XMM-Newton Calibration Update

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on behalf of the XMM-Newton Calibration Team

IACHEC #13, 9-12 Apr 2018, Tenuta dei Ciclamini

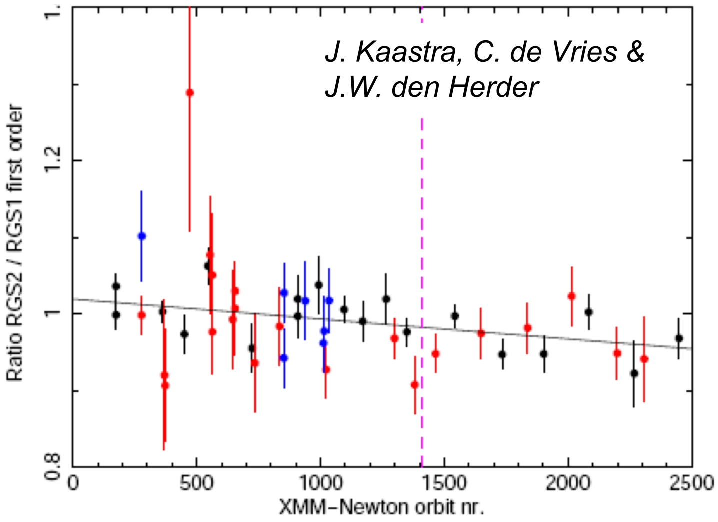
Outline

1. Recent calibration file releases

2. Current calibration topics

3. Cross calibration status

RGS: Effective Area Correction



Systematic decrease in the ratio of the fluxes from both RGS

On average, the flux ratio RGS2/RGS1 decreases by ≈ 0.4 % / yr

λ (Å)	% per year	% in 15 years
10	-0.1	-1.5
20	-0.6	-9
30	-0.5	-7.5
35	-0.2	-3

Rate of change depends on wavelength:

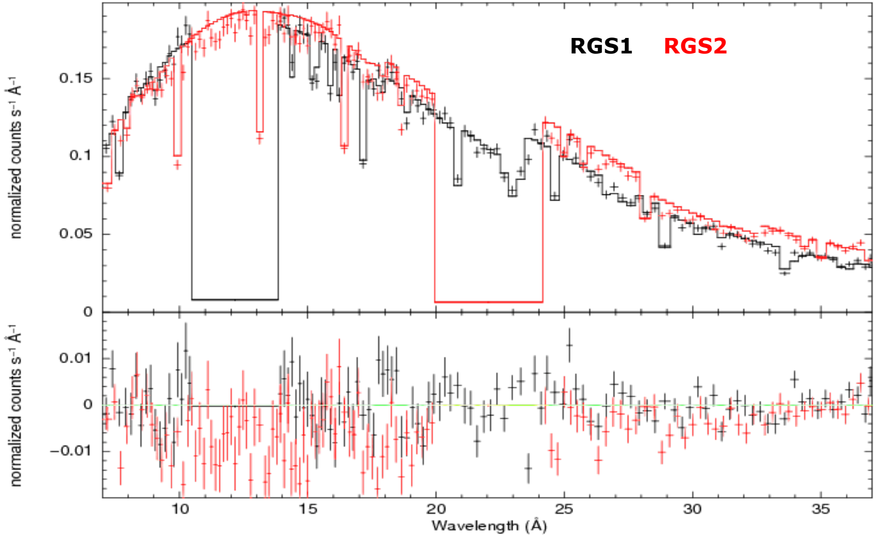
- significantly < 0 in the range 15-30 Å,
- close to zero or positive at shorter and longer wavelengths

RGS: Effective Area Correction

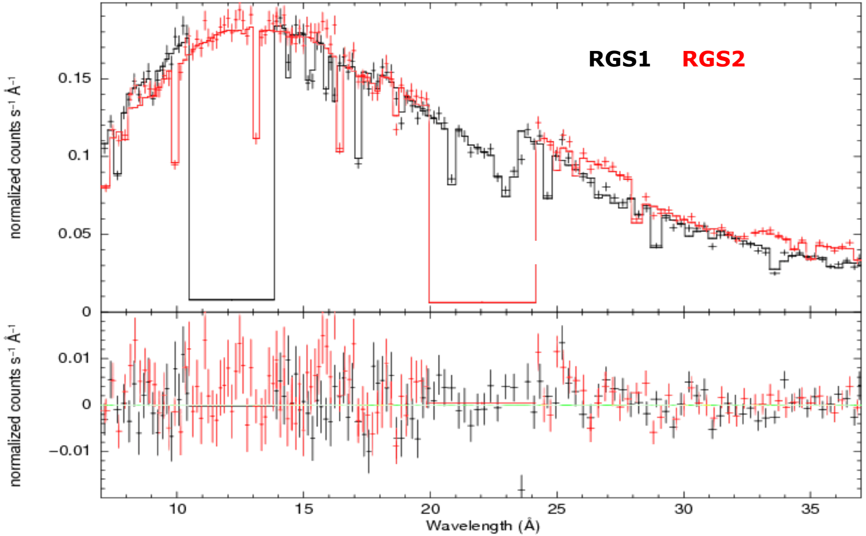
Testing: RGS1 v. RGS2

3C 273 @ rev 1465

without correction



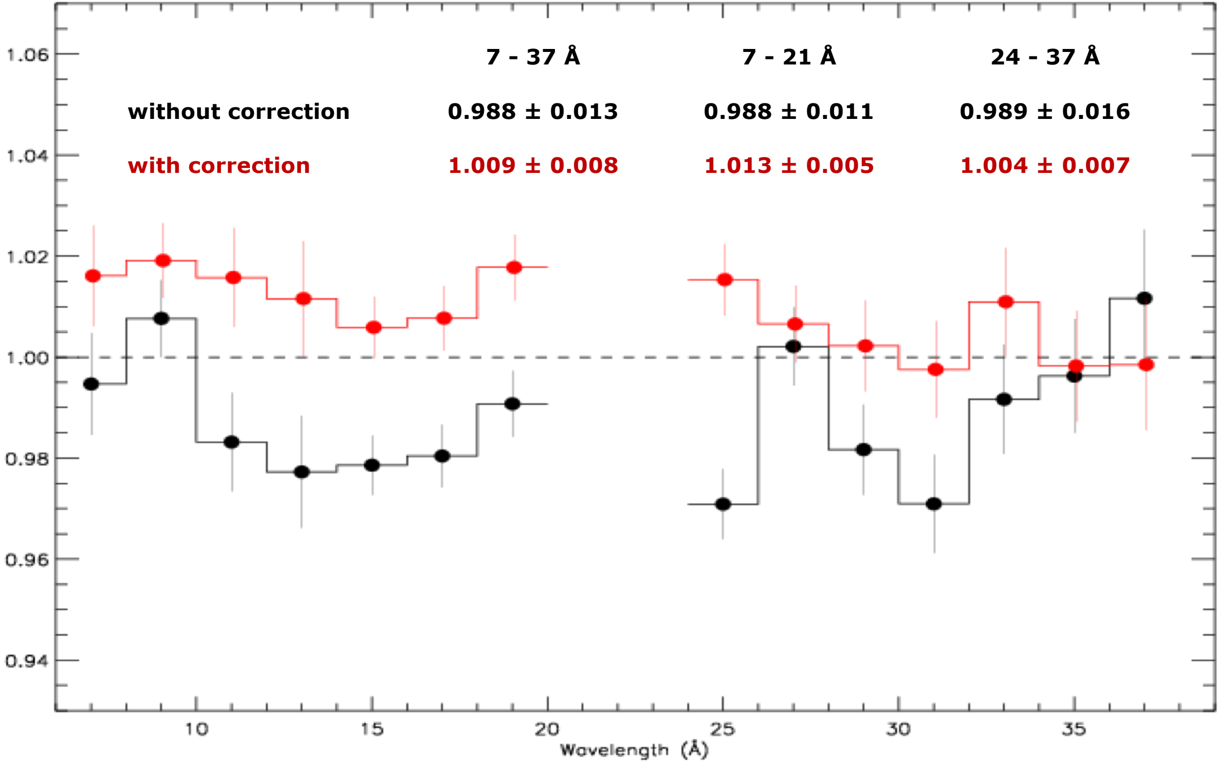
with correction



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

RGS: Effective Area Correction

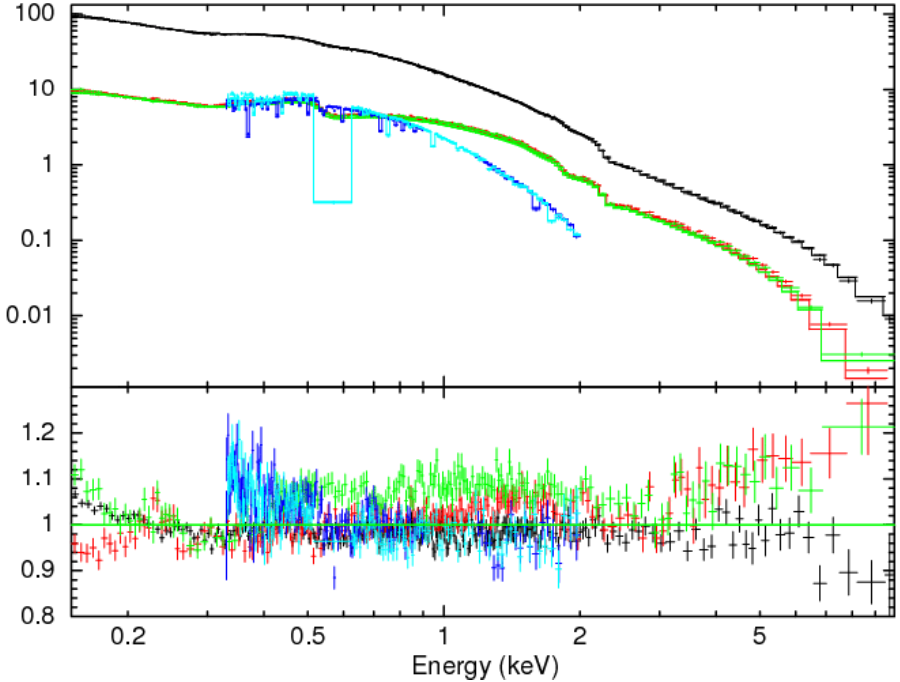
Testing: RGS2 / RGS1 Flux Ratio



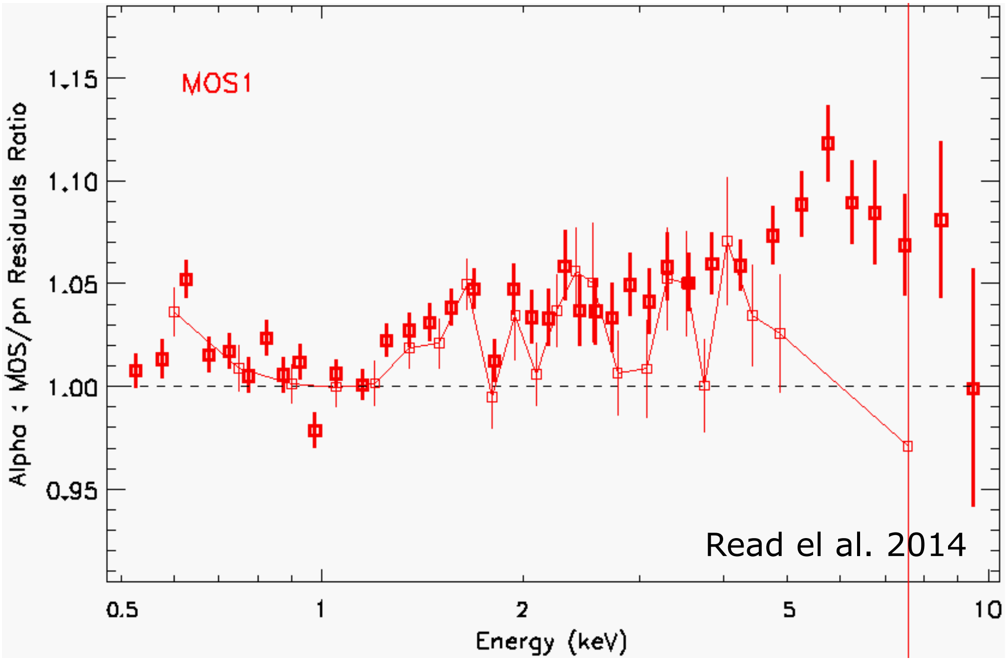
Based on observations of PKS 2155-304 and 3C 273

XRT PSF Modification

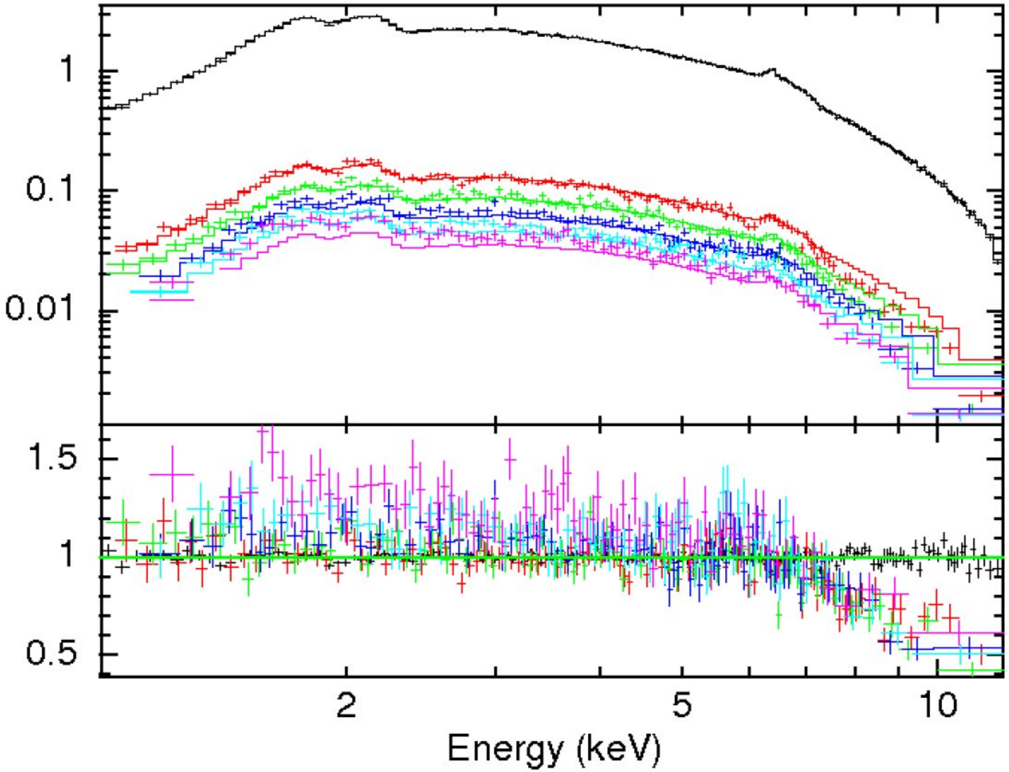
PKS 2155-304
- Piled-up
- Annular extraction regions for EPIC



Sample of non-piled-up on-axis sources



XRT PSF Modification



NGC 5506 (Seyfert 2)

Dominated (>90%) by point source emission.

PN spectral comparison:

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

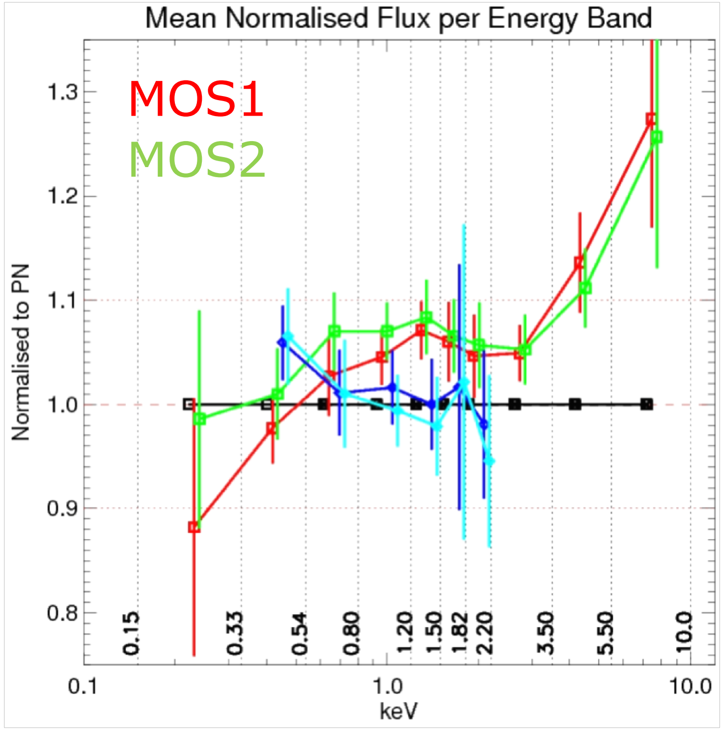
Other sources show similar results

XRT PSF Modification

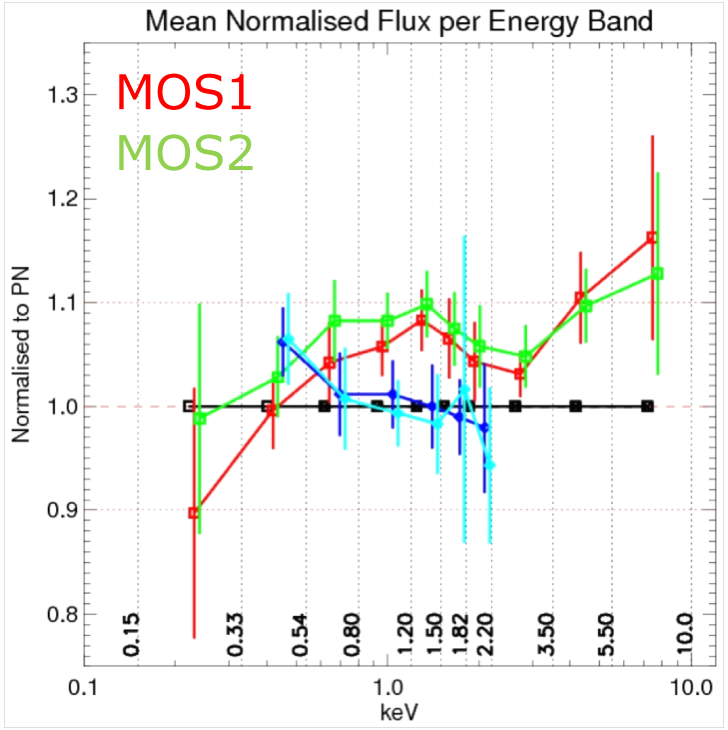
- Systematics in the current PSF modelling for all 3 XRTs
- Improve by iterative tuning of the PSF model parameters
- Source sample consists of 11 observations of bright non-piled-up point sources located at the nominal aim point
- 5-6 nested annuli being compared (up to 60” outer radius)
- 2 PSF model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

In XMM-CCF-REL-348, 08/2017

XRT PSF Modification



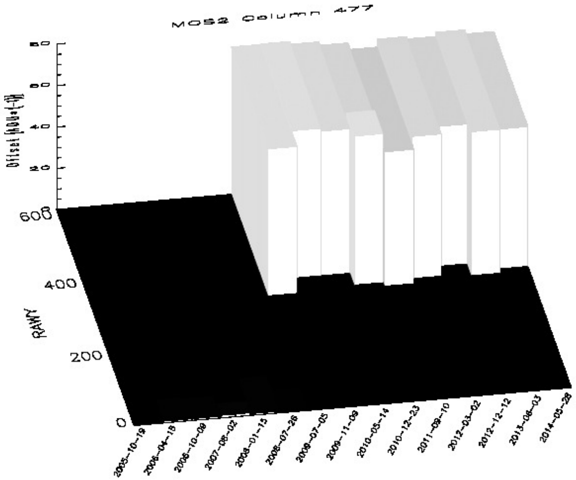
Old XRTn CCFs



New XRTn CCFs

MOS CTI and Gain Update

- New set of MOS CTI & Gain CCFs released (02/2018, XMM-CCF-REL-354 / 355):
    - MOS1: 24 epochs
    - MOS2: 27 epochs
- Epoch conformity between MOS1 and MOS2 broken after rev. 1163 (04/2006), mainly due to evolving charge traps within CCD columns



- ➢ Improvement of energy reconstruction of up to 5 eV @ 1.5 keV and 15 eV @ 6 keV (for peripheral CCDs in latest epoch).

- ➢ Energy scale is now accurate to < 5 eV for all CCDs.

Outline

1. Recent calibration file releases

2. **Current calibration topics**

3. Cross calibration status

Current calibration priorities

Following the recommendation by the XMM-Newton Users Group

1. *XMM internal xcal*
    - ***2D PSF***
    - ***CORRAREA and A_{eff}***

2. *Time-resolved quiescent-background gain-dependence (pn)*

3. ***NuSTAR - XMM-Newton cross-calibration***

4. ***PN fast modes calibration (burst and timing)***

5. *Using NuSTAR as hard X-ray standard candle (off-axis Crab observations): implication on 1, 3 and 4.*

6. Monitoring activities
    - ***MOS and RGS contamination***
    - OM sensitivity degradation

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 16, and current public CCFs.
- Larger source sample + more instrument modes.
- Revised screening: common GTIs, background selections, pile-up evaluation.
- Largely automated pipeline from data reduction to spectral and residual fitting.

→ **See Cornelia Heinitz talk in Detectors and Background WG**

PN Fast Mode Investigations

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, expected ~20 eV)

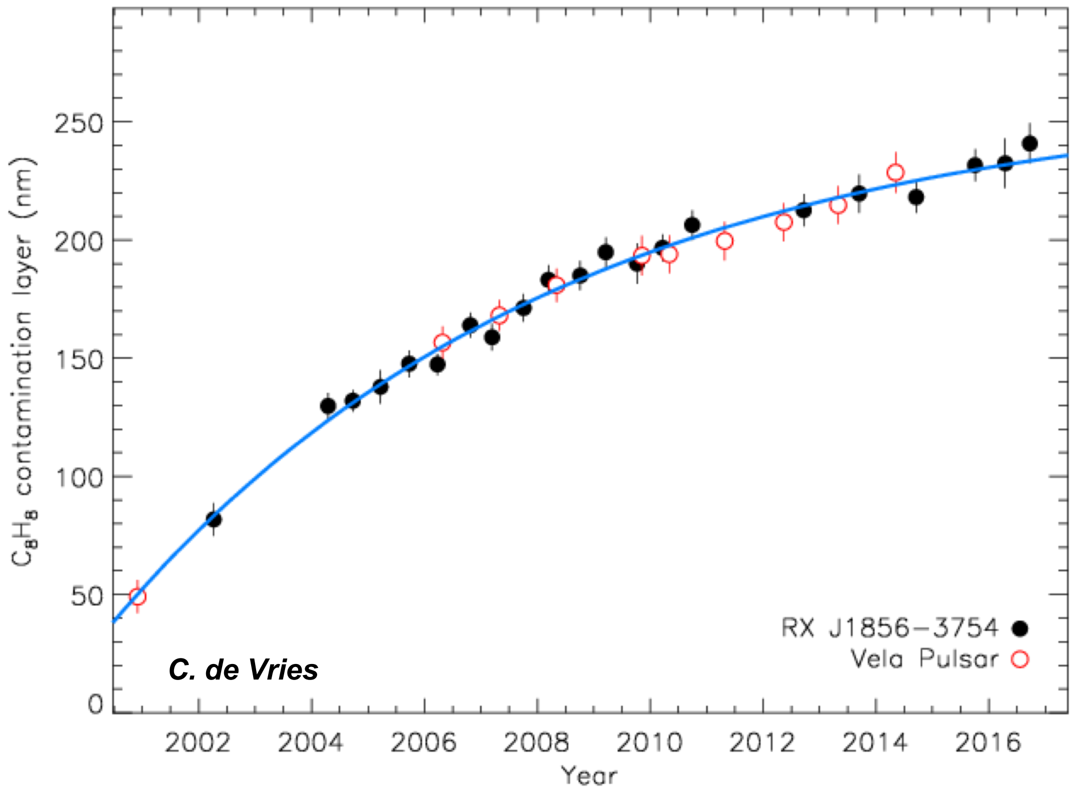
Sources are in the moderate count rate regime.

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

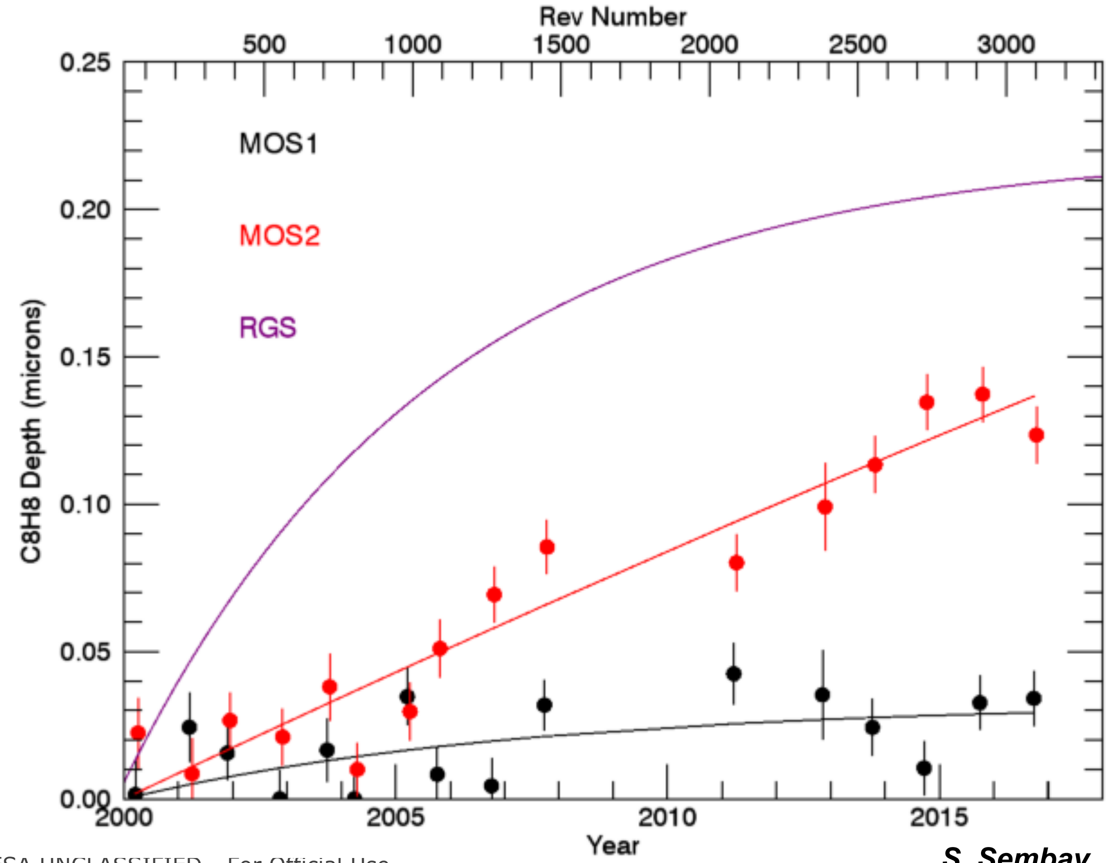
RGS Contamination Monitoring



Carbon contamination layer building-up slowly

No changes in the trend

MOS Contamination Monitoring



S. Sembay

Primary monitoring source:
SNR 1E0102

Contamination status shows no change in trend:

- MOS1 stable
- MOS2 steadily increasing

Outline

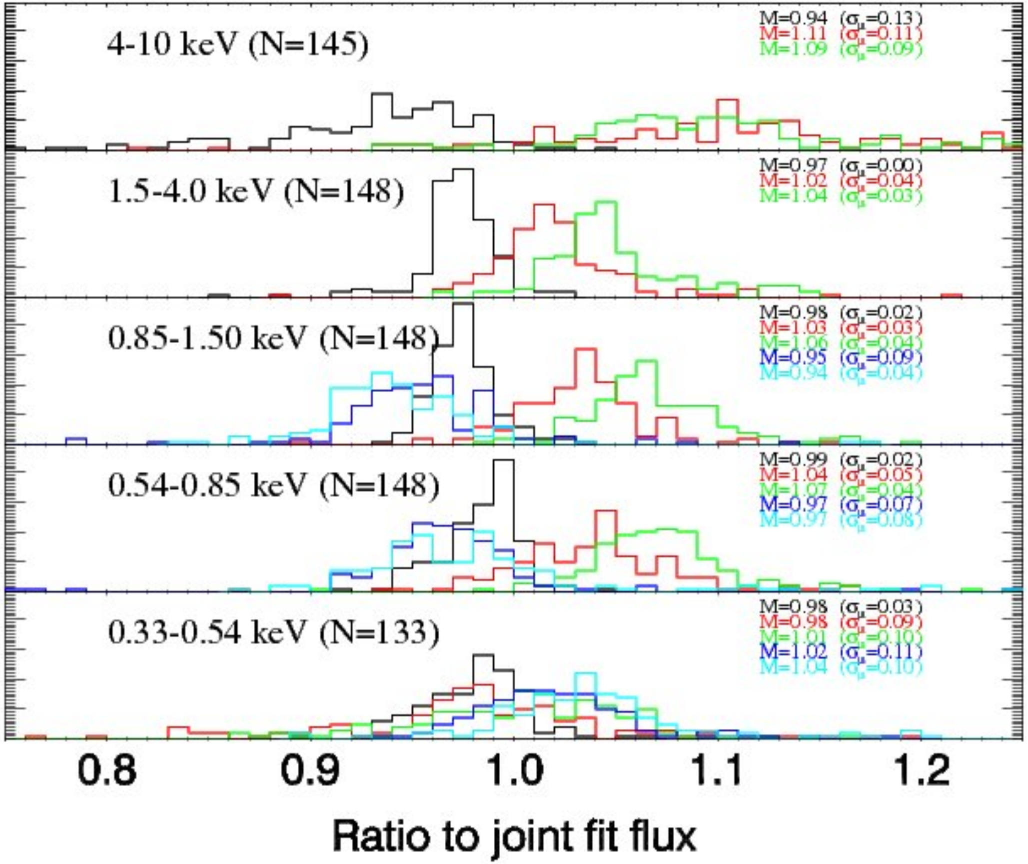
1. Recent calibration file releases

2. Current calibration topics

3. **Cross calibration status**

XMM-Newton Cross Calibration

- Instrumental flux ratios derived from a set of ≈ 150 observations in the XMM-Newton Cross-Cal Database.
- MOS1 / pn:
  - ≈ 1.00 (E < 0.54 keV)
  - ≈ 1.05 (E > 0.54 keV)
- MOS2 / pn:
  - ≈ 1.03 (E < 0.54 keV)
  - ≈ 1.08 (E > 0.54 keV)
- RGS / pn: From 1.06 to 0.96 with increasing E (using C-statistic)
- > 6 keV low statistical quality



EPIC-pn and NuSTAR

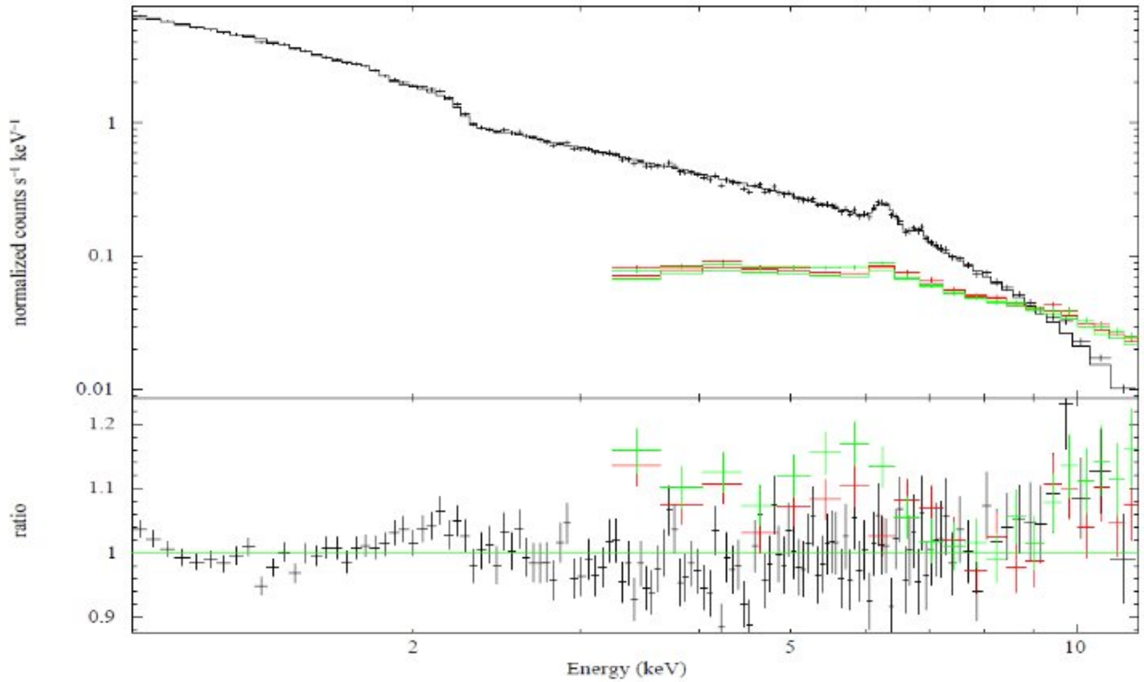
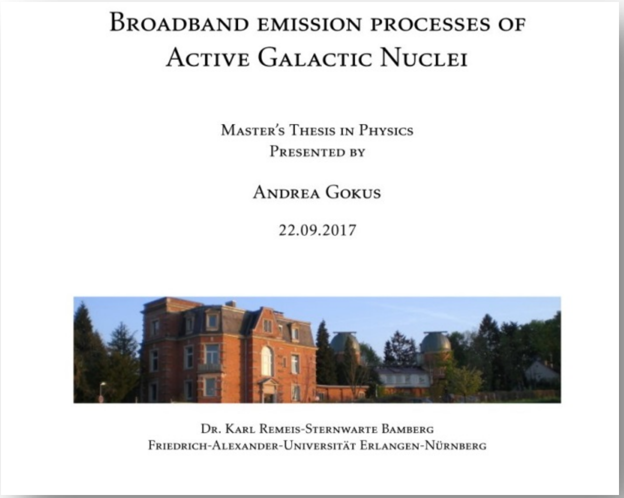
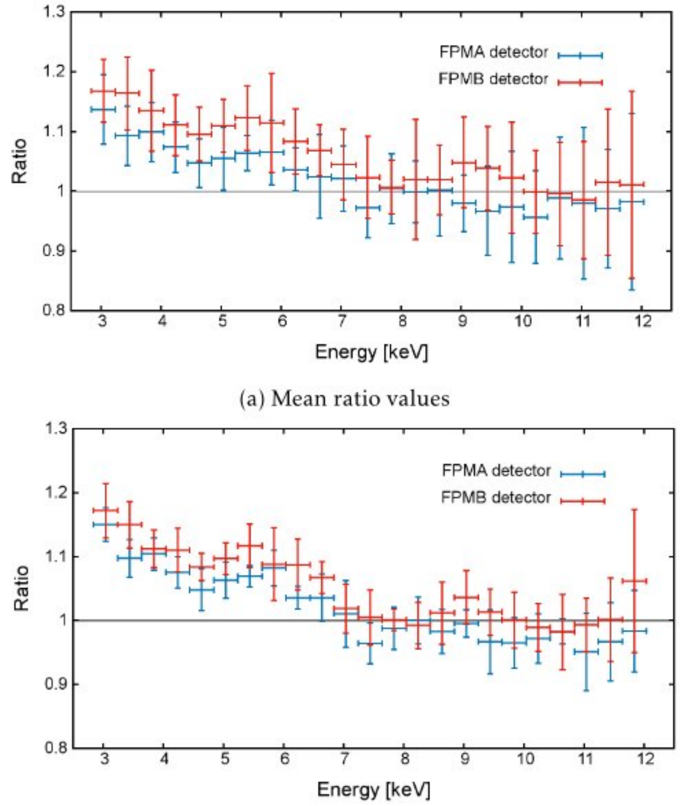


Figure 4.3: Fitted EPIC-pn spectrum (black) of Ark 120 with spectra from both detectors of *NuSTAR* (FPMA: red, FPMB: green) in the upper window. In the lower window ratio values for model vs. data are given for each spectrum.





(a) Mean ratio values

(b) Median ratio values

4.5: Ratios from FPM spectra compared to best fit to EPIC-pn spectra

Sample of 10 AGNs

Ratio = FPMx/pn-model

Broadband emission processes of Active Galactic Nuclei

Master's Thesis in Physics
Presented by

Andrea Gokus

22.09.2017

Dr. Karl Remeis-Sternwarte Bamberg
Friedrich-Alexander-Universität Erlangen-Nürnberg

NuSTAR

THE ASTROPHYSICAL JOURNAL, 841:56 (5pp), 2017 May 20
https://doi.org/10.3847/1538-4357/aa697(

CrossMark

Measurement of the Absolute Crab Flux with *NuSTAR*

Kristin K. Madsen[1], Karl Forster[1], Brian W. Grefenstette[1], Fiona A. Harrison[1], and Daniel Stern[2]
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Received 2017 January 9; revised 2017 March 10; accepted 2017 March 23; published 2017 May 23

- NuSTAR off-axis Crab observations provide the best absolute flux determinations of the Crab
- The combination of NuSTAR off-axis and NuSTAR on axis Crab observation will allow very accurate calibration of the NuSTAR effective area
- New NuSTAR response & effective area files are expected in summer 2018

XMM-Newton EPIC-pn calibration

The NuSTAR calibration can be used to re-calibrate the XMM-Newton EPIC-pn

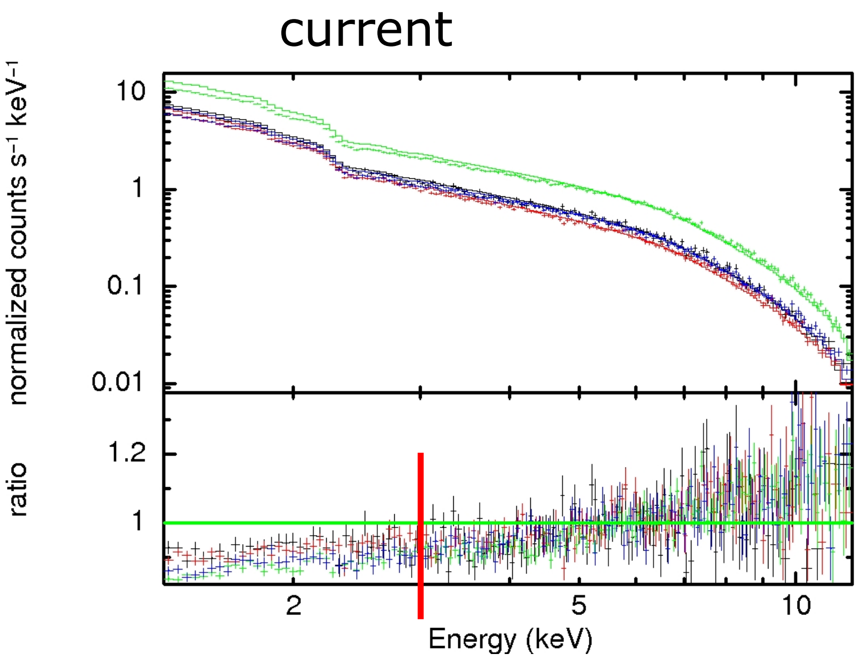
- Analysis of sources which:
  1. Have simple spectra
  2. Were observed simultaneously with NuSTAR and XMM-Newton

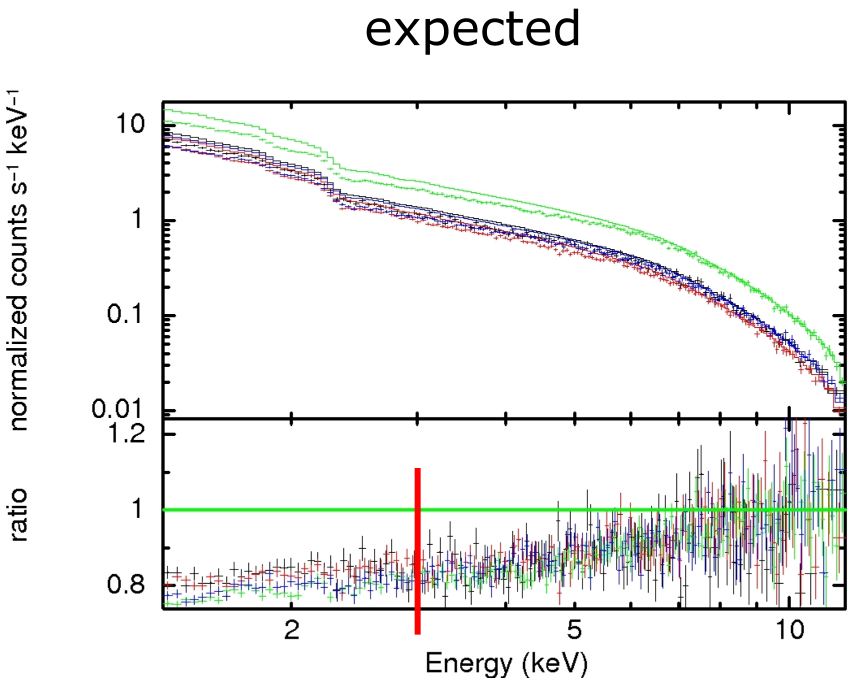
➔ 3C 273

- Challenges:
  1. Gain-shift (effective area is quite sensitive to gain-shifts)
  2. Number of photons at high energies (>7keV)
  3. Pile-up

  (2. basically always implies 3 and not the FF mode)

pn-spectra versus NuSTAR models





The End

RGS: Effective Area Correction

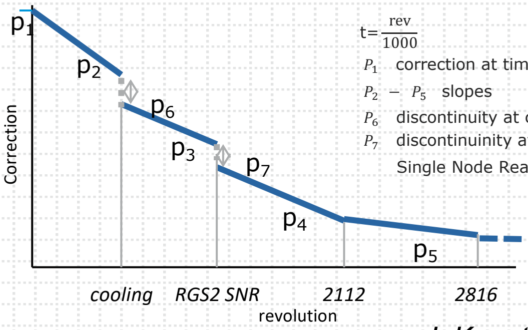
Algorithm and Implementation:

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

For each 0.05 Å bin:

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

+narrow gaussians at specific wavelengths



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

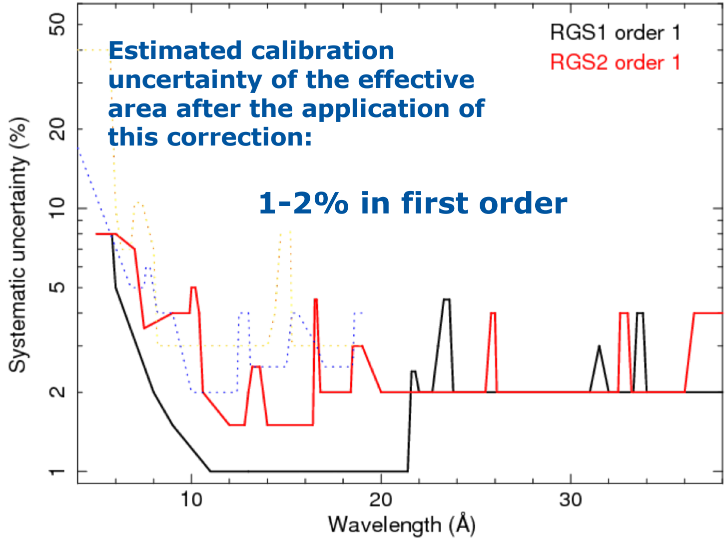
P_1 correction at time 0

$P_2 - P_5$ 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 CCFs issued:

XMM-CCF-REL-340 (12/2016)

XMM-CCF-REL-349 (06/2017)

RGS: Effective Area Correction

Testing: RGS1 v. RGS2

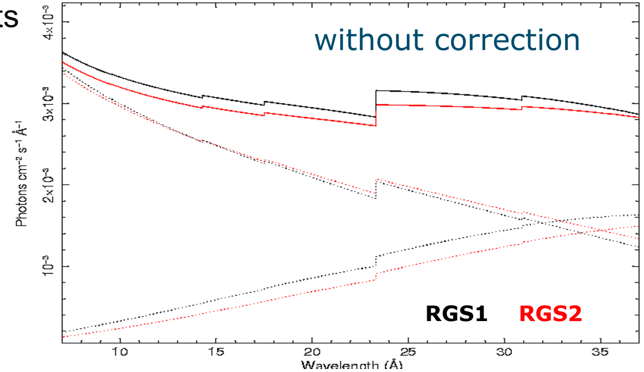
3C 273 @ rev 1465

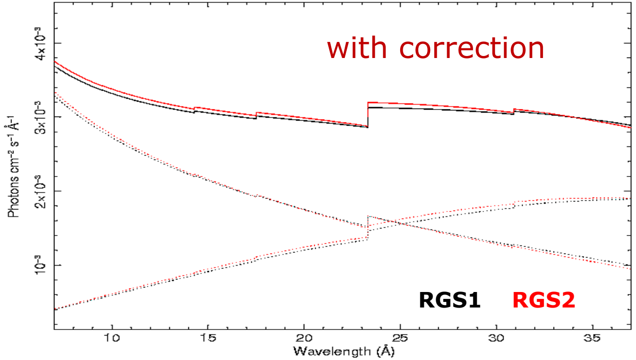
independent RGS1 and RGS2 fits

	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





XRT PSF Modification

Iterative scheme for the empirical correction of XRT XPSF parameters:

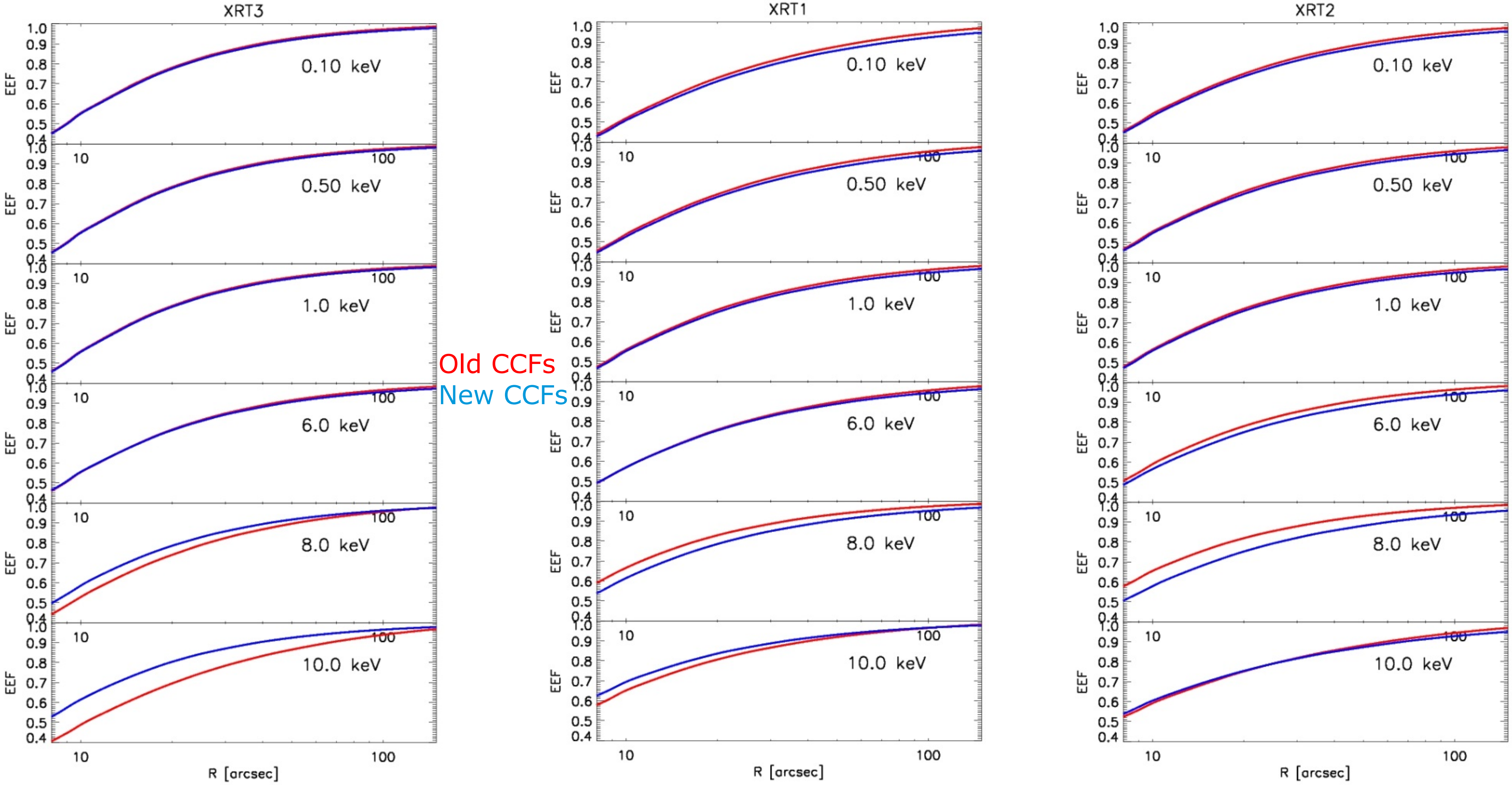
- Per source:
  - Extract spectrum from circular region
  - Extract spectra from several nested annular regions
  - Create respective RMFs
  - Create respective ARFs
  - Fit model to circular region spectrum
  - Apply this as reference model to annular spectra, derive residuals
- For all annular spectra,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

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

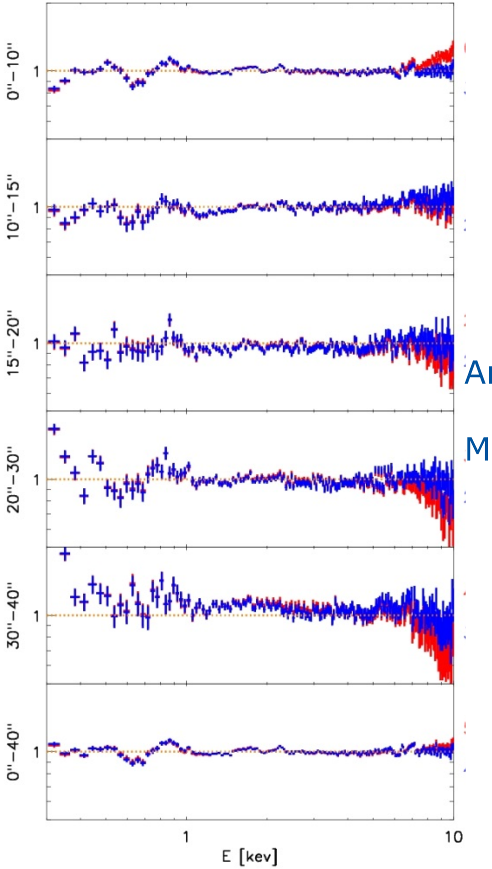
- Modify ELLBETA parameters in order to minimise the statistic

→ New XRTn_XPSF CCFs released: 08/2017 (XMM-CCF-REL-348)

XRT PSF Modification

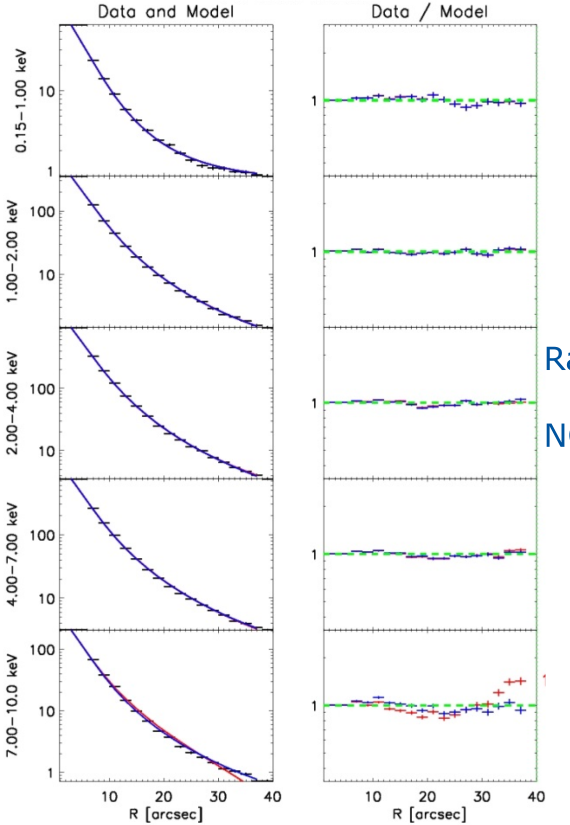


XRT PSF Modification



Annular spectral residuals

MCG-5-23-16 (PN)



Radial profiles

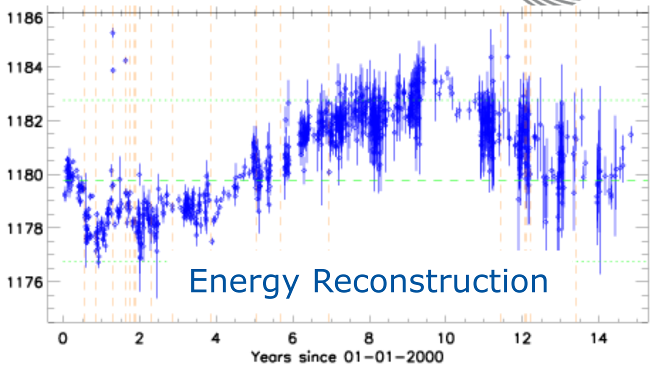
NCG 5506 (PN)

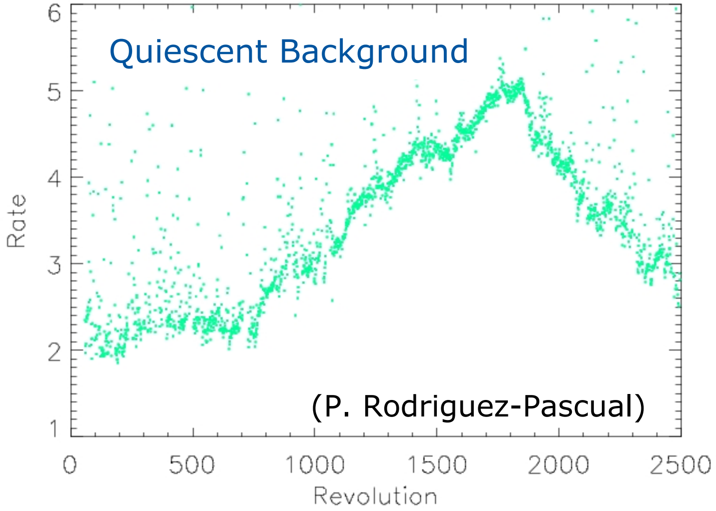
Outline

1. Recent calibration file releases
2. **New in SAS 17**
3. Current calibration topics
4. Cross calibration status

PN Quiescent Background Gain Correction

- PN gain dependency on quiescent background.
- Energy scale correction uses the discarded line rate as proxy for the quiescent background.
- Current SAS implementation uses 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 → **SAS 17**
- Also requires recalibration and robust handling of telemetry gaps, outlier values, intrinsic noise.





Current High and Medium Priority Tasks

High priority

- EPIC flux cross-calibration:
  CORRAREA and mirror Aeff
- Off-axis EPIC PSF
- XMM Cross Calibration Archive maintenance and development
- EPIC cross-calibration with other observatories
- Monitoring of EPIC energy scale, bad pixels and offsets
- PN quiescent background-dependent gain correction
- PN fast modes calibration
- Monitoring of PN flux stability
- Monitoring of PN timing accuracy
- Monitoring of MOS and RGS contamination

Medium priority

- EPIC vignetting
- EPIC particle-generated background characterisation
- PN energy scale for windowed modes

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- MOS2 / pn:
  - ≈ 1.03 (E < 0.54 keV)
  - ≈ 1.06 (E > 0.54 keV)
- RGS / pn: From 1.00 to 0.93 with increasing E

  (using χ^2 statistic)