EPIC Calibration

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

25th XMM-Newton Users' Group Meeting, 26 June 2024

2023 XMM Users' Group recommendations on calibration priorities for EPIC

2020-06-08/09: [..] continue the investigations into the pn empirical RMF modelling (e.g., expand to energies >1.7 keV, include other modes, epochs, and spatial regions) and incorporate the outcome into SAS.

2020-06-08/11: [..] continue the investigations into the off-axis flux calibration of the EPIC cameras.

2022-05-17/05: [..] further streamline the process of CTI correction and to fully implement the energy scale calibration at Cu Kα with that at Al Kα and Mn Kα.

2022-05-17/06: [..] verify the pattern fractions determined from in-orbit data with the expected pattern fractions.

2022-05-17/07: [..] creation of proton response matrices and to make them available through SAS.

2023-05-11/01: The UG acknowledges the ongoing efforts to improve the cross-calibration of XMM-Newton instruments and reduce the discrepancies between MOS and pn in the soft-energy band and at higher energies. The UG recommends continuing the investigation of the possible causes of the differences and monitoring the temporal evolution of factors already identified (contamination, rmf, ...) to regularly update their impacts.

2023-05-11/02: [continue] efforts to improve cross-calibration between XMM-Newton's EPIC detectors and those of NUSTAR. It recommends monitoring the evolution of the flux and shape of the PN and MOS spectra relative to NUSTAR, using regular simultaneous observations to update, when appropriate, the empirical correction of the EPIC spectral shape [..]

Empirical PN RMF modelling

EPIC PN empirical RMF modelling:

Ongoing work by MPE team.

To date, modelling has concentrated on low E response, for PN Small Window mode data.

Aim is to:

- Expand beyond 1.7 keV – requires suitable sources with sufficiently reliable spectral models;
- Include other modes, epochs, spatial regions.

Work in progress...

EPIC Off-axis flux calibration

Issues concerning EPIC off-axis calibration reported by e.g.:

- Mateos et al., A&A 496 (2009)
- Lusso, Astron. Nachr. 340, 4 (2019)

EPIC flux comparisons (based on 2XMM / 3XMM data) show radial (and possible azimuthal) dependency of EPIC flux ratios.

Results reproducible with 4XMM data, however interpretation not straightforward due to:

- Count rates–to–flux conversions
- Background
- Source variability

In order to investigate vignetting calibration:
investigate individual sources, e.g. raster observations (archival and new)

EPIC Off-axis flux calibration

Analysis of raster scan observations of SNRs 3C58 (2002) and G21.5-09 (2001, 2021):

For PN:

vignetting correction accurate to ± 5%

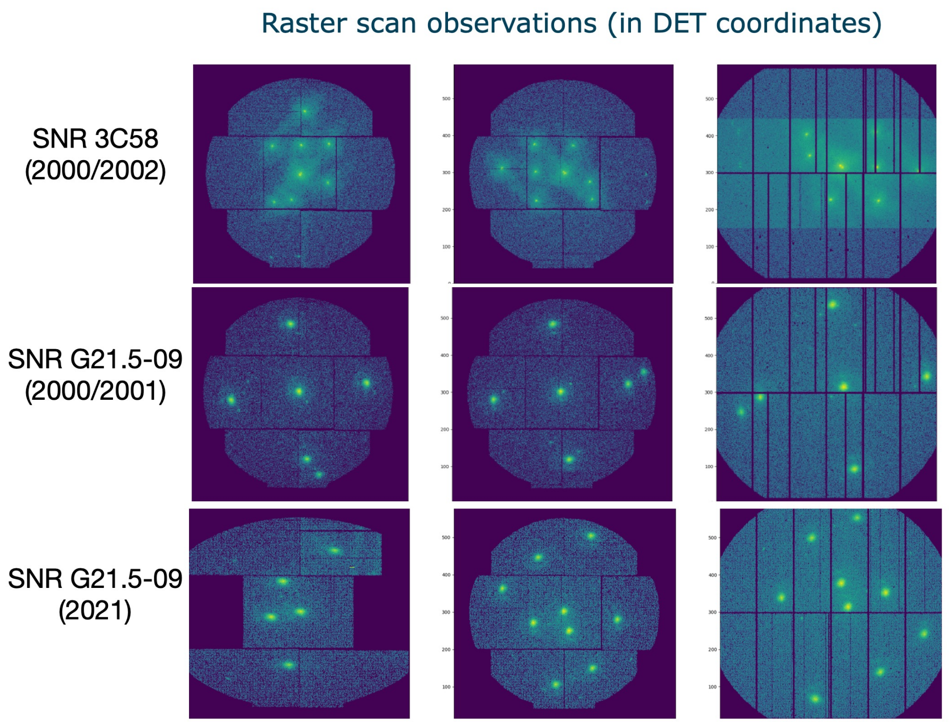
For MOS:

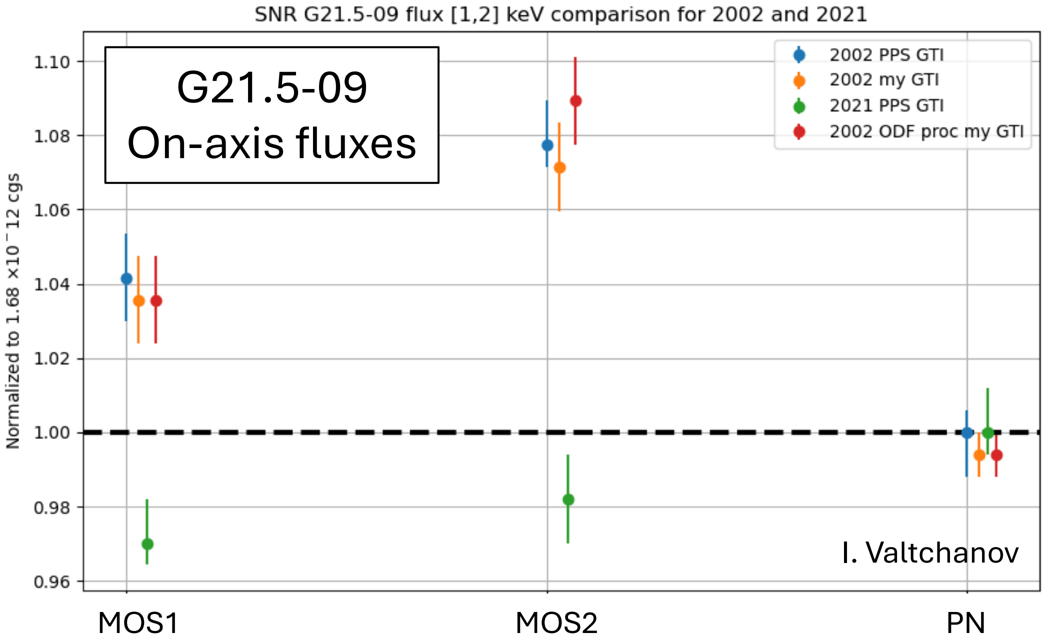
Interpretation complicated due to on-axis flux differences for earlier and recent observations (4-8% effect, E-band dependent).

Vignetting results dependent on choice of epoch of on-axis observation (used for normalisation).

Initial suspicion: due outdated MOS response + contaminant calibration.

However, reanalysing with updated MOS calibration (released April 2023) issue remains.

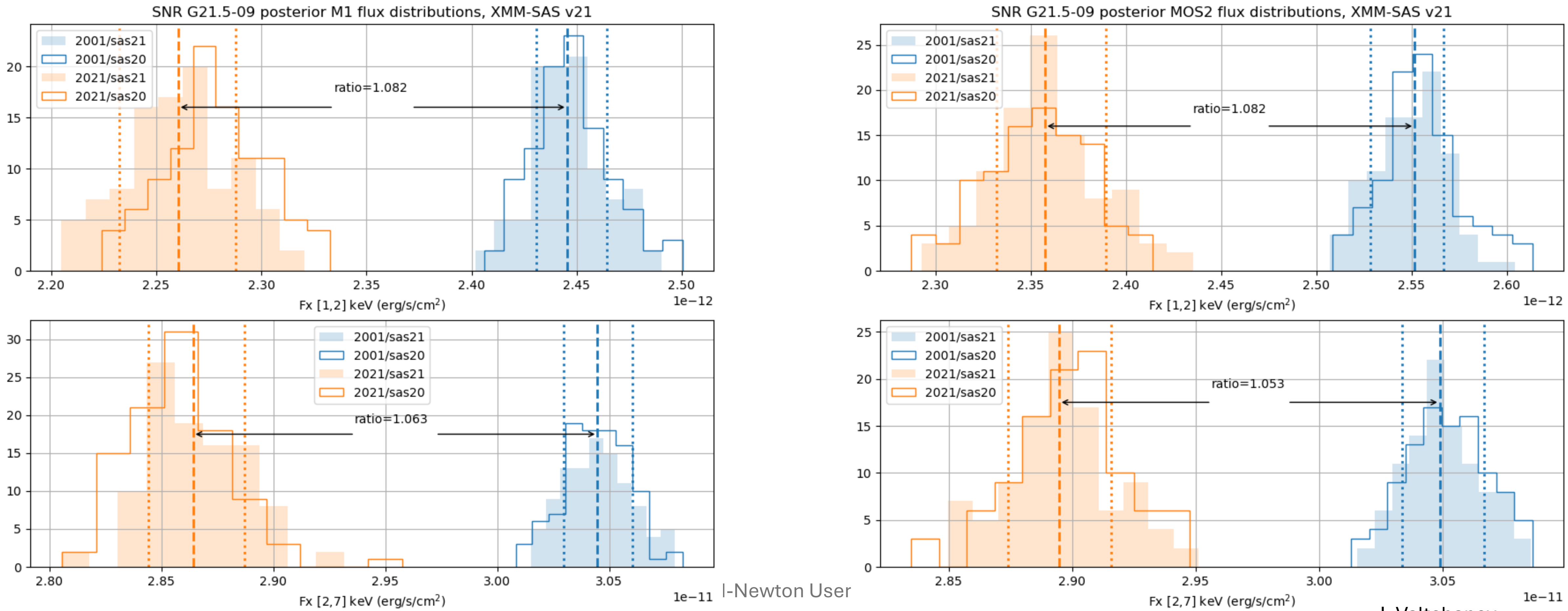




EPIC Off-axis flux calibration

Using latest MOS response calibration

- SNR G21.5-09, on-axis fluxes, from 2001 to 2021:
  ~ 5 – 8% decrease for MOS1 and MOS2



I. Valtchanov

EPIC Off-axis flux calibration

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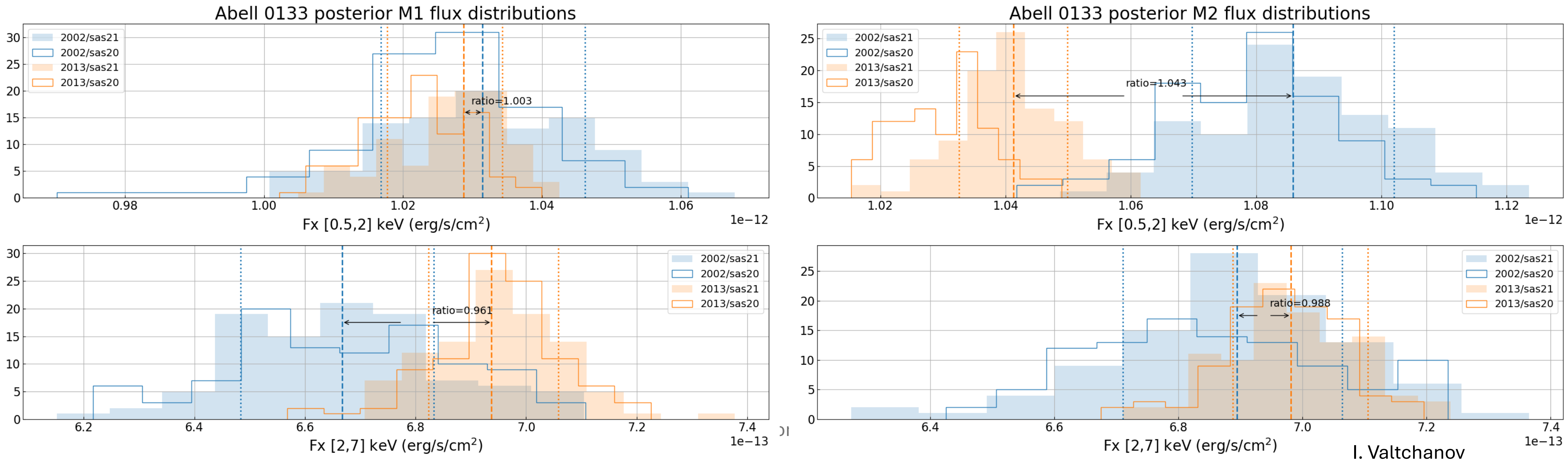
- Abell 0133 galaxy cluster, on-axis fluxes, from 2002 to 2013:
  ~ 4% increase for MOS1 (2-7 keV band)
  ~ 4% decrease for MOS2 (0.5 – 2 keV band)

- PN shows no significant evolution (consistent within 2-3%)



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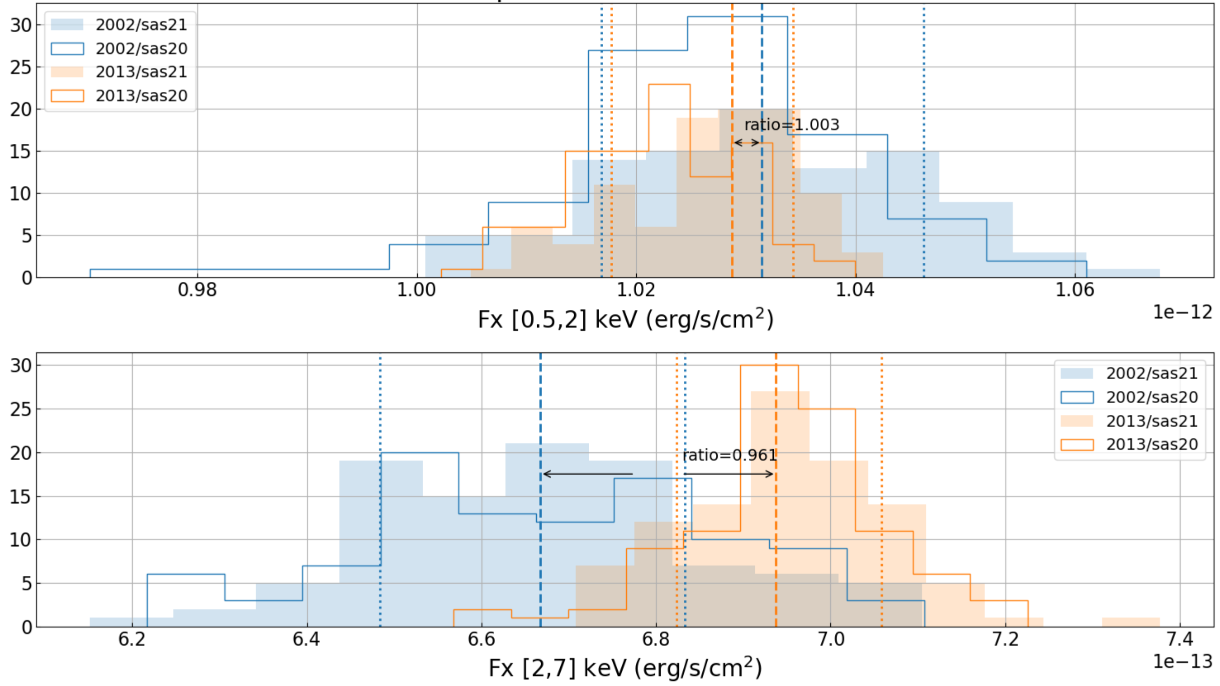
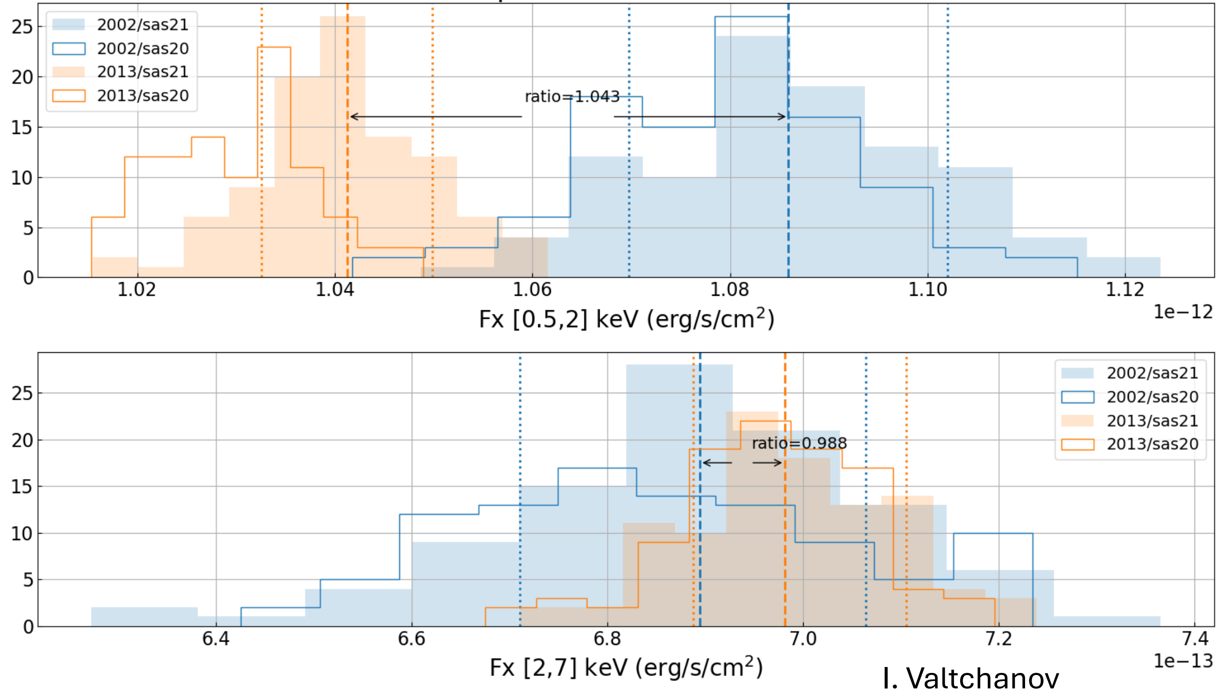
Requires further investigation:

- Analysis of stable sources with >2 observations over sufficient baseline;
- Compare temporal evolution of MOS / PN fluxes for a sufficiently large sample of sources.

Abell 0133 posterior M1 flux distributions



Abell 0133 posterior M2 flux distributions



I. Valtchanov

Consolidation of PN energy scale

Analysis for the latest update to PN long-term CTI correction (XMM-CCF-REL-407, Valtchanov+) involved substantial integration of Al Ka (1.5 keV), Mn Ka (5.9 keV) and Cu Ka (8.0 keV) emission line data.

Main outstanding issue is: revisiting the Quiescent Background Dependent Gain correction.

- Previously calibrated at Al Ka and Mn Ka.
- Cu Ka should be incorporated.
- Also, since original calibration, additional solar cycle's worth of data.
- The analysis should be streamlined: manual iteration ➔ simultaneous fit

Work in progress...

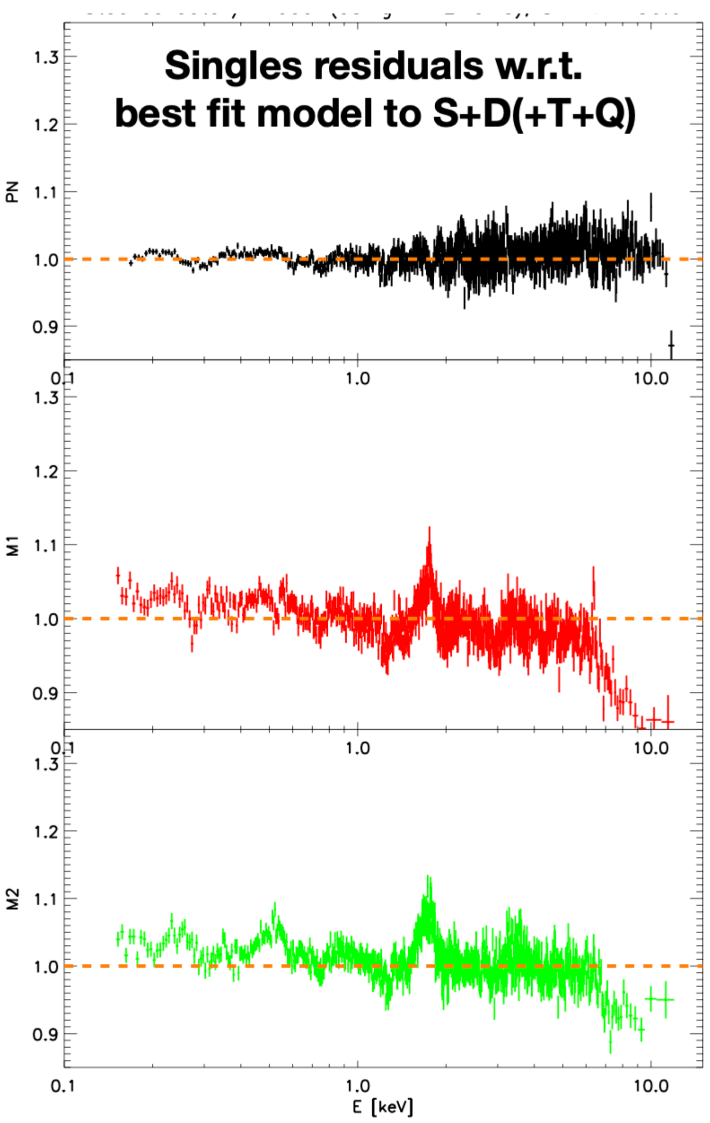
MOS pattern fractions

Analysis shows unaccounted for differences between MOS spectra created with singles versus s+d+t+q:

- Mainly affects data > 6 keV
- Assumed pattern fractions and respective QEs affect effective area
- Compare in-orbit data pattern fractions with calibration curves

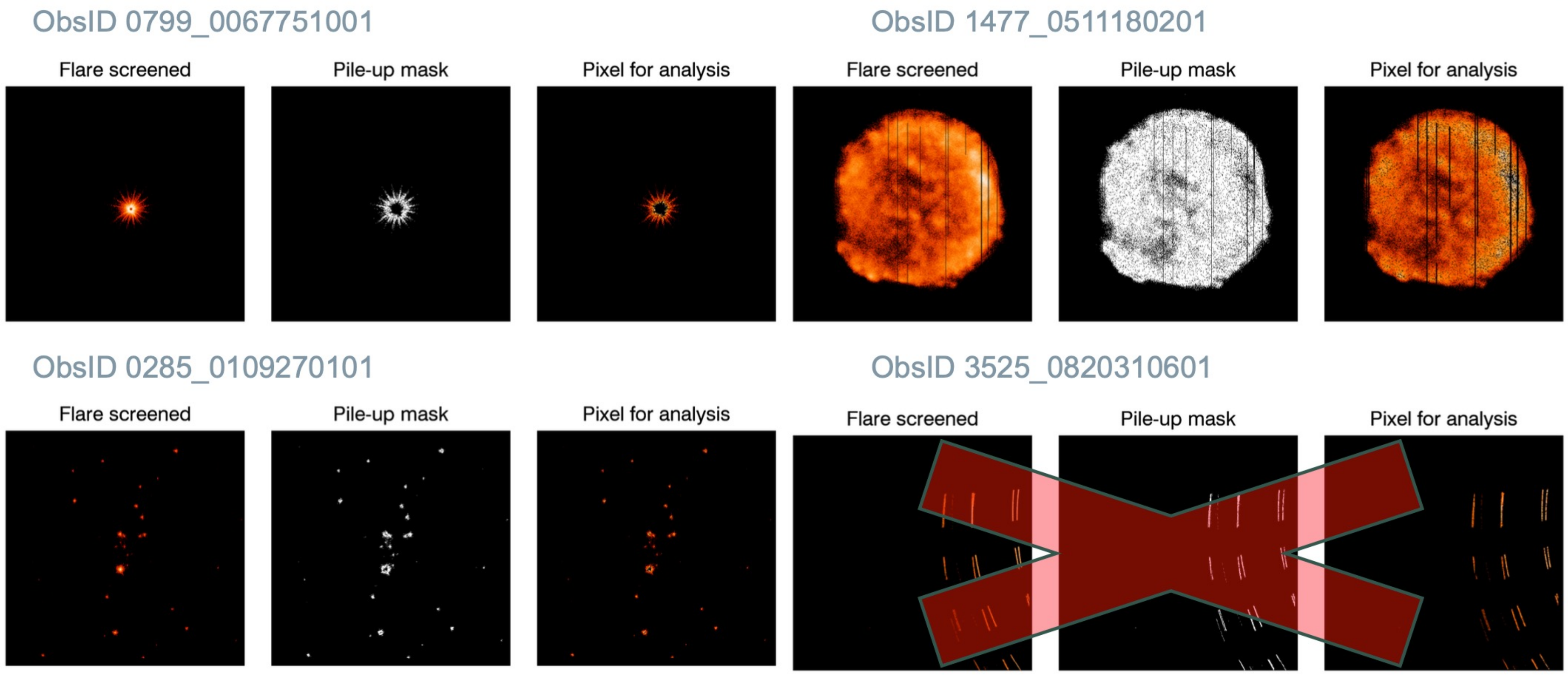
For observations from full XMM-Newton archive, select observations and events (as of now, just CCD01):
- > 20000 counts after flare screening;
- >= 10 counts/pixel;
- pile-up fraction < 1.0%;
- > 1000 counts with E > 3 keV.

Distinguish spatial regions:
- On-patch (patch centre / patch wing)
- Off-patch
- All data



MOS pattern fractions

Data selection; FF mode examples



M. Stuhlinger

MOS pattern fractions

Comparison of measured in-orbit pattern fractions with calibration curves.

3 epochs:

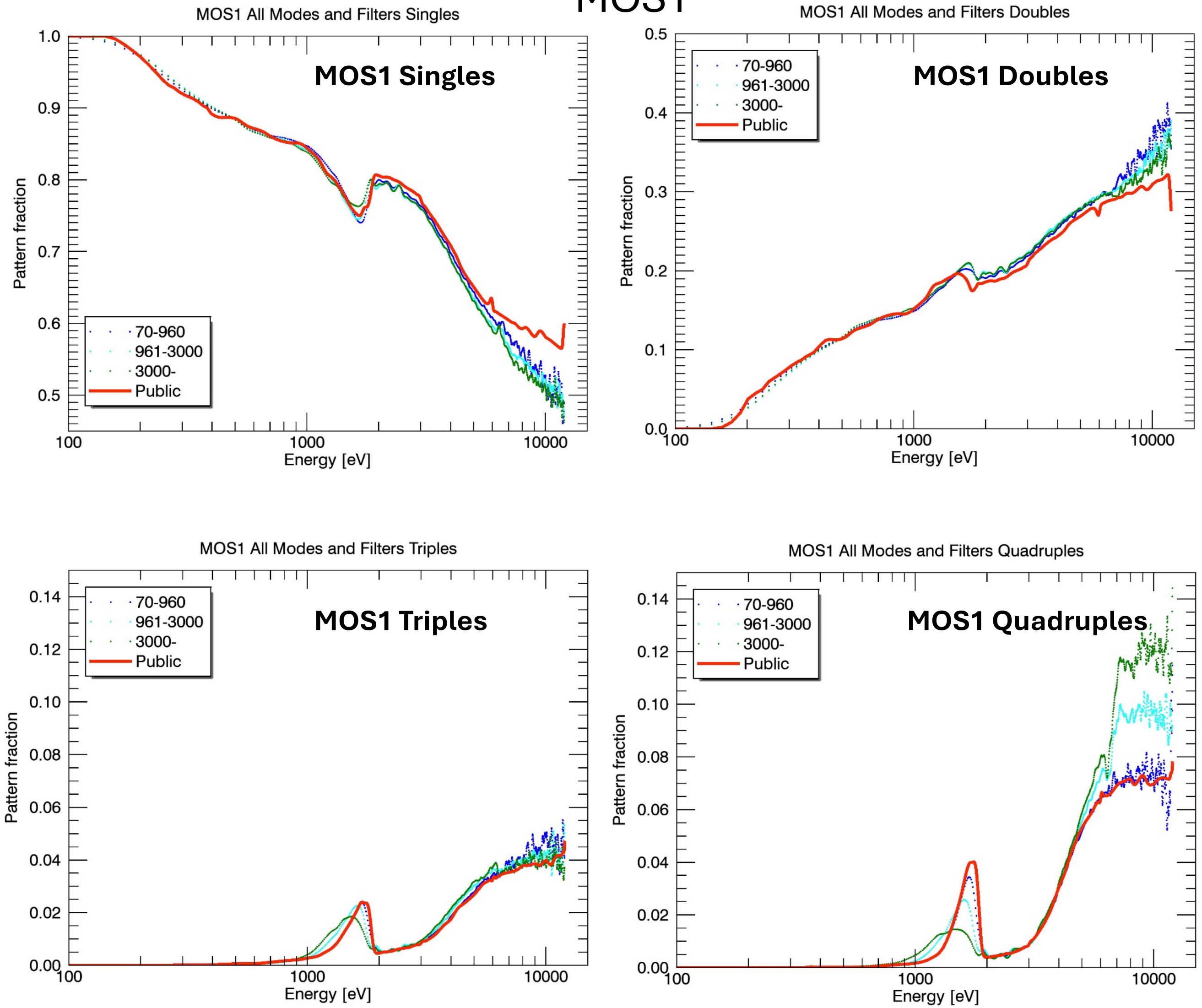
- Rev 70 – 960
- Rev 961 – 3000
- Rev 3000 –

Significant deviations from calibration curve:

- > 6 keV:
  - deficit of singles; excess of doubles;
  - T-dependent excess in quadruples for MOS1
- T-dependent widening at Si-edge

pattern fraction v. instrumental energy

MOS1



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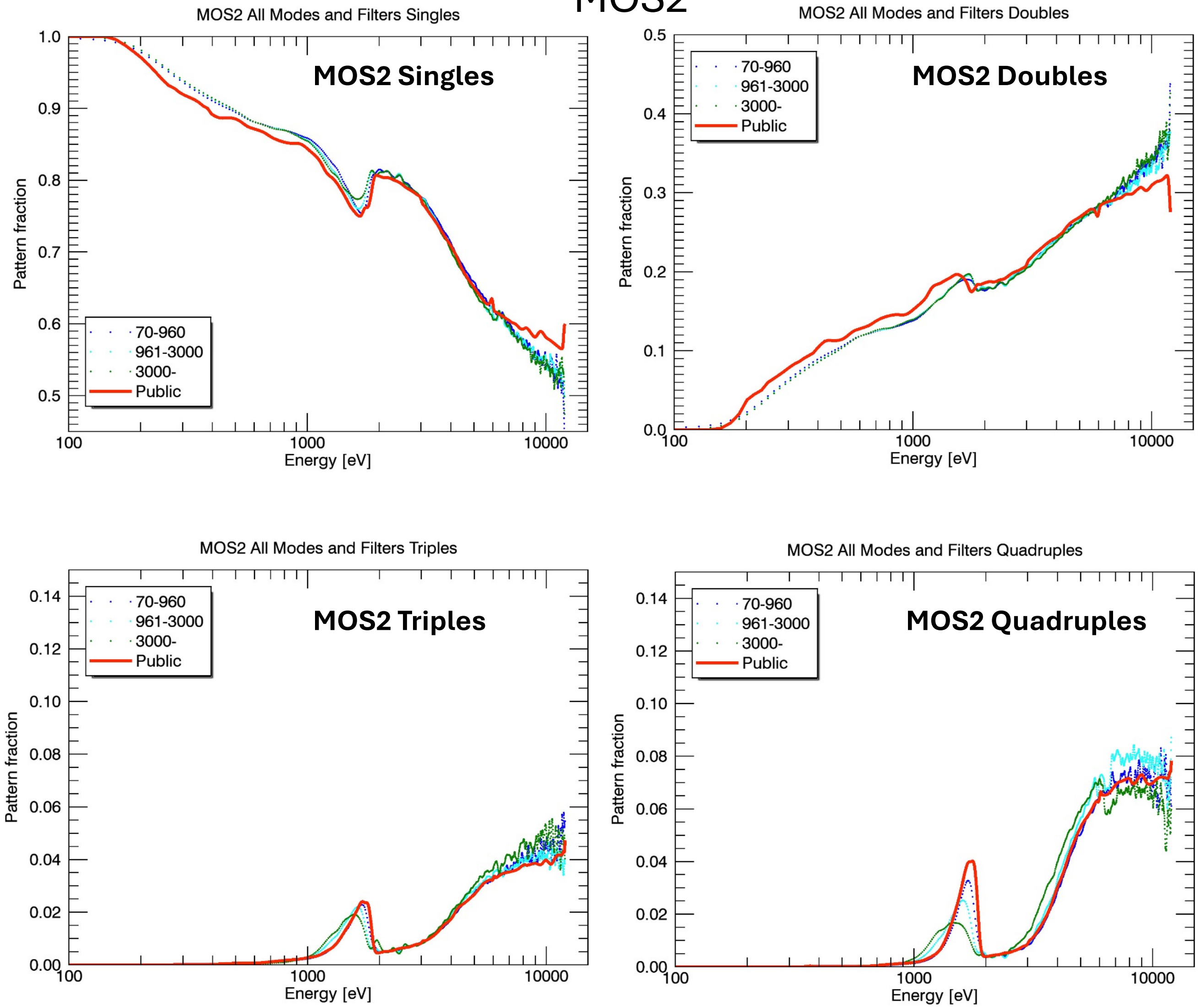
pattern fraction v. instrumental energy
MOS2



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- > 6 keV:
  - deficit of singles; excess of doubles;
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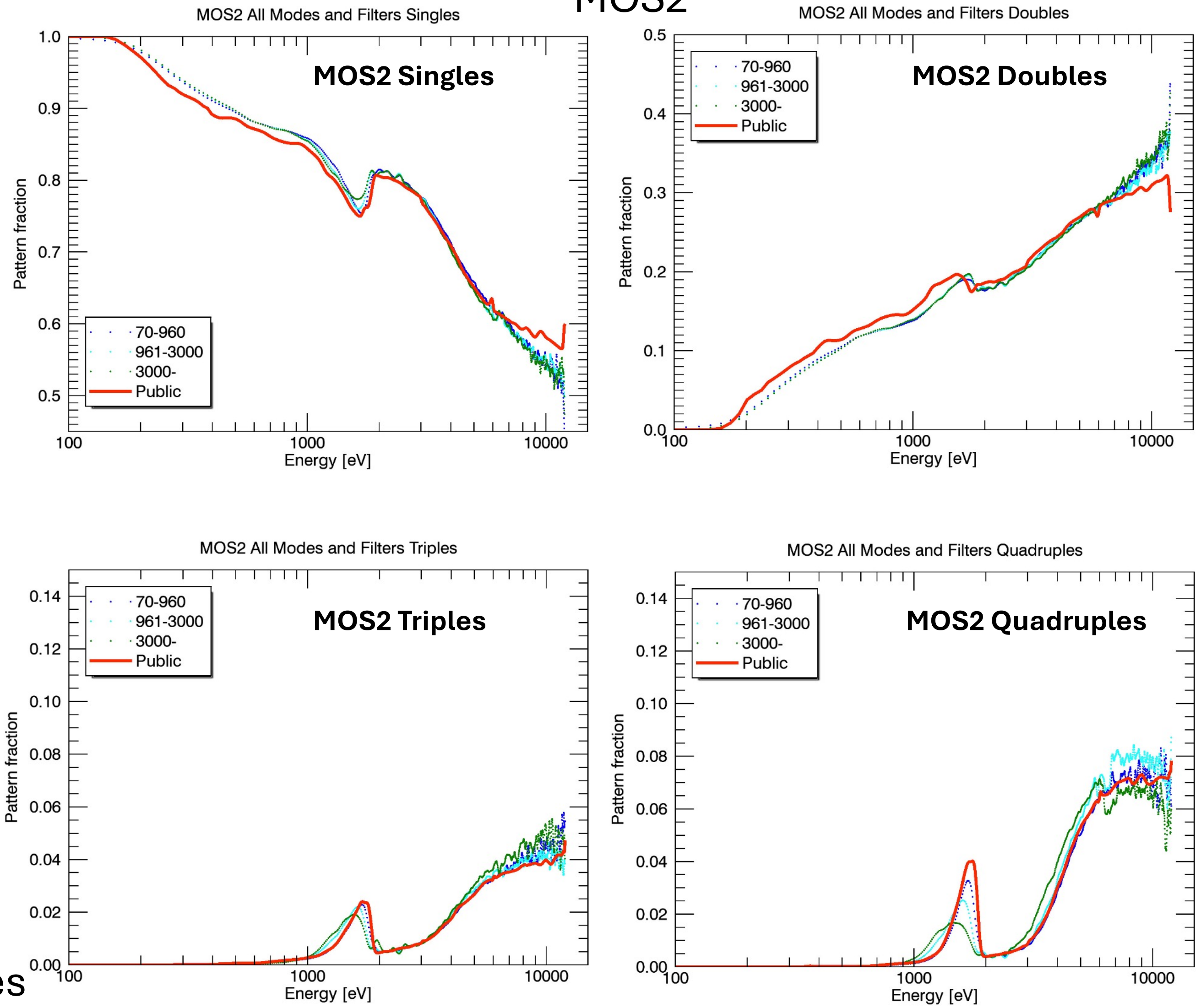
- T-dependent widening at Si-edge

Next steps:

- derive new curves (already being tested);
- “deconvolve” to photon energy space (these curves are used in the creation of response files).

pattern fraction v. instrumental energy
MOS2



M. Stuhlinger

Proton response matrix

”Design and characterisation of a prototype proton response matrix for the XMM-Newton mission” Fioretti et al. Proc. SPIE, V 11822, id. 118221F (2021)

- Describes the effective area and energy redistribution of protons entering the mirror aperture;
- Should allow a better understanding of the proton radiation environment, with the aim of modelling the in-flight non X-ray background.

The matrices have now been released by the development team.

Currently investigating how to make these matrices available via a SAS task.

Update of the MOS-to-PN empirical effective area correction

So-called “CORRAREA” correction introduced in 2014.

Empirical correction of MOS A_{eff} to match PN flux measurements.

Choice to normalise to PN essentially arbitrary.

Previous update in 2021: addressed the > 2 keV A_{eff}

New calibration extends the correction down to 0.15 keV

Same methodology, larger sample (IAAT team): ~ 200 observations of

- On-axis point sources
- Bright, but not piled-up

1. Determine the instrumental residuals to the best fit PN models
2. Stack the residuals for increased signal-to-noise
3. Normalise stacked residuals to those of PN

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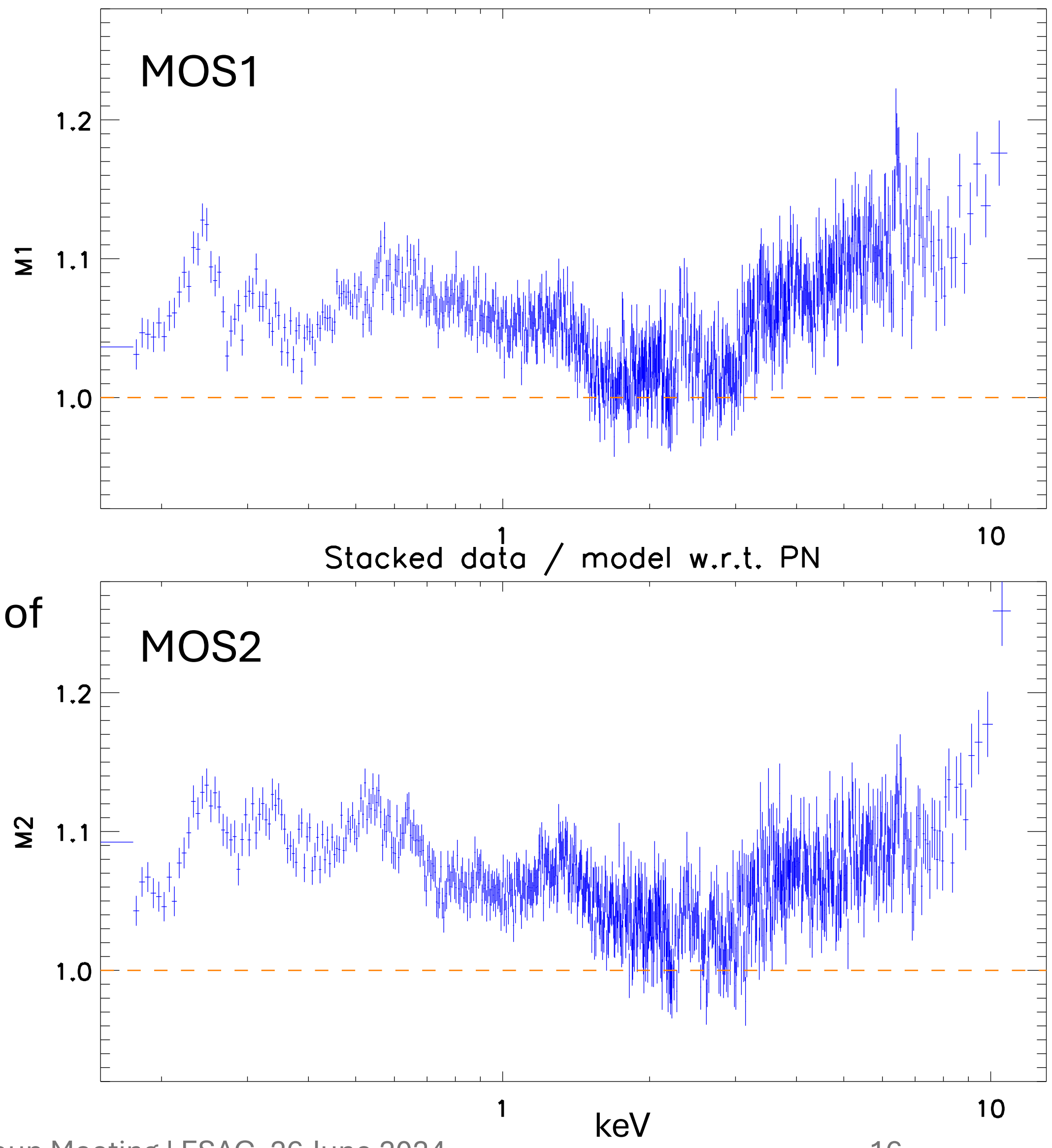
Stacked data / model w.r.t. PN

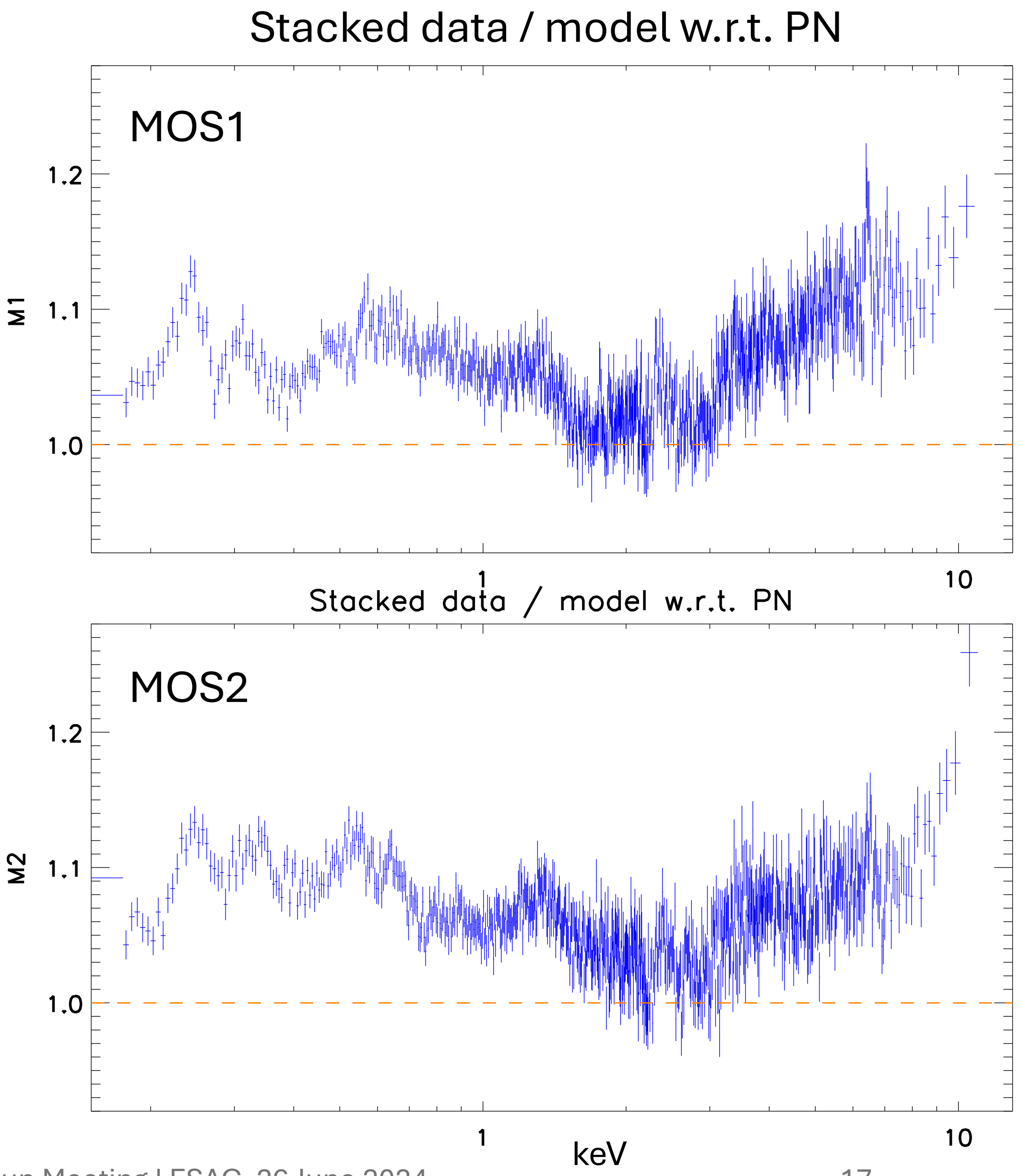


Update of the MOS-to-PN empirical effective area correction

For each MOS:

Define A_{eff} correction models:
Spline functions of multiplicative factors applied to standard A_{eff} file.

Derive the A_{eff} correction functions (simultaneous fit over all observations) that minimise the stacked residuals



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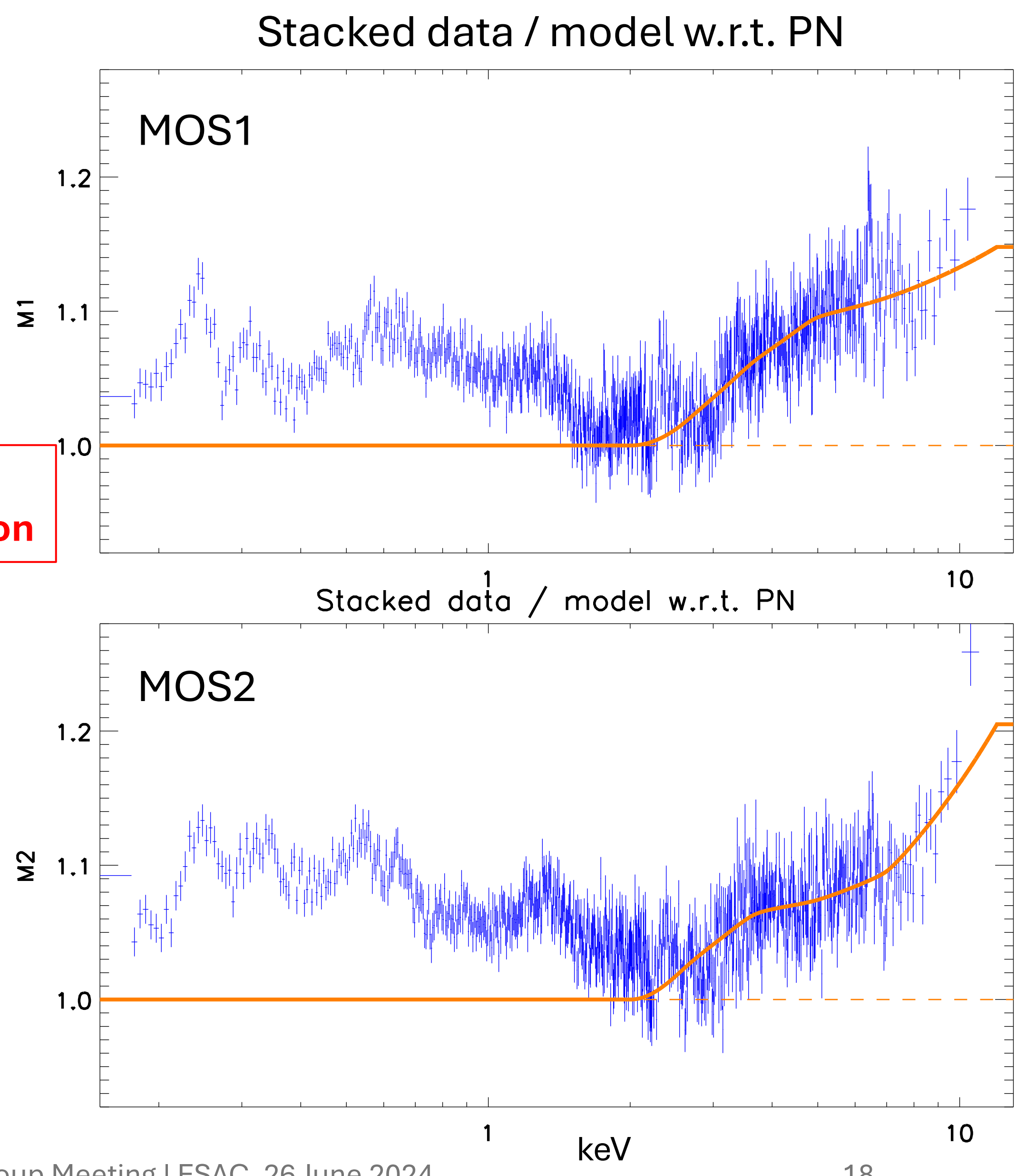
Previous Aeff correction



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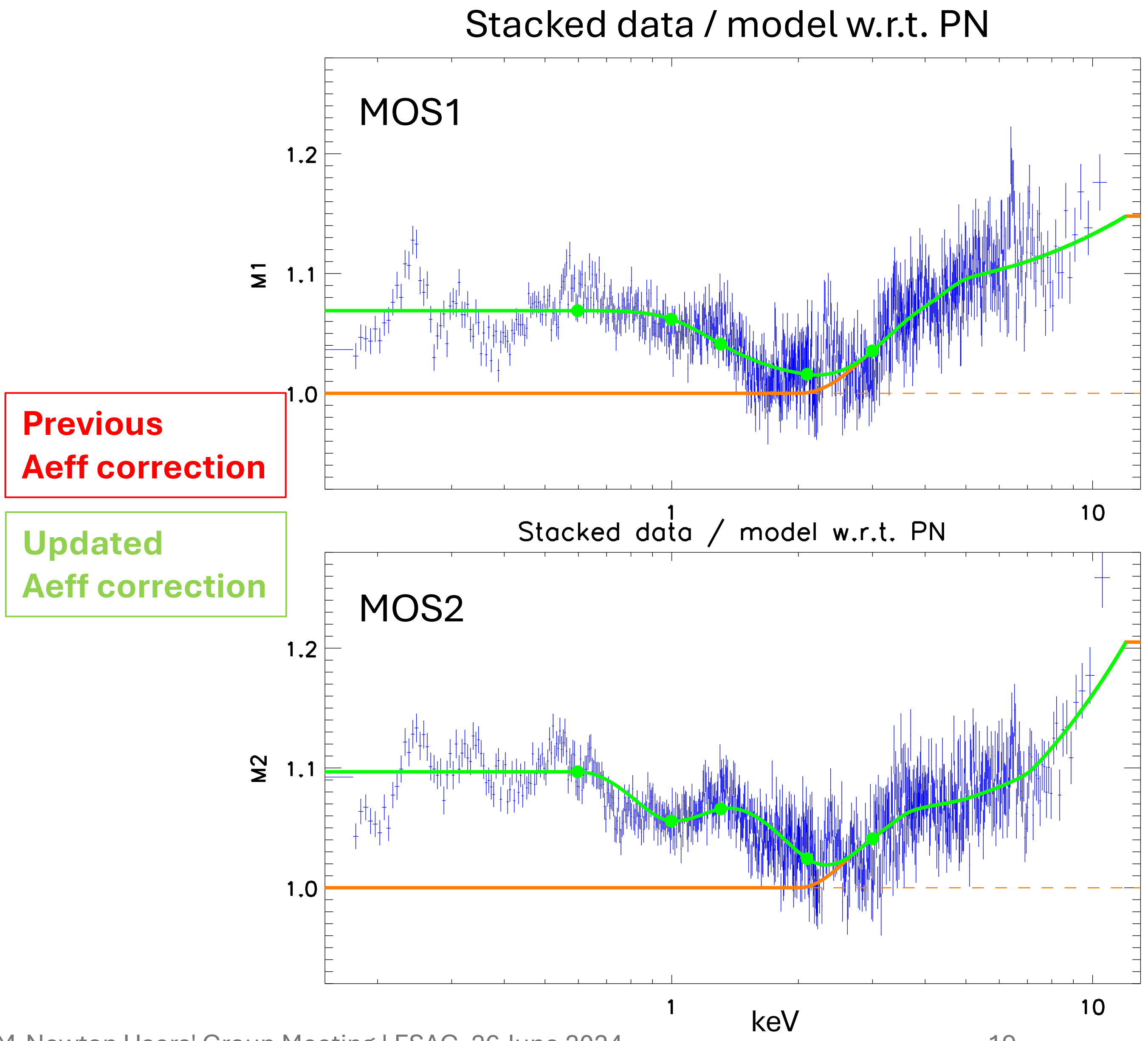
For each MOS:

Define A_{eff} correction models:
Spline functions of multiplicative factors applied to standard A_{eff} file.

Derive the A_{eff} correction functions (simultaneous fit over all observations) that minimise the stacked residuals.

No attempt to correct features below 0.6 keV, which could be due to residual calibration inaccuracies:

- Effective area
- Redistribution
- Energy scale

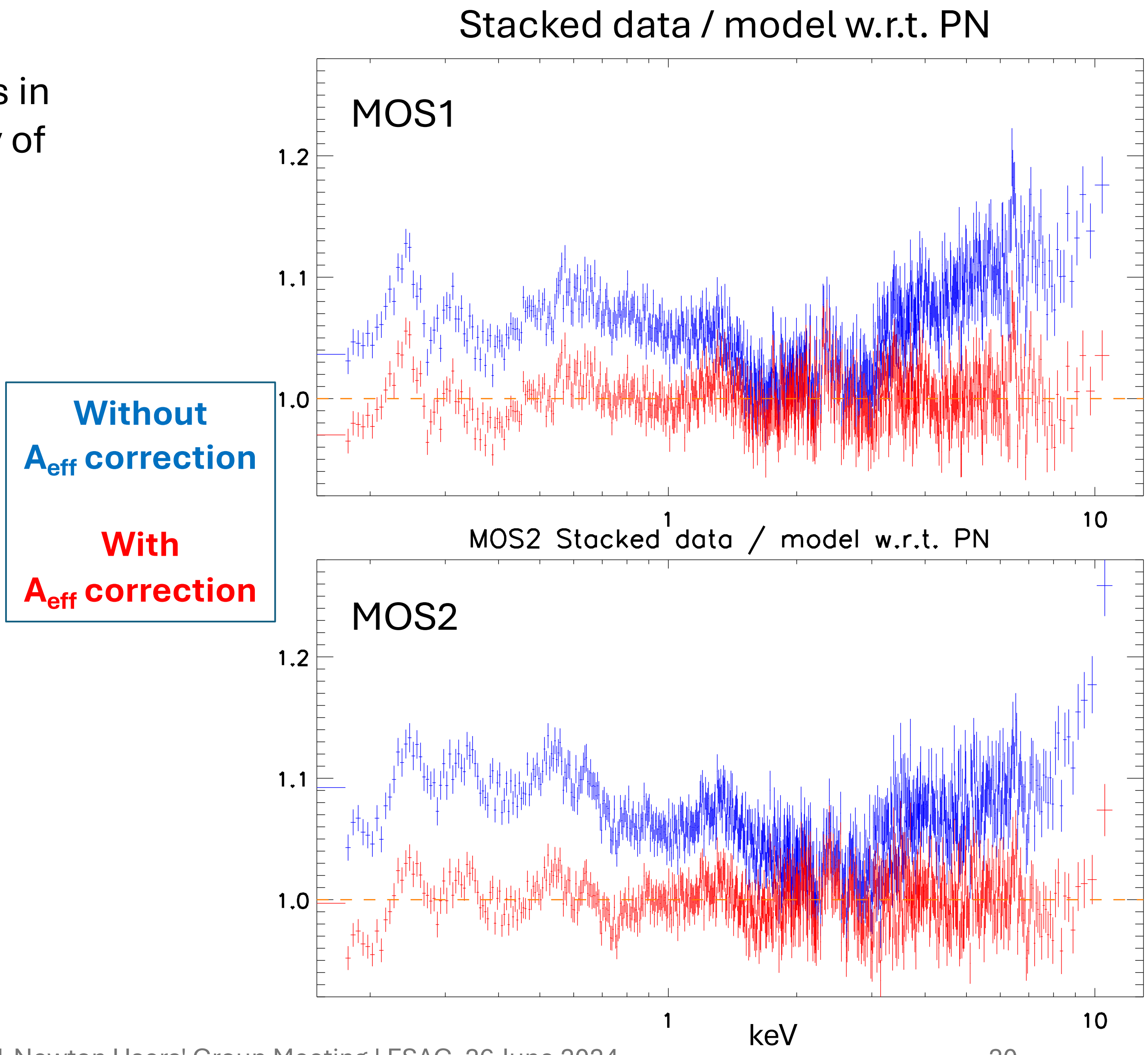


Update of the MOS-to-PN empirical effective area correction

Applying the correction significantly reduces residuals in joint MOS-PN spectral fits, on average, and in majority of individual observations.

Features at ~5% level mainly below 1 keV remain; likely due to residual calibration inaccuracies in:

- Effective area
- Redistribution
- Energy scale



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- Effective area
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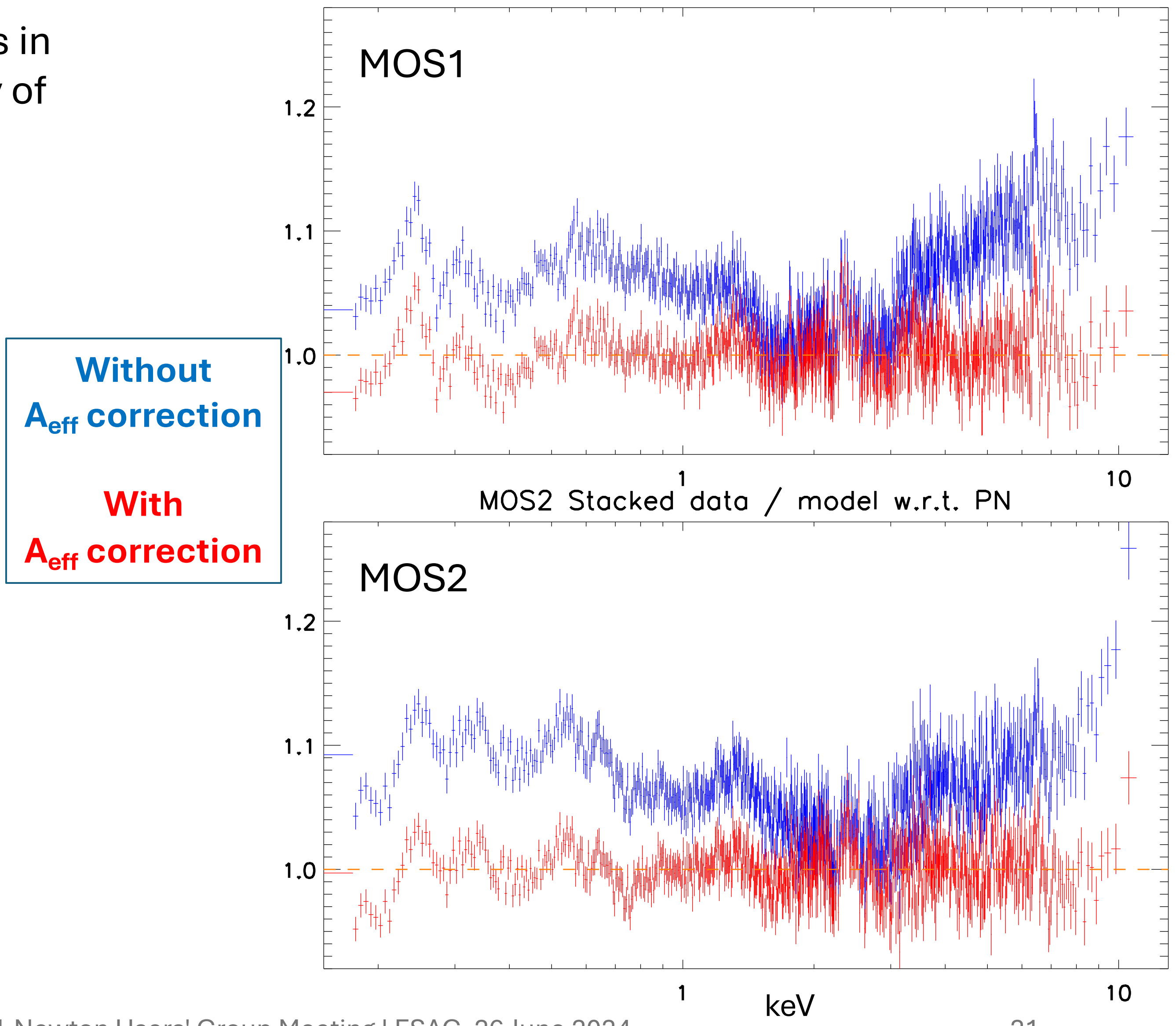
Up to now, the correction is not applied by default (needs to be explicitly invoked in the `arfgen` task).

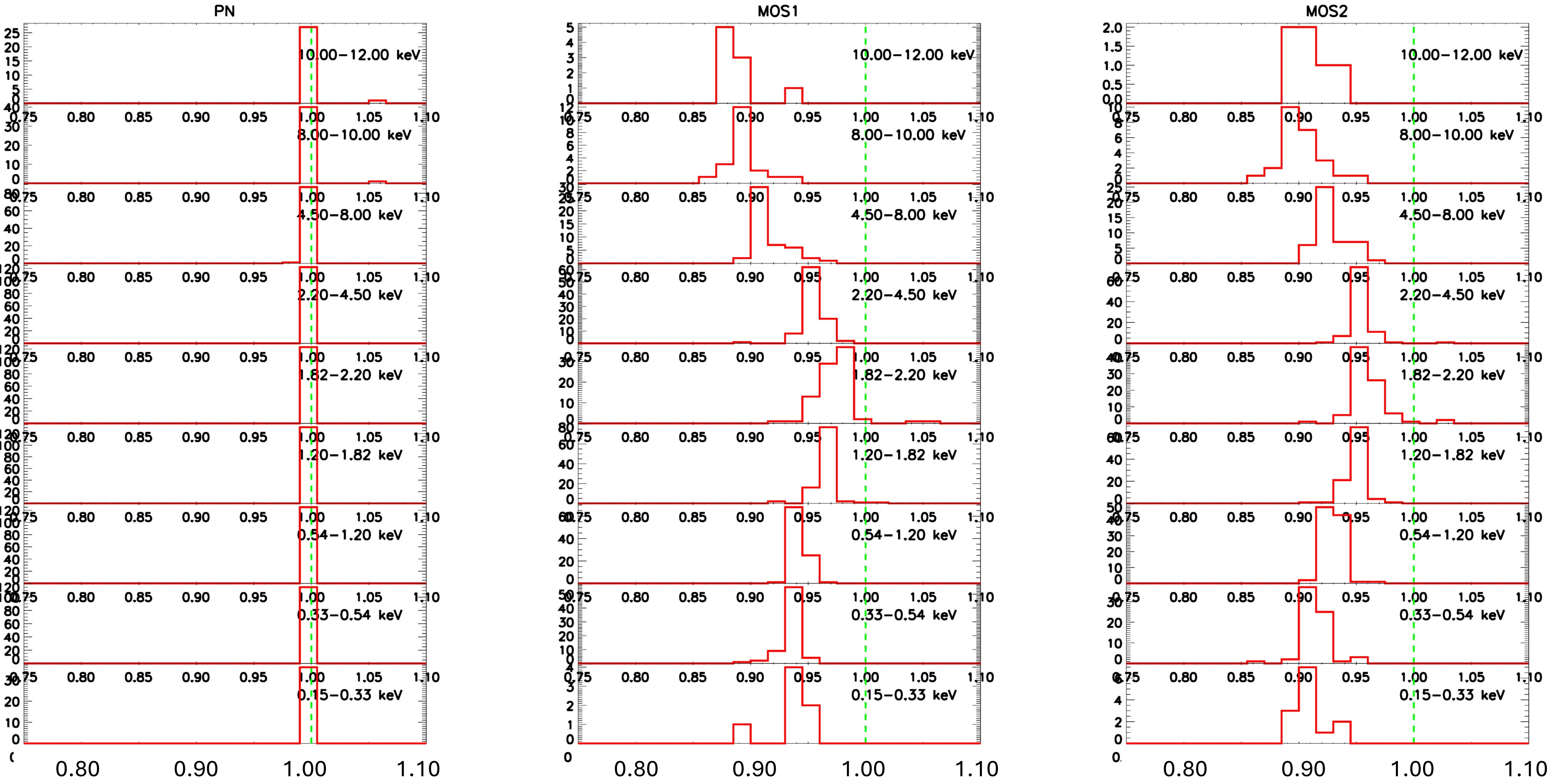
As of SAS 22 (~ autumn 2024) the correction will be applied in the default processing:

```
arfgen applyxcaladjustment=yes
```

Stacked data / model w.r.t. PN



Relative changes in instrumental flux ratios comparing with / without CORRAREA correction

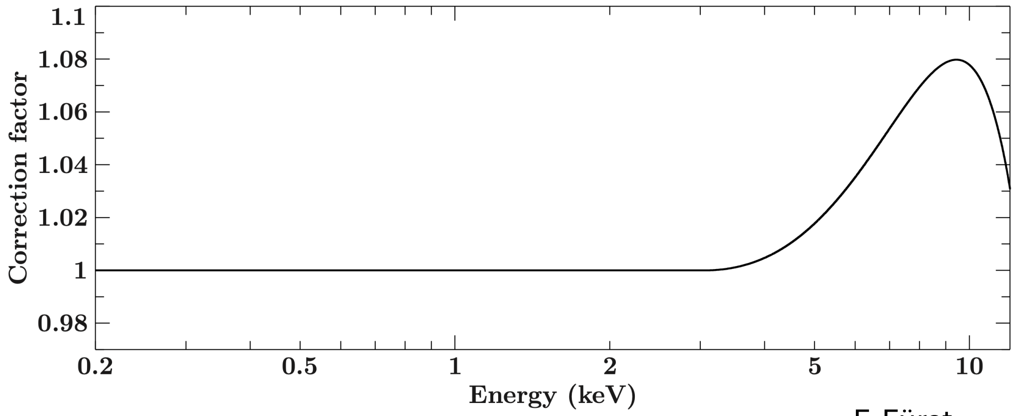


EPIC-NuSTAR empirical effective area correction

EPIC-NuSTAR empirical effective area correction released in April 2022

Based on comparison of simultaneous PN – NuSTAR observations (above 3 keV):
- 3C 273 (PN SW mode), sample of AGN (PN SW mode), Crab nebula (PN Burst mode)

Findings showed discrepancies could be described by:
- Difference in spectral shape (up to ~ 6% difference in terms of flux)
- Overall cross normalisation offset (18%)



F. Fürst

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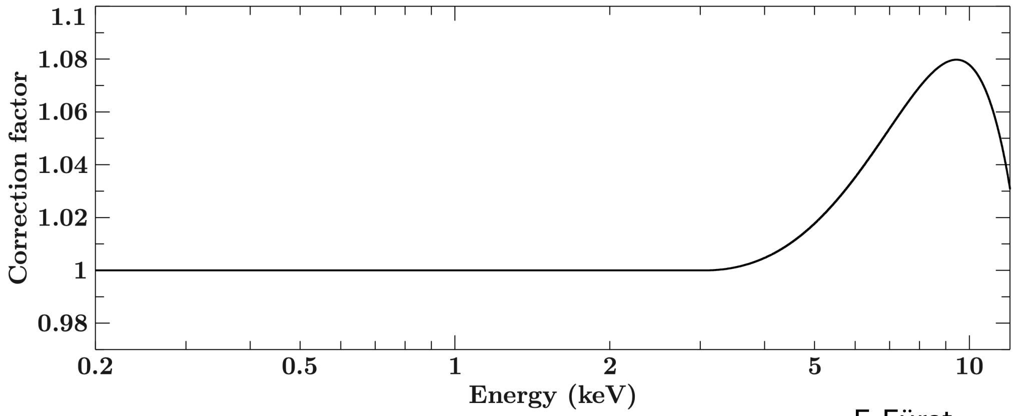
Findings showed discrepancies could be described by:
- Difference in spectral shape (up to ~ 6% difference in terms of flux) → contained in calibration
- Overall cross normalisation offset (18%) → *not contained* in calibration



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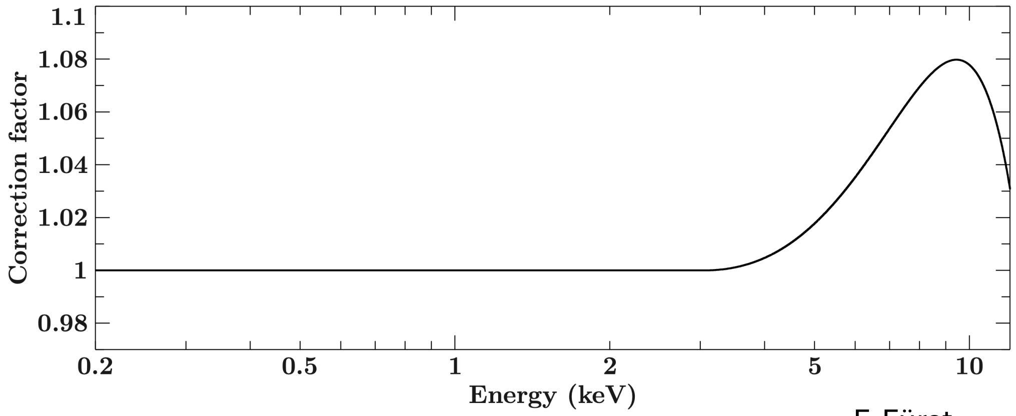
Up to now, the correction is not applied by default (needs to be explicitly invoked in the `arfgen` task).

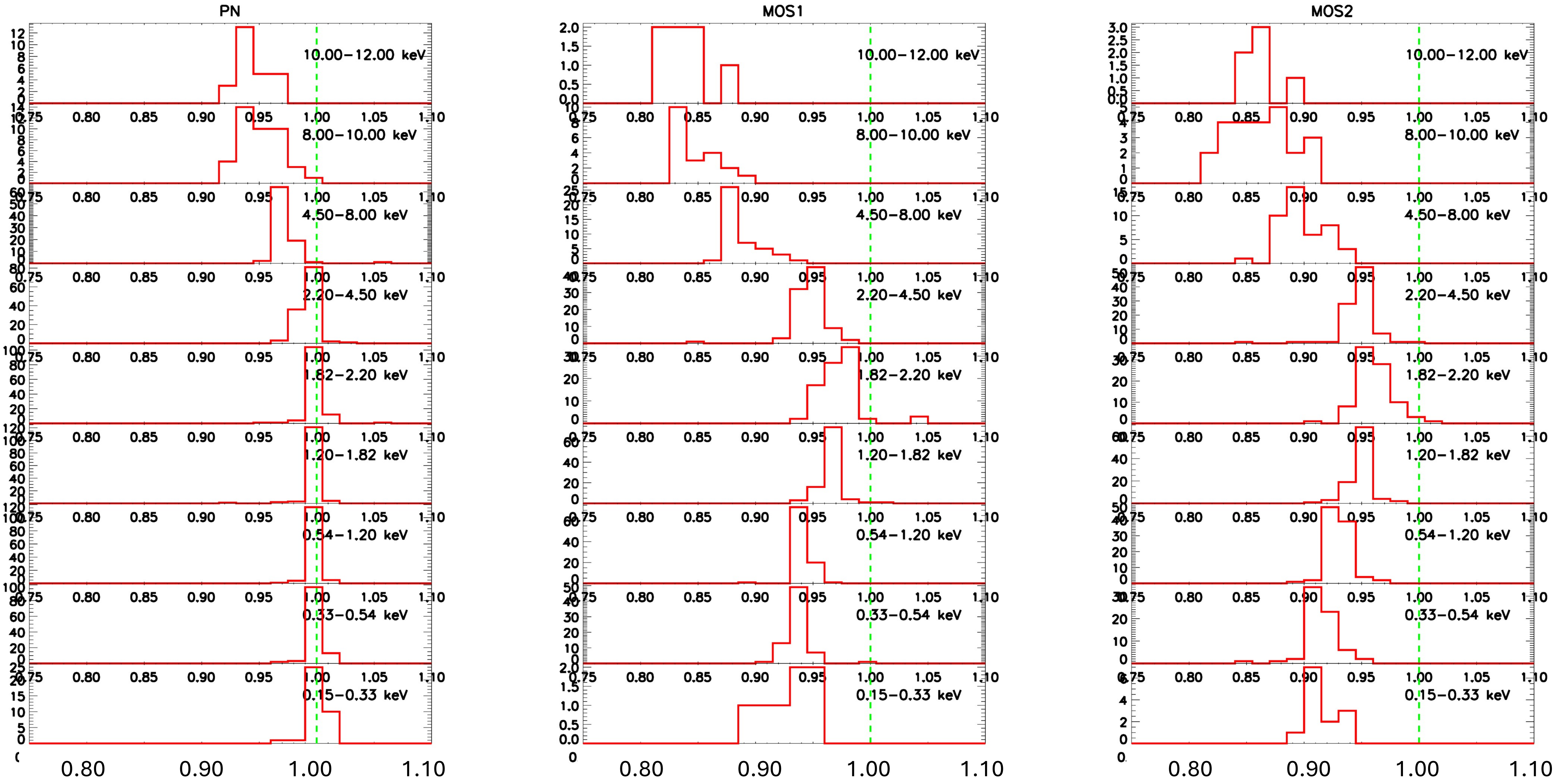
As of SAS 22 (~ autumn 2024) the correction will be applied in the default processing:

```
arfgen applyabsfluxcorr=yes
```



F. Fürst

Relative changes in instrumental flux ratios comparing the default processing of SAS 22 / SAS 21



Sco X-1 single reflection observations

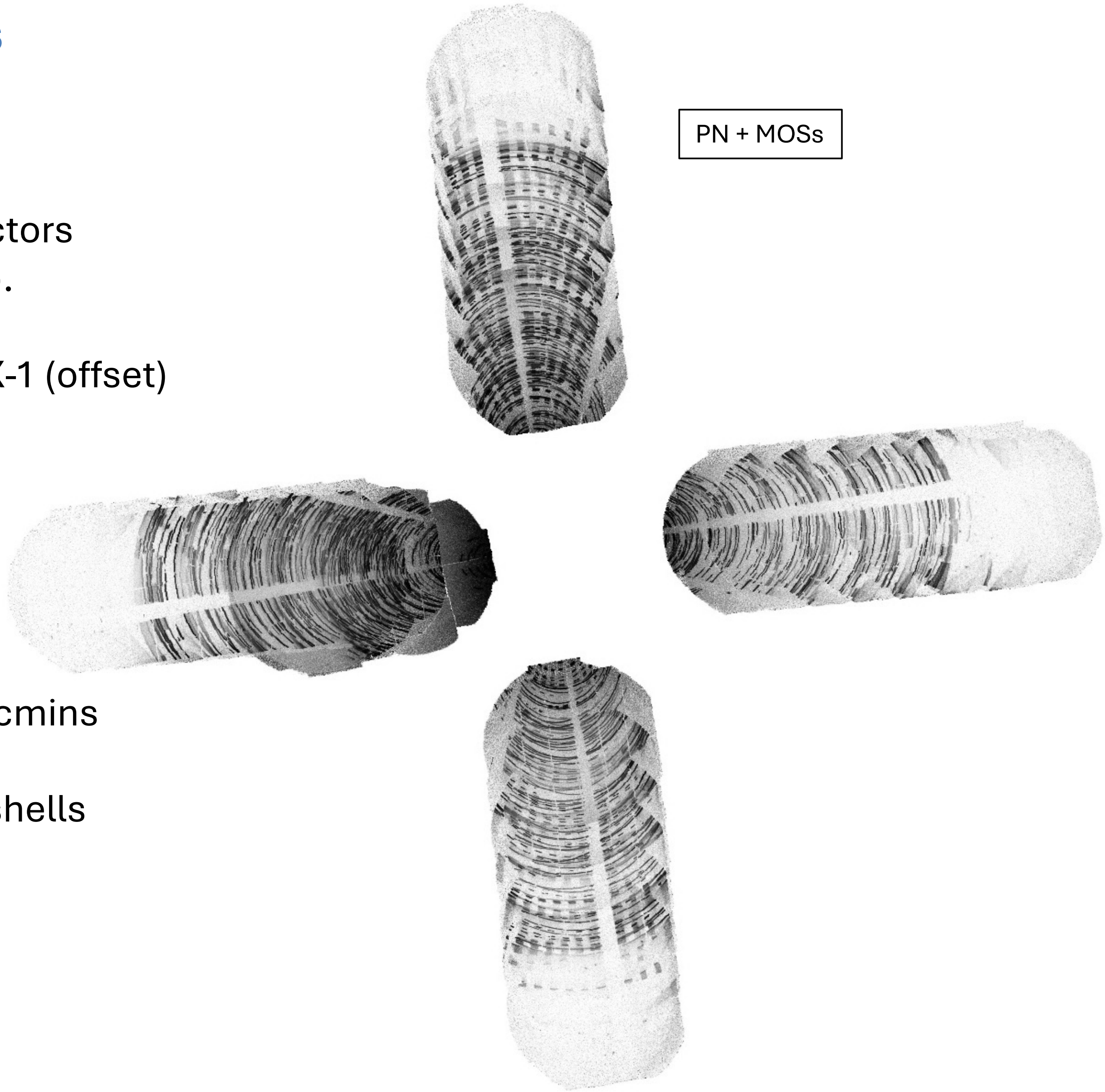
Single reflections (from hyperboloid mirror) reach detectors for offsets in the 35 – 79 arcmin (for on-axis detections).

Non-routine calibration observation performed of Sco X-1 (offset) in March 2024.

4 mosaic observations:
- azimuths of 0, 90, 180 and 270 degrees

Each consisting of 7 exposures:
- offsets from Sco X-1 stepped between 34.0 – 79.0 arcmins

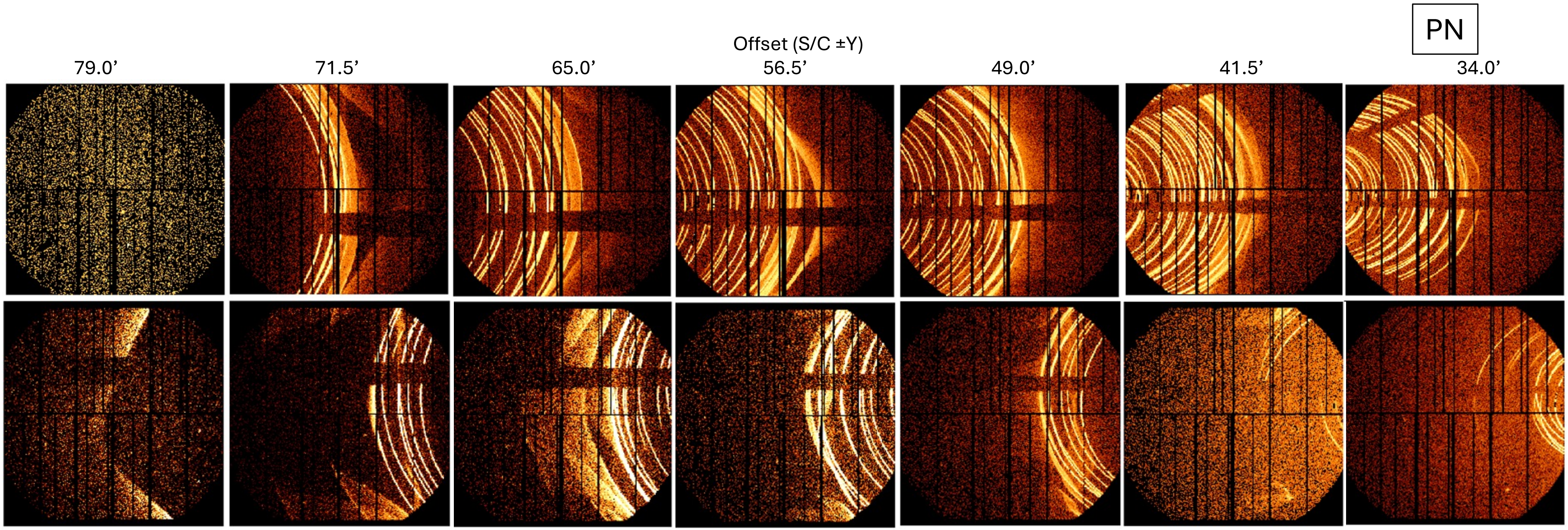
Yields single reflection arcs observations for all mirror shells (over 4 segments) of all 3 mirror assemblies.



Sco X-1 single reflection observations

Aim is to compare observations with simulator output (SciSim, SIXTE).
Very preliminary results, based on significant asymmetry in transmitted flux in S/C Y direction for PN telescope:

- Could be explained by a PN telescope stray-light baffle tilt of ~ 1.5 arcmin
- Implies A_{eff} loss of ~ 5% at PN boresight



D. Lumb

PN Timing mode v. NuSTAR cross-calibration

Reported issues in spectral fitting of combined NuSTAR and PN Timing mode data, with any of:

- spectral shape
- energy scale
- normalisation

However, there are also cases of consistent spectral results.

In order to better understand the origin of the issues:

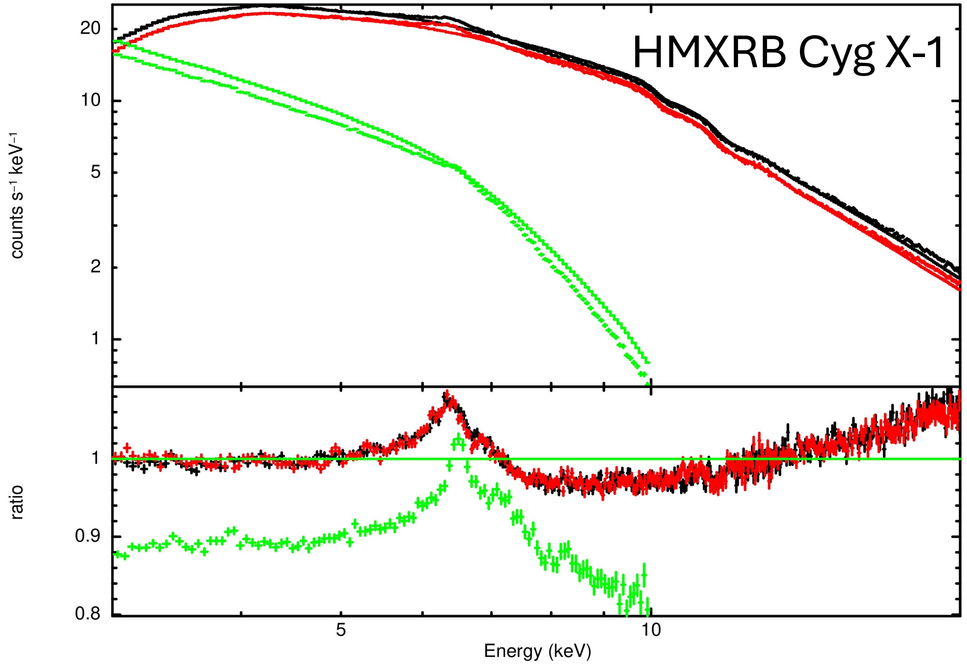
Currently undertaking a systematic comparison of PN Timing mode and NuSTAR spectra.

Sample consists of ~ 80 coordinated observations (mostly XRBs).

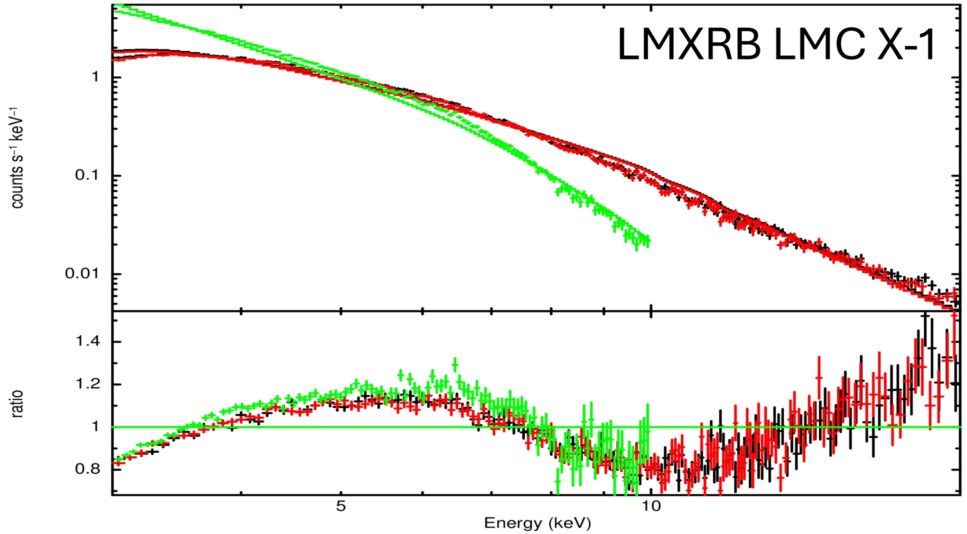
Aim is to analyse a sufficient number to identify commonalities of spectral discrepancies with spectral shape, count rates, etc.

Work in progress…

Preliminary results:



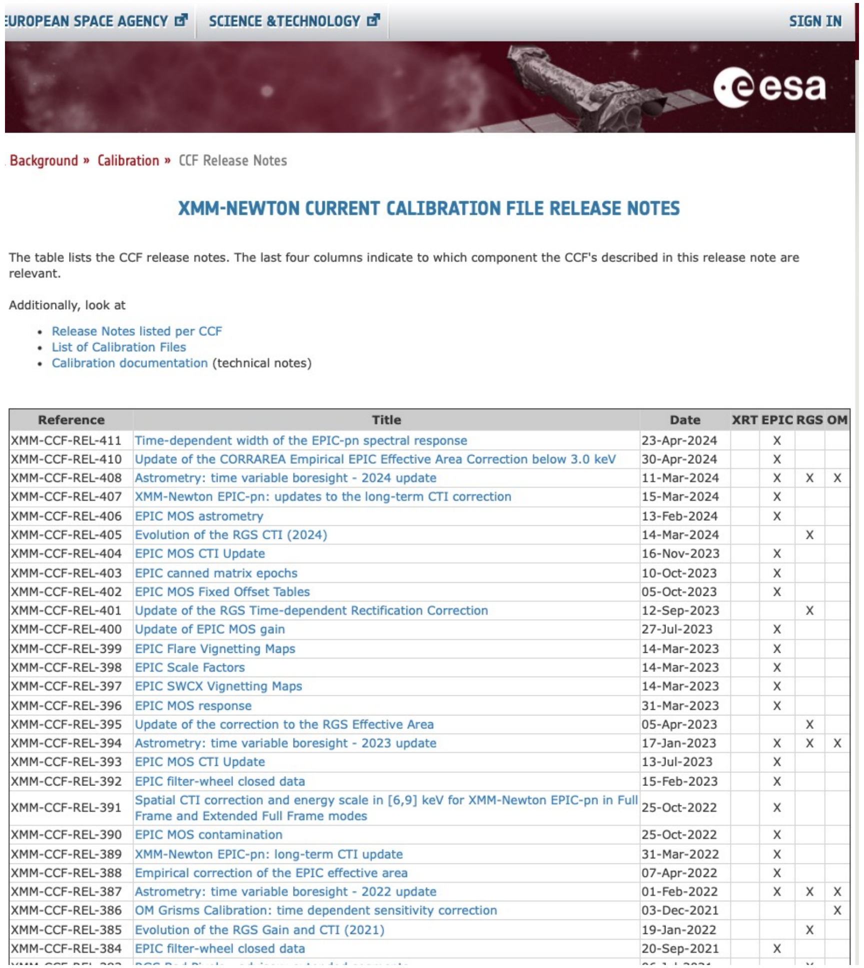
G. Matzeu



EPIC related calibration files released over last 12 months

Update of EPIC MOS gain	XMM-CCF-REL-400	27-Jul-2023
EPIC MOS Fixed Offset Tables	XMM-CCF-REL-402	05-Oct-2023
EPIC canned matrix epochs	XMM-CCF-REL-403	10-Oct-2023
EPIC MOS CTI Update	XMM-CCF-REL-404	16-Nov-2023
EPIC MOS astrometry	XMM-CCF-REL-406	13-Feb-2024
XMM-Newton EPIC-pn: updates to the long-term CTI correction	XMM-CCF-REL-407	15-Mar-2024
Astrometry: time variable boresight - 2024 update	XMM-CCF-REL-408	11-Mar-2024
Update of the CORRAREA Empirical EPIC Effective Area Correction below 3.0 keV	XMM-CCF-REL-410	30-Apr-2024
Time-dependent width of the EPIC-pn spectral response	XMM-CCF-REL-411	23-Apr-2024

https://www.cosmos.esa.int/web/xmm-newton/ccf-release-notes



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Background » Calibration » CCF Release Notes

XMM-NEWTON CURRENT CALIBRATION FILE RELEASE NOTES

The table lists the CCF release notes. The last four columns indicate to which component the CCF's described in this release note are relevant.

Additionally, look at

- Release Notes listed per CCF
- List of Calibration Files
- Calibration documentation (technical notes)

Reference	Title	Date	XRT	EPIC	RGS	OM
XMM-CCF-REL-411	Time-dependent width of the EPIC-pn spectral response	23-Apr-2024		X		
XMM-CCF-REL-410	Update of the CORRAREA Empirical EPIC Effective Area Correction below 3.0 keV	30-Apr-2024		X		
XMM-CCF-REL-408	Astrometry: time variable boresight - 2024 update	11-Mar-2024		X	X	X
XMM-CCF-REL-407	XMM-Newton EPIC-pn: updates to the long-term CTI correction	15-Mar-2024		X		
XMM-CCF-REL-406	EPIC MOS astrometry	13-Feb-2024		X		
XMM-CCF-REL-405	Evolution of the RGS CTI (2024)	14-Mar-2024			X	
XMM-CCF-REL-404	EPIC MOS CTI Update	16-Nov-2023		X		
XMM-CCF-REL-403	EPIC canned matrix epochs	10-Oct-2023		X		
XMM-CCF-REL-402	EPIC MOS Fixed Offset Tables	05-Oct-2023		X		
XMM-CCF-REL-401	Update of the RGS Time-dependent Rectification Correction	12-Sep-2023			X	
XMM-CCF-REL-400	Update of EPIC MOS gain	27-Jul-2023		X		
XMM-CCF-REL-399	EPIC Flare Vignetting Maps	14-Mar-2023		X		
XMM-CCF-REL-398	EPIC Scale Factors	14-Mar-2023		X		
XMM-CCF-REL-397	EPIC SWCX Vignetting Maps	14-Mar-2023		X		
XMM-CCF-REL-396	EPIC MOS response	31-Mar-2023		X		
XMM-CCF-REL-395	Update of the correction to the RGS Effective Area	05-Apr-2023			X	
XMM-CCF-REL-394	Astrometry: time variable boresight - 2023 update	17-Jan-2023		X	X	X
XMM-CCF-REL-393	EPIC MOS CTI Update	13-Jul-2023		X		
XMM-CCF-REL-392	EPIC filter-wheel closed data	15-Feb-2023		X		
XMM-CCF-REL-391	Spatial CTI correction and energy scale in [6,9] keV for XMM-Newton EPIC-pn in Full Frame and Extended Full Frame modes	25-Oct-2022		X		
XMM-CCF-REL-390	EPIC MOS contamination	25-Oct-2022		X		
XMM-CCF-REL-389	XMM-Newton EPIC-pn: long-term CTI update	31-Mar-2022		X		
XMM-CCF-REL-388	Empirical correction of the EPIC effective area	07-Apr-2022		X		
XMM-CCF-REL-387	Astrometry: time variable boresight - 2022 update	01-Feb-2022		X	X	X
XMM-CCF-REL-386	OM Grisms Calibration: time dependent sensitivity correction	03-Dec-2021				X
XMM-CCF-REL-385	Evolution of the RGS Gain and CTI (2021)	19-Jan-2022			X	
XMM-CCF-REL-384	EPIC filter-wheel closed data	20-Sep-2021		X		

2023 XMM Users' Group recommendations on calibration priorities for EPIC

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2020-06-08/11: [..] continue the investigations into the off-axis flux calibration of the EPIC cameras. Ongoing

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2022-05-17/06: [..] verify the pattern fractions determined from in-orbit data with the expected pattern fractions. Ongoing

2022-05-17/07: [..] creation of proton response matrices and to make them available through SAS. Ongoing

2023-05-11/01: The UG acknowledges the ongoing efforts to improve the cross-calibration of XMM-Newton instruments and reduce the discrepancies between MOS and pn in the soft-energy band and at higher energies. The UG recommends continuing the investigation of the possible causes of the differences and monitoring the temporal evolution of factors already identified (contamination, rmf, ...) to regularly update their impacts. Ongoing

2023-05-11/02: [continue] efforts to improve cross-calibration between XMM-Newton's EPIC detectors and those of NUSTAR. It recommends monitoring the evolution of the flux and shape of the PN and MOS spectra relative to NUSTAR, using regular simultaneous observations to update, when appropriate, the empirical correction of the EPIC spectral shape [..] Ongoing