Summary of the 2022 EPIC Calibration and Operations Meeting

Calibration sessions: 25 & 27 April 2022 (virtual)
Operations session: 29 April 2022 (virtual)

Attendees

J. Ballet, P. Calderon, I. de la Calle, K. Dennerl, J. Ebrero, K. Forster, M. Freyberg, F. Fuerst, F. Gastaldello, R. Gonzalez, F. Haberl, A. Ibarra, M. Kirsch, P. Kretschmar, L. Lober, D. Lumb, K. Madsen, H. Marshall, J. Martin, N. Meidinger, C. Pommranz, P. Rodriguez, S. Rosen, J. Sanders, M. Santos-Lleo, R. Saxton, N. Schartel, S. Sembay, M. Smith, M. Stuhlinger, I. Valtchanov, E. Verdugo, C. Wang, U. Weissman

Calibration Sessions

1. Review of open actions (M. Smith)

EPIC TTD-030/3 on I. Valtchanov:
Investigate whether the PN doubles-to-singles offset derived at Cu-K requires an update to the energy resolution at this energy.
Closed: no significant change in E-resolution introduced by doubles-to-singles offset in FF, EFF and LW modes.

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

EPIC TTD-031/1 on R. Saxton:
Propagate the 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, reformulated as:
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.

2. 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 should be monitored to track developments.

Action **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).

- 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 2nd order polynomial at Mn, whereas a linear model is sufficient at Al. Decay of calibration source means there are ever fewer observations of sufficient length to determine the CTI.
- CCD averaged energy reconstruction at Mn and Al within calibration requirements.
- Steadily decreasing intrinsic energy resolution, by about 0.03-0.05 ADU/yr at Al and 0.1-0.2 ADU/yr at Mn.
- Increase in noisy pixels (at low energy, just above threshold) in MOS1 CCD1 column 324 since ~ rev 4030. This is the column affected by a micrometeoroid impact, which undergoes changes in offset value, and similar episodes of increased noise have been seen in the past. No immediate action required.
- MOS background map analysis shows on-board offset should be changed by 1 ADU for MOS2 CCDs 5 and 6, although there is no immediate urgency.

3. MOS monitoring (M. Stuhlinger)

- MOS line width evolution nearly stable, a small increase of less than 2 eV/yr at Mn.
- Recent MOS line energy reconstruction underestimated by about 5 eV at Al and 10 eV at Mn for focal CCDs, but can reach about 15 eV at Al and 30 eV at Mn for worst case peripheral CCDs.
- CTI and ADUCONV CCF update required. Calibration source strength is insufficient for CTI measurements, at least for MOS1. Looking into candidate astrophysical sources.
- Bad pixel levels still low for active CCDs: MOS1 3-6% (except CCD4), MOS2 up to 3%.
- MOS1 “meteorite column” calibrated offset level if still consistent with quiescent state. However, currently the column is showing up as hot, as has happened on some past occasions. Expectation is it will return to quiescent level.
- Mission operations very successfully avoid science observations being performed at non-nominal focal plane temperatures.
- MOS2 anomaly (obs 088206100, rev 3981): diagonal low energy (PI < 200 eV) noise, seems to be connected to bright column section at readout side. Consists of two single flaring frames and a 17-frame continuous period. No impact on science.

4. PN timing monitoring (S. Rosen)

- Crab observed in pn timing mode (0.03ms resolution) and in burst mode (7μs resolution), twice per year.
- Latest XMM observation in rev 4068 (Feb 24 2022) – awaiting Jodrell Bank radio ephemeris update.
- Radio ephemeris used to provide absolute reference times of radio pulses; X-ray pulses wrt radio determined.
- Barycentrically corrected pn events are folded on radio ephemeris.
- Moffat plus linear function fitted to data to derive arrival phase/epoch wrt radio.

Relative timing dP/P (BU mode):

- Mean = 6×10^{-10}
- SD = 5.6×10^{-9}

Absolute timing: offset with respect to radio is ~ 350μs.

- A possible indication of cyclic behaviour on ~10 year timescale (solar cycle)?
- Good agreement of BU mode data with NICER (within 30μs).
- IACHEC timing group analysis shows generally good agreement with NICER and NuSTAR measurements.

5. IACHEC Concordance and XMM calibration implications (H. Marshall)

The concordance analysis aims at an in-flight calibration of X-ray telescopes without absolute references. A main objective is to derive estimates of instrument effective areas changes required for optimal agreement through 'multiplicative shrinkage' method.

Input data used so far includes

- SNR 1E0102 (at O and Ne)
- a sample of 42 2XMM catalog targets
- ~107 bright XCal targets.

Results were published.

Validation simulations show concordance method is better estimator than flux ratios and yields reasonable answers. More complex situations will need to handle outliers, global correlations of band fluxes and time dependency of effective areas.

6. EPIC-NuSTAR effective area correction (F. Fuerst)

Aim is to correct the EPIC-pn ARF to reduce cross-calibration features seen with NuSTAR. Correction is derived using simultaneous observations of Crab and 3C 273, and tested on a sample of AGN observations.

Currently no corrections of absolute flux offset are implemented.

Stacked residuals (13 observations) of the PN-to-NuSTAR model (powerlaw) shows a spectral “bump” in 6-10 keV. The residuals are corrected through a spline model (anchored at 1 and 12.5 keV); the correction is applied upwards of 3 keV and is ~ 5% at 9 keV.

Similar residuals are seen in simultaneous observations of 3C 273 (7 epochs of data, more complicated spectrum than Crab), and can be significantly reduced using same spline effective area correction.

Further validation tests on two dozen simultaneous AGN observations (PN in SW mode) and larger and diverse set of target types (PN in FF mode) show improvement with spline effective area correction.

Absolute flux comparison, including NuSTAR effective area reduction released October 2021, implies a pn cross calibration constant of 0.8198 ± 0.0021 corresponding to a ~18% reduction of the effective area (in the 3-12 keV band).

New CCF being released containing the > 3 keV changes to spectral shape, but not the 18% effective area reduction.

K. Madsen: after NuSTAR effective area change of 5-15% no feedback from community. NuSTAR was initially adjusted to match XMM-Newton, Swift, Suzaku (despite ray-tracing giving similar results as now).
High confidence in straylight measurements, given the 98% detector efficiency and avoiding uncertainties due to optics.

J. Ballet: are spectra compared of the Crab pulsar or nebula?
K. Madsen: combining pulsar and nebula results in a spectrum well described by a powerlaw.

F. Haberl: using RX J1856, PN is consistent with Chandra LETG (applying the modified PN redistribution). So hesitant to apply normalisation g=factor at low energies.

S. Sembay: given PN QE of 100%, only the mirror could account for 18% discrepancy.

D. Lumb: simulations with dust and molecular contamination th approximate energy dependent differences. Changes between 3-9 keV would affect low energies as well. So difficult to see one single physical origin.

H. Marshall: Cluster science is interested in fluxes.
Regarding Chandra: probably least well calibrated is HRC+LETG. Using ACIS+LETG on INS shows lower flux compared to PN and HRC+LETG, by ~30%. Discrepancies partly due to uncertainties in pulse-height distribution near threshold. Caution is warranted.

M. Freyberg: difficult to explain 18% discrepancy. With mirror effective area issues one would expect to see issues at the Au-edge.
It is important to well document which instruments have been adjusted to others.

7. PN spatial and temporal energy scale correction at Cu Ka (I. Valtchanov)

Recent update to EPN_CTI CCF file released:
- CalClosed update to Al Kα and Mn Kα for FF and EFF modes.
- New long-term CTI curves for Cu Kα fluorescent line for FF and EFF; requires a two-step approach for acceptable results; probably because of the different RAWY distribution of line versus continuum.
- Pattern offsets derived with Cu Kα.

Work in progress:
- Spatial CTI offsets derived and validated for Cu Kα using prototype python script; a SAS tool is under discussion.
- Validation checks with Mn Kα and Fe Kα using galaxy clusters.
- Energy scale compression in the 6-9 keV band with 6-lines model.

Future work:
- Combine CalClosed and fluorescent line analysis.
- Properly address the RAWY distribution in line core.
- Attempt simultaneous long-term CTI and quiescent background correction.

8. Analytic modelling of the PN particle background spectrum (W. Chen)

Objective is to find analytic PN background model from filter wheel Closed spectra.

For the continuum part (using diagonal RMF), singles:
- powerlaw for the soft energy band (start at 0.2 keV)
- broken powerlaw
- Small features:
    - smedge ~ 0.5 keV
    - step ~ 1.5 keV

Emission lines are modelled with a lorentz function (using instrumental RMF).
The small lines in 4 – 7 keV are too faint to be fitted individually by the user.
- Central energies are tied based on the theoretical value.
- Normalization ratios are fixed within the same elements.
- For the lines of the same element, the widths were also linked.

Looking at double events spectra:
Horizontal doubles (pattern==2,4) have identical spectra, apart from normalization.
Vertical doubles (pattern==1,3) require different spectral models.

Global model for singles + doubles:
- powerlaw
- modified κ-velocity distribution
- broken powerlaw

- notch model
- lorentz for fluorescence lines

The modified κ-velocity distribution is required due to issues with RAWY dependence, especially at low and high RAWY values.
This gives 7 free parameters for the continuum and 11 for the lines.
For single events only, 4 free parameters for the continuum.

Compared with Richard Strum's model:

- More stable due to fewer free parameters.
- More accurate, especially in the soft energy band, for singles + doubles.
- For singles only, accuracy is comparable.

9. MOS to PN flux stability (I. Valtchanov)

Investigating PN to MOS flux ratios as function of epoch motivated by comparison of observations of SNR G21.5-09 in 2001 and 2021.

All observations:

- have the target centre at the boresight;
- were identically processed;
- identical source and background regions (in sky coordinates).

Fluxes were derived using XSPEC using recent models. Flux ratios were normalised by the PN/MOS ratio from the most recent observation.
Targets in this study:

- SNR G21.5-09
- Kepler SNR
- Abell 0133

Also, a check with 4XMM-DR11 sources:

- Targets with on axis, repeated observations since 2001 (only FF and EFF modes, separate by filter).
- Relative MOS/PN count rate ratio per observation avoiding problems with variability. Count rates of 4XMM-DR11 band 2 (0.5-1.0 keV).

Preliminary conclusions

- Analysis of 3 non-variable sources (SNR G21.5-09, Kepler SNR and Abell 0133) show systematic ~8% higher MOS2 flux before rev. 1000 with respect to after rev 1000.
- Trend is confirmed with 4XMM-DR11 sources (preliminary analysis, limited subset).
- Not yet clear whether the trend is gradual or a jump at rev ~1200.
- CORRAREA sources show hint of a similar trend.
- Need to look at MOS1/MOS2 in more detail.

Comment by M. Santos-Lleo: results may be affected by MOS response and MOS RMFs need to be revised before drawing firm conclusions.

10. MOS contamination and redistribution (S. Rosen)

Update of the MOS contamination and RMFs in progress – there is some degeneracy between the two.

Regarding contaminant:

- Some hints that O contaminant could be more relevant than C, but not fully consistent picture.
- No clear signature of O-edge feature in ratios of N132D for MOS2 - perhaps in MOS1 and in 1E0102.
- RXJ1856 requires C (not O).

Possible tentative explanation could be a change in the recent epoch MOS1 RMF pushing events to lower energies (this could cause a late/early spectral ratio increase and filling C edge mimicking an O edge.

Current consensus: update contamination model based on previous C contaminant (also for consistency with previous epochs), then update the RMF for latest epoch.

H. Marshall notes Chandra sees a change in contaminant composition, with distinctive time and spatial dependencies. Also notes contaminant may decrease as seen with Suzaku.

J. Ballet notes effects at low energy due to individual MOS columns. M. Stuhlinger mentions in theory these problematic columns are corrected for on an epoch basis (which may however not be sufficient to remove their effects in individual observations).

11. MOS vs PN astrometry (J. Ballet)

It is known that there are issues with the off-axis astrometry. Analysis by C. Motch (Obs. Strasbourg) presented at the October 2021 SSC consortium meeting 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.

A further investigation has been done following the algorithm:

1. Extract source positions separately for per camera
2. Correlate sources between the cameras. Does not require any catalogue associations (purely internal, any good point source will do)
3. Compute offsets between MOSs and PN (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. After deriving and applying the respective geometric corrections improvements in terms of absolute coordinate shifts are seen on a CCD level (not on a global “focal plane” level).

The derived corrections assume PN is absolute astrometry reference. This was investigated with the same algorithm, but cross-matching with “Best Localised Million

Quasar" positions. Resulting PN coordinate shifts form a less clear pattern. But applying correction does improve the situation, both at global level and per-CCD level (although individual CCDs, like CCD 12 shows larger values – perhaps due to PSF distortion).

For further investigation it would be useful to have a suitably modified CCF.

N. Schartel notes PSF effects may explain some of the apparent shift patterns. J. Ballet mentions the shifts are CCD related.

M. Smith mentions SOC could investigate creating the required test CCFs, depending on the priority of this issue.

<u>Operations Session</u>

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

- Mission performance indicators well above requirements throughout the whole mission. No effects from COVID. Recovered from SPACON merger.
- Spacecraft subsystems are all healthy.
- Orbit has healthy perigee. There are 2 periods in 2021-23 and 2027-28 requiring operational collision avoidance due to elevated debris in GEO equator, although collision probabilities are very low.
- Life time based on fuel estimates is beyond 2032.
- Fuel migration status:
  - Migration A performed in 2017
  - Migration B performed in 2019
  - 1st replenishment performed in 2020
  - Next replenishment May 2022
- Tolhuin ground station in Argentina is being added; will help close apogee gap from 2028, and also gives negotiating leverage with respect to other stations.
- XMM-Newton cannot be de-orbited, has insufficient fuel for spacecraft disposal.
- Future on-ground automation will focus on simulator training, g/s and on-board antennae handovers, further end-to-end instrument automation, real time data analysis and inclusion of AI into nominal operations.
- Mission Control System migration (Solaris baseline (10) with control domain on Solaris 11) expected to be lees effort than previous migrations.
- Lela radiation monitoring system needs migration into Solaris.
- Changes to control room will be required to accommodate Euclid.
- Investigating INTEGRAL Z-flip (zero fuel consumption operations) for XMM-Newton. Initial study indicates it would be feasible.

Comment from P. Rodriguez: science program should be included in estimates of efficiency impact of Z-flip.
Comment from P. Kretschmar: the potential implementation of Z-flip strategy for XMM-Newton needs to be looked at seriously.

2. Status of EPIC Operations (P. Calderon)

EPIC instruments are still working well after more than 20 years (but do show signs of ageing). Very few incidents over the last year:

- 2x PN EPEA s/w auto reboots (different quadrants).
- PN B powered ON by SEU (LCL trip on).
- RM B powered on by SEU. This has not happened before.

Instrument incidents had almost no impact (~2 hrs lost over the whole year).

MOS2 B digital electronics chain has now been operational for longer than the original A chain.

Operations were very routine, with two routine eclipse seasons and two periodic resynchronisations.

RM recovery operations are now fully automatic. A project to automate science operations after radiation returns within limits is underway.

Summary of open actions

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