EPIC-pn Burst Mode X-ray loading and rate-dependent CTI calibration

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In 2010, significant effects from X-ray loading (XRL) were discovered in the timing mode and burst mode offset maps (Guainazzi & Smith 2013, XMM-CAL-SRN-0302).

As of 23rd March 2012 offset maps with closed filter rather than science filter.

But pre-2012 observations need XRL correction.

Causes not understood.

Empirical correction:

\[ \Delta \text{PHA} = a + b \times \text{XRL} \]

In Timing Mode \( a=0, b=1 \) already implemented.

Since in burst mode, no offset at low count rates: \( a=0 \). Further \( b=1 \) was chosen and subsequent Rate Dependent Charge Transfer Inefficiency (RDCTI) calibration adjusted.

XRL/RDCTI corrections in burst mode...
Rate Dependent CTI correction

Energy shifts caused by Charge Transfer Inefficiencies (CTI) are corrected with a parameterized function (hard-coded in the SAS) called Gain factor:

$$G = (a0 \ C^{a1}) + a2$$

with C the average number of shifted electrons in the events file and $a0$, $a1$, $a2$ adjustable parameters that are stored in the CCF component

$$\text{EPN}_{\text{CTI}}_{\text{0045}}.\text{CCF}$$

where 0045 is the current version number. Thus the values of $a0$, $a1$, $a2$ control the rate dependent correction and are determined empirically.
To detect possible energy shifts in the final spectra, distinct features such as emission lines would be ideal, but most burst mode spectra only contain continuum with very weak emission/absorption lines which might even be shifted by high velocities.

- Use instrumental edges of Si (CCD) and Au (mirror) that are included in the response.
- Method: perform a spectral fit including a gain parameter that shifts the entire spectrum.
- Ideal: gain parameter zero.
- Use non-zero gain parameters to empirically determine calibration parameters.
XMM-Newton Science Archive (XSA) contains 123 burst mode exposures (small sample)

Since we are calibrating rate dependent effects, only observations of non-variable sources can be used.

Only include sources with variations within 3 times the standard deviation

=> even smaller sample

Sources with sharply-peaked variability patterns can be included when applying time filtering (gti)
The currently public CCF for burst mode contains energy scale corrections:
- **XRL**: \( a=0, b=0 \) EPN_REJECT_0007.CCF thus no correction
- **RDCTI**: \( a0=0.003, a1=0.3050, a2=0.943 \)

- **withdefaultcal=**yes
Energy scale correction: Without any corrections

- The currently public CCF for burst mode contains energy scale corrections
  - XRL: $a=0$, $b=0$ EPN_REJECT_0007.CCF thus no correction
  - RDCTI: $a0=0.003$, $a1=0.3050$, $a2=0.943$

withdefaultcal=$\textbf{NOoooooo}$

no XRL: $a=0$, $b=0$

no RDCTI: $a0=a1=0$, $a2=1 \Rightarrow G=1$

XRL/RDCTI corrections in burst mode
Energy scale correction: Only XRL correction

- The currently public CCF for burst mode contains energy scale corrections
  - XRL: $a=0$, $b=0$  EPN_REJECT_0007.CCF thus no correction
  - RDCTI: $a0=0.003$, $a1=0.3050$, $a2=0.943$

- New: XRL: $a=0$, $b=1$
  => recalibrate $a0$, $a1$, $a2$ for RDCTI
Energy scale correction: Determine parameters for gain factor

- Normalise gain shifts from spectral fits to the energy of the gold edge:
  \[ G = \frac{\text{gain}}{2200 \text{eV}} + 1 \]

- Perform a fit to datapoints with \( a_0, a_1, a_2 \) as free parameters

XRL/RDCTI corrections in burst mode     JU Ness     ESAC, April 9 2015
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- XRL: $a=0$, $b=0$  EPN_REJECT_0007.CCF thus no correction
- RDCTI: $a0=0.003$, $a1=0.3050$, $a2=0.943$

New: XRL: $a=0$, $b=1$
RDCTI: $a0=0.1$, $a1=0.047$, $a2=0.8$
Energy scale correction: Validation

- One burst mode exposure contains emission lines, Cas A, and there is a Large Window exposure for direct (model-independent) comparison:

- The new calibration (red) is slightly worse than present one (blue)
- But: this is the faintest target in the sample and not representative for typical use of burst mode
- GRO J 1655-50 has absorption lines of Fe XXV

- The new calibration (red) is clearly better than present one (blue)
4U 1700-37 has Fe XXV/XXVI emission lines and a neutral Fe absorption edge:

- The new calibration (red) is much better than present one (blue)
- Note that these observations have no offset map, thus XRL correction not effective