XMM-Newton Calibration

Michael Smith, on behalf of XMM-SOC and Instrument Teams

18th XMM-Newton Users' Group Meeting, ESAC, 11 May 2017

Outline

1. Status of calibration related to the Users' Group resolutions and recommendations
2. Calibration monitoring and improvements over the last 12 months
3. Additional future calibration activities

2016 UG Recommendations

Recommendation 2016-06-08/01:

- As result of some recent investigations, there is now a requirement to implement an iterative adjustment to the parameters for the 2-D PSF. […] This activity needs to be considered as of the highest priority because of its impact on many other aspects of the calibration.

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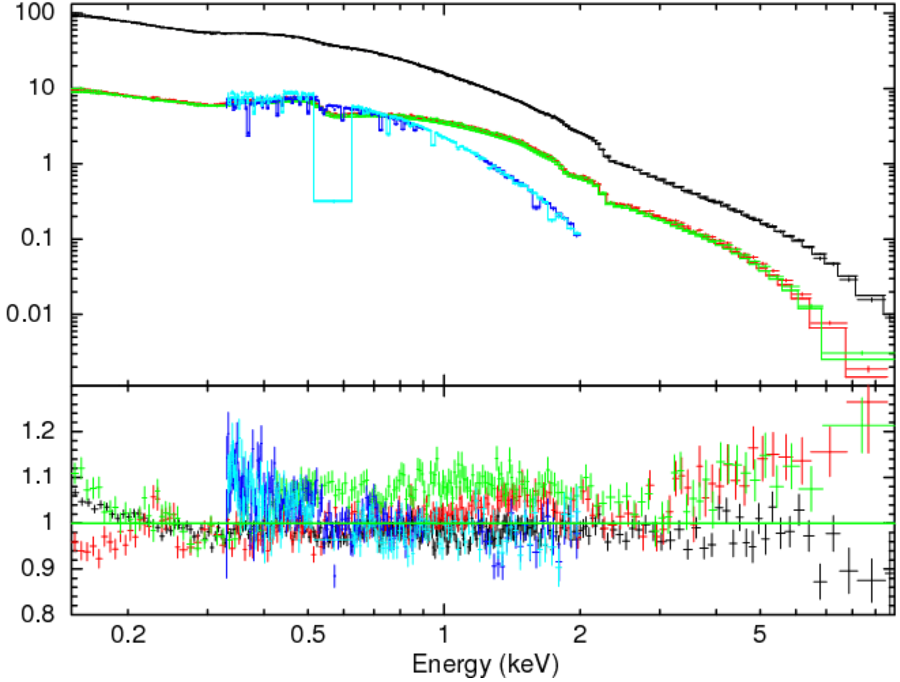
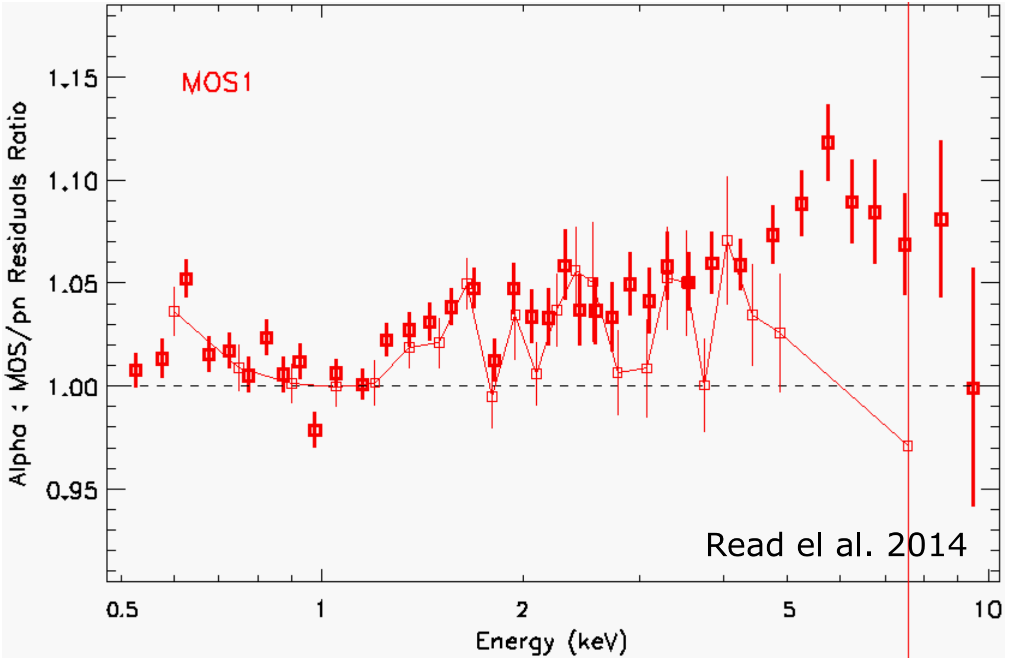
EPIC: PSF Investigations

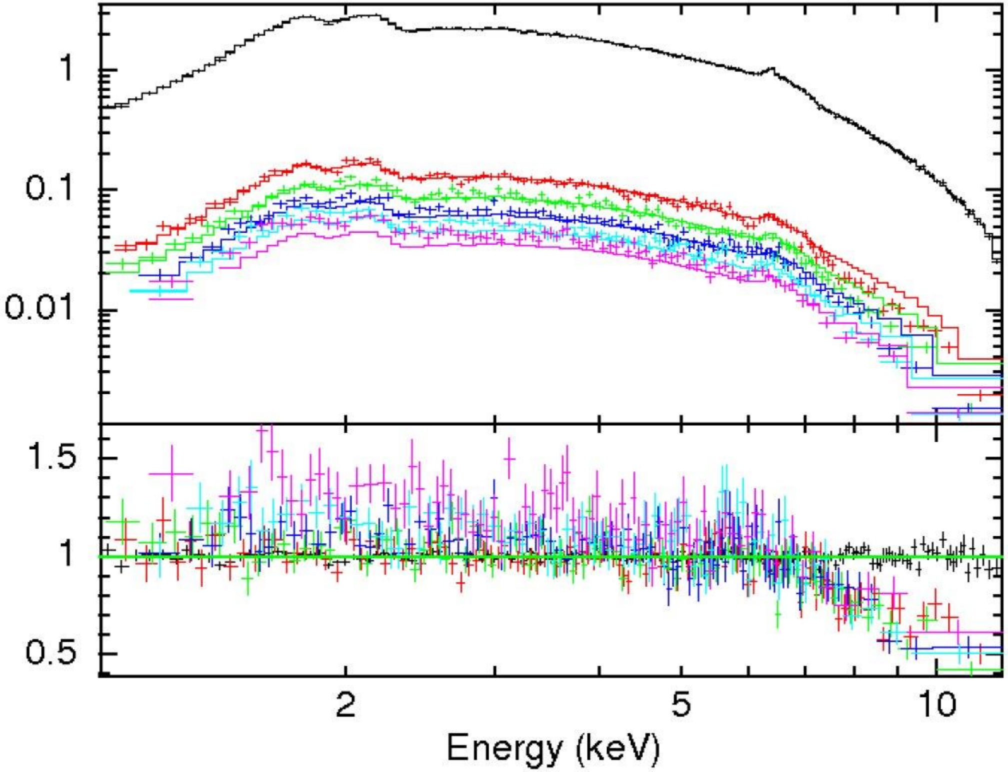
PKS 2155-304
- Piled-up
- Annular extraction regions for EPIC



Sample of non-piled-up on-axis sources



EPIC: PSF Investigations



NGC 5506 (Seyfert 2)

Dominated (>90%) by point source emission.

PN spectral comparison:

- annuli from 20″-25″ to 40″-45″
- compared with 20″ circle

Other sources show similar results

EPIC: PSF Investigations

- Systematics in the current PSF modelling for all 3 XRTs
- Hopefully can be improved by tuning the PSF model parameters
- Source sample consists of 11 observations of bright non-piled-up point sources located at the nominal aim point
- 5-6 nested annuli being compared (up to 60″ outer radius)
- 2 PSF model parameters ($r0$ and α) being varied – changes affect off-axis angles < 3′

EPIC: PSF Investigations

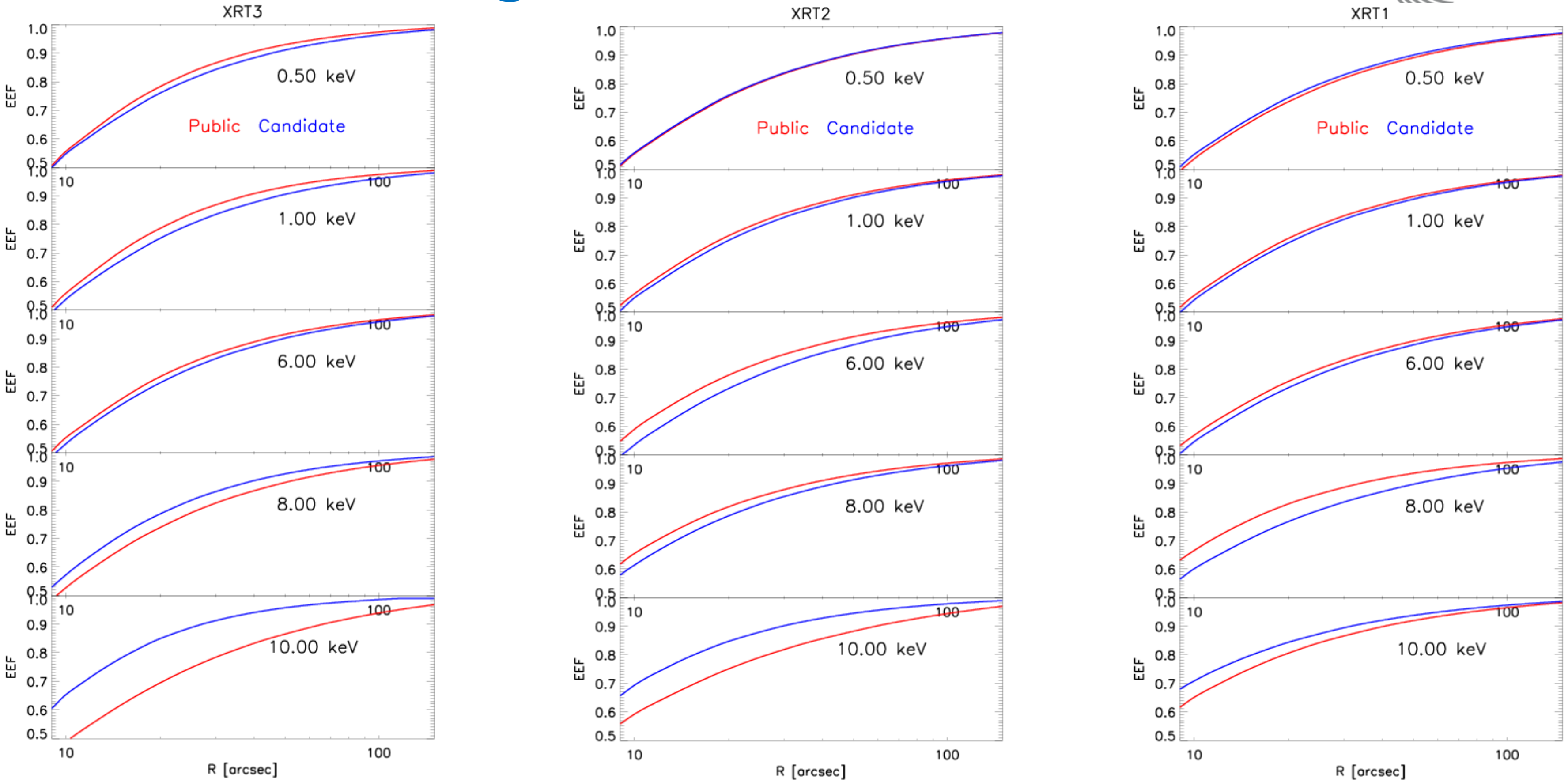
Iterative scheme for the empirical correction of XRT XPSF parameters:

- Per source:
  - Extract spectrum from circular region
  - Extract spectra from several nested annular regions
  - Create respective RMFs
  - Create respective ARFs
  - Fit model to circular region spectrum
  - Apply this as reference model to annular spectra, derive residuals
- For all annular spectra, and all sources, determine a suitable statistic:

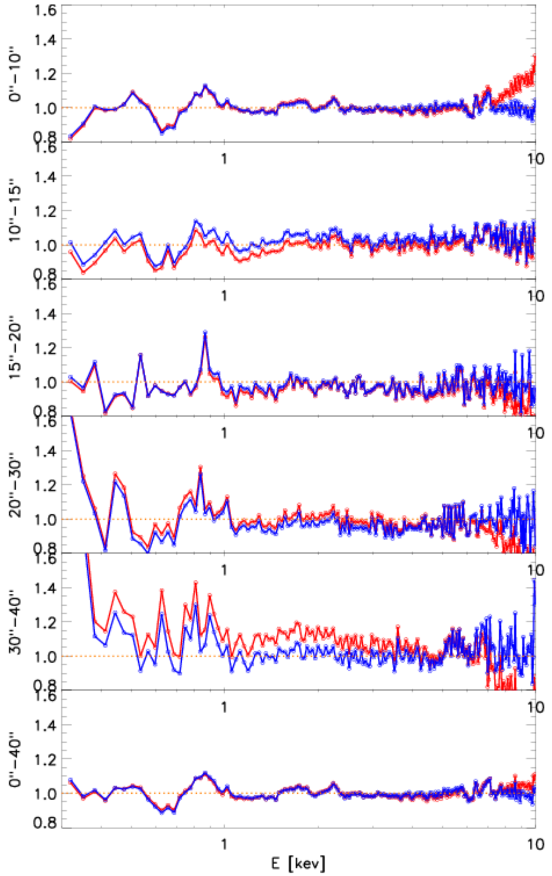
$$\sum_i \frac{(di - mi)^2}{{e_i}^2}$$

- Modify ELLBETA parameters in order to minimise the statistic

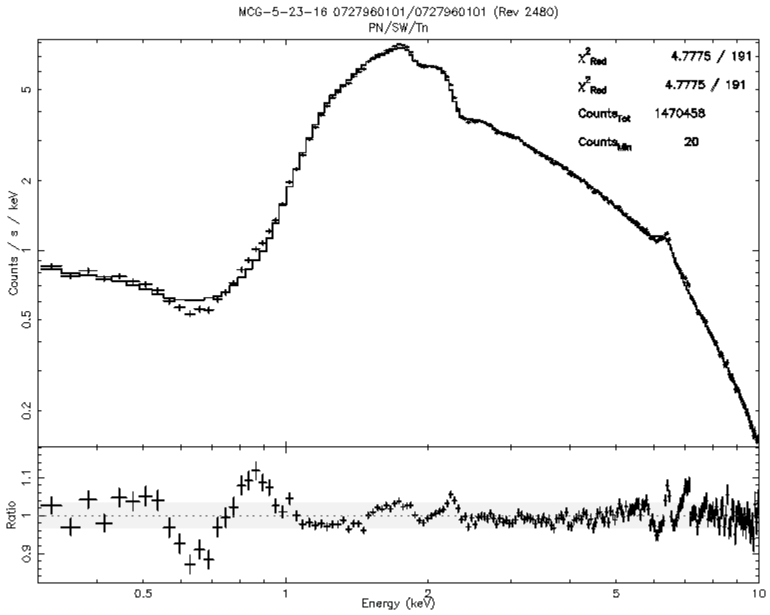
EPIC: PSF Investigations



EPIC: PSF Investigations



PN: MCG-5-23-16



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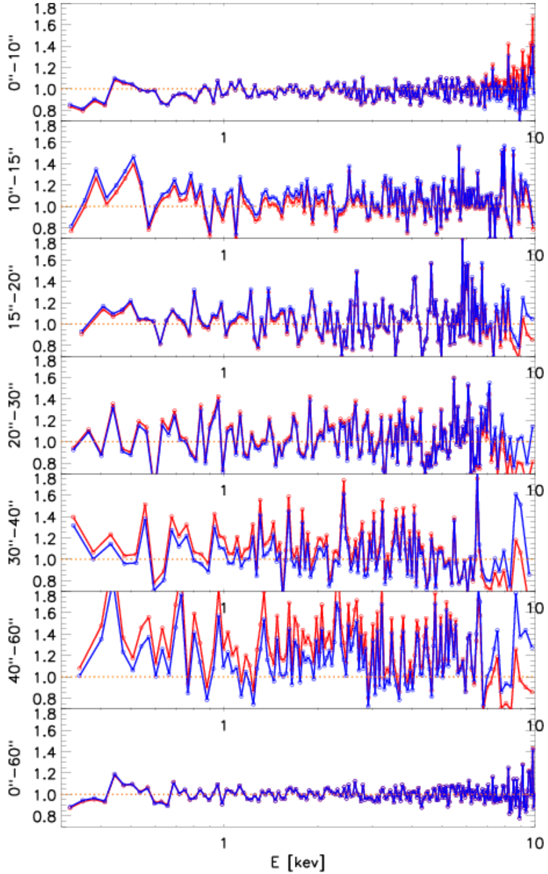
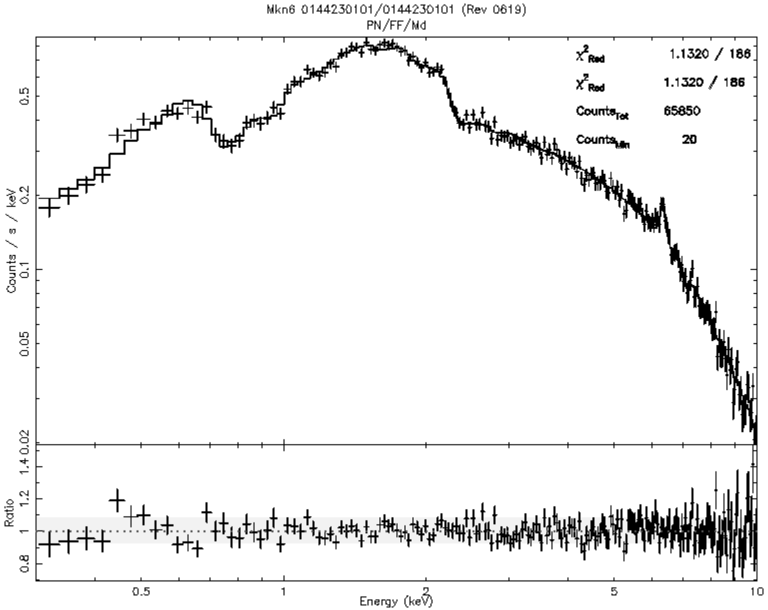


PN: Mkn 6



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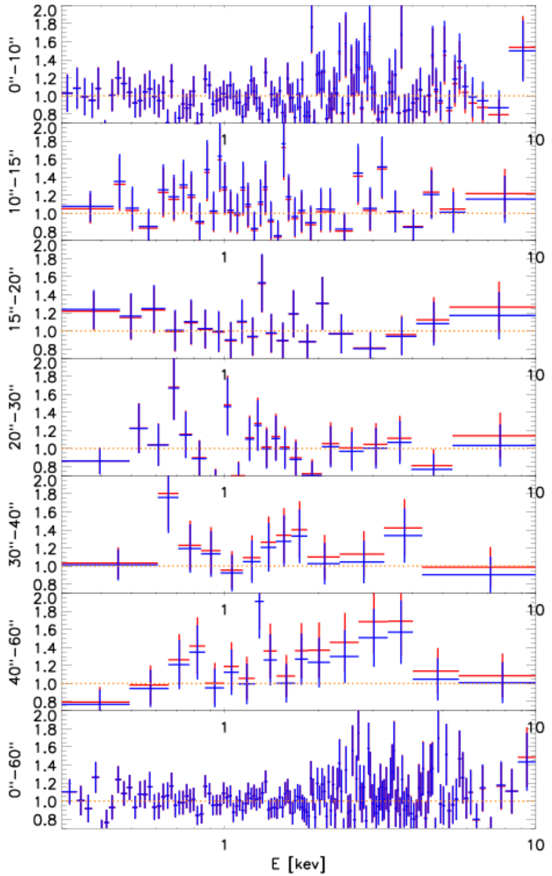
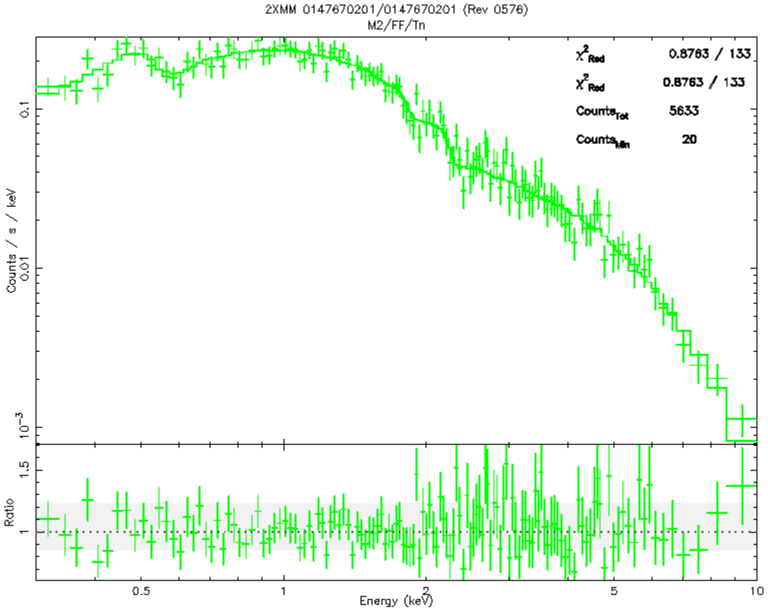
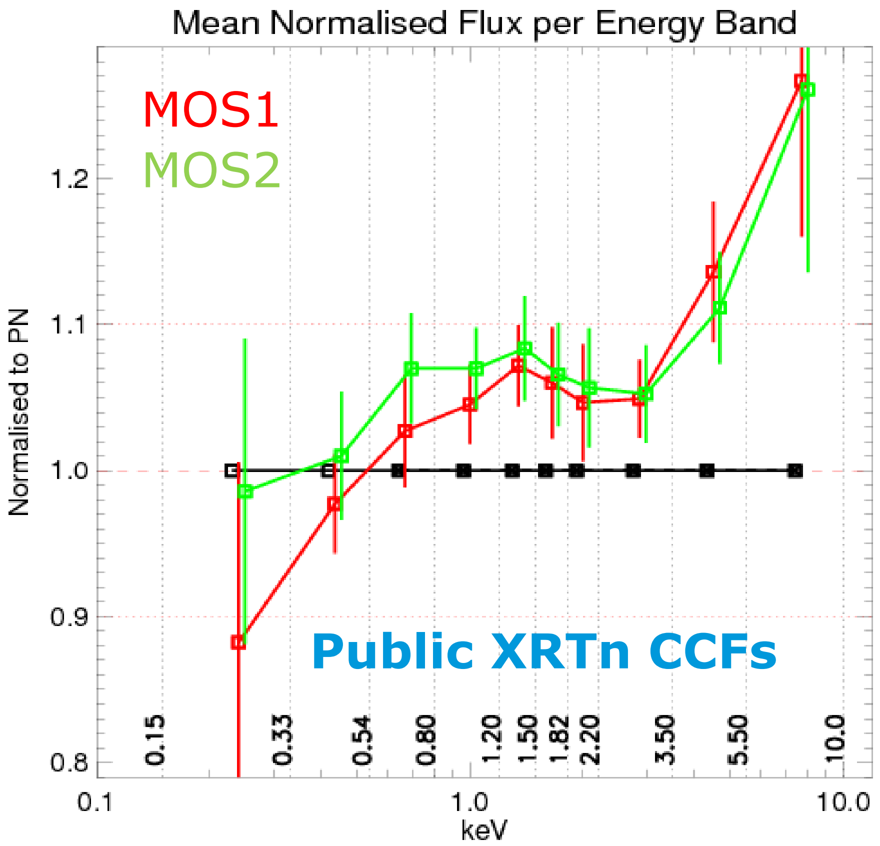
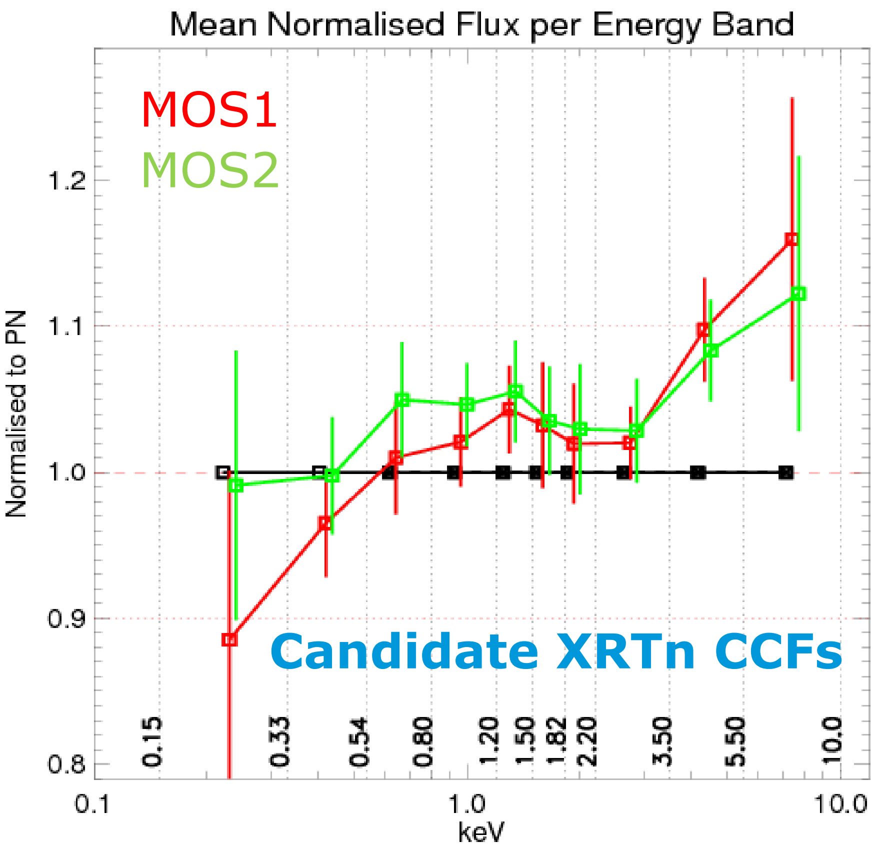


MOS2: PKS B1334-127



EPIC: PSF Investigations





2016 UG Recommendations

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Recommendation 2015-05-22/02: The UG identifies the following tasks in order of priority;

1. Cross-calibration of the responses of the XMM-Newton X-ray cameras and spectrometers. This is a longstanding issue, and it should be resolved as far as is possible in the near future.
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RGS: Effective Area Correction

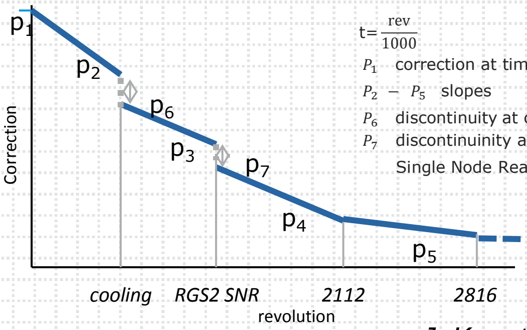
Algorithm and Implementation:

Time and wavelength dependent correction RGS1 and RGS2, 1st and 2nd order

For each 0.05 Å bin:

$t<0.538$	$P_1 + \left(\frac{t}{0.538}\right) P_2$
$0.538 \le t<1.408$	$P_1 + P_2 + P_6 + \left(\frac{t-0.538}{0.870}\right) P_3$
$1.408 \le t< 2.112$	$P_1 + P_2 + P_3 + P_6 + P_7 + \left(\frac{t-1.408}{0.704}\right) P_4$
$2.112\le t<2.816$	$P_1 + P_2 + P_3 + P_4 + P_6 + P_7 + \left(\frac{t-2.112}{0.704}\right) P_5$
$t>2.816$	$P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7$

+narrow gaussians at specific wavelengths



$t=\frac{rev}{1000}$

P_1 correction at time 0

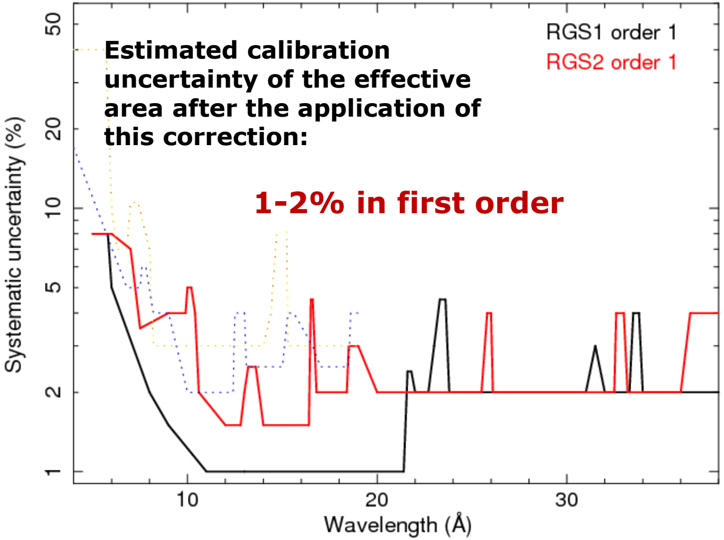
$P_2 - P_5$ slopes

P_6 discontinuity at cooling

P_7 discontinuinity at change to RGS2

Single Node Readout mode

J. Kaastra, C. de Vries & J.W. den Herder



implemented in SASv16
as a non-default option

new CCF issued
XMM-CCF-REL-340

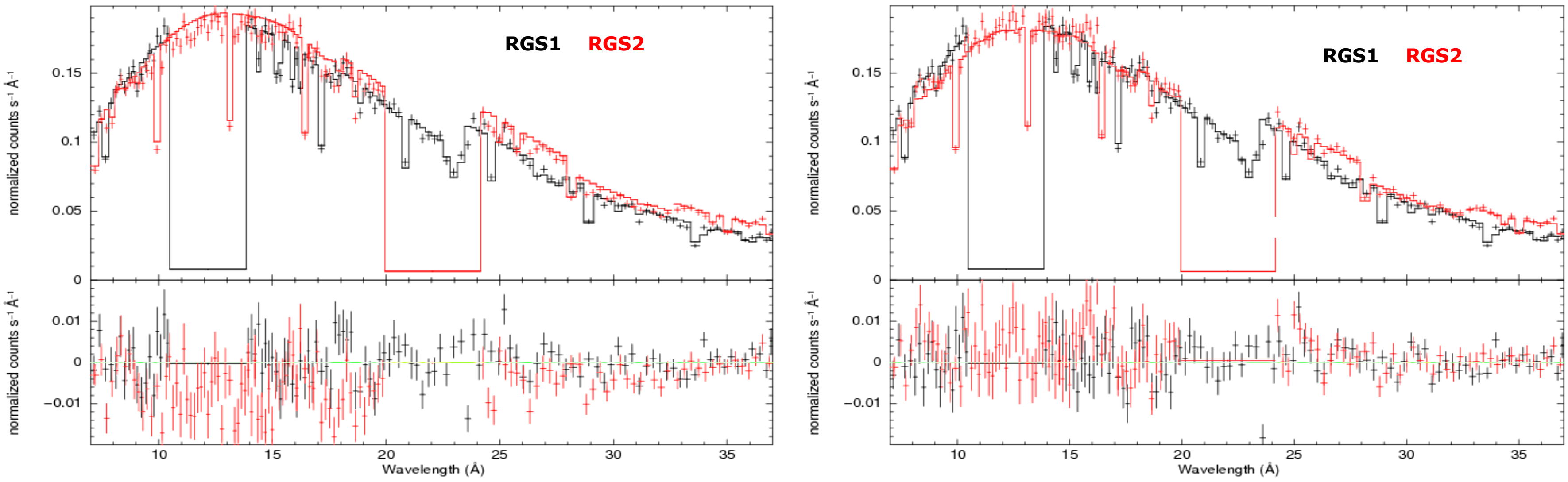
RGS: Effective Area Correction

Testing: RGS1 v. RGS2

3C 273 @ rev 1465

without correction

with correction



residuals with respect to best fit RGS1 model [two absorbed power-laws]

RGS: Effective Area Correction

Testing: RGS1 v. RGS2

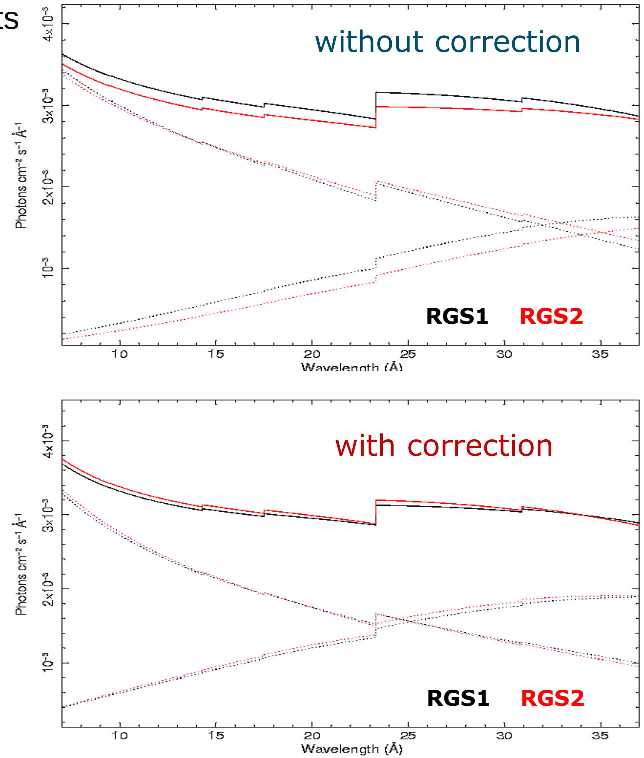
3C 273 @ rev 1465

independent RGS1 and RGS2 fits

	RGS1	RGS2
N_H (10^{20})	$2.28^{+0.55}_{-0.56}$	$1.89^{+0.95}_{-0.79}$
	$1.85^{+0.53}_{-0.52}$	$2.19^{+0.77}_{-0.69}$
Slope power-law #1	$1.68^{+0.15}_{-0.33}$	$1.68^{+0.17}_{-0.41}$
	$1.51^{+0.22}_{-0.43}$	$1.52^{+0.26}_{-0.56}$
Norm (10^{-2}) power-law #1	$3.61^{+0.41}_{-1.02}$	$3.52^{+0.42}_{-1.28}$
	$3.13^{+0.67}_{-1.20}$	$3.20^{+0.78}_{-1.52}$
Slope power-law #2	$3.61^{+0.76}_{-0.70}$	$3.69^{+1.18}_{-0.97}$
	$3.16^{+0.70}_{-0.52}$	$3.20^{+0.93}_{-0.65}$
Norm (10^{-2}) power-law #2	$0.56^{+0.94}_{-0.34}$	$0.43^{+1.19}_{-0.31}$
	$0.97^{+1.14}_{-0.61}$	$1.01^{+1.45}_{-0.69}$

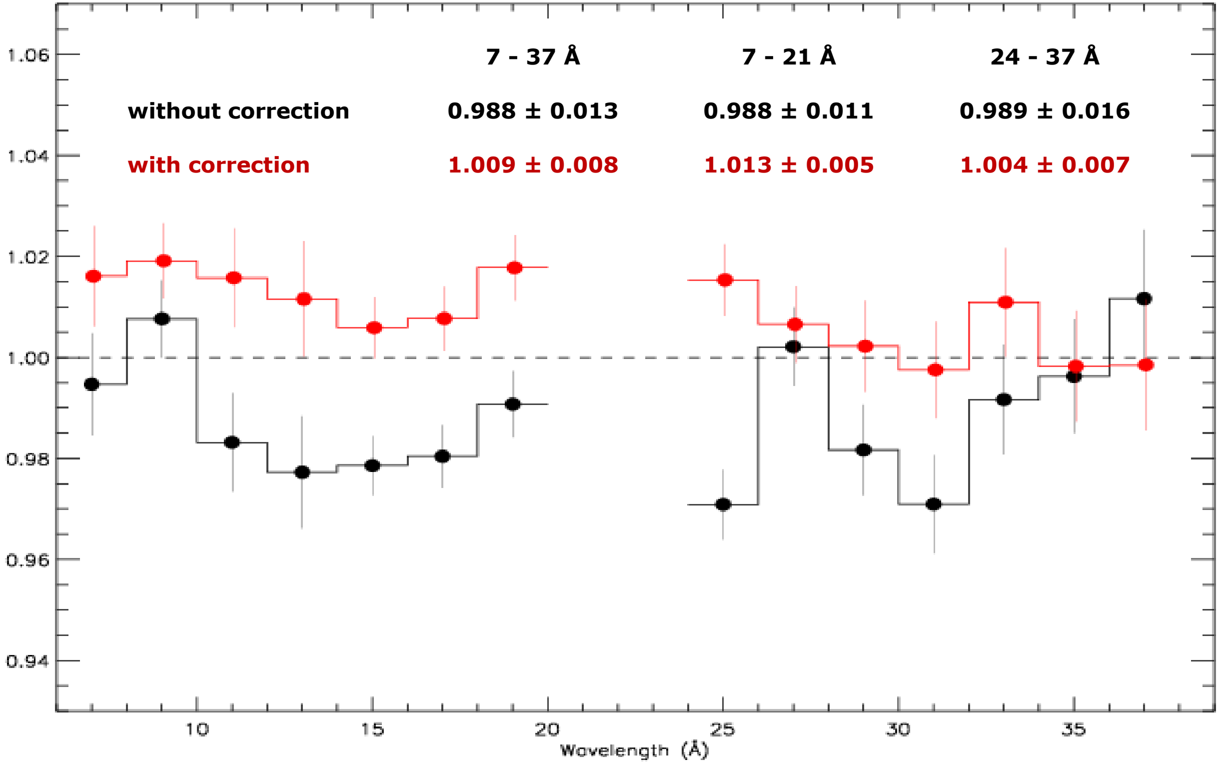
without correction
with correction

Model: two absorbed power-laws



RGS: Effective Area Correction

Testing: RGS2 / RGS1 Flux Ratio

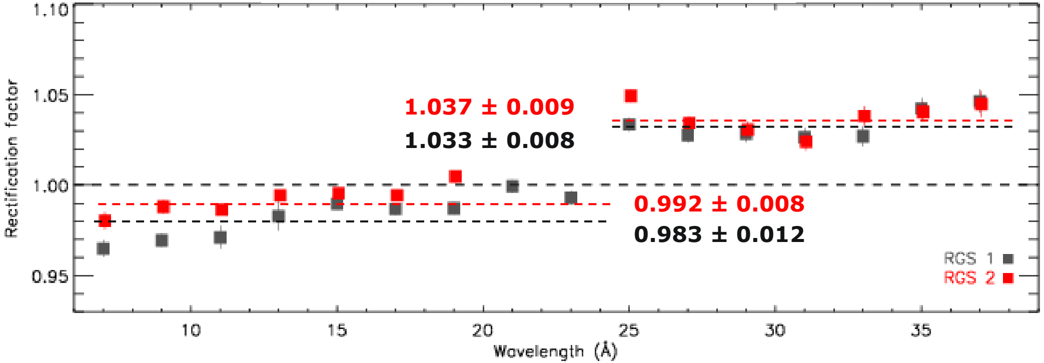


Based on observations of PKS 2155-304 and 3C 273

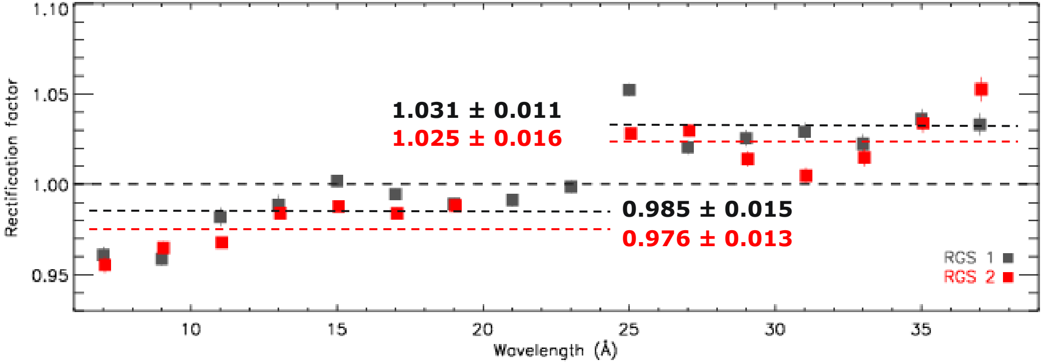
RGS: Effective Area Correction

Testing: RGS to EPIC-pn Rectification Factors

With effective area correction



in current CCF



Based on 42 observations of bright BL Lac

EPIC-pn in Small Window mode

EPIC: Update of the CORRAREA Correction

The `CORRAREA` tool was implemented in SAS 14 (autumn 2014):

- Applies an empirical correction to the EPIC effective areas.
- Can be used to evaluate the impact that the current relative EPIC A_{eff} uncertainties have on astrophysical parameters derived from spectral fitting.
- Currently, a non-default SAS option.

A recalibration and full validation of the `CORRAREA` correction is currently being undertaken:

- Based on SAS 15.1, and latest calibration (as of Oct 2016).
- Revised screening: common GTIs, background selections, pile-up evaluation.
- Largely automated pipeline from data reduction to spectral and residual fitting.
- A new `CORRAREA` correction is close to release (⇨ summer 2017).

Outlook:

- Include a wider sample of sources, observing modes (LW, SW) and filters (Thick) (⇨ autumn 2017).
- Cross-mission comparison in order to justify absolute A_{eff} correction.

Mirrors: Effective Area Simulations

- In mid 2016 an investigation (by D. Lumb) was started into possible unaccounted for mirror contamination present pre-launch.
- Using industry reports on expected contamination, SciSim was used to compare telescope effective areas. Results show the currently implemented values are inconsistent.
- The discrepancies are telescope-dependent, implying absolute and relative changes to the EPIC (and RGS) effective area calibration.
- Progress has been made, resulting in preliminary estimates based on the best knowledge of the telescope contamination. Assuming this contamination is present after launch this would mean:
    - Absolute changes in telescope effective area: ~ 2 - 4%.
    - Relative changes between EPICs (esp. XRT3 and XRT1/2): ~ 0 – 3%.

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PN: Quiescent Background Gain Correction

- Details of the quiescent background gain correction (QBGC) were presented at the 2016 Users' Group meeting.

- In order to correct the PN gain, the discarded line rate is used as proxy for the quiescent background.

- Original implementation envisaged the use of an *observation averaged rate*, already stored in the events file (`NDISCLIN` keyword).

- However, the QB may vary significantly within an observation, necessitating the use of the *instantaneous discarded line rates*, included in the housekeeping data stream.

- This requires a fundamentally different implementation at S/W level.

- Main issue is the robust handling of telemetry gaps, outlier values, intrinsic noise.

⇨ *Aim is for SAS 17 implementation (end of 2017).*

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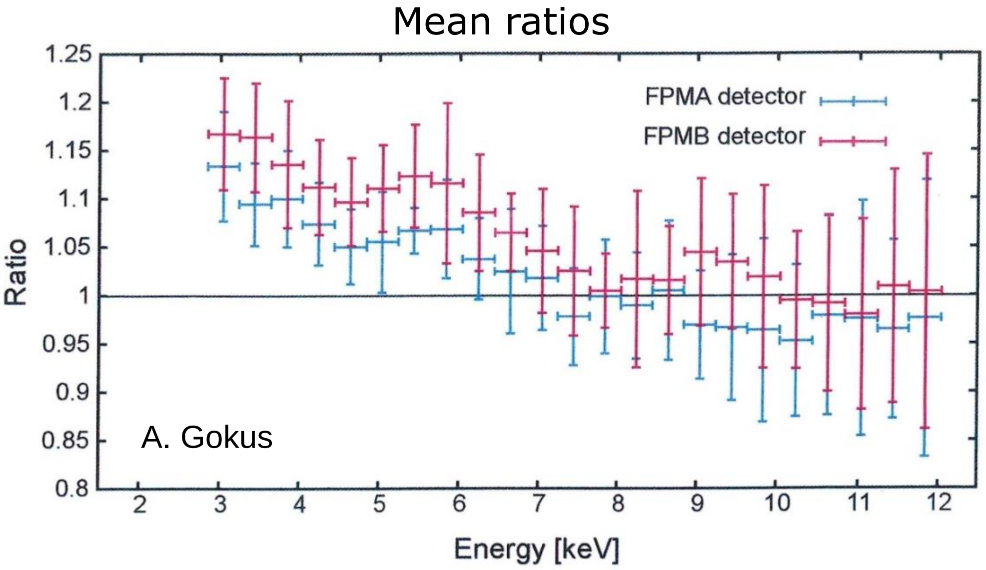
EPIC-pn / NuSTAR Comparison



Comparison of 18 AGN spectra:

- PN imaging modes
- Strictly simultaneous PN-NuSTAR data
- Models fit to PN

⇒ Systematic NuSTAR residuals

⇒ Slope differences of ~0.15

However:

- Recent NuSTAR results (Madsen et al. 2017, comparing focused with non-focused measurements of the Crab) confirm NuSTAR normalisation underestimated by ~ 10%.
- Change in PSF parameters may affect EPIC spectral slope.

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PN: Timing & Burst Mode Issues

PN Timing Mode observations show several cases of sources with:

- larger than expected residuals at instrumental edges
- significant differences in line energies with respect to e.g. grating data (up to 70 eV at ~ 6 keV)

Sources are in the moderate count rate regime.

Possible issue with rate dependent correction in Timing Mode (and Burst Mode).

The chain of corrections affecting the TI & BU mode energy scale is being systematically evaluated.

- Rate dependent correction (pattern recognition)
- Find event patterns
- Rate dependent correction (applied to charges)
- Gain correction
- Mode-specific gain correction
- CTI correction
- Long-term CTI correction
- CCD offset correction

Work in progress…

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1. Status of calibration related to the Users' Group resolutions and recommendations

2. Calibration monitoring and improvements over the last 12 months

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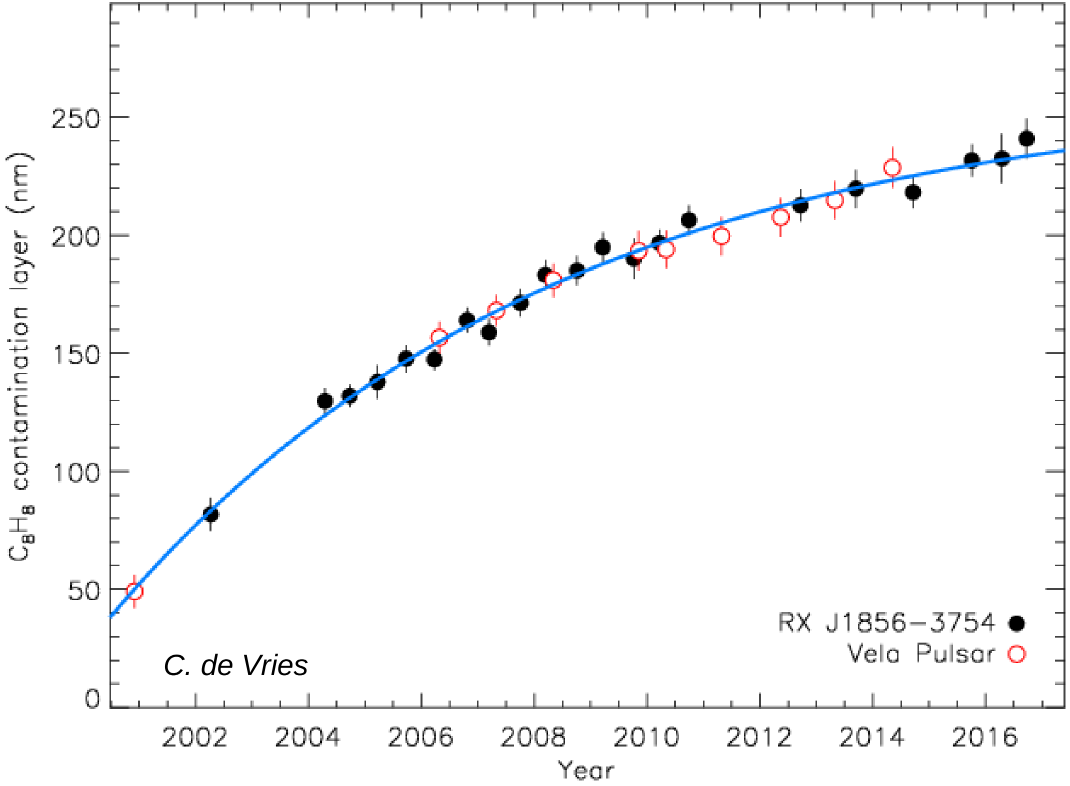
Summary of Calibration Monitoring

- EPIC bad pixels (XMM-CCF-REL-338)
- EPIC background and offset maps (XMM-CCF-REL-339)
- EPIC energy scale (XMM-CCF-REL-336)
- EPIC variable boresight (XMM-CCF-REL-343)
- EPIC-MOS contamination
- EPIC-pn flux stability
- EPIC-pn timing

- OM sensitivity degradation (XMM-CCF-REL-346)
- OM photometric stability
- OM grism flux stability
- OM astrometry
- OM variable boresight (XMM-CCF-REL-343)

- RGS bad columns (XMM-CCF-REL-347)
- RGS wavelength scale
- RGS CTI & gain (XMM-CCF-REL-345)
- RGS background
- RGS contamination
- RGS flux stability
- RGS offsets (XMM-CCF-REL-342)

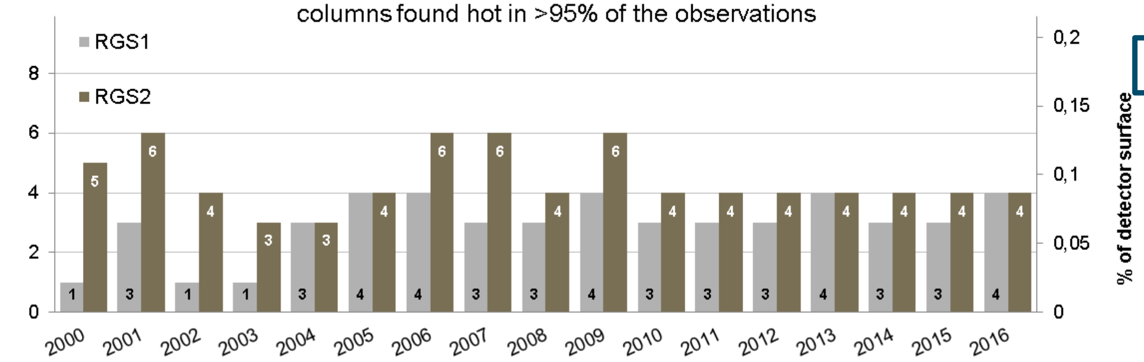
RGS: Contamination Monitoring



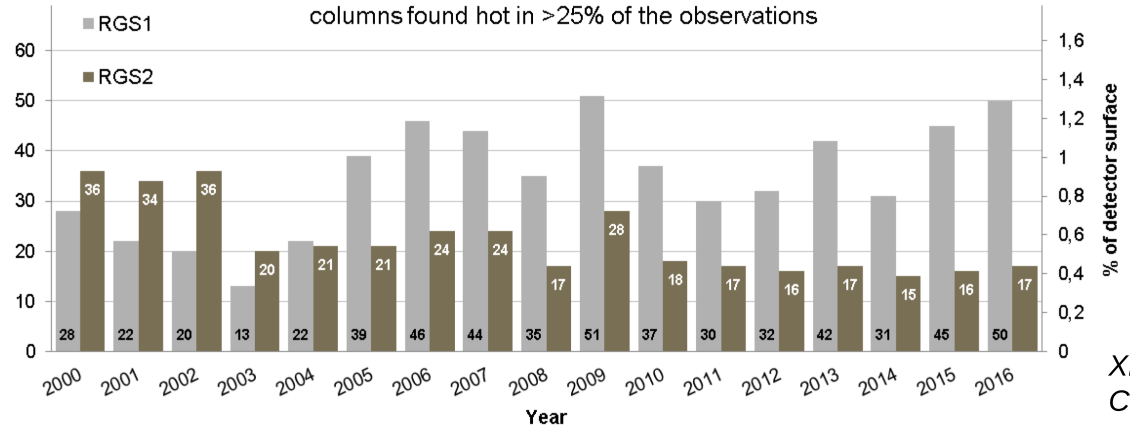
Carbon contamination layer building-up slowly

No changes in the trend

RGS: Bad Surface Monitoring



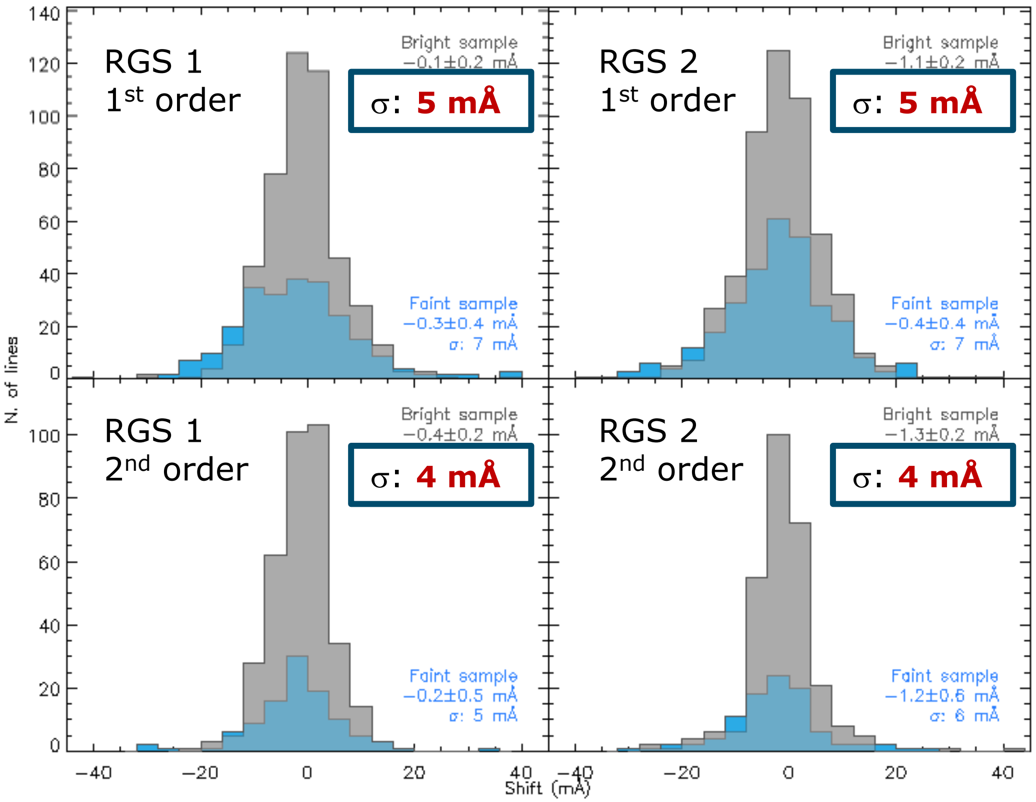
<< 1% of detector surface



< 1.5% of detector surface

XMM-SOC-CAL-TN-0209
C.Gabriel

RGS: Wavelength Scale Monitoring



Bright sample

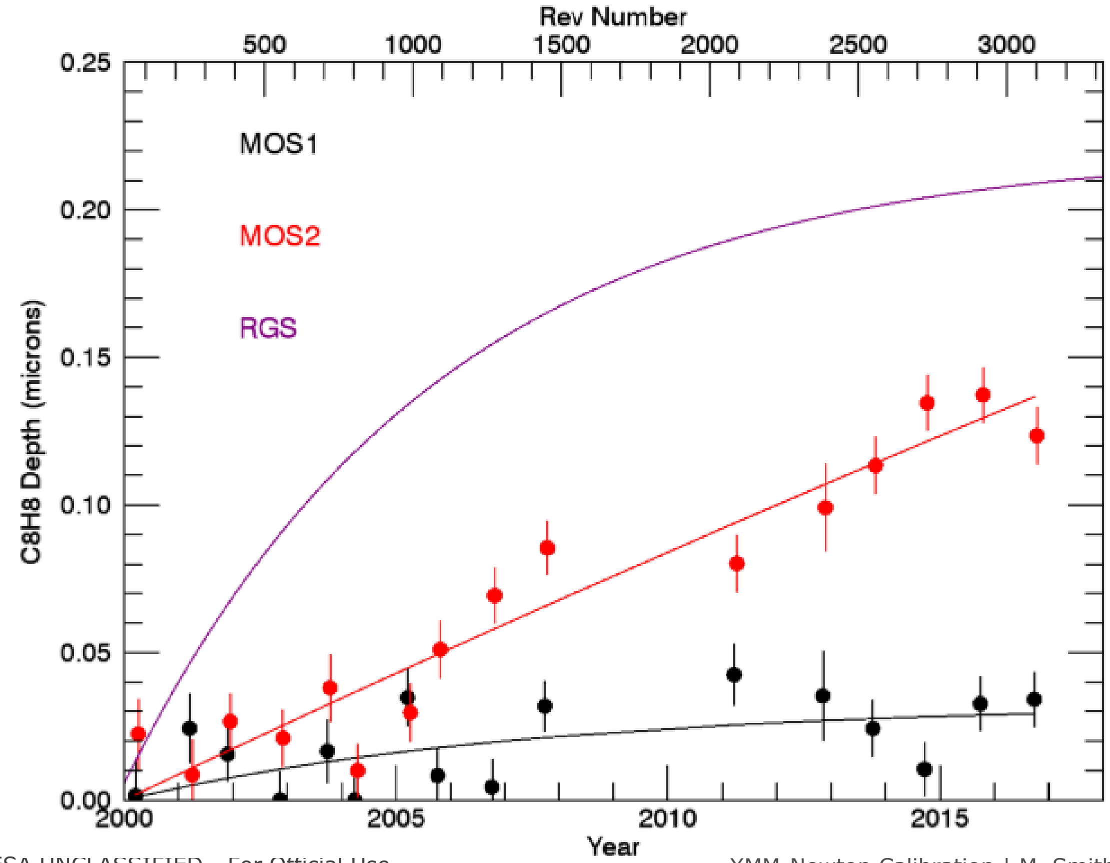
85 observations of AB Dor, Capella, HR 1099 and Procyon

Faint sample

70 observations of fainter emission line stars

Heliocentric and Sun angle corrections applied; most recent XMM variable boresight

MOS: Contamination Monitoring

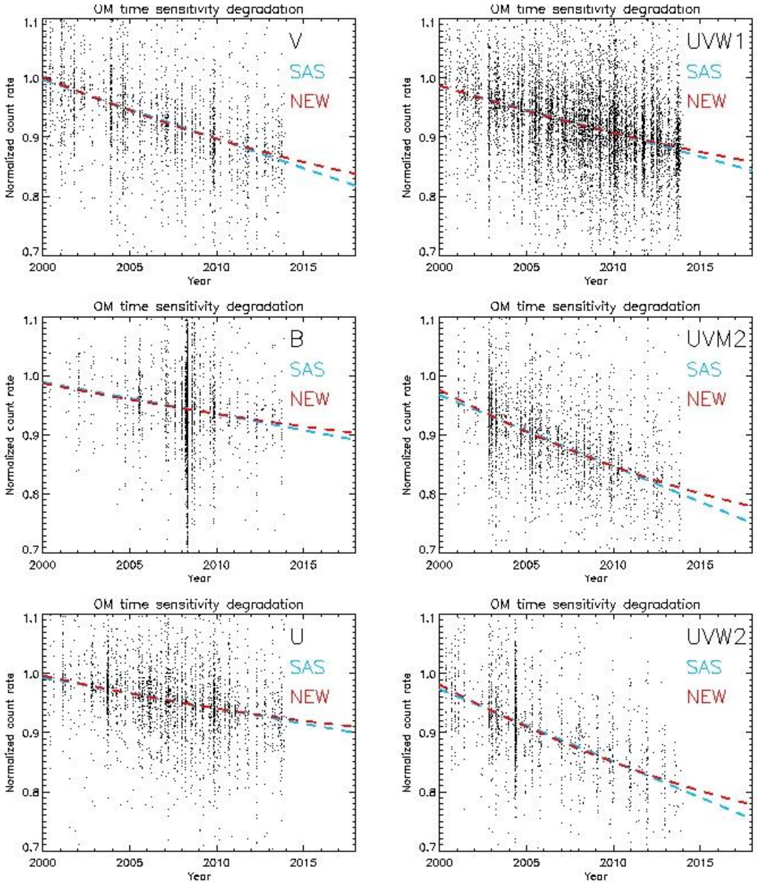


Primary monitoring source:
SNR 1E0102

Contamination status shows no change in trend:

- MOS1 stable
- MOS2 steadily increasing

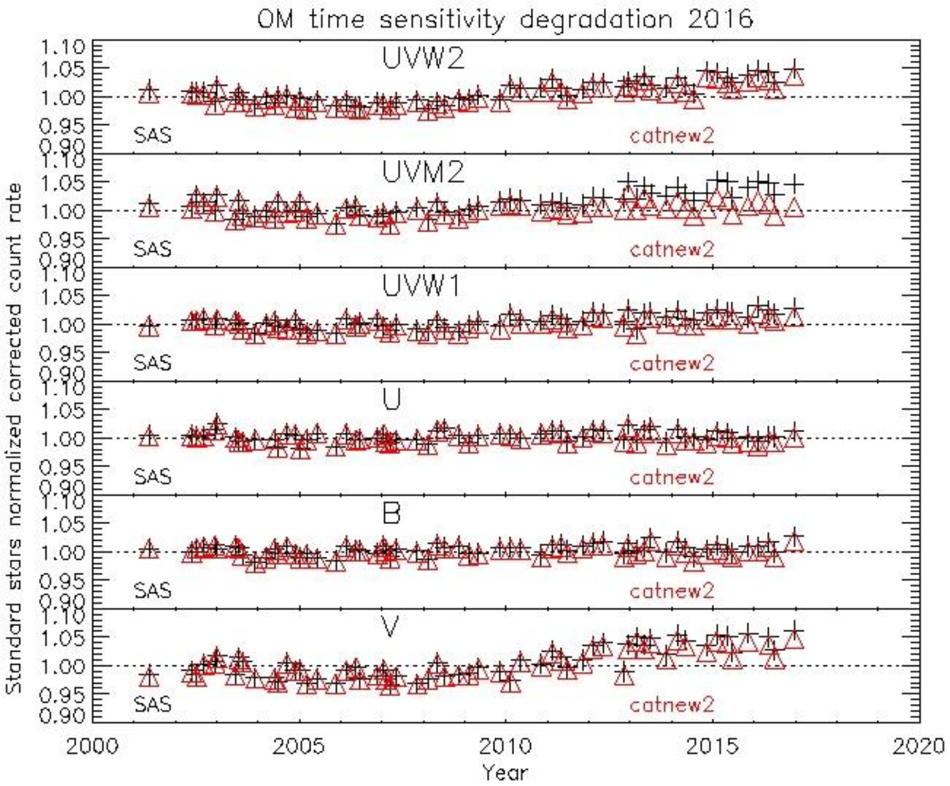
OM: Time Sensitivity Degradation



Originally based on linear fit to standard stars:
OM_PHOTTONAT_0005.CCF

Now based on a quadratic fit to selected catalogue sources:
OM_PHOTTONAT_0006.CCF

OM: Time Sensitivity Degradation



Testing of the new correction on standard stars:

+ old correction

△ new correction

OM: Repeatability of Filter Photometry

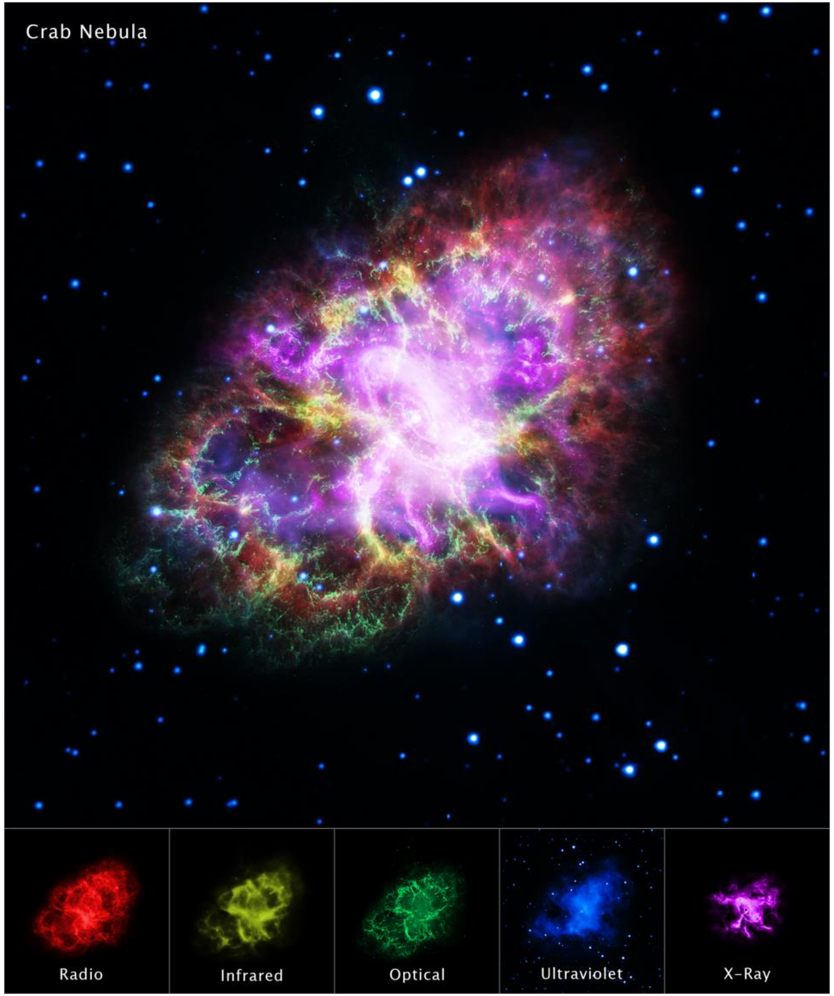
SAS 16 data processing:
Count rates (cts/s) of standard stars observed regularly since 2001:

Star	Nobs	UVW2	UVM2	UVW1	U	B	V
GD 153	14	83.1	161.8	329.5	420.5	283.5	71.4
error (%)		1.4	1.5	0.8	1.4	1.0	2.1
Hz 2	17	23.8	48.3	111.7	168.8	148.8	43.7
error (%)		2.0	1.3	1.3	0.9	0.8	2.9
BPM 16274	32	14.7	30.3	72.9	112.7	107.8	33.0
error (%)		1.7	1.2	1.0	0.8	0.8	2.2

OM: Serendipitous UV Source Survey

- New version 3 of the XMM-Newton Serendipitous Source Survey ("the OM Catalogue"): SUSS3
- Released in March 2017
- Observations till mid-2015:
  - 7866 XMM-Newton pointings
  - 6,9 million entries
  - 4,8 million sources
  - 0,9 million sources with multiple observations
- Full reprocessing with SAS 15 & new time-dependent sensitivity degradation correction (**`OM_PHOTONAT_0006.CCF`**)
- New flag: **`Sky_Image`** to identify sources detected in mosaic / stacked images

- Available through the ESA XSA: query I/F or full catalogue download
- Catalogue sources can be overlaid in the ESA-Sky utility



Multi-wavelength study of the Crab (Dubner et al., ApJ, 2017)

UV data from the XMM-Newton Optical Monitor

UVW1 filter (291 nm):
- 75 exposures (2001 – 2015)
- 221 ks exposure time

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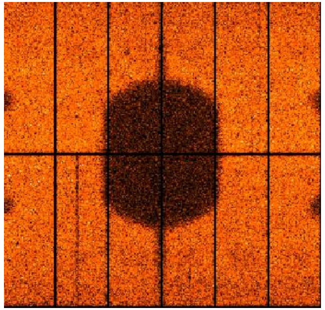
Additional Future Calibration Activities



EPIC-pn: Include Cu-Ka fluorescence emission (8.0 keV) in the long-term CTI correction; will complement the existing data points at 1.5 keV (Al-Ka) and 5.9 keV (Mn-Ka).

OM: Continued study of time-dependent sensitivity degradation.

RGS: Re-evaluation of effective area corrections.
Assessment of background templates and background correction methods.

Cross-Calibration:
Streamlining the XMM-Newton Cross Calibration Archive in order to improve flexibility in validating calibration products.

- 51 targets
- 228 exposures
- on and off-axis
- point and extended sources

Summary of Calibration Plans & Activities

▪ EPIC encircled energy correction: new XRTn XPSF parameters	Summer 2017
▪ EPIC CORRAREA:	
recalibration	Summer 2017
extended validation	Autumn 2017
▪ EPIC-pn quiescent background gain correction in SAS 17	End of 2017
▪ EPIC-pn empirical RMF modelling	
▪ Implications of mirror contaminant simulations	In progress
▪ Re-evaluation of EPIC-pn fast mode energy scale corrections	