Summary of the 2024 EPIC Calibration and Operations Meeting

ESAC, with remote participation, 3-4 June 2024

Attendees

J. Ballet, P. Calderon, I. de la Calle, K. Dennerl, M. Freyberg, F. Fuerst, R. Gonzalez, M. Kirsch, J. Lopez, G. Matzeu, S. Peschke, C. Pommranz, P. Rodriguez, S. Rosen, J. Sanders, M. Santos-Lleo, R. Saxton, N. Schartel, M. Smith, M. Stuhlinger, L. Tomas, L. Valencic, 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.

EPIC TTD-031/1 on R. Saxton:
Open SAS SCR regarding propagation of PN SW mode discarded line rates to the calibrated events file (similarly to FF, EFF and LW modes).
In addition, verify that the SW mode discarded line related exposure time correction is properly accounted for.
First part: Closed (SAS SCR was submitted).
Second part: changed actionee to M. Freyberg:

> **EPIC TTD-034/1** on M. Freyberg:
> Verify that the SW mode discarded line related exposure time correction is properly accounted for.

CALIBRATION SESSION

1. 2023 Users' Group EPIC calibration recommendations (M. Smith)

- **Recommendation 2020-06-08/09:** The UG recommends to 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.

  Work on this is progressing and will be handed over within MPE for continuation.

- **Recommendation 2020-06-08/11:** The UG recommends to continue the investigations into the off-axis flux calibration of the EPIC cameras.

  Vignetting work halted due to issues with epoch dependency of MOS on-axis fluxes seen in raster scan observation of SNR G21.5 (and e.g. Galaxy cluster Abell 0133). Priority is to understand origin of this issue (confirm with other sources, e.g. 1E0102, N132D, CORRAREA sample).

- **Recommendation 2022-05-17/05:** The UG strongly recommends to 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.

  Work on recalibrating QBG correction including Cu Ka is already underway (early stages).

- **Recommendation 2022-05-17/06:** The UG recommends to verify the pattern fractions determined from in-orbit data with the expected pattern fractions.

  In orbit pattern fraction data for MOS1/2 CCD1 has been analysed. New calibration curves in instrumental energy dimension already being tested. Conversion to photon energy dimension currently being investigated.

- **Recommendation 2022-05-17/07:** The UG recommends the creation of proton response matrices and to make them available through SAS.

  The Fioretti et al. group will be contacted again to verify status of response matrices.

- **Recommendation 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.

  Empirical CORRAREA correction extended to lower energies. Temporal evolution of response, contaminant regularly monitored and updated. Sco X-1 NRCO on single reflections can be mentioned in this context as attempt to understand origin (or estimate/justify systematic uncertainties) of EPIC flux differences.

- **Recommendation 2023-05-11/02:** The UG recommends continuing 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 (Fürst 2022, CAL-TN-0230-1-3.pdf).

  Systematic investigation into PN Timing mode versus NuSTAR spectral differences is underway. Also, the latest 3C 273 observation will be analysed in terms of comparison with NuSTAR. The Sco X-1 NRCO is also relevant in this context.

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.
- First CTI CCFs based on new method published May (and December) 2023.
- Subsequent ADUCONV CCF published in September 2023 corrected for MOS2 CCD4 line energy jump after eclipse season around rev. 4140.
- Current line monitoring results show recent data does not well match model extrapolation, and CTI update is required for several CCDs.

MOS bad pixel numbers are quite stable: MOS1 3-6% (except CCD4), MOS2 < 3%.

MOS1 meteorite column monitoring: just one new FF/LW/SW set of diagnostics available since last meeting. Column offset consistent at ~ 117 ADU for all imaging modes.

EPIC telemetry monitoring: nominal. PN average FF telemetry show slight increase since ~ rev 4360.

The issue of MOS exposure out of nominal focal plane temperature has not affected any scientific exposure for the last 7 eclipse cycles.

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.

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.

The noise from both events is regularly being monitored.

PN offset maps are very stable.

MOS background maps (based on median *EnergyE4* values) are within +/- 0.5 ADU for all CCDs – the recently updated MOS offset tables are still valid.

4. Updates to PN long-term CTI corrections (I. Valtchanov)

Incremental update of LTCTI for all EPIC-pn modes (including TI & BU modes). CCF file EPN_CTI_0058 is already released and is being used in the bulk reprocessing.

- Existing CCF model was no longer valid for recent observations (under-correction for t > 2021).
- Model extrapolation to t = 2030.
- No QPB correction available in LW mode, so basing Al, Mn and Cu LTCTI modelling on FF CalClosed data with no LTCTI and no QPB applied.
- Change in SW modelling at 6.4 keV using only NGC 4151 (some have Chandra HETG or and XRISM data) and change of reference energy to 6.3752 keV.
- TI and BU modes also updated, as no QPB is applied in these modes, the LTCTI model was derived from FF CalClosed with no LTCTI and no QPB applied.
- Validation with other AGN sources, e.g. NGC3516, MCG05-23-16 for SW mode, and Kepler SNR for LW mode gives acceptable results.

5. Update of the time-dependent pn redistribution function (S. Rosen)

Previous update of the time-dependent PN resolution was in 2014. The analysis was based on pn FF observations of Circinus Galaxy from revs 304 and 2605, fitting intrinsically narrow Fe lines, mainly 6.4 Fe-Kα keV. The time dependency is encoded in the noise parameters (N4).

A recent NRCO on the Circinus Galaxy was performed in rev 4423 (100 ks).

Contaminant field sources (stars) complicate the analysis. A too small aperture around the galaxy would distort the relative numbers of singles versus doubles. A larger aperture was chosen, while excluding regions containing the stars.

N4 parameters were adjusted on the basis of spectral fits (on singles and doubles respectively) to the three observations (the short rev 2605 observation was generally poorly constrained), in order to obtain same residual width (~ 21 eV) for all three epochs. This required modest adjustment of the epoch 2 values, and of new values for epoch 3.

There are off-axis variations, but this is not yet being addressed.

REDIST CCF issue 0013 released.

6. 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 criterea, 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 need to be suitably converted to “energy fraction” curves without changing the scientific pattern totals; a test CCF has been created, and currently being evaluated.

It was commented that the increase in quadruples could indicate an increase in larger pattern types. This could go towards explaining the residuals that remain at high energies after correcting for patterns 0-12.

7. MOS-to-PN empirical effective area correction (M. Smith)

CORRAREA correction updated in 2021 above 2 keV. The correction has now been expanded down to lowest energies. Same methodology as before, but significantly larger data sample (thanks to work done at IAAT): now covering a temporal baseline up to May 2021 (previously only up to August 2016).

Methodology:

- Per observation:
  - Determine best-fit model to PN data (PATTERN == [0:4]).
  - Apply model to MOS data (PATTERN == [0:12]), including multiplicative E-dependent correction function to MOS arfs (individual correction function for each MOS).
- Across all observations in the sample:
- Per instrument, stack source spectra, scaled background spectra, and model.
- Determine instrumental stacked data / model ratios.
- Normalise to that of PN.
- Iteratively adjust the correction function to minimise normalised stacked data to model residuals.

A spline is chosen as correction function, defined by a number of nodes at chosen energies + additional constraints. Ideally, should only correct for A_{eff} issues, but hard to disentangle from residual calibration inaccuracies in redistribution and energy scale (attempts to do so, by comparing correction functions of varying complexity, and evaluating results on individual spectra, yielded generally inconclusive outcomes).

Applying new CORRAREA correction significantly improves MOS-to-PN fits across the sample average, and in most individual cases. However, some fits worsen, in specific energy bands. Lack of spectral shape commonality in these cases makes it hard to draw conclusions from these results.

The correction was tested on an independent sample of bright blazars (generally piled-up, necessitating annular source extractions) with significantly improved MOS-to-PN fits (except in the very lowest band, 0.15-0.33 keV, but still acceptable within the large uncertainties).
The new correction reduces MOS fluxes by ~2-3% around 2 keV, and down by 5-10% towards lower and higher energies.

Both the CORRAREA and the EPIC-to-NuSTAR corrections will be applied by default in SAS 22, and are being applied in the current pipeline for the bulk XMM reprocessing.

8. 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 (there are ~ 80 in total, currently ~36 are being analysed).

Currently focusing on fitting the continuum to NuSTAR and evaluating the difference in PN versus NuSTAR residuals. Some cases show very significant discrepancies (in slope, energy scale and cross normalization) but there are also some remarkably consistent results.

Flux differences are of the order of ~20% and slope differences ~10% in most of the 36 sources with some pronounced outliers. As yet, no clear correlation is seen between PN count rate and overall normalization offset or difference in slope.

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 commented that the order of issues to address is important, as energy scale could affect slope. The energy scale could be verified with a constant source observed in different positions along the readout. Also, comparison of early with late observations could indicate an issue with e.g. long-term CTI.

It was also suggested to use total count rates (in e.g. 0.2-10.0 keV band) to find possible correlations.

9. Discussion (All)

Regarding micrometeoroid impacts:

- It is not clear why we do not see optical flashes in PN; perhaps there are too many events and thus are rejected. Estimates of number of XMM impacts based on

eRosita experience is higher than what is seen, but uncertainties on predictions is high (and also the orbits are very different).
- An automated search for PN impacts which may have been missed could be put in place (for MOS this is already being done, using flash signatures as trigger).

Regarding Sco X-1 single reflection arc NRCO:

- For MOS the analysis is significantly more complicated due to the RGAs. Some features seen are not clear – this could be due to lack of knowledge of the assembly and components. The question arose whether there is documentation that could inform us whether the estimated baffle tilt is realistic in terms of specs.

Regarding outcome of the recent IACHEC meeting:

- XRISM data will be very useful narrowing down uncertainties in energy scale. For N 132D a paper using XRISM data is being prepared.

General comments:

- It was suggested that perhaps it would be useful to reanalyse galaxy clusters with the latest CORRAREA correction.
- The question was raised whether MOS column traps are being tracked and taken into account. The Leicester energy scale code does do this, but this is becoming very hard given the weak calibration source. One could use an extended SNR to obtain sufficient statistics, at least for part of the detector (CCD1).
- It was noted that PKS 2155-304 is being included in the routine calibration plan as RGS target (once every 2 years); this is also useful for EPIC.

OPERATIONS SESSION

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

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

- Optocouplers perhaps critical after 2028 (they measure the speed of the reaction wheels and, as optical devices, are subject to radiation aging).
- Solar cell power has sufficient margin.
- Fuel estimates give life time to 2034+. 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 ~ 25 years). 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.

XMM automation is limited due to storage capacity, and is mainly related to s/c safety. An NSM patch for 2025 includes fuel-less safe mode (similar to Integral) plus further instrument monitoring and onboard safety.

XMM Ground Automation 3.0 (2020-23) results in significant reduction of SPACON workload in time for Euclid joining, and consists of:

- Full end to end operations of nominal instrument ops including radiation rejoin (2023);
- Full ground stations and on board antenae handover without manual interaction neither of FCT nor ground station staff (2023, 2024).

XMM Ground Automation 4.0 (2024-25) underway and includes tank replenishment ops, further automated rejoinder of instruments, and near real-time analysis with ARES (planned).

Mission ops for the family of missions (XMM, Integral, GAIA and Euclid) runs smoothly. Team knowledge management is crucial in maintaining this.

New safe mode and Z-flip (similar to INTEGRAL) could extend mission towards the launch of NewAthena.

2. EPIC instruments' status (P. Calderon)

EPIC instruments continue working well.

Incidents over the last year:

- PN EPCE S/W auto reboot on 7/12/2023:
  - clean warm reset;
  - ongoing exposure not affected;
  - high radiation at the time;
  - previous cases were in 2019, 2016 and 2012 (one every 3 or 4 years).
- MOS-2 RBI crash on 6/2/2024 (stopped communicating with the S/C):
  - during intensive manual configuration commanding;
  - manual recovery was correct as per procedure, but just after the filter wheel position was lost (at S/W level) due to too fast ground commanding;
  - first S/W crash on MOS-2 since 2010.

New MOS offset tables (v. 22) installed, in use since rev 4334 (8/11/2023).

Solar Geomagnetic Storm starting 10/5/2024:

- described as G4 "severe" on NOAA scale;
- minor impact on EPICs: in terms of normal science time, PN lost ~ 6 hours and MOSs ~ 14 hours;
- the MOIS Automation avoided losing more time, but in some periods kept starting and immediately stopping exposures, mainly for MOSs (~ 20 exposures more than scheduled in this period).

Automation of instrument recovery after radiation is now fully in place. Planning fixed internal calibration observations at the beginning of the revolution now substituted by planning science from the earliest possible time and starting observation when radiation is sufficiently low via automation.

MOS start-stop in MOIS automatic when subject to radiation results in multiple exposures with associated full FW rotations. E.g., rev 4479 with 10 and 7 exposures for MOS1 and 2 respectively. We should think about reducing FW movements as the number of movements has already exceeded design. Suggestion is to change the configuration of some calibration exposures (e.g. non-planned, during high radiation) to Closed rather than CalClosed (the FW is always in Closed during idle).

In ensuing discussion it was decided to treat this with high priority; some investgations regarding impact of dropping CalClosed would need to be made.

Action EPIC TTD-34/2 on M. Smith:
Investigate impact on energy scale calibration of dropping unscheduled CalClosed observations due to radiation.

PN enters counting mode more frequently than the MOSs; for 2023 the numbers for PN, MOS1 and MOS2 are 20063, 10837 and 1238 times, respectively. The suggestion is to modify the BRAT accordingly, as follows (in kbps):

PN	24	->	30
MOS1	12	->	8 (or 9)
MOS2	12	->	10 (or 9)

In ensuing discussion it was mentioned that counting mode is not necessarily due to high flaring background (which would generally not be scientifically interesting anyway, so no good reason to reduce CM), but that in PN it could be due to offset maps affected by particle incidence, and that the respective observation would be scientifically valid. Thus, there are clear cases in which reducing CM would benefit PN science output. It was agreed to modify the BRAT (the exact numbers for MOS still TBD, but not too much effort should go into deciding between 8/9/10 kbps).

Summary of open actions

EPIC TTD-030/8 on R. Saxton: Start investigating the implementation of the parameterised RMF into SAS S/W.

EPIC TTD-034/1 on M. Freyberg: Verify that the SW mode discarded line related exposure time correction is properly accounted for.

EPIC TTD-34/2 on M. Smith: Investigate impact on energy scale calibration of dropping unscheduled CalClosed observations due to radiation.