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Approximate correction for parallel CTI in GRADED mode data

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Abstract

We show the ACIS trap maps developed for the CTI correction algorithm can be applied to the GRADED mode data. The technique uses the fltgrade information available in the GRADED mode telemetry, and average 3×3 PHAS images for each fltgrade pre-calibrated using the FAINT mode data. The results (recovery of photon energies and energy resolution) are nearly identical to those from the CXC CTI corrector implemented in `acis_process_events`.

1 Introduction

ACIS CTI is a strong function of position (both column and raw #'s), but these dependencies have been extensively calibrated. In particular, the so called "trap maps" available in the *Chandra* CALDB tabulate the trap density distribution with a 1-column spatial resolution. They also provide the energy dependence of the charge loss for each CCD. To fully use this information, we need to work with the 3×3 photon island images; this is implemented in the CTI correction algorithm provided in `acis_process_events`. CTI correction restores the average photon energies (Fig.1) and slightly improves the energy resolution because the column-to-column variations are taken into account.

Below, we describe how the charge loss can be corrected approximately, using the information available in the GRADED mode telemetry.

2 CTI correction *light*

First, let us consider a very simple algorithm, which we call "cti correction *light*". Assume that all charge is deposited in one pixel (i, j) (which would be true if we had only `grade` = 0 events). The charge cloud volume can be obtained by interpolating the lookup tables in the `AXAF_CTI` extension of the trap map file — in fact, it is just a power law,

$$V = V_0\,\mathtt{PHA}^{\alpha}. \tag{1}$$

The charge loss is proportional to integrated trap density at this location, n_{ij} (tabulated in the `AXAF_PCTI_IMAGE` extension), and the cloud volume, so

$$\mathtt{PHA}^{\rm true} = \mathtt{PHA}^{\rm obs} + V\,n_{ij}. \tag{2}$$

Several iterations over equations 1 and 2 restore the originally deposited charge. Of course, this algorithm is quite naïve, but Fig.2 shows that it works surprisingly well. We must be on the right track.

3 CTI correction *demi*

The effects that are taken into account in the CTI corrector but missing in the *light* algorithm are (listed in order of importance):

1. charge split between CCD columns. For `grade` $\neq 0$ events, if the charge is split between different CCD columns, this can strongly affect the total loss because the cloud volume is a non-linear function of charge deposited ($\alpha \approx 0.5$ in eq.1):

$$V_1 + V_2 = V_0\,(\mathtt{PHA}_1^{\alpha} + \mathtt{PHA}_2^{\alpha}) \neq V_0\,(\mathtt{PHA}_1 + \mathtt{PHA}_2)^{\alpha}, \tag{3}$$

and so the total loss depends on the split even if there are no column-to-column variations in the trap density.

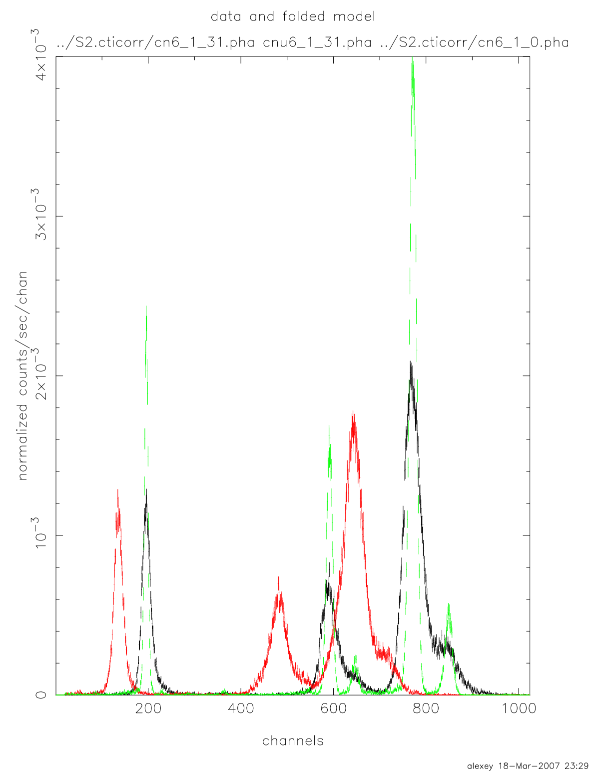

Fig. 1— The observed ECS spectra in the top (31st) segment of S2, node 1, Epoch 0, before *(red)* and after *(black)* the CTI correction. The spectra are extracted in the PHA space, binned by 2. For comparison, the green points show the spectrum observed near the readout (can be considered as an undamaged spectrum).

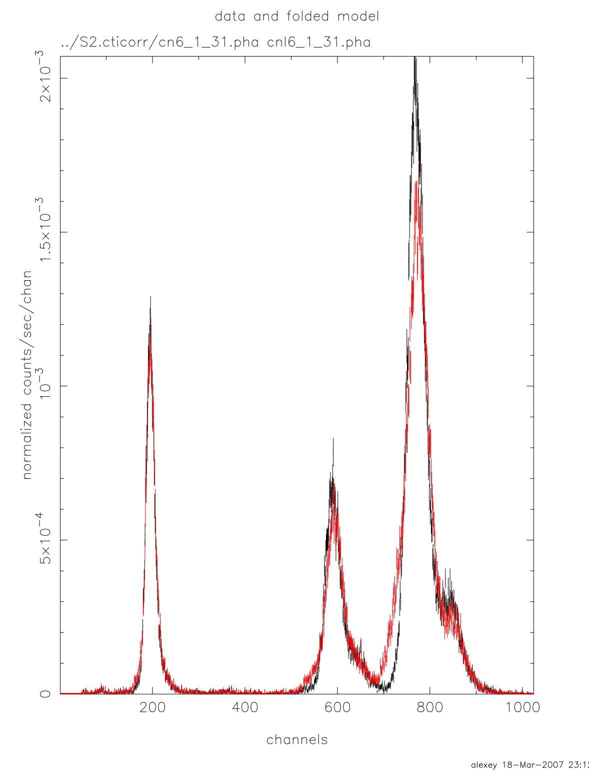

Fig. 2— Same as Fig.1 but the *red* points show the data corrected using the *light* algorithm.

2. sacrificial charge. The charge loss in the leading pixels of the same CCD column protects the trailing pixels, so the total effect depends on how the charge is split within the column.

3. charge redeposition. A fraction of charge trapped in the leading pixels is redeposited in the trailing pixels. The redeposited charge may end up either within or outside the event island, affecting the observed total `PHA`.

A full treatment of these effects requires an access to the 3×3 event images, unavailable in the `GRADED` mode. The main idea of the "cti correction ***demi***" algorithm is to use instead the average images pre-calibrated for each `fltgrade`.

3.1 `fltgrade` images

3.1.1 Images for Mn-Kα

The best statistics to calibrate the `fltgrade` images is available for the Mn-Kα line. The `PHAS` for the bottom 256 of the CCD can be considered as relatively uncorrupted by the CTI effects. For example, Fig. 3 shows the average image for the `fltgrade` = 8 events.

Interestingly, the average image for the same type of events in the top 256 rows of S2 shows nearly the same relative amplitudes for the most significant pixels. We do observe increased flux in the trailing pixels but their relative brightness remains small, hence only insignificantly affects the CTI charge loss calculations. We are going to postulate, therefore, that the average image for the same `fltgrade` events at a given energy is the same at all locations.

The average images, I^f_{kl}, have been computed for `fltgrades` $f = 0, 2, 8, 16, 64, 10, 18, 72, 80, 11, 22, 104,$ and 208 (c.f. Fig.4)

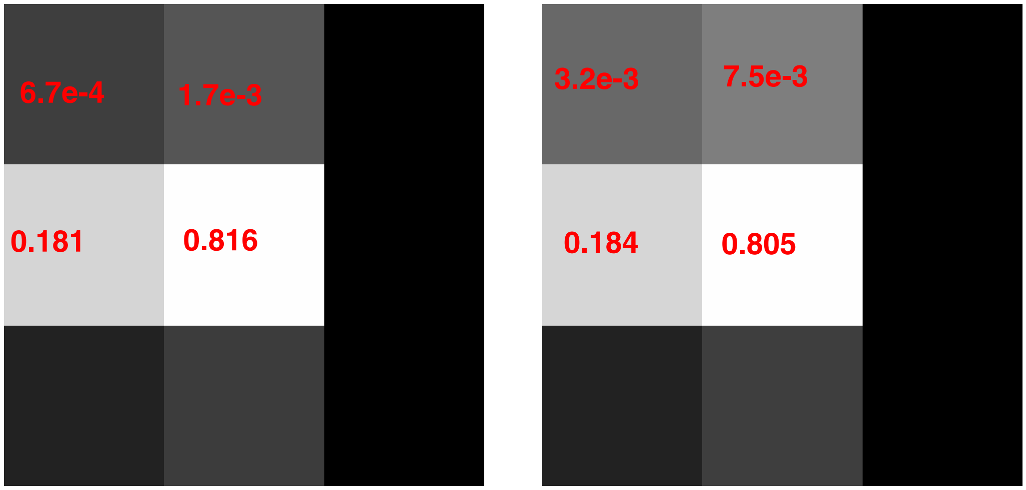

Fig. 3— Average image for the `fltgrade` = 8, Mn-Kα events in the bottom *left* and top *right* 256 rows of S2. The images are normalized to a total flux of 1. The labels indicate the relative brightness of pixels.

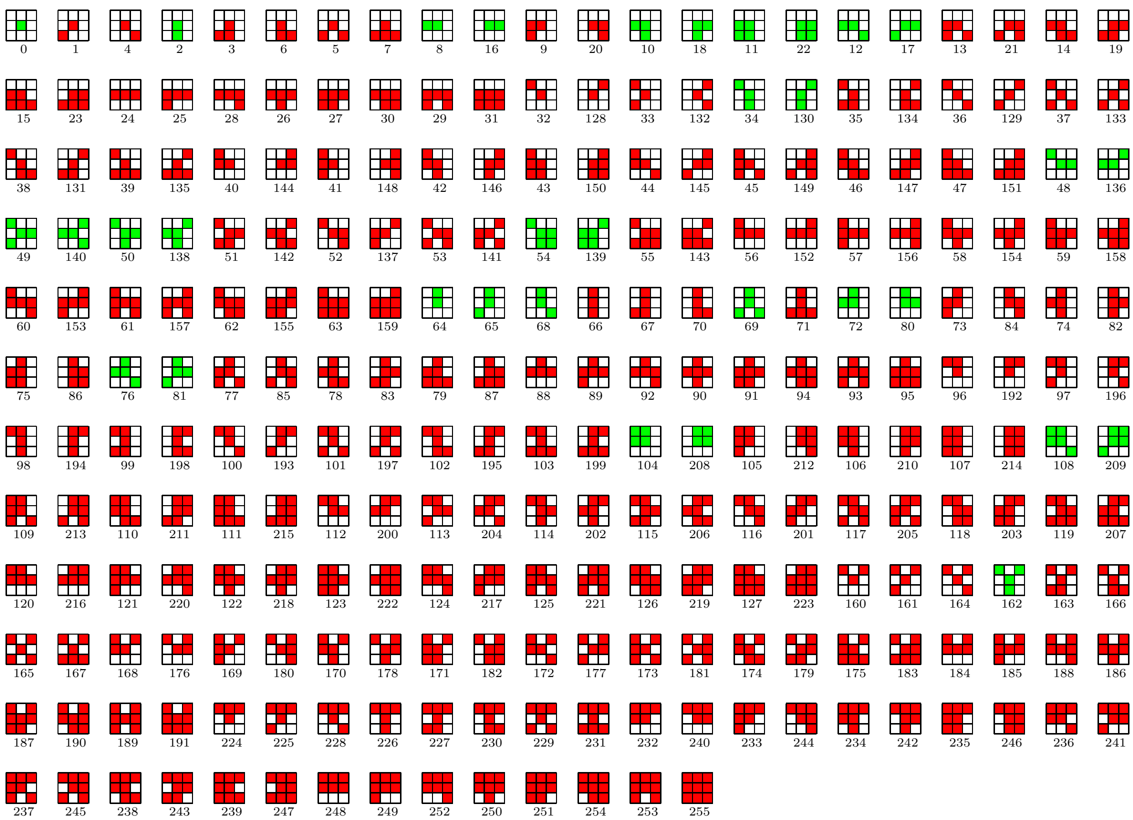

Fig. 4— Definition of the ACIS flight grades. "Good" events are shown in green.

and stored in a calibration file. The rest of "good" `fltgrade`s makes a negligible contribution to the detected flux.

3.1.2 *Images for E ≠ Mn-Kα*

For the same flight grade, the fraction of charge in the split pixels is different at different energies. The charge split is the strongest of the "missing" effects in the *light* algorithm (see above), so we need to take the energy dependence into account. We cannot calibrate I^f_{kl} at any energy, therefore we need a good prescription how to scale I^f_{kl} for Mn-Kα to other energies. We propose the following scheme:

1. Derive the flux fraction in the central pixel for the 5 ECS lines and approximate with an analytic function.
2. Assume that only the relative flux of the central and off-axis pixels changes with energy. Using $F_{\rm central}(E)$, we can then scale the Mn-Kα calibration for I^f_{kl}.

We find that $F_{\rm central}(E)$ can generally be approximated with a power law,

$$1 - F_{\rm central}(E) = F_0\, E^{-\beta} \qquad (4)$$

but the slope should be derived independently for each grade group, specifically

$$\begin{aligned} \beta &= 0.13 && \text{for } \texttt{fltgrade} = 2, 8, 16, 64 \\ \beta &= 0.34 && \text{for } \texttt{fltgrade} = 10, 18, 72, 80 \\ \beta &= 0.11 && \text{for } \texttt{fltgrade} = 11, 22, 104, 208 \end{aligned} \qquad (5)$$

(see Fig.4 for the choice of the grade groups).

3.2 *demi* correction algorithm

1. Apply the *light* algorithm to the observed event PHA and the gain file for cti-corrected data to obtain the approximate photon energy.

2. Compute the average `PHAS` image, I_{kl} for the telemetered `fltgrade` and given energy, using the approach outlined in §3.1.

3. For each column of I_{kl}, compute the expected charge loss:
   (a) Compute volumes: $V_l = V_0\,(\texttt{PHA} \times I_{kl})^{\alpha}$ (c.f. eq.1).
   (b) Compute the total charge loss

   $$\Delta Q_k = n_{i,j} \times [V_1 + \max(V_2 - V_1, 0) + \max(V_3 - V_2 - V_1, 0)], \qquad (6)$$

   where n_{ij} is the trap map, $i = \texttt{chipx} + l - 2$, and $j = \texttt{chipy}$. This equation takes into account the sacrificial charge but neglects redeposition in the trailing pixels[1]
   (c) The total charge loss for the event is the sum over 3 columns, $\Delta Q = \Delta Q_1 + \Delta Q_2 + \Delta Q_3$.

4. Apply correction to the `PHA`,

   $$PHA = PHA_{\rm raw} + \Delta Q, \qquad (7)$$

   and iterate steps 3 and 4 three times.

3.3 Results

The results of applying the ***demi***-correction algorithm are shown in Fig.6. The results are very close to those from CTI-correction of the same data. The small problem with the line wings present in the *light* algorithm (Fig.2) is gone.

[1] I couldn't make the redeposition terms to work properly. But the results are good without it anyway, see below.

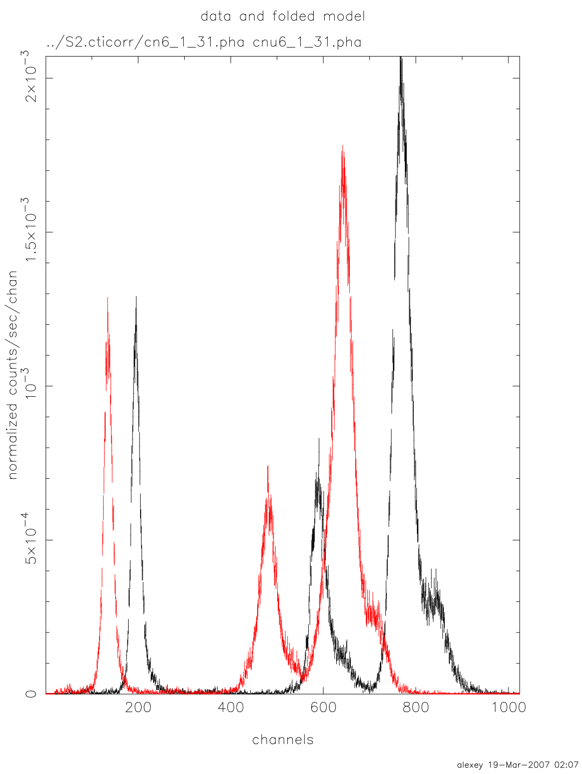

Fig. 5— Fig.1, reproduced.

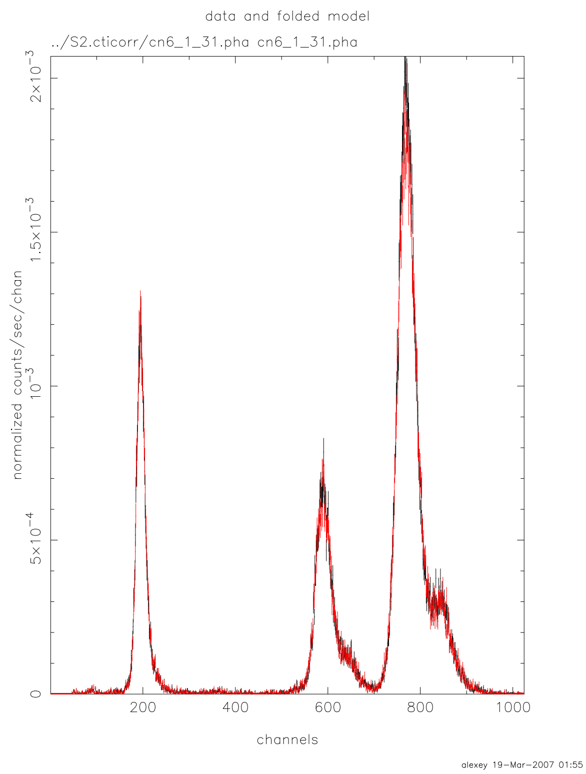

Fig. 6— Results of the ***demi***-correction *(red)* compared with the CTI correction *(black)*.

4 Implementation

Both *light* and ***demi*** algorithms are implemented as a simple fortran code, which can be found in `/data/alexey3l/chandra3/pha_pi`. The calibration file that tabulates `fltgrade` images and their energy dependence is put in `/data/alexey3l/chandra3/CAL/grdimg.fits`. The program used to create this file is in `/data/alexey4/WORK.ECS/GRADED/Epoch1/FI_GRADE_IMAGES`.

```
 USAGE:

Demi:
/data/alexey3l/chandra3/pha_pi/cti_corr_demi \
    evtfile=epoch1_s2_testD.fits \
    ctifile=/soft/ciao/CALDB/data/chandra/acis/bcf/cti/acisD2000-01-29ctiN0006.fits \
    gainfile=/soft/ciao/CALDB/data/chandra/acis/bcf/gain/acisD2000-01-29gain_ctiN0006.fits \
    grdimgfile=/data/alexey2/WORK.ECS/GRADED/Epoch1/FI_GRADE_IMAGES/grdimg.fits

(takes 51 sec to demi-correct the entire Epoch 0 for S2)


Light:
/data/alexey3l/chandra3/pha_pi/cti_corr_light \
    evtfile=epoch1_s2_test.fits \
    ctifile=/soft/ciao/CALDB/data/chandra/acis/bcf/cti/acisD2000-01-29ctiN0006.fits
```