XMM-Newton EPIC calibration and health status

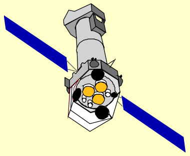
Marcus G. F. Kirsch

with the input of the whole EPIC consortium

Special Thanks to A. Read, S. Sembay, A. Abbey, F. Haberl
and the ESAC EPIC team

menu

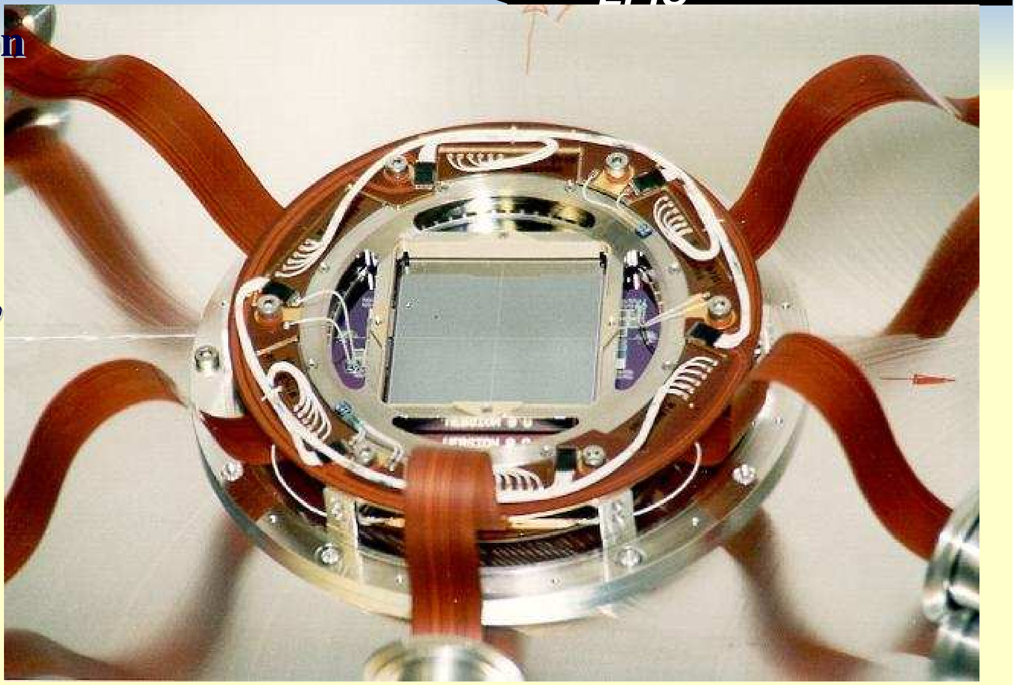
- MOS
  - patch and RMF
  - Micro-meteoroids: lost one CCD
  - CTE
- pn
  - RMF
  - Effective area
  - CTE
- Cross-calibration
- The need for calibration standards

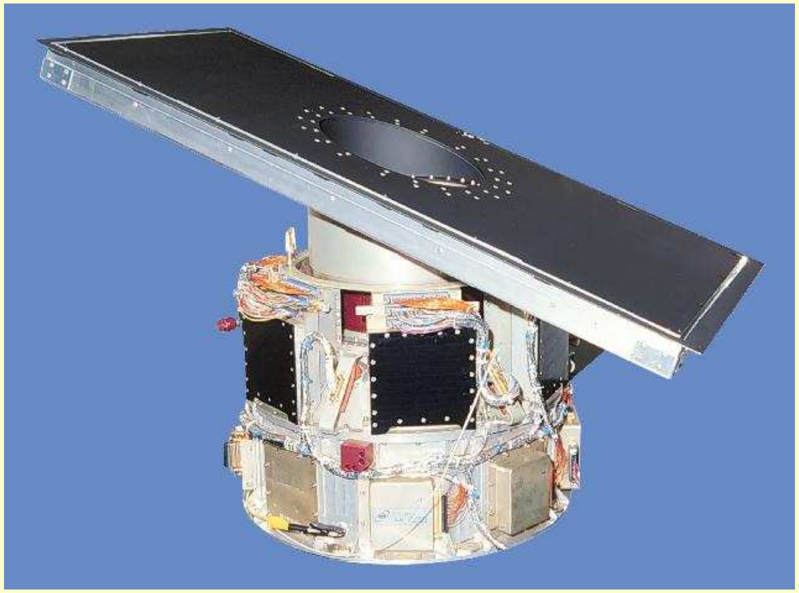


EPIC-pn

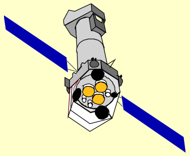
12 back illuminated pn-junction CCDs integrated on one single Si-wafer, each with :

- **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**

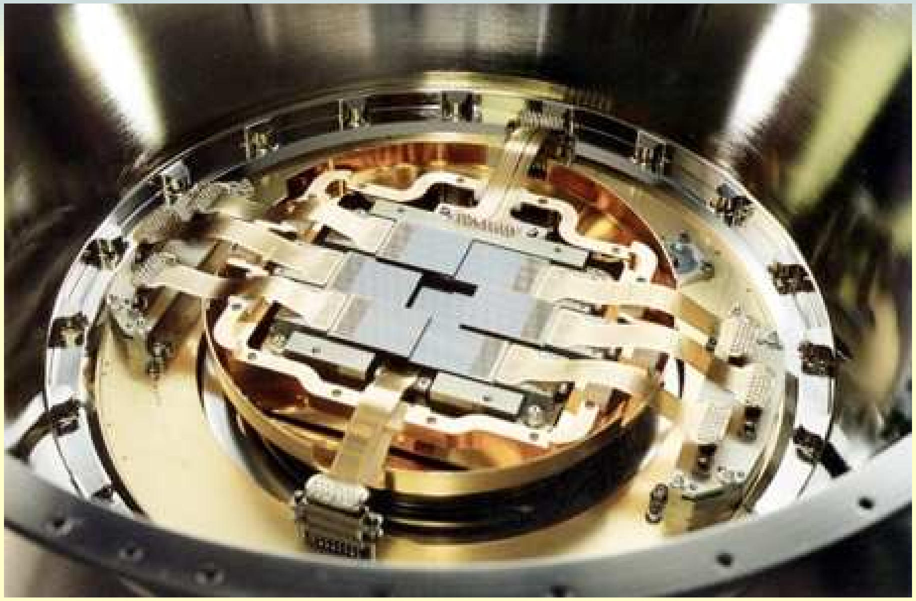




- **X-ray interaction with the silicon atoms, generates electrons and holes ~ energy of photon.**
- **average energy required to form an electron-hole pair is 3.7 eV at -90° C.**
- **signal charges (electrons), are drifted to the potential minimum and stored under the transfer registers.**
- **the electrons, 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

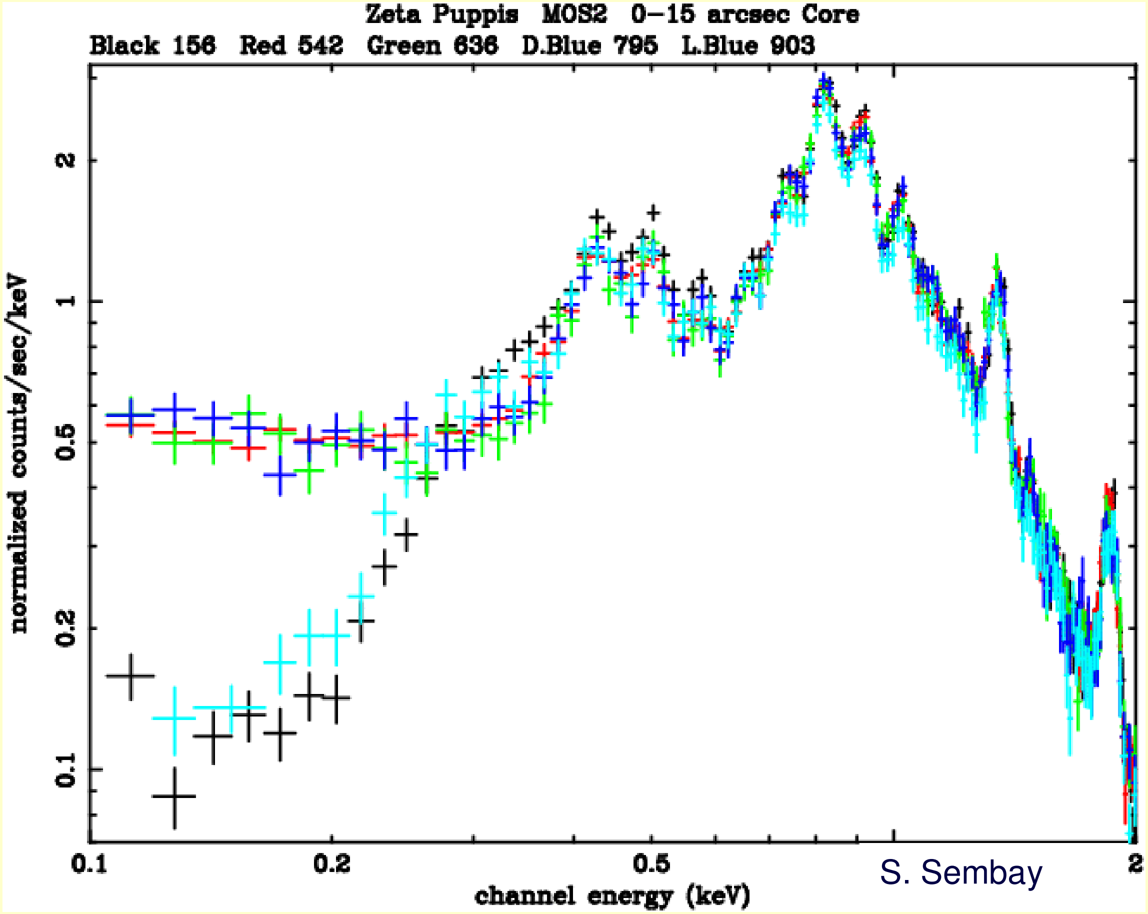


7 front illuminated Metal-Oxide Semi-conductor CCDs, each with:

- **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**

MOS:
Low Energy Epoch Dependent Response Variation



S. Sembay

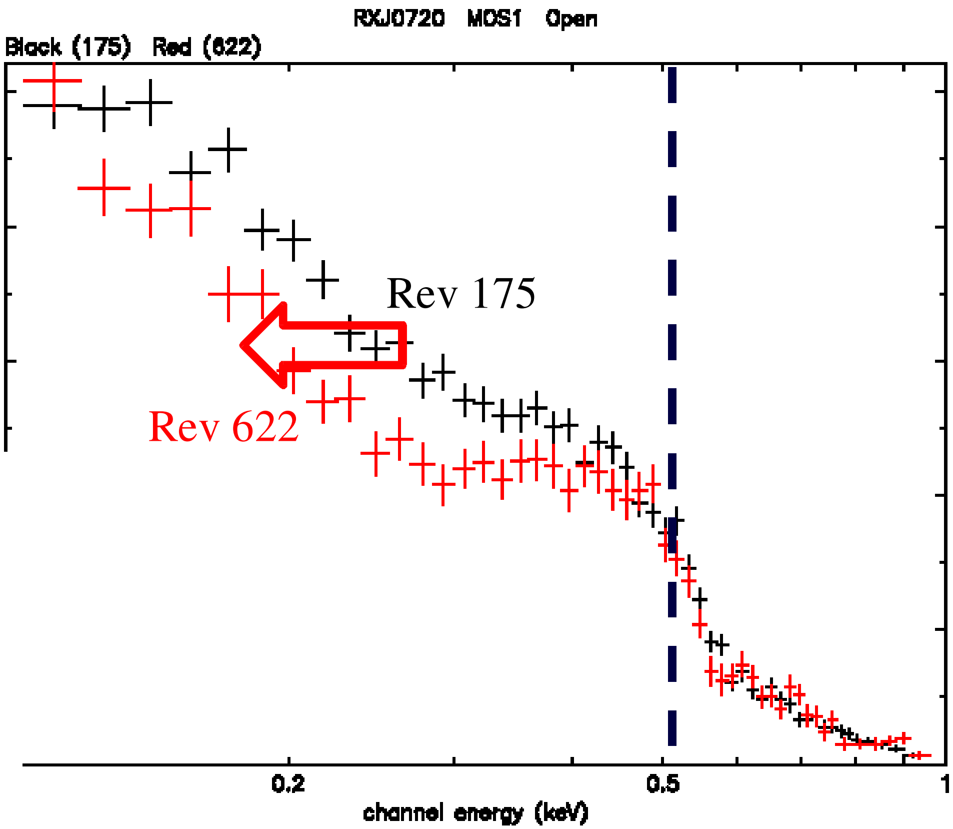
- Flux increase at energies below 0.3 keV
- Flux loss around 0.5 keV
- What happened to the cameras?
  - Contamination on filters?
  - Change in surface collecting efficiency of the CCDs?

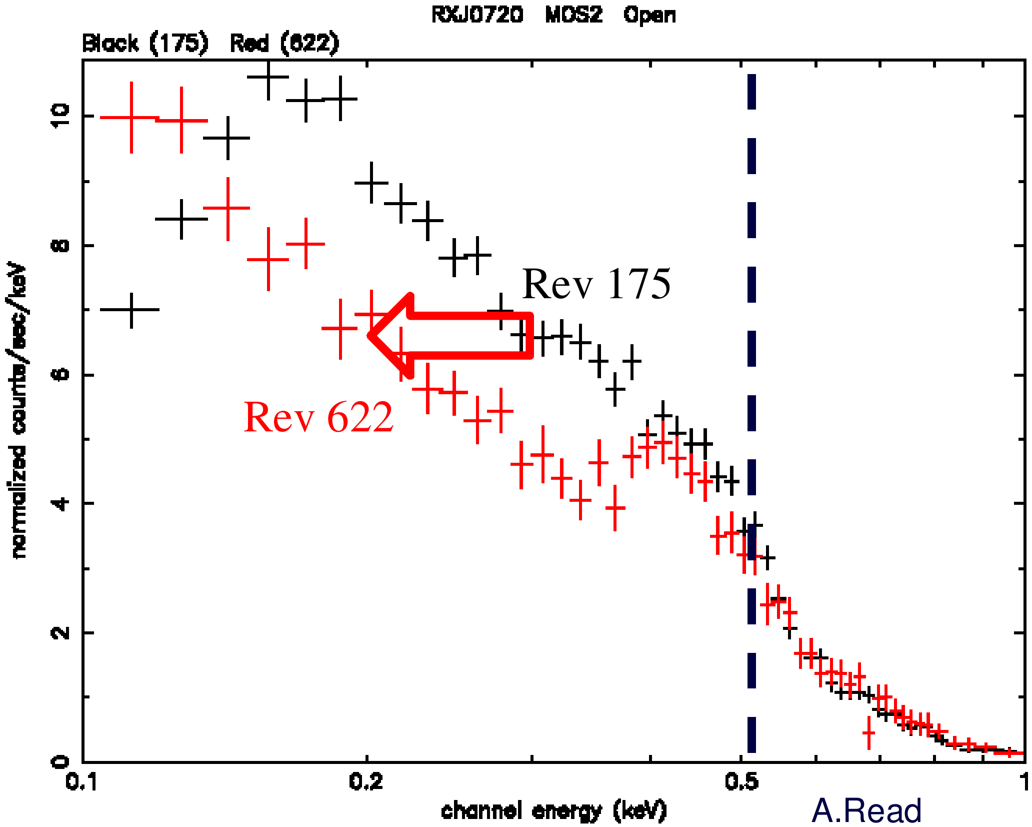
Check for contamination

Open filter observations of

the Isolated Neutron Star RX J0720

→ NO CONTAMINATION

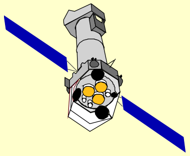




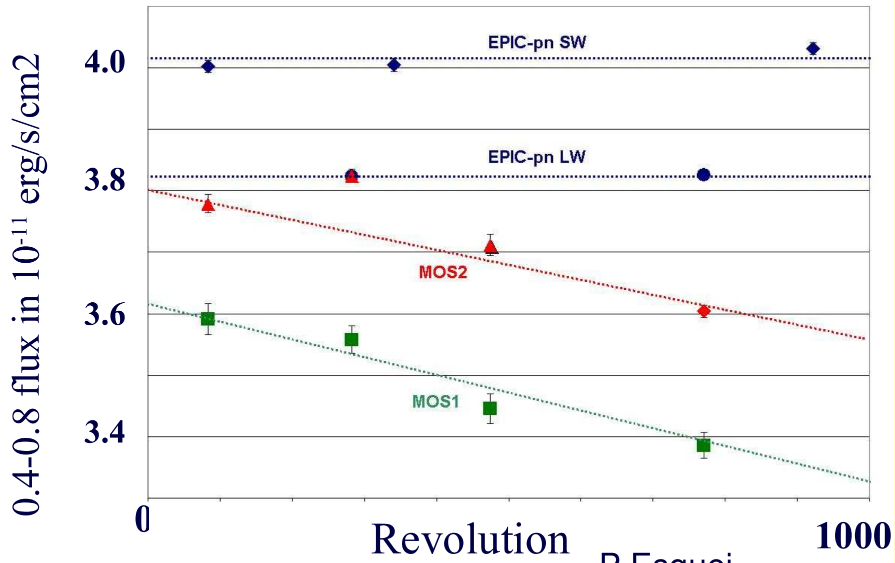
A.Read

Shift in spectrum to lower energies

Effect most pronounced at lower energies



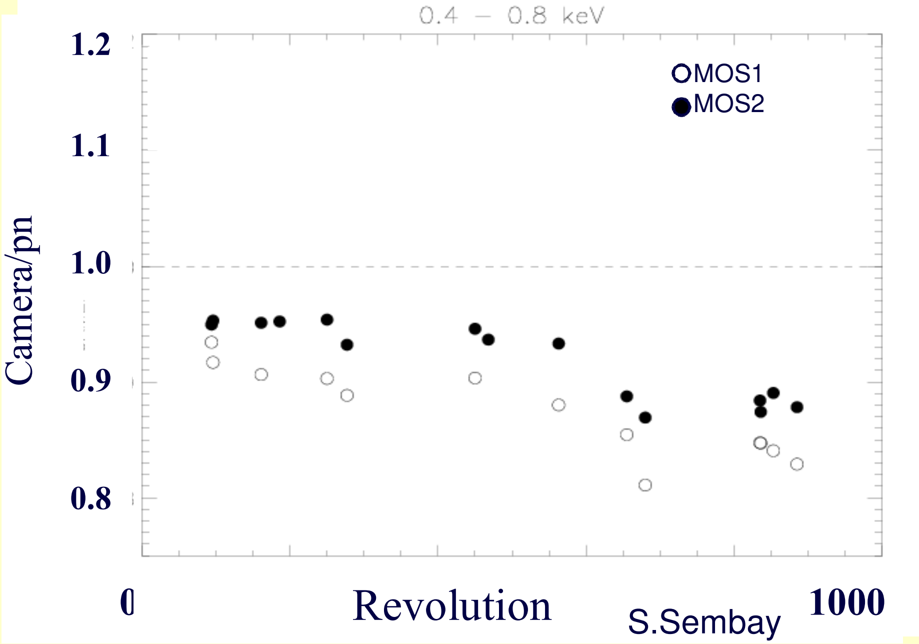
stability check



P.Esquej

N132D

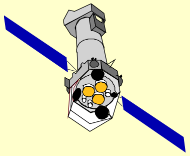
- Flux comparison of N132D in 0.4-0.8 keV band
- pn extremely stable (~5% lower flux for the LW mode with respect to the SW due to a pile-up effect).
- MOSs show a decreasing trend of ~5% up to revolution 800.
- MOS1 flux is lower than that of MOS2 by ~5%.
- lower flux of MOS with respect to pn is probably due to pile-up in the MOS LW mode (all MOS observations plotted here have been performed in this mode).



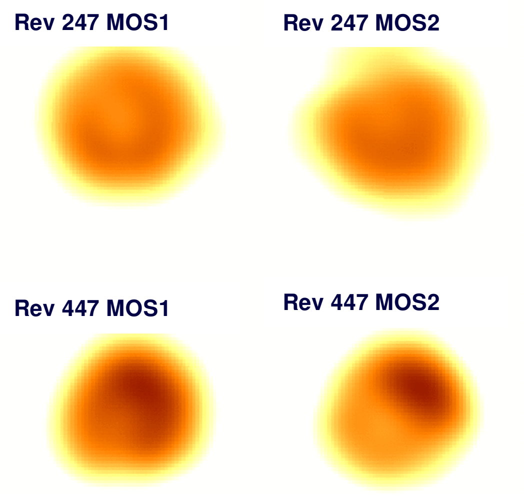
S.Sembay

Various AGN

- Data from a sample of AGNs were analysed with SAS 6.1 and fluxes were computed.
- The relative long-term trend obtained has evidence that MOSs lose sensitivity over time in the soft energy band 0.4-0.8 keV with respect to pn. This trend leads to a deficit of 15% for MOS2 and 15-20% for MOS1 after 800 revolutions (5% of deficit at launch), which is consistent with SNR studies.

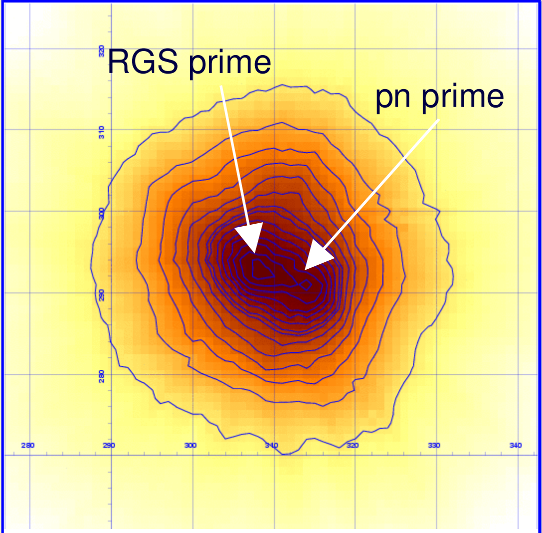


the MOS patch



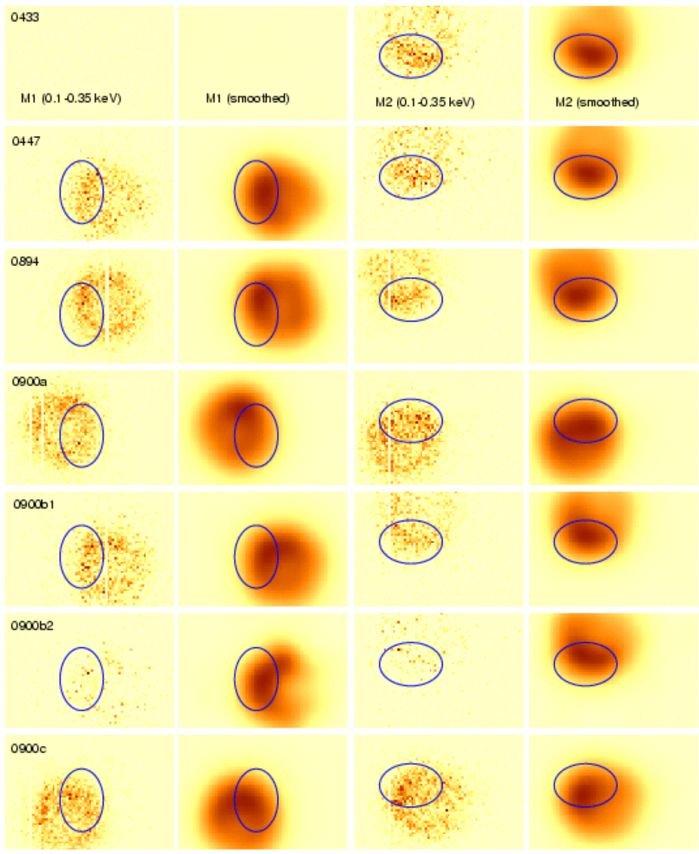
smoothed images 1ES0102
0.1-0.35 keV

A.Read



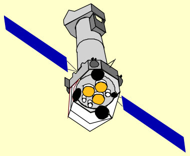
total mission x-ray dose M1

Raster scan of the patch region



A.Read

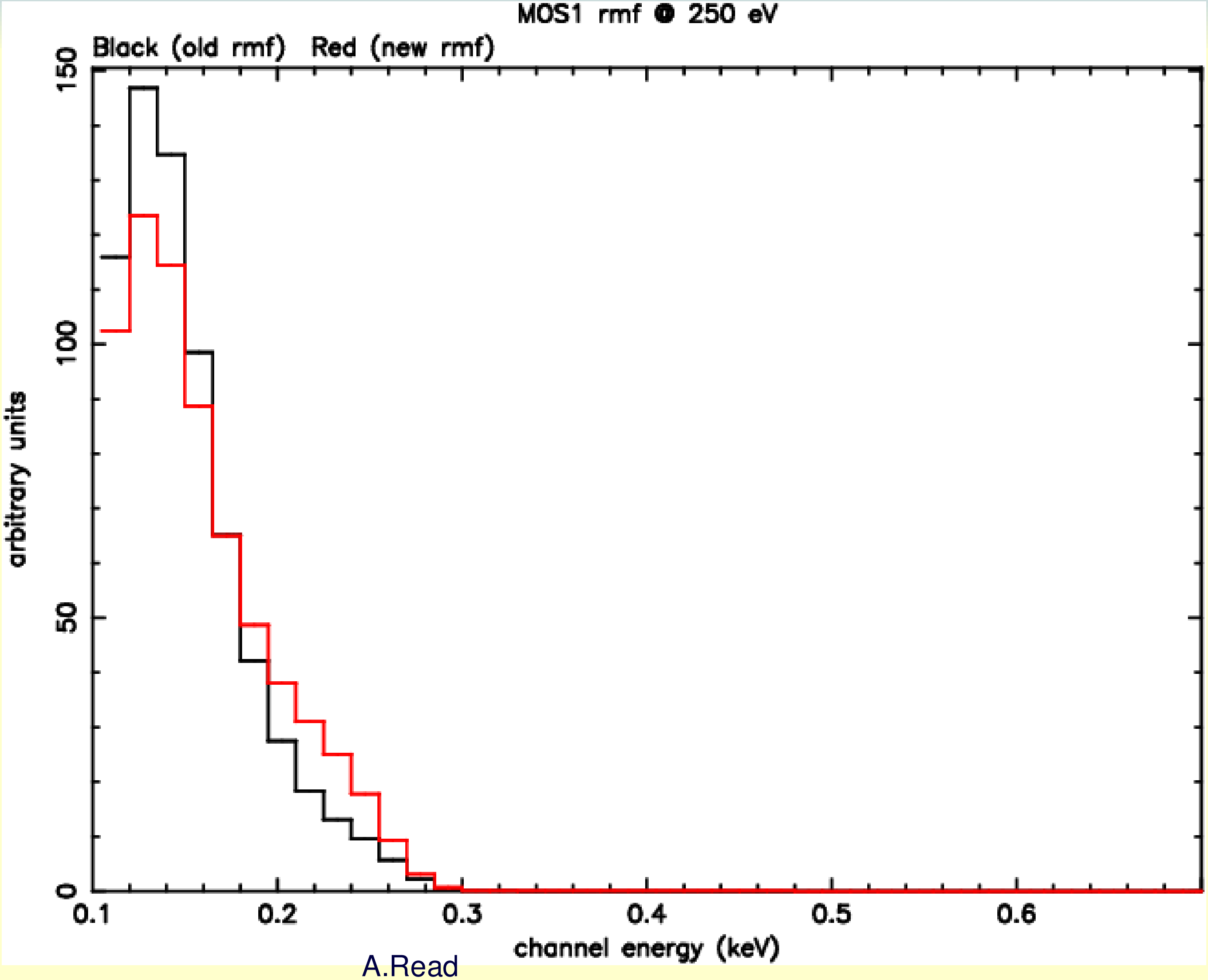
- small patch on each detector discovered
- used all archive 1ES0102 observation and performed raster scan to identify position and time variability
- patch has degraded over time ➔ broadens the redistribution function at energies around 0.5 keV
- coincident with the nominal position of sources when placed at pn and RGS boresights.
- coincident with the peak in received photon dose of the detectors



New MOS rmf (on-axis)

Old rmf

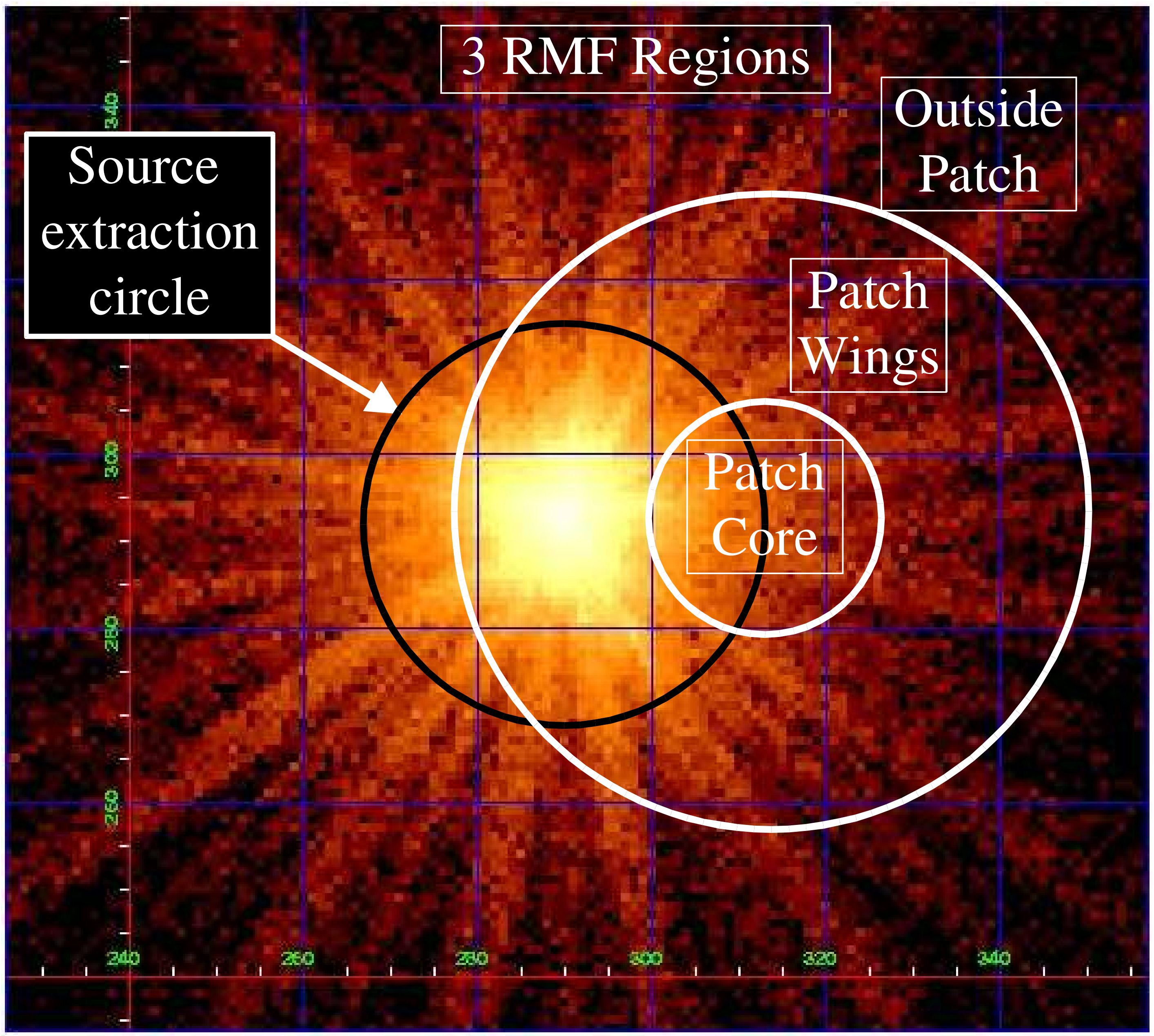
New rmf



A.Read

Original shoulder has evolved into flatter 'shelf'

rmf implementation


3 RMF Regions
Source extraction circle
Outside Patch
Patch Wings
Patch Core
340
300
280
260
240
260
280
300
320
340

As of SAS v6.5:

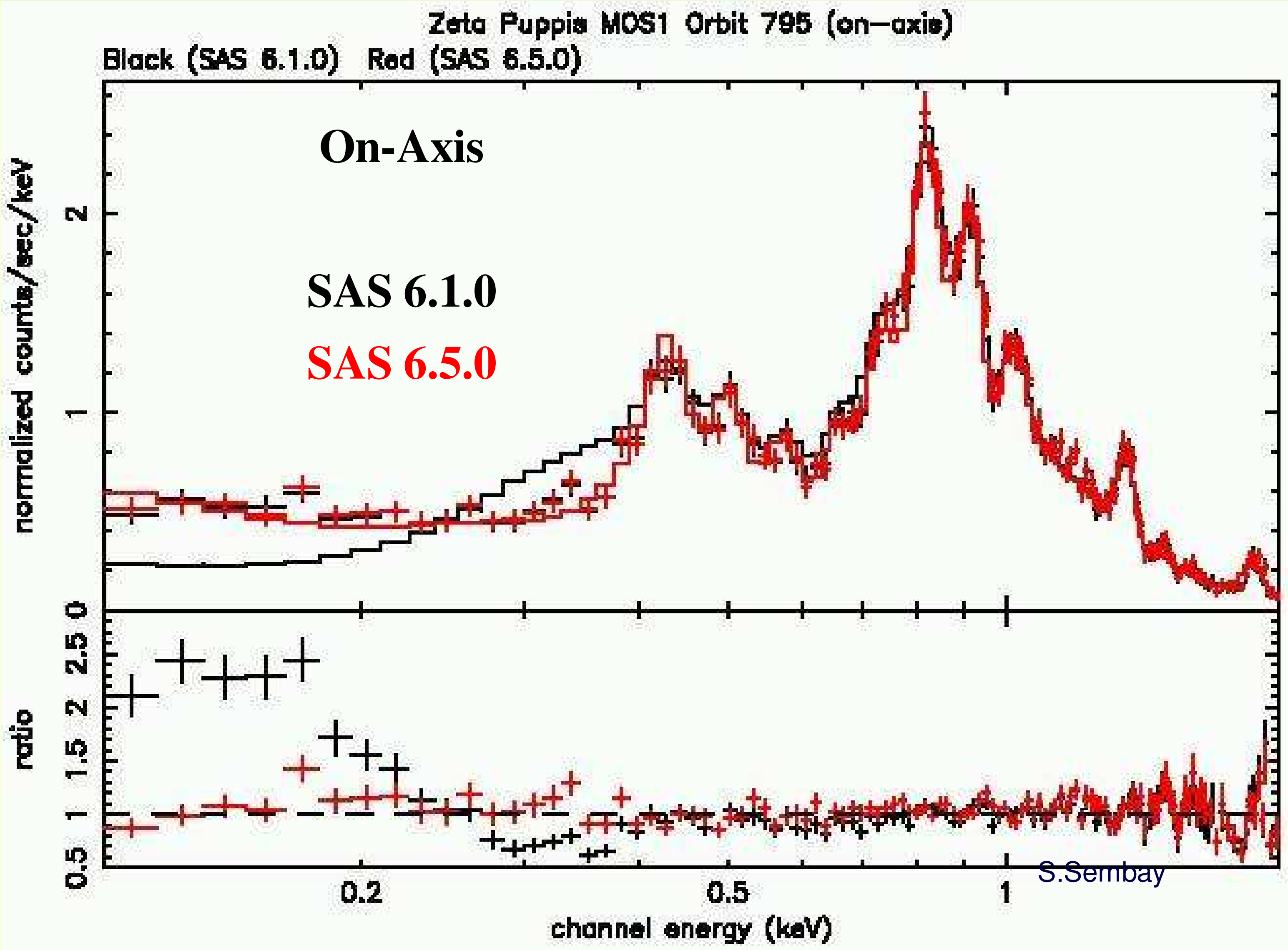
- 3 RMF regions
- 2 Instruments
- 9 Epochs

- 54 RMFs

- PSF (rmfgen default) or flat weighting to create average RMF

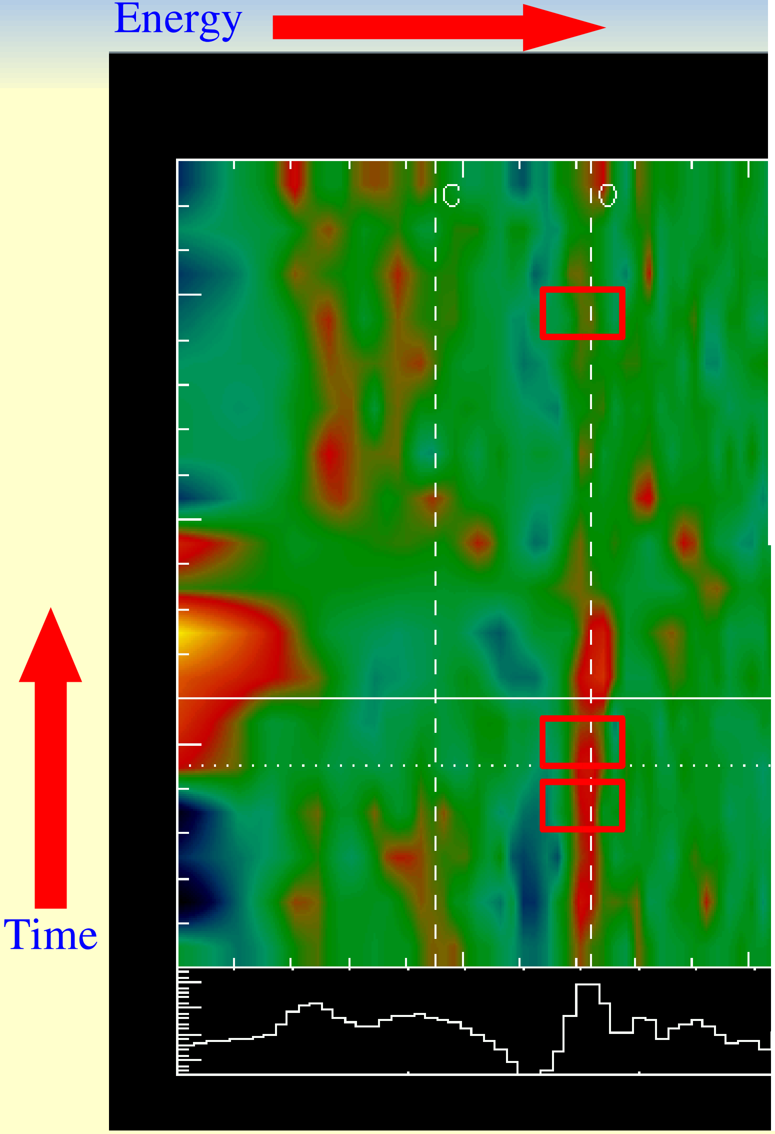
- (automatically generated in SAS)

before and after

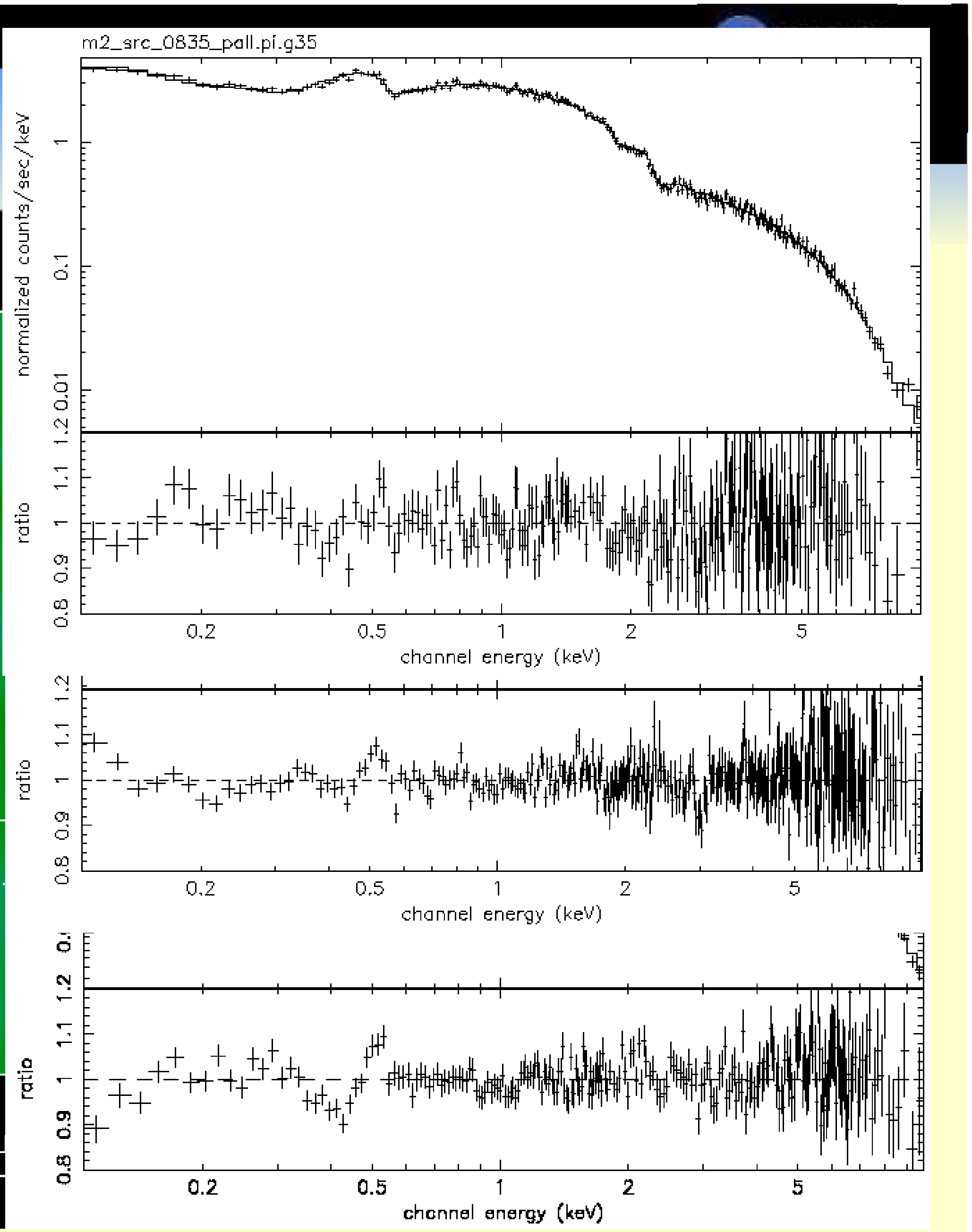


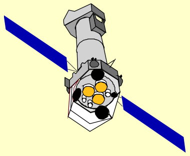
S.Sembay

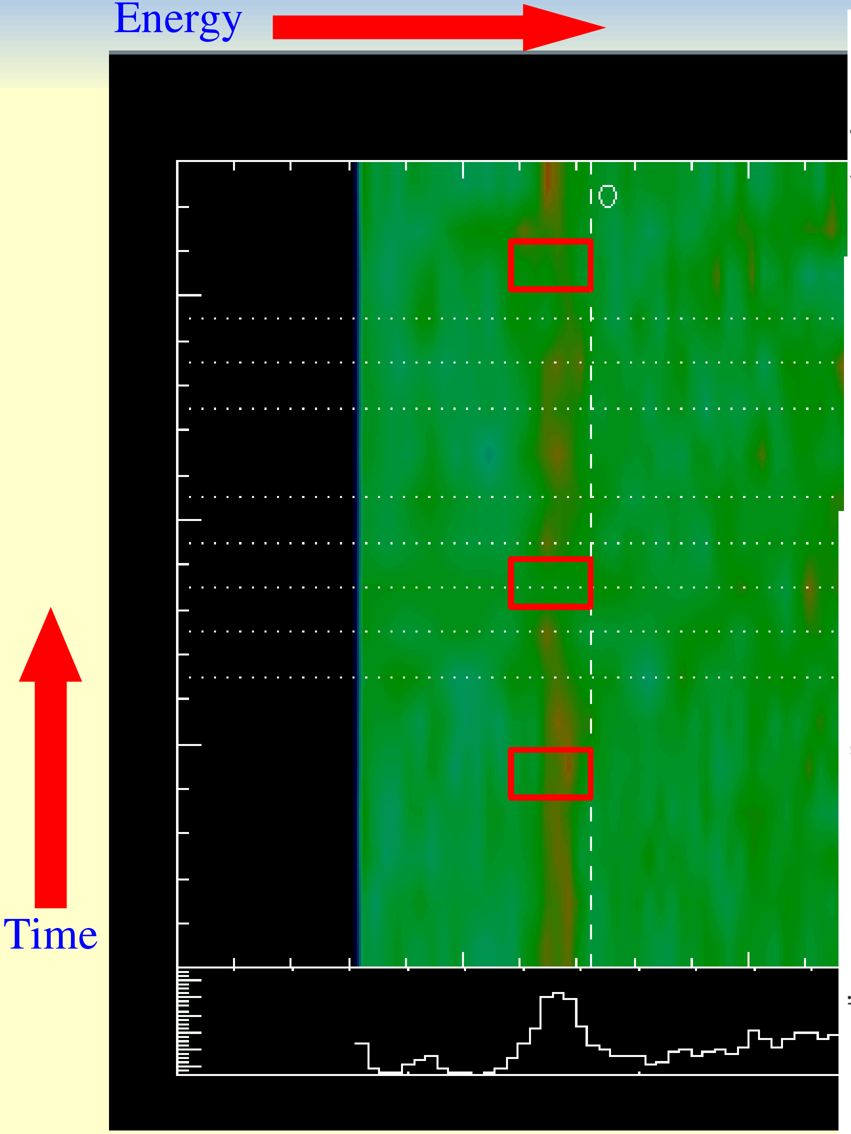
Response quality

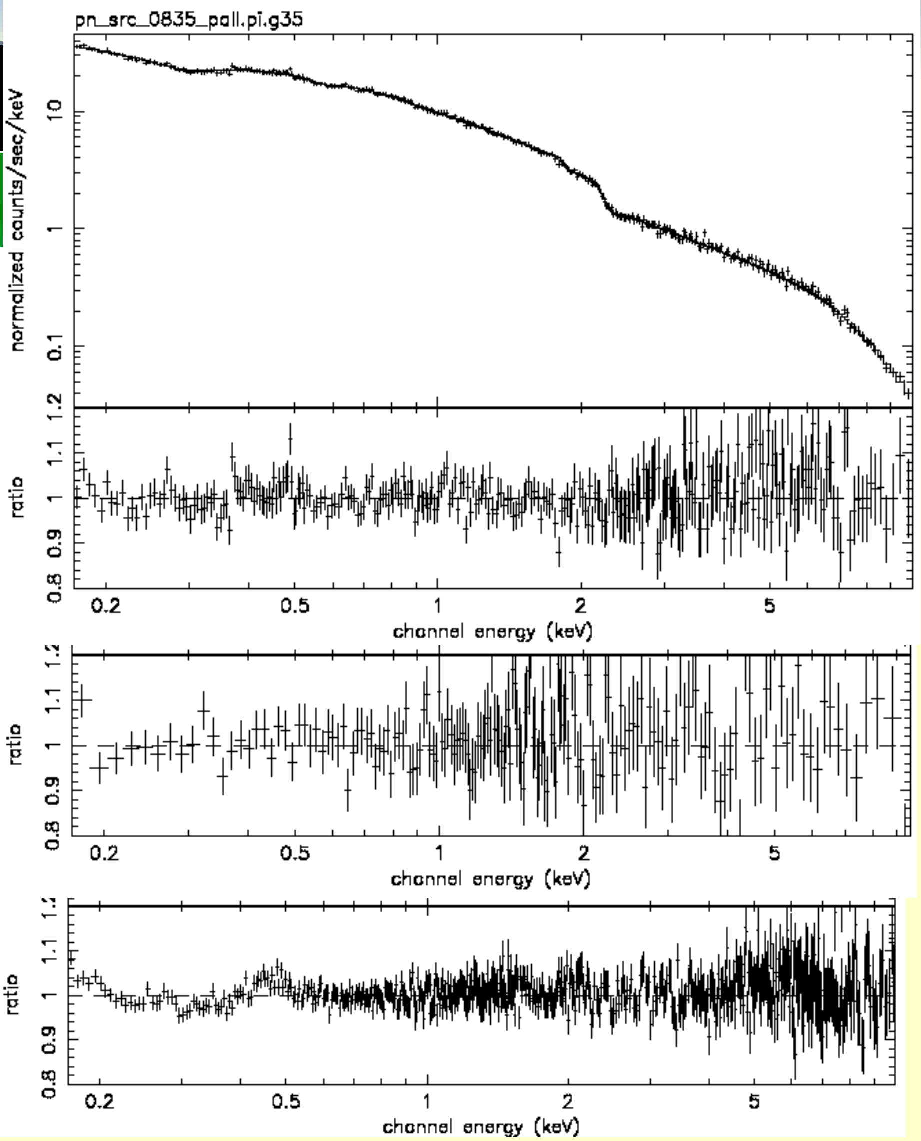


MOS2 ratio image

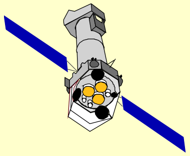








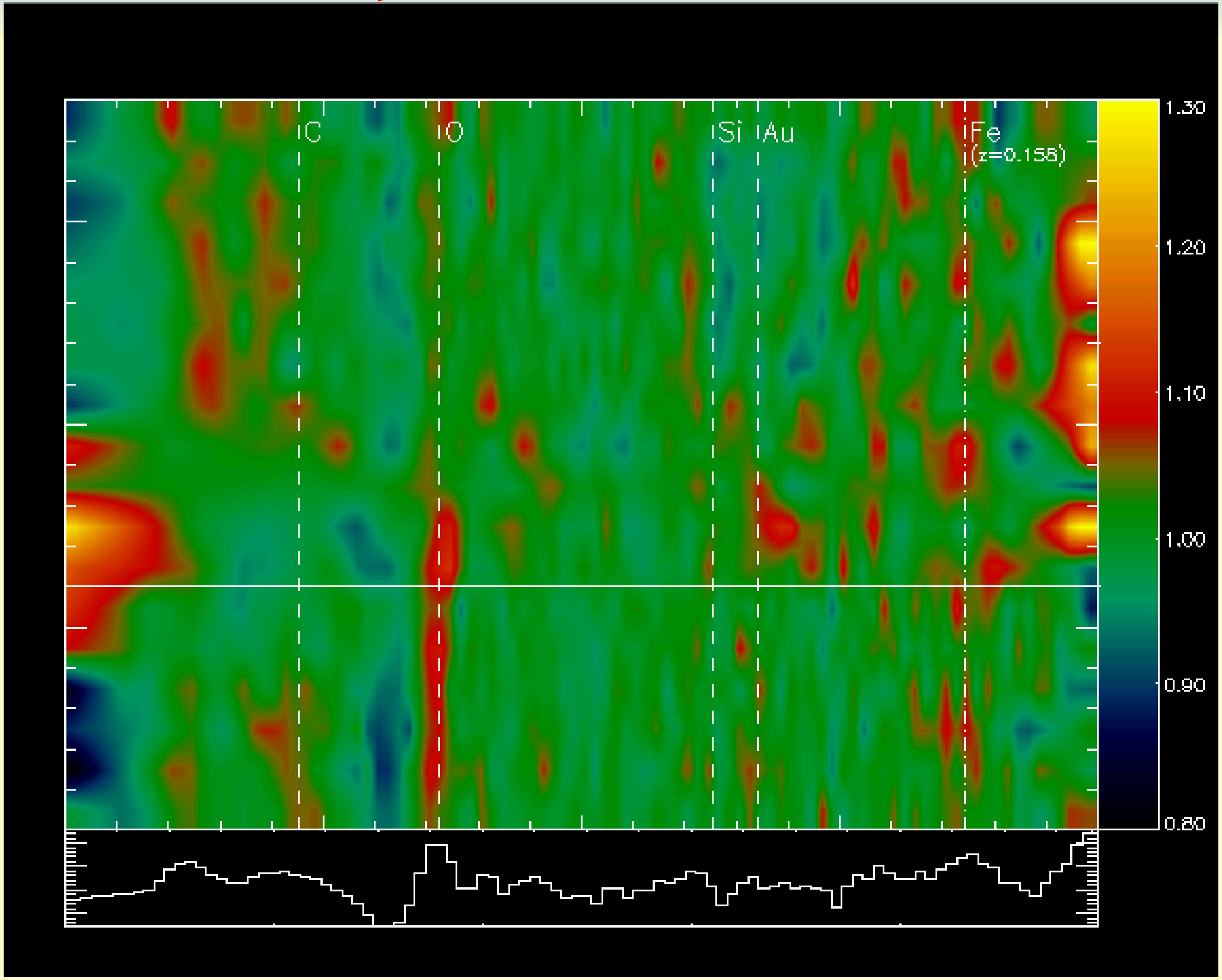
PN ratio image



MOS2 ratio image

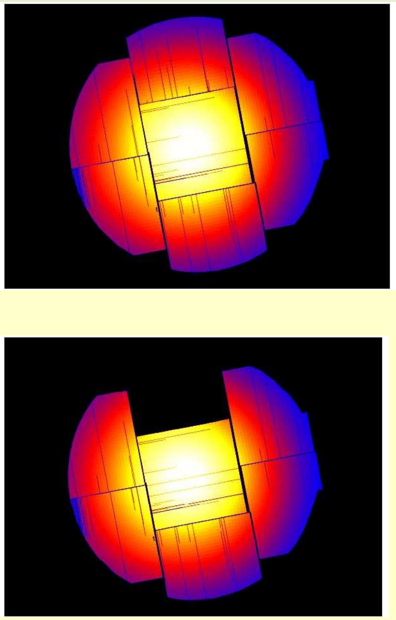
Energy

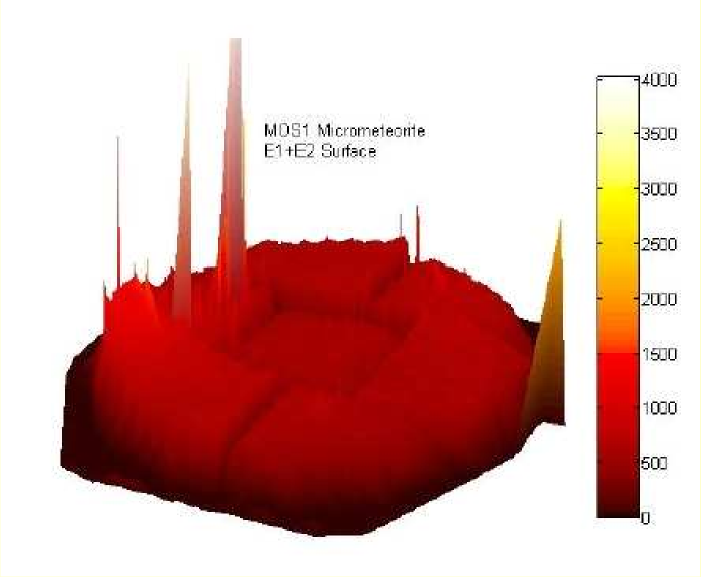
Time

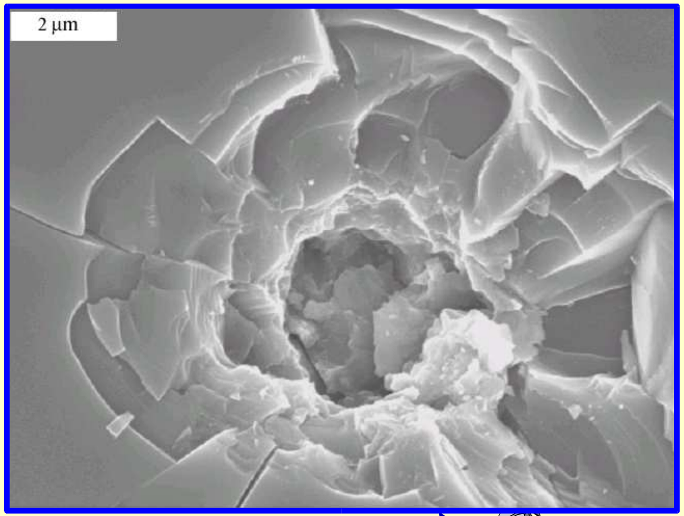


Micrometeoroids hits on XMM-Newton

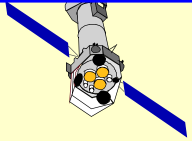
- **4 impacts so far in the mission**
- **Last one in rev 961 (March 05) caused the loss of MOS1 CCD6 and a new hot column passing very close to the MOS1 boresight.**
- **After a sudden optical flash, bright hot pixels appear**
- **Interpreted as a dust micrometeoroid scattered off the mirror surface under grazing incidence and reaching the focal plane detector.**
- **Typical size ~< 1 micron**
- **Interplanetary (or interstellar) dust but not linked to meteor shower (higher sizes/masses)**







top view of a crater in silicon caused by a particle scattered off the mirror surface under grazing incidence

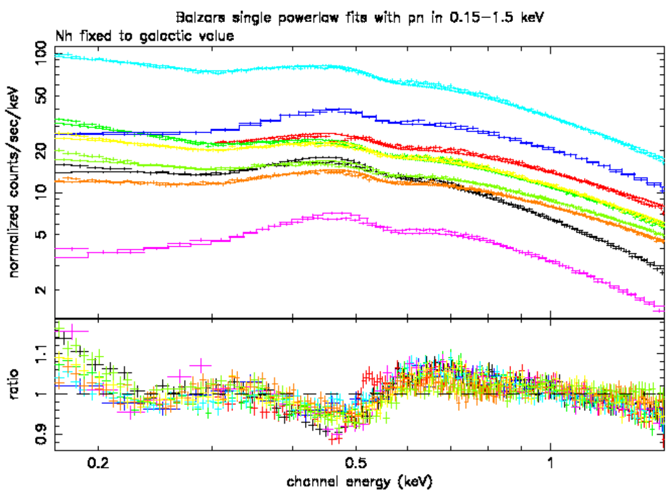


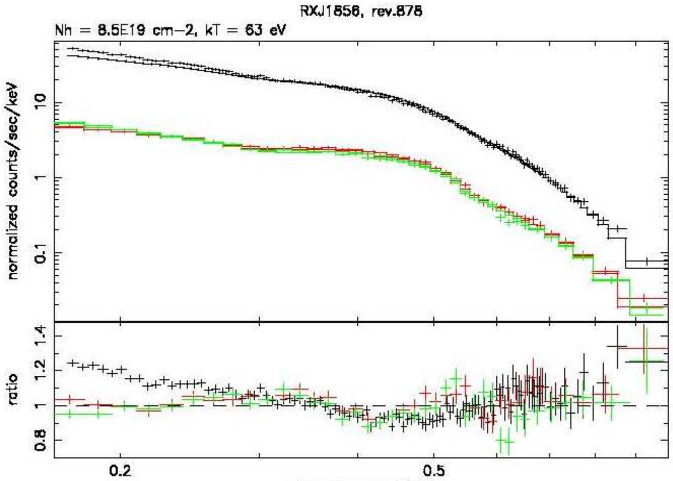
Implications for other Missions with Grazing Incidence Optics-1

- ASCA – in similar low earth orbit to Swift, but no reports of impact damage – was this due to use of thin foil mirrors of 137µm thickness? Perhaps incoming micrometeoroids are not deflected by such mirrors.
- Rosat – in similar low earth orbit to Swift but detectors probably insensitive to such damage
- on 27 May 2005 Swift XRT – only 6 months into the mission showed similar event
- Chandra 6 years in orbit - in similar deep elliptical orbit to XMM-Newton, but no reports of impact damage – geometry? – 5X smaller effective area – expect impact anytime now!

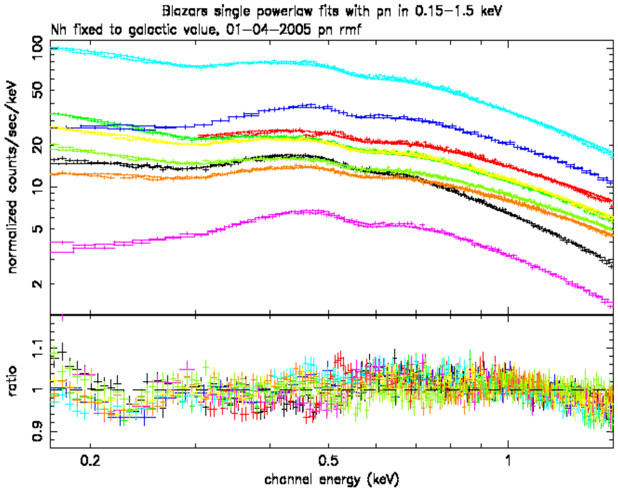
pn: redistribution

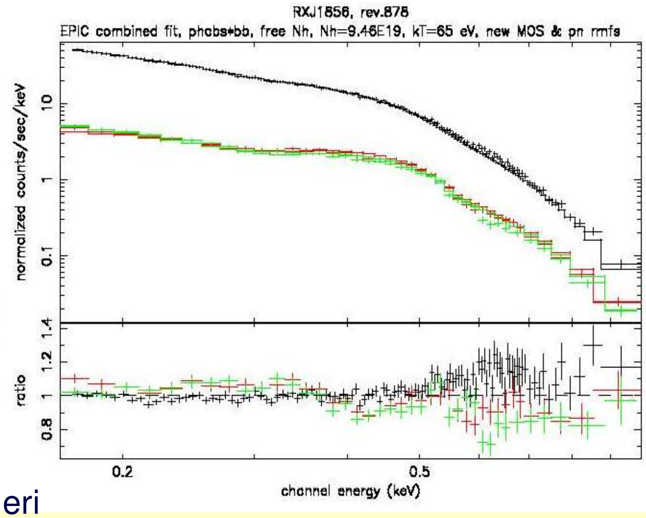
current





future



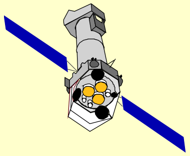


B.Altieri

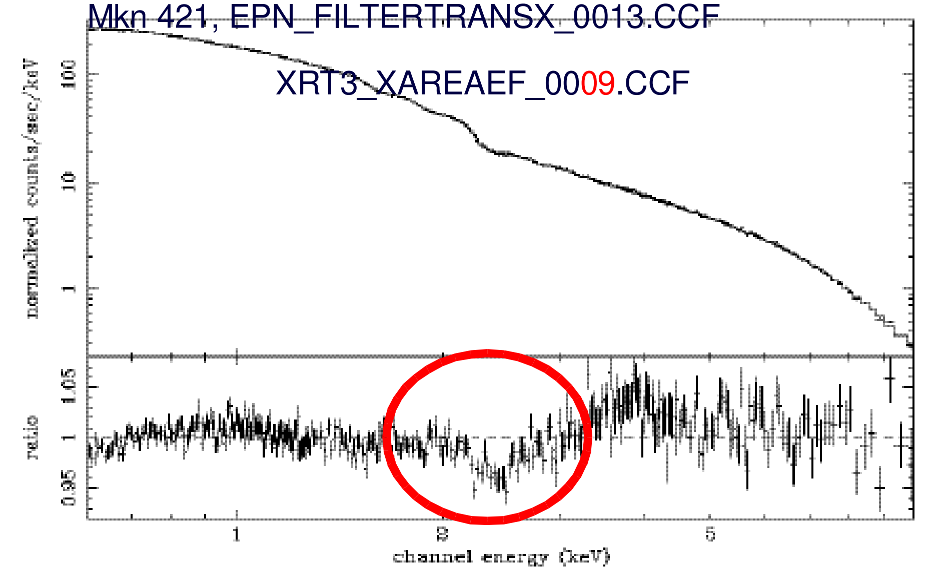
EPN_REDIST_0009.CCF
SAS 6.1

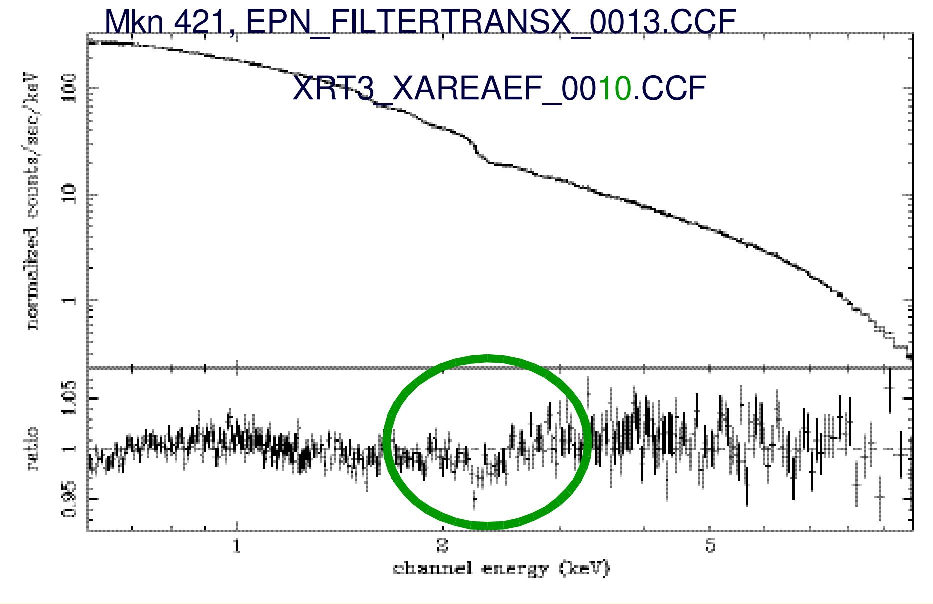
EPN_REDIST_0010.CCF

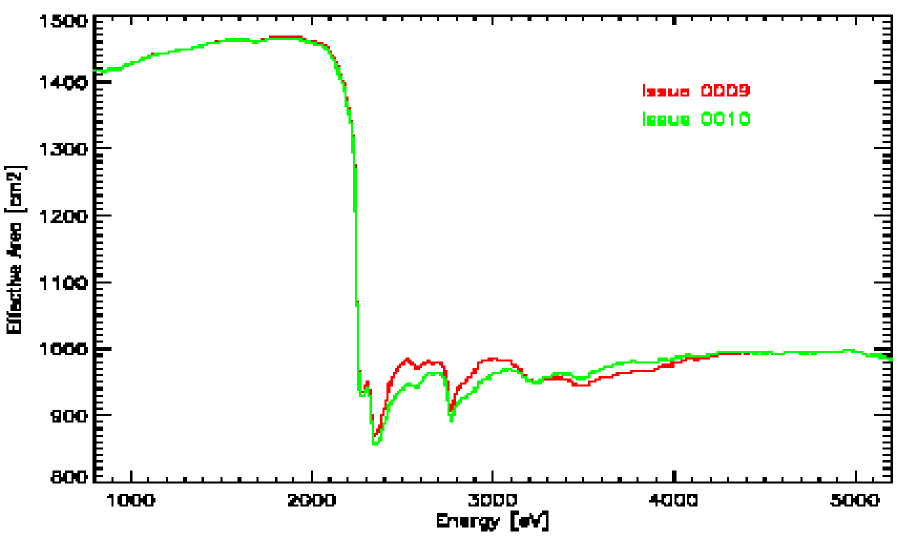
- SAS 6.1: pn redistribution back to ground cal. measurements
  ➔ agreement between pn and MOS at low energies improved
  ➔ analysis of Zeta Puppis showed good modelling of its spectral lines
- However for RX1856.5-3754 pn-spectrum showed soft excess with respect to MOS model below 0.4 keV
  ➔ column density derived from that pn spectrum was 7*10^{19} cm^{-2} lower than Chandra LEGTS
- Analysis of a set of Blazar spectra, which are expected to be fit well with single power-law models in 0.1-2 keV, showed a consistent set of residuals
- energy-dependent re-working of the RMF flattens these residuals.
- The new RMFs improve the fit to other continuum sources such as RX J1856.5-3754 and bring the pn and MOS into better agreement



pn: XRT effective area

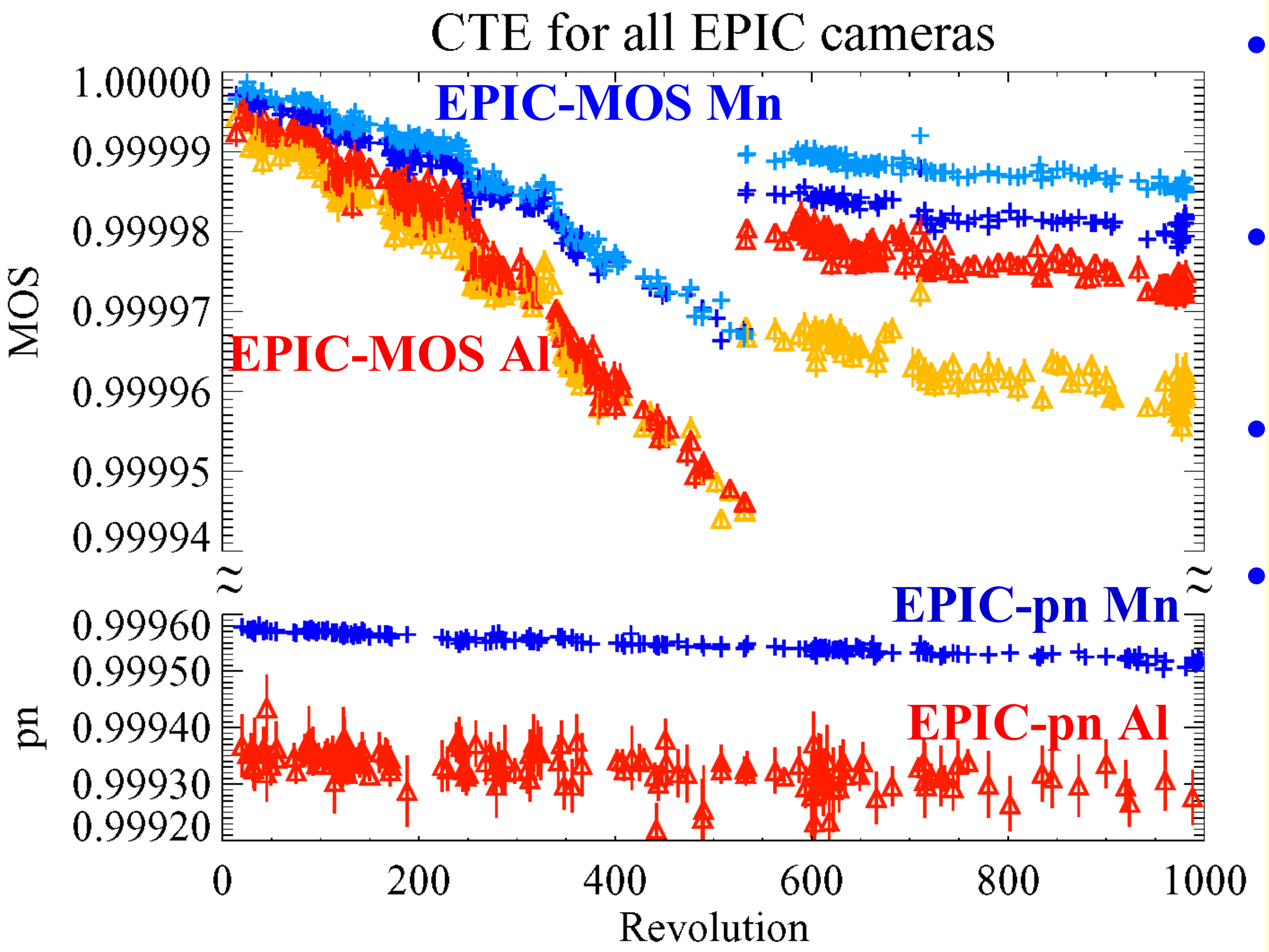




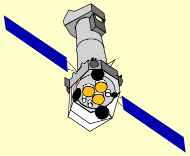


- Further improvement of modeling of the telescope effective area around Au edge
- NOTE: we are touching here the below 5 % calibration accuracy level
- public since 28.04.2005

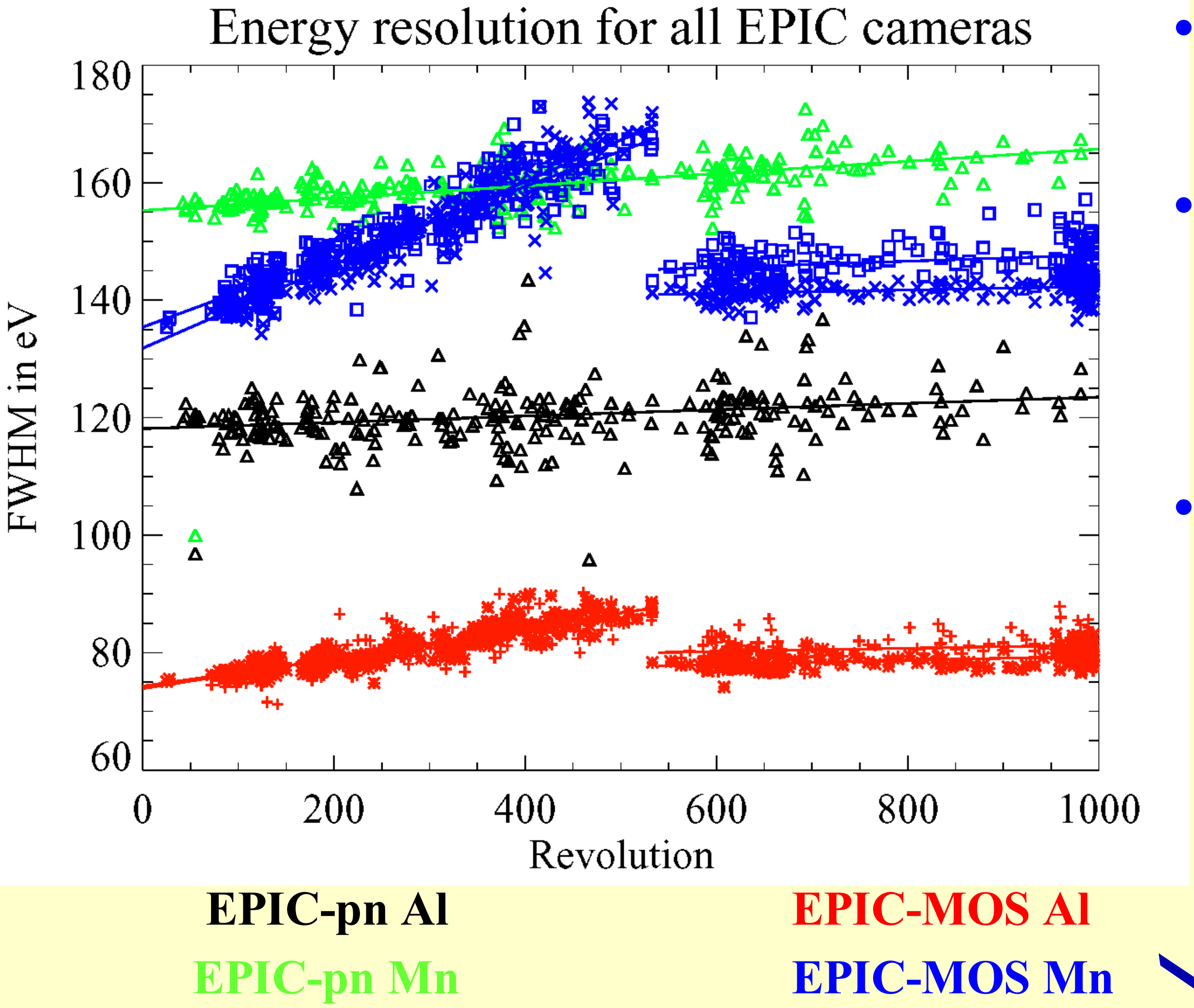
EPIC-Charge Transfer Efficiency



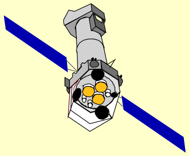
- EPIC-pn CTE degradation is slight and in agreement with pre-launch predictions
- no clear correlation between the EPIC-pn CTE degradation and proton flares
- Solar flares created a series of jumps in the EPIC-MOS cameras CTE
- EPIC-pn CTE is degrading independently of the solar flares with a nearly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



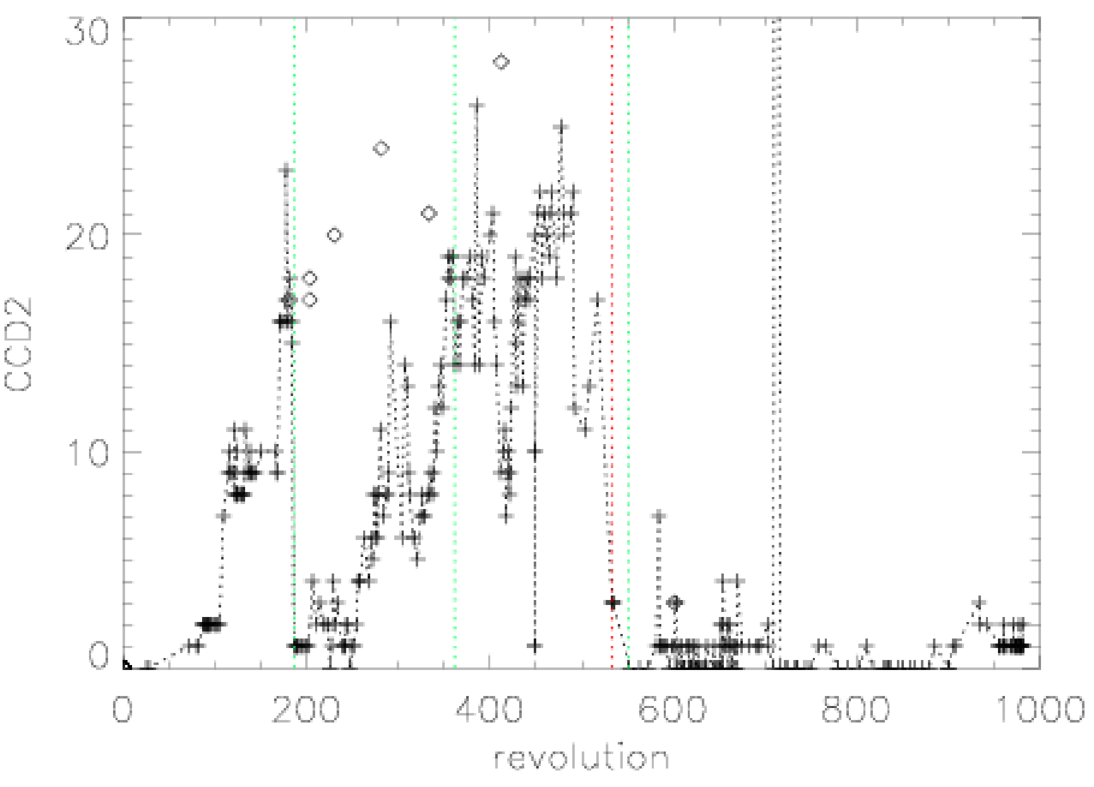
EPIC-Energy resolution



- EPIC-MOS energy resolution at low energies is much better than the EPIC-pn
- at high energies EPIC-MOS energy resolution was degrading up to the cooling of the EPIC-MOS cameras up to the same level as the EPIC-pn
- after cooling the EPIC-MOS cameras have again a better energy resolution also for high energies.



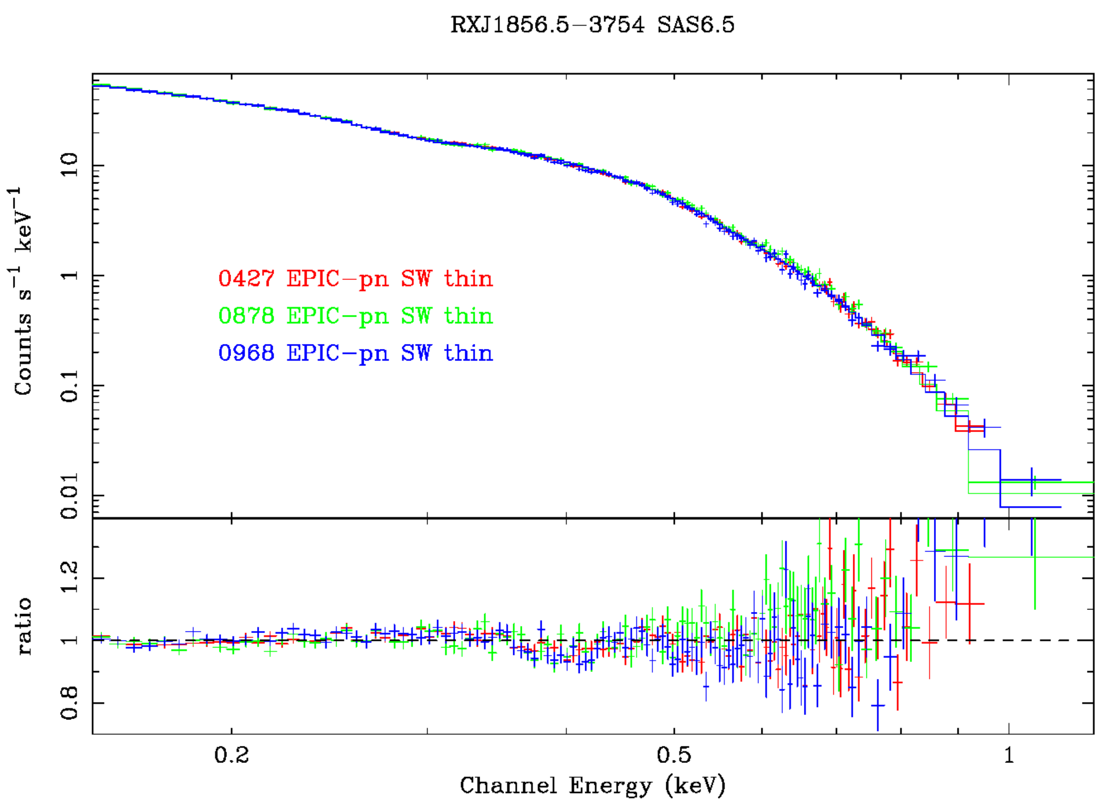
Bad Pixel



MOS

- As "bad/hot pixel" we consider pixels within a CCD exhibiting abnormal behaviour which make them useless for scientific evaluation due to its tendency to mimic a signal (hot) or giving no signal (bad).
- For the EPIC-MOS cameras the number of hot pixels increased over the mission time due to meteoroid events and aging due to hard particles.
- after the cooling in rev 533 most of the hot pixels have disappeared and the onboard bad pixel table could have been relaxed to a few pixels per CCD.
- For the EPIC-pn camera a small number of hot pixels, i.e. pixels with high dark current generation, were present in the CCDs at launch
- Damage resulting from a suspected micrometeoroid impact in revolution 156 caused the sudden appearance of 35 additional hot pixels

Contamination monitoring-EPIC

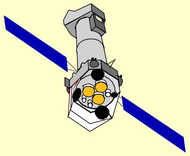


- isolated neutron star RXJ1856-3754 is used as a target to monitor contamination on the EPIC cameras
- very soft spectrum → well suited to measure possible contamination, which would affect the low energy regime most strongly
- observations can be used to derive upper limits for an additional contamination between Revolutions 427 und 968 for carbon and oxygen
- SNRs N132D and 1ES0102 are used to measure contamination and stability of the energy calibration of the EPIC cameras.
- This analysis showed that the EPIC-MOS cameras have changed in their redistribution characteristics but not in a way consistent with contamination.

CAMERA	CARBON	OXYGEN
EPIC-pn	$< 2.7 \cdot 10^{-7}$gcm^{-2}	$< 2.5 \cdot 10^{-6}$gcm^{-2}
EPIC-MOS	$< 7.2 \cdot 10^{-7}$gcm^{-2}	$< 1.3 \cdot 10^{-5}$gcm^{-2}

cross cal examples

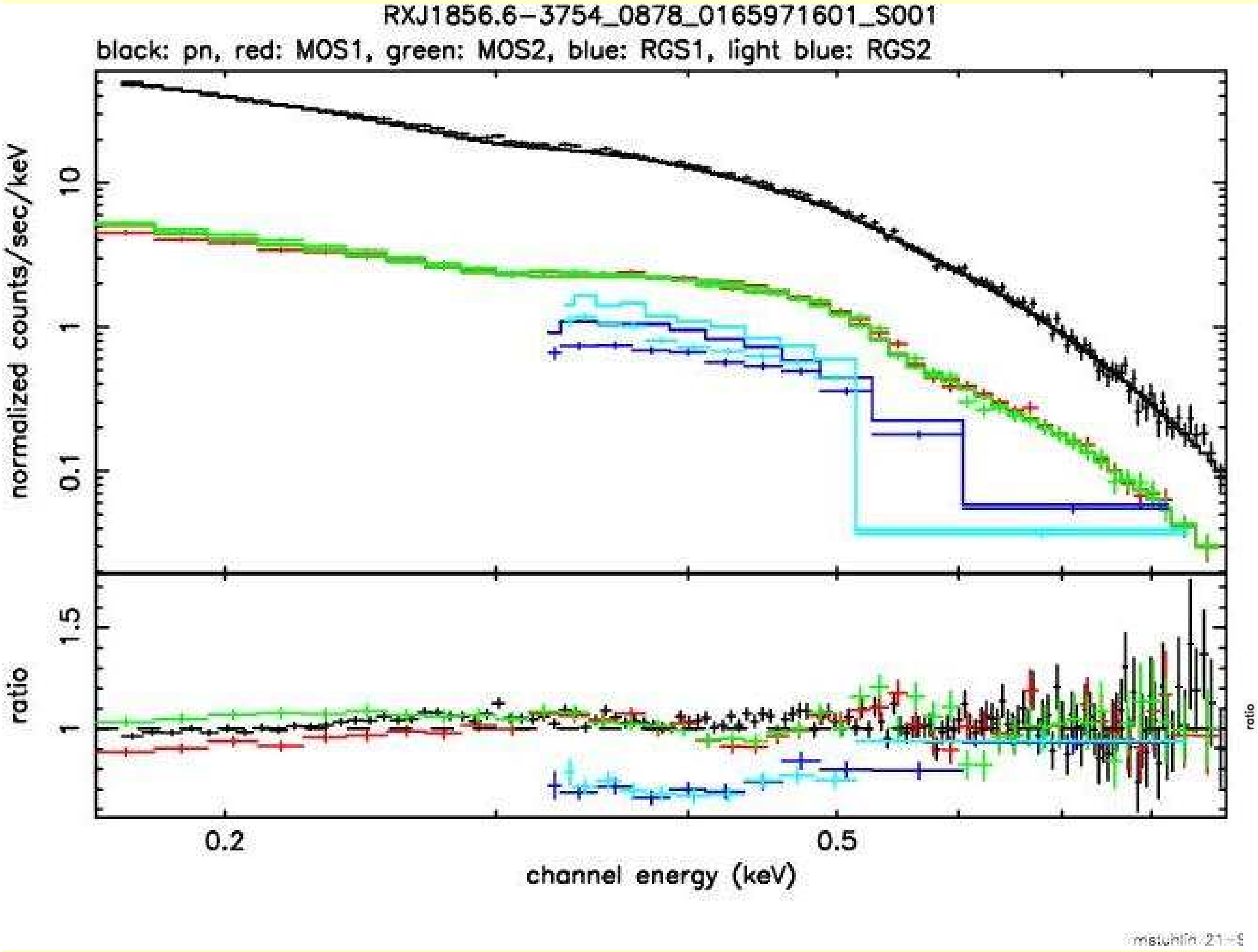
- EPIC
- EPIC-RGS
- XMM-Newton Chandra
- XMM-Newton and the others



RXJ1856-3754

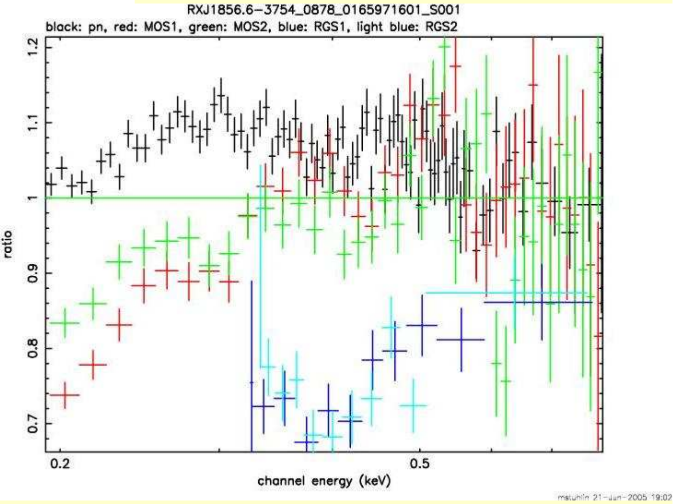
EPIC

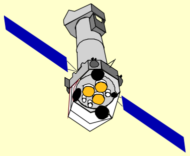
SASv6.5



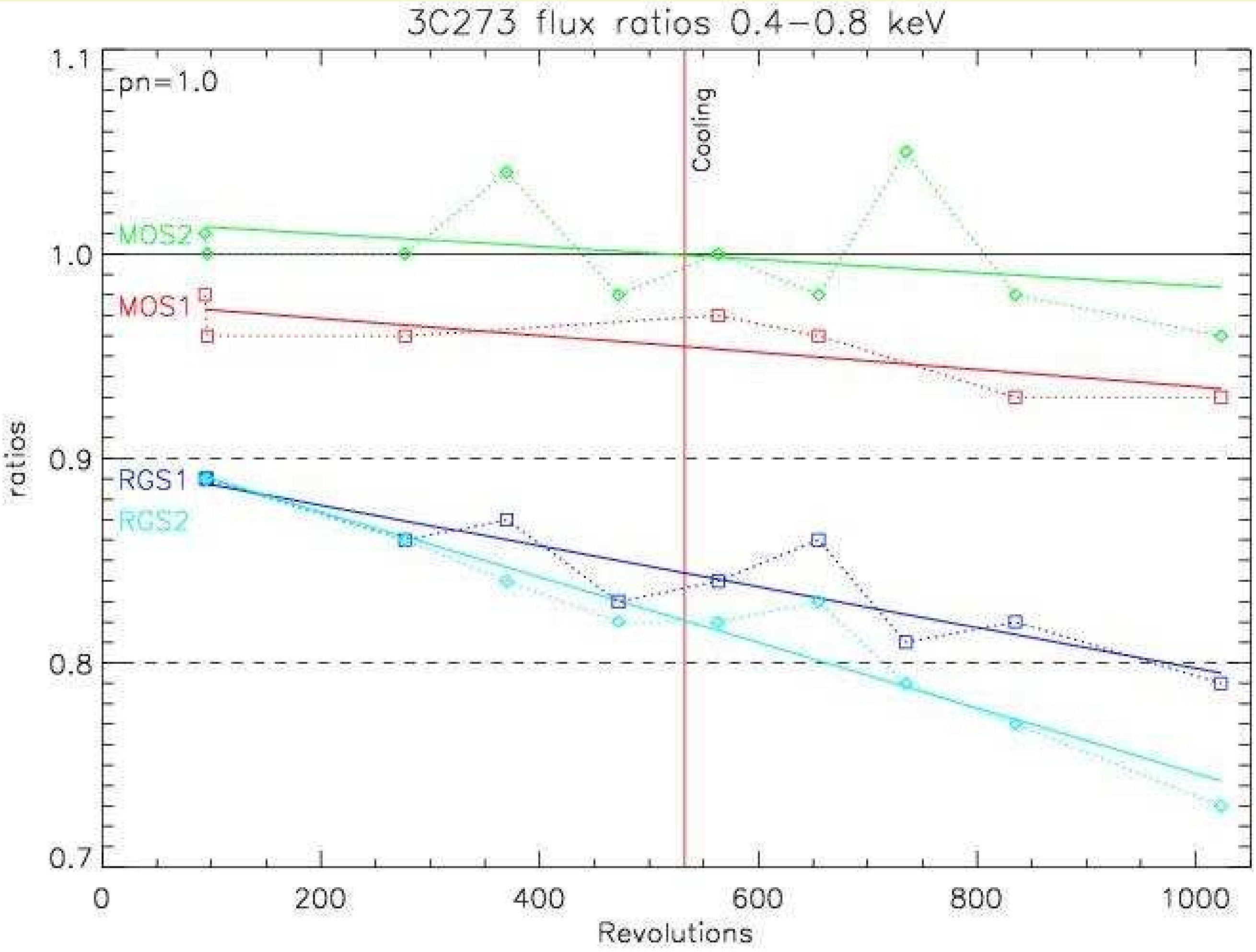
- Rev. 0878
- Thin filter, SW
- Great improve-ments in consistency with SASv6.5

SASv6.1



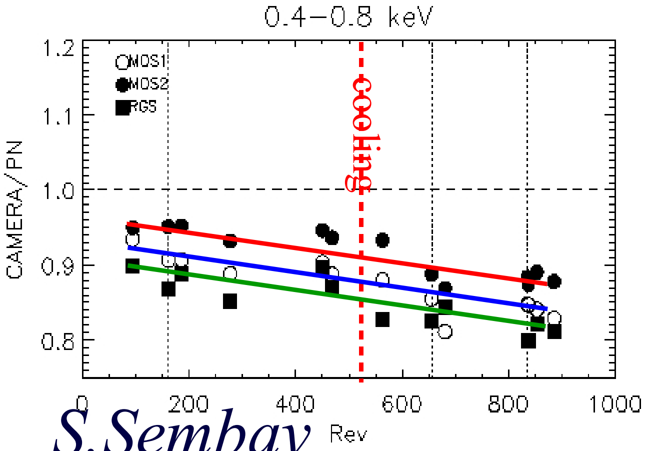


3C273: Low-energy flux ratios



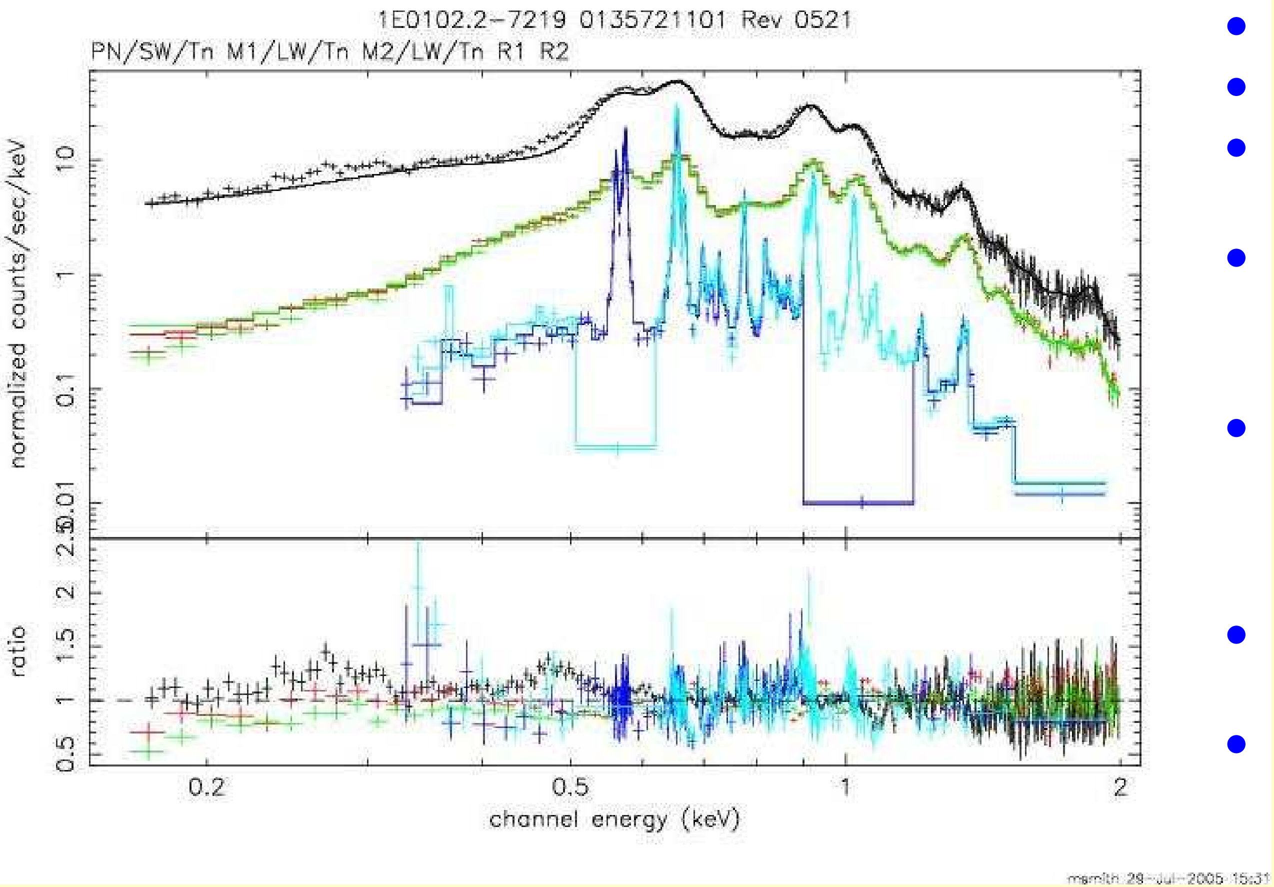
- 0.4-0.8 KeV
- MOS to pn ratios decrease by less than 5%
- RGS ratios decrease by 10-15%
- Possible different changes for RGS1 and RGS2?

SASv6.1



S.Sembay

1ES0102-7219

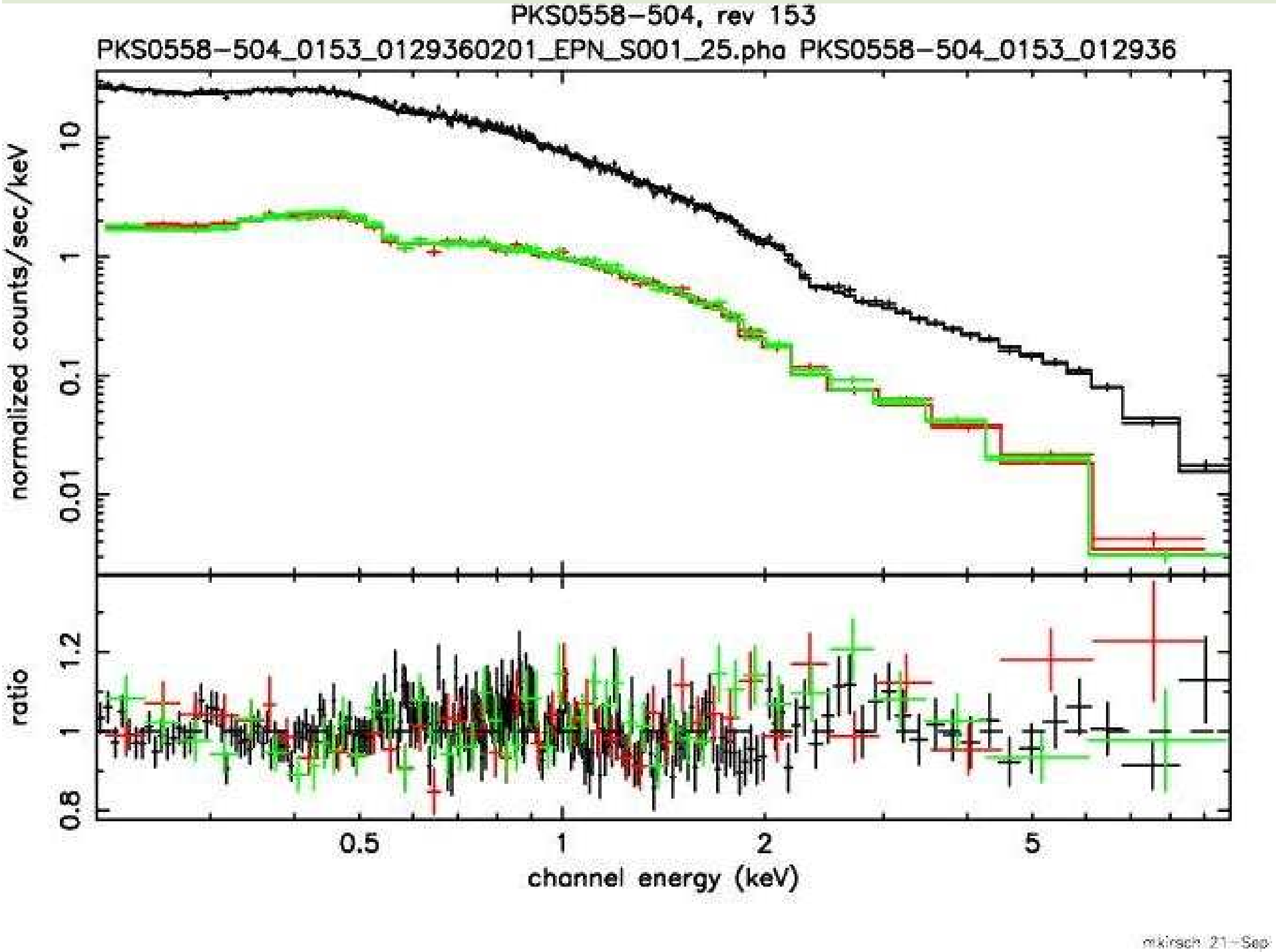


M. Smith

- Rev. 0521
- Thin filter
- PN SW, MOS LW
- 40 lines plus absorbed bremsstrahlung
- Line energies fixed to laboratory values

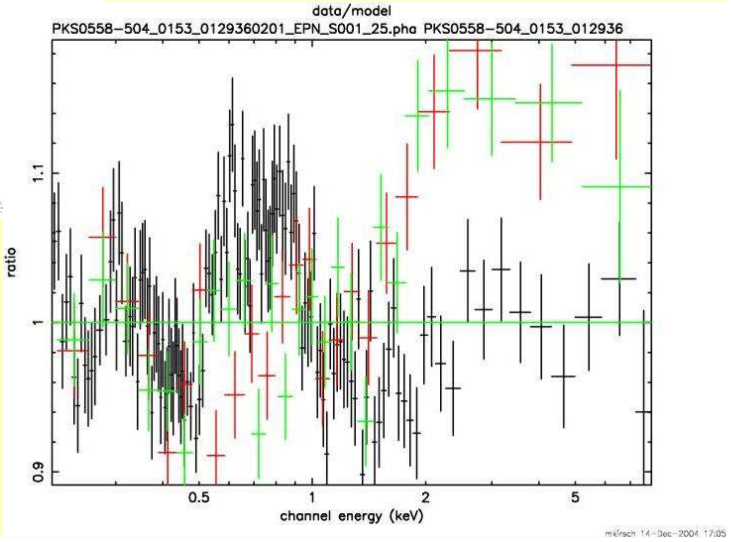
- pn response under-estimates redistribution, most evident at O-lines
- Above 0.6 keV the agreement is good
- Background subtraction is problematic for pn SW mode

PKS0558-504


PKS0558–504, rev 153
PKS0558–504_0153_0129360201_EPN_S001_25.pha PKS0558–504_0153_012936

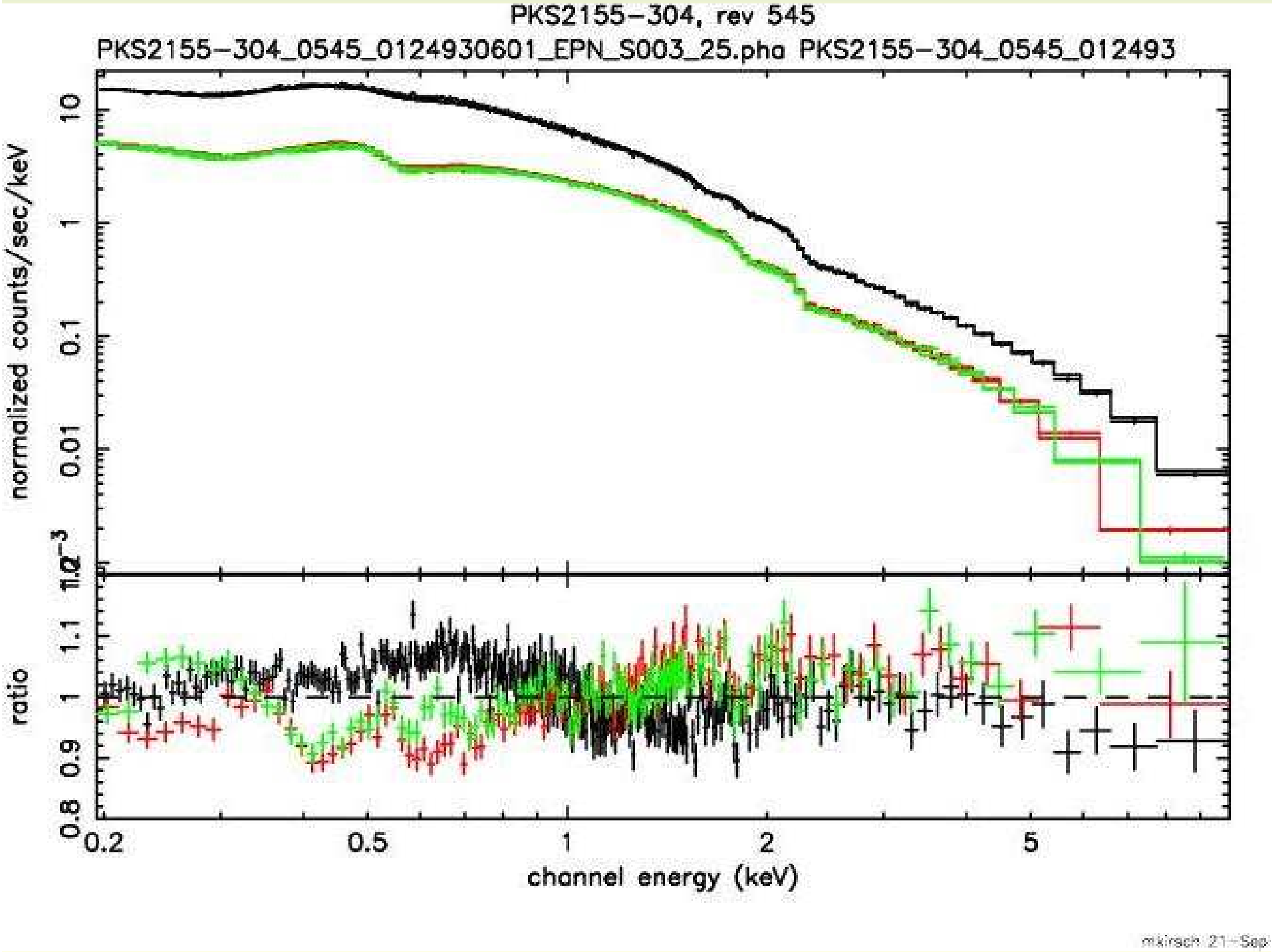
- Rev. 0153
- Thin filter
- PN SW, MOS LW
- Early epoch, before MOS "patch"
- Excellent agreement between all EPIC instruments

SASv6.1


data/model
PKS0558–504_0153_0129360201_EPN_S001_25.pha PKS0558–504_0153_012936

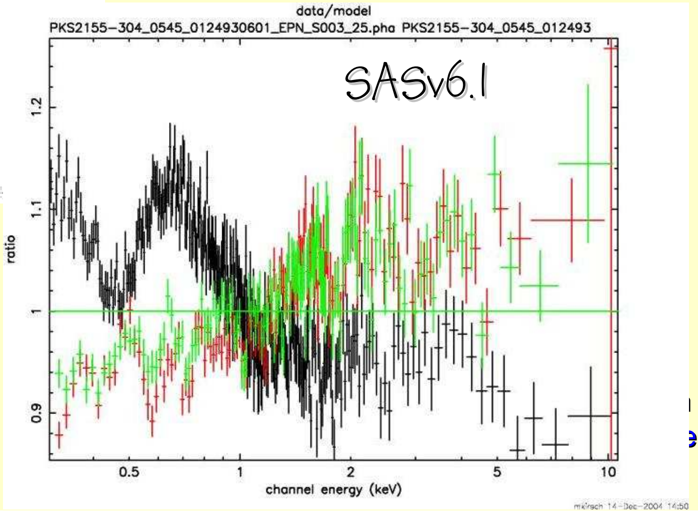
M. Kirsch

PKS2155-304



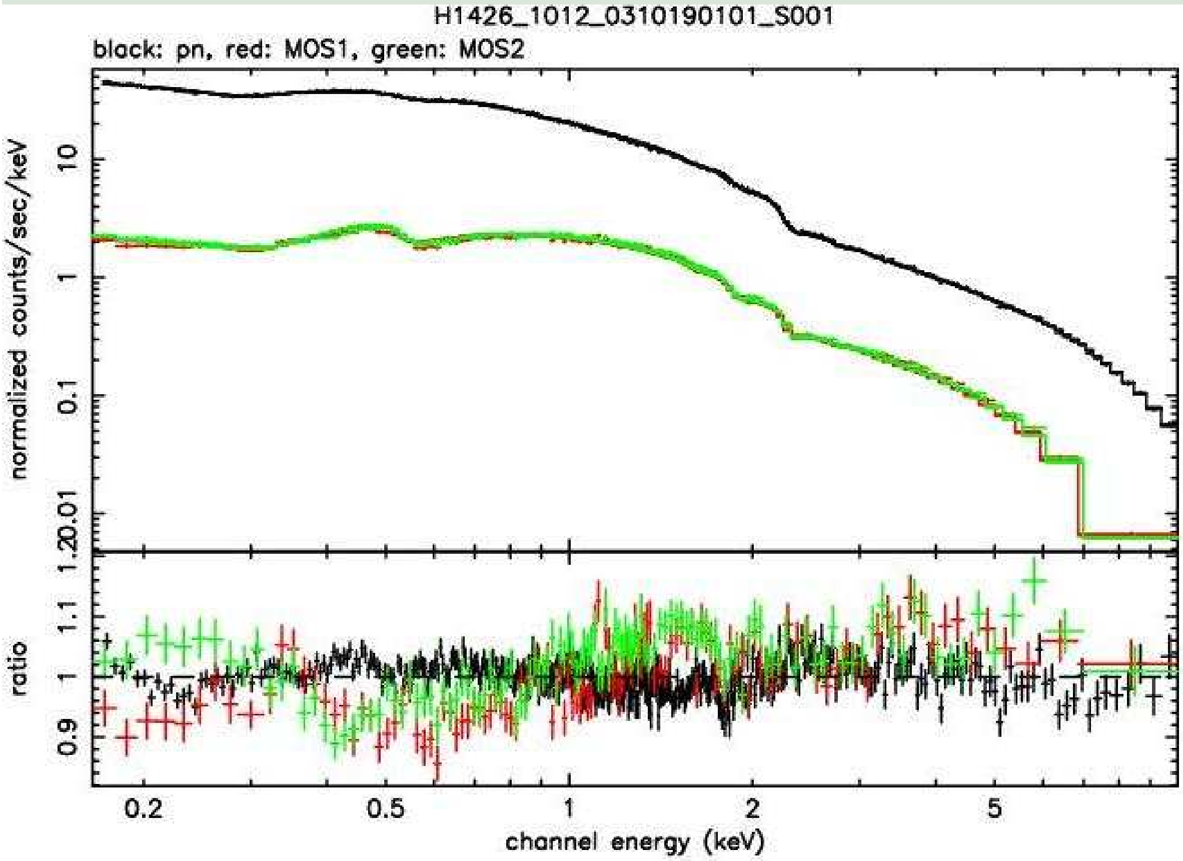
- Rev. 0545, med., SW
- MOS "patch" present
- Good agreement at lowest and medium energies
- MOSes lower by ~15% between 0.4-0.8 keV
- pn lower above 5 keV

M. Kirsch

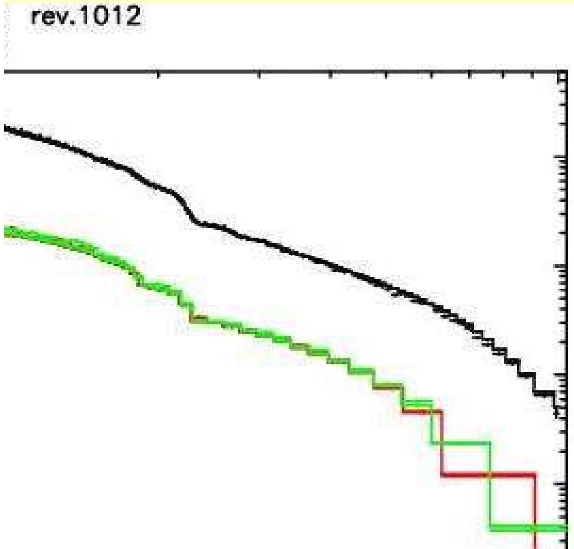


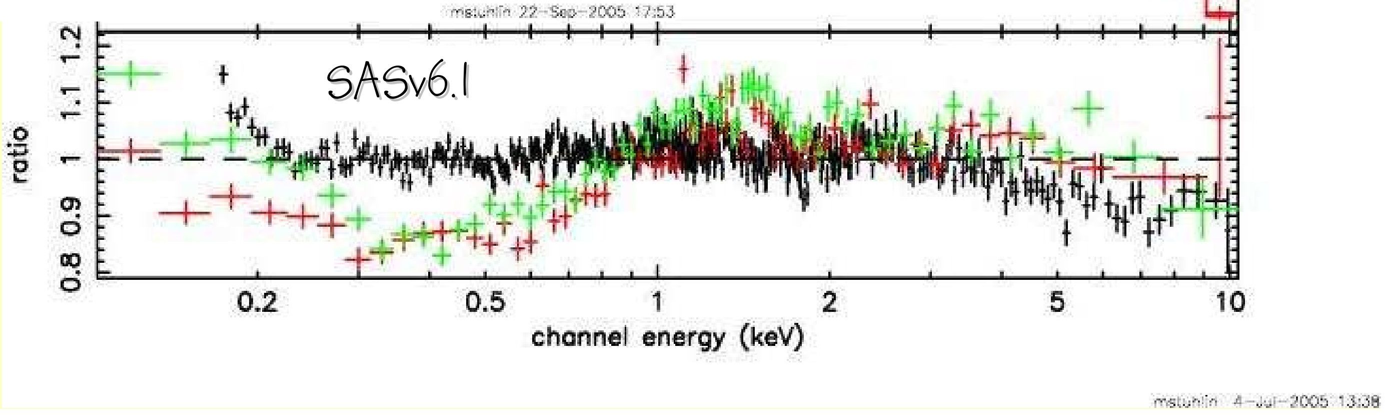
H1426+428

- Rev. 1012
- Medium filter, SW
- Discrepancies reduced by ~10%

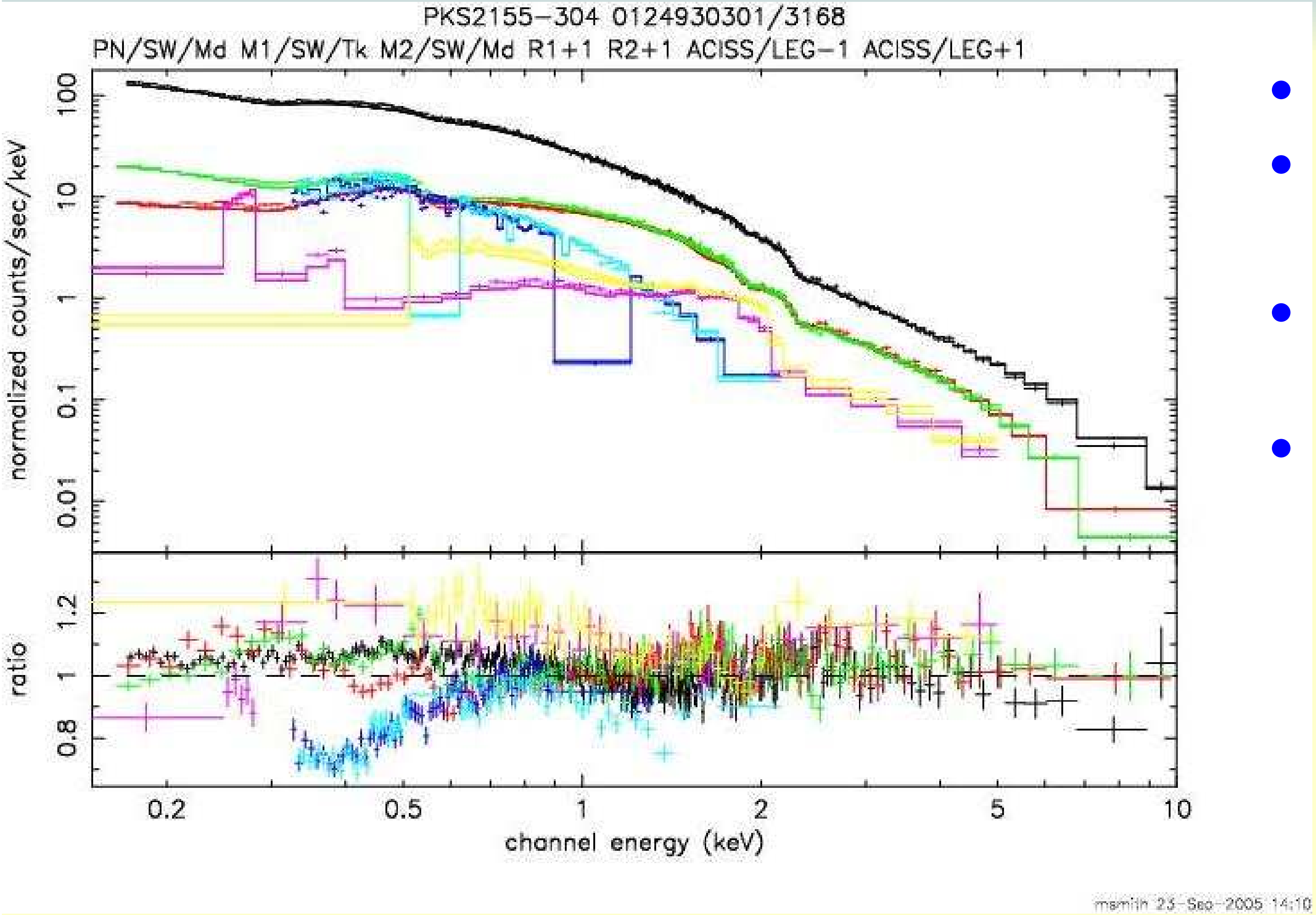

H1426_1012_0310190101_S001

black: pn, red: MOS1, green: MOS2


rev.1012


SASv6.1

XMM-Newton versus Chandra LETG

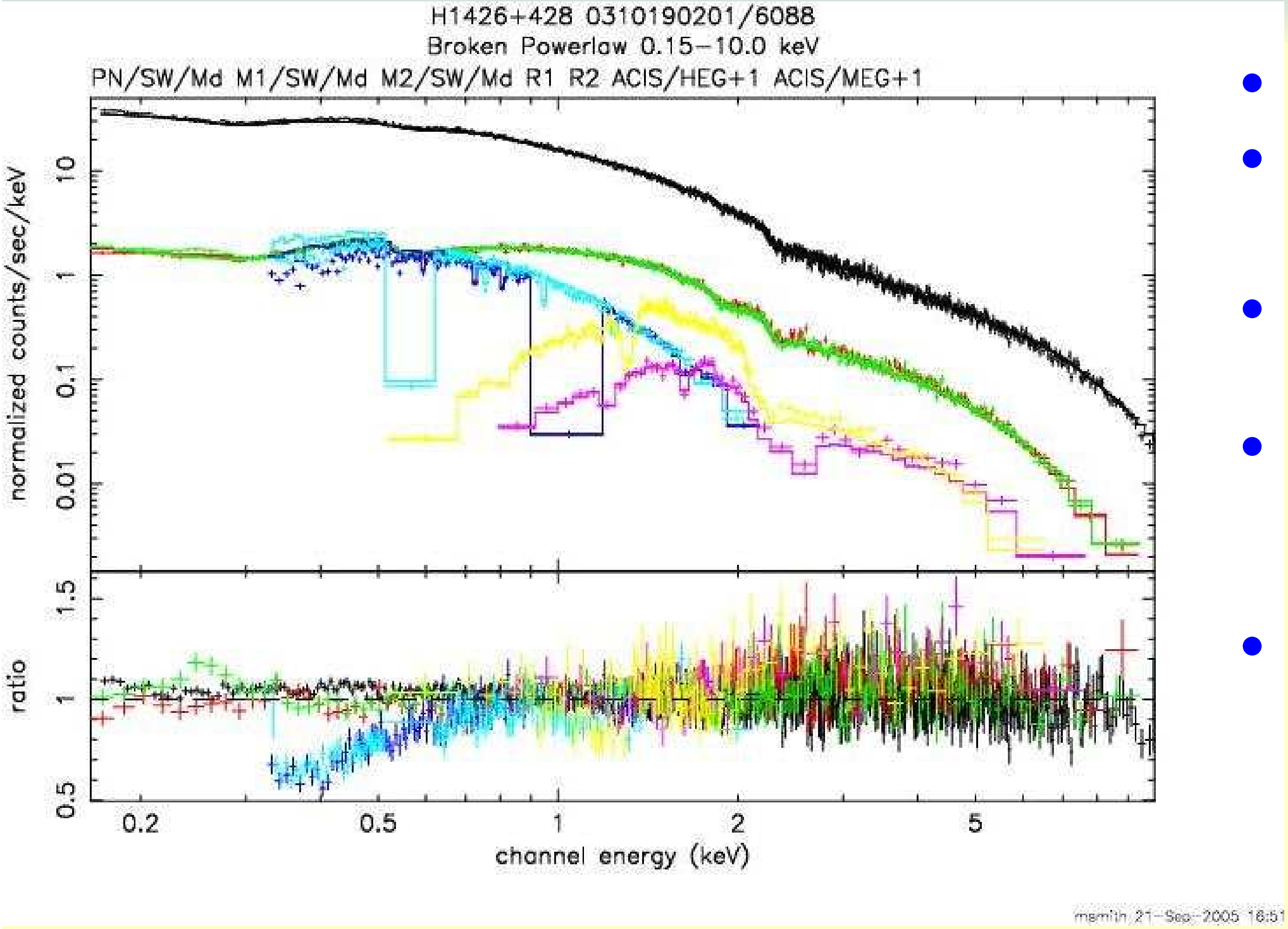


M. Smith

- PKS2155-304
- XMM rev. 0362

- Good agreement above 1 keV
- ACIS/LETG has higher normalisation than the EPICs below 1 keV

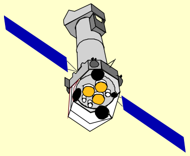
XMM-Newton versus Chandra HETG



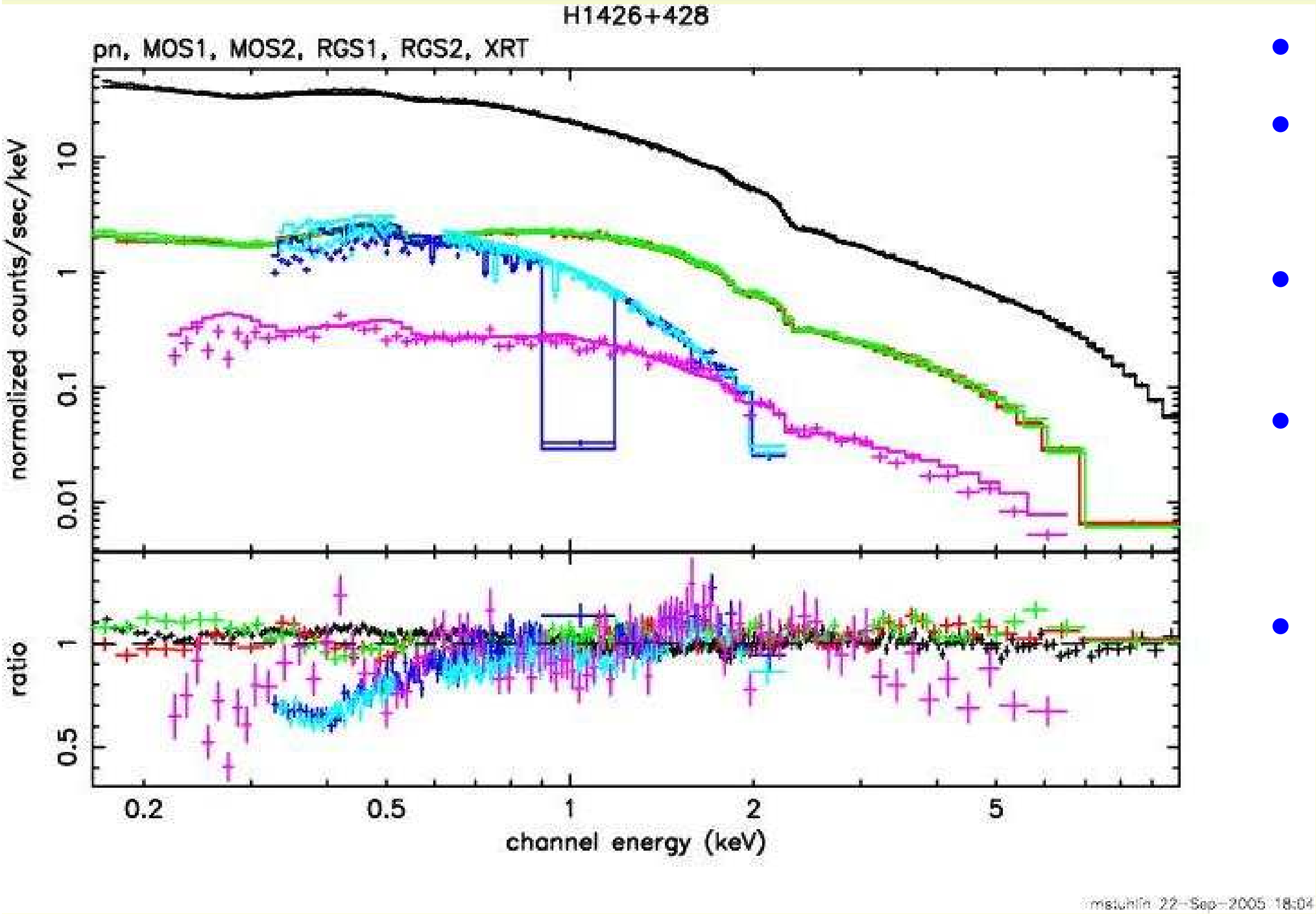
M. Smith

- H1426+428
- XMM rev. 1015

- Very good agreement below 2 keV
- Above 2 keV, ACIS/ HEG shows a flatter slope than the EPICs
- Above 2 keV, MOS is closer to ACIS/ MEG than pn



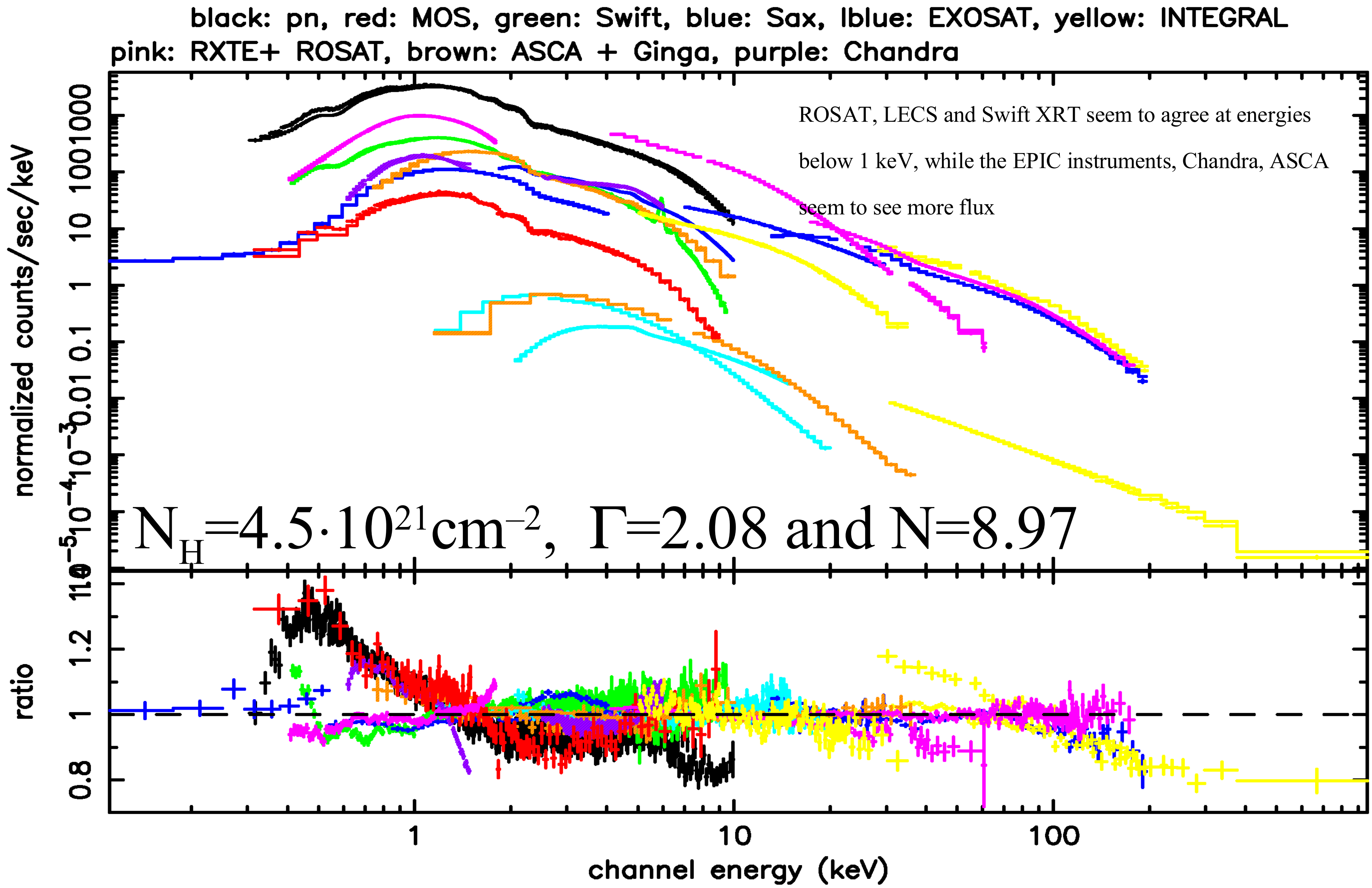
XMM-Newton versus Swift XRT



- H1426+428
- XMM rev. 1012
- Good agreement between ~0.6 keV and ~3.0 keV
- XRT measures steeper slope at high energies than the EPICs
- Large discrepancies below ~0.6 keV

The Crab- Joint fit

EPIC



black: pn, red: MOS, green: Swift, blue: Sax, lblue: EXOSAT, yellow: INTEGRAL
pink: RXTE+ ROSAT, brown: ASCA + Ginga, purple: Chandra

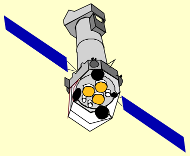
ROSAT, LECS and Swift XRT seem to agree at energies below 1 keV, while the EPIC instruments, Chandra, ASCA seem to see more flux

$N_H=4.5\cdot10^{21}\mathrm{cm}^{-2}$, $\Gamma=2.08$ and $N=8.97$

Conclusions

- Health and Cleanliness of EPIC
  - Cameras are in good shape (despite of the lost CCD ☹)
  - MOS-CTE degradation slowed down after cooling and less sensitive to solar flares
  - EPIC-pn seems to be rock solid
  - no contamination

- Calibration:
  - New low-energy time- and spatial-dependent MOS redistribution and optimized pn redistribution and effective area in SASv6.5 improves drastically EPIC cross calibration
  - High energy slopes still different for MOS and pn (MOS gives usually more flux for high energies)
  - Still room for fine-tuning of both MOS and pn responses
  - RGS :
    - Low-energy flux difference ~10% at launch
    - Sensitivity at the longest wavelengths has decreased by ~10-20% over the mission
  - Status in SASv6.5: EPIC and RGS are not yet consistent below ~0.7 keV (but improvements ongoing at RGS team)



The need for X-ray standards

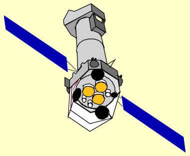
- As much need in the X-ray domain for a set of objects to serve as photometric or spectrometric standards as at longer wavelengths

- The X-ray equivalents are much harder to define, not least because variability is a very common property of X-ray sources.

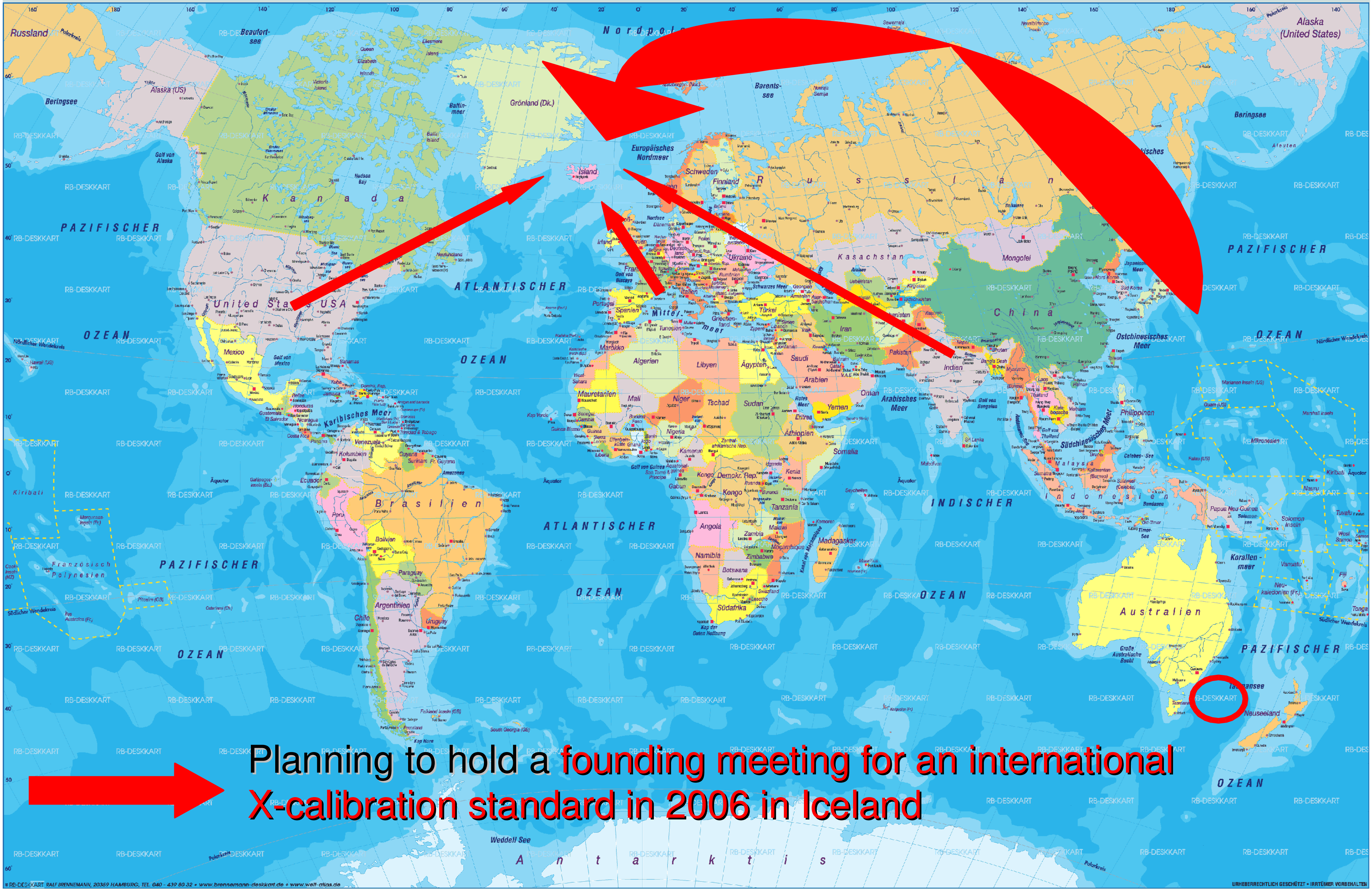
- Crab nebula has served as a reference which in common with other fainter SNRs is confidently expected to be constant, but may be to bright for future missions

- XMM-Newton has repeatedly observed a small set of objects that have been judged to serve as X-ray standards with the intention of both monitoring the evolution of instrument performance and providing straightforward comparisons with other instruments.

- strong need for a set of standard calibration sources for the X-ray regime → luxury situation of having 6 satellites (XMM-Newton, Chandra, RXTE, Swift, Integral, Astro-E2) in orbit that are having X-ray instruments as their payload for the coming years we strongly recommend to found an international calibration group that may steer the cross calibration efforts



The need for X-ray standards


Russland
Alaska (United States)
Grönland (Dk.)
Island
K a n a d a
United States USA
Mexico
Brasilien
Argentinien
Chile
Peru
Bolivien
R u s s l a n d
Kasachstan
Mongolei
C h i n a
Indien
Indonesien
Australien
Neuseeland
Algerien
Libyen
Ägypten
Sudan
Tschad
Niger
Mali
Mauretanien
Nigeria
Äthiopien
Somalia
Kongo Demokr. Rep.
Angola
Namibia
Südafrika
Madagaskar
Tansania
Saudi Arabien
Iran
Türkei
Ukraine
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PAZIFISCHER OZEAN
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Planning to hold a founding meeting for an international X-calibration standard in 2006 in Iceland