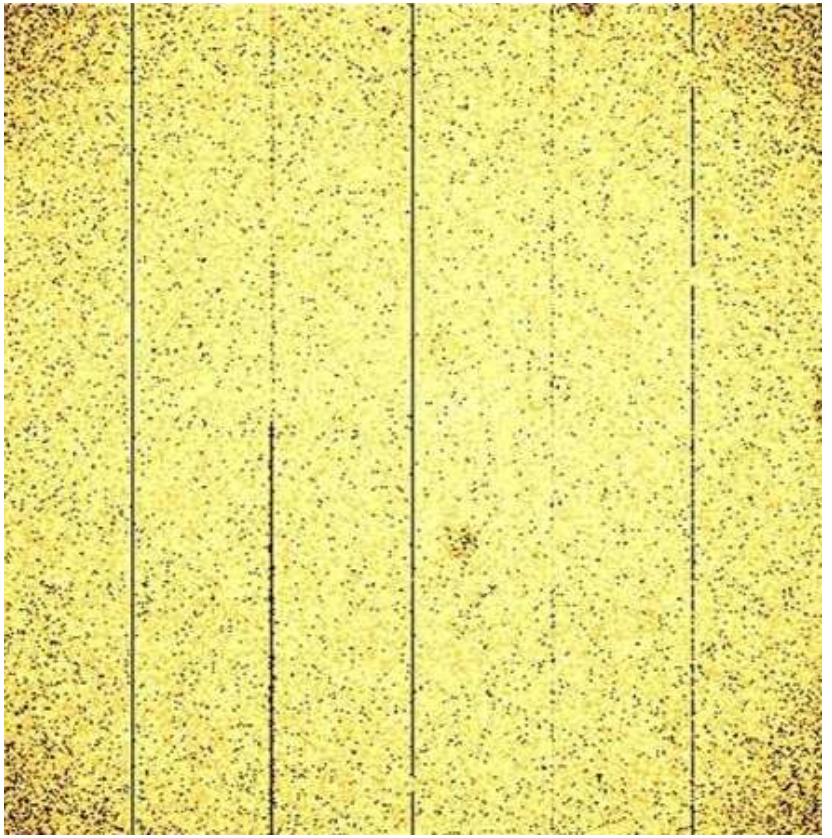


How to access Blank Sky Files

Which background to use? – 1. Blank Sky Fields

What are a Blank Sky event files ?

Event file made out of the superposition of many pointed observations that have undergone source removal and flare-screening.



EPIC pn FF mode

Which background to use? – 1. Blank Sky Fields

Users can download **generic** or specific tailor-made Blank Sky files

XMM-Newton EPIC Background Blank Sky file repository

Individual blank sky files can be downloaded from the links presented on this page. The sections *Generic files (ghosted) Generic files (unfilled)* contain links to blank sky files made without specific selection criteria applied. They are listed by instrument, mode, filter and the ghosted or unfilled status. Additional generic files have been made for EPIC-MOS1. These have been split into two epochs, occurring before and after the loss of CCD 6 (revolution 0961). These files are found in section *MOS1 split files*. Other blank sky files made using other selection criteria (such as exposure time, revolution number etc.) can be found in the section *Specific Requests*.

Request from the EPIC Blank Sky team:
We politely request that should the files here contribute to work that leads to publication, that the reference to the Blank Sky work (Carter and Read (A&A 464, p1155, 2007)) be cited.

Generic files (ghosted):

Number	ID	Inst.	Filt.	Mode	Status	SAS
					Unfilled (U) or ghosted (G)	
1	pn_t_ff_g	PN	T	FF	G	9.0
2	m1_t_ff_g	M1	T	FF	G	9.0
3	m2_t_ff_g	M2	T	FF	G	9.0
4	pn_m_ff_g	PN	M	FF	G	9.0
5	m1_m_ff_g	M1	M	FF	G	9.0
6	m2_m_ff_g	M2	M	FF	G	9.0
7	pn_k_ff_g	PN	K	FF	G	9.0
8	m1_k_ff_g	M1	K	FF	G	9.0
9	m2_k_ff_g	M2	K	FF	G	9.0
10	pn_t_ef_g	PN	T	EF	G	9.0
11	pn_m_ef_g	PN	M	EF	G	9.0
12	pn_k_ef_g	PN	K	EF	G	9.0

Generic Files

- For pn and MOS
- For the 3 filters: Thick, Medium and Thin
- For Full Frame (FF) mode
    - For pn also Effective Full Frame (EFF)
- Ghosted and Unfilled event files

Which background to use? – 1. Blank Sky Fields

Users can download generic or **specific** tailor-made Blank Sky files

Specific requests:

ID	Inst.	Filt.	Mode	Status	SAS	Time	Date	Revn	Exposure	Galactic column	Count rate	Coord	Max no. events
				Unfilled (U) or ghosted (G)		limits (s)		limits	limits (ks)	limits (cm-2)	limits (ct/s)	RA, Dec (or Gal. (G) l, b), radius (deg)	
0584	M1	M	FF	G	9.0			0962,2000	10.0,20.0			286.77,4.52,15	
0583	PN	M	FF	G	9.0			0962,2000	15.0,30.0			286.77,4.52,45	
0582	M2	M	FF	G	9.0			0962,2000	15.0,30.0			286.77,4.52,45	
0581	M1	M	FF	G	9.0			0962,2000	15.0,30.0			286.77,4.52,45	
0579	M1	T	FF	G	9.0			0962,2000				260.04,26.63,20	
0576	PN	T	FF	G	9.0					8.0e19,1.2e20		150.0,55.0,20	
0575	PN	T	FF	G	9.0			0963,2200		1.0e21,2.0e21		85.93,-67.86,90	
0574	M2	T	FF	G	9.0			0963,2200		1.0e21,2.0e21		85.93,-67.86,90	
0573	M1	T	FF	G	9.0			0963,2200		1.0e21,2.0e21		85.93,-67.86,90	
0572	PN	T	FF	G	9.0			0963,2200		1.0e20,3.0e20		33.85,-3.73,2	
0571	M2	T	FF	G	9.0			0963,2200		1.0e20,3.0e20		33.85,-3.73,2	
0570	M1	T	FF	G	9.0			0963,2200		1.0e20,3.0e20		33.85,-3.73,2	
0569	PN	T	FF	G	9.0			1000,2200		5.0e20,1.0e21		280.47,-32.89,60(G)	
0568	PN	T	FF	G	9.0				20,70	1.0e19,1.0e20		181.69,67.17,45	
0567	PN	M	FF	G	9.0							190.99,32.17,18	
0566	PN	M	FF	G	9.0		2000-01-01,2005-03-01		10,100	1.8e20,6.0e20		220.00,-0.5,80	
0565	M2	M	FF	G	9.0		2000-01-01,2005-03-01		10,100	1.8e20,6.0e20		220.00,-0.5,50	
0564	M1	M	FF	G	9.0		2000-01-01,2005-03-01		10,100	1.8e20,6.0e20		220.00,-0.5,50	
0563	PN	M	FF	G	9.0			0962,2500	10,200	1.0e20,6.0e20	0.0,10.0	221.23,1.95,25	
0562	M2	M	FF	G	9.0			0962,2500	10,200	1.0e20,6.0e20	0.0,2.0	221.23,1.95,25	
0561	PN	M	FF	U	9.0		2008-01-01,2010-12-31					266.57,-32.23,30	
0560	M1	M	FF	G	9.0			0962,2500	10,200	1.0e20,6.0e20	0.0,2.0	221.23,1.95,25	

Specific Request

Users up to Sep 2013 could make requests for different instruments, filters and modes:

- Time based requests
  Time, Date, Revolution, Exposure
- Sky region requests
  Coordinates, N_H
- Other
  Count Rate, Max. Number of Events per file

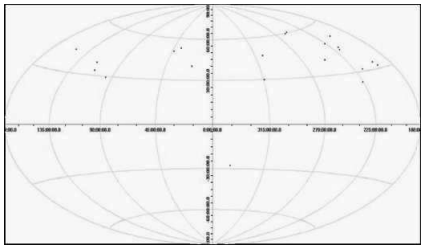
Which background to use? – 1. Blank Sky Fields

XMM-Newton EPIC Background Blank Sky Products Delivery

Request id:
0045

Delivered files:

1. Blank sky event file 1: blanksky_events.fits
2. Blank sky exposure file, non-vignetted 1: blanksky_expn.fits
3. Blank sky exposure file, vignetted 1: blanksky_expv.fits



Request sent:
Mon, 16 Jan 2009

Request summary:

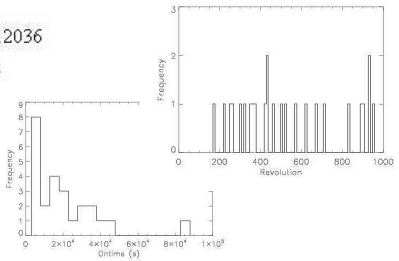
Instrument:	MOS1
Filter:	Medium
Mode:	Full-Frame
Type:	Ghosted

Advanced selection:

Revolution:	No selection
Date:	No selection
Time (s):	No selection
Exposure (ks):	No selection
Galactic column (cm-2):	3.0e20 to 4.0e20
Count rate:	No selection

Positional selection:

Equatorial coordinates selected:	193.274, -9.2036
Galactic coordinates selected:	No selection
Radius selected (degrees):	100



Number of events:
Maximum number of events: 1.0e6

Diagnostic files:

1. Revolution histogram 1: revnhist.jpg
2. Ontime histogram (post flare cleaning) 1: ontimehist.jpg
3. Component map (galactic coordinates) 1: map_selection.jpg

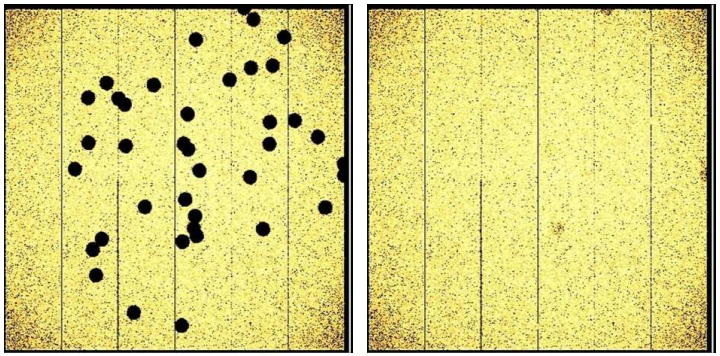
Comment: Files were created for the selection requested. Details of the selection procedure:

1. The instrument, filter, mode and filled status selection was completed successfully, events were found
2. The selection by coordinates was completed successfully, events were found
3. The selection by galactic column density was completed successfully, events were found
4. The selection by maximum number of events was completed successfully, events were found

Request from the EPIC Blank Sky team:
We politely request that should the files here contribute to work that leads to publication, that the reference to the Blank Sky work (Carter and Read (A&A 464, p1155, 2007)) be cited.

Products from Specific Requests

Each Blank Sky file is constructed from several different event files



Which background to use? – 1. Blank Sky Fields

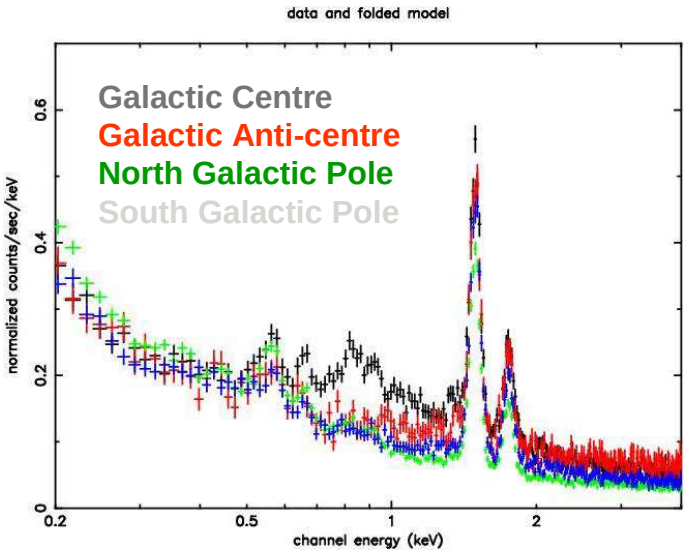
Software available related to background files (shell scripts calling SAS/FTOOLS):

- Skycast: to cast an EPIC background dataset onto the sky, at the position given by an input template event dataset (e.g. the event file you are interested in producing a background for); *attcalc SAS task*
- BGrebinimage2SKY: to re-bin and re-project exposure maps onto the sky to the spatial scale and sky position of a user-input image.
- Ghostholes_ind: to fill in regions that are extracted from each individual image.

Caveats: Variations in spectra…

1. … with count rate &
2. … over the sky:

   Note: higher count rate of galactic center due to higher levels of soft X-ray emission



Which background to use? – 2. XMM-ESAS

- Alternative approach ⇒ use "model" to generate background spectra
- Recommended option: **(tool produced for BGWG by Snowden & Kuntz, US GOF):**

XMM-ESAS: Extended Source Analysis Software package

http://xmm2.esac.esa.int/external/xmm_sw_cal/background/epic_esas.shtml

  - Allows to model quiescent particle background for MOS & PN
  - Produces background spectra for user-defined regions & background images
  - Output files are FITS standard
  - Package consists of PERL scripts (calling SAS tasks) & stand-alone Fortran 77 programs

- Documentation:

  - XMM-ESAS is based on software used for background modeling described in Snowden, Collier & Kuntz (2004, ApJ, 610, 1182) and updated & applied to catalog of cluster observations in Snowden et al. (2008, A&A, 615).

  - Cookbook: incl. example data & recipe of spectral & image data processing

http://xmm.esac.esa.int/sas/current/howtousesas.shtml

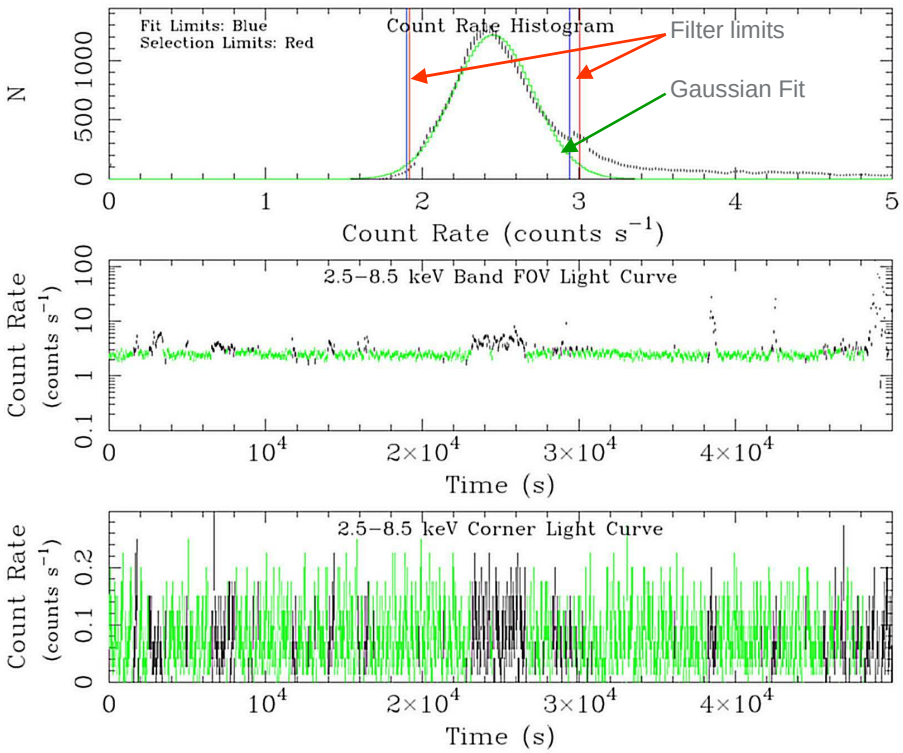
  - Threads: recipe of spectral & image data processing

http://xmm.esac.esa.int/sas/current/documentation/threads/

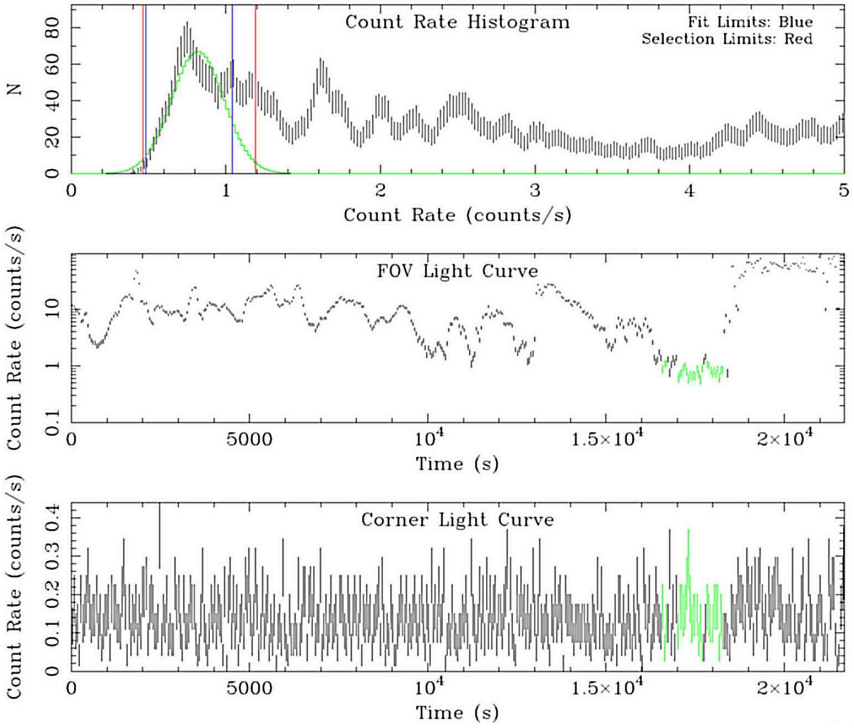
Background flare removal: the ESAS way

Instead of GTIs from count-rate limits > 10 keV…

XMM-ESAS: filtering in user def. band & based on count rate histogram: SAS task espfilt (MOS & pn)



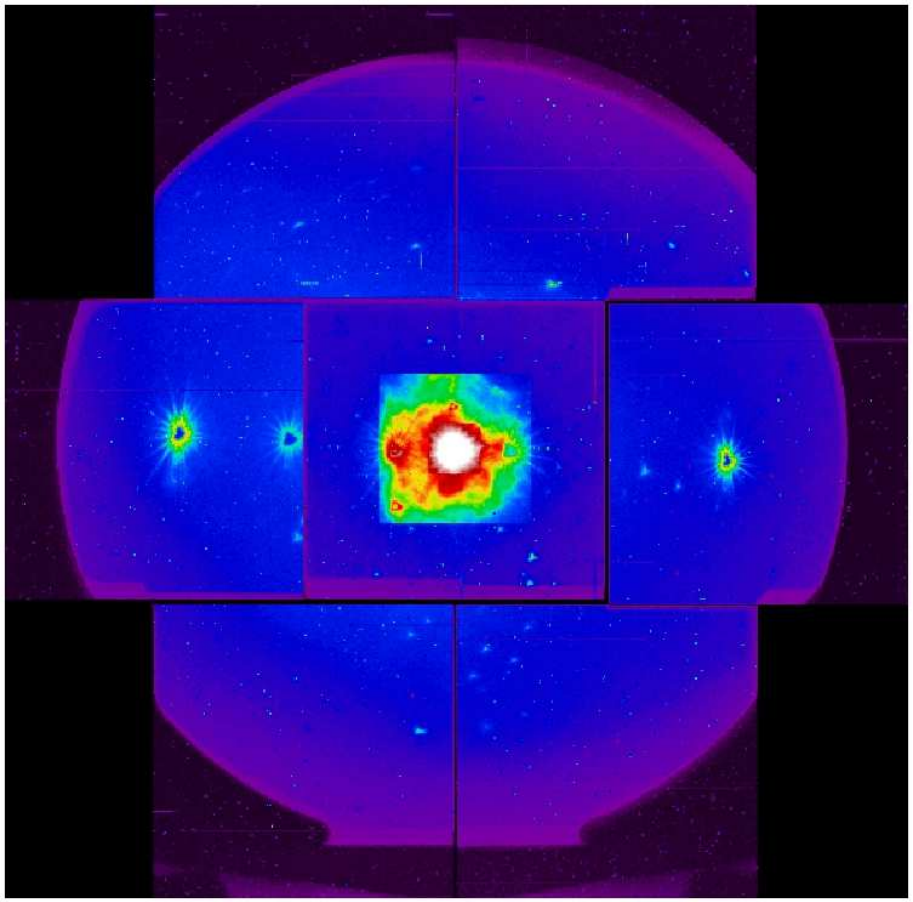
High count rate excursions due to soft protons rather than higher-energy particles (which would produce increase in corner data)



Strong soft proton flaring ⇒data not useful for study of diffuse emission; 2 ks left are likely to be still contaminated

Which background to use? – 2. XMM-ESAS

- Method: MOS **corner pixels are a measure of the particle background**



- Use as many known parameters as possible rather than relying on local bkg determinations and blank-sky background data sets

- E.g., use FWC data, RASS, soft proton distribution, archived observation data sets

Which background to use? – 2. XMM-ESAS

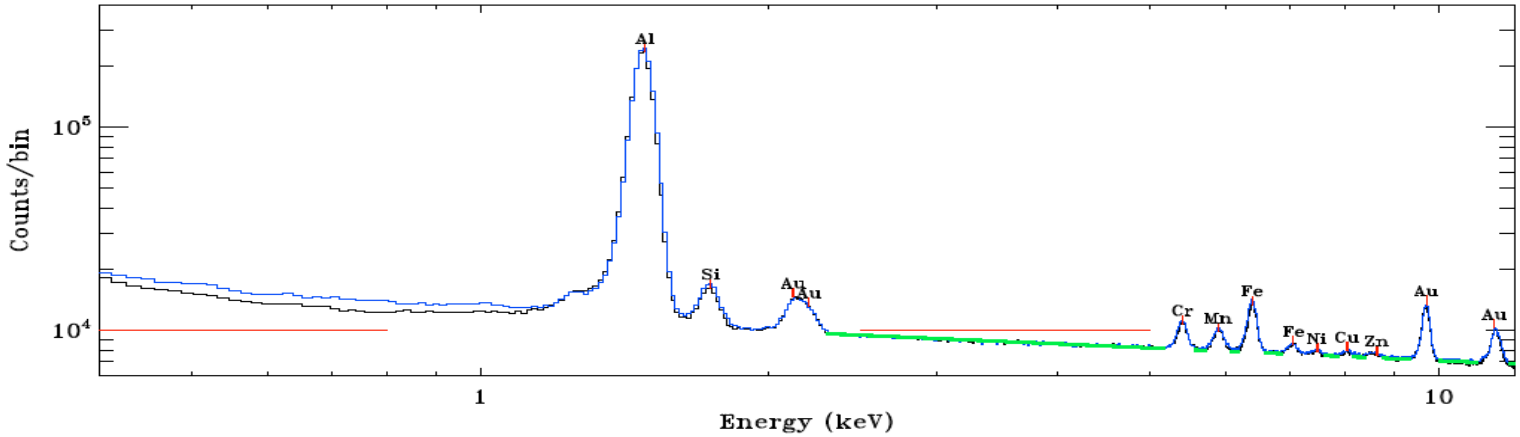
- Model the Quiescent Particle Background (QPB)

  (after removal of flaring background)

- **<u>Determine the corner spectral parameters</u>: high-energy power law slope [2.4-12.0 keV] and hardness ratio [(2.5-5.0)/(0.4-0.8)] from the observation data set**

Which background to use? – 2. XMM-ESAS

- Quiescent Particle Background (QPB)



Mean QPB spectrum derived from unexposed corner pixel data from all public screened data (~76 Msec for each camera). MOS1 black, MOS2 blue.

Red lines: two regions used to measure hardness ratio (HR)
Green line: fitted power law above 2.4 keV

HR & slope used for parameterization of QPB; Prominent background lines are labeled.

Both continuum and line contributions are both position and temporally varying

Which background to use? – 2. XMM-ESAS

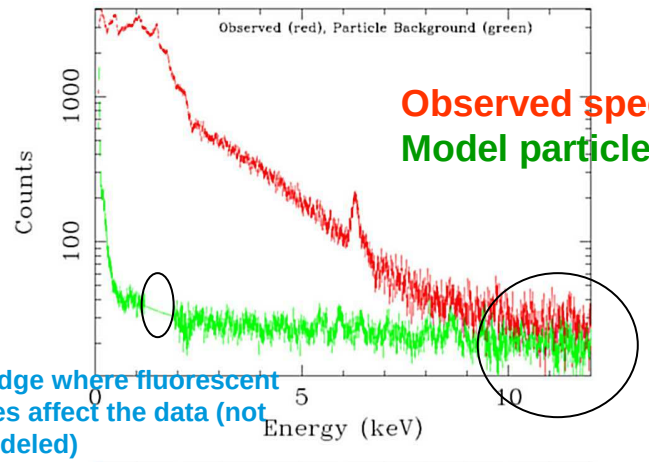
- Model the Quiescent Particle Background (QPB)
  (after removal of flaring background)

- **Determine the corner spectral parameters: high-energy power law slope [2.4-12.0 keV] and hardness ratio [(2.5-5.0)/(0.4-0.8)] from the observation data set**

- **Search an archived-observation data base for observations with similar parameters**
- **Augment the observation data set corner spectra with data from the archived-observation data base**
- **Scale the Filter Wheel Closed (FWC) spectra (treat each CCD separately) for the region of interest by the ratio of the augmented observation corner spectra to the FWC corner spectra**
- **Combine augmented & corrected corner-region spectra from different CCDs, correctly weighted, to form single bkg spectrum for object region**

XMM-ESAS: Spectral analysis

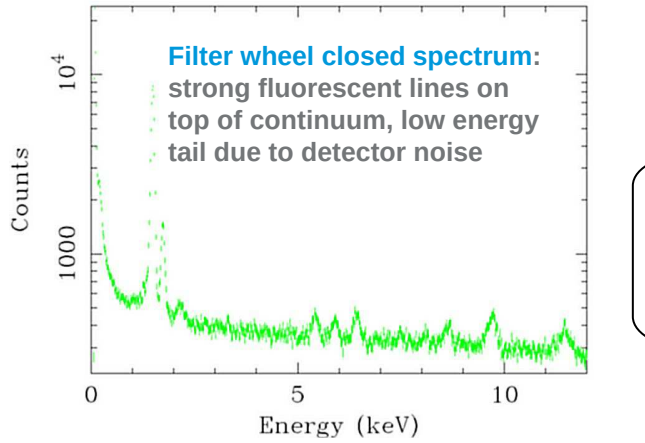
- Some results from XMM-ESAS (Abell 1795):



Observed spectrum
Model particle bkg.

Discrepancy due to residual soft proton contamination

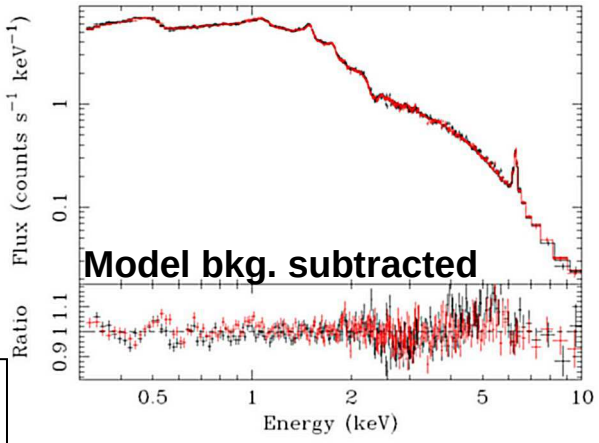
Bridge where fluorescent lines affect the data (not modeled)



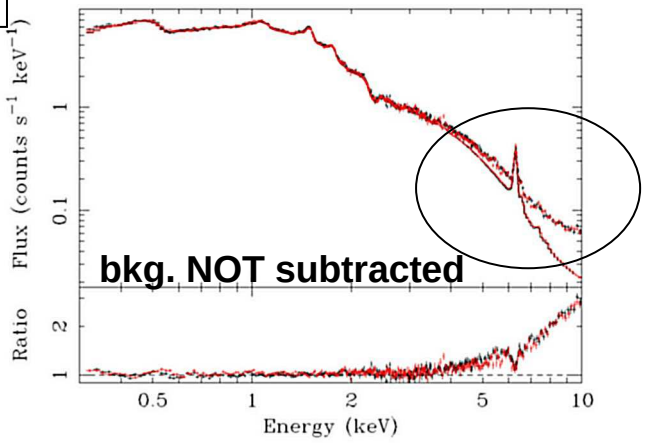
Filter wheel closed spectrum: strong fluorescent lines on top of continuum, low energy tail due to detector noise

Fitted MOS1 & MOS2 spectra

Details of the rather complex fit model are given in the ESAS Cookbook …



Model bkg. subtracted

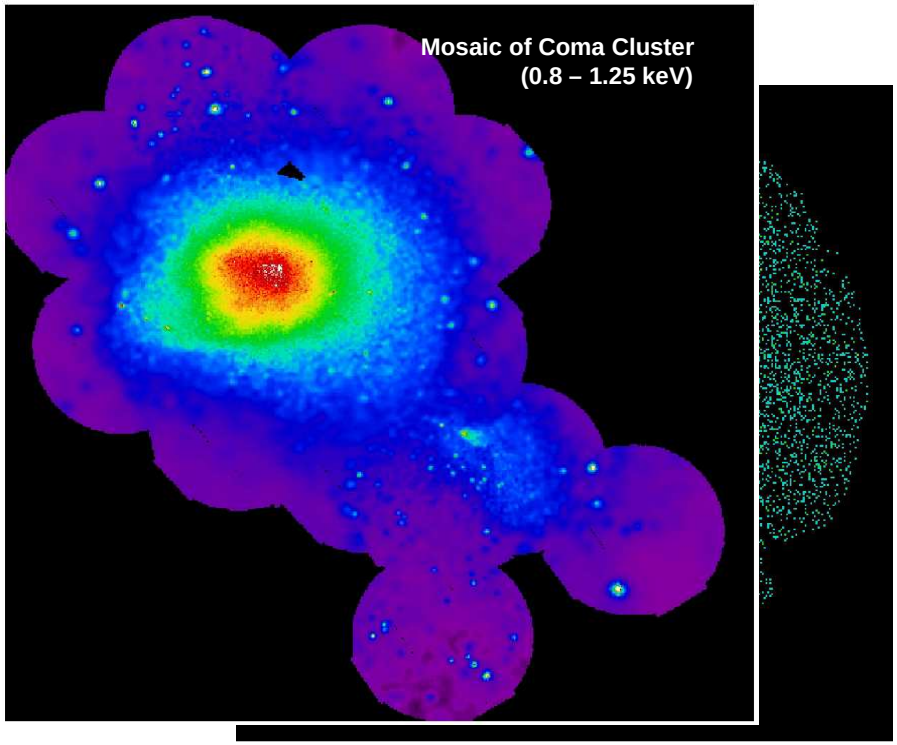


bkg. NOT subtracted

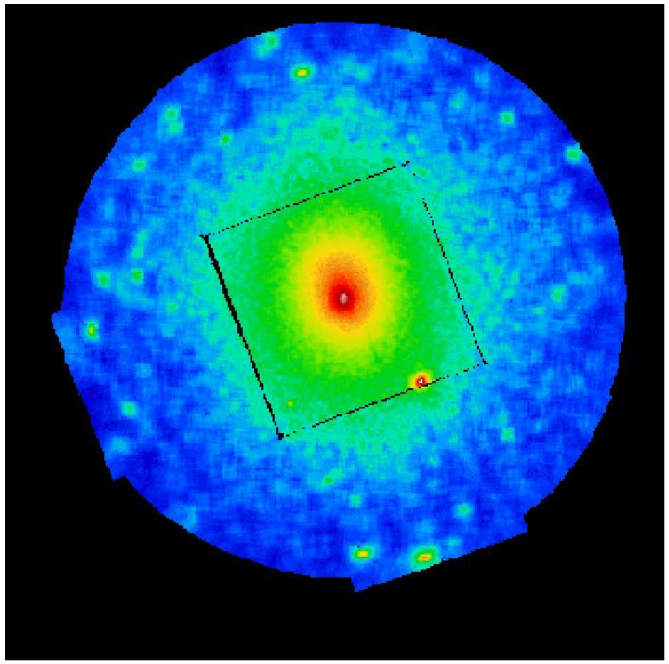
XMM-ESAS: Image generation

SAS task *asmooth* is one option …

XMM-ESAS: adaptive smoothing of background subtracted & exposure corrected images & merging of EPIC data & mosaicing of multiple pointings (see ESAS Thread)



Abell 1795 (0.35-1.25 keV)



observed counts **&** **bkg-subtracted & exp. corrected, smoothed image**

Addition: Filter wheel closed data

- Filter Wheel Closed (FWC) data
  - From calibration obs. with filter wheel in closed position
  - Released in September 2006:
    stacked collections of FWC data available for MOS and pn

- What for?
  - Closed position ⇒ blocking X-rays & soft protons from outside
  - Cosmic rays, however, still penetrate to the detectors

    ⇒ allows clean measure of (internal) bkg components:
    - high energy particles producing charge directly in CCDs
    - particle induced X-rays (continuum and fluorescent lines), generated inside the camera
    - electronic readout noise (at lowest energies)

- BGWG provides them for MOS (fullframe) & PN (all modes), see,
  http://xmm2.esac.esa.int/external/xmm_sw_cal/background/filter_closed/

- These components are distributed non-homogeneously and are time dependant !

Filter Wheel Closed Data: MOS

- MOS FWC Data:
  http://xmm2.esac.esa.int/external/xmm_sw_cal/background/filter_closed/mos/index.shtml

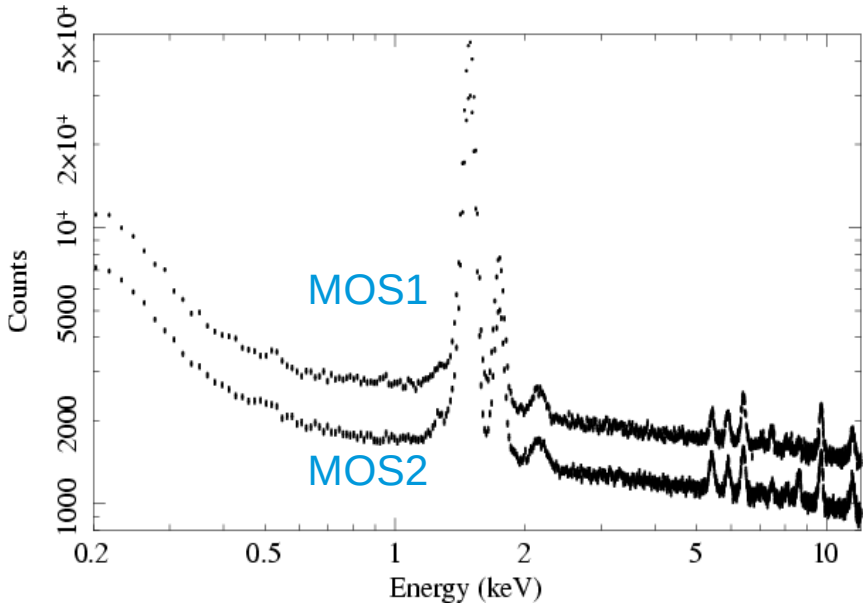
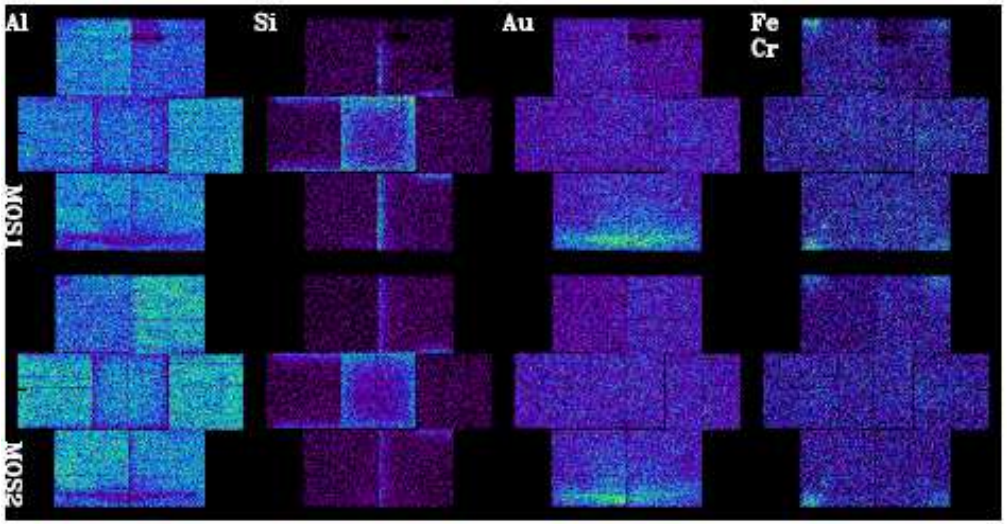


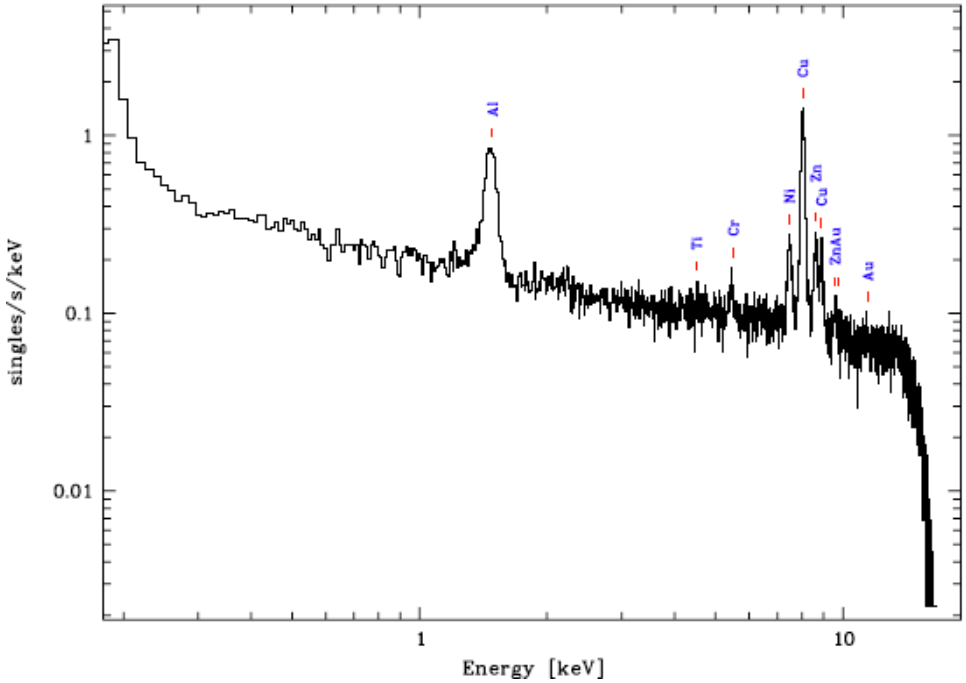
Fig. from Snowden et al. 2008, A&A 478, 615

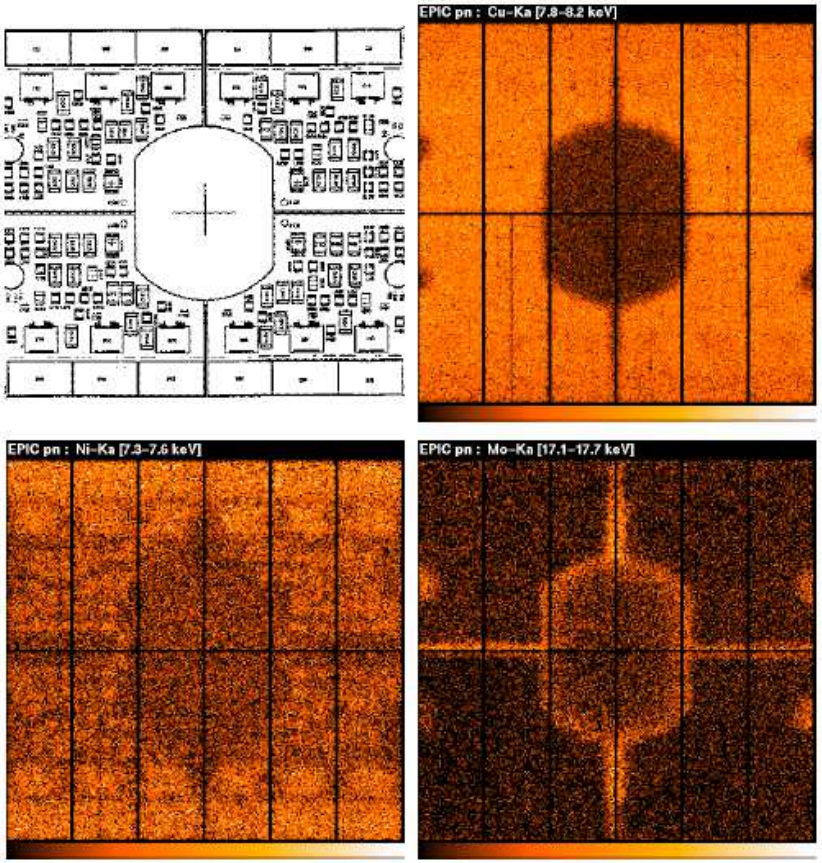
Very strong Al & Si fluorescent instrumental lines (~1.49 keV and ~1.75 keV) on top of QPB continuum. Other fluorescent lines at higher energies; strong low-energy tail due to detector noise



Filter Wheel Closed Data: PN

- PN FWC data:
  http://xmm2.esac.esa.int/external/xmm_sw_cal/background/filter_closed/pn/index.shtml

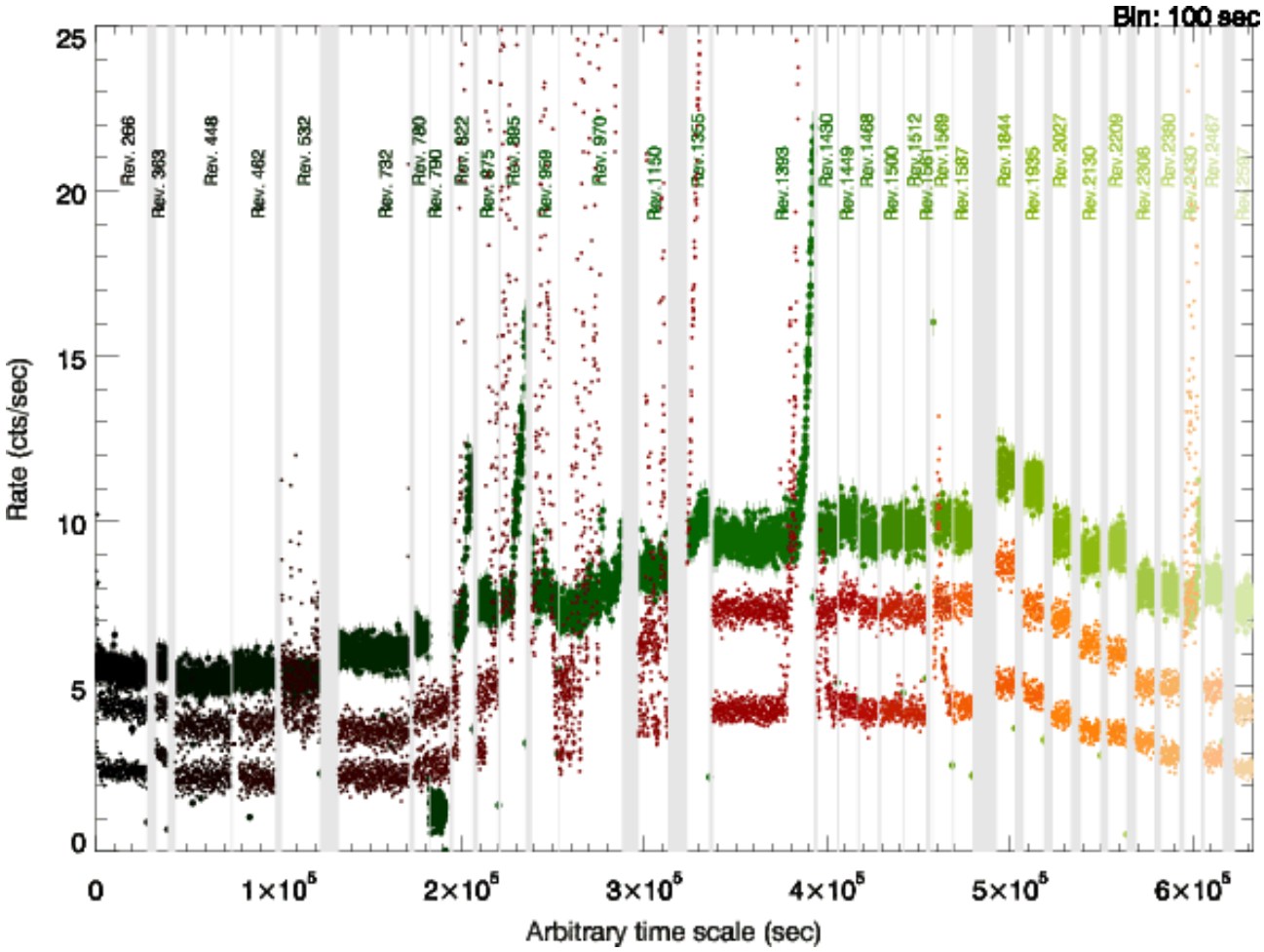




⇒ It is highly recommended not to combine event files from different readout modes!

Filter Wheel Closed Data: Time Evolution

- Time Evolution (example, pn Full Frame mode)



Useful References

XMM-Newton BKG pages:

http://xmm2.esac.esa.int/external/xmm_sw_cal/background/index.shtml

XMM-Newton BKG components & their temporal, spectral, spatial properties:

http://www.star.le.ac.uk/~amr30/BG/BGTable.html

Blank Sky Fields:

http://xmm2.esac.esa.int/external/xmm_sw_cal/background/blank_sky.shtml

ESAS Package:

http://xmm2.esac.esa.int/external/xmm_sw_cal/background/epic_esas.shtml

Filter Wheel Close Data:

http://xmm2.esac.esa.int/external/xmm_sw_cal/background/filter_closed/index.shtml