# XMM-Newton CCF Release Note

XMM-CCF-REL-388

## Empirical correction of the EPIC effective area

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## 1 CCF Components

| Name of CCF | VALDATE | EVALDATE | Blocks Changed | CAL Version | XSCS Flag |
|---|---|---|---|---|---|
| `XRT3_XAREAEFF_0014.CCF` | 2000-01-13T00:00:00 | | ABSCORRAREA | 3.251 | |

## 2 Changes

*XMM-Newton* and *NuSTAR* perform a large number of coordinated observations in which they measure spectral parameters necessary to understand the underlying physics of astrophysical sources. Because of this coordination, very good calibration and cross-calibration of the different X-ray instruments is necessary. *NuSTAR* has recently updated their calibration based on a novel approach of observing the Crab nebula via stray-light. By circumventing the X-ray optics, this approach eliminates one of the main drivers of uncertainties of the energy dependent effective area (Madsen et al., 2017, ApJ 841, 56 and Madsen et al., 2021, arXiv:2110.11522). Given that these measurements provide the best information currently available for the true astrophysical spectrum of the Crab, we have created correction parameters to the EPIC effective area based on these *NuSTAR* results. This correction is the topic of this release.

The release describes for the first time the `ABSCORRAREA` extension, which is a new extension added to the `XRT3_XAREAEF_0014.CCF` file. This correction applies an identical change to the effective areas of the three EPIC cameras in order to obtain a better agreement of EPIC-pn with *NuSTAR* FPMA and FPMB. The changes include corrections of the order of 6–8% between 3 and 12 keV to reduce differences in spectral shape. No attempt, however, is made to correct any overall relative spectral normalization of EPIC-pn with respect to *NuSTAR*. The corrections consist of energy dependent multiplicative functions which modify the standard instrumental effective area curves as produced by the `arfgen` task. The correction is currently not applied by default, and the user should invoke it explicitly by running `arfgen` with the parameter `applyabsfluxcorr=yes`.

While the changes are based solely on EPIC-pn data, they will also be applied to the MOS effective area, if `arfgen` is run for MOS with `applyabsfluxcorr=yes` to avoid any artificial discrepancy between pn and MOS. The `applyabsfluxcorr` keyword is available in version SAS 20.0 or later.

Details on how these corrections were calculated can be found in Tech Note XMM-SOC-CAL-TN-0230, and a quick summary is given below.

### 2.1 Method

The effective area corrections are based on simultaneous observations between *XMM-Newton* and *NuSTAR* of the Crab Nebula, 3C 273, and 1ES 0229+200. *NuSTAR* data were extracted with CALDB v20211020, which introduced a major update to the *NuSTAR* effective area and response. These updates were made to improve the absolute flux calibration of the *NuSTAR* detectors.

We use 13 Crab observations taken between 2013–2021, to correct the effective area of EPIC-pn based on the measured spectral slope. In previous releases the Crab spectrum in the 3–10 keV energy band, when fitted with a simple power-law, showed significant residuals at high energies (see Figure 1a). By performing simultaneous fits with *NuSTAR* we could describe these residuals with a spline function and consequently remove them (see Figure 1b).

Data from 3C 273 (7 observations between 2021–2020, taken in Small Window mode) and 1ES 0229+200 (one observation in 2021, taken in Full Frame mode) were then used to confirm the correction factors implied by the Crab data. Simultaneous fits between EPIC-pn and *NuSTAR* then show that the pn fluxes are on average 18% below the flux measured by *NuSTAR*, which the user should take into account via a cross calibration constant in their model. The final correction function as implemented in the new CCF file is shown in Figure 2.

## 3 Scientific Impact of this Update

The corrections presented here provide an update to the EPIC effective areas aligning them better with the expected Crab spectrum and simultaneous *NuSTAR* data. Therefore, users modelling simultaneous *XMM-Newton* and *NuSTAR* data should expect an improvement in fit quality and agreement between the instruments.

The cross-normalization of EPIC-pn towards *NuSTAR* is expected to be around 0.8, when using *NuSTAR* data extracted with CALDB v20211020 or later, i.e., the fluxes implied by EPIC are about 20% below the ones implied by *NuSTAR*.

The impact of these corrections were tested against a large sample of AGN observed simultaneously between *NuSTAR* and *XMM-Newton*, during which EPIC-pn was operated in the Small Window mode (see Figure 3). We find a significant improvement in fit quality for the stacked residuals in this sample. We also checked the corrections against a sample of 35 Full Frame observations of sources of various types, taken simultaneous between *XMM-Newton* and *NuSTAR* and also find a significant improvement on average.

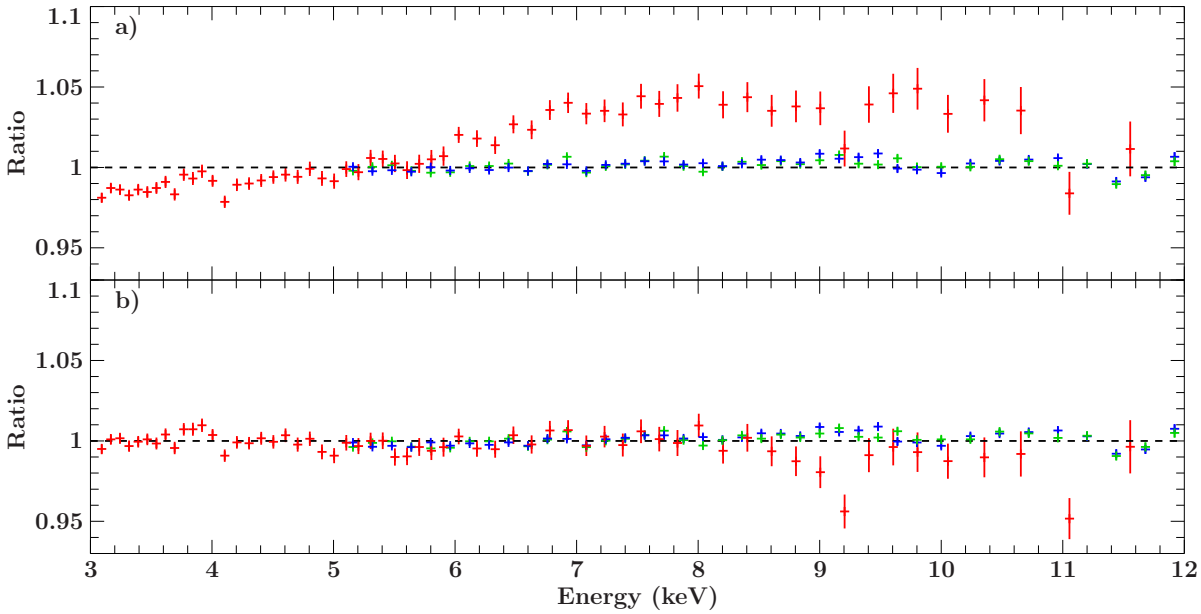


Figure 1: Stacked EPIC-pn (red) residuals, FPMA (blue), and FPMB (green) residuals of a joint fit to all Crab epochs, requiring the same photon index for all instruments in each epoch but allowing for a free-floating relative normalization. *a)* Without any correction function for EPIC-pn. *b)* After applying the spline correction function.

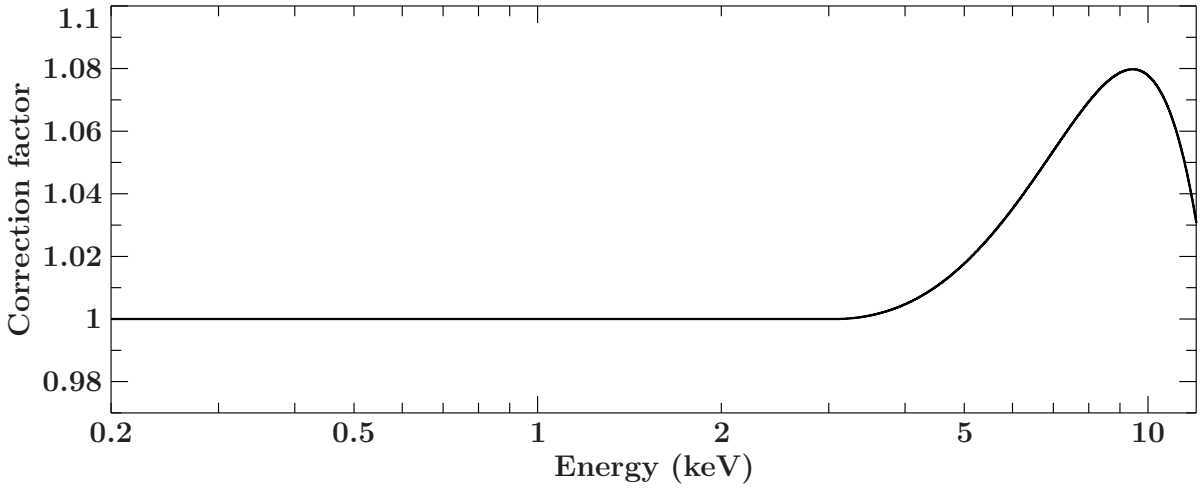


Figure 2: Final correction function to the EPIC-pn ARF description, taking into account the slope and shape difference to *NuSTAR* in the 3–12 keV band. These values are published in the `ABSCORRAREA` extension of `XRT3_XAREAEF_0014.CCF`.

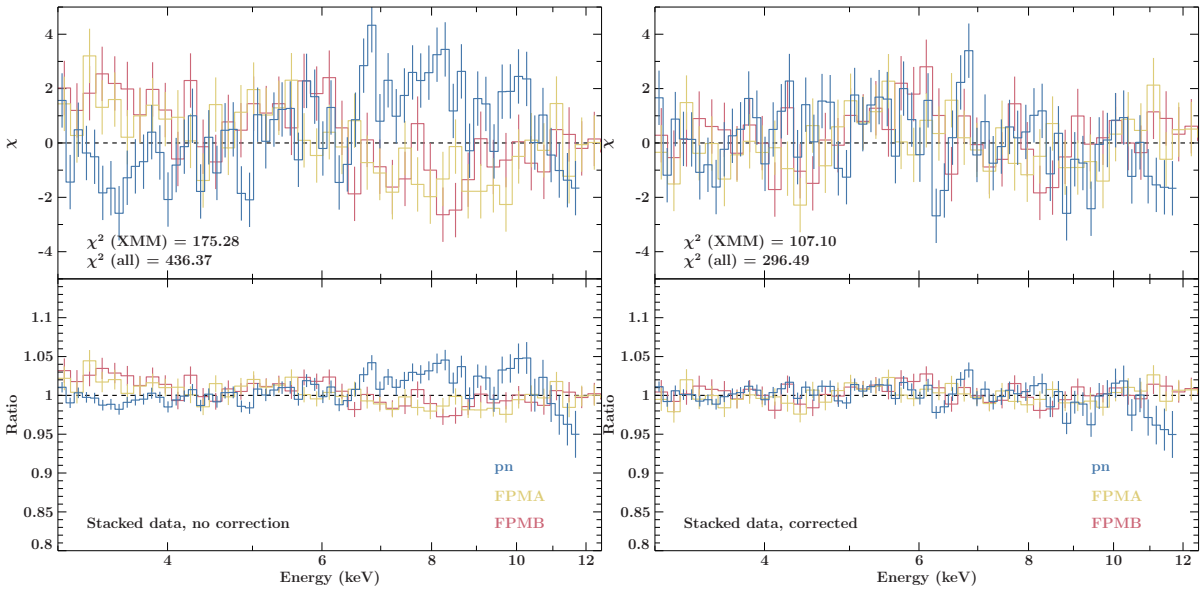


Figure 3: Residuals of the best-fit models to the stacked data of 22 AGN spectra in terms of $\chi$ (top) and as ratio data/model (bottom). In blue the EPIC-pn residuals are shown, in red and yellow the *NuSTAR* FPMA and FPMB residuals, respectively. The left column shows the results for the non-corrected fits, the right column the results when using the table model. A free-floating relative normalization was used to allow for the known flux differences between all instruments. For details see text.

## 4 Estimated Scientific Quality

The corrections are based on bright, on-axis point sources observed in Small Window mode, extracted with patterns 0–4 (singles and doubles). They have been tested against observations in other modes (in particular Full Frame mode) and for off-axis sources and should be applicable to all *XMM-Newton* data.

## 5 Expected Updates

The correction does not change the effective area below 3 keV. Work is in progress to also update the effective area at lower energies. Tests are currently conducted to study the impact of the corrections with data from other observatories, in particular towards *Chandra*.

## 6 Test Procedures and Summary of the Test Results

Functional tests with `cifbuild` and `arfgen` (SAS 20.0) were successful.