XMM-Newton CCF Release Note

XMM-CAL-SRN-0369

Rate and Energy-Dependent PHA Correction for EPIC-pn Timing Mode

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1 CCF components

Name of CCF	VALDATE	EVALDATE	Blocks changed	XSCS flag
EPN_CTI_0049.CCF	2000-01-01T00:00:00		RDPHA_DERIV	NO
EPN_CTI_0050.CCF	2000-03-23T05:00:00		RDPHA_DERIV	NO

We created a new CCF file to correct a rate-dependent effect in the EPIC-pn Timing Mode that affects the energy-scale precision. This rate-dependent correction, called RDPHA, is calculated in the PHA space (see Guainazzi et al. 2013, 2014). The RDPHA is a third correction to be applied for energy-scale accuracy of the EPIC-pn timing mode, the other two being X-ray Loading and the special gain correction (Guainazzi et al. 2014). RDPHA corrects a rate-dependent shift in PHA-channels of the collected photons: above a certain threshold, the higher the total count-rate the larger the shift to higher PHA-channels. Furthermore, within a single observation, the higher the spectral energy-channel, the higher the shift.

2 Description

The rationale of the RDPHA correction applied to Timing Mode observations is described in Guainazzi et al. 2013 and 2014. Herewith, we summarize the scope and methods:

In order to assess the energy precision at low energy, we analysed the energy-channel location of the Si K-edge at ~ 1.8 keV and Au M-edge at ~ 2.2 keV, where the EPIC-pn has the strongest gradients of the effective area. Moreover, to assess the high energy range and investigate if there is any energy dependence in the energy shift, we also analyse the energy-channel location of the Au L-edge at ~ 11.9 keV. In order to simplify the fit of the edges and convert it to simple Gaussian fits in the channel-spectrum, Guainazzi et al. (2013, 2014) defined an empirical Color Ratio (hereafter, CR; please note that in the quoted references the CR is often called 'derivative') that turns out to be very sensitive to changes in the effective area. The CR is defined as:

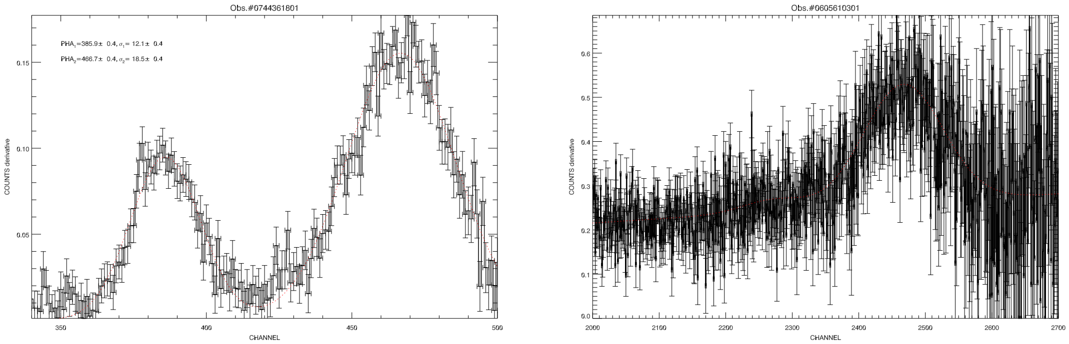


Figure 1: Example of CR showing the two peaks in correspondence to the Si (left peak) and Au (right peak) edges in the effective area. The red dotted line is the best-fit model using a power law plus two Gaussians

$$CR(PHA) \equiv \frac{|C(PHA) - C(PHA - Shift)|}{C(PHA) + C(PHA - Shift)} \tag{1}$$

where $C(PHA)$ are the counts in a particular PHA channel and $Shift$ was empirically determined to specifically emphasise those edges: $Shift = 25$ for the low-energy edges at ~ 1.8 and ~ 2.2 keV, and $Shift = 150$ for the high-energy edge at ~ 11.9 keV. Indeed, the CR forms sharp peaks at the Si K-edge, Au M-edge (Fig. 1, left) and at the Au L-edge (Fig. 1, right). These peaks can be robustly fitted with a phenomenological model comprised of simple Gaussians plus a power law for the continuum.

The calibration procedure was the following.

1) We collected 445 timing-mode EPIC pn observations in the XMM-Newton science archive until 29/01/2019.

2) We filtered out extended sources and sources with suspected pileup.

3) We filtered out the observations with no offset map and applied the XRL correction to the remaining sample.

4) We created the CR for each observation in the sample and fitted them with a model of Gaussians plus a power-law.

5) We applied a second filter to the sample based on the goodness of fit of the CR: we kept the observations for which the estimated best-fit values of the PHA peaks have a significance of more than 5σ.

6) We collected the best-fit values of the two PHA Gaussian peaks and plot them against the number N_e of shifted electrons per pixel per second. N_e is an instrumental proxy of the total count rate, calculated as:

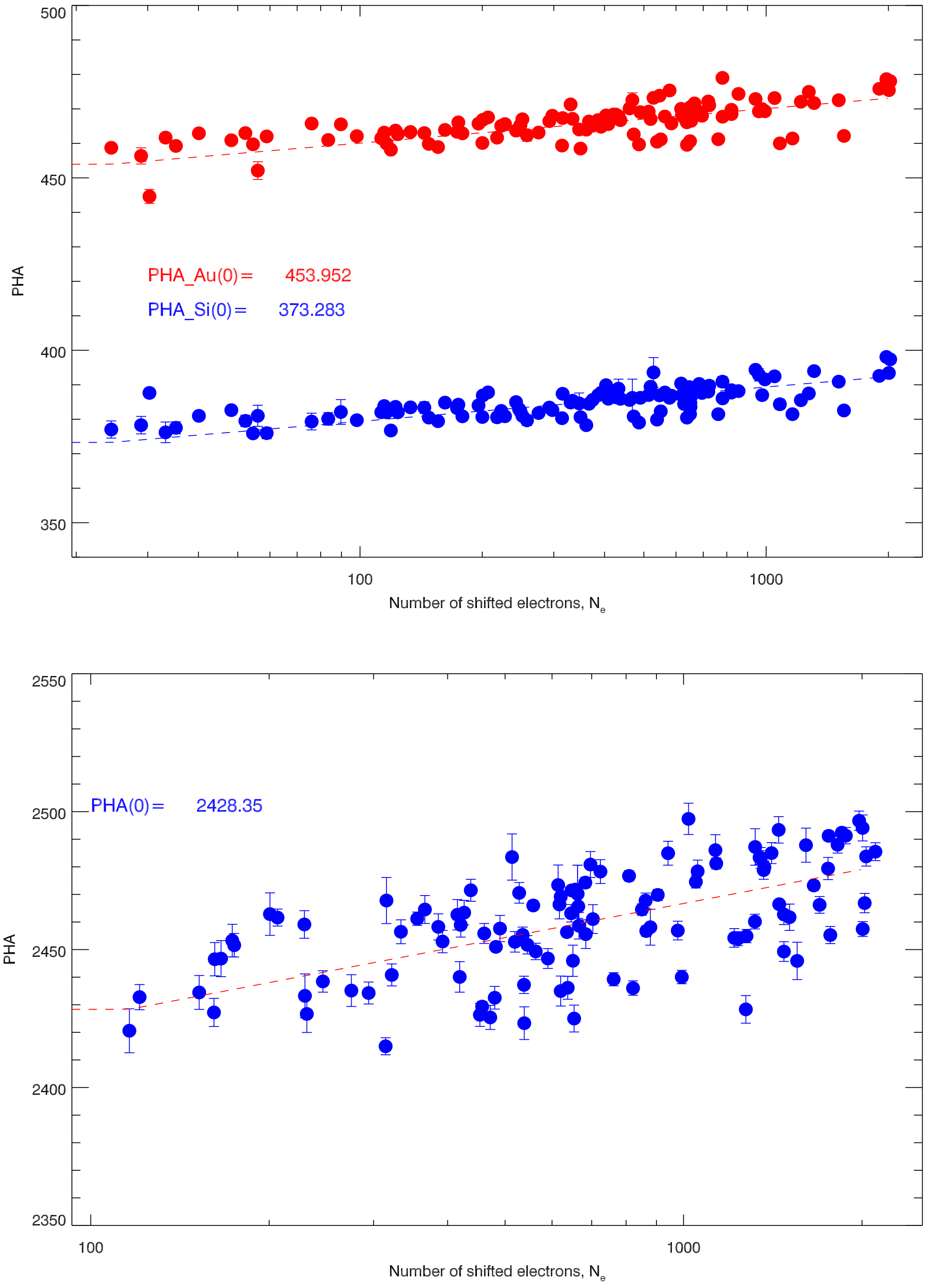


Figure 2: Calibration of the RDPHA correction, showing the best-fit PHA peaks as a function of the number of shifted electrons per pixel per second at the Si K-edge (upper panel, blue) and Au M-edge (upper panel, red) and Au L-edge (Lower panel, blue).

$$N_e = \frac{\sum_{i=1}^{N_{ph}} E_i}{N_{pxl} \times T_{exp} \times 3.6} \tag{2}$$

where E_i is the energy of the i-th photon (estimated using ADU=5 eV), N_{ph} is the number of detected photons, N_{pxl} is the number of pixels of the column where each spectrum was extracted, T_{exp} is the exposure time and the factor 3.6 (in eV) is the energy required to produce an electron-hole pair (see also Guainazzi et al. 2014b). In Fig. 2, we show the PHA peaks as a function of N_e.

7) We excluded from the sample the observations with N_e larger than ~ 2000 that are likely to have a significant fraction of pile up. For the remaining sample, we estimated the RDPHA correction by fitting the three edges correlations independently, using power-law functions:

$$\begin{array}{ll} PHA = A_1 & \text{for} \quad N_e < N_e^{low} \\ PHA = A_2 + A_3 Log(N_e) & \text{for} \quad N_e^{low} \leq N_e \leq N_e^{high} \\ PHA = A_4 & \text{for} \quad N_e > N_e^{high} \end{array}$$

where N_e^{low} and N_e^{high} are respectively the lowest and highest N_e in the sample. A_1 and A_4 are determined by the condition of continuity with $PHA = A_2 + A_3 Log(N_e)$ at N_e^{low} and N_e^{high}.

9) We created the CCF file which contains the values:

$$\begin{array}{ll} \Delta PHA = 0 & \text{for} \quad N_e < N_e^{low} \\ \Delta PHA = PHA(N_e) - PHA(N_e^{low}) & \text{for} \quad N_e^{low} \leq N_e \leq N_e^{high} \\ \Delta PHA = PHA(N_e^{high}) - PHA(N_e^{low}) & \text{for} \quad N_e > N_e^{high} \end{array}$$

This new correction improves on that of Guainazzi et al. (2013, 2014) in that a significantly larger sample, spanning 19 years, is used. For the first time, we calibrate using an instrumental edge at ~ 1.8 keV, ~ 2.2 keV and ~ 12 keV, substantially widening the base line of the energy dependence of the correction. In fact, Guainazzi et al. (2014) already implemented an energy dependent correction using a sample of 10 observations of 4 ad hoc targets, for which the energy of the source iron lines in the range 6-7 keV are assumed based on the literature. This new calibration makes use only of the large sample of instrumental edges at low and high energy and assumes a linear energy dependence in the ranges between the calibrated edges, and constant above ~ 12 keV.

3 Changes

In the `EVN_CTI_0049.CCF` and `EVN_CTI_0050.CCF` files, the extension `RDPHA_DERIV` includes a table with a grid of 100 rows between N_e=10 and 2100 and columns corresponding to the correction at the three edges. SAS uses a flat interpolation between the correction values of the grid that is applied directly to the channels in the event file.

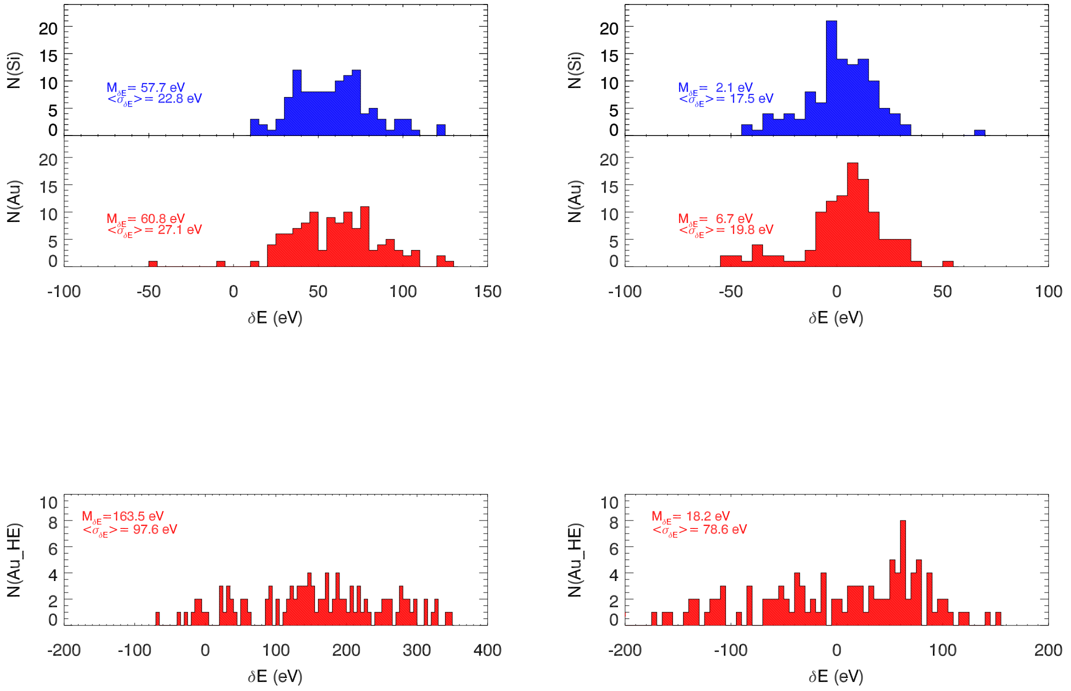


Figure 3: Distribution of the energy scale accuracy at the energies of the Si K-edge (Upper panels, blue) and Au L-edge (Upper panels, red) and Au M-edge (lower panels, red) i.e. ~ 1.8 keV, ~ 2.2 keV and ~ 11.9 keV, respectively. The histograms represent the difference between measured and modelled $\Delta Energy$, in eV, for the sample. On the left, we show the distributions assuming a flat correlation, that corresponds to the case where no correction is applied. On the right, we show the distributions using the best fit power-law function (see Fig.2), i.e. applying the correction.

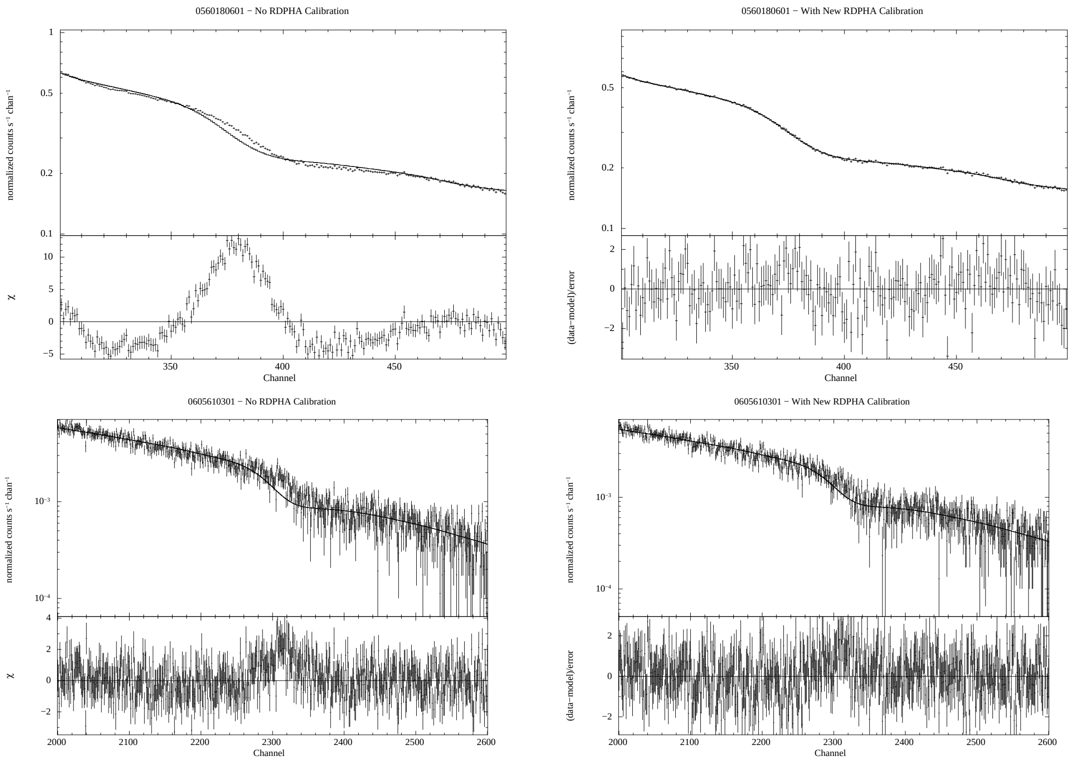
4 Scientific Impact of this Update

This RDPHA correction provides the most up-to-date energy-scale calibration of the EPIC-pn Timing Mode. Currently, and as of SAS v14.0, the RDPHA correction is applied automatically by `epproc/epchain` through the default parameter `withdefaultcal=yes` that implies `runepreject=yes withxrlcorrection=yes withrdpha=yes runepfast=no`.

5 Estimated Scientific Quality

The accuracy of the RDPHA channel correction can be estimated using the distribution of the residuals relative to the fitting model of the data. In Fig. 3, we show the histograms of the δE (in eV) between the measured and modelled ΔPHA for the sample used in the RDPHA calibration.

The larger-than-zero average of the distribution for the Si and Au edges is consistent with the systematic uncertainties of the gain for a typical observation. These medians together with the inctrinsic standard deviations give a final average systematic error of


0560180601 − No RDPHA Calibration

0560180601 − With New RDPHA Calibration

0605610301 − No RDPHA Calibration

0605610301 − With New RDPHA Calibration

Figure 4: Energy spectra with residuals of the observations 0560180601 (upper panels) and 0605610301 (lower panels) showing the improvement around the instrumental edges using the new calibration.

1% at $\sim$ 2 keV and 0.7% at $\sim$ 12 keV. The accuracy of 1% around 2 keV is comparable with the previous RDPHA correction (Guainazzi et al. 2013).

5.1 Testing the RDPHA correction

In order to quatify the improvement in energy precision with the new RDPHA calibration, we compared corrected and non-corrected edge regions of two test observations with high count rate (see Table 1).

OBS ID	Target	Date	Exp (s)	Ne
0605610301	SWIFT J1753.5-0127	2009-09-29	33642	2020.8
0560180601	SAX J1808.4-3658	2008-09-30	63919	1217.8

Table 1: XMM-newton EPIC-pn timing mode observations analysed to test the RDPHA correction. Indicated in the table are the Observation ID, the Exposure time and the number of N_e calculated in the energy channels 140-4000.

First, we created the event files with no rate-dependent PHA corrections using:

```
epproc withdefaultcal=N withxrlcorrection=N runepreject=Y

runepfast=N runrdpha=N
```

We extracted the energy spectra and isolate the ranges 300-500 and 2000-2500 channel-energies. We fitted each spectra with a power law and check the residuals around the edges that are due to the uncalibrated energy shift.

Then, we created the event files with the new rate-dependent corrections using:

`epproc` (which implies `whithdefaultcal=Y`)

We repeated the analysis descibed above, abeit with calibrated spectra, and compared the residuals. In Fig. 4, we show the significant improvement of the low energy edges for the observation 0560180601 and of the high-energy edge for the observation 0605610301.

6 Expected updates

The assumption of energy linearity from 2 to 12 keV can be further investigated with a larger sample of observations where emission or absorption lines in the energy range between the currently calibrated edges are identified and their energy is known.

7 References

Guainazzi M. 2013, XMM-CCF-REL-0299,
"Coefficients of the Rate-Dependent PHA (RDPHA) correction based on the derivative spectra"
(available at: `http://xmm2.esac.esa.int/docs/documents/CAL-SRN-0299-1-1.ps.gz`)

Guainazzi M., et al. 2014b, XMM-SOC-CAL-TN-0083,
"Spectral calibration accuracy in EPIC-pn fast modes"
(available at: `http://xmm2.esac.esa.int/docs/documents/CAL-TN-0083.pdf`)

Guainazzi M. 2014a, XMM-CCF-REL-0312,
"RDPHA calibration in the Fe line regime for EPIC-pn Timing Mode"
(available at: `http://xmm2.esac.esa.int/docs/documents/CAL-SRN-0312-1-1.pdf`)