Corrections for time-dependence of ACIS gain

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Abstract

There is a secular drift of the average PHA values for photons of a fixed energy E. This drift is caused primarily by gradual changes of the CTI in ACIS CCDs and also due to electronic drift in I2. These percent-level changes in the gain are very important for the scientific analysis. However, the gain changes are sufficiently small so that possible modifications of the *shape* of the ACIS spectral response can be neglected. This opens a possibility for a simple but sufficiently accurate correction: a pre-computed time- and energy-dependent shift can be added to the PHA values and the existing gain table is applied to the modified PHA's to recompute the photon energies and PI channels. Existing RMF calibration can be used with the corrected data.

This document describes the gain change correction algorithm which was derived for the CTI-corrected data in the FI chips and the uncorrected data in S3. This correction will be implemented in `acis_process_events` in a future release of CIAO. In the mean time, an equivalent standalone C program and calibration data is available from the *Chandra* software exchange page.

1 Time dependence of ACIS CTI and gain

ACIS spectral response slowly evolves both because of changes in the CTI and evolution of the electronic gain in some of the CCDs. All relevant information can be found in C. Grant's presentation at 2002's *Chandra* calibration workshop: `http://space.mit.edu/~cgrant/acis.html`

2 Calibration data and time periods

Two different datasets are available for calibration of the time dependence of ACIS gain:

- *External cal source* (ECS). These measurements are taken regularly and cover the entire ACIS detector. They allow to study the time-dependence of ACIS gain with a 1 month resolution and its positional dependence in regions as small as 32×32 pixels. Unfortunately, the low energy part of the ACIS response is not adequately sampled by ECS because there are no bright emission lines below 1.49 keV.
- *E0102-72.* This SNR has a line-dominated spectrum with bright O and Ne emission lines whose energies are known from the HETG observation. We observe E0102-72 twice a year to monitor the evolution of the low-energy ($0.55 < E < 1.1$ keV) ACIS gain. Unfortunately, E0102-72 is observed only in a small number of locations and it is almost impossible to deduce the position-dependence of ACIS gain from these data.

Our current approach is to derive the gain corrections from the ECS data and to verify their extrapolation to low energies by E0102-72 data. We use the ECS data integrated in a number of short observations spanning 3 months long periods starting in February 2000. This time resolution is adequate to sample the slow gain evolution (§ 3.3).

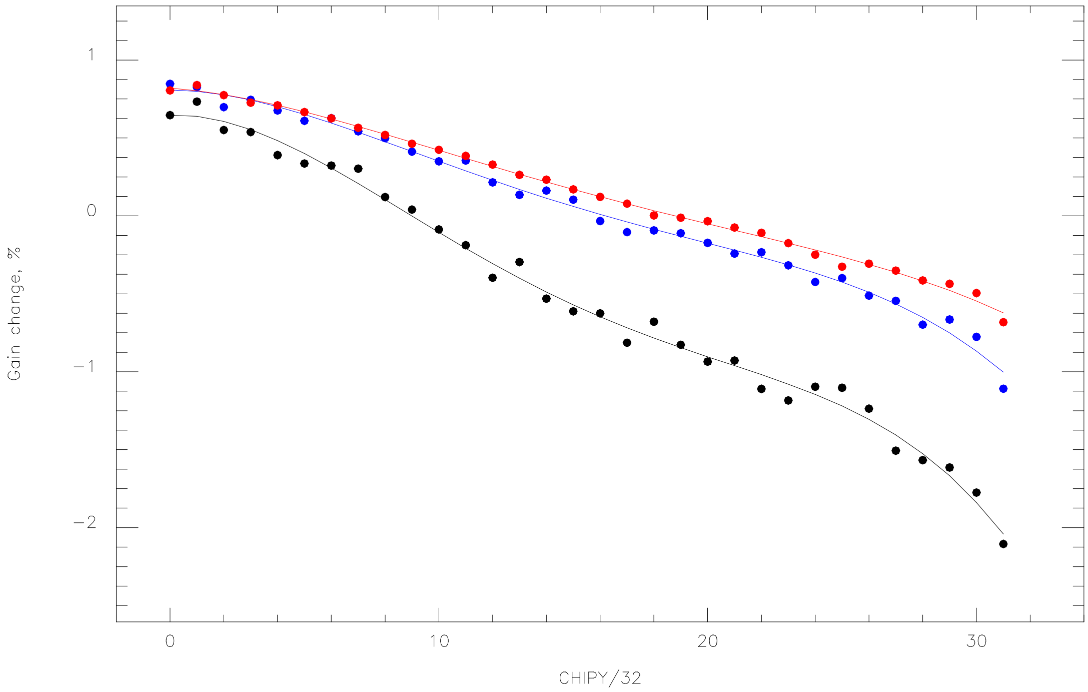

Figure 1: Example of fractional gain change as a function of `CHIPY` for ECS emission lines of Al ($E = 1.49$ keV, black), Ti ($E = 4.51$ keV, blue), and Mn ($E = 5.89$ keV, red). Solid lines show the 4-th order polynomial fits. The data are for node 2 of the I2 CCD. The *rms* scatter arround the polynomial fits is 0.08% for the Al Ka line and below 0.03% for the Ti and Mn lines. The positive gain change at small CHIPY is due to the evolution of the electronics gain for this CCD (it is almost energy-independent).

3 Calibration procedure

The released ACIS gain and RMF calibration was adjusted to the data taken in early 2000 (February–April), just after the ACIS focal plane temperature was lowered to -120 C. Using these calibration products, we derive the fractional change relative to these epoch by fitting the calibration data taken at later times.

The ECS data are fitted with a model which has 6 Gaussian lines representing the main emission lines in the ECS spectrum. The ratio of the best-fit energies and the nominal energies gives the fractional gain change, $\Delta E/E$, for the given epoch as a function of position.

The E0102-72 spectra are fitted with a physically motivated model consisting of an absorbed bremsstrahlung continuum and a number of emission lines whose energies and flux ratios are fixed based on the HETG observation. The model also includes two multiplicative factors to the line energies for O and Ne emission complexes. The best-fit values of these factors represent the gain change at $E \simeq 0.6$ keV (O) and $\simeq 1.0$ keV (Ne).

3.1 `CHIPY`-dependence of the ECS gain change

Figure 1 shows an example of `CHIPY`-dependence of the fractional gain change at $E = 1.49$, 4.51, and 5.89 keV. To smooth out statistical uncertainties, we use the 4-th order polynomial fits shown by solid lines. Note that the fractional gain change increases at large distances from the readout and towards low energies.

3.2 Energy dependence of the gain change

Using the released gain table, we can convert the fractional gain change ($\Delta E/E$) to the channel shift for each energy (ΔPHA). Without changes in the internal electronics gain, ΔPHA represents the charge loss due to CTI. The phenomenological model of the CTI developed by the ACIS IPI team predicts that the energy dependence at each location is approximately $\Delta\mathrm{PHA} = AE^{1/2}$. A similar energy dependence is indeed observed for the time-varying component of ACIS gain in most CCDs (Fig. 2).

At least one CCD (I2) shows strong variations in the internal electronics gain on top of the increase in the CTI. Such changes can be represented by a linear function of energy, $\Delta\mathrm{PHA} = BE + C$. Therefore, the general function which describes the dependence of gain correction on energy is

$$\Delta\mathrm{PHA} = AE^{1/2} + BE + C \tag{1}$$

This is an over-determined model because we have to fit three coefficients to three data points. At present, we fix $C = 0$ and $B = 0$ in all CCDs except for I2 and S3. In I2, the internal gain evolution seems to be described by the BE term and so we fix $C = 0$ and fit B in this CCD. In S3, the electronic gain is almost stable but there seem to be a secular zero-point drift by ~ 2 ADU (`http://space.mit.edu/~cgrant/acis.html`). Therefore we fix $B = 0$ and fit C in this CCD.

Equation (1) is fit to the data at 32 `CHIPY` steps for each node of the FI CCDs and for Δ`CHIPX` $= 32$ steps in S3. Whenever B or C coefficients are needed, they are likely to be independent of `CHIPY`. Therefore, we average their best-fit values over the `CHIPY` steps and then refit the A coefficients with B or C held fixed.

The best-fit relation (1) is used to precompute the correction lookup tables, ΔPHA(PHA), for each location and epoch. A simple C program uses these tables to apply correction to the PHA values in either level1 or level2 event files.

3.3 Time dependence of the gain change

After Spring 2000, ACIS gain changes in most CCDs are slow (Fig. 3). Even at early times, the gain changes between the neighboring 3-month intervals are on the acceptably low (0.3% level).

4 Validation

4.1 (No) changes in the shape of the spectral response

External cal. source data do not show any detectable changes in the shape of the ACIS response except for the PHA shifts described above (e.g., Fig. 4 and 5).

4.2 Gain: External cal. source

For a sanity check, we measured the locations of the bright Ka lines in the time-corrected ECS data. Since the corrections were derived from these data, the best-fit line energies should be very close to the nominal values. This is indeed achieved (see, e.g., the following table obtained for node 3 in I3 during Nov2002-Jan2003).

```
'% Diff' in the following table is defined as (E_measured-E_nominal)/E_nominal*100%

CCD: 3, NODE: 3,
        AlKa,1.487keV   TiKa,4.510keV   MnKa,5.898keV
yseg      % Diff          % Diff          % Diff
   0     -0.081          -0.120          -0.124
   1      0.054          -0.111           0.036
   2     -0.087          -0.089           0.010
   3      0.087          -0.111          -0.014
   4      0.101          -0.144          -0.073
   5     -0.128          -0.111          -0.044
   6     -0.101          -0.069          -0.049
   7     -0.262          -0.118          -0.090
   8     -0.081          -0.035          -0.063
   9     -0.027          -0.113          -0.066
  10      0.034          -0.100          -0.054
  11      0.007          -0.075          -0.061
  12     -0.027          -0.031          -0.109
  13     -0.161          -0.013          -0.088
```

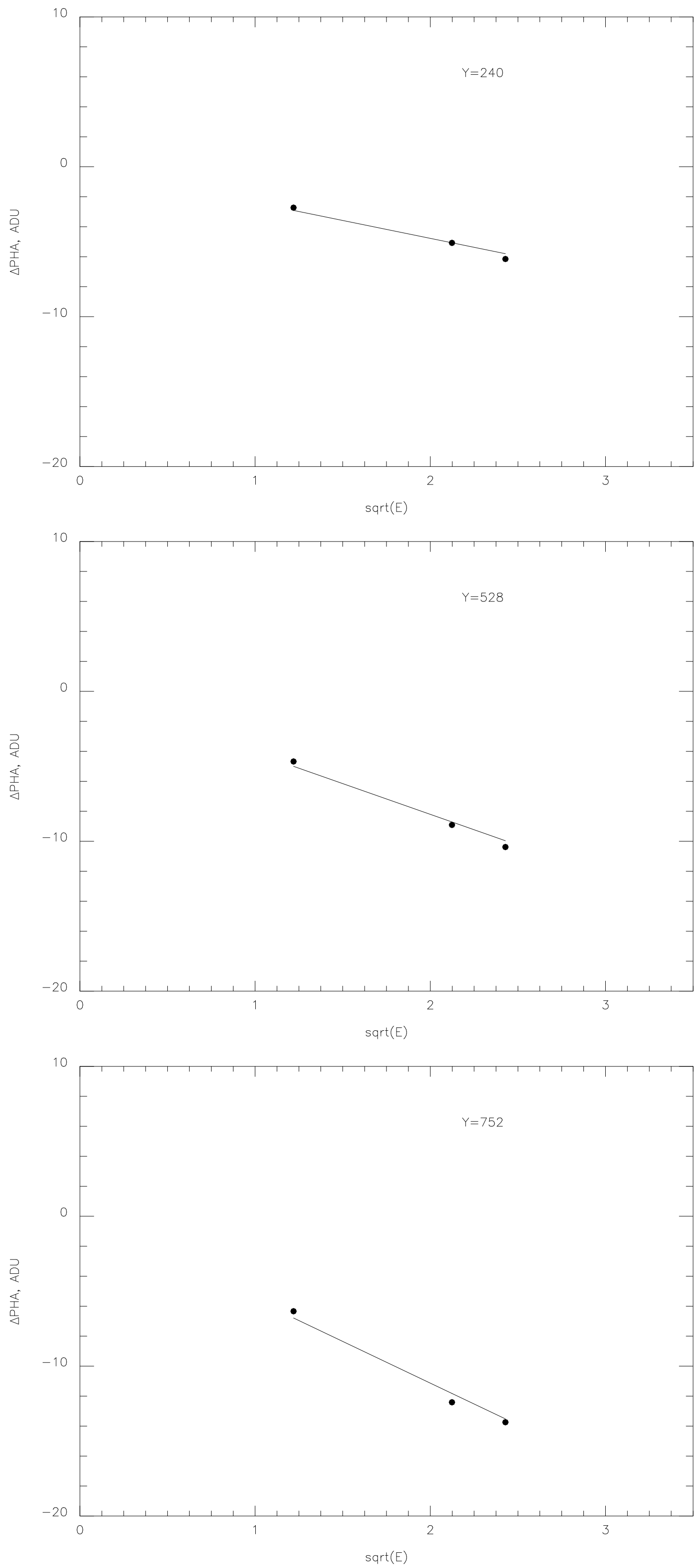

Figure 2: PHA shift as a function of energy for 3 locations in node 2 of I3. Lines show the best fit $\Delta\mathrm{PHA} \propto E^{1/2}$ relations.

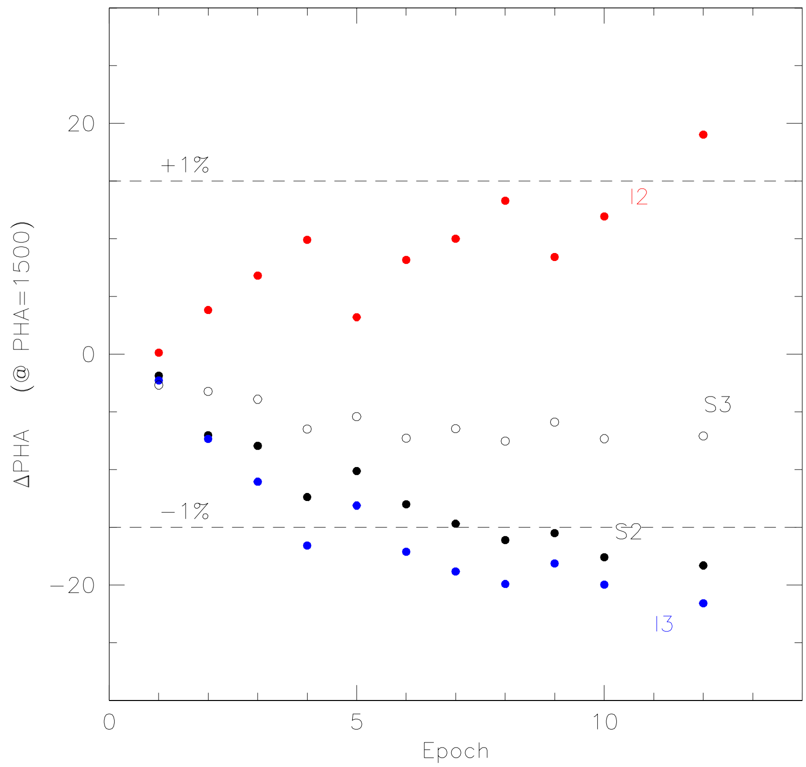

Figure 3: History of the gain changes (ΔPHA at PHA = 1500) at several representative locations in I2, I3, S2, and S3. Each epoch spans 3 months starting February, 2000. Note the positive drift in I2 which is caused by the evolution of the electronic gain.

14	-0.155	-0.011	-0.088
15	0.161	-0.129	-0.081
16	-0.094	-0.086	-0.078
17	-0.087	-0.084	-0.083
18	0.182	-0.027	-0.078
19	0.067	0.000	-0.073
20	0.202	-0.109	-0.054
21	0.027	0.000	-0.110
22	-0.161	-0.206	-0.085
23	0.047	-0.244	-0.122
24	-0.020	-0.222	-0.129
25	-0.148	-0.197	-0.137
26	0.040	-0.047	-0.102
27	0.256	-0.111	-0.110
28	0.101	0.031	-0.070
29	0.148	-0.111	-0.117
30	0.175	-0.111	-0.163
31	0.161	-0.222	-0.259
Mean	0.007	-0.097	-0.085
Standard deviation	0.129	0.069	0.052

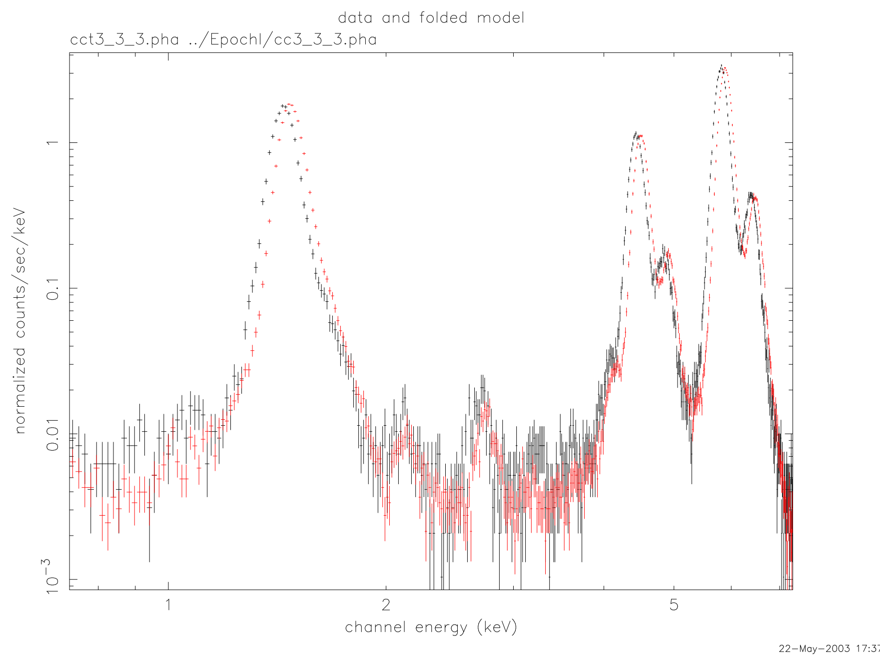

Figure 4: Comparison of the ECS spectra in the aim point quadrant of I3 observed in Feb–Apr of 2000 (red) and Nov2002-Jan2003 (black). No correction has been applied.

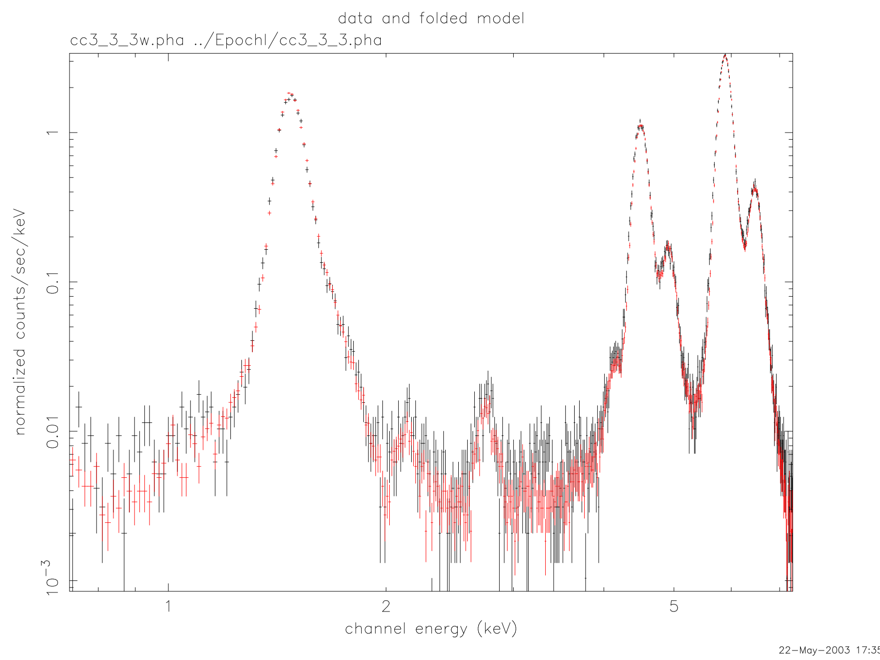

Figure 5: Same as Fig. 4 but with the PHA correction applied. Note an excellent agreement, both in terms of the peak locations and their shape.

4.3 Gain: E0102-72

To verify the time-dependent gain correction at low energies we used the calibration observations of E0102-72. The summary of the results is given below. Essentially, the line energies for both O ($E \approx 0.6$ keV) and Ne ($E \approx 0.9$ keV) came out within 1% or better of their nominal values.

```
O_gain and Ne_gain in the following table are defined as the ratio of the
measured and nominal energies for the O and Ne complexes.

CCD     OBSID   Epoch   chipx    chipy          O_gain  Ne_gain
 I0     1542    VI      257:512  513:544        1.0075  0.9970
 I0     2840    VIII    257:512  513:544        1.0075  0.9970
 I1     444     I       1:256    97:128         1.0073  1.0040
 I1     445     I       1:256    481:512        1.0320  1.0240
 I1     1543    VI      257:512  481:512        1.0072  1.0060
 I1     2841    VIII    257:512  449:480        1.0073  1.0060
 I2     1544    VI      257:512  513:544        0.9990  0.9970
 I2     2842    VIII    257:512  513:544        1.0074  0.9970
 I3     1537    VI      1:256    481:512        0.9987  1.0025
 I3     2839    VIII    1:256    449:480        0.9988  0.9970
 I3     1536    VI      257:512  481:512        1.0073  0.9970
 I3     2838    VIII    257:512  449:480        1.0072  0.9970
 I3     420     I       513:768  97:128         1.0083  1.0100
 I3     140     I       513:768  289:320        1.0073  0.9970
 I3     136     I       513:768  449:480        1.0128  1.0140
 I3     1535    VI      513:768  481:512        1.0075  0.9970
 I3     2837    VIII    513:768  449:480        1.0074  0.9970
 I3     439     I       513:768  673:704        1.0085  1.0085
 I3     440     I       513:768  897:928        1.0048  0.9970
 I3     1533    VI      769:1024 97:128         1.0072  1.0060
 I3     2835    VIII    769:1024 97:128         1.0074  1.0060
 I3     1534    VI      769:1024 481:512        1.0075  0.9970
 I3     2836    VIII    769:1024 449:480        0.9988  0.9970
 S2     1539    VI      513:768  481:512        0.9988  0.9970
 S2     2847    VIII    513:768  481:512        0.9987  0.9970
```

5 corr_tgain usage

The time-dependent gain correction will be implemented in the future release of acis_process_events. In the meantime, we provide a stand alone C program, `corr_tgain.c`. The only external library required by `corr_tgain` is `CFITSIO` which is widely distributed with FTOOLS.

Note also that `corr_tgain` should be applied to the CTI-corrected data in the I0–I3 and S2 chips (there is no reason to use uncorrected data in these chips!). The program will not modify the data for other FI CCDs and S1. Note that S0, S1, S4 and S5 are used primarily for grating observations so the time-depenedent gain change is less important.

Here is a typical data correction thread:

1. Save your data:

   ```
   cp evt2.fits evt2-save.fits
   ```

   Note that `corr_tgain` will change the `PHA` column in the events file and the original PHA values cannot be easily restored. Therefore, **always save your data and run corr_tgain only once!**

2. Find out the observation date:

   ```
   dmkeypar evt2.fits DATE-OBS ; pget dmkeypar value
    2002-02-05T22:41:52
   ```

3. Select the appropriate calibration file and apply correction to the `PHA` column. The calibration files provided with `corr_tgain` use the CALDB naming scheme — the date in the file name shows when the dataset becomes valid:

```
% ls corrgain*.fits
corrgain2000-01-29.fits  corrgain2001-02-01.fits  corrgain2002-02-01.fits
corrgain2000-05-01.fits  corrgain2001-05-01.fits  corrgain2002-05-01.fits
corrgain2000-08-01.fits  corrgain2001-08-01.fits  corrgain2002-11-01.fits
corrgain2000-11-01.fits  corrgain2001-11-01.fits
```

Select the latest file still appropriate for your data. For example, for the observation date above (February 5, 2002) the correct file is `corrgain2002-02-01.fits`. PHA correction is performed by the following command:

```
corr_tgain evt2.fits -tgain corrgain2002-02-01.fits
```

4. Recompute the photon energies and PI values:

```
acis_process_events\
infile=evt2.fits\
outfile=gov.fits\
acaofffile=none stop=none\
gainfile=/soft/ciao/CALDB/data/chandra/acis/bcf/gain/acisD2000-01-29gain_ctiN0001.fits\
gradefile=none\
apply_cti=no doevtgrade=no calculate_pi=yes check_vf_pha=no\
clobber+

mv gov.fits evt2.fits
```

5. Response files (ARFs and RMFs) should be generated as usual from the released calibration files.

Note that the `corr_tgain` calibration was derived for the CTI-corrected data in the FI chips. We expect that a similar correction applies to the non-corrected data as well. In this case the user should run `corr_tgain` as usual but use a different gain file on step 4.