EPIC Calibration anecdotes

–

from 3 years before till 6 years after launch

M.G.F. Kirsch,
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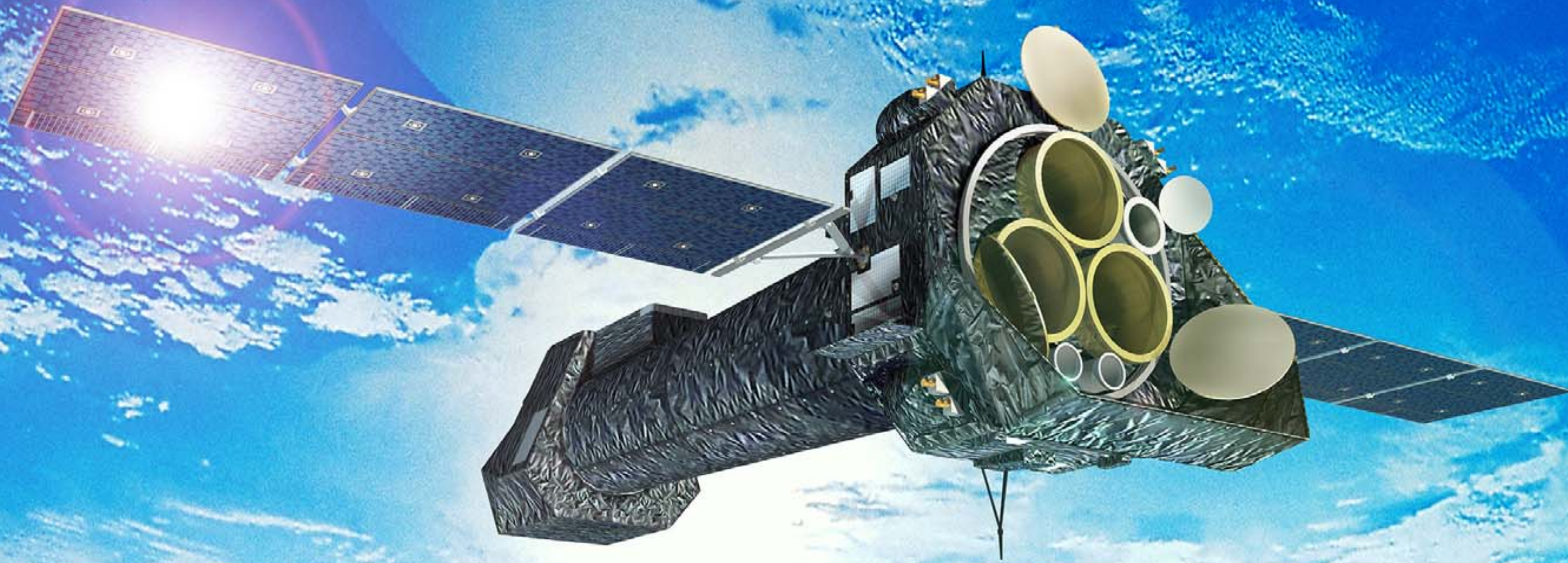
and the EPIC CAL Team

[a]European Space Agency,
[b]MPE, [c]Leicester University, [d]CEA/Saclay & APC

The Mission



Xray-**M**ulti-**M**irror-Mission

Cornerstone Mission of

ESA’s Horizon 2000 Program

the spacecraft

- weight: 3.8 t, length: 10 m
- squarish service module also carrying three 'mirrors modules' at its forward broader end
- the focal plane assembly housing the X-ray cameras and detectors at its other extremity
- 3 Wolter telescopes with 58 mirrors each
- 2 solar panels with 16 metre span
- Optical monitor

The Launcher

XMM

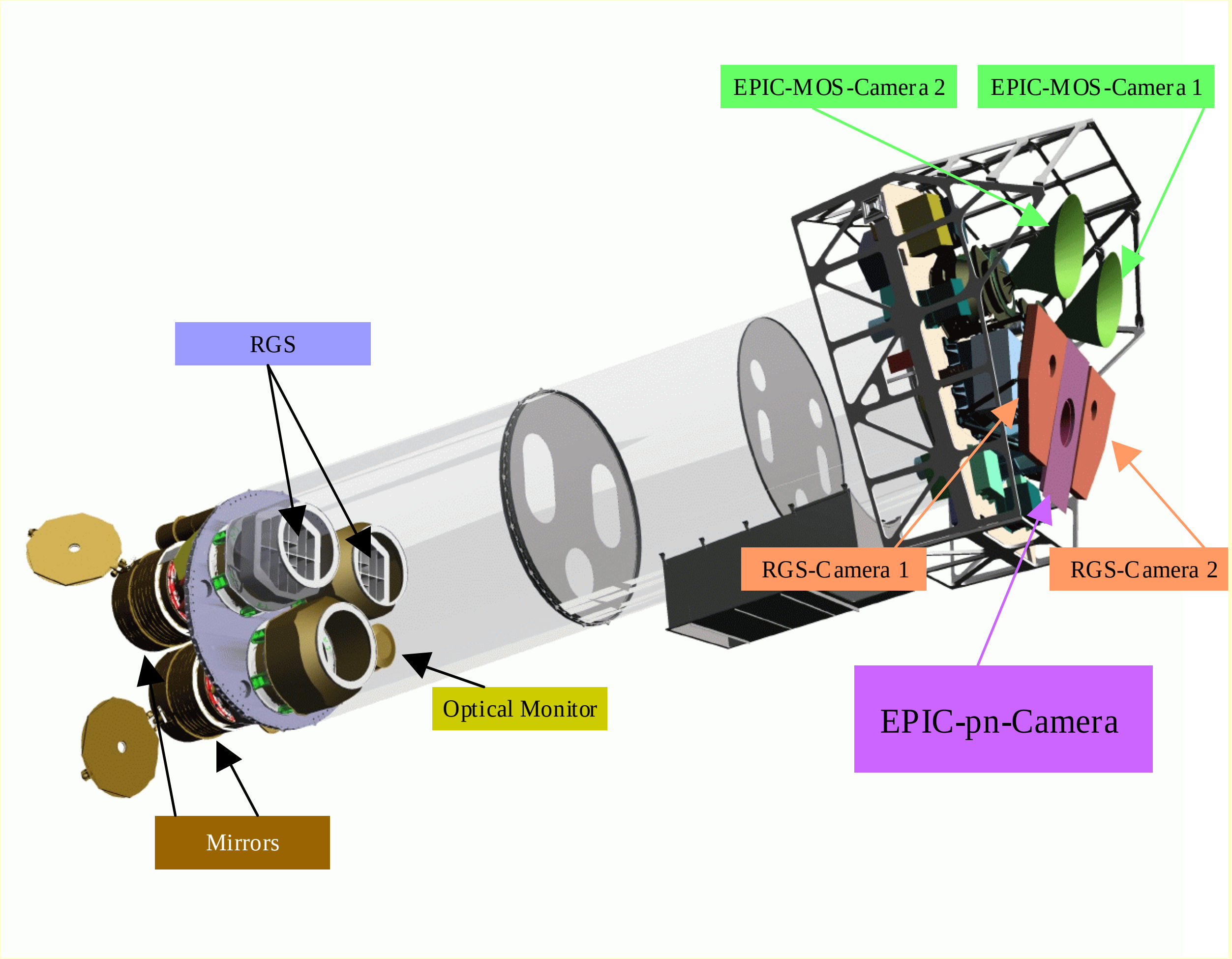
successfully launched

on board the Ariane-5 Flight 504

Dec. 10th 1999 14:32 GMT

from Kourou

EPIC hardware features

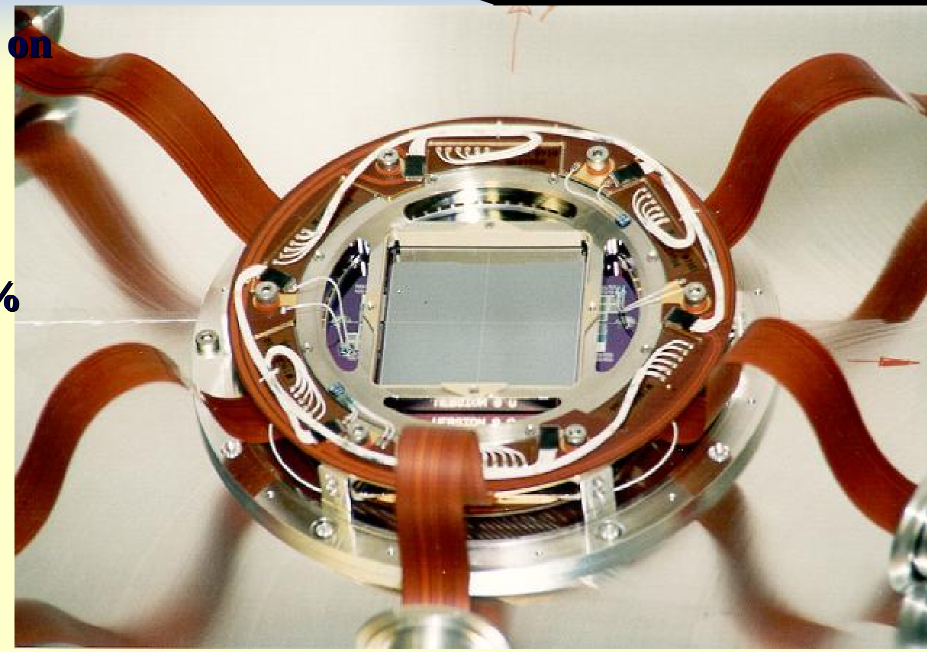


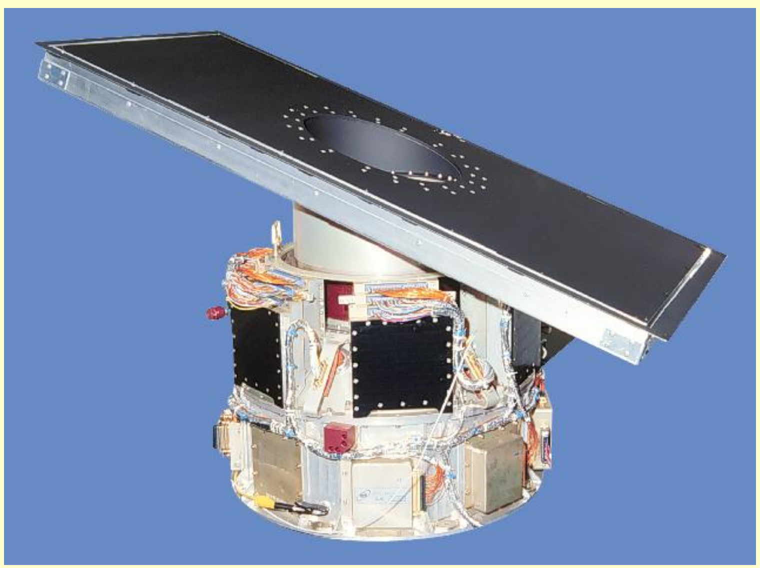
- 3 independent CCD-cameras (2 MOS & 1 PN), observing simultaneously the same field
- 3 different light filters for both camera types
- different modes
  - imaging modes - to accommodate brightness
  - timing modes - time resolution up to 7 μs (PN-Burst)

EPIC-pn

12 back illuminated pn-junction CCDs intergrated on one single Si-wafer, each with :

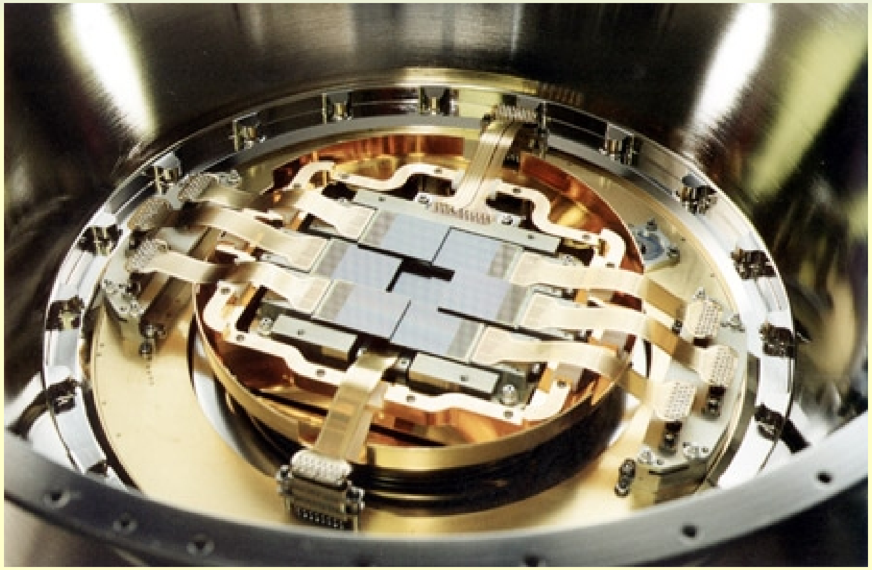
- **280 µm fully depleted Si,**
  - **useful QE from 0.1-15 keV**
  - **giving a very high QE of more than 90% between 0.5 and 10 keV**
- **200 lines**
- **64 columns**
- **Pixelsize: 150 µm x 150 µm**





- **X-ray interaction with the silicon atoms, generates electrons and holes ~ energy of photon.**
- **average energy required to form an electron-hole pair is 3.7 eV at -90° C.**
- **signal charges (electrons), are drifted to the potential minimum and stored under the transfer registers.**
- **the electrons, captured in the potential wells 10 microns below the surface can be transferred towards the readout nodes upon command**
- **each CCD line is terminated by a readout amplifier.**

EPIC-MOS



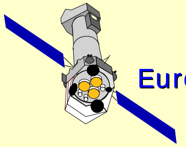
7 front illuminated Metal-Oxide Semi-conductor CCDs, each with:

- **100 μm Si**
- **600 lines**
- **600 columns**
- **Pixelsize: 40μm x 40μm**

- **frame transfer device on high resistivity epitaxial silicon with an open-electrode structure**
- **useful quantum efficiency in the energy range 0.2 to 10 keV**
- **low energy response of conventional front illuminated CCD is poor below ~700 eV because of absorption in the electrode structure.**
- **one of the three electrodes has been enlarged to occupy a greater fraction of each pixel, and holes have been etched through this enlarged electrode to the gate oxide. This gives an "open" fraction of the total pixel area of 40%; this region has a high transmission for very soft X-rays that would have otherwise be absorbed in the electrodes.**
- **the actual mean depletion of the flight CCDs is between 35 to 40 microns**

menu

- general approach of calibrating a CCD technology based X-ray camera (EPIC)
- calibration strategy for various physical phenomena regarding X-ray CCDs
- organization of calibration software and files
- major calibration steps and improvements
- lessons learned



First plans

XMM

System Calibration Document

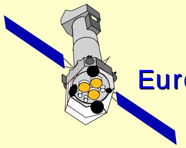
XMM-PS-GM-02 Issue 1

Written by: C. Erd, P. Gondoin, D. Lumb, R. Much
and the XMM System Calibration Team

January 23, 1996

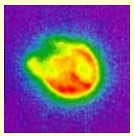
Revision history

Revision number	Date	Revision author	Comments
Draft	June 19, 1995		Initial draft version
Issue 1	January 23, 1996		Formal Issue



general approach of calibration

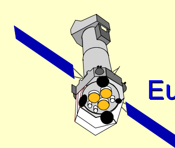
In orbit calibration (O/C) using
- Super novae: N132D, Cas-A
- Continuum sources: PKS2155-304
- Isolated neutron stars: 1856



- refinement of ground calibration
- system now exposed to orbital environment (radiation, temperatures, ...)
- necessity of tracking time dependent effects

- main calibration of all system components
- system still virginal
- no time dependence measurements possible

Ground calibration (G/C) at
- PANTER/Germany
- Lure/ France
- Bessy/Germany



G/C facilities

LURE/ORSAY
Synchrotron

pn: 6 weeks → 2100 man-hours=262 man-days
+ 5 people for integration and 6 test facility
MOS: 12 weeks → 6050 man-hours=756 man-days

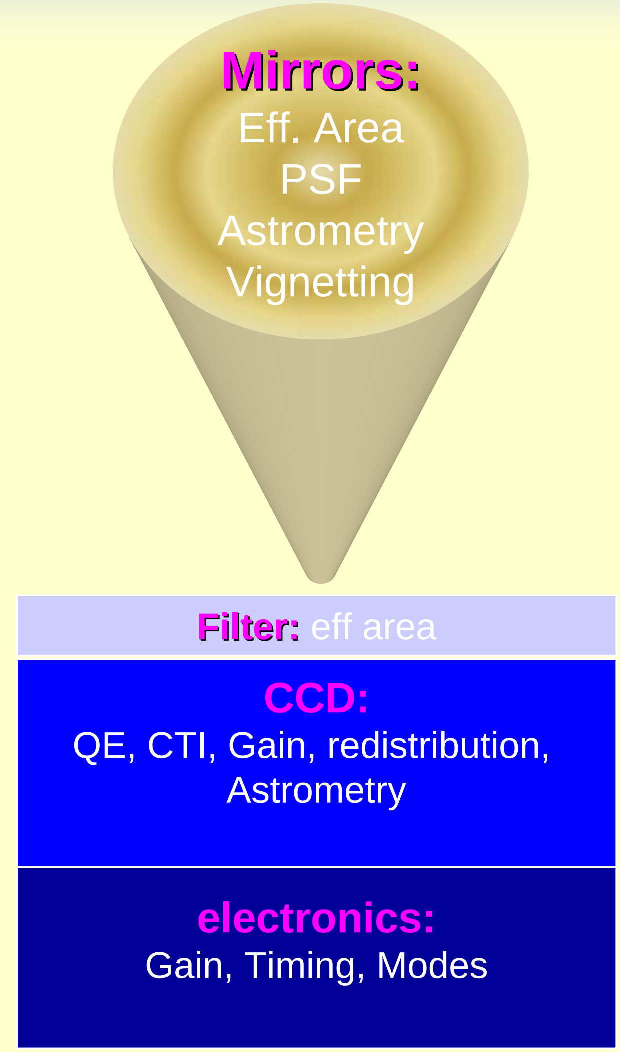
Anecdote: note: G/C coincided with world-cup 1998

PANTER/MUNICH
X-ray tube test facility

pn: 5 weeks → 2200 man-hours =250 man-days
+ 5 people for integration and 4 test facility
MOS: 4 weeks → 2200 man hours =250man-days

calibration topics

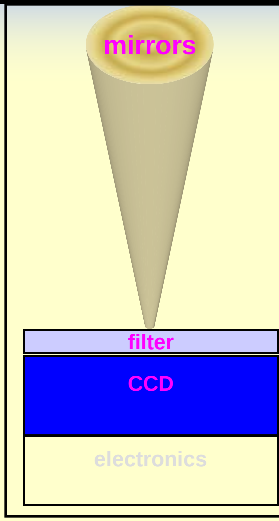
- imaging
- effective area
- energy redistribution
- Gain/CTI
- timing
- background



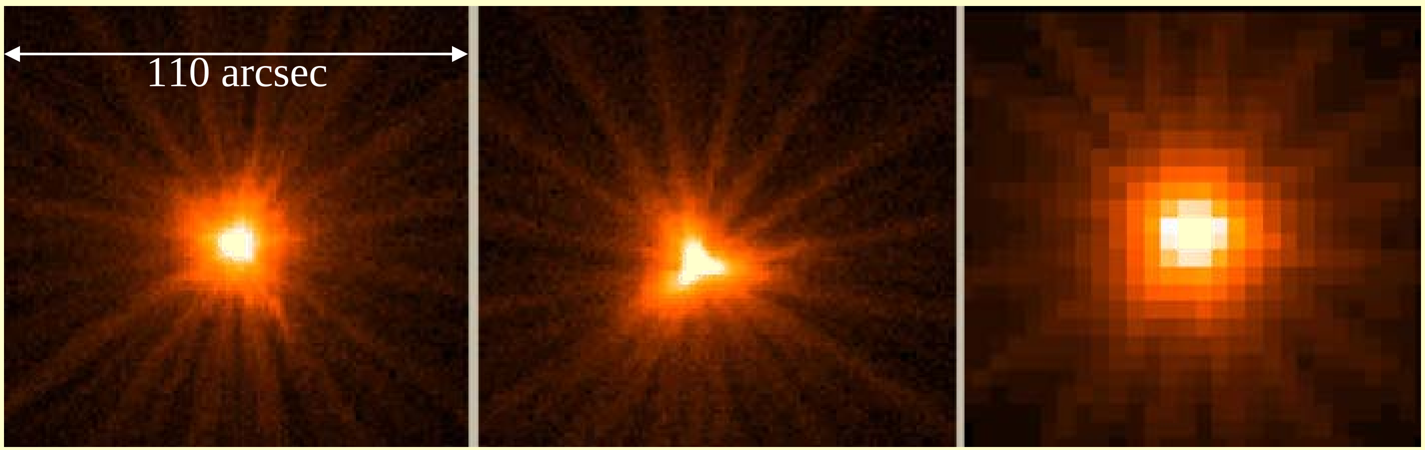
Point Spread Function:

Def.:

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.



MOS1 | MOS2 | pn



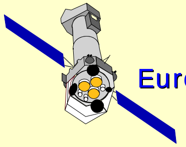
G/C:

- measurements at PANTER for various monochromatic lines
- simulations with SCISIM
- analytical model: King function
  $PSF=A[1+(r/r_0)^2]^{-\alpha}$

- problems with ground cal concerning spectral shape and normalization of spectra for different extraction regions

O/C:

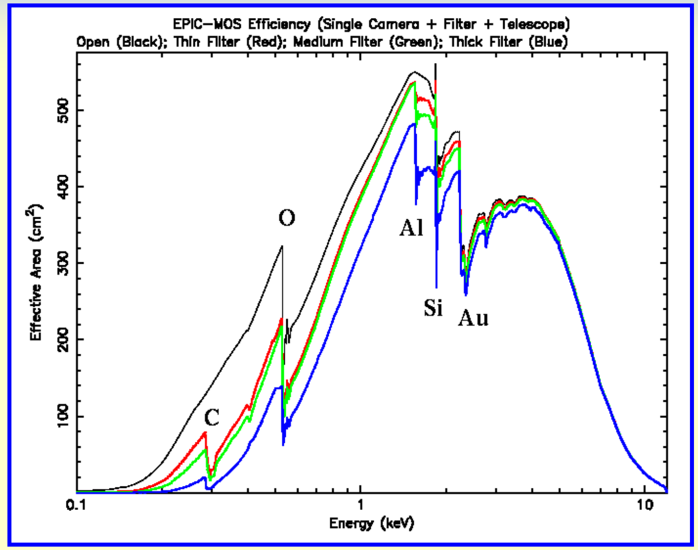
- refinement of parameters using the BHC MCG-06-30-15

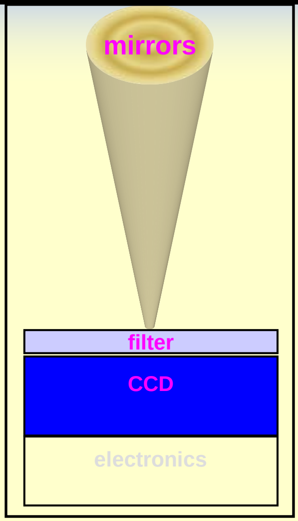


effective area

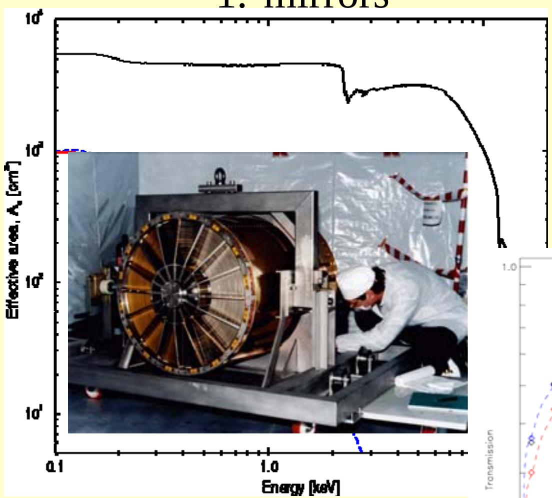
Def.: the effective area is the collecting area of the optical elements and detector system of the EPIC cameras as a function of energy.

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

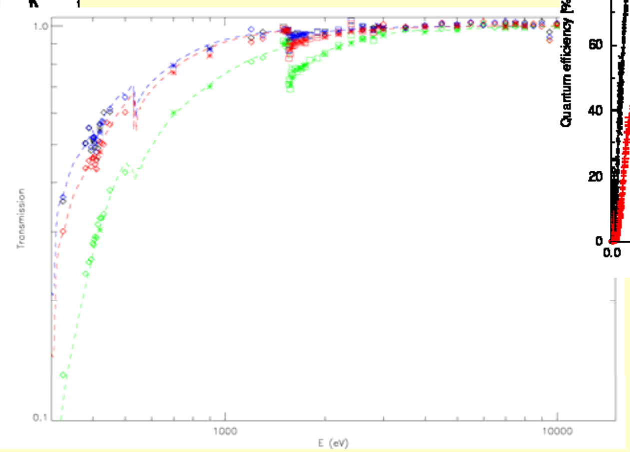


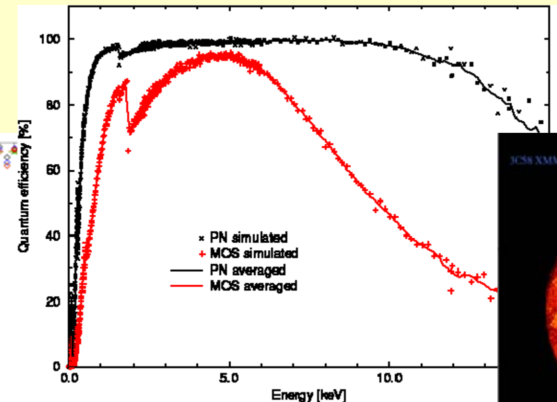


1. mirrors



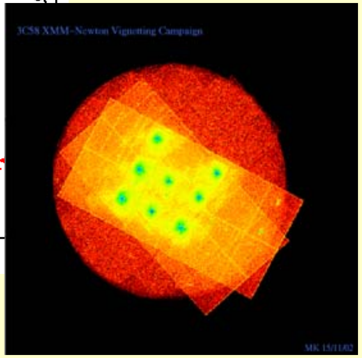
2. Filter transmission





3. QE of CCDs

4. Vignetting



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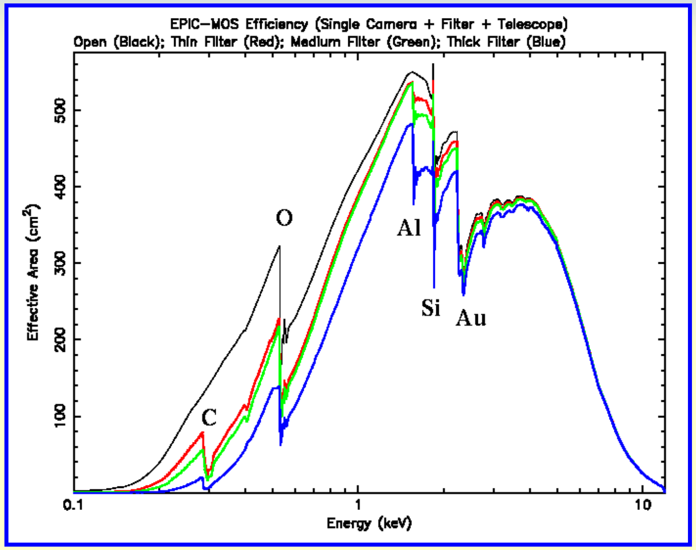
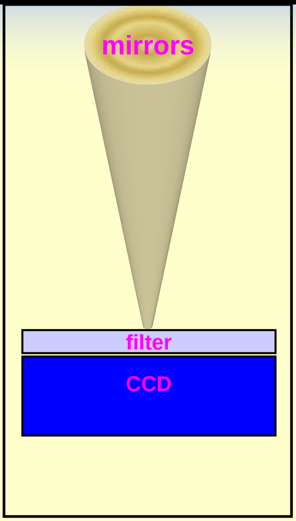




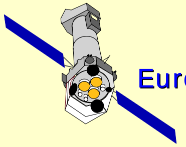
G/C:

- mirror effective area measurements at PANTER for all mirror modules
- yhick filter troughput measurements at Bessy
- thin and medium filter measurements at the Osservatorio Astronomico di Palermo
- long measurements for QE at PANTER for various monochromatic lines
- edge scans at LURE for Si and Au

O/C:

- pn-QE refinement due to other thickness of wafer and SiO_2 layer
- refinement of mirror parameters around edges using very bright sources (much higher statistical accuracy possible than on ground)
- vignetting refinement needed due to uncertainty in optical axis position: various pointings of 3C58

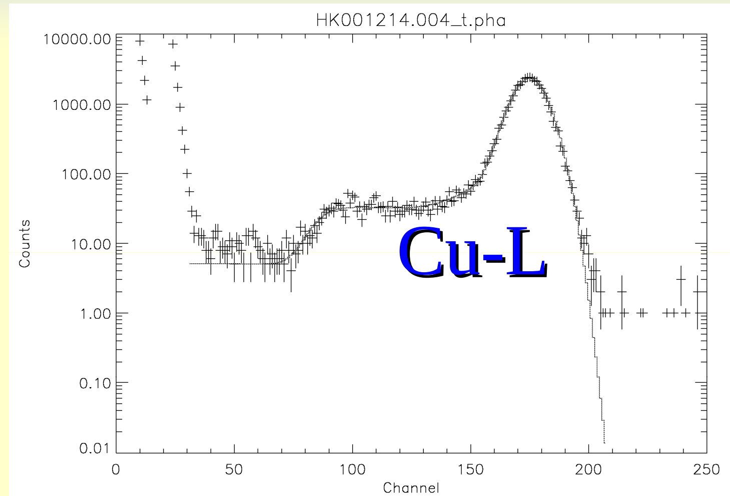
Anecdote: thickness of CCD, lime on mirrors?



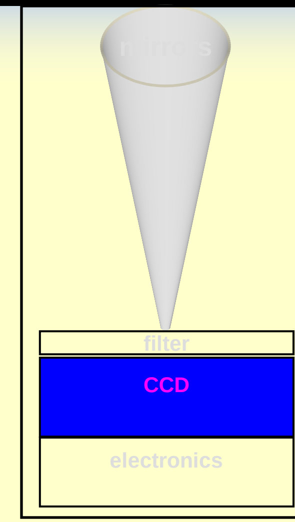
energy redistribution

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

- mode/time dependent - different rmfs required
- difficult at low energy (large interplay between redistribution and efficiency)



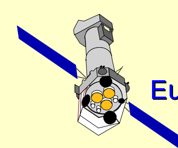
pn-response to monochromatic ground calibration source



G/C:
- long measurements at PANTER for various monochromatic lines
- edge scans at LURE for Si and Au

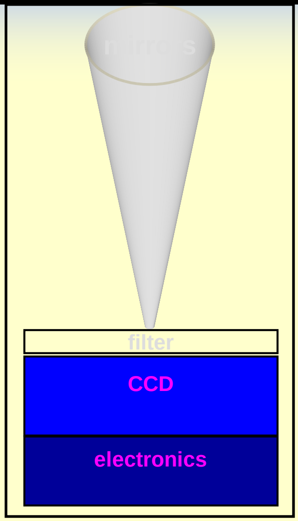
O/C:
- refinement using various Blasars and the isolated neutron star RXJ1856
- MOS time dependent RMFs needed due to evolving patch → see talk by Andy Read

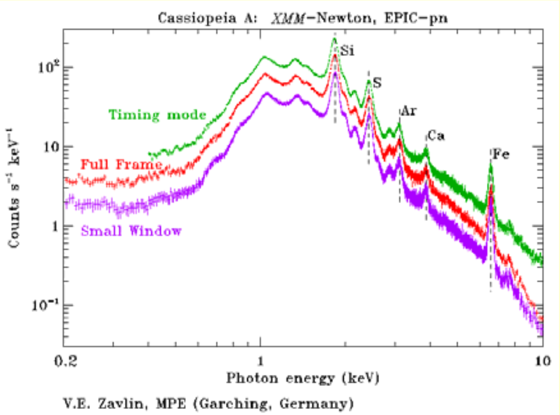
Anecdote: pn flight and flight spare model



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).





G/C:

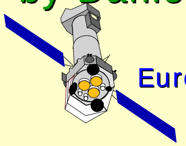
- long measurements at PANTER for various monochromatic lines
- measurements with a floureszence tube at LURE

Anecdote: Ag line

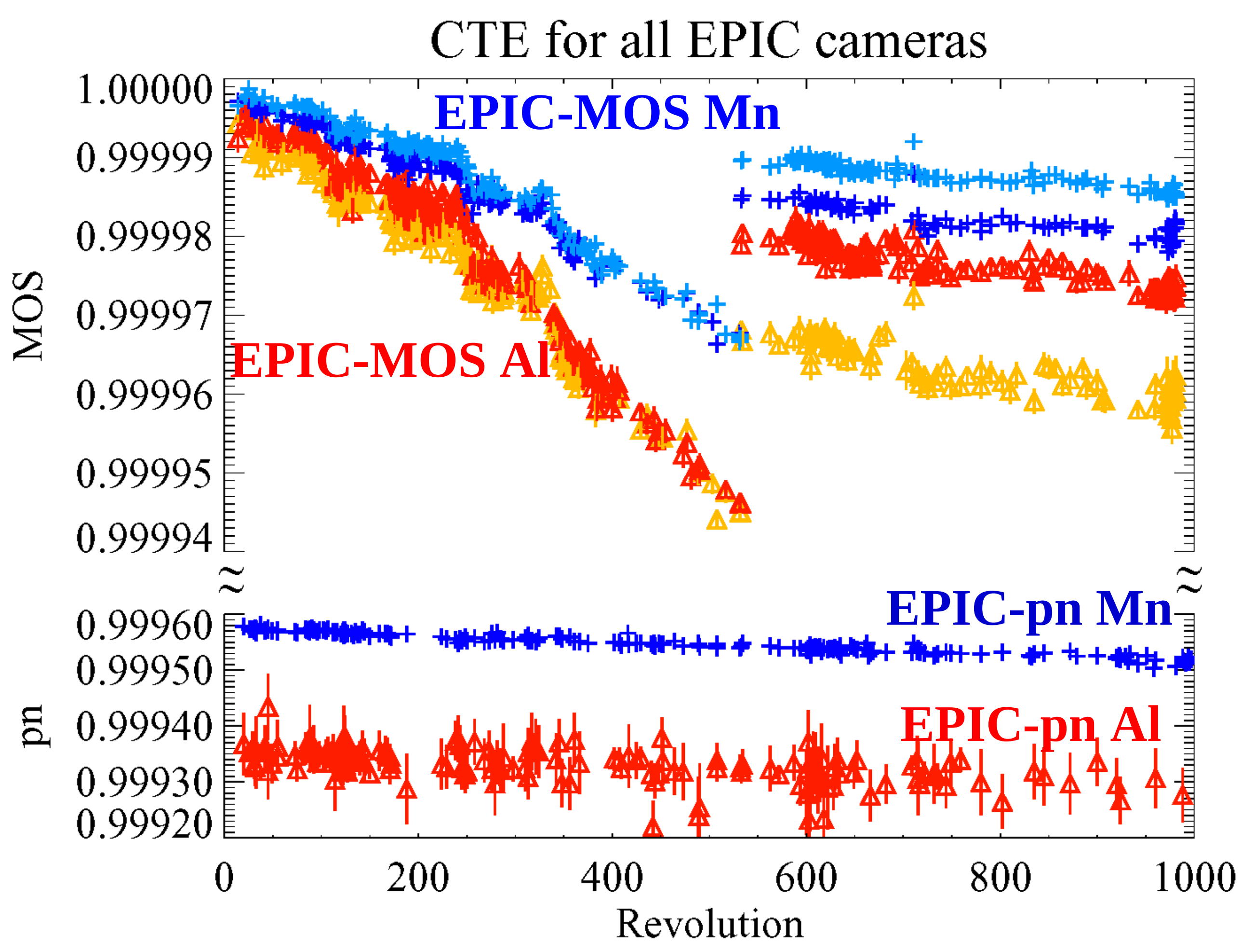
O/C:

- refinement using line rich SNRs N132D and Cas-A
- CTI degradation in orbit due to radiation: Time dependence is monitored with internal calibration source (Al-K and Mn-K lines)

→ see poster by Daniel Harbarth



EPIC-Charge Transfer Efficiency

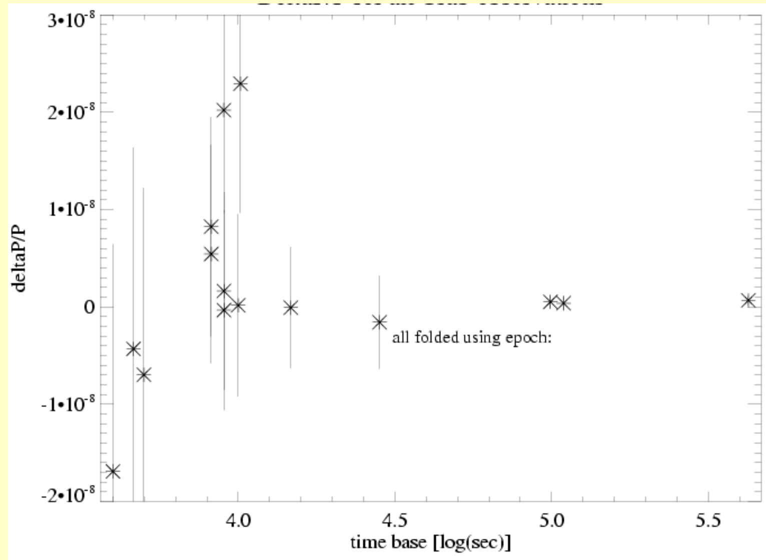


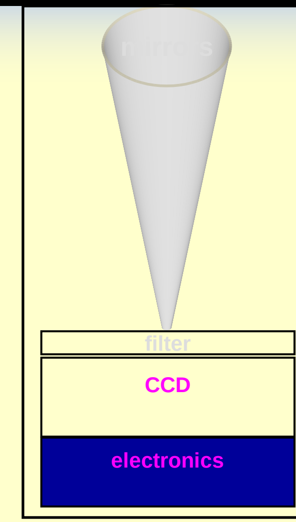
see M. Kirsch, SPIE 5898-29

- EPIC-pn CTE degradation is slight and in agreement with pre-launch predictions
- no clear correlation between the EPIC-pn CTE degradation and proton flares
- solar flares created a series of jumps in the EPIC-MOS cameras CTE
- EPIC-pn CTE is degrading independently of the solar flares with a nearly constant rate

timing

- **relative time accuracy of EPIC-pn:**
  $\Delta P/P = (P_{radio} - P_{x\text{-}ray})/P_{Radio}$
- **absolute time accuracy:**
  $T_{Radio} - T_{X\text{-}ray}$



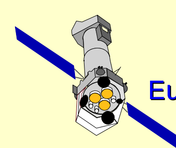


G/C:
- chopper measurements down to 1 ms Period at University of Tuebingen and Panter

O/C:
- monitoring of Timing accuracy with the Crab (Period: 33 ms)

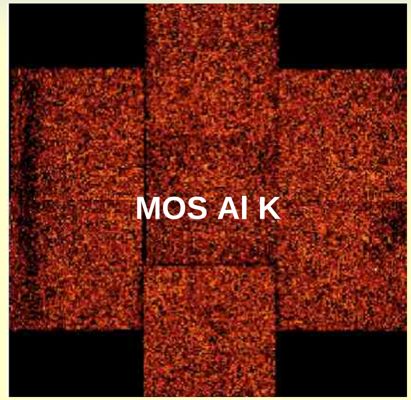
  → see Poster by Isabel Caballero

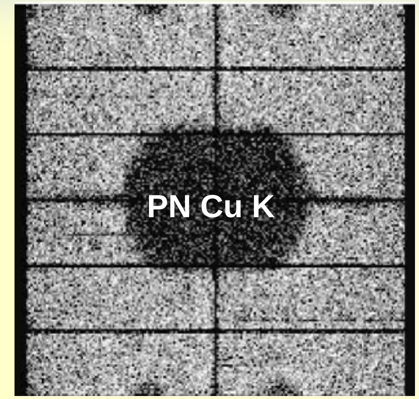
Anecdote: barycen

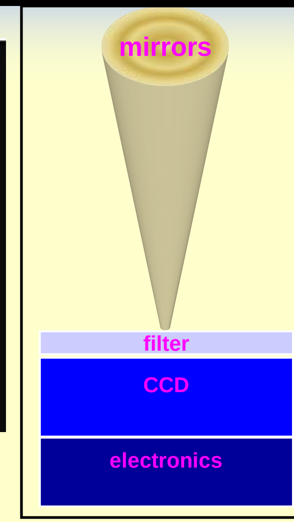


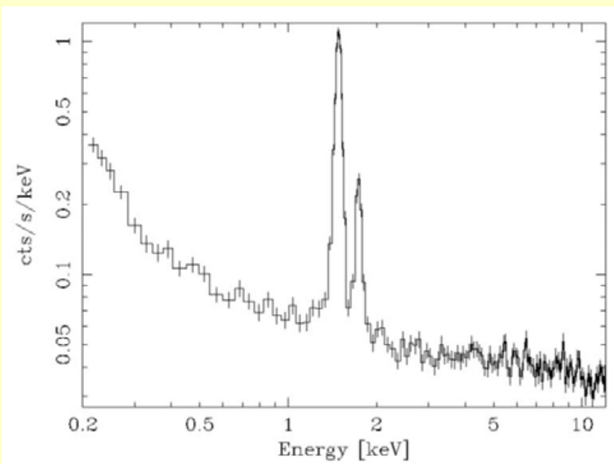
background

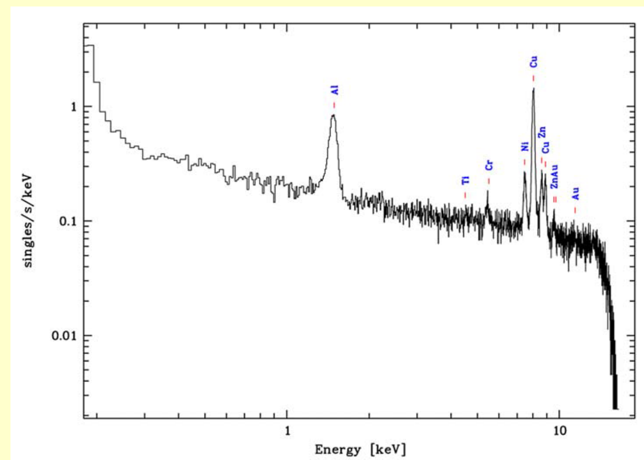
- low energy electronic noise
- soft proton “flares”
- quiet time high energy proton induced
- astrophysical background





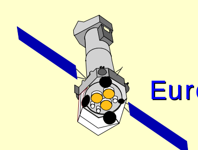




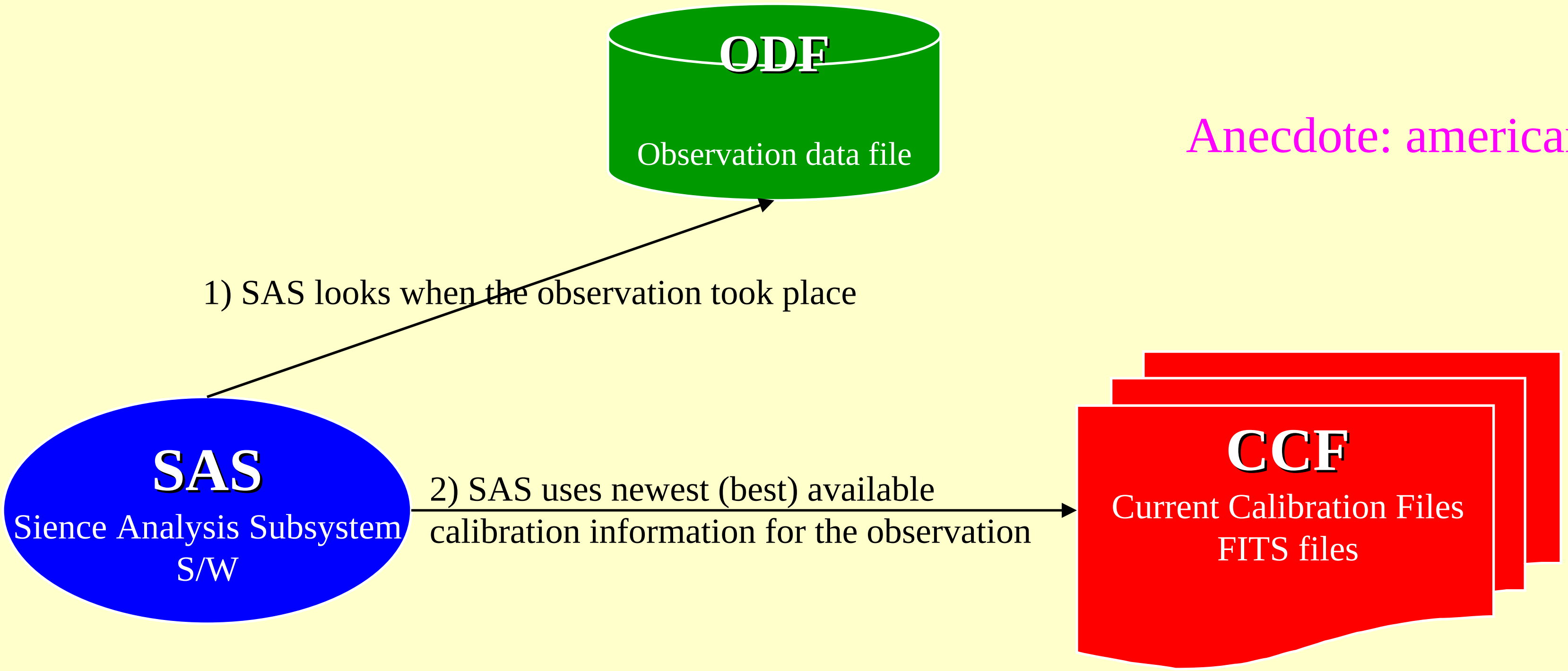


G/C:
- long CLOSED measurements at PANTER

O/C:
- CLOSED measurements
- various BG modells



Organization of calibration software and files



Anecdote: american times

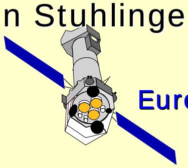
- calibration algorithms
- various versions as of launch
- currently 1 version per year

- parameters for calibration algorithms
- update possible every day

Very flexible system for calibration updates

major calibration steps and improvements

- Ground calibration (1997-2000)
  - PANTER, Orsay, Bessy
- Launch 10.12.1999
- 19.01. 16:19 h first light pn
- 21.01. 15:11 h first light MOS
- CAL-PV-phase (2 Feb – 24 June 2000)
  - 22 calibration 29 performance verification targets
  - CTI orbit calibration, RMF tuning
  - pn offset calculation method
- Routine phase
  - 2001: pn-Timing modes energy calibration
  - 2002:
    - relative timing problem solved
    - MOS CTI degradation requires epoch dependent energy calibration
    - cooling of the MOS cameras to slow down degradation process
  - 2003:
    - vignetting recalibration (optical axis)
    - major cross calibration campaign started
    - pn-QE refinement
  - 2004:
    - recalibration of PSF
    - astrometry recalibration
  - 2005:
    - discovery of spatial and time-dependent redistribution change in both MOSs
      → epoch and spatially dependent RMFs and recalibration of pn effective area and rmf
      (major step in cross calibration → see Cross Cal talk by Martin Stuhlinger)
    - micro-meteoroids → **see talk by Tony Abbey**

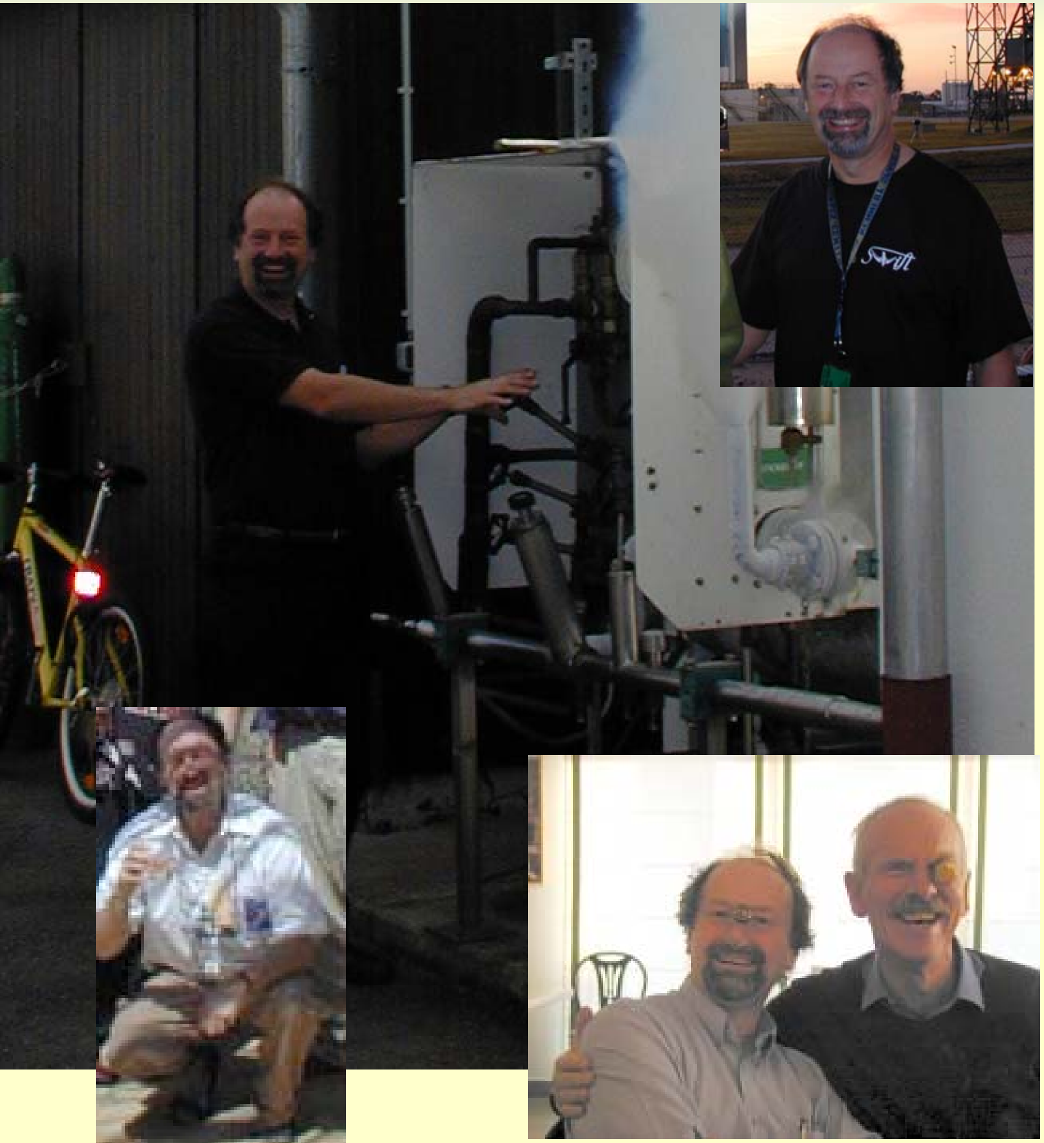


9 years of calibration-some impressions

before

after

9 years of calibration-some impressions



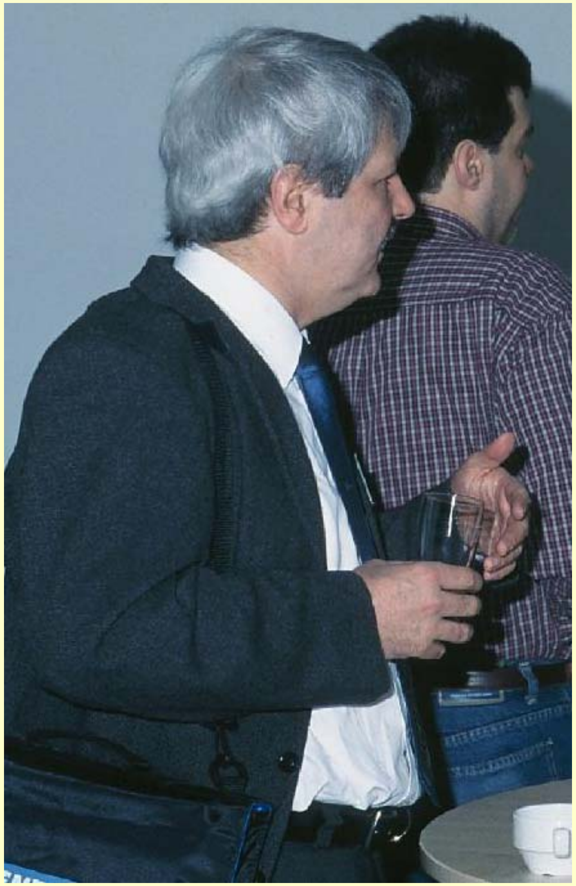
Some things never change

9 years of calibration-some impressions

Calibration inspection by the (old) boss of MPE

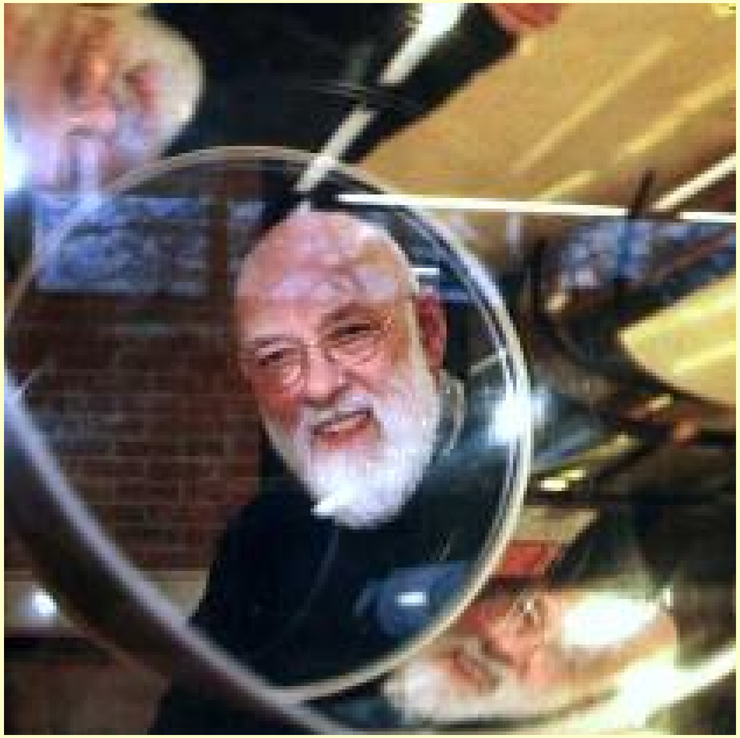
Calibration inspection by the (new) boss of MPE

9 years of calibration-some impressions



The daddy of the EPIC-pn CCD

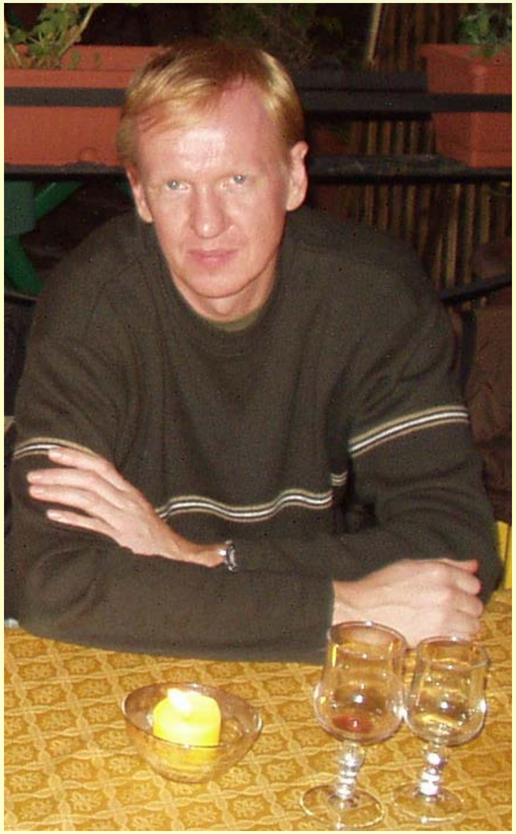
9 years of calibration-some impressions



the EPIC PI

9 years of calibration-some impressions

Calibrating the EPIC-MOS detector response is a tough job !!!



Will it ever end ....

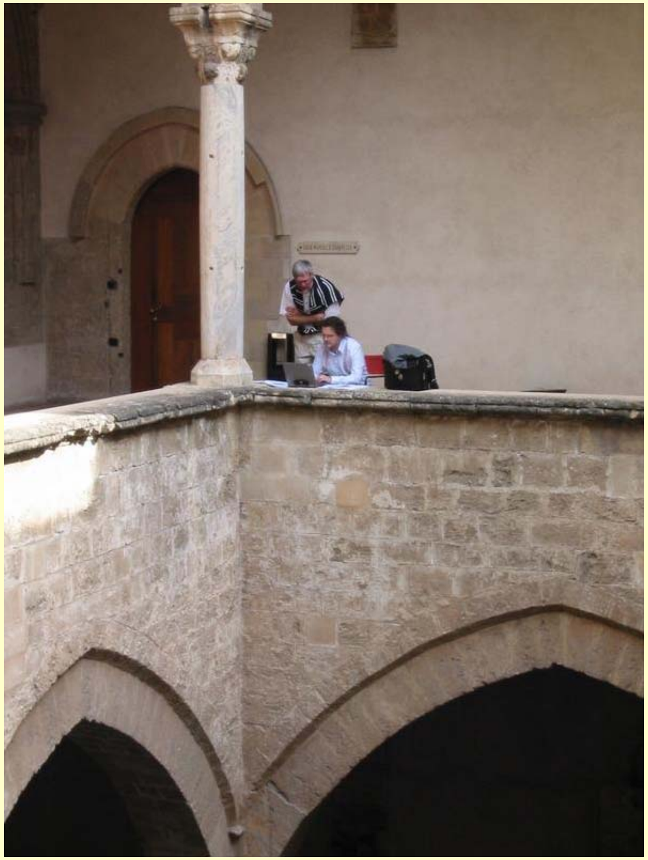
9 years of calibration-some impressions

Calibrating makes you hungry

9 years of calibration-some impressions

Spotting
the
MOS patch

9 years of calibration-some impressions



EPIC calibration scientist needs some advice from pn-expert

The future

Wee keep on calibrating...

Thanks
a lot to all old and new still heavily involved
EPIC-consortium calibrators
and
to the ESAC EPIC calibration team

And lets carry on with that pace for the next 9 years

Monitoring of the EPIC cameras at the XMM-Newton SCIENCE OPERATIONS CENTRE

D.M. Harbarth[1/4], M.P. Kirsch[1], M. Stuhlinger[1], M. Smith[1], D. Baskill[2], M. Freyberg[3]
[1]ESAC; [2]University of Leicester; [3]Max Planck Institute for Extraterrestrial Physics, [4]University of Tuebingen

EPIC

2 MOS cameras

7 front illuminated metal-oxide semi-conductor CCDs, each with:

- 100 µm Si
- 600 lines
- 600 columns
- pixel size: 40µm x 40µm

- frame transfer device on high resistivity epitaxial silicon with an open-electrode structure
- useful quantum efficiency in the energy range 0.2 to 10 keV
- low energy response of conventional front illuminated CCD is poor below ~700 eV because of absorption in the electrode structure.
- one of the three electrodes has been enlarged to occupy a greater fraction of each pixel, and holes have been etched through this enlarged electrode to the gate oxide. This gives an "open" fraction of the total pixel area of 40%; this region has a high transmission for very soft X-rays that would have otherwise be absorbed in the electrodes.
- the actual mean depletion of the flight CCDs is between 35 to 40 microns

PN camera

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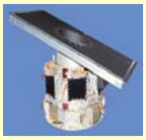
- 64 columns
- pixel size: 150 µm x 150 µm



- X-ray interaction with the silicon atoms, generates electrons and holes ~ energy of photon.
- average energy required to form an electron-hole pair is 3.7 eV at -90° C.
- signal charges (electrons), are drifted to the potential minimum and stored under the transfer registers.
- the electrons, captured in the potential wells 10 microns below the surface can be transferred towards the readout nodes upon command
- each CCD line is terminated by a readout amplifier.

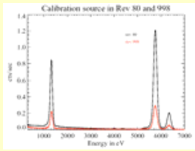
Monitoring flow

Real time health monitoring:

Since XMM-Newton is in continuous contact with its Science Operations Centre (SOC) at the European Space Astronomy Centre (ESAC), near Madrid in Spain, we can perform a real time health monitoring. The health monitoring of the instruments is carried out in two steps.

- **Instrument Controller**
  the Instrument Controllers (INSCON) monitor the instrument performance 24 hours a day. Suspicious behaviour of the instruments is immediately reported to the instrument teams at ESAC and the PI institutes for further investigation.
- **Offline monitoring** through the monitoring of the measured energies and widths of the internal calibration source lines
  - the tools employed are largely automatic supporting the trend analysis of parameters which affect instrument performance and health.
  - main targets of the monitoring are the behavior of:
    - *Charge Transfer Efficiency* (CTE)
    - *Amplification*
    - *effective area*
    - *bad/hot/noisy pixels*
    - *offset and noise maps*

The monitoring is performed by combination of calibration observations with an **internal radioactive calibration source** and **observations of astronomical targets**.



internal radioactive calibration source is becoming fainter. revolution 80 black line. revolution 998 red line

results

CTE & energy resolution

- **CTE** (Charge Transfer Efficiency) is efficiency of the transfer of charge as it is transported through the CCD to the output amplifiers
- harsh radiation conditions may induce the formation of electron traps in the detectors, thus degrading the CTE
- the filter wheel is put in a closed position during such periods of high background radiation to protect the detector
- EPIC-pn CTE degradation is slight and in agreement with pre-launch predictions
- no clear correlation between the EPIC-pn CTE degradation and proton flares
- figure A shows the evolution of the CTE for the different EPIC cameras
  - solar flares created a series of jumps in the CTE of the EPIC-MOS
  - improvement of the MOS CTE after cooling in revolution 533
  - the EPIC-pn CTE degrades independently of solar flares at a nearly constant rate per year

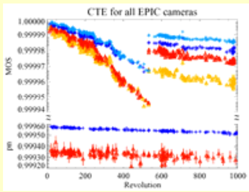
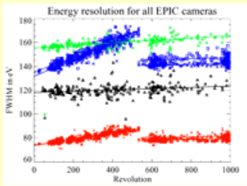


Figure A. Evolution of the CTE of the EPIC camera CCDs for the energies of the internal calibration source at Mn, 5896 eV, (blue crosses) and Al, 1486 eV (red triangles). Upper panel: EPIC-MOS, Lower panel EPIC-pn. The different blue and red tones in the upper panel of the figure represent the EPIC-MOS1 (light blue (Mn), orange (Al)) and EPIC-MOS2 (dark blue (Mn), red (Al)). The discontinuity around rev.533 is related to the cooling of the EPIC-MOS cameras. Note that all EPIC-MOS CCDs have recovered some CTE after the cooling. Only the EPIC-MOS1 boresight CCD has not recovered as strongly - as shown by the orange crosses

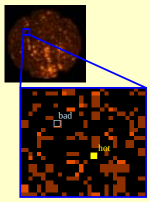
- The EPIC-MOS **energy resolution** at low energies is much better than that of EPIC-pn.
- at high energies, and prior to the cooling of the EPIC-MOS cameras, their energy resolution was degrading towards the level for the EPIC-pn
- after cooling they have again a better energy resolution, also for high energies (for more information see: *http://xmm.esac.esa.int/external/xmm_news/items/cooling02/index.shtml*)

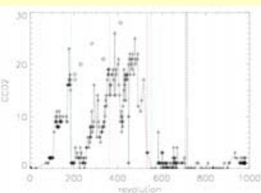


Energy resolution of the central CCDs of the EPIC camera for different energies. EPIC-pn Al: black triangles, EPIC-pn Mn-K green triangles, EPIC-MOS1(2) Al: red crosses (asterisks), EPIC-MOS1(2) Mn-K: blue squares(x). Note that the improvement in energy resolution at revolution 533 is related to the cooling of the EPIC-MOS cameras (see 3.2.1). Note that the absolute values for Al for the EPIC-pn camera are slightly higher (5-10 eV) than the one by Meidinger15 since no BG modeling has been performed

"hot" and "bad" pixels

- "bad" or "hot" are pixel within a CCD exhibiting abnormal behaviour
  - "**hot**" pixel mimic a signal
  - "**bad**" pixel yield no signal
- monitoring of number and location of bright pixels
  - they reduce loading of the spacecraft telemetry budget
  - they affect science quality
- for the **EPIC-pn** camera:
  - a small number of hot pixels were present at launch
  - damage resulting from a suspected micrometeoroid impact in revolution 156 caused the sudden appearance of 35 additional hot pixels
- for the **EPIC-MOS** cameras the number of hot pixels increased due to:
  - micrometeoroid events
  - aging caused by hard radiation particles
  - the figure shows the evolution of hot pixels for CCD2 in EPIC-MOS2





Hot pixel evolution of EPIC-MOS2 CCD2. The diamonds show the absolute number of hot pixels. The crosses show the number of hot pixels that are not yet masked out on board (candidate hot pixels). The green lines indicate an update of the onboard bad pixel table that masks out hot pixels. Note that after the cooling in rev 533 most of the hot pixels have disappeared and the onboard bad pixel table could be relaxed to a few pixels per CCD.

strategy of data acquiring

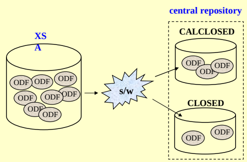
Calclosed measurements

normal calclosed observations:

The collection of the observations with an internal radioactive calibration source (calclosed observations) has been automated by a software:

the software:

1. searches in the archive (XSA) for calclosed observations
2. provides the calclosed observations on a central repository



use for calibration:

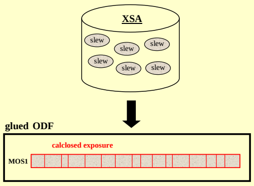
- CTE
- energy resolution
- energy position
- background
- ...

calclosed slews for the MOS:

- pn slew data are useful for a science slew survey
- **MOS slew data are NOT useful for a science slew survey, but can be used for calibration purposes**
  - this saves about 2% exposure time for science

but: a single slew is too short !

- a certain amount of slews has to be "glued" together (see the box "time approximation") in order to get good statistics for CTE determination



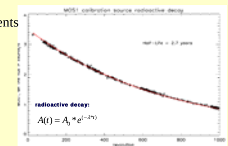
current situation:

- NO dedicated calclosed measurements will be performed any more.
- pn will use parasitical (long) calclosed measurements during RGS/OM calibration observations approximately every 2-3 month
- MOS will also use those observations.
- as of revolution 918 the MOS slew measurements in calclosed mode replace the dedicated calclosed measurements
- software collects and "glues" the calclosed MOS slews together and provides them as event lists

Time approximation

"gluing" slews:

In order to have good statistics in a calclosed measurements enough events have to be collected. Because of the decay of the internal radioactive calibration source the needed time in calclosed mode increases with mission time:



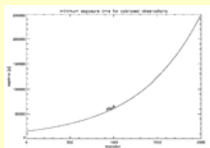
radioactive decay of the internal calibration source as a function of revolution

time approximation:

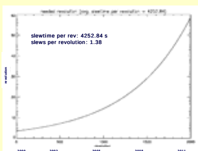
- mission time dependent
- 10 ksec were needed at revolution 1
- extrapolation in order to calculate the needed slewtime as a function of revolution

sampling frequency:

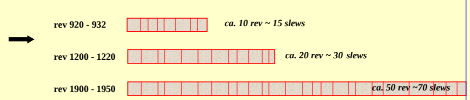
- at the moment ~10 revolutions are needed in order to get one data point
- in 2 years ~20 revolutions will be needed
  - *strategy may have to revised in the coming years depending on sampling frequency requirements*



needed exposure time as a function of revolution. So far 6 "glued" calclosed observations were created (crosses).



needed revolutions to get enough slews



The X-ray Universe
26-30 September 2005, El Escorial, Spain

XMM-Newton EPIC timing monitoring

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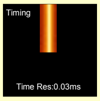
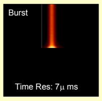
[c]Department of Physics, University of Warwick, [d]Eberhard Karls Universität Tübingen

TIMING MONITORING

The EPIC-pn camera is the fastest instrument on board XMM-Newton. The highest resolution is reached in Timing and Burst modes:

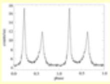


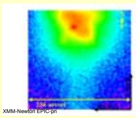


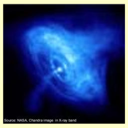
TARGETS

XMM-Newton performs two observations a year of the Crab in order to monitor the timing accuracy.
The pulsars PSRB0540-69, PSRB1509-58 and PSRB1055 have also been observed.

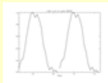
CRAB: Very bright source. Characteristic stable pulse profile. Observed many times with other instruments.
- Distance ~2.2kpc
- Period ~33 ms

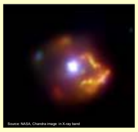




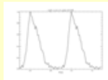


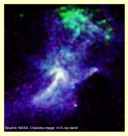
PSR B0540-69 (Large Magellanic Cloud)
- Distance ~50kpc
- Period ~50ms



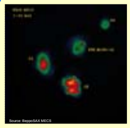


PSR B1509-58 in SNR MSH 15-52
- Distance: ~6kpc
- Period: ~ 150ms





PSR B1055-52 (one of *the three musketeers*)
- Distance: ~0.5-1.5 kpc
- Period: ~197ms



RELATIVE TIMING ACCURACY

The relative timing accuracy is monitored by calculating the period of a pulsar and comparing it with that period measured in radio frequencies. The relative error gives the timing accuracy.

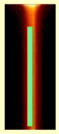
X-Ray Period =>P_X Radio Period =>P_R

$$\frac{P_R - P_X}{P_R} = \frac{\Delta P}{P} = Relative\ Error$$

PROCESSING OF DATA

Data obtained from the XMM-Science Archive, analyzed with the SAS v6.5

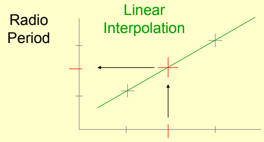
ODF (Raw data) $\xrightarrow{epproc}$ Event File $\xrightarrow{barycen}$ Event File Barycentric Corrected $\xrightarrow{evselect}$ Source Region



PERIOD DETERMINATION

RADIO PERIOD OF THE PULSARS

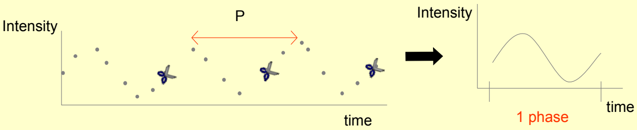
- For the Crab pulsar, the radio period is obtained using data from the Jodrell Bank Observatory (University of Manchester), where one observation of the Crab is performed every month. The way to obtain the radio period for the precise epoch we need is doing a linear interpolation with the data available. An automatic tool has been created to obtain this radio period.

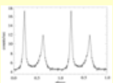


- For the other pulsars data is taken from the Princeton Pulsar Group. There are fewer observations for these pulsars. The radio period is obtained extrapolating the radio period to the epoch we need.

X-RAY PERIOD OF THE PULSARS

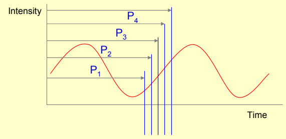
X-ray period obtained using epoch folding



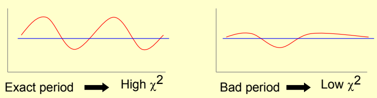


Folded light curve of the Crab

Method consists in folding the data over a range of test periods P_i



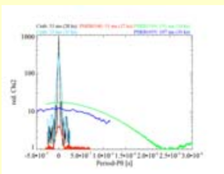
For each test period determine χ^2 of the fit of the folded light curve vs. a uniform distribution



χ2 distribution

Plot χ2 vs. the test periods. The weighted mean of the periods gives the best period

$$P_x = \frac{\sum_{i=1}^{n} \chi^2 \cdot P_i}{\sum_{i=1}^{n} \chi^2}$$

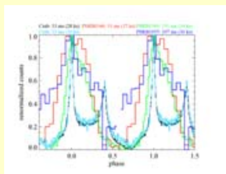


Plot shows the different χ2 distributions for the different pulsars used.

FWHM≈P^2/T

The FWHM obtained agrees with the expected theoretical values

Pulsar	Theoretical FWHM	Obtained FWHM
Crab (Rev. 698)	2.24e-07	1.61e-08
Crab (Rev. 700)	6.21e-07	4.45e-08
PSRB0540	1.52e-07	1.57e-07
PSRB1509	2.4e-06	1.95e-06
PSRB1055	7.50e-07	2.06e-06

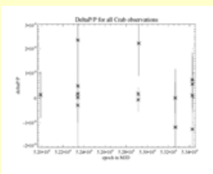


Different light curves obtained for the different pulsars (y axis has no units for plotting reasons)

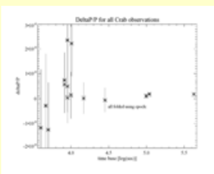
This search for the period is done with *efsearch*, available in XRONOS, a Timing Analysis Software Package from NASA HEASARC

RESULTS

ΔP/P for the Crab

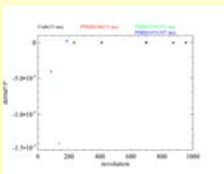


ΔP/P vs. epoch for all Crab observations. Allows to check the relative timing accuracy along the mission

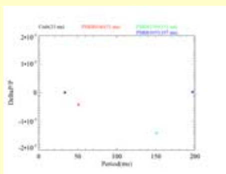


ΔP/P vs. observation time for all Crab observations. Better accuracy obtained as the time base increases.

ΔP/P for all pulsars



ΔP/P vs. the revolution number for all pulsars



ΔP/P vs. the period for all pulsars

Object	Revolution	RA (J2000.00)	DEC(J2000.00)	Mode	Epoch (MJD)	P_{radio}(ms)	P_{X-ray}(ms)	ΔP/P
Crab	0234	05 34 31.973	+22 00 52.061	Burst	51988.6356	33.521309	33.521309	1.6e-10
	0411			Burst	52340.6823	33.534101	33.534100	-4.3e-09
	0411			Burst	52341.2884	33.534123	33.534122	-3.4e-10
	0411			Timing	52341.4150	33.534127	33.534128	2.0e-08
	0411			Burst	52341.8420	33.534143	33.534143	1.6e-09
	0698			Timing	52341.5070	33.554913	33.554913	-1.6e-09
	0700			Timing	52918.3013	33.555087	33.555088	2.3e-08
	0874			Burst	53264.0985	33.567652	33.567652	-7.9e-11
	0874			Burst	53265.5726	33.567705	33.567705	-1.7e-08
	0955			Burst	53425.7223	33.573526	33.573553	8.2e-09
	0955			Burst	53426.2665	33.573545	33.573545	-7.0e-09
	0955			Burst	53426.7744	33.573564	33.573564	5.4e-09
B0540-69	0085	05 04 11.049	-69 19 55.188	Timing	51691.5371	50.519485	50.519282	-4.0e-06
B1509-58	0137	15 13 55.617	-59 08 08.872	Timing	51794.2595	151.115731	151.113602	-1.4e-05
B1055-52	0187	10 57 58.76	-52 26 56.91	Timing	51893.7331	197.111810	197.111855	2.3e-07

Pulse ephemeris obtained from timing analysis

"The X-ray Universe 2005" Symposium, El Escorial, Madrid, Spain 26-30 September 2005