

Summary of the 2025 EPIC Calibration and Operations Meeting

ESAC, with remote participation, 23-24 April 2025

Attendees

M. Alexandersen, J. Ballet, L. Ballo, D. Bogensberger, P. Calderon, I. de la Calle, S. Chakraborty, K. Dennerl, M. Freyberg, P. Friedrich, F. Fuerst, R. Gonzalez, L. Gu, A. Ibarra, M. Kirsch, K. Kuntz, E. Kuulkers, J. Lopez, H. Marshall, G. Matzeu, N. Meidinger, J. Perea, C. Pommranz, P. Rodriguez, S. Rosen, C. Sanchez, J. Sanders, M. Santos-Lleo, R. Saxton, N. Schartel, R. Singh, M. Smith, M. Stuhlinger, A. Tiengo, L. Tomas, I. Valtchanov

Review of open actions (M. Smith)

EPIC TTD-030/8 on R. Saxton:

Start investigating the implementation of the parameterised RMF into SAS S/W.

Open.

As this action is essentially SAS related, and a very similar SAS development action already exists, it was decided to remove this duplicate action.

EPIC TTD-034/1 on M. Freyberg:

Verify that the SW mode discarded line related exposure time correction is properly accounted for.

Closed.

This was tested on a 2-hr long slew observation, where it was verified that the relevant information in the header is fully consistent.

EPIC TTD-34/2 on M. Smith:

Investigate impact on energy scale calibration of dropping unscheduled CalClosed observations due to radiation.

Closed.

The impact in terms of lost CalClosed time on PN is very small. On MOS it is larger, but the loss may to some extent be compensated through properly justified dedicated CalClosed observations either as NRCOs, but preferably via a change to the Routine Calibration Plan.

CALIBRATION SESSION

1. 2024 Users' Group EPIC calibration recommendations (M. Smith)

The recommendations for EPIC calibration from the 2024 UG were presented, along with a short summary of their respective status (see presentation). All items mentioned are currently being worked on and are at various stages of progress. The only items likely to be closed for this year's UG meeting is the inclusion in SAS (for SAS23) of the code for the proton response matrices, and possibly an updated calibration of the MOS pattern fractions.

2. MOS Monitoring (M. Stuhlinger)

The MOS CTI monitoring methodology is currently in transition phase:

- Due to the decay of the Fe55 source, the Leicester code no longer yields useful results for direct measurement of CTI.
- The new method empirically estimates parallel CTI from CCD averaged values of line centroid. Serial CTI and gain are assumed to be constant.

MOS line monitoring shows decrease of reconstructed line energies for focal and some peripheral CCDs approximately since the eclipse season around revs ~4230. Needs to be corrected through an update of long-term CTI and/or gain CCFs.

MOS line widths show a moderate increase of FWHM.

Owing to decay of on-board calibration source, MOS1 Mn line energy and Al/Mn line width measurements require merged data sets to increase statistics.

Bad pixel levels are still low for active CCDs: MOS1 3-6% (except CCD4), MOS2 up to 3%.

MOS1 meteorite column offset calibration is fine with the quiescent state, allowing the column to be included in many science observations.

Following change in telemetry allocation (new BRAT) reducing MOS telemetry to 9 kbit/s, no telemetry issues present for EPIC-MOS except 2-3 individual exposures within about 80 revolutions.

Mission operation and planning successfully prevents science observations at non-nominal focal plane temperatures. No scientific exposure affected for last 9 eclipse cycles.

A comment was made regarding the significance of the increase in FWHM. Indeed it is significant, and the higher increase recently is possibly related to the solar max.

3. PN Monitoring (M. Smith)

Increased PN noisy pixels for CCD1 (RAWX==33) and CCD12 (RAWX==35) (all coordinates in the [0..63] [0..199] convention).

CCD1 noise due to change in pixel (33,199) around rev 3707 (exact onset time not possible to determine). Possible micrometeoroid event, although accumulated radiation damage cannot be excluded). No significant impact on telemetry, and in terms of science impact, column is generally flagged in *epproc* processing. In some (but not all) LW exposures the column is not flagged.

It was decided to flag the column as bad in the BADPIX CCFs (as so-called “advisory” pixels). Some investigation what part of the column needs to be flagged needs to be done.

ACTION EPIC TTD-35/1 on M. Smith:

In view of suppressing noise due to micrometeoroid impact, investigate flagging of noisy

pixels in CCD1 column 33 as “advisory” bad pixels in the corresponding CCF file (i.e., the on-board bad pixel table will *not* be modified).

CCD12 noise is a result of a micrometeoroid impact in rev 4307 (2023-06-16 ~ 00:55) affecting four pixels simultaneously:

CCD1 (45,148)
CCD3 (18,199)
CCD8 (33,197)
CCD12 (35,148)

Main impact is due to noisy column associated with the CCD12 pixel. However, no significant impact on telemetry, and in terms of science impact, column is generally flagged in *epproc* processing.

PN offset maps are very stable.

Despite decay of Fe55 source, some CalClosed observations still allow CTI measurements at Al Ka, but no longer at Mn Ka, at least with exposures times currently performed. Also, Cu Ka emission allows CTI measurements. CTI increases steadily over the course of the mission.

Energy reconstruction does not rely on CTI measurements, as we empirically derive the CTI required to shift the measured energies to the expected values. The LTCTI model is derived regularly, but newest observations are corrected through an extrapolation of the model. Current model extrapolations still largely valid for most CCDs at Al Ka, Mn Ka and Cu Ka for Full Frame mode. Also, the reconstruction is optimized for CCD04 at the B/S is still valid for FF mode. For EFF mode there is probably a slight over-correction at Al Ka and a slight under-correction at Mn Ka, both formerly still consistent with lab values, within uncertainties.

In view of decay of the Fe55 source, predictions are made for the required exposure time necessary to obtain line centroid estimates with given uncertainties. Predictions are made for all 3 EPICs. The most critical are PN and MOS1, at Mn Ka. Until 2028, 60 ks would be required for a line centroid estimate with 1-sigma confidence of 3 ADU, averaged over the full CCD. For optimization at PN CCD04 B/S, the required exposure time would be 100ks.

The width of the PN emission lines is steadily increasing over time; values vary per CCD, and are:

- Al Ka: 0.03 – 0.05 ADU/yr
- Mn Ka: 0.1 – 0.2 ADU/yr
- Cu Ka: 0.1 – 0.2 ADU/yr

It was suggested to use the yearly tank replenishment observations for CalClosed measurements (in some combination with science observations, depending on the selected targets).

ACTION: EPIC TTD-35/2 on M. Smith:

Amend Routine Calibration Plan to include EPIC CalClosed observations during the tank replenishment operations, science priorities permitting.

4. MOS pattern fractions investigations (M. Stuhlinger)

Motivation for investigation: on sample of sources, significant discrepancies seen in MOS stacked residuals of singles data with respect to best fit model to singles-to-quadruples spectra.

In-orbit pattern distributions determined from all observations in XMM archive (only CCD1), with suitable criteria, including per-pixel limits on acceptable pile-up fraction.

Results:

- no significant mode / filter dependencies for individual MOS detectors;
- there are differences between MOS1 and MOS2 pattern ratios;
- pattern ratios show time evolution, e.g. broadening at Si-feature;
- possible differing time evolution in on-patch/off-patch spatial regions, however, data sampling is problematic.

“Pattern fraction” CCF entries modified based on measured fractions. For the “epatplot” task, this yields improved pattern fraction data/model results, for e.g. piled-up sources. However, these CCF entries do not affect response files.

“Energy fractions” CCF entries are used in spectral response creation:

- quantum efficiency curves of respective pattern types, most likely based on ground calibration measurements;
- non-scientific patterns are included in the total.

“Pattern fraction” curves have been suitably converted to “energy fraction” curves without changing the scientific pattern totals; test CCFs have been created. Test CCFs reduce the drop at highest energies by about 50%. There is a slight improvement in the overall slope difference between MOS/pn. Nearly no changes for residual structures at instrumental edges except at O-edge.

5. PN-NuSTAR cross calibration with Timing mode (G. Matzeu)

EPIC-pn Timing mode and NuSTAR spectral cross-calibration is being systematically investigated on a sample of IACHEC cross-calibration and XRB observations.

Already reduced and analysed a large sample (70 observations) of coordinated XMM-Newton & NuSTAR targets (mostly XRBs) in a semi-automated pipeline for XMM-Newton (EPIC-pn in timing mode) and NuSTAR.

Now working on quantifying the discrepancies found between XMM pn-timing and NuSTAR FPM spectra.

Currently focusing on fitting an empirical model (e.g. spline + other components) to NuSTAR and evaluating the difference in PN versus NuSTAR residuals, and also try to correlate the differences in PN versus NuSTAR constant and spectral slope with e.g. PN

count rate, hardness ratio, or similar. Tentative correlations are found, with largest discrepancies generally toward lower count rates

The observations still need to be compared using strictly simultaneous GTIs. Also, as long-term goal the change in energy scale will be investigated in more detail.

It was suggested to perhaps also try the method of comparing fluxes across narrow bins.

6. Simulations of Sco X-1 out-of-field observations with SciSim (M. Alexandersen)

The Sco X-1 single reflection arc observations were described.

SciSim simulator is now available in ESA Datalabs, allowing parallel instances to be run.

Some initial comparisons between observations and SciSim simulations were shown, with various small tilts of the whole mirror module around the Y and Z axis. Significantly different tilts would be required to align different mirror shells.

Some effective area changes were derived using some basic mirror module tilts.

Parameter space is likely too large to search via simple grid search. Algorithms being investigated to efficiently search through the parameter space, using a quantitative score of similarity of simulation versus data.

Also mentioned was that mirror shell #1 is missing in the simulated data – this requires further investigation and needs to be understood first.

It was mentioned that there is some indication that the MOS telescope data also shows asymmetries, although it is not yet clear whether these go in the same direction as seen for the PN telescope.

7. Update on the EPIC-pn RMF and ARF (K. Dennerl)

The presentation showed the development of the PN empirical response modelling, and the significant improvements it yields in terms of data-to-model residuals for almost all observations of 1E0102 and RX J1856, for all three filters.

The response (which includes a slight increase in O absorption included in the ARF), is so far derived for Small Window mode, singles only, and up to ~ 1.7 keV. It needs to be investigated how applicable the response is to other modes, and pattern selections - the latter could be tested now, the former requires more analysis.

The source code for creating the RMF was delivered as initial step to investigate how to include this into the SAS.

Given the substantial improvements of the new response, the idea is to merge it with the high-E part of the current SAS RMF and make it available through the SAS (with requisite checks, e.g. that it is used for correct mode & pattern types).

8. Plans for contributions to the EPIC calibration (J. Sanders)

Several different project ideas for XMM were presented:

- Incorporation of parametric RMF in SAS: help port this towards the XMM SAS, adding further documentation, etc.
- Further improvement of energy calibration of EPIC-pn: similar to what has already been done for the Cu Ka emission, other lines (Al, Ti, V, Cr, Au and Mo) could be used, especially for the central region, and could also be useful for other detector modes.
- Improvement of PSF model: expand the work done by Read et al. (2011) by stacking a sources and fitting PSF models.
- Improvement of distortion correction: cross match Gaia sources to build up a distortion correction model across the FOV.
- Joint calibration of effective area / vignetting.

In terms of priorities it was suggested to focus on improving the energy calibration for the central region, and expanding the PN parametric RMF.

9. XMM-XRISM cross-calibration using NGC 3783 (L. Gu)

Cross-calibration campaign (10 days, July 18-27, 2024) of XRISM (430 ks) with:

- XMM-Newton (380 ks)
- NuSTAR (220 ks)
- Chandra/HETGS (155 ks)
- HST/COS
- Swift & NICER

Method consists of fitting spline to high-resolution spectrum, and fold lower resolution instrument through this model, and inspect residuals. Residuals can then be modelled to create a rectification function for the low resolution instrument. This is a relative comparison – the origin of any residuals could be due to both instruments.

In some cases, gain shifts of a few % are required to account for gain variations. Background smoothing is applied to all data.

Plots were shown showing pair-wise comparisons and resulting modelling of residuals.

Resolve versus RGS shows little overlap. RGS lower by ~20% (1.8 – 2.2 keV).

Perhaps weak pile-up in PN spectra. Annular extraction regions used. Residuals of 8% near Fe K (narrow feature), up to 3% in RGS band. Perhaps due to pile-up, or uncertainties in PSF correction.

Summary of results:

- 0.5 – 1 keV: all agree within 10%
- 1 - 2 keV: RGS is lower than CCDs by 20%
- 2 keV: Resolve is higher by 10% than Xtend
- 3 keV: Resolve, Xtend and NuSTAR agree in 5-10%
- EPIC is 10-20% lower than other instruments above 2 keV

It was commented that the XRISM is independently calibrated, i.e. not calibrated to other instruments.

It was noted that stacking Mkn 421 spectra, the spectral slope of which is variable, and likely changes between observations, does not yield a power law in the stacked spectrum. This goes to the validity of assuming a power law describes the RGS stacked spectrum.

In this context it was also noted that, over a wide bandpass, AGN show curvatures (described e.g. by log-parabola models).

It was also suggested that XRISM spectra could be useful in extending the PN parameterised RMF to higher energies.

10. Investigation of PN/MOS flux ratios (S. Chakraborty)

The PN / MOS flux ratios can be an interesting probe for the consistency over the full EPIC FOV.

Using 4XMM DR13 (~ 900k sources) together with XMM2ATHENA WP4 and WP6. Basic Γ and NH based on fit over 5 band rates (for ~ 400k “good” sources): 0.2-0.5, 0.5-1, 1-2, 2-4.5, 4.5-12 keV. ECFs are derived from Γ , NH off axis angle and time. Fluxes are derived from these ECFs (not from DR13, which uses fixed ECFs).

Common sources are selected, limited to point sources passing detection likelihood criteria (~ 100k sources). Then, appropriately weighted average PN / MOS flux ratios are derived across spatial bins (it was noted that in the ECF determination the latest MOS-to-PN empirical effective area corrections are not applied). Depending on instruments and band, uncertainties in binned flux ratios are in the 2-5% range.

PN / MOS2 flux ratios in band 3 (1 – 2 keV) shows overall offset of 0.90 for both on-axis and off-axis. There are some spatial features, perhaps corresponding to CCD edges.

PN / MOS2 flux ratios in band 1 (0.2 – 0.5 keV) shows value of 0.78 and 0.73 for on and off, respectively. Features related to CCD edges are more pronounced. Moreover, there is an anomalous feature coinciding with CCD 5 in MOS2 (with lower average flux ratio, at ~ 0.64).

Splitting data set into two temporal ranges (before and after rev 2000) the band 1 PN / MOS2 flux ratios increase, to 0.84, 0.76 and 0.67 for on, off and CCD5, respectively.

Similar systematic outlying data is absent from the reference band 3.

It was confirmed that the observed patterns in band 1 are not explainable merely through statistical variations. This could point to anisotropy of the MOS2 contaminant.

It was mentioned that MOS2 CCD5 is known to have an additional noise component. Regarding this, it was noted that background subtraction could, to 1st order, probably remove this. A complication is that the catalog data has no indicator of status of CCD5 noise level.

Regarding the ECFs, it was noted that power laws are not very good approximations for e.g. stars, and the resulting ECFs would be off towards higher energies, thus impacting

results (perhaps consider using fixed ECFs). However, it was also mentioned that sources are dominated by AGNs, so the impact would in any case be small.

A technical note describing the analysis and outcomes will be written.

11. Discussion (All)

Two actions arising from the calibration session (mentioned previously) were noted. It was clarified that the action on investigating the flagging of the micrometeoroid affected pixels, the flagging will be done at the CCF level, and not on-board (through the Bad Pixel Table).

OPERATIONS SESSION

1. XMM-Newton MOC and spacecraft status (M. Kirsch)

S/C subsystems are all healthy for into the 2030s.

- Optocouplers (which measure the speed of the reaction wheels and, as optical devices, are subject to radiation aging) issue identified in previous years no longer seen as a problem.
- Fuel estimates give life time to 2034 (with conservative margin). This is mainly due to 4WD fuel savings, introduced in 2013). Fuel consumption and predictions are being monitored.

XMM is currently essentially operating beyond its spec lifetime (10 years, versus current ~ 26th year). This implies system predictions are less reliable. No1 battery shows trend of capacity reduction, but this requires further investigation to confirm, and there are margins of redundancy.

Tolhuin ground station (Argentina) has been broken for ~ half a year, resulting in apogee gaps.

The XMM-Newton orbit is in a good place, without entering too deeply into the proton belts. Unlike INTEGRAL, which suffered a substantial drop in solar array power because of deep incursions into the belts, XMM-Newton shows a stable degradation, with sufficient margins.

Batteries continue having healthy capacity. There is however a decrease in available capacity for battery #1. An assessment is underway to forecast the possible impact on eclipse operations.

The Attitude Anomaly Detector (AAD) is being monitored in terms of risk triggering a false ESAM (similar AAD on SOHO was degraded through radiation and caused false safe modes to be triggered). However, the system is not critical and there is redundancy through other systems.

Fuel estimate gives a lifetime to 2034+. Without ESAMs, lifetime is estimated up to 2040. A new safe mode would allow fuel savings, as it does not consume any fuel. An INTEGRAL-type Z-flip after 2034+ is under consideration, but the science impact on XMM would likely be higher than that for INTEGRAL.

Aging of optocouplers likely overestimated, when calculating using non-ionising dose as derived from RadMon data rather than a radiation model. Previous prediction of issues around 2028 likely far too conservative, and now is not expected to exceed design specs until ~ 2045.

Regarding on-board automation, the 2025 New Safe Mode (NSM) patch enables fuel-less safe mode plus further instrument monitoring and onboard safety. Not yet live.

“Mini system” at Cebreros: some systems for safety operations can be run from Cebreros mini MOC.

A review is ongoing with industry of all subsystems and life limiting items with the view to operate XMM towards the launch of Athena (>2037).

It was asked why after failure of 2 reaction wheels this would essentially be a mission ender. Reason is that the s/c would no longer allow stable pointings. It was noted that slews could potentially still be made. The science case for such observing mode would have to be justified, though.

2. EPIC instruments' status (P. Calderon)

EPIC instruments continue working well.

Notable events over the last year:

- One MOS 2 EMCR autoreboot to ROM sw version;
- Some changes in operations, mainly new nominal BRAT (maximum TLM) definition and reduced FW rotations.

Regarding changes to the BRAT:

From ODB version 7.21, 24-Oct-24, rev 4556, the maximum TLM bandwidth usable by each of the EPICs (BRAT) was modified:

Before:	MOS1: 12 kbps	MOS2: 12 kbps	PN: 24 kbps
After:	MOS1: 9 kbps	MOS2: 9 kbps	PN: 30 kbps

The motivation being to reduce the number of times that PN enters in counting mode. But it is too soon to see a significant impact.

Regarding the reduction of EPIC Filter Wheels rotations:

Since 28/11/2024 (rev 4574) MOIS Automation 3.6 changed the way in which the unscheduled exposure at high radiation are done. Previously CalClosed was used, now the FW is set to Closed. The advantage is that now the FW does not rotate from Closed to

CalClosed and subsequently the full revolution to return back to Closed. With the MOIS automation, the number of such exposures (and thus FW revolutions) had increased notably. The main disadvantage is some loss of CalClosed exposures.

Future changes (“Automation 4.0”) includes:

- Recovery from Safe Standby
- Rejoinders after slews ending late
- Dealing with ground station and TC

Summary of open actions

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