XMM EPIC-pn: Introducing spatial CTI correction using Cu-Kα

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IACHEC, 23 May 2022, virtual

Outline

• Modelling the long-term CTI correction (LTC) for Cu K α :

→ two step approach

- Results: EPN_CTI_0055/0056.CCF
- Release note: XMM-CCF-REL-389
- Technical note: CAL-TN-0231
- Pattern offsets
- Spectral resolution
- Spatial CTI correction (Sanders, Dennerl et al. 2020, Gatuzz et al. 2022)
- Future work

Using Cu K α to extend energy scale



EPIC-pn FF and EFF modes

Spatial distribution: a hole, masked in next analysis

Mask boundaries follow Sanders et al. (2020)

Only affects central CCDs (1,4=boresight,7,10)

For non-central CCDs we use the full CCD area: RAWX in (1,64), RAWY in (1,200)

Example for modelling the LTC per CCD, CCD02



TCOEF model:

1 - (1-a) x Q(t)^{1/RAWY},

where a is normalisation and by design a = TCOEF(t=0)

 $Q(t) = E_{obs}/8.04 \text{ keV}$

Using <RAWY> per observation

Running average per 0.3 years bins (red curve)

Example for modelling the LTC, CCD02



 $Q(t) = E_{obs}/8.04$

Cyan curve: [(1-TCOEF(t))/(1-a)]^{190}

Using <RAWY> for all observations

Second step, residuals, single events



Pattern offsets from Cu K α



before

after



Add the offsets in the CCF file No time or energy dependency!

Spatial CTI offsets

Following Sanders, Dennerl et al. (2020):

- 1. Apply the derived per-CCD long-term CTI correction for Cu K α
- 2. Stack event lists in bins of 500 revolutions, with step 250 (with overlap)
- 3. For each stacked table, extract spectra for each CCD, RAWX (64) and in bins of 20 pixels on RAWY.
- 4. Fit the Cu K α line and derive the residual \rightarrow the spatial offsets as function of epoch, CCDNR, RAWX, RAWY.
- → Spatial offset table dimensions: mode,epoch,CCDNR,RAWX,RAWY
 → 5-dimensional table: 2 x 8 x 12 x 64 x 200

Cu $K\alpha$ before and after





Example, correction





Procedure:

- 1. Apply derived offsets to the stacked event list
- 2. $PI \rightarrow PI_CORR$ for all events
- 3. Fit Cu Ka using PI_CORR

Overall: going down from ~30 eV to ~3 eV

Taking the rms as redshift and then c*z

→ Improvement in velocity space:

~1120 km/s (30 eV) to **~112 km/s (3 eV)**



Full Frame Mode

Before, st.dev.

After, st.dev.



Extended Full Frame Mode

Before

After

Significant improvement in this quandrant!

Applying the spatial offsets to other energies?

• In Sanders et al. (2020) the derived offsets are applied to energies down to ~ 6 keV, i.e. for the iron line at 6.4 keV (galaxy clusters)

- To validate, we apply the offsets to the Mn K α line at ~6 keV, internal calibration source
 - Source is faint after rev. 2000 → no results in most of the spatial bins
 - Check at rev. < 2000 for validation

Mn K α before and after



Mn K α before and after



No correction in the copper hole







Mn K α before vs after

FF mode

Mn K α spatial offset correction

- Different spatial distribution of Mn K α vs Cu K α
- No correction around the boresight → only some use cases will benefit
- Marginal improvement in *rms*, but systematic to all CCDs → no harm applying it?
- With *rms* of ~10 eV (after correction) →
 Δv = ~500 km/s
 (750 km/s before correction)

In progress

- Apply the spatial CTI offsets to Perseus cluster (and other mosaic observations, Virgo) as in Sanders et al. (2020), Gatuzz et al. (2022) and check if the Fe line redshift, as function of location, is in agreement with published results.
- Third stage correction: energy scale in 6 to 9 keV with six line model
 - Check if this is really needed
 - Model the energy scale compression as in Sanders et al.

6-lines model examples, full CCD areas



Rev in [2500,2999]

Rev in [500,999]

Preliminary results on energy scale

Results for FF and CCDNR = 02

After applying long-term CTI but no spatial offsets!

Using 4-lines model for now:

Ni Kα (7470 eV) Cu Kα (8038 eV) Zn Kα (8630 eV) Cu Kβ (8900 eV)

TODO: full 6-line model after applying the spatial CTI offset



Energy dependence of the long-term CTI



Conclusions and on-going works

- Update to EPN_CTI CCF file released and available:
 - CalClosed update to Al K α and Mn K α for FF and EFF modes
 - New long-term CTI curves for Cu K α fluorescent line for FF and EFF
 - Pattern offsets for double events derived with Cu K $\!\alpha$
- Work-in-progress:
 - Spatial CTI offsets derived and validated for Cu K α , with prototype python script \rightarrow SAS tool under discussion. Add the table as extension to EPN_CTI or a new CCF?
 - In progress: checks with Mn K α and Fe K α (galaxy clusters)
 - In progress: energy scale compression in 6 to 9 keV with 6-lines model
- Future work:
 - Next update to long-term CTI: combine CalClosed and fluorescent line analysis. Properly address the RAWY distribution in line core. Correction is extremely sensitive to RAWY!
 - Attempt simultaneous long-term CTI and quiescent background correction

The end