EPIC

EPIC introduction and calibration

Presentation for the

XMM-Newton SAS Workshop

(Only slightly modified by M.Guainazzi

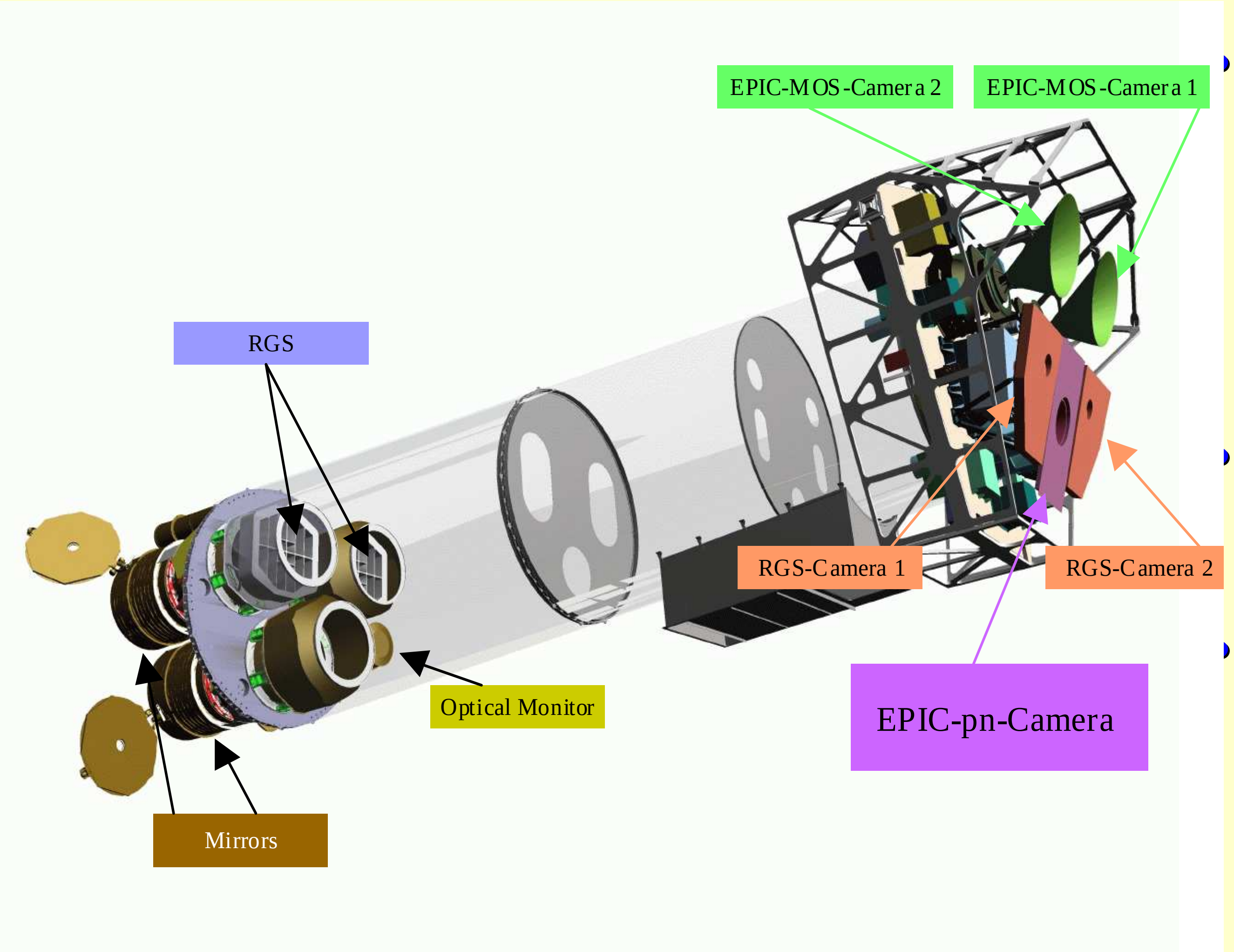
on the basis of a presentation by)

Marcus G. F. Kirsch (ESA)

EPIC calibration status document:

http://xmm2.esac.esa.int/docs/documents/CAL-TN-0018.pdf

EPIC hardware features



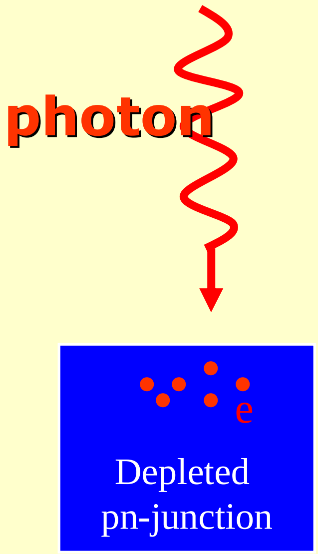
- 3 independent CCD-cameras (2 MOS & 1 PN), observing simultaneously the same field
  - MOS, 7CCDs, FI
  - PN, 12CCDs, BI
- 3 different light filters for both camera types
- different modes
  - imaging modes - to accommodate brightness
  - timing modes - time resolution up to 7 μs (PN-Burst)

What is a CCD

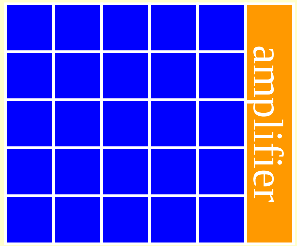
- Charge Coupled Device
- You know that from your digital cam or mobile phone
  - our CCDs however work also for X-ray photons
- Silicon device to measure photons energy, position and time

1. Take positive and negative doped silicon

2. Create depletion zone by adding voltage

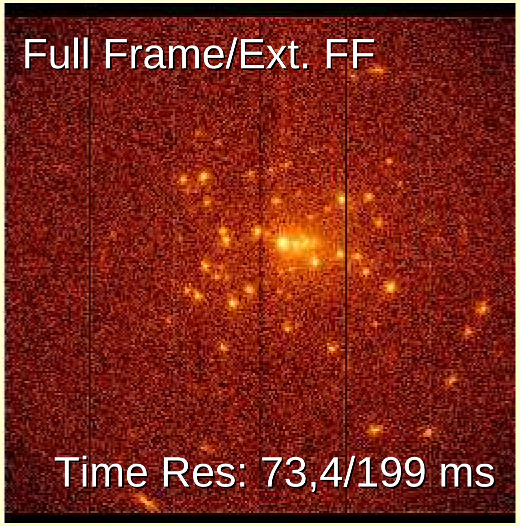


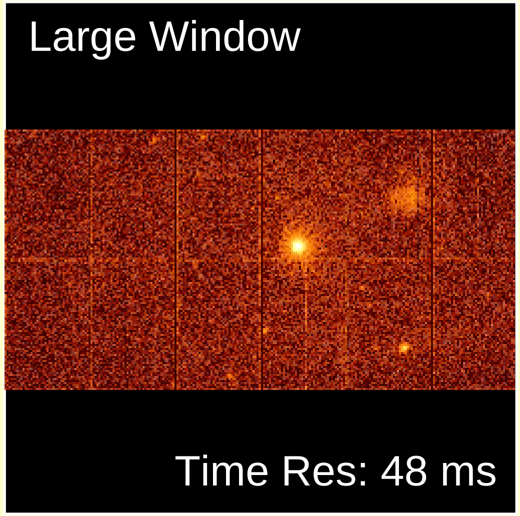
3. Arrange pn-junctions as pixels in structure, that can be read out by changing potentials

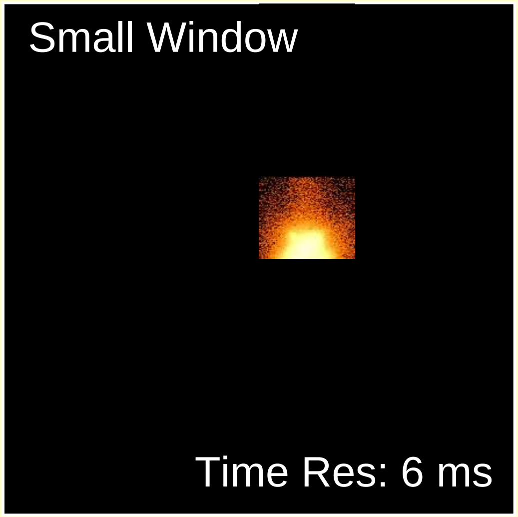


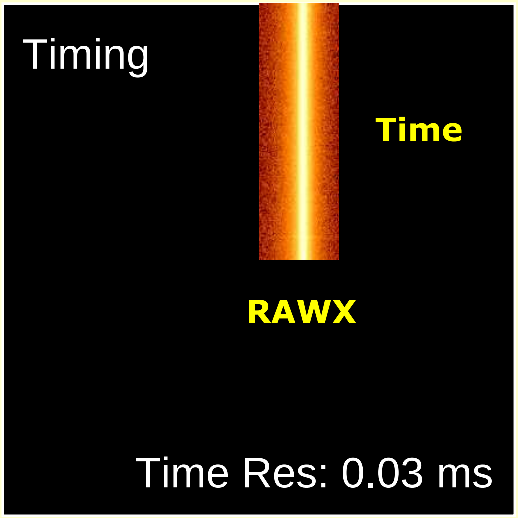
! During shifts some electrons may be lost

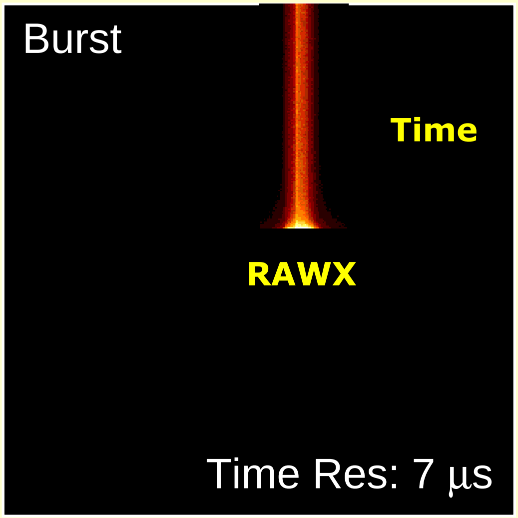
PN operating modes



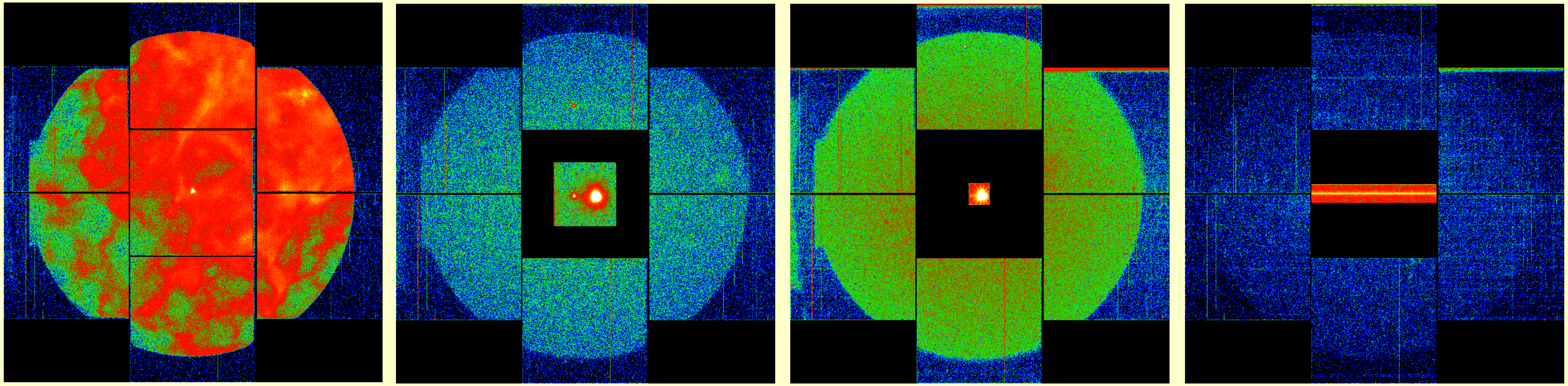








MOS operating modes



Full Frame
Time Res.: 2.6 s

Large Window
Time Res:
0.9 s central CCD
2.7 s outer CCDs

Small Window
Time Res.:
0.3 s central CCD
2.7 s outer CCDs

Timing
Time res. :
1.8 ms central CCD
2.6 s outer CCDs

In MOS the external CCD are always used in the same way!

General truth: each mode can be combined with any of the optical blocking filter: `THIN`, `MEDIUM`, `THICK`

esa ESAC EPIC

Summary of modes properties

Table 3: *Basic numbers for the science modes of EPIC*

MOS (central CCD; pixels) [1 pixel = 1.1"]	**Time resolution**	**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	0.70 (0.24)
Large window (300 × 300)	0.9 s	99.5	110	1.8 (0.6)
Small window (100 × 100)	0.3 s	97.5	37	5 (1.7)
Timing uncompressed (100 × 600)	1.75 ms	100.0	N/A	100 (35)
pn (array or 1 CCD; pixels) [1 pixel = 4.1"]	**Time resolution**	**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)	6 (0.7)
Extended full frame[5,6] (376 × 384)	199.1 ms	100.0	370	2 (0.25)
Large window (198 × 384)	47.7 ms	94.9	1500	10 (1.1)
Small window (63 × 64)	5.7 ms	71.0	12000	100 (11)
Timing (64 × 200)	0.03 ms	99.5	N/A	800 (85)
Burst (64 × 180)	7 μs	3.0	N/A	60000 (6300)

This table is extracted from the source of any wisdom as far as XMM-Newton instruments are concerned: the *XMM-Newton Users Handbook*

http://xmm.esac.esa.int/external/xmm_user_support/documentation/uhb/index.html

What is eventually calibration?

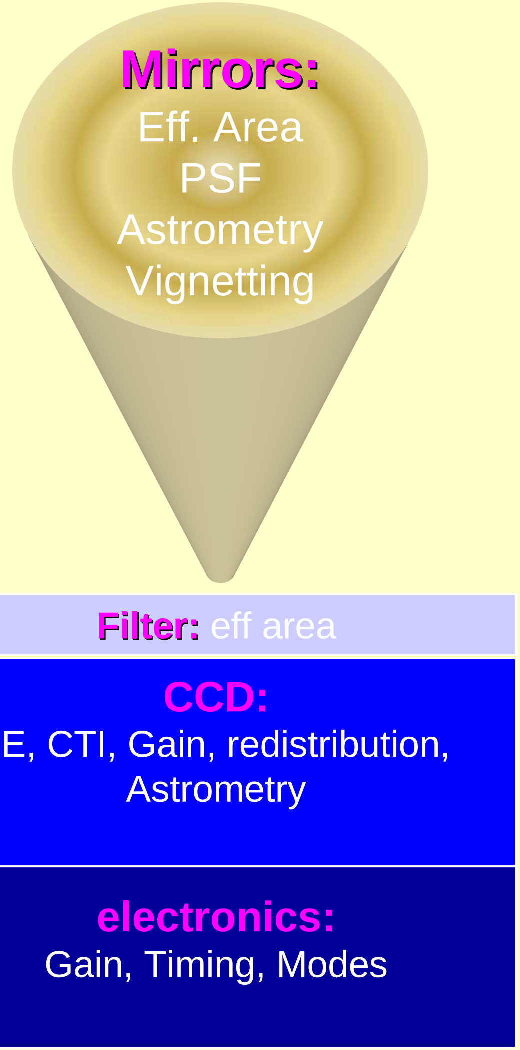
In X-ray astronomy we are measuring individual photons

[Marcus Kirsch]

- Where are the photons coming from?
- How many?
- Which "sort" (energy) of photons?
- When do the photons arrive?
- What is source and what is background?

Calibration topics

- Astrometry where
- Effective area how many
- Energy redistribution which
- Gain/CTI which
- Timing when
- Background what



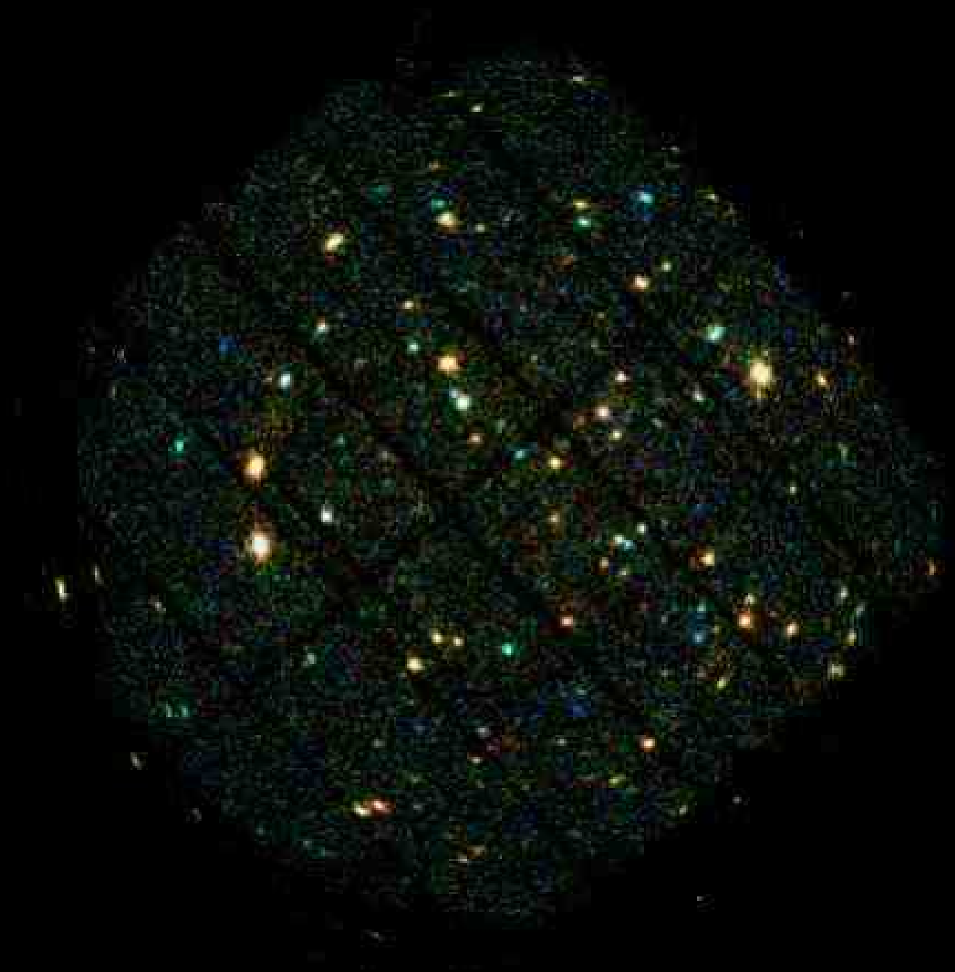
ESA ESAC EPIC

Astrometry

- Definition:
  The precision with which astronomical coordinates can be assigned to source images in the EPIC focal plane.

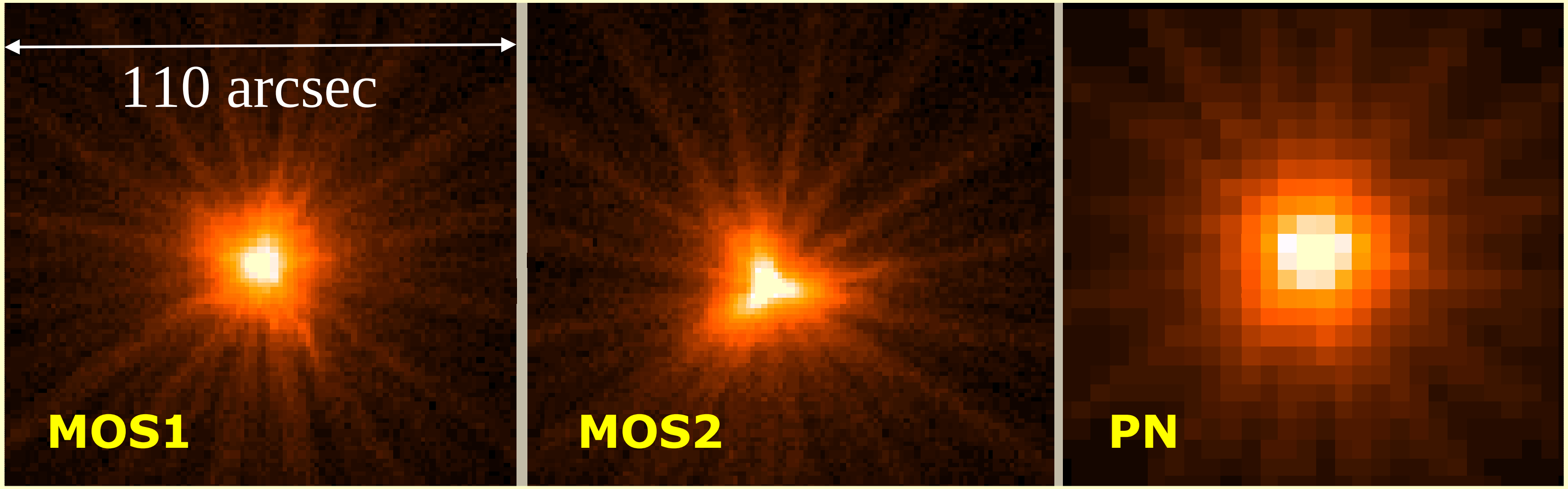
- Relative astrometry within each camera is accurate to better than 1-2 arcsec for all cameras and the full FOV

- Absolute astrometry now limited only by S/C attitude accuracy: 2 arcsec



Point Spread Function:

Definition:
spatial distribution of light in the focal plane in response to an observed (monochromatic) point source. The PSF integrates to 1 over the infinite focal plane.



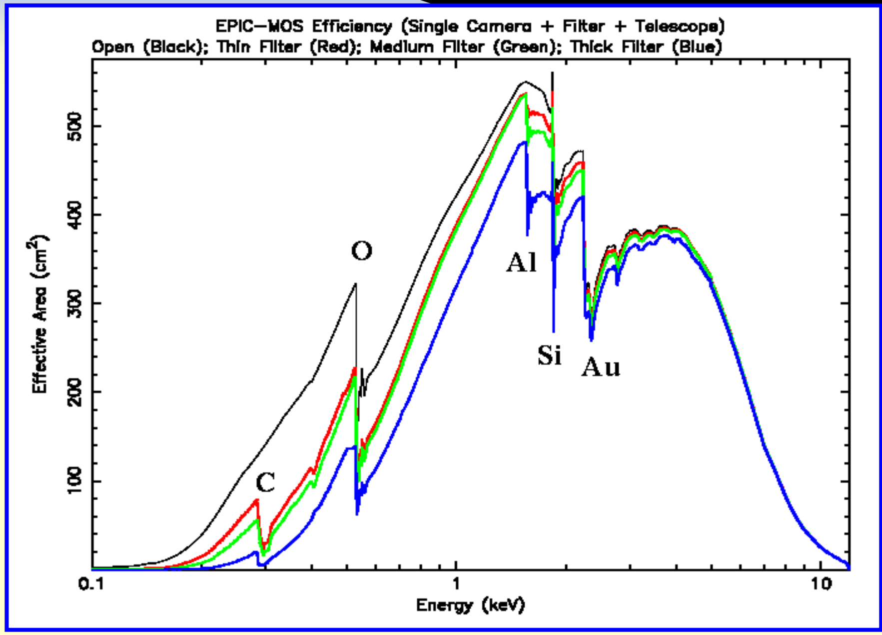
The default model (ELLBETA) is derived from the analysis of a stack of a large number of sources for different off-axis angles and energies.

For more details: **Read et al., 2011, A&A, 534, 34**

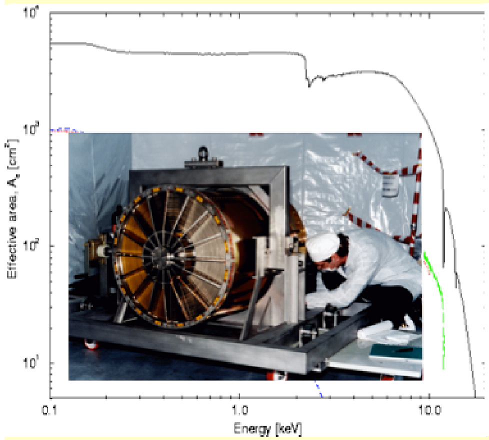
Effective area

Def.: the effective is the collecting area of the optical elements and detector system of the EPIC cameras as a function of energy.

1. Collecting area of mirror
2. Filter transmission
3. Quantum Efficiency of CCDs
4. Vignetting (shadowing)

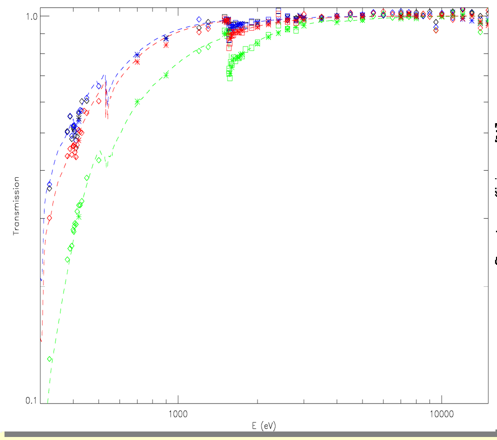


1. Mirrors



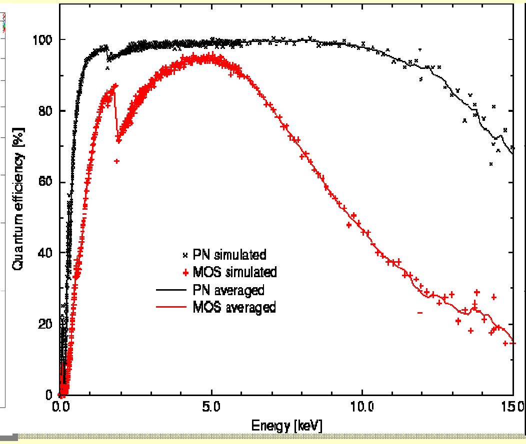
How many photons are focused by the mirrors (in units of area)

2. Filter transmission



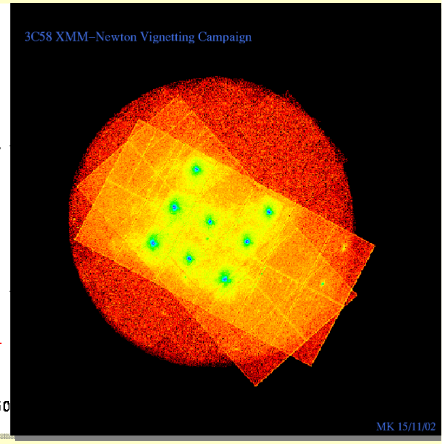
How many photons are not blocked by the filter

3. QE of CCDs



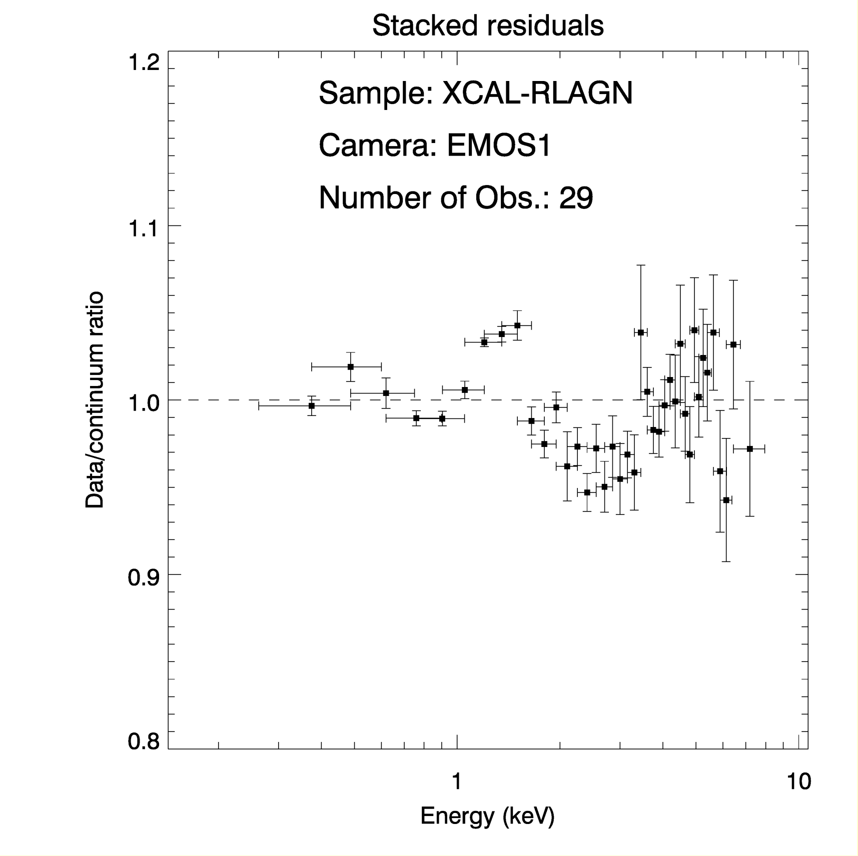
How many photons are detected as such by the camera

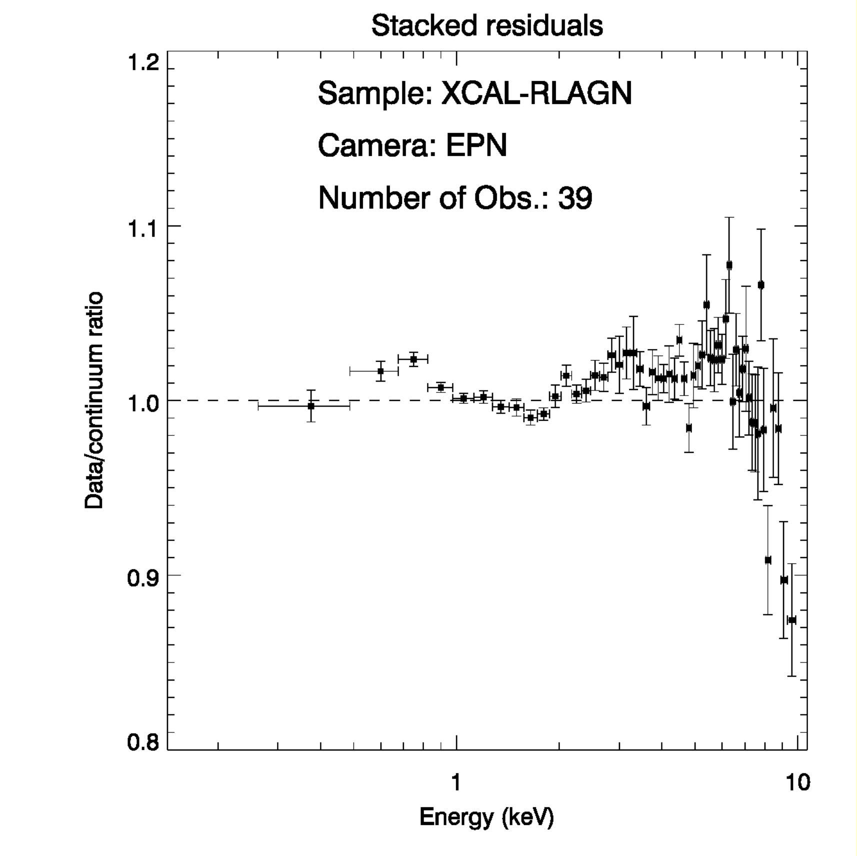
4. Vignetting



How many photons are prevented from reaching the focal plane due to shadowing

Effective area calibration accuracy

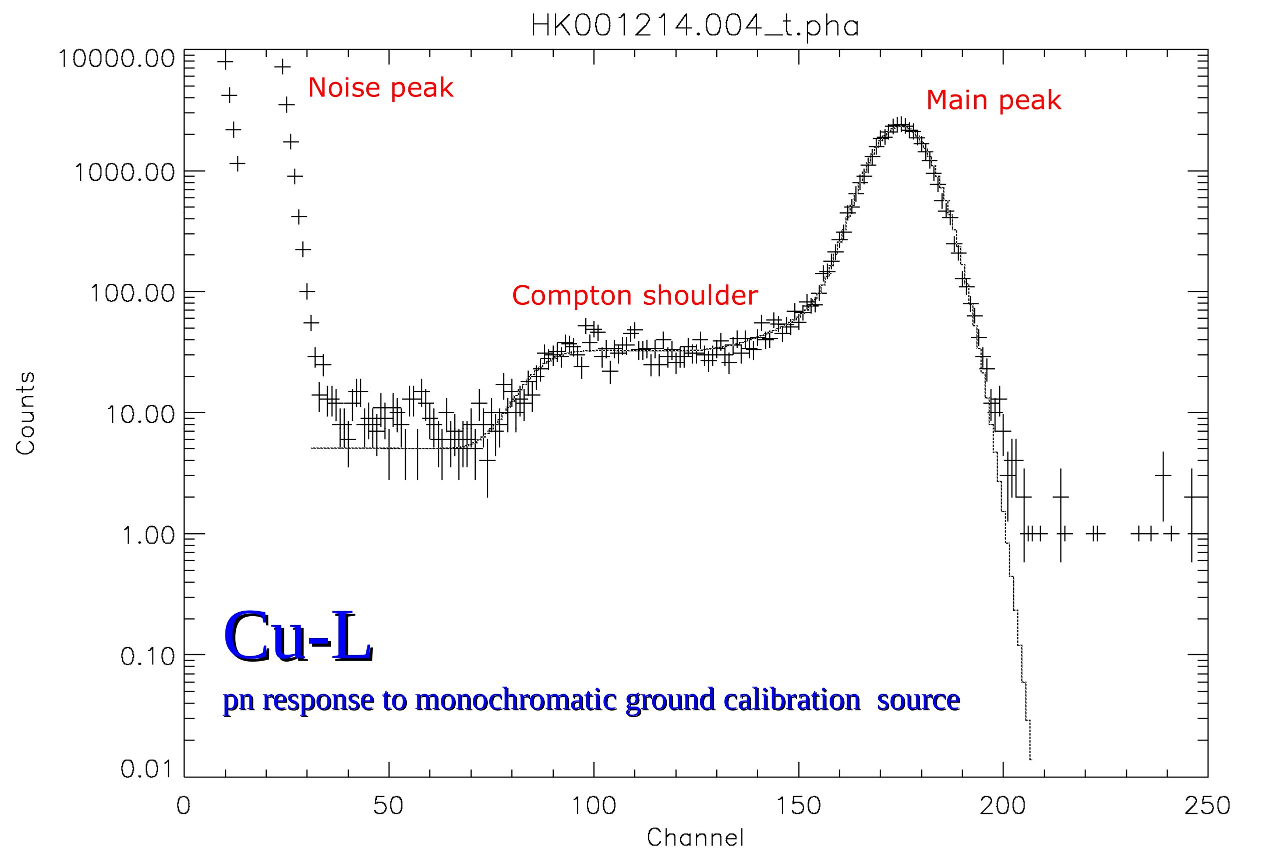




Summed (=stacked) residuals on a large sample of non-thermal AGN, each fit with its own best-fit model

Energy redistribution

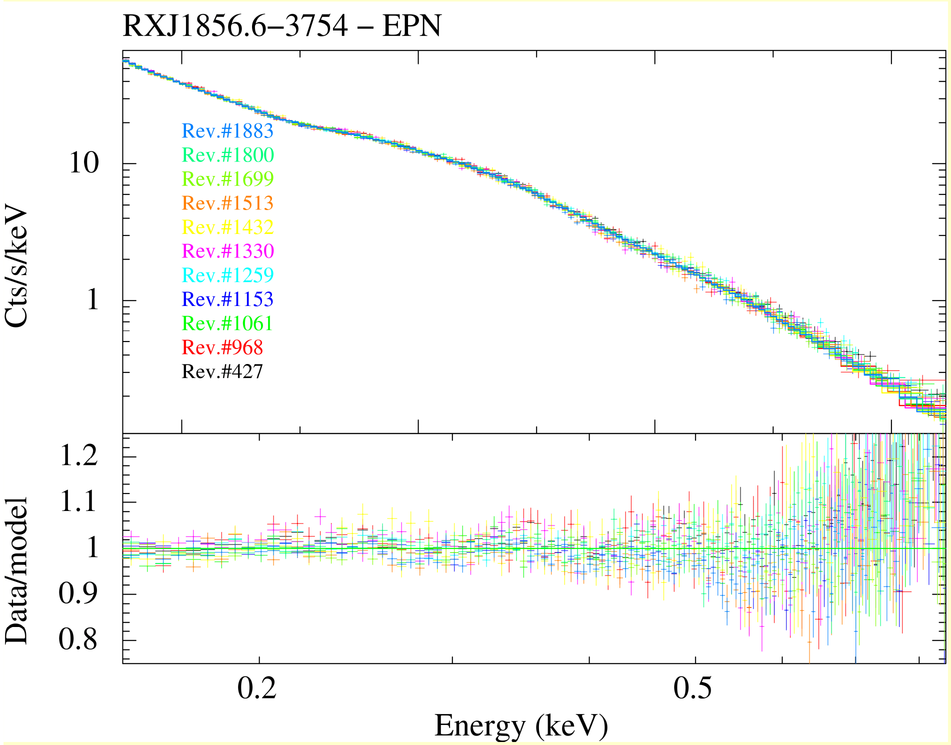
Definition: The energy profile recorded by the detector system in response to a monochromatic input.



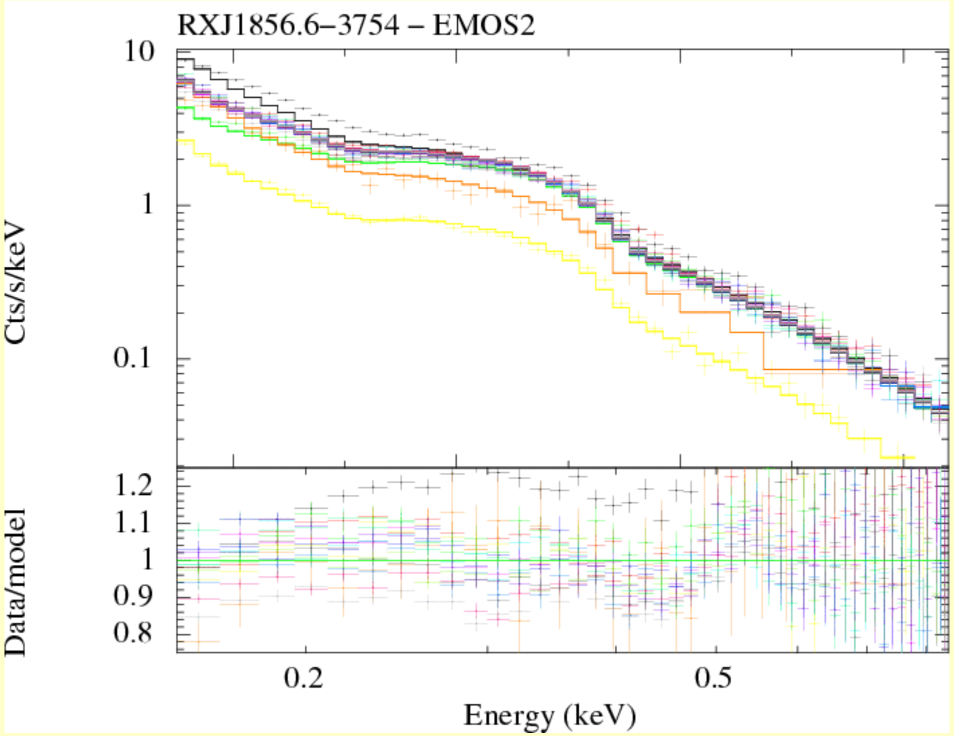
- Mode/time dependent - different redistribution matrices required
- Difficult to measure at low energy (large interplay between redistribution and efficiency) – this limit the calibrated energy band-pass to ≥300 eV

Instrument stability

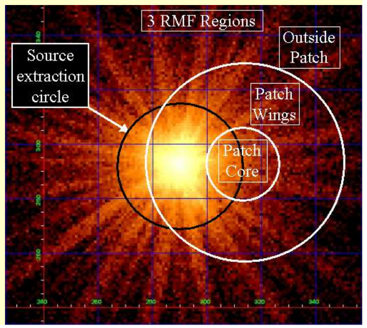
EPIC-pn



EPIC-MOS



The difference in count rate among the MOS spectra is due to the time variability of the redistribution, which is *also* position dependent – SAS takes care of that (talk by Saxton)!



EPIC patterns (="grades" in ASCA/Chandra)

The EPIC response depends also on patterns, i.e. the event shape

MOS patterns

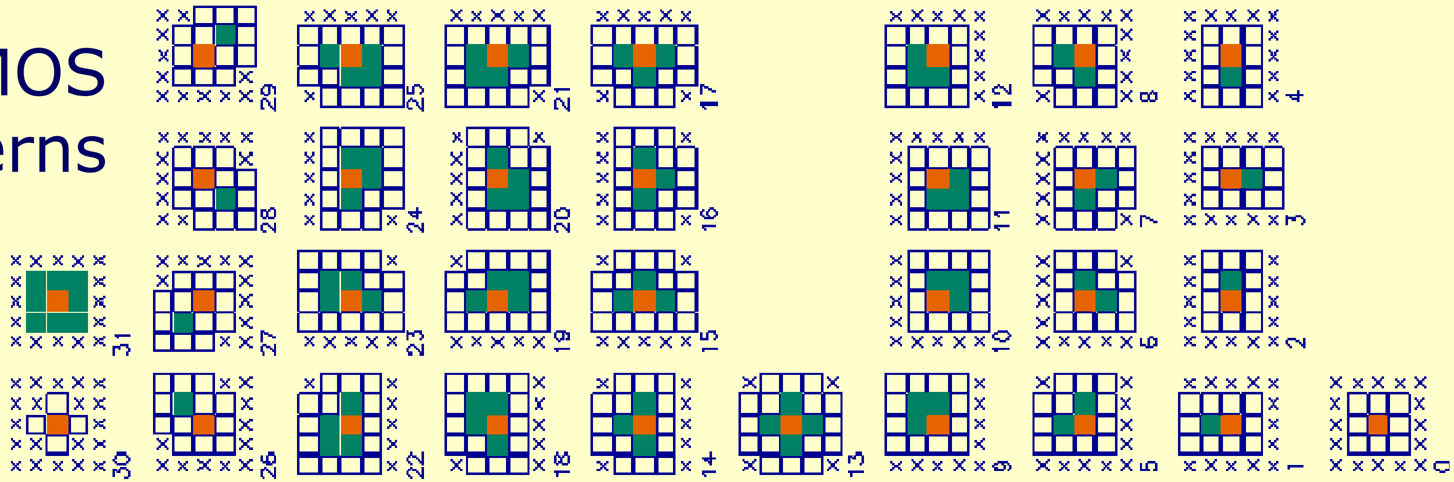


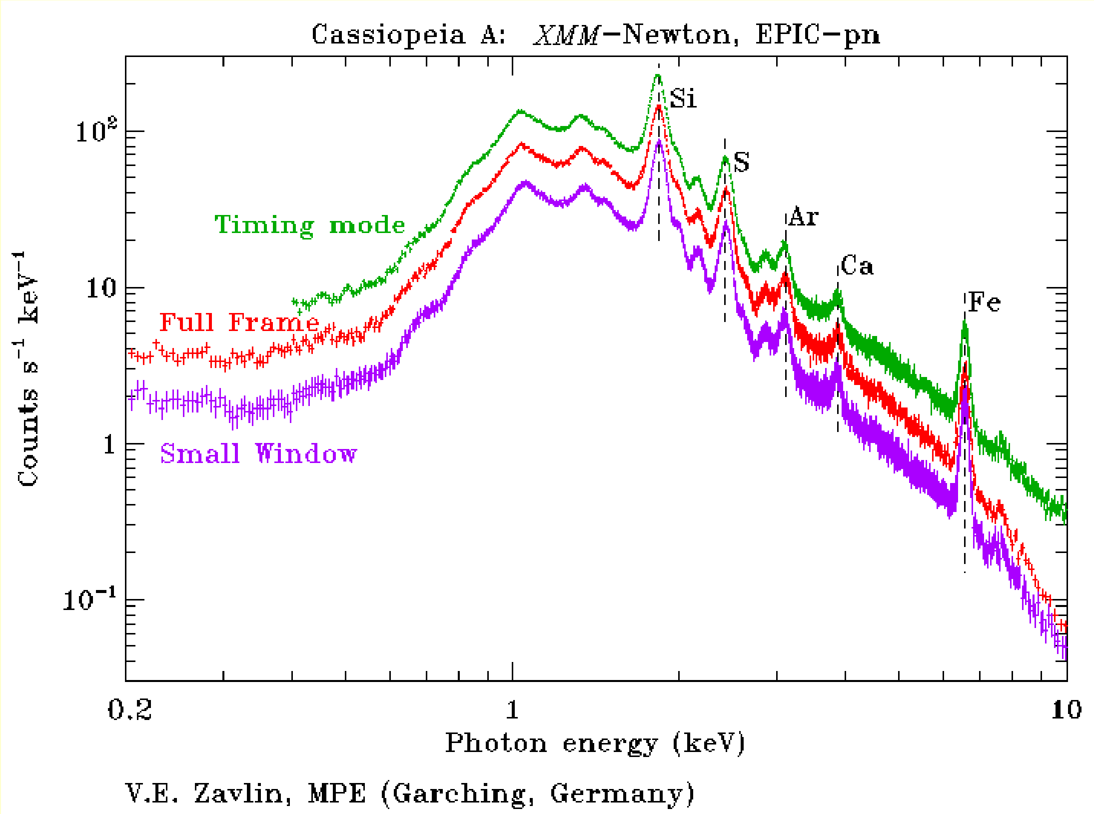
Table 7: *List of EPIC event patterns*

Camera	Mode	X-ray generated pattern singles	doubles	triples	quadruples	higher	no X-ray[1]
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

CTI & Gain

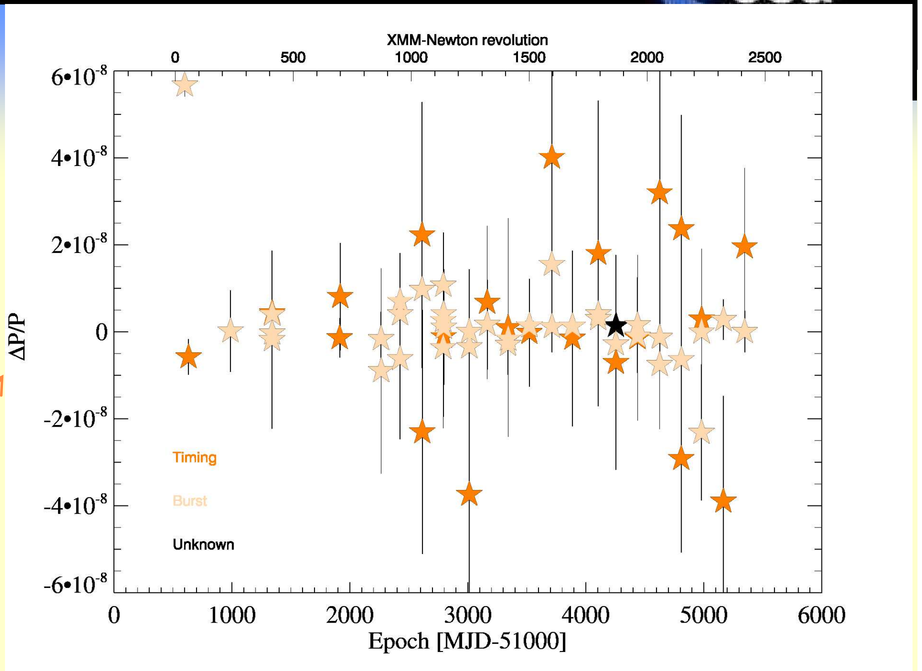
- CTI (*Charge Transfer Inefficiency*) is the imperfect transfer of charge as it is transported through the CCD to the output amplifiers during read-out.
- Gain is the conversion (amplification) of the charge signal deposited by a detected photon, from ADU (Analogue to digital unit) charge into energy (electron-volts).

- Gain/CTI are well known so that line energies can be determined with ±**10 eV** in imaging modes under normal conditions
- Accuracy of energy determination is poorer in Timing Modes: ±**20-30 eV**
- MOS: CTI correction implemented in order to take energy degradation into account
- Gain / CTI long term monitoring provided by regular internal calibration source observations.



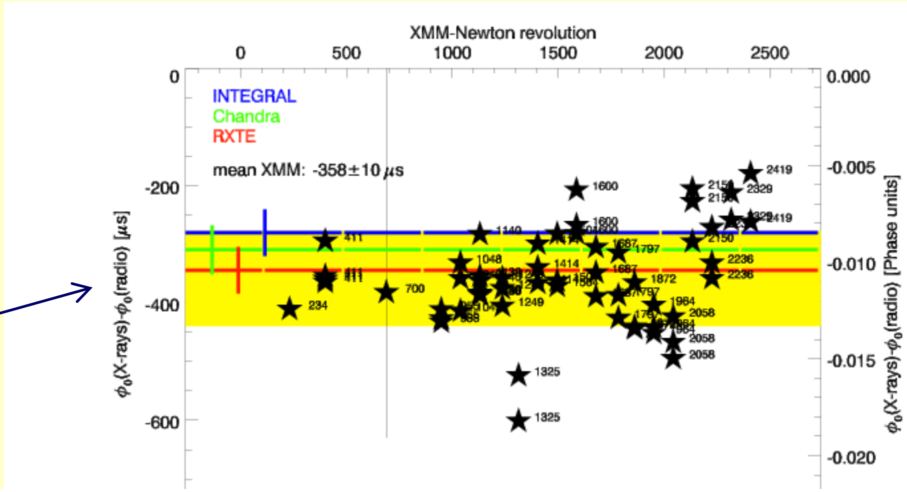
Timing

- XMM-Newton allows :
  - pulse analysis
  - pulse-phase resolved spectral analysis for ms pulsars



- Current relative time accuracy of EPIC-pn: $\Delta P/P \approx 2\times10^{-9}$

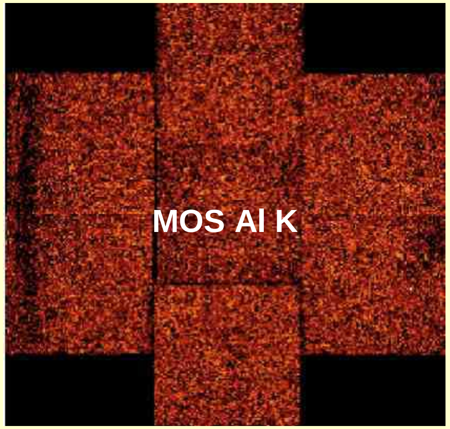
- Absolute accuracy: 70 μs

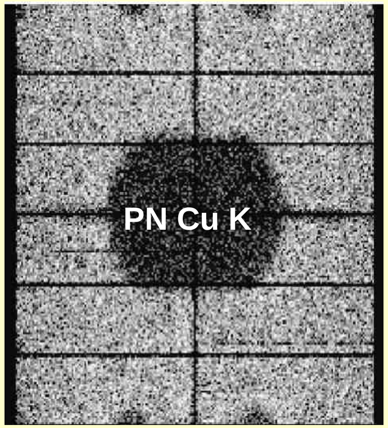


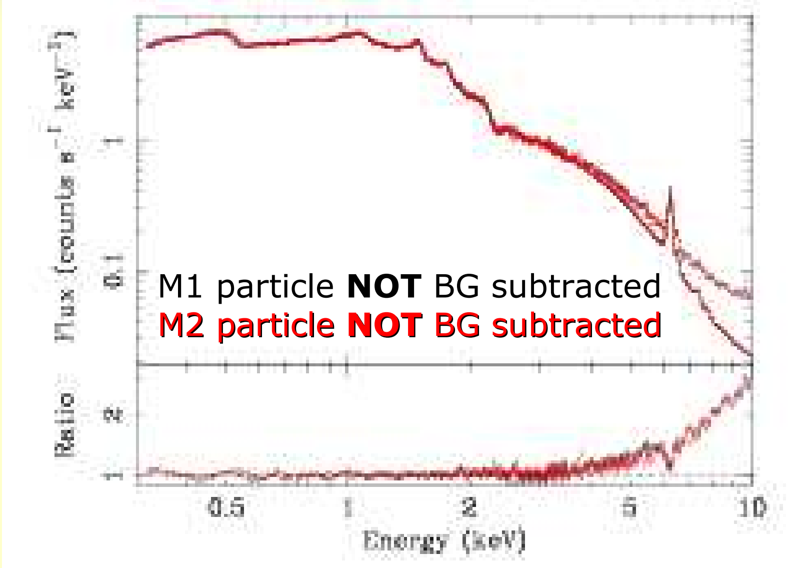
EPIC-pn is the fastest X-ray CCD available at the moment

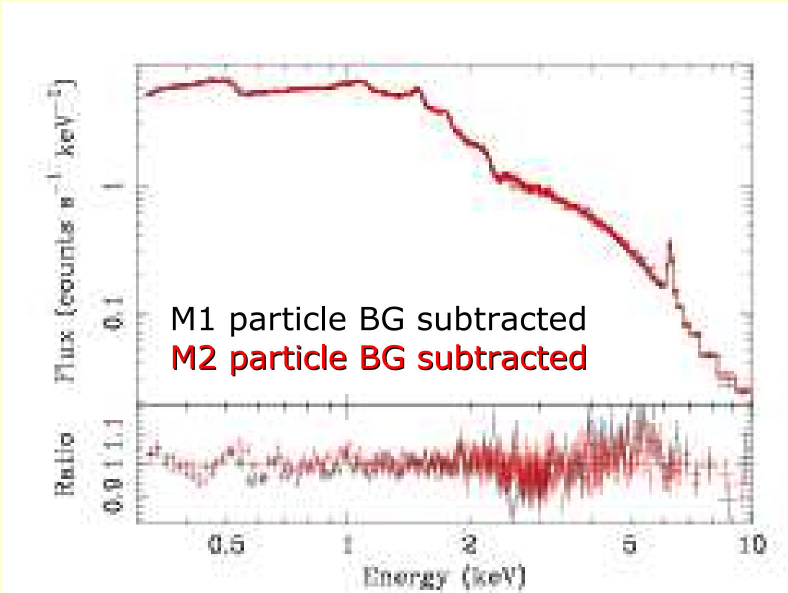
Background

- Low energy electronic noise
- Soft proton “flares”
  - energy shape varying from flare to flare
  - for weak sources **only solution: select quiet time periods**
- Quiet time high energy proton induced
  - directly in the CCD
  - indirectly via fluorescent lines (strong metal line features make background subtraction complex especially for large clusters & radial temperature determination)
- Astrophysical background







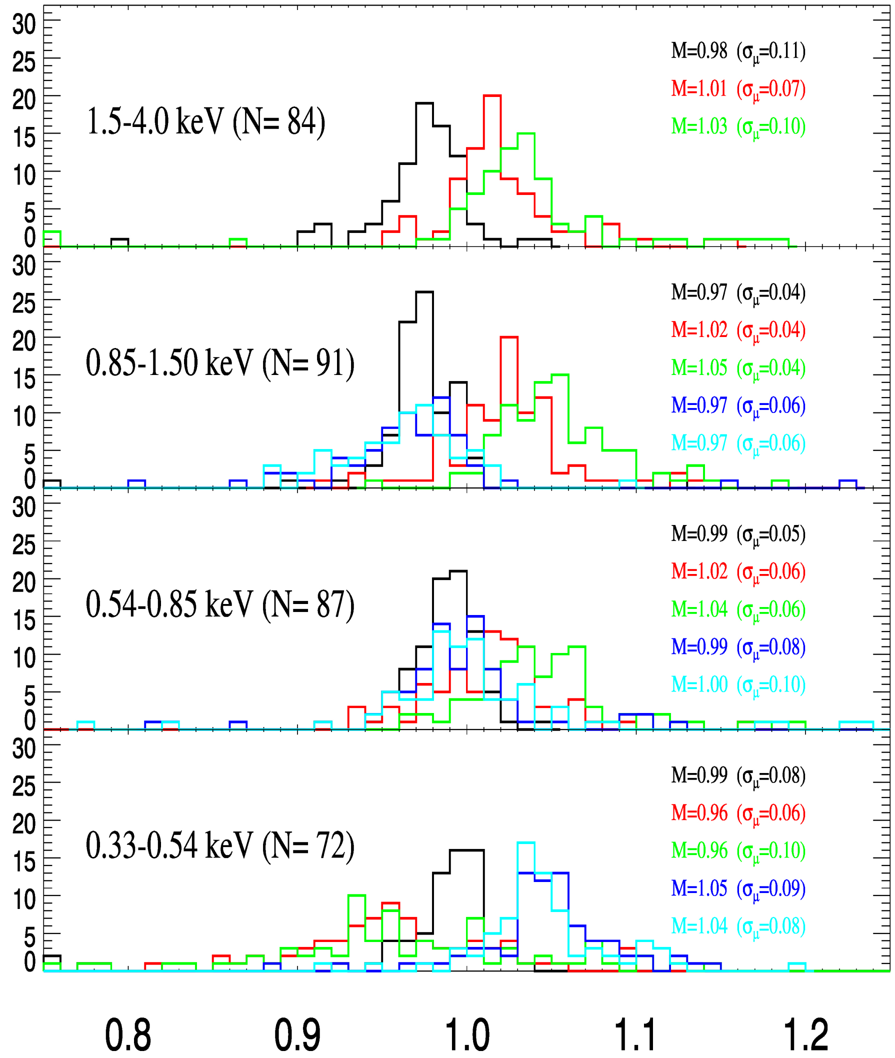


Details:
http://xmm.esac.esa.int/external/xmm_sw_cal/background/index.shtml

Cross-calibration

Flux ratios (as of SASv13)

- RGS/pn (<0.54 keV) ≅ 1.07
- RGS/pn (≥0.54 keV) ≅ 1.00
- MOS/pn (<0.54 keV) ≅ 0.95
- MOS/pn (≥0.54 keV) ≅ 1.05-.10
- MOS1/MOS2 ≅ 1.00
- Typical $\sigma \cong 0.03$-0.05



For XMM-Newton versus other missions cross-calibration, look at:
http://web.mit.edu/iachec/papers/index.html

[I have a slide on this topic, but it takes further 5 minutes …]

Cross-calibration status document (Stuhlinger et al.)
http://xmm2.esac.esa.int/docs/documents/CAL-TN-0052.ps.gz

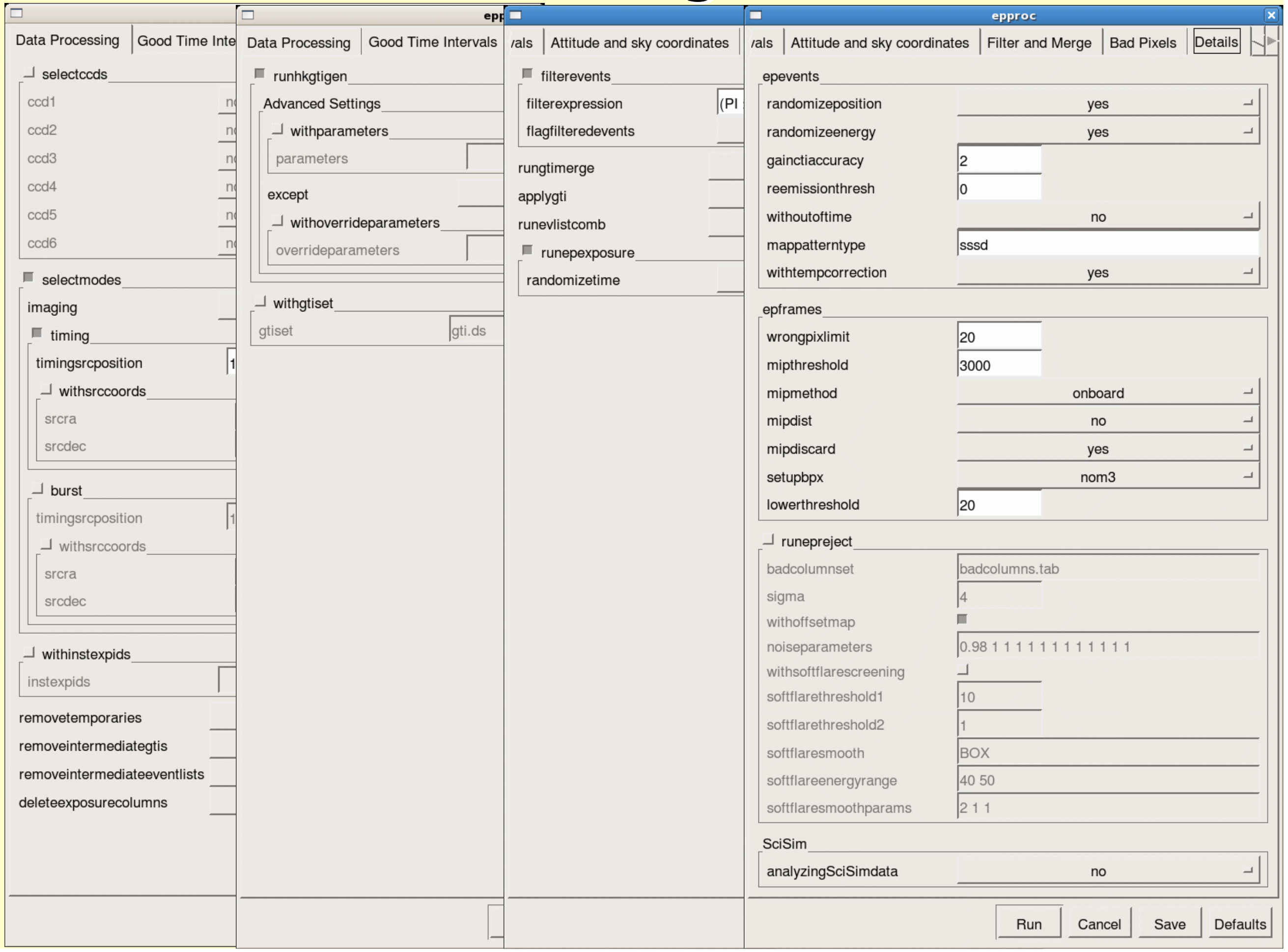
esa ESAC EPIC

Calibration summary

Effect	Max. Error	Energy dependent	Off axis angle dependent
Relative Astrometry	1.2’’(r.m.s.)	NO	YES
Absolute Astrometry	1.5’’	NO	YES
PSF	2 %	YES	YES
Relative Effective Area	± 5 %	YES	YES
Absolute Effective Area	±15 %	YES	YES
Line Energies	± 10 eV	YES	YES
Relative Timing	$\Delta P/P = 2 \times 10^{-9}$	NO	NO
Absolute Timing	70 µs	NO	NO

e[mp]proc

- Meta task to process MOS and/or pn data
- It generates calibrated, possibly filtered event lists
- User remains in control data screening
- **How to run it:**
  - **emproc** (MOS)
  - **epproc** (pn)
  - GUI →
- A pair of Perl scripts doing exactly the same job (no GUI):
  - **emchain**
  - **epchain**

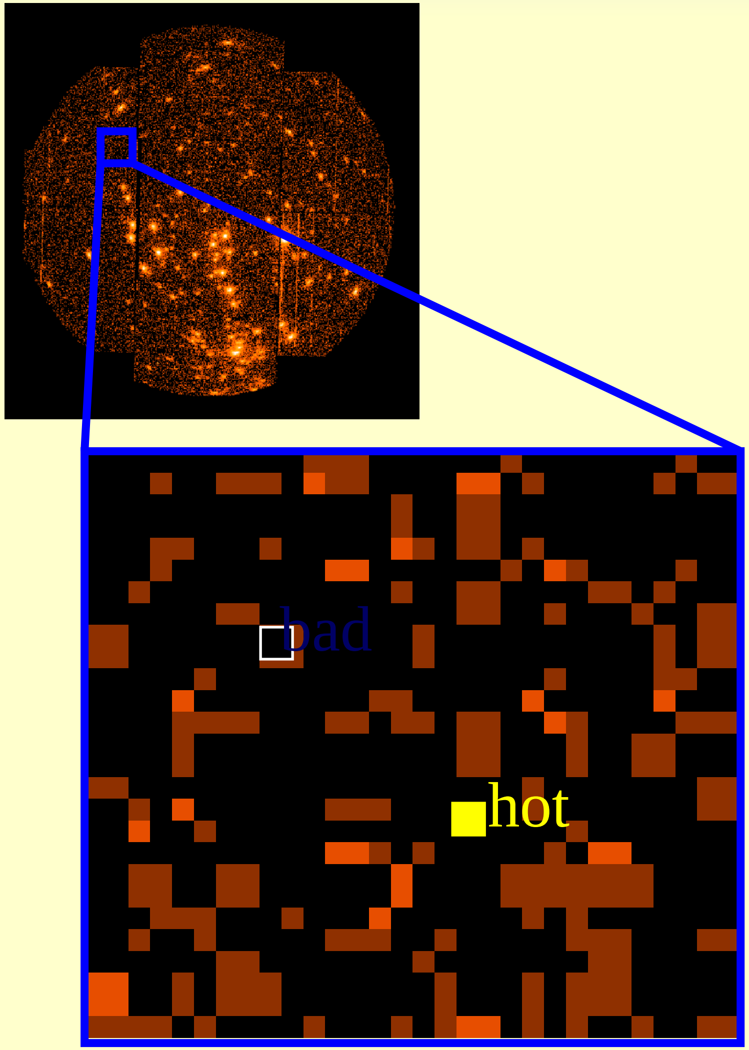


Default or not default?

- Exposure selection
  - by default all imaging and timing exposures are processed
  - selection of data modes to be processed
    - imaging
    - timing
    - burst → **`epproc burst=YES`**
  - exposures to process can be selected individually via strings:
    `epproc withinstexpids=yes instexpids='PNS001'`

- Attitude and housekeeping, GTI
  - **`atthkgen`** is run by the **`procs`**
    - it produces a FITS file containing the entire attitude information for a complete observation
  - **`hkgtigen`** is run by the **`procs`**
    - It filters the event lists according to housekeeping parameters

Bad pixels



- Dead pixel: no events are detected
- Hot pixel: pixel “produces” ghost events very often
- By default the `procs` will try to detect bad pixels for any imaging exposure.
- The new bad pixels are then used in the data reduction together with any others known (via the calibration files) bad pixels
- You may see “holes” and “dark columns” in your science images. SAS corrects flux, effective area … due to their presence

Data filtering

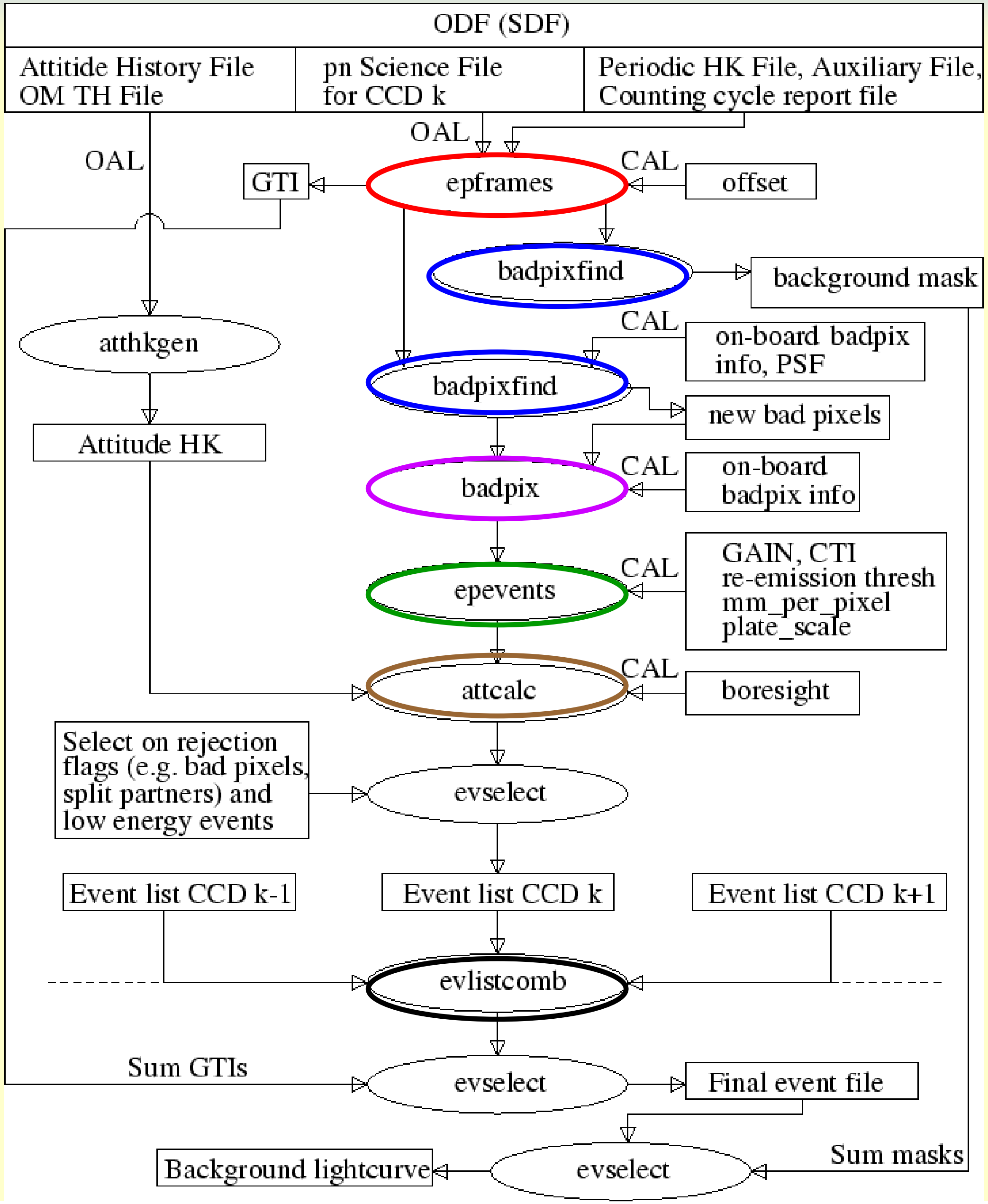
- By default the event lists are filtered means that the filtered events are removed
- The filter expression can be controlled by the user
  - **`flagfilteredevents == true`**
    In this case all events are retained, and a flag column will be set to indicate what events would have been removed.
- Flagged events can be removed at a later stage via, e.g., **`fselect`** (LHEASOFT)

ADDITIONAL MATERIAL

Summary of 2011 IACHEC status

- 2-10 keV
  - Cluster temperatures: consistent between ACIS, EPIC-MOS, EPIC-pn, XIS
    - Slight inconsistency (5%) among the XIS units
  - Power-law indices in G21.5-0.9: if ACIS is the reference:
    - XRT, MOS1, pn: $\geq \Gamma_{ACIS}$-0.05; XIS, MOS2: $\leq \Gamma_{ACIS}$+0.05
  - Fluxes: If EPIC-MOS=1
    - EPIC-pn≅0.95-0.90; ACIS≅1.05-1.10 (also with L-HETG); HRCS-LEGS≅1.05; 0.95≤XISi≤1.05
- 0.5-10 keV
  - If EPIC-pn is the reference (T_{pn}=temperature measured in the 0.5-7 keV)
    - $T_{ACIS} \cong 1.2T_{pn}$; $T_{XIS0} \cong 0.9T_{pn}$; $T_{XIS1-3} \cong 1.2T_{pn}$
    - Relative ACIS to EPIC-pn difference @0.5 keV respect to @2 keV 10%
  - ±10% agreement between XMM-Newton and Chandra gratings

Example: epproc



- **epframes** to process a CCD, exposure and datamode specific ODF file, creating the output raw event list and GTI data set
- **badpixfind** to find new bad pixels
- **badpix** to process the raw event list, adding the BADPIX extension
- **epevents** to process the event list file, flagging trailing events, performing split events pattern recognition CTI and gain correction to create the calibrated event list
- **attcalc** to calculate the X and Y sky coordinates.
- **evlistcomb**, the CCD specific data sets are merged into a single event list.