Summary of the 2023 EPIC Calibration and Operations Meeting

ESAC, with remote participation, 22-23 May 2023

Attendees

J. Ballet, P. Calderon, I. de la Calle, K. Dennerl, M. Freyberg, F. Fuerst, R. Gonzalez, F. Haberl, A. Ibarra, J. Kajava, M. Kirsch, P. Kretschmar, K. Kuntz, J. Martin, N. Meidinger, N. La Palombara, S. Peschke, C. Pommranz, P. Rodriguez, S. Rosen, C. Sanchez, M. Santos-Lleo, R. Saxton, N. Schartel, M. Smith, M. Stuhlinger, C. Tenzer, A. Tiengo, L. Tomas, I. Valtchanov

Review of open actions (M. Smith)

EPIC TTD-030/8 on R. Saxton and K. Dennerl:
Start investigating the implementation of the parameterised RMF into SAS S/W.
Open.
A test version of the RMF has been provided. The action regarding implementation is now on R. Saxton.

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.
Open.

EPIC TTD-032/1 on M. Smith and M. Freyberg:
Track PN CCD01 noisy column resulting from recent bad pixels. If required, implement mitigating measures (e.g. add advisory bad pixels to CCF or change on-board offset/BPT).
Closed
Noisy column is tracked as part of the regular monitoring. No mitigating measure required.

Operations Session

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

XMM-Newton mission extension until end of 2026, indicative extension until end 2029.
Industrial contract with Airbus extended until end 2025.
INTEGRAL extended until 31/12/2024, thereafter s/c monitoring until re-entry in ~ Feb 2029.

No change in mission performance indicators, which are well above requirements throughout mission lifetime.

S/C subsystems are all healthy. Optocouplers perhaps critical after 2028 – in discussion with industry to evaluate failure impact.

Orbit perigee also healthy, increasingly out of the proton belts. Collision avoidance was not necessary in 2021-23. 2027/28 is the next period with elevated debris flux necessitating operational collision avoidance.

Fuel estimates show a lifetime beyond 2032 (mainly due to 4WD fuel savings, introduced in 2013). Fuel consumption and predictions are being monitored.

Currently in the 3rd fuel migration exercise (previous migrations performed in 2017 and 2019, replenishments of main tank from auxiliary tanks were successful).

Main ground stations are Santiago and Kourou. Alternatives are New Norcia, Villafranca, Maspalomas, Yatharagga and Canberra. Inclusion of additional G/S in Tolhuin underway, expectation by end of 2023.

XMM-Newton S/C disposal is not possible due to lack of fuel. No manoeuvre strategies available to avoid GEO crossings, or significantly reduce GEO zone dwell times.

Automation implementation and plans are ongoing. Fully automated instrument saving and reactivation in case of radiation has been implemented. Plans include:

- fully automatic G/S handover (2023)
- fully automatic S/C antennae handover (2024)
- improvements to instrument rejoin procedures (2024)
- instrument auto eclipse recovery (2024)
- periodic check of instrument status and corrective activities (2025)
- G/S coverage only for OBS window (2026, TBC)

MOC control room readied to include Euclid (post commissioning). By end of 2023, SPACON routine work will include XMM-Newton, INTEGRAL, Gaia and Euclid.

The new safe mode developed for INTEGRAL (independent of thruster control, using reaction wheels and SAS, IMU/gyros) is being investigated for use with XMM-Newton. Currently being prepared for ground control adaptation. Depending on effort and funding, may be extended to autonomous on-board CDMU control.

INTEGRAL Z-flip momentum control (rotation about sun-line to control solar radiation pressure) investigated for application to XMM-Newton. Appears a feasible strategy to operate without RCS (save fuel, and contingency in case of RCS failure). There are constraints regarding mission planning and flight dynamics S/W. Tests could be performed soon.

Future success is dependent of a proficient team and knowledge management.

2. EPIC operations status (P. Calderon)

EPIC instruments continue working well. Incidents over the last year:

- internal: PN Q0 CPU S/W crash and auto-reboot to the ROM version of 1/10/2022
    - known issue (NCR#87)
    - most recent instance occurred last year (different quadrant) – lately occurs once every ~18 months (no periodicity)
    - probably due to radiation induced SEU (happened just after perigee)
    - recovery without issues

- external: CDMU halt and reset on 30/8/2022. No major impact, but some science time lost
- external: F-RTU trip-off on 4/1/2023. Affected the TLM/TC for the power and thermal subsystem of the focal plane Power Distribution Unit. Occurred ~ 1 hr before an eclipse, resulting in a pre-launch defined configuration for the instruments. All parameters remained within limits (although out of normal with some temperature higher than expected).

Some changes in EPIC operations after putting in safe following high radiation:
- No PN CalClosed during high radiation (however, MOSs continue with CalClosed)
- All EPICs left disabled in Auto Stack
- MOS radiation limit set to the normal (no cal source) value as calibration source has decayed significantly.

Preparation for automated recovery after radiation:
- Initiation of automatic rejoinder is currently manual, requiring SPACON decisions.
- Plan is to automate the decision to start rejoinder. Quite complicated tree of automated procedures is currently being tested.

Very stable instrument monitoring results.

Future work:
- preparation of new MOS offset tables (v. 22)
- procedures for recovery of the EPICs from Safe Standby mode are starting to be automated
- MOIS 1500 T/L rejoinder procedures (v. 2)
- Investigate further automations

Calibration Session

1. PN monitoring (M. Smith)

Increase in PN noisy pixels in CCD 1, column 33, since revolution 3707 due to new hot pixel at (33,199) and a developing hot pixel at (33,198). Besides the hot pixels, the noise level in the column is at very low energy (just above threshold).
Operational impact in terms of increased telemetry load is minor.
Scientific impact: since rev ~4000 the noisy pixels are consistently flagged by ebadpixfind.
No immediate actions, either operational or in terms of CCF, are required, but situation continues to be monitored.

Otherwise, PN bad pixel levels and offset map trends very stable.

PN CTI shows continued smooth increase, can in general be well modelled with a 2^{nd} order polynomial. Decay of calibration source means there are ever fewer observations of sufficient length to directly determine the CCD-averaged CTI.

CCD averaged energy reconstruction at Mn Kα and Al Kα within calibration requirements.

As of recently, the energy reconstruction at Cu Kα is also being monitored. Data accumulated since the derivation of the LTCTI correction at this energy (March 2022) shows deviations from the extrapolation of the model for several CCDs. This needs to be corrected in an update of the LTCTI parameters.

The energy correction at Cu Kα will also be integrated into the existing calibration in order to update the quiescent background dependent gain correction.

The energy resolution continues its steady decrease, by about 0.03-0.05 ADU/yr at Al and 0.1-0.2 ADU/yr at Mn.

The increase seen in noisy pixels (at low energy, just above threshold) in MOS1 CCD1 column 324 since ~ rev 4030 is no longer present in recent observations. This column, which is affected by a micrometeoroid impact, undergoes such periodic changes in offset value, and similar episodes of increased noise have been seen in the past.

MOS background map analysis shows on-board offset should be changed by 1 ADU for MOS1 CCDs 1 (FF mode) and 4, and for MOS2 CCDs 1 (FF mode), 2, 3 and 5 and by 2 ADU for MOS2 CCD 6. A new on-board offset table with these changes has been delivered for inclusion in an upcoming OBDB update.

2. MOS monitoring (M. Stuhlinger)

MOS energy reconstruction shows significantly underestimated energies for several CCDs in recent epoch. Because of the decay of the on-board calibration source, a new method to correct for long-term trends has been implemented.

Previous method:

- CTI monitoring code provided by MOS team of University of Leicester
- Per epoch, measure parallel CTI, serial CTI and gains to adjust energy scale.

New method:

- CCD averaged calibration line energies can still be measured.
- Calculate required parallel CTI to shift Al/Mn line energies to expected values.
- Assume serial CTI and gain values from previous epoch..
- Assume gains to be constant (values of previous epochs).

CTI CCFs applying this new method released (May 2023). Results are very much improved, yielding reconstructed energies to within ~ 10 eV. Method may be improved in future.

A apparent jump in MOS2 CCD4 gain (around rev. 4140, possibly related to the eclipse season) will need to be corrected through an update of the ADUCONV CCF.

MOS line width evolution quite stable, a small increase of less than 2 eV/yr at Mn.

Bad pixel levels still low for active CCDs: MOS1 ~ 3-5% (except CCD4), MOS2 up to ~ 3%.

MOS1 “meteorite column” monitoring with dedicated diagnostics stopped. Nominal calibration plan includes two series of diagnostics per year. Most recent series show consistent offset level at 117/118 ADU.

EPIC telemetry monitoring nominal.

Last exposure affected by out-of-nominal FP temperature was in rev. 3935. No scientific exposure affected for the last 5 eclipse cycles.

3. Investigation into EPIC pattern fractions (M. Stuhlinger)

Spectral comparison between PN and MOS show stacked residuals dependency on pattern selection. E.g., a feature near the Si edge, and increasing discrepancies toward high energies.

Current CCFs were created in 2002, with one before and one after cooling. Identical values for MOS1 and MOS2, and for all imaging modes. Origin of CCF values (physical model / measurement) currently not clear.

In order to investigate in-flight pattern fractions: data of CCD1 for all observations in the XMM-Newton archive were analysed, after applying suitable data selection criteria to limit data to source emission and ensure it to be pile-up free.

Results show different pattern fractions for MOS1 and MOS2. There are some significant departures from the CCF models. However, there is no large mode/filter dependency.

Time evolution needs to be investigated, as should be the spatial dependency, e.g. patch related. Also need to understand the QE fractions entries in the CCF.

4. EPIC-pn PSF modelling for Large Window mode (I. Valtchanov)

Background to this investigation is an analysis performed by D. Lumb (in 2022) of the PSF for a sample of 16 AGN observed in PN Large Window mode (on-axis) and comparing with current calibration.

Methodology used in this investigation:
Simultaneous fit for radial profiles of 16 point-like sources in PN Large Window mode: core radius and β are tied for each of the 16 profiles, amplitude and flat background are free parameters.

Results:

- The derived PSF parameters are consistent for 0.4-1.4 and 1.5-2.5 keV bands
- The derived PSF parameters are slightly off from the CCF ELLBETA parameters
    - The derived core radius is 0.17” larger than the value in the CCF
    - The derived β is 0.07 smaller than the value in the CCF

- The EEF curve with the best-fit core radius and β is different from ELLBETA-derived EEF and from D. Lumb-derived EEF (recast from radial profile)
    - EEF(31”) = 0.88 in CCF, 0.84 with this method
    - EEF(61”) = 0.95 in CCF, 0.93 with this method.

It is noted that deriving the EEF from the empirical radial profile (recasting) is affected by pixelization, leading to overestimates of the EEF out to ~ 20”.

This analysis will be extended to higher energies, and, if necessary, enlarged sample of observations. It could be extended to the MOS PSFs.

5. A detailed study of the XMM-Newton flaring particle background (A. Tiengo)

Significantly different count rates are measured when observing the same flaring episode in different filters for MOS1 and MOS2. Filters stop low-E protons. Thick filter more effective at stopping protons towards higher energies. But above threshold protons may become detectable due to energy loss.

Archival low-gain observations are used to analyse the SP spectrum: the effective band pass is increased from nominal 0.2-12 keV to 2-120 keV.

Assuming respective thin and thick filter material layer thicknesses (polyimide + Al, and polypropylene + Al, respectively), the proton energy loss is estimated. If the final energy is in the 2-120 keV range, the energy loss per filter is only weakly dependent on energy.

The resulting fit in the 20-120 keV band is good. But extrapolation of the fit to lower energies is not satisfactory – the constant energy loss assumption is not valid at low energies. A simultaneous fit with a modified empirical model yields better results to low energies, and compatible energy loss curves.

Alpha particles do not satisfactorily describe the data, especially towards high energies.

Work in progress includes energy loss simulations, evaluation of maximum contribution from alpha particles, and reconstruction of SP spectrum from nominal gain data. The latter could potentially allow recovery of high background intervals. A possible observing strategy could result, with PN and MOS2 with Thick filter (less SP contamination), and MOS1 with Thin filter (better SP spectral model).

6. Update of where we (the SSC) stand on the MOS vs PN astrometry (J. Ballet)

At the October 2021 SSC consortium meeting an analysis of issues with the off-axis astrometry was presented. The analysis is based on average offsets between XMM positions and counterparts (amplified) implied that the outer MOS CCDs locations are not consistent with values in the CCF.

Further investigation was done following the algorithm:
1. Extract source positions separately per camera
2. Correlate sources between the cameras- this does not require any catalogue associations
3. Compute offsets between cameras (PN is used as reference)
4. Derive linear shifts and rotation for each MOS CCD

Results show detector coordinate shifts in terms of translation, rotation and scale.

The LINCOORD CCF files were modified accordingly, with some necessary coordinate transformations being obtained with the *ecoordconv* task. A numerical bug in *ecoordconv* was found. Also, it is noted that the Z0 values do not affect *ecoordconv* or *edet2sky* output. Therefore, the scale was not modified. The resulting corrections work as expected, and the scale correction is not critical.

The derived corrections assume PN is absolute astrometry reference. This was investigated by cross-matching detections with the "Best Localised Million Quasar" positions. A difficulty arises due to the effects of the imperfect XMM pointing. The initial assumption is that these errors cancel out over large numbers. Results without using *eposcorr* show offsets by up to 1". Using *eposcorr* and *astcor*, these are reduced down to 0.6". The general pattern of systematic offsets is unrelated to that seen for the MOSs.

In the discussion, N. Schartel mentions that there is a worry that the PSF model may introduce biases which affect these results (a shift of the centroid, especially towards CCD edges), and which should be corrected first.

It was suggested that another PSF model than the ELLBETA could be used to obtain results for comparison. This would apparently be a quite straightforward exercise. Other methods of determining centroids (e.g. geometric mean of N x N pixels) are less applicable (sources are faint, workflow uses *emldetect*).

7. Update of the MOS contamination and response matrices (S. Rosen)

MOS RMF evolution previously determined for 14 epochs (most recent in use since September 2011), for

- Patterns 0 and 0-12
- For patch core, wings and off-patch regions

A C-based contaminant was assumed (following RGS). Also, assumed to be uniform across field. Changes in redistribution and contamination produce similar energy dependent effects. The contaminant is determined first, and the RMF derived subsequently.

Some earlier results indicated some observations of N 132D (but not RX J1856) favoured an O-contaminant. In current analysis, C-based absorber is still assumed, but investigation of possible O component should be pursued.

Contaminant is derived from off-patch observations of 1E 0102-72.3. MOS2 is more heavily impacted than MOS1 (where contaminant losses appear to be stable since very early). The newly derived contaminant depth is larger than that derived before – impact on absorption is ~ 5%. The new function shows a clearer flattening of the contaminant growth.

New contaminant improves spectral fits for 3C 273, RX J1856 and 4XMM J111857.7+580323. But impact on CORRAREA sample (120 sources) is negligible.

The redistribution is derived using assumed physical spectral models (from IACHEC) of 1E 0102, RX J1856 and Zeta Puppis. 5 new epochs (covering 2013 to the present) were defined. The sources are observed on patch (i.e., core + wings) and off-patch. The process iteratively modifies parameters of the empirical redistribution model to optimise fit of data to spectral models.

CalClosed data were not used in this derivation (Mn K emission could constrain redistribution at ~ 6 keV). Potential residual gain shifts were not fitted, the impact of this is expected to be low.

Results show a broadly systematic continuation of the evolution of the redistribution, with possible “quantisation” related to updates. The new RMF models show significant improvement in spectral fits for most observations investigated. Impact on CORRAREA sample results is minimal.
Flus stability was tested on RX J1856: the fluxes are stable to 4% (MOS1) and 2% (MOS2), but the absolute fluxes do change by 2-5% with respect to previous response calibration, exacerbating flux difference with PN (by up to 5% for MOS1).

The revision of the contamination implies RMFs need to be re-derived for all previous epochs as well. Ideally, need to derive contamination and RMF simultaneously.

8. MOS flux stability (I. Valtchanov)

Results from the EPIC vignetting analysis showed a change in MOS fluxes for boresight observations of SNR G21.5-09 comparing data from 2002 with that from 2021. PN fluxes do not show a change.

Further dedicated analysis, including using the latest MOS response calibration, confirms the apparent epoch dependent flux changes of the order of 8% in the 1-2 keV band and 5% in the 2-7 keV band, for MOS1 and MOS2, with the higher fluxes in the early epoch.

Analysis of Abell 0133 (comparing 2002 with 2013) shows somewhat different results, with the most significant difference being a MOS2 flux decrease of ~ 4% in 0.5-2 keV.

PN fluxes are stable to within 3% for both sources and all bands considered.

Further analysis on a larger sample of stable targets over a long baseline would be useful, but such targets are rare.

In the discussion it was mentioned that SNRs could change over such baselines at the few % level. But that such changes should be seen in PN data too.

9. EPIC(-pn) single reflections (M. Freyberg)

Single reflections could be used to inform the mirror calibration. Typical single reflections seen are those from the hyperbola (those from the parabola are too close). They originate from 20’-80’ off-axis. X-ray baffle reduces the straylight by a factor of 5-10.

Clear reflection arcs are obtained from off-axis point sources (e.g. Sco X-1), and fuzzy arcs from extended sources (e.g. Crab), where the shells are not resolved

The X-ray baffle significantly reduces off-axis efficiency, although there is some discrepancy between model and data. Investigations into in-flight straylight measurements were presented at several previous EPIC Background and Calibration meetings. Since then, more single-reflection observations of similar regions, close in time have been made.

Given the importance of absolute flux calibration, single reflection data could be a very useful tool to diagnose mirror imperfections. Proper interpretation of results will also rely on simulations. A way forward could be to collect single-camera mosaic images of regions around bright sources, complementary to existing data.

Ensuing discussion:

- It was mentioned that some single-reflection arcs appear to touch each other. This is due to the fact that the shells are not perfectly concentric, and this was already seen in some on-ground measurements.
- The question arose which simulator should be used, as SicSim is not maintained, and expertise is very limited. For eROSITA the SIXTE simulator was used, could be used for XMM as well.
- A question arose regarding who would have the expertise and time to do the required work (knowledge of simulator, collecting and introducing 10s-100s of mirror parameters). This will also depend on the priority given to this topic.

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-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.